TUNABLE MILLIMETERWAVE GUNN OSCILLATOR AT 100 GHz

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Project Report

BY

SUNIL K. VASANT

MANOHAR RAJU

SHASHANK GOVINDRAJ

GUIDED BY

DR. VIVEK DHAWAN
SCIENTIST, MMW LAB
RAMAN RESEARCH INSTITUTE
BANGALORE

DR. T.S. RUKMINI
DEPT. OF ELECTRONICS
R.V.C.E.
BANGALORE

R. V. COLLEGE OF ENGINEERING

BANGALORE-560 059

R. V. College of Engineering

BANGALORE-560059

CERTIFICATE

This is to Certify that this Project work entitled TUNABLE MILLIMETERWAVE GUNN OSCILLATOR AT 100 GHz

has been suceussfully completed by

1. SUNIL K. VASANT
2. SHASHANK GOVINDRAJ
3. MANOHAR RAJU

as a partial fulfilment of final year B.E. (Electronics degree course) during the year 1991 -1992 in the department of Electronics at R. V. College of Engineering as prescribed by the Bangalore University.

J. S. Rukmini
Signature of Guide

4/5/92
Head of the Department

1991 -1992

RAMAN RESEARCH INSTITUTE

DR. VIVEK DHAWAN
Millimeterwave Laboratory

1st May 1992

CERTIFICATE

This is to certify that the project work entitled "TUNABLE MILLIMETERWAVE GUNN OSCILLATOR AT 100 GHz" was carried out by:

MR. MANOHAR RAJU
MR. SUNIL K. VASANT
MR. SHASHANK GOVINDRAJ

in the Millimeterwave Radio Astronomy Laboratory of the Raman Research Institute, Bangalore under my guidance for the partial fulfilment of the requirements, for the award of Bachelor's Degree in Electronics Engineering of Bangalore University.

(VIVEK DHAWAN)
Scientist

Address:
C.V. Raman Avenue

Tel: (812) 340122
Fax: (812) 340492

Telex: 845 2671 RRI IN
Telegrams: RAMANINST

" The individual self is the passenger in the chariot of the material body, and intelligence is the driver. Mind is the driving instrument, and the senses are the horses. The self is thus the enjoyer or sufferer in the association of the mind and senses."

(Katha Up.1.3.3-4,ch..6 vrs.34 purport, Bhagavad-Gita)

TUNABLE MILLIMETER GUNN OSCILLATOR
AT 100 GHZ

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Finally, we would like to thank our parents for all their love, understanding and affection.

TUNABLE MILLIMETER WAVE GUNN OSCILLATOR AT 100 GHz

SYNOPSIS

In this project we have characterised a Gunn Oscillator for the frequency band of 85-115 GHz by using a Resonant Cap structure in a rectangular wave guide which is of reduced height.

One goal of the project was to improve the power output of existing Gunn Oscillators over the 100-115 GHz range,whose frequency can be electronically tuned approximately ±300 MHz by varying the bias voltage on the Gunn diode package.

The oscillator consists of a commercially available packaged GaAs Gunn diode (Varian) whose fundamental frequency of oscillation is about half the output frequency of the oscillator. This is thread mounted in a adjustable waveguide cavity.

The power output of this oscillator was attempted to be maximized by trying :

(a) Different diode packages.

(b) Different Resonator structures.

(c) Different output waveguides.

Another goal was to carry out extensive experiments to compile a data base of voltage tuning characteristics of the oscillator. This will be used for future work on Phase Locking of the oscillator.

CHAPTER I

CHAPTER I

INTRODUCTION

Microwaves can be defined as very high frequency electromagnetic waves of the range of 300 MHz to 300 GHz or with wavelengths of 30 cm to 0.3 mm.

Information transmission by microwaves can be effected by guided waves or by free-space propagation. Waveguides and transmission lines of various types are used for guided propagation.

At higher microwave frequencies, notably at wavelengths below 10 cm, a hollow pipe i.e., a waveguide is preferred to transmission lines because of better electrical and mechanical properties. The disadvantages of a transmission lines to a waveguide are as follows:

1) Wave guides are simpler to manufacture than co-axial lines since the inner conductor is missing.

2) Owing to the fact that there is neither an inner conductor nor a dielectric in a waveguide, flash over is less likely to occur.

3) Consequently, the power handling capacity of a wave guide is more, and maybe about ten times as high as that of co-axial air dielectric rigid cables of similar dimensions.

4) In a wave guide the propagation is by reflection from the walls, power losses in a wave guide are lower than in comparable transmission lines.

Many different field configurations can be found to have no tangential component of electric field at the walls. Each such configuration is known as a MODE.

The most striking difference between wave guides and transmission lines is that a particular mode propagates down a waveguide with low attenuation only if the wavelength of the waves is less than some critical value determined by the dimensions and geometry of the guide. If the wavelength corresponding to the operating frequency is greater than this cut-off value, the waves in the wave guide die out rapidly in amplitude even if the walls of the guide have infinite conductivity.Different modes have different cut-off wavelengths, the particular mode for which the cut-off wavelength is the greatest is termed as DOMINANT MODE.

In case of TEM lines, all wavelengths are passed.

1.1 HISTORICAL BACKGROUND

Recent astronomical observations at radio wavelengths have created a new branch of astronomy called 'radio-astronomy'. The older astronomy in the visible spectrum is now often called 'optical-astronomy', to distinguish it from the newer branch.

Early observations in the science of radio astronomy were made as far back as 1936 by Karl G. Jansky, a radio engineer at Bell Telephone Laboratory, U.S.A. Over the past three decades, several remarkable astronomical objects have been discovered by observations with ground based radio telescopes. Prominent among them are 'Quasars'(Quasi Stellar Radio sources) and 'Pulsars' (Pulsating radio sources).

The positions of optical and radio astronomy in the electromagnetic spectrum coincide with the two principle bands of the earth's atmosphere and ionosphere. These transparent bands are commonly referred to as the optical window, which extends from about 0.4 to 0.8 micron (1 octave) and the much broader radio window which extends from about 1 cm to 10 M (about 10 octaves) because of some relatively transparent bands in the millimeter region and occasional ionospheric "holes" at decameter wavelengths, more extreme limits of the radio window may be placed at 1 mm and 150 M as shown in Fig. 1.1.(With the availability of low noise receivers at millimeter wavelengths in the early seventies, a large number of organic and inorganic molecules were identified.)

The presence of water vapour and oxygen in the earth's atmosphere contributes to the absorption of the incoming

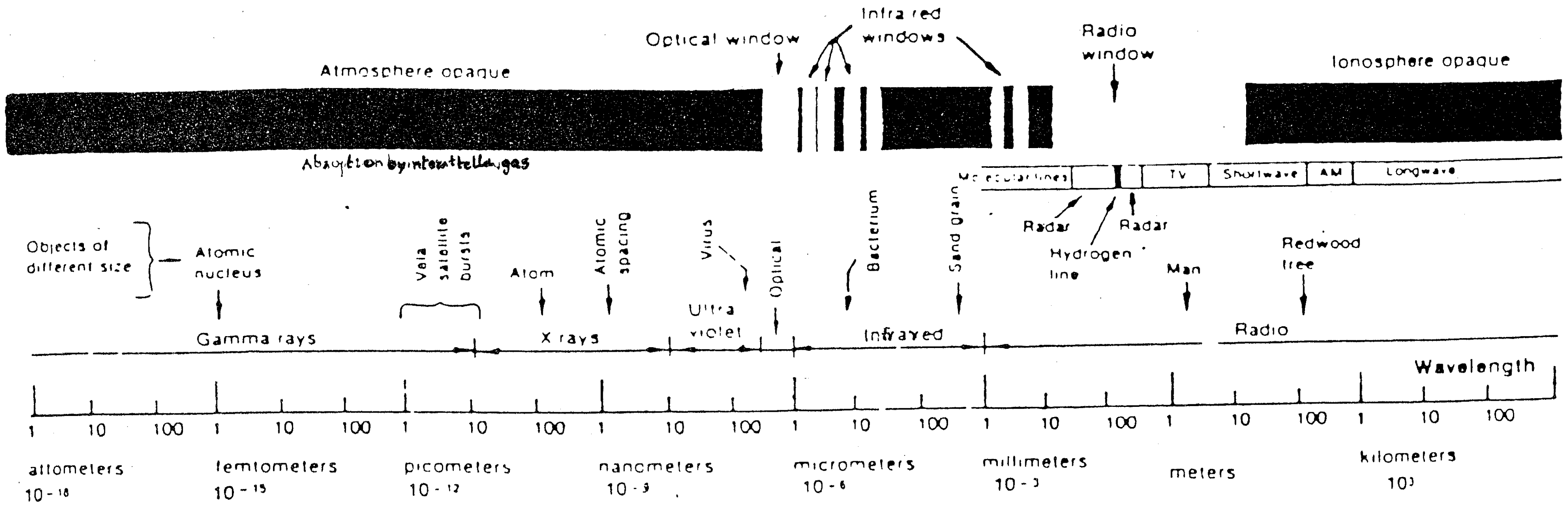


Fig. 1-1. Electromagnetic spectrum showing relative transparency of the earth's atmosphere and ionosphere.

millimeter-wave radiation.

The Fig. 1.2[20] shows two typical atmospheric absorption curves for radio waves of 1-500 GHz frequency range, passing vertically down through the atmosphere for a dry (precipitable water vapour $W^V = 3$ mm) and a comparitively humid ($W^V = 21$ mm) atmosphere. Several low absorption window regions are easily discernible in the figure. Ground based millimeter wave radio telescope are designed to exploit these window regions of the radio spectrum. Two of these windows 33-50 GHz and 75-115 GHz are of particular interest for molecular spectroscopy since the rotational transitions of several astrophysically important molecules lie in these frequency bands.

1.2 MILLIMETER WAVE RADIO ASTRONOMY RECEIVERS

Receivers for millimeter wave radio astronomy are of super heterodyne design in which the incoming radiation is first down converted to an intermediate frequency (IF) signal by multiplying or mixing it with a strong signal from a local oscillator (LO).

Metal semi-conductor junctions like Schottky barrier diodes are used as mixers or frequency down coverters for this purpose. The IF signal is then amplified in a low noise amplifier in the front end of the receivers. The back end of these receivers generally consists of a spectrometer of filter banks. All this

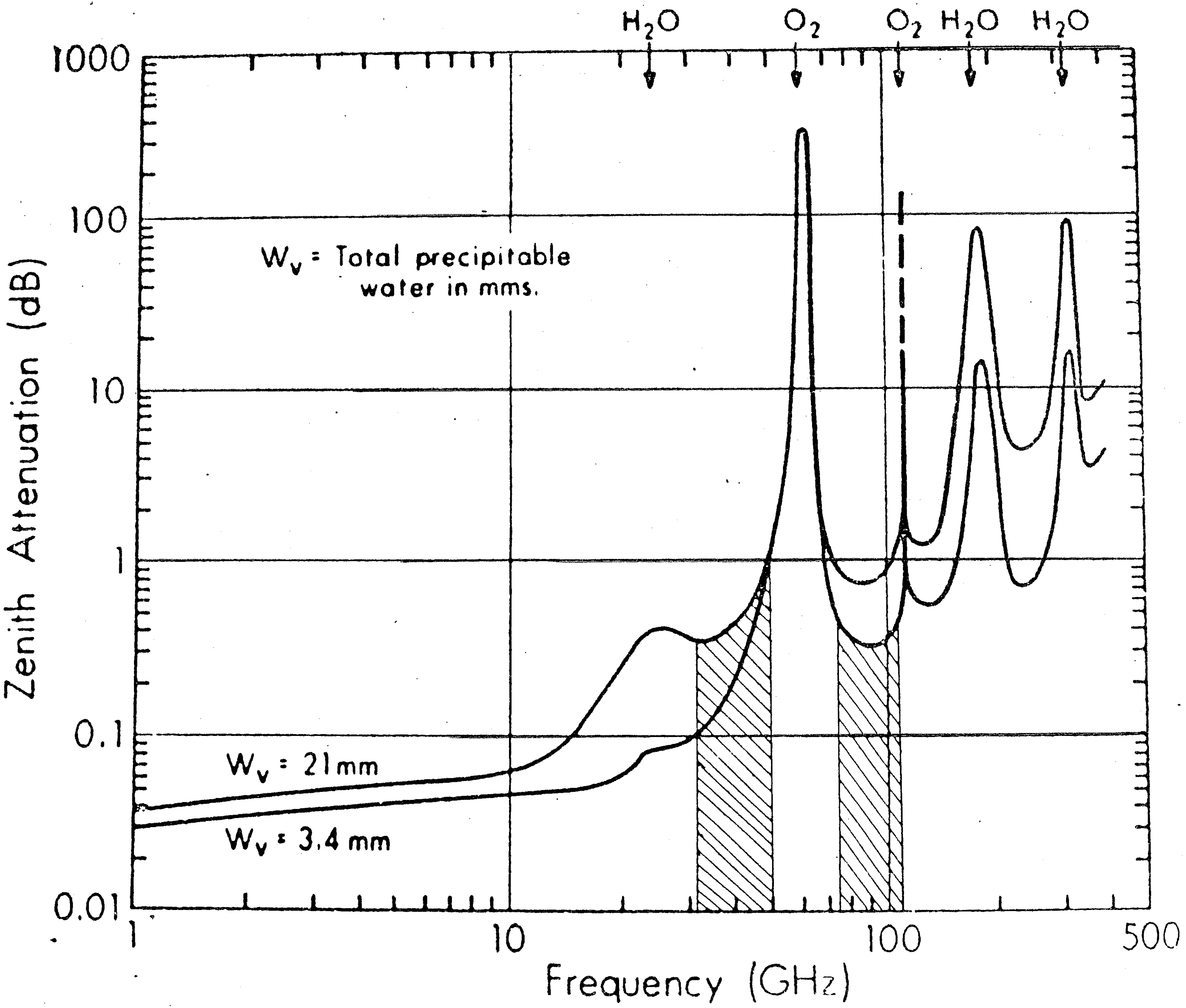


FIG 1.2 ATMOSPHERIC ABSORPTION OF MILLIMETRE-WAVES. (after Penzias and Burrus, 1973)

data is then fed to a Data Acquisition System (DAS) for further processing. A block diagram of the set up is shown in Fig. 1.3.

The noise added to the signal by the mixing process depends on the temperature of the device.Therefore they are cooled to cryogenic temperatures to minimise their noise contribution. Since mixers are lossy devices the IF amplifier has to be of high gain and ultra low noise design. In RRI radio astronomy receivers an IF (Intermediate Frequency) of about 1.4 GHz is chosen. Since this IF is much smaller than the Local Oscillator (LO) frequency both the signals (LO + IF) and the image (LO - IF) bands get converted to IF resulting in a Double side band (DSB) receiver.

In addition to the noise contribution of the mixer and the IF amplifier there is yet another noise called the side band noise of the Local Oscillator (LO). At the signal and image frequency it is also converted to IF along with the input signal thus worsening the signal to noise ratio. Therefore, only oscillators with low sideband noise are chosen for LO application in these receivers. The power requirement of the LO source depends on the type of mixer used. With the present day technology where mixers are cooled to cryogenic temperatures (using helium), the mixers typically require 0.1 to 1 mW of continous wave (CW) power for efficient operation. The LO frequency must also be precisely known for measuring the

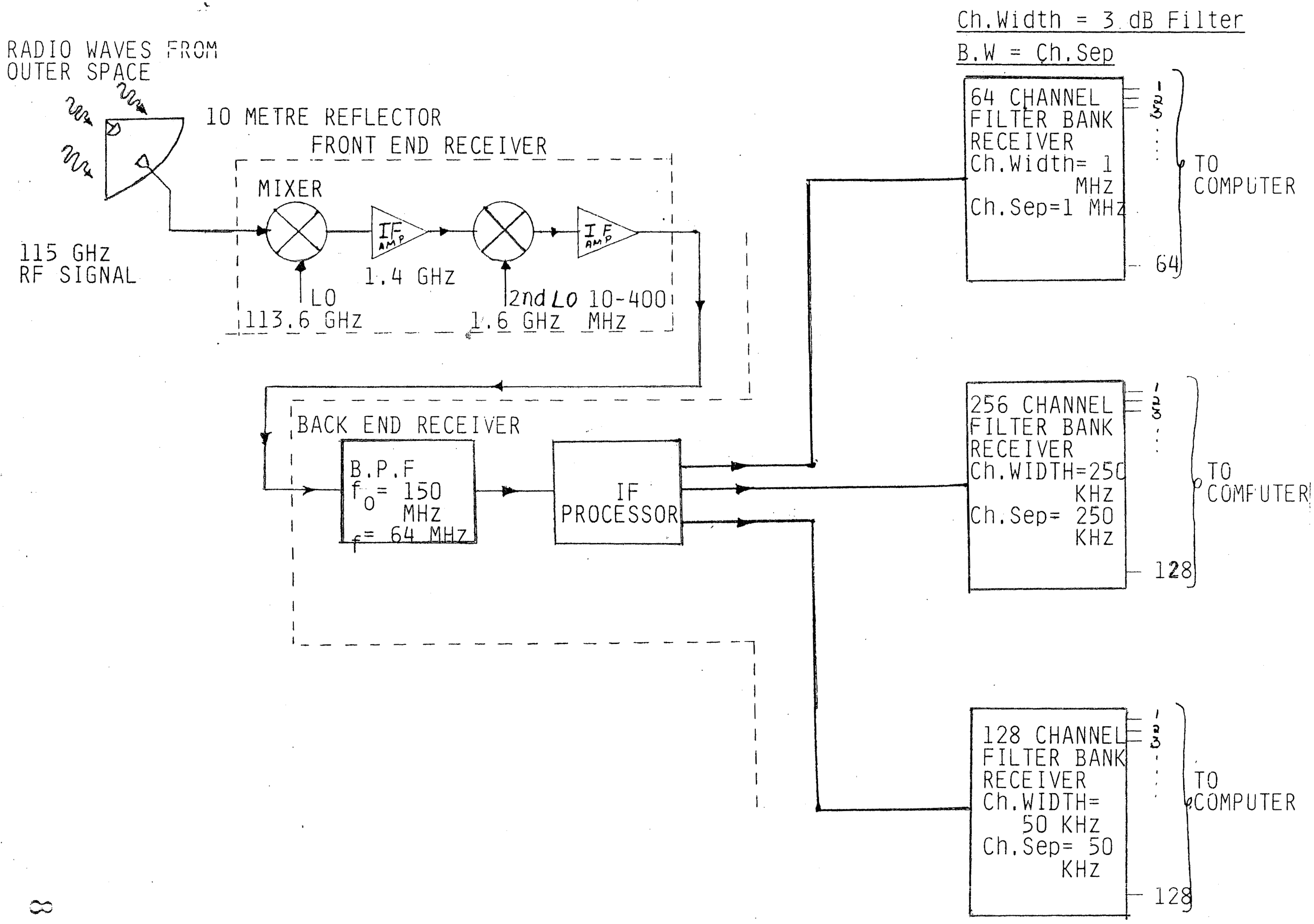


FIG. 1.3: SIMPLIFIED BLOCK DIAGRAM OF THE RECEIVER AT RRI

frequency of the incoming line radiation for identifying the molecular species. The advantages of Gunn Oscillators over Reflex Klystron tubes which are presently in use are as follows:

(i) Gunn Oscillators provide very low Amplitude Modulated (AM) noise.

(ii) Klystron tubes have limited operating life (approx.5000 hrs.)

(iii) High voltage supplies are needed for Klystron tubes.

(iv) Klystron tubes are costlier than Gunn Oscillators.

With recent availability of solid state millimeter devices like IMPATT diodes and Gunn diodes, these disadvantages have been taken care of.

IMPATT diodes although more efficient and having higher power levels than Gunn devices, have not replaced Gunn diodes as Gunn devices have less AM noise particularly at modulation frequency away from the carrier. IMPATT diodes also have the disadvantages of higher voltage requirement and do not lend themselves to tuning over nearly as wide a frequency range as Gunn diodes.

Moreover with recent development of superconductivity tunnel junction mixers for millimeter wave frequencies which require extremely low LO powers (a few 10's nano watts), The interest in solid state LO sources like Gunn oscillators has increased considerably.

1.3 SCOPE OF PRESENT WORK

The present work is concerned with the development of Gunn oscillator for millimeter wave radio astronomy receivers for 75-110 GHz atmospheric transmission window band. Resonant cap Gunn oscillators operating in a harmonic extraction mode have been constructed for the 75-115 GHz frequency range.

A new design for millimeter wave Gunn oscillators using a rectangular waveguide has been developed by researchers at RRI. The scope of the present project was the detailed experimental investigation of the effects of the various oscillator circuit parameters.

The large amount of data thus collected has been analyzed and interpreted based on the requirements of oscillator design.

The advantages of building an oscillator at this high frequency over using a frequency multiplier and an low frequency oscillator are the following :

(i) The oscillator is extremely reliable since it is constructed using a packaged Gunn diode.

(ii) The oscillator frequency is insensitive to load mismatches, since its fundamental mode cannot propagate through the output waveguide, thus a broad band isolator is unnecessary.

(iii) The output power is higher than would be produced by a frequency multiplier.

This oscillator has to be phase-locked for application in receivers designed for molecular spectroscopy.

CHAPTER II

CHAPTER II

PREVIOUS WORK

Ever since J.B. GUNN [9] discovered the Transferred Electron Effect in 1963, a remarkable breakthrough of great importance came to light. It marked the first instance of useful semicondcutor device operation depending on the bulk properties of a material.

Having taken the microwave world more or less by storm, Gunn diode oscillators are widely used and also intensely researched and developed. They are employed frequently as low and medium power oscillators in microwave receivers and instruments. The Klystron oscillator was a good means of obtaining microwave oscillations.

Although the Klystron has a good noise performance, it could not be employed in Local oscillator applications because of a very limited operating life. Moreover it required a costly, bulky high voltage regulated power supply. Thus the need for a reliable solid state alternative to the Klystron LO was felt for a long period of time.

With the advent of the millimeter wave GaAs Gunn diodes a cheaper and less bulky alternative for low noise LO applications was realised.(Kramer 1976)[15]

These Gunn oscillators were of Post-coupled design and worked in the 33-50 GHz band. (Ondria 1979)[19].

These Post-coupled oscillator worked in the fundamental mode of oscillation which was limited by the Transferred electron effect of the Gunn diode.(Ruttan 1974-75) [21,22].

To increase the upper frequency range (Barth 1981)[3] improved the design and proposed a Resonant Cap Gunn Oscillator which worked in the range of the fundamental frequency of the diode.

The past few years have seen the development of numerous designs for second harmonic Gunn oscillators.

In every case, a packaged Gunn diode is embedded in a waveguide resonator at its fundamental frequency and its second harmonic is coupled out using suitable waveguides whose cut-off frequency is above the fundamental frequency of the Gunn-diode.

The oscillator may consist of a diode embedded in a waveguide cavity having a disk and post configuration which are tuned with a mechanically adjustable backshort. To improve power a dual backshort system may be adopted.

A second harmonic oscillator with a continuous tuning range of 35 GHz between 70-105 GHz and a power output of 1 to 5 mW have been earlier described by Haydl.[11,12,13].

More recently a team of Scientists [4] from University of California at Berkeley have described a second harmonic Gunn oscillator which is mechanically tunable over a range of 50 GHz band width from 65-115 GHz which has a power output of 2 to 20 mW over most of this frequency range.

They clearly mentioned that the power dips drastically after the 105 GHz frequency and may be this was atributed to the upper cut-off frequency limitation of the Transferred electron effect of GaAs.

The oscillator described in this project is based on the Gunn Oscillator built by T.K.Sridharan[RRI] which consists of disk and post resonator with a mechanically adjustable post length essentially, a variable co-axial cavity. In this report, extensive measurements of the power output are reported, as well as the tuning range of oscillator with different resonator dimensions.With a careful optimization of these dimensions, a frequency tuning of around 30 GHz (85 GHz to 115 GHz) has been attempted with a power output of approximately 0.2 to 3 mW over most of this band.

CHAPTER III

CHAPTER III

BASIC GUNN OSCILLATOR DESIGN

3.1 INTRODUCTION (OSCILLATOR REQUIREMENTS FOR ASTRONOMY)

As discussed in Chapter I, the 85-115 GHz frequency band is also an atmospheric transmission window for ground based radio astronomical observations. The rotational transitions (spectral lines) of several astrophysically important molecules eg. acetal dehyde (CH_3-CHO 79.150 GHz), methyl alcohol(CH_3-OH-96.741 GHz), silicon monosulphide (SiS-108.924 GHz), carbon monoxide (Co-115.8 and 230.64 GHz) lie in this frequency band. Over 70 molecules with over 1000 transition lines are known in interstellar space, earth's atmosphere, comets, star forming regions, etc. This band is known as the W-band of the electromagnetic spectrum.

Observations of these molecules gives information on the physical conditions eg., temperature, density, ionization state, radiation environment, magnetic field, turbulence, etc., in the region being studied.

Here Gunn diodes have been used to develop a solid state source due to their low noise characteristics. The resonant cap circuit was first developed for milimeter wave IMPATT diodes (Lee et. al., 1968). In this circuit, a metal cap of about half-wavelength diameter was placed directly above the diode and the output tapped using a rectangular waveguide. The oscillation frequency of this circuit was mainly determined by the dimensions of the resonant cap.

In this project measurements for the 85-115 GHz band Gunn oscillator using a resonant cap circuit in a rectangular waveguide are presented. The effect of various circuit parameters i.e., Dimensions of resonant cap, different diode packages, waveguides, chokes and filters, on the oscillation frequency and power is investigated experimentally. The various results and tabulations are given in the chapters to follow. The graphs which show the results are also enclosed.

For use in millimeter radio astronomy it is desired to have a reliable, stable oscillator (LO) system which can be tuned in the 3 mm atmospheric window from roughly 85 to 115 GHz.

Since the mixers now used for this purpose are cryogenically cooled (20° K), a power of 0.1 mW is more than sufficient, considering the losses in coupling the LO to the mixer. One way to meet these requirements is to use a frequency multiplier to double or triple the output of lower frequency Gunn oscillators, but this causes an additional complexity to the system as it is not reliable and needs a broad band isolator to do away with the insensitivity to load mismatches. Moreover the power output of

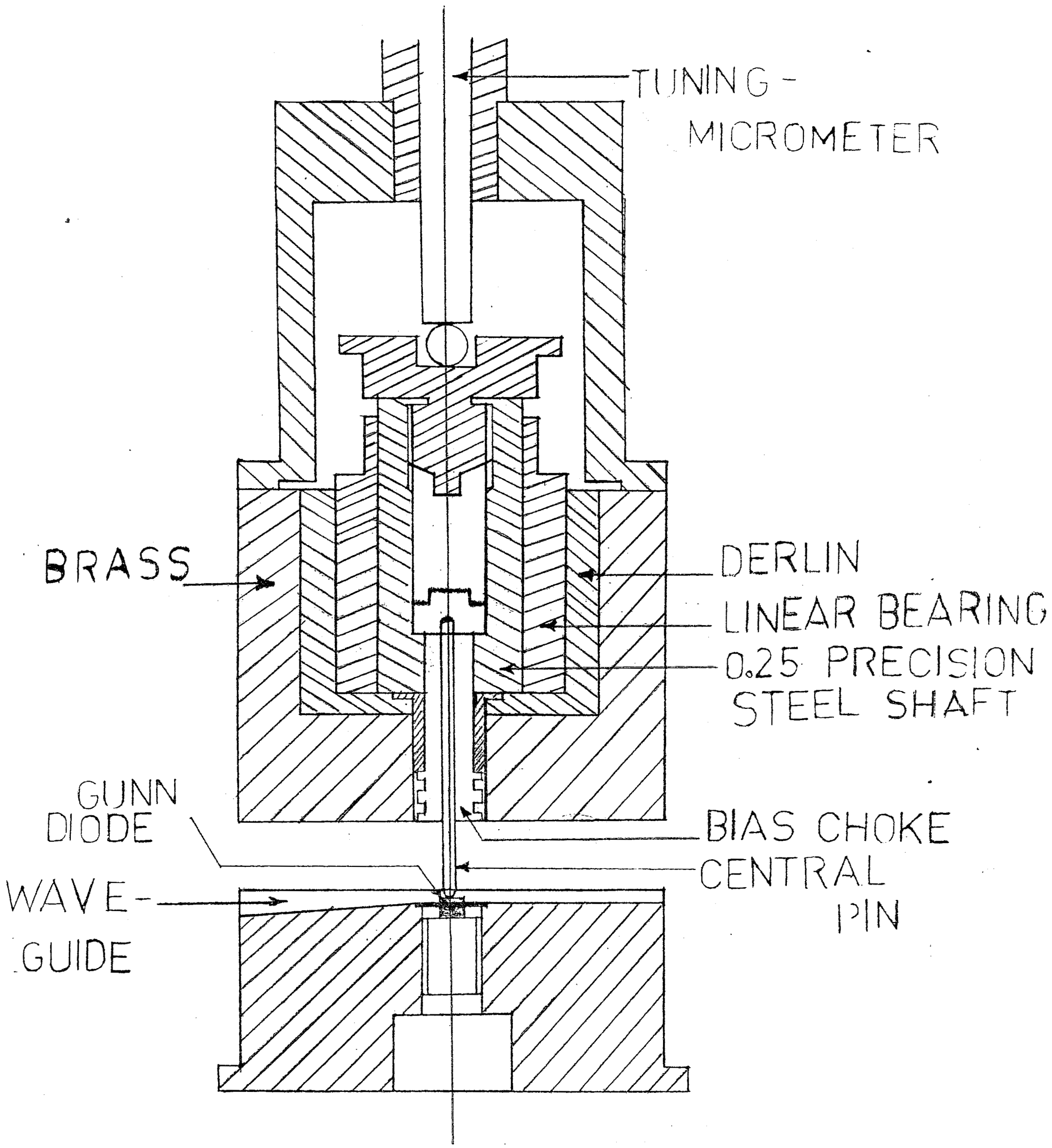


FIG. 3.1: CROSS-SECTIONAL VIEW OF THE ENTIRE OSCILLATOR BLOCK

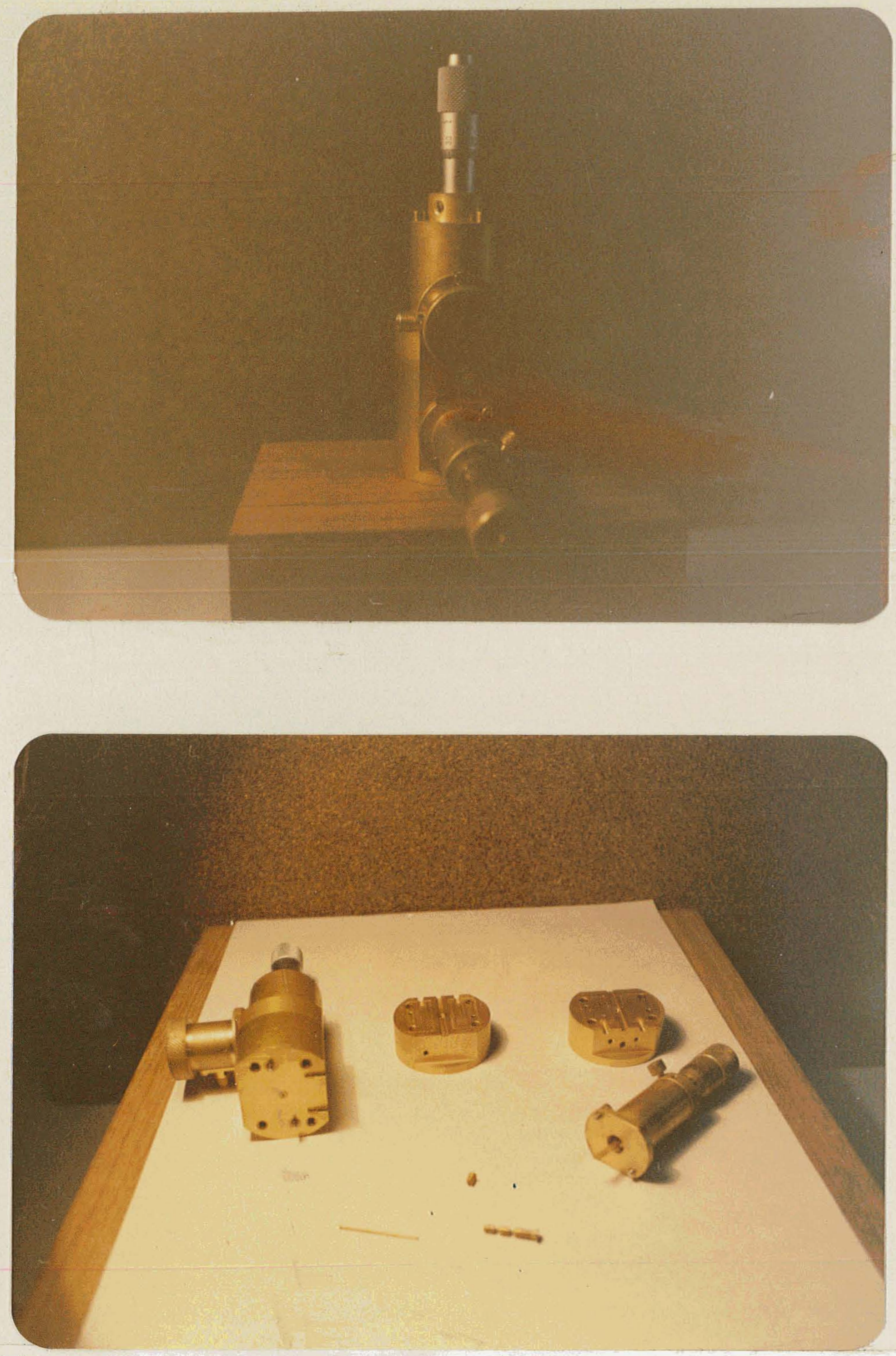


Fig 3.2 PHOTOGRAPH OF THE 85-115 GHz BAND GUNN OSCILLATOR IN A RECTANGULAR WAVEGUIDE.

(a) ASSEMBLED VIEW, (b) EXPLODED VIEW.

these multipliers are lower than that which can be produced by Gunn oscillators.

3.2 DESIGN AND CONSTRUCTION

A cross sectional view of the Gunn Oscillator is shown in Fig. 3.1 and a photograph is shown in Fig. 3.2. The Gunn diode is mounted on a massive copper plug which acts as a heat sink and is screwed into a section of a rectangular waveguide ~~and~~ which serves ~~at~~ as the bottom wall of the cavity. The waveguide used is either a WR-10 waveguide (2.54 mm wide to 1.27 height) or WR-8 (2.32 mm x 1.02 mm) which is reduced to half height. The d.c. bias for the Gunn diode is provided through a metal post which has a resonant cap at its end.

A bias choke forms the top wall of the cavity. The cavity's length is mechanically adjusted by sliding this choke up and down over the central pin. This is done using a micrometer arrangement. As shown in Fig. 3.1, a compression spring inside the choke ensures that the pin always makes contact to the diode. A micrometer driven non-contacting backshort is also provided in the waveguide section behind the Gunn diode.

The coaxial cavity and Gunn diode form a resonant circuit which produce oscillation at the fundamental frequency which is one half of the desired output frequency. By changing the length of the coaxial cavity, one can tune over the fundamental frequency range of roughly 40 to 60 GHz.

As the current waveform of the Gunn diode is non-sinusoidal, higher harmonics of the fundamental frequency are also generated inside the cavity. These harmonics are coupled out using a WR-10 or WR-8 waveguides.

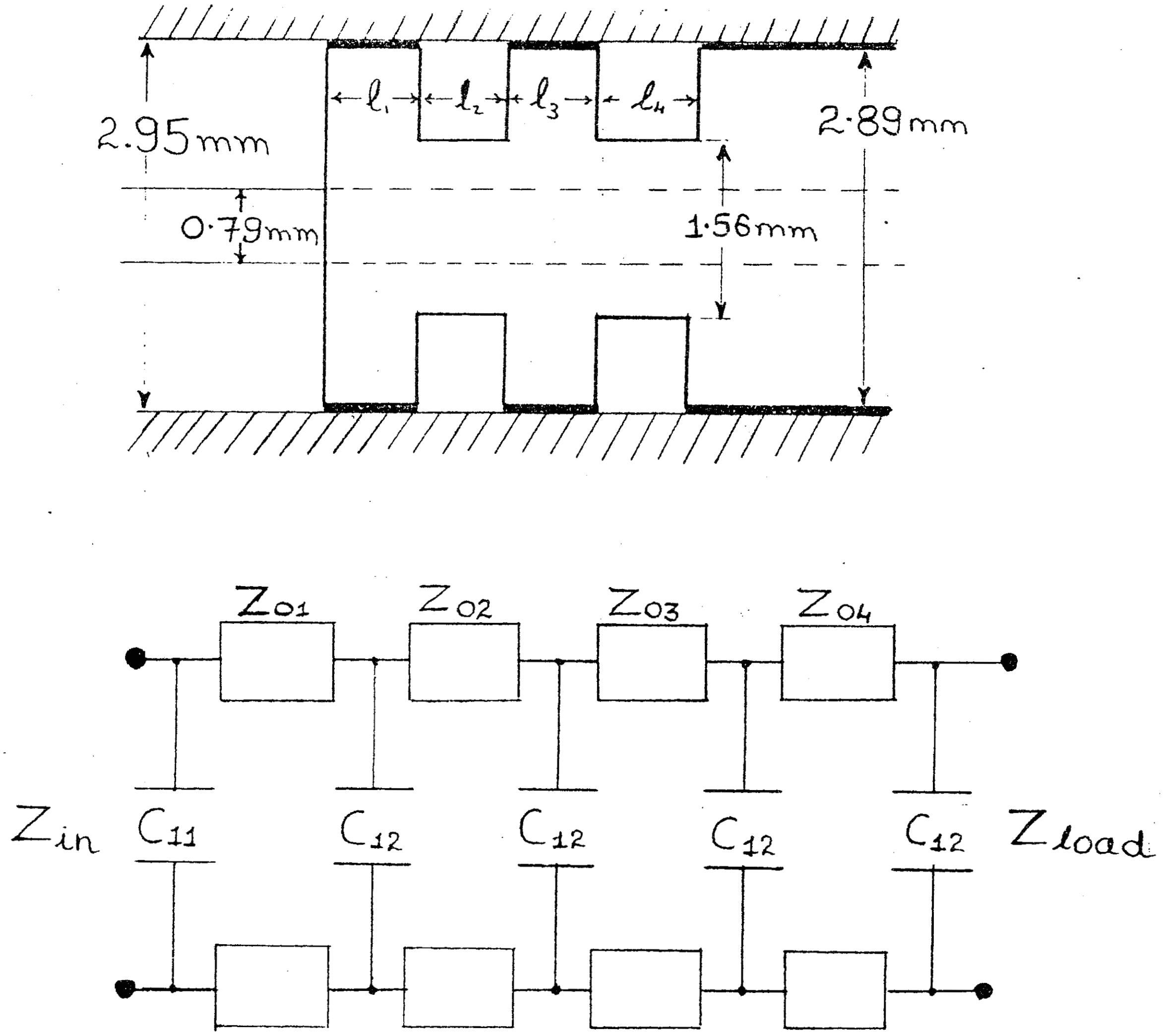
3.3 BIAS CHOKE

The design for the bias choke has been earlier proposed by Carlstrom, Plambeck and Thornton.[4]

The choke used in this oscillator is a four section non-contacting design which was optimised with the aid of a computer program for circuit analysis (COMPACT, from Comsat General Integrated System, Palo Alto, CA). The dimension and design of the choke are given in Fig. 3.3. The equivalent circuit used is also given.

The fringing capacitances used in the equivalent circuit were calculated from the curves given by Whinnery, Jamuson and Robbins.[25] Because of Transverse dimensions and distance between discontinuties are not insignificant compared to a wavelength, the capacitances calculated are only a rough approximation.

FIG. 3.3: BIAS LINE FILTER AND EQUIVALENT CIRCUIT



C_{11} = 0.17pF
Z_{in} = 78.6
Z_{01} = 1.3
Z_{02} = 38.1
Z_{03} = 1.3
Z_{04} = 38.1

C_{12} = 0.15pF
Z_{load} = 1.3
l_1 = 0.71mm
l_2 = 0.67mm
l_3 = 0.76mm
l_4 = 1.14mm

To ensure that the choke does not touch the cavity wall, the upper section of the choke assembly is encased in a hard plastic material - Delrin. The tuning mechanism used is illustrated in Fig. 3.4. The choke is mounted on a 0.25 mm Idiam precision steel shaft which slides up and down in a linear bearing. To avoid backlash error the shaft is spring loaded against the tuning micrometer. The entire linear bearing is electrically insulated from the oscillator block by a plastic insert.

3.4 WAVEGUIDE

The above Gunn oscillator was constructed and tested for two standard waveguides. We first used a WR-10 (75-110 GHz) which has dimensions of 2.54 mm width and 1.27 mm height which has a cut off frequency of 59.055 GHz in its dominant mode TE_{10} for rectangular waveguides. As the power was dropping drastically for frequencies above 100 GHz, we used another waveguide with the resonator circuit.

The second Gunn oscillator was built with a WR-8 waveguide which operates in the F-band of the electromagnetic spectrum. It operates in the range of 93-140 GHz with dimension 2.03 mm width and 1.02 mm height and has a cut off frequency of 73.892 GHz.

Experimental studies on these two waveguide showed that the WR-10 waveguides gave power outputs of 1 mW and more while the WR-8 waveguide had a power of 0.2 mW and more.

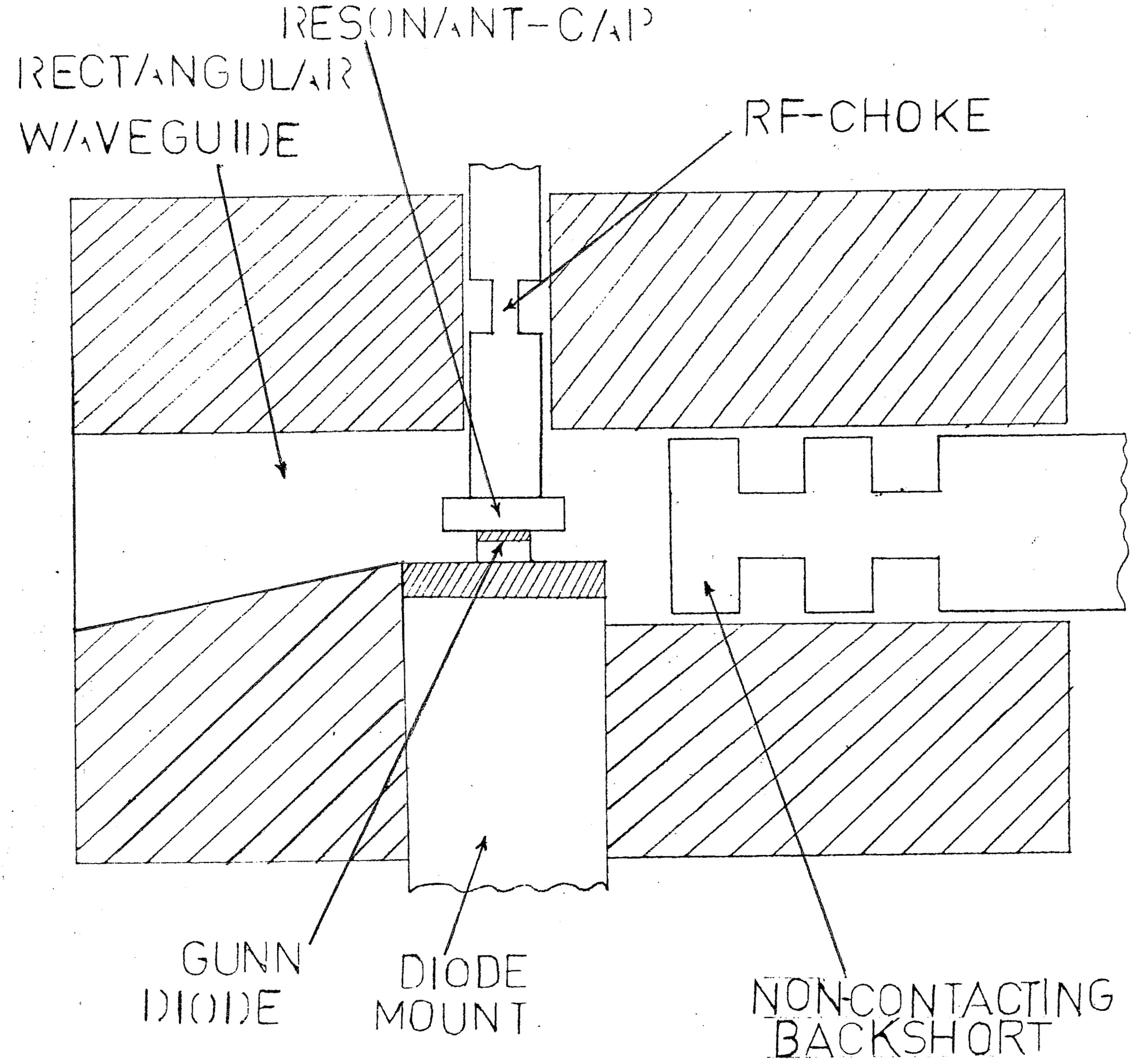


FIG. 3.4: TUNING MECHANISM OF THE RESONANT CAP GUNN OSCILLATOR IN A RECTANGULAR WAVEGUIDE.

But in the WR-8 waveguide we could widen the band width of the oscillator till 120 GHz. Since both the waveguides were milled in the bottom blocks of the oscillator and were using the same top block, some minor changes had to be incorporated so that no load mismatches were formed. The changes incorporated in the WR-8 waveguide are as shown in Fig. 3.5.

The waveguides used were of half height for the following reasons.

1) Since the impedance of the waveguide and the diode are different, a reduced height waveguide is used for impedance matching. 2) As the height of the diode above the heat sink is about 0.5 mm and the height of the standard waveguide about 1 mm, half height waveguides had to be used.

However, the output powers obtained with the reduced height waveguide Gunn oscillator are slightly lower than those obtained with the standard waveguide circuit, perhaps due to the lower quality factor (Q) of the reduced height waveguide cavity.

The waveguides are machined to suit the dimension of the backshort behind the diode. Fig. 3.5 shows the constructional changes.

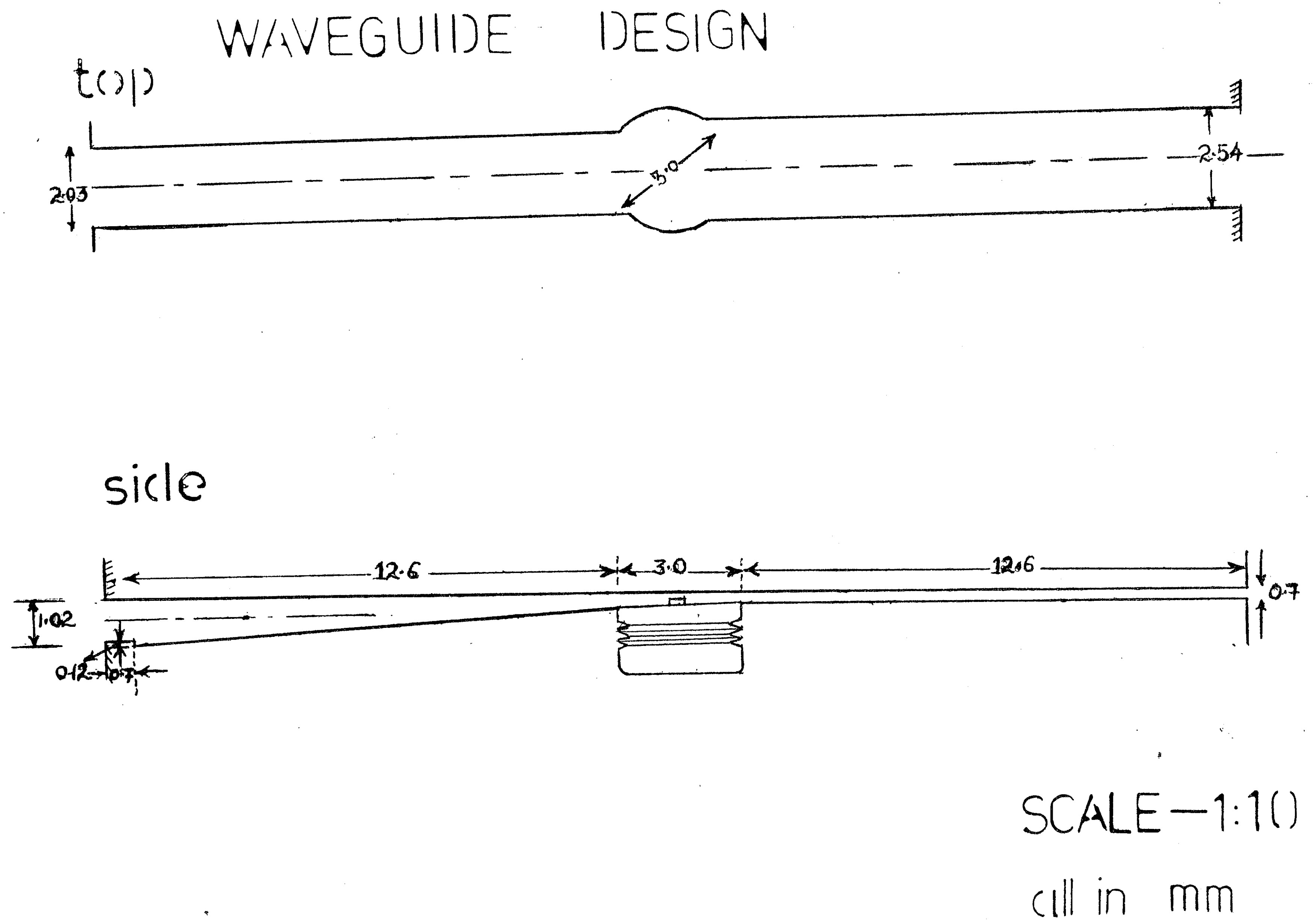


FIG. 3.5: CONSTRUCTIONAL CHANGES OF WAVEGUIDE INCORPORATED IN THE BOTTOM BLOCK OF WR-8 WAVEGUIDE.

3.5 WAVEGUIDE BACKSHORT

The waveguide backshort is a two-section noncontacting choke. The backshort position is adjusted only to maximize the power output of the oscillator. If the backshort is kept sufficiently far away from the co-axial cavity (mnore than about 1 mm) its position has only a minor effect on the oscillation frequency. Typically tuning the backshort over a full guide wavelength pulls the second harmonic frequency less than 50 MHz.

3.6 RESONANT CAP PINS

Four different Resonant cap pins were milled and extensive experiments were performed on each one of them. The pins were inserted into the Gunn Oscillator block and the frequency versus power characteristic noted.

This also acts as a central conductor and carries the bias voltage to the Gunn diode. The pin is machined to a tolerance of approximately ± 0.005 MM so that it fits snugly into the hole in the centre of the choke assembly, yet allows the choke to slide up and down smoothly. The disk is machined as an integral part of the pin. No solder connections are made to the central pin, so that pins with different sized disks can easily be interchanged. The dimensions of the resonant cap is as shown in Fig. 3.6.

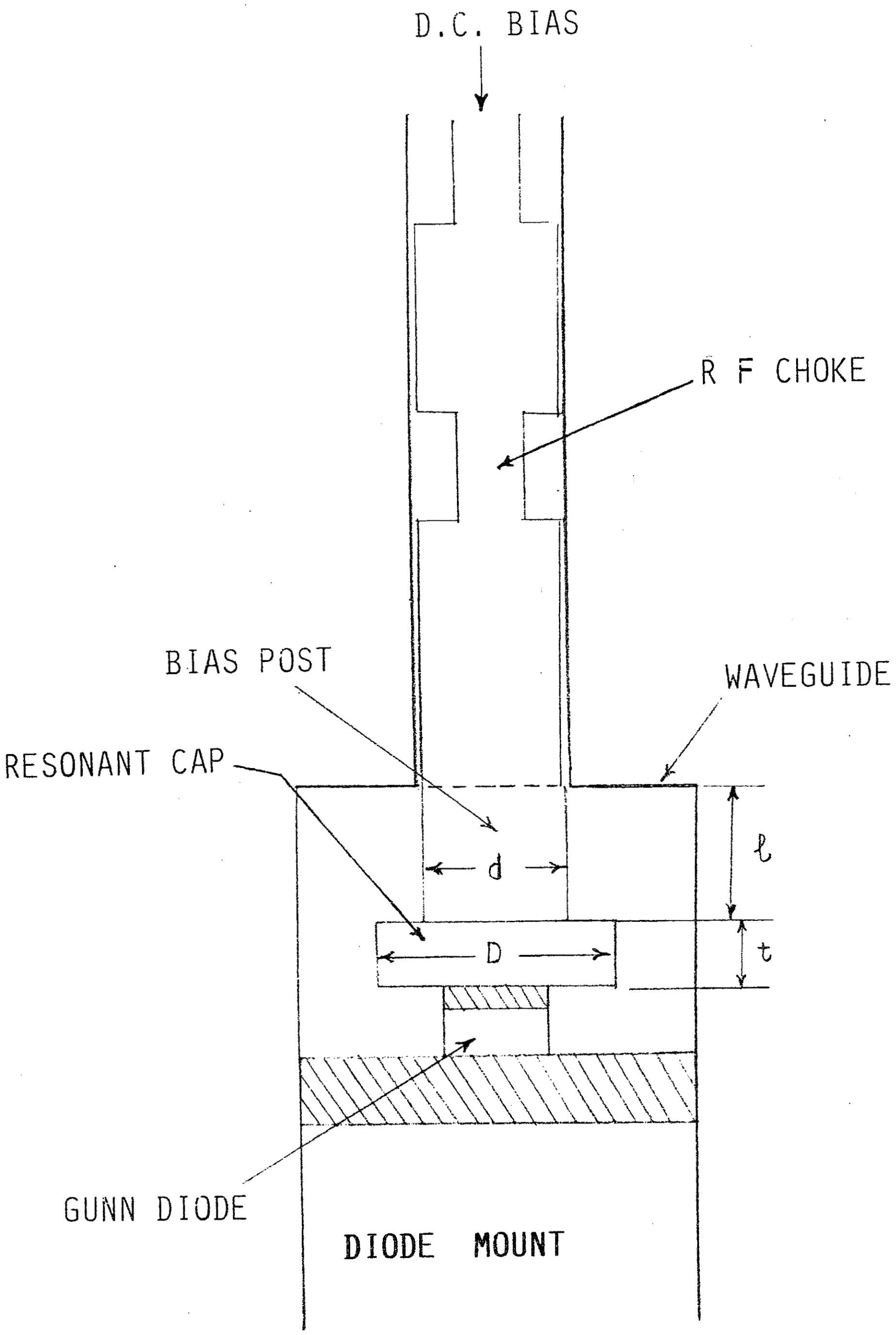


FIG. 3.6: DIMENSONAL PARAMETERS OF THE RESONANT CAP GUNN OSCILLATOR IN A RECTANGULAR WAVEGUIDE.

At the oscillator fundamental frequency the disk acts as a capacitor. At the second harmonic frequency the disk is roughly $\lambda/4$ in radius and serves as a radial line transformer, to tune out the diode reactance. The length of the radial line depends not only on the diameter of the disk but also the fringing capacitance formed by the edge of the disk to the cavity wall. Therefore the thickness (t) of the disk also plays a important role. The impedence of the radial line transformer depends on the height (h) of the disk above the waveguide floor. Thus the oscillator's output power also depends on all of these dimensions.

The post of the resonant cap having a diameter 'd' and length 'l' behaves like an inductor.

The cap and the post together form a fundamental frequency resonant circuit below the cut off frequency of the waveguide.

In order to optimize the disk dimensions extensive tests were conducted and tuning range and power output of the oscillator were studied by varying disk diameter, thickness and height. The results have been plotted as given in the next chapter. The data collected is given in the APPENDIX-I of this report.

An increase in disk diameter 'D' or disk thickness increases the capacitance of the fundamental resonant circuit thereby decreasing the oscillation frequency on the other hand, increasing the diameter of the post 'd' increases the length of the radial line transformer thus increasing the oscillation frequency. We also note that by decreasing the length of post 'l' the frequency increases.

By increasing the disk height, the impedance of the transformation ratio decreases for the second harmonic and thus lowers the output power.

Since the fringing capacitance of the disk also depends on the diameter of the co-axial cavity any change in disk dimensions will also lead to changes in diameter of the cavity.

We did not change the diameter of the coaxial cavity as the diodes we were using had a fixed heat sink diameter of 2.95 mm. So a standard cavity of 2.95 mm was used throughout our experimental studies.

Thus optimising power at higher frequencies depends on a combination of its parameters. Only a 'cut and try' method can give us a solution. This method has been attempted here.

CHAPTER IV

CHAPTER IV

GUNN DEVICES

4.1 INTRODUCTION

Gunn effect devices (or Gunn diodes) are named after J.B.Gunn, who in 1963,[9] whilst studying the properties of thin specimens of gallium Arsenide (GaAs) and Indium Phosphide (InP) under high electric stress ; discovered periodic fluctuations in the current passed by both materials when the applied voltage exceeded a certain critical value. The particularly interesting feature of these experiments was that the frequency of oscillation could be made to lie in the microwave range by using specimens a few thousandths of an inch in thickness, and peak power outputs of several watts could be obtained with inputs of only a few volts. (The mechanism responsible for this effect has been predicted by Ridley and Watkins and by Hilsum).[24]

It is essentially that of the transfer of electrons from the lowest valley in the conduction band to the valleys of higher energy where the mobility is less, leading to negative differential resistivity of travelling domains of high electric field within the semiconductor.

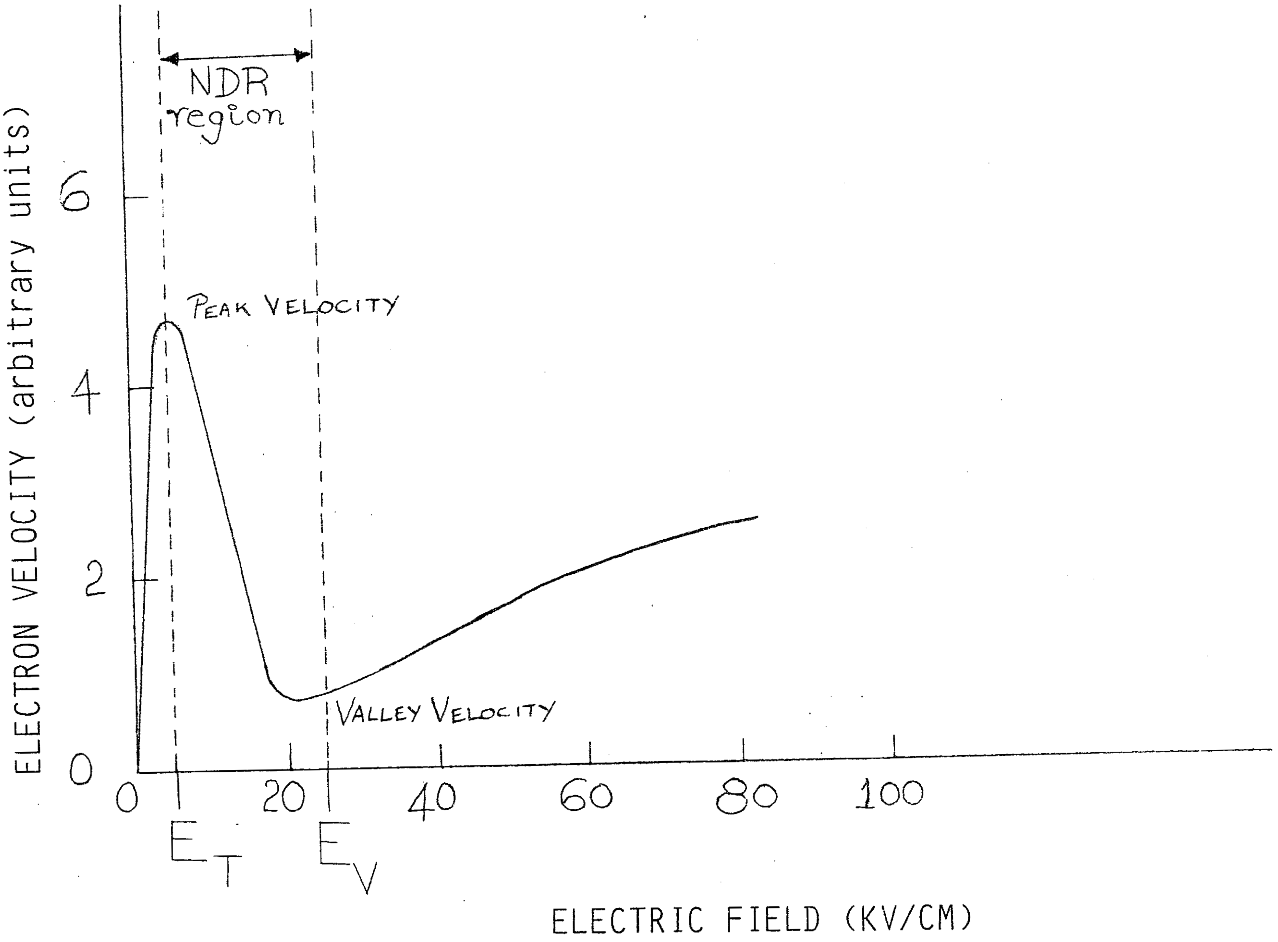


FIG. 4.1: VELOCITY VS. FIELD FOR n-TYPE GaAs

4.2 THEORY OF GUNN EFFECT OSCILLATION

The carriers in a semiconductor move about at random colliding with the lattice, with impurities and amongst themselves, and, in the presence of a small electric field they have a net drift in the direction of the field. On the application of a high electric field, the carriers gain energy from the field, the whole of which they cannot dissipate through the different collision processess. The average carrier energy as a result increases and with increase in carrier energy the loss process also becomes more efficient. An equilibrium is soon reached out with the carriers having an effective temperature greater than that they had before. This hot electron behaviour may give rise to an interesting effect in n-GaAs whose band structure is as shown in Fig. 4.2. The carriers are in the higher mobility lower valley initially, but with increasing electric field they become hot and go into the higher valley which has lower mobility. The current voltage characteristic can therefore be characterised by a negative resistance region. The negative differential resistance causes a periodic nucleation of a space charge layer at the cathode which moves towards the anode causing the current to oscillate between a maximum and a minimum value where the period of oscillation is essentially determined by the transit time of the dipole domain to traverse the length of the sample.

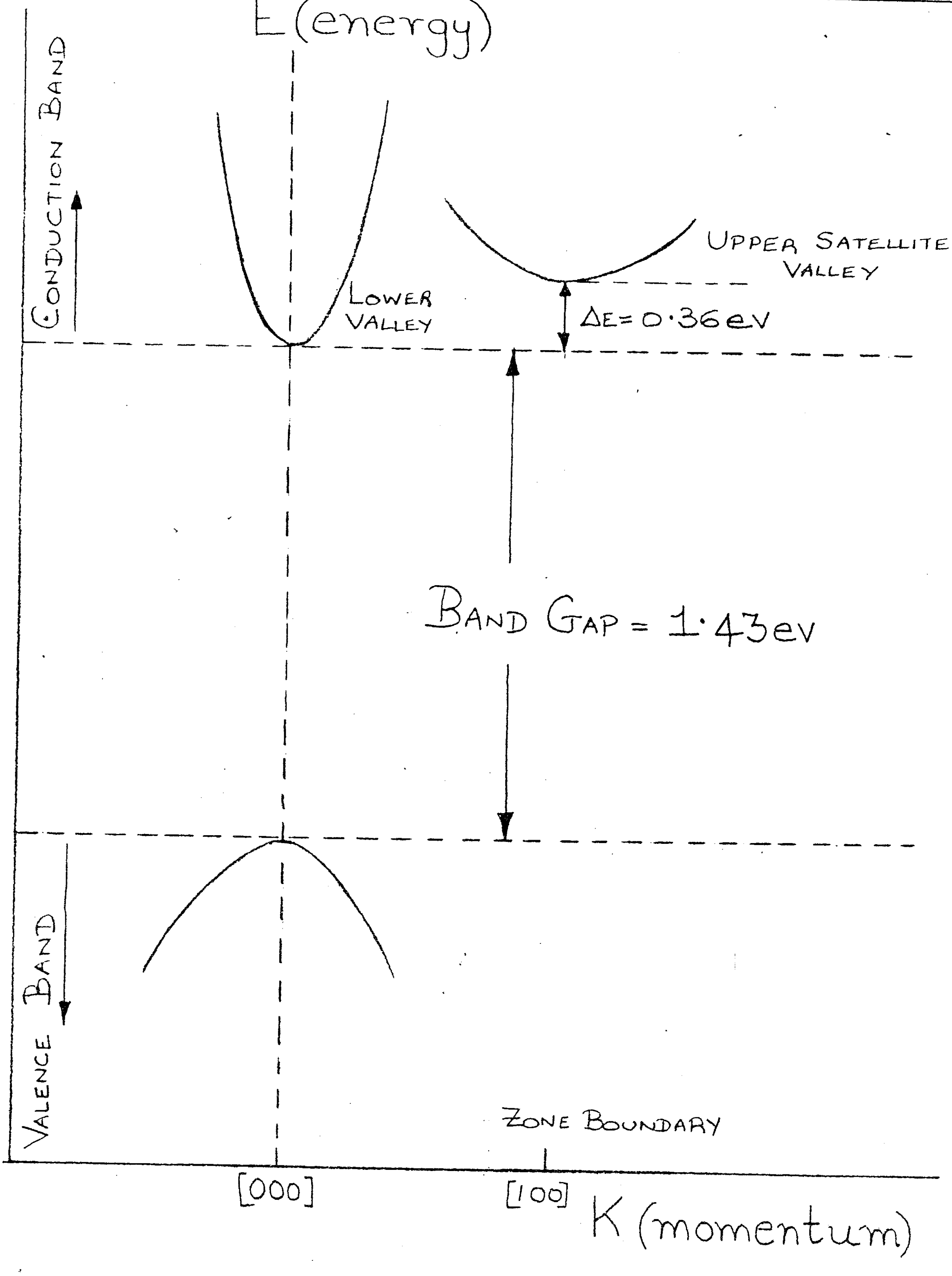


FIG. 4.2: ENERGY BAND DIAGRAM FOR GaAs ILLUSTRATING THE LOWER AND UPPER VALLEYS OF THE CONDUCTION BAND.

When the diode is placed in a cavity, there is an r.f. voltage swing across the diode which may delay the launching of a domnain or may 'quench' a domain during its transit. The diodes would then oscillate at the resonant frequency of the cavity and fairly wide tuning range of the oscillators could be achieved.

The conduction of an Negative Differential Mobility (NDM) material such as n-GaAs can be described in terms of a two conduction valleys model shown in Fig. 4.2.[8].

In order for a material to be useful for NDM, its band structure must satisfy the following criteria : (refer.Fig.4.3)

1) The energy difference between the bottom of the upper and lower valleys should be several times larger than the thermal energy (0.026 eV at room temperature). Otherwise the upper band would be highly populated at room temperature because of thermal excitations, even in the absence of an applied electric field.

2) The energy difference between the upper and lower valleys should be considerably smaller than the semiconductor band gap (1.43 eV for GaAs). Otherwise the semiconductor would break down and become highly conductive before electrons can be transferred to the upper valleys.

3) The electron mobility dV/dE should be much lower for the upper valleys than for the lower valley.

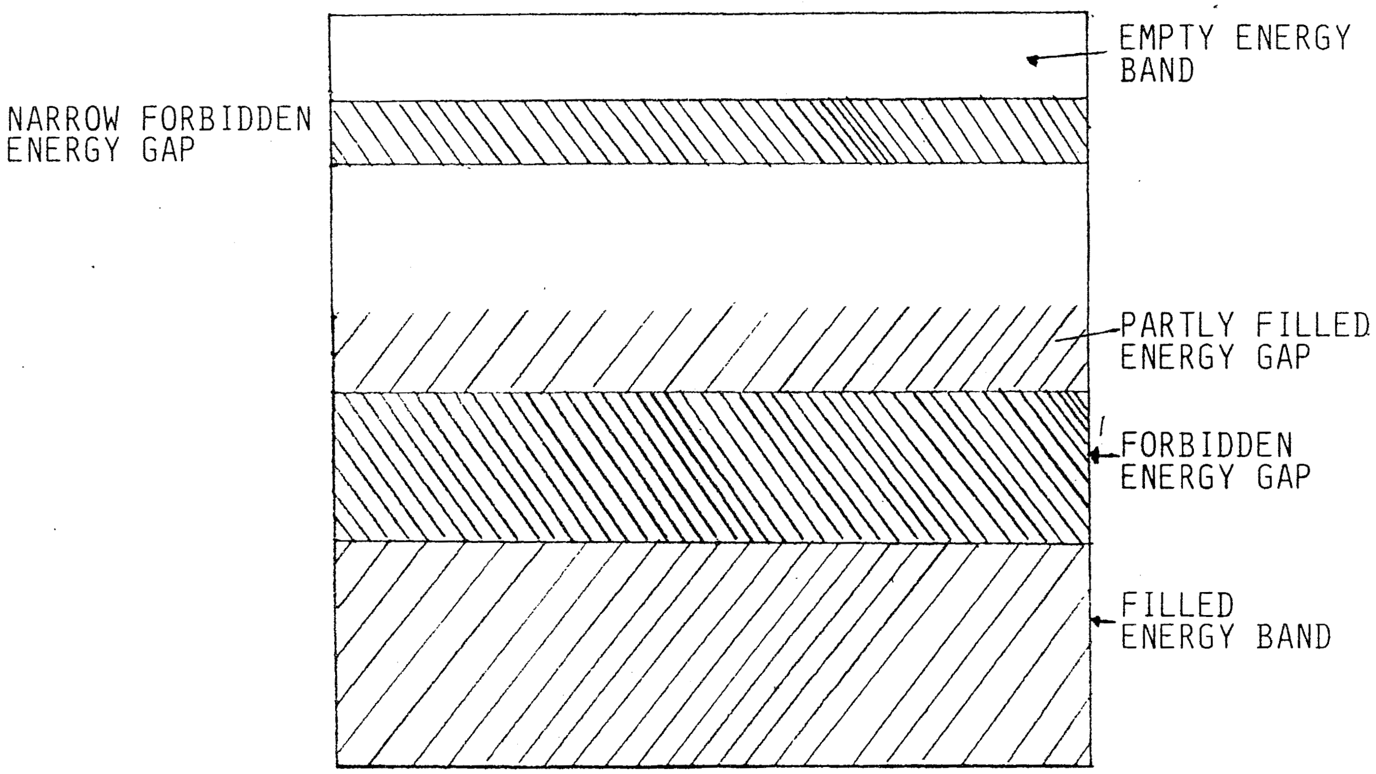


FIG. 4.3: IMPORTANT ENERGY LEVELS IN GaAs

Of all the NDM materials, n-GaAs is the most used because of its advanced technology.

The negative differential resistance property of Gunn devices gives rise to oscillations when placed in a suitable resonant cavity.

4.3 MODES OF OSCILLATION

The various modes in which the Gunn diode can oscillate depending on the device and circuit parameters are :

1) Transit time mode.
2) Quenched and delayed domain modes.
3) Limited space charge Accumulation (LSA) mode.
4) Hybrid mode.
5) Harmonic mode.

A reference to Fig. 4.4 [18] is solicited.

Transit time mode

This is the classical mode discovered by J.B. Gunn. In this mode the Gunn device is operated in a low Q resonant circuit just above the threshold voltage. When the device is biased into the negative differential mobility regime stable dipole domains are formed. Thus, the oscillation frequency of any device operating in this mode is directly related to the time these domains take to transit the device length, which is given by

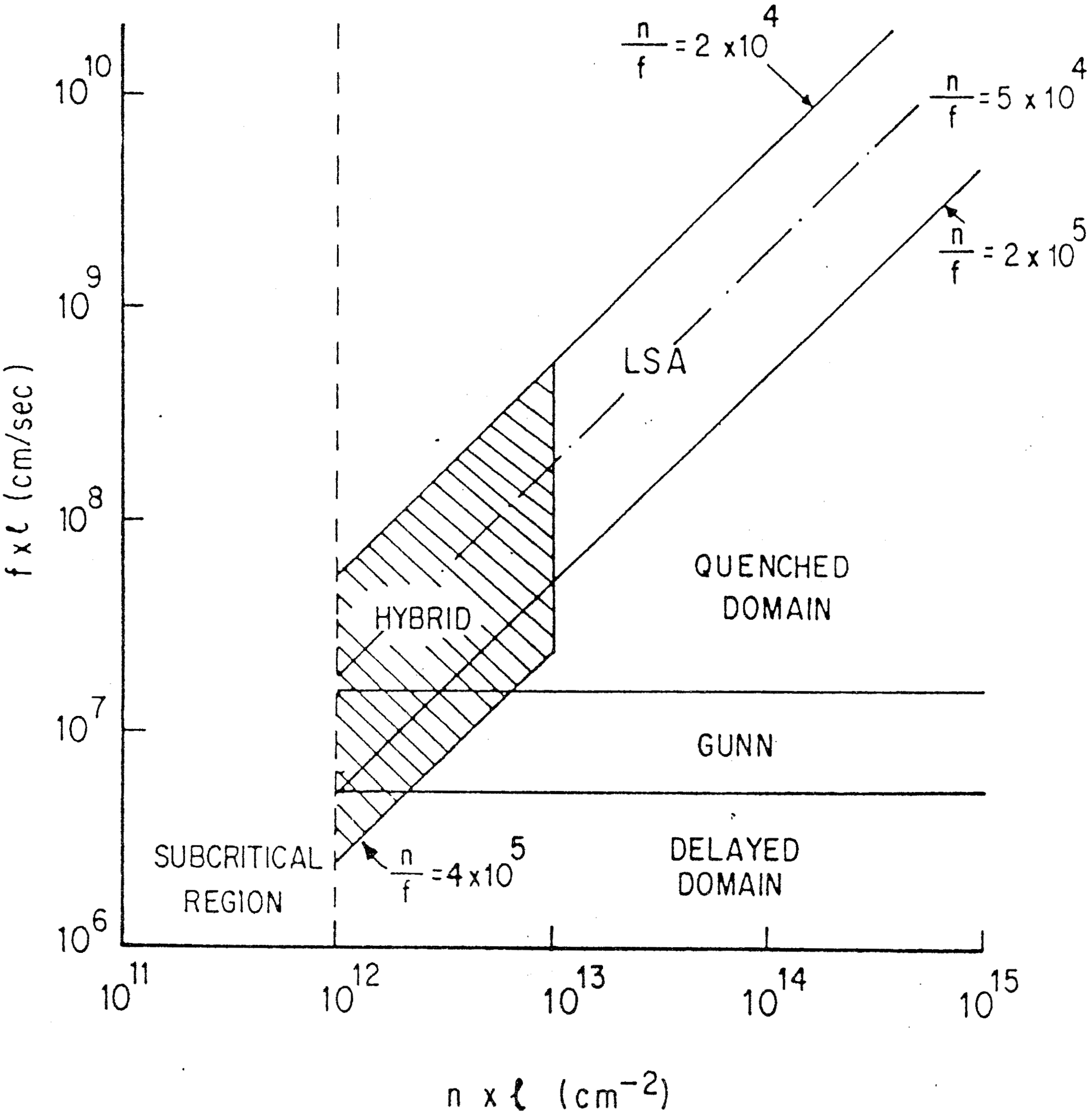


FIG. 4.4 OSCILLATION MODES OF A GUNN DIODE.
(after Narayan and Sterzer, 1970)

$f = V/l$ where,

f = oscillation frequency in GHz

V = saturated carrier velocity in Km/sec.

l = length of device active layer in micrometres.

Quenched and delayed-domain modes

If the resistive load at which the transit time modes were observed is replaced by a resonant circuit with a high Q-factor, the efficiency may be increased considerably. In these circumstances, period of oscillations will now be determined by the resonant behaviour of the external circuit. Thus, the two modes having the delayed (under voltage or inhibited) and the quenched (over voltage) domain modes result.

In the quenched mode, a fully formed domain is discharged or "quenched" before it reaches the anode. The period of r.f. oscillations can be smaller than a full domain transit time. In the delayed doman mode, period of r.f. oscillations is larger than the transit time, and the domains travel the full length of transferred electron device. Nucleation of new domains is across the TED's (Transferred electron devices) is below threshold.

Limited space charge Accumulation (LSA) mode

Discovered by Copeland in 1966.[6].In this mode of operation, the device is placed in a resonator tuned to a frequency several times the transit time frequency. A biasing several times the threshold voltage is applied to the device. As voltage goes above threshold, the space-charge starts building up at the cathode, but the voltage swings below the threshold before a domain can form. The accumulated space charge drains in a very small fraction of RF cycle. Though the device spends most of the time in the negative mobility regime, the space charge is not allowed to build up. This mode requires the following condition to be met :

$2 \times 10^4 < n/f < 2 \times 10^5 \text{ S.cm}^{-3}$

Hybrid Mode

This mode lies mid-way between the domain and LSA modes. For operation in this mode, device and circuit parameters are so adjusted that mature domains are allowed to exist over part of the RF cycle. This mode discovered by Huang and Mackenzie in 1968 is not limited by the equation of LSA mode.

Harmonic Mode

Due to the 'cut-off' of the transferred electron effect in GaAs (Bosch and Thim, 1974) fundamental frequency operation of GaAs Gunn diodes is limited to 60 GHz.

However, by operating as efficient harmonic generators, GaAs Gunn devices are capable of yielding useful CW powers upto 100 GHz. This mode of operation was discovered by Eddison and Brookbanks in 1981 [7] when working on a W-band (75-110 GHz) resonant cap Gunn oscillator. In this mode of operation, the resonator is tuned to the fundamental frequency, while power delivered to the load is at harmonic frequency.

4.4 GUNN DIODE STRUCTURE AND PACKAGING

There are two main processes for the epitaxial growth of GaAs layers for Gunn diodes (Eastman, 1976) one is called vapour phase epitaxy (VPE) and uses pure arsenic trichloride and gallium as chemical sources. The other method, called liquid phase epitaxy (LPE), employs pure gallium saturated with GaAs as the chemical source.

The diodes which we have used (manufactured by Varian) are liquid phase epitaxially grown, bulk effect, transferred electron devices. Most commercially available Gunn diodes use GaAs material for their construction, since GaAs epitaxial processes are fully developed.

The features of Varian's Gallium Arsenide Gunn diodes are :

- High efficiency
- Low package parasitics

- High reliability
- Low FM and AM noise
- Good power and frequency stability

Since their noise characteristics are comparatively better than a reflex Klystron, they are particularly well suited for use as local oscillator (LO) sources and as transmitter oscillator sources for secure communication links.

Maximum Ratings

- Storage Temperature -54° C to + 175° C.
- Heat Sink Temperature -54° C to + 71° C.
- Active Layer Temperature 260° C
- Soldering Temperature 230° C for 5 sec

Structure

It consists of an n^+ GaAs substrate of about 25 micrometer thickness on which an n^+ buffer layer and an n-active layer are grown epitaxially as shown in Fig. 4.5.[2] A n^+ contact layer is then grown on the active layer and metal contacts are evaporated on this contact layer as well as on the n^+ substrate. An alloy of gold-indium-germanium is usually employed for metal contacts.

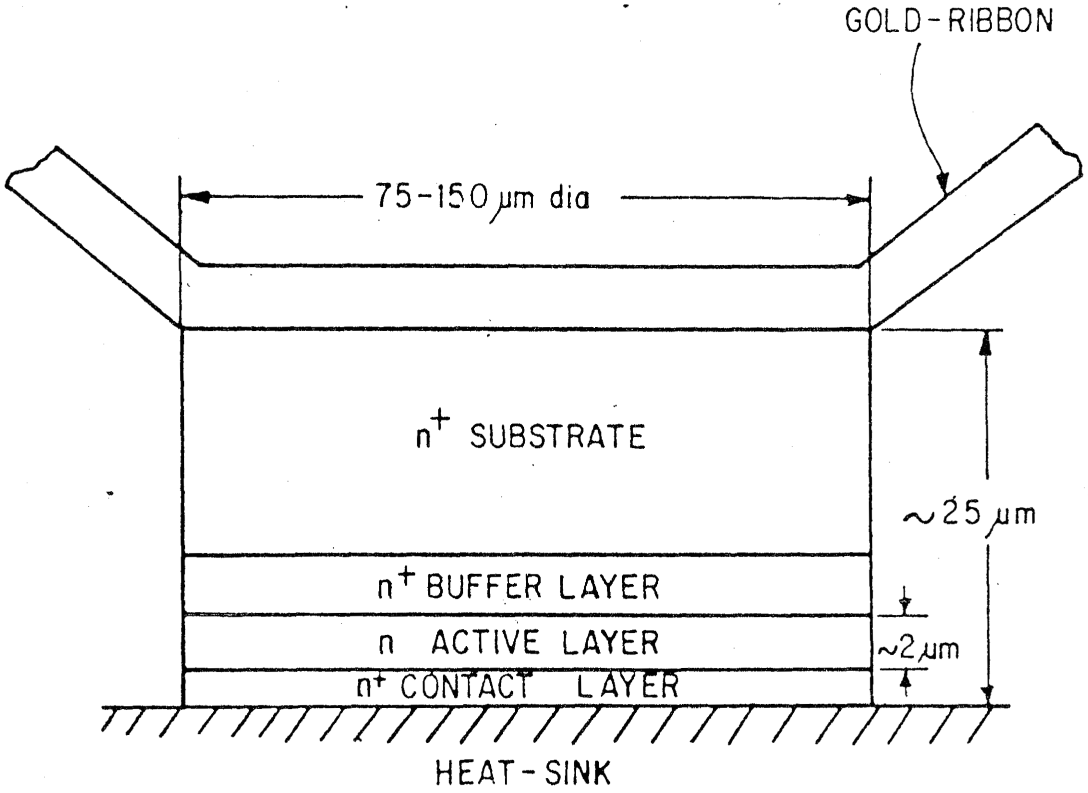


FIG. 4.5 STRUCTURE OF A TYPICAL MILLIMETRE WAVE GUNN DEVICE.
(after Kramer, 1976)

Owing to the fact that GaAs is a poor thermal conductor and that the contact layers and the solder joints of the device to the package also add to the overall thermal resistance, a major design consideration for CW Gunn diodes is an efficient heat transfer from the device to the surroundings.

A convenient device packaging helps in handling and circuit mounting of these devices. The package also must provide for heat transfer from the diode chip to the surroundings. A commonly employed sealed package is as shown in Fig. 4.6.[1]

The diode chip is soldered on top of a gold plated copper screw of surrounded by a miniature ceramic ring. A pair of crossed gold ribbons is thermocompression bonded to the top metallization of the chip, with the ceramic ring acting as an insulator. A metal cap is now brazed on to the ceramic ring to seal the package. This package is sufficiently rugged for easy circuit replacement and operates quite well for frequencies upto 100 GHz.

4.5 EQUIVALENT CIRCUIT

A simplified lumped equivalent circuit of a millimeter wave Gunn diode is shown in Fig. 4.7. The device is represented by a negative conductance Gn in shunt with the GaAs dielectric capacitance Cg package parasitics are represented by series inductance Ls and shunt capacitance Cp.

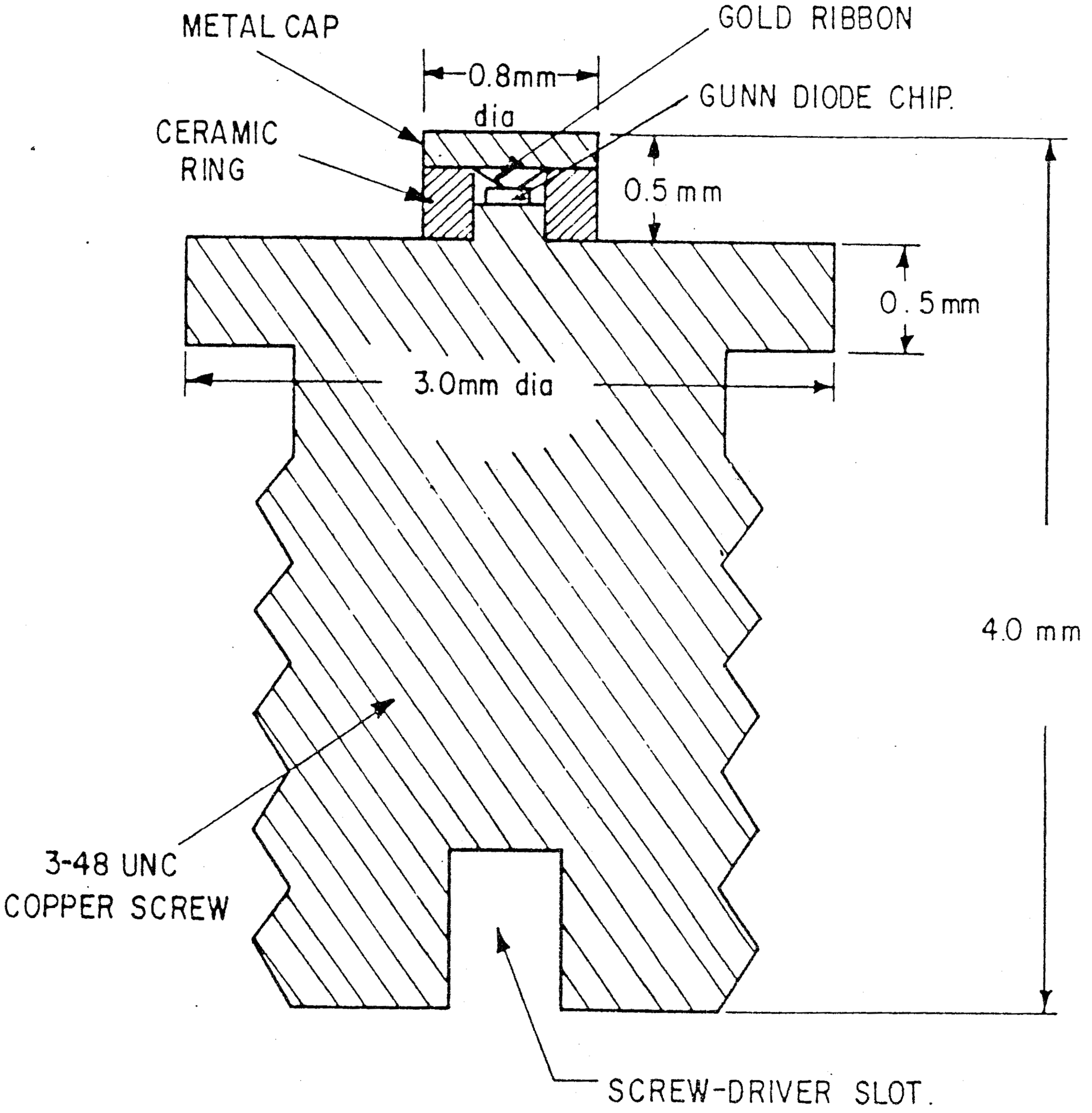


FIG. 4.6 MILLIMETRE-WAVE GUNN DIODE PACKAGE.

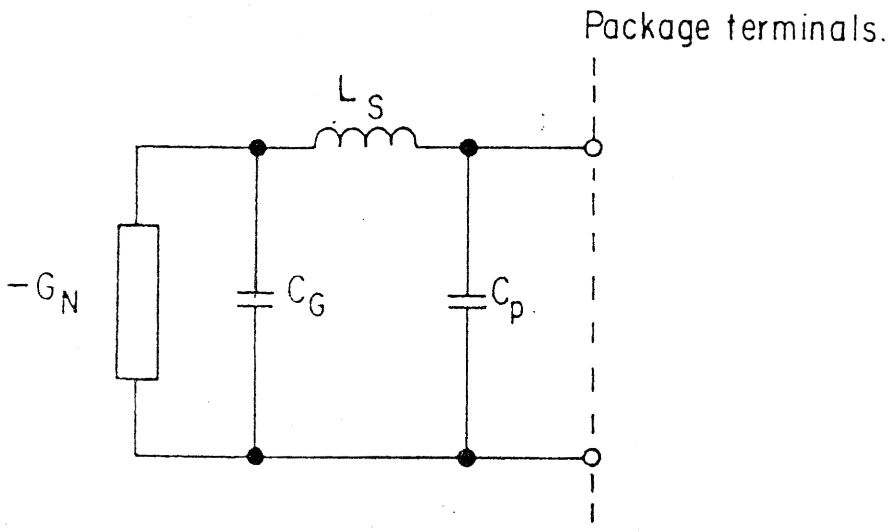


FIG. 4.7 SIMPLIFIED LUMPED EQUIVALENT CIRCUIT OF A PACKAGED GUNN DIODE. (after Bischoff, 1979)

4.6 OSCILLATOR DESIGN CONSIDERATIONS

Gunn diodes are two terminal negative resistance devices which require a suitable resonant circuit for generation of microwave power.

The design of Gunn oscillators is mostly carried out empirically. The performance of the Gunn oscillator is then optimized by experimentally observing the effect of various circuit parameters.

CHAPTER V

CHAPTER V

EXPERIMENTS AND GRAPHS

5.1 DESCRIPTIONS

The performance of the oscillator is evaluated in a standard 75-110 GHz rectangular waveguide measuring system.

A block diagram of the measurement set up is as shown in Fig. 5.1 and a photograph in Fig. 5.2. This consists of a ROTARY VANE TYPE precision variable attenuator, a waveguide cavity type frequency meter and a power meter employing a thin film thermocouple as the power sensor.

The Gunn oscillator is connected to the attenuator using standard waveguide couplers (Hughes). The variable attenuator works on a principle in which a vane is moved in and out of the waveguide. At maximum attenuation the vane,which consists of a resistive card absorbs the energy. At intermediate attenuation levels, a pre-determined section of the waveguide is obstructed which corresponds to a calibrated value on the rotary scale. This attenuator is used to ensure sufficient attenuation at all times between oscillator and the measuring system to avoid load pulling of the oscillator. However, no significant load pulling effects on the oscillation frequency was observed even when all attenuation was removed. The attenuator also avoids any

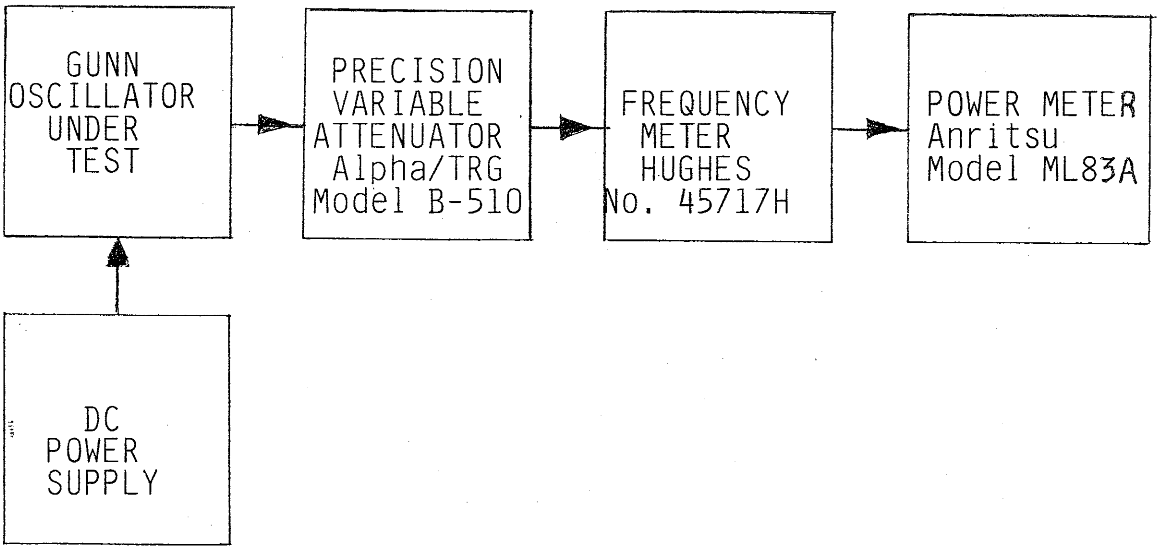


FIG. 5.1: BLOCK DIAGRAM OF THE MEASURING SETUP FOR THE 85-115 GHz FREQUENCY BAND GUNN OSCILLATORS.

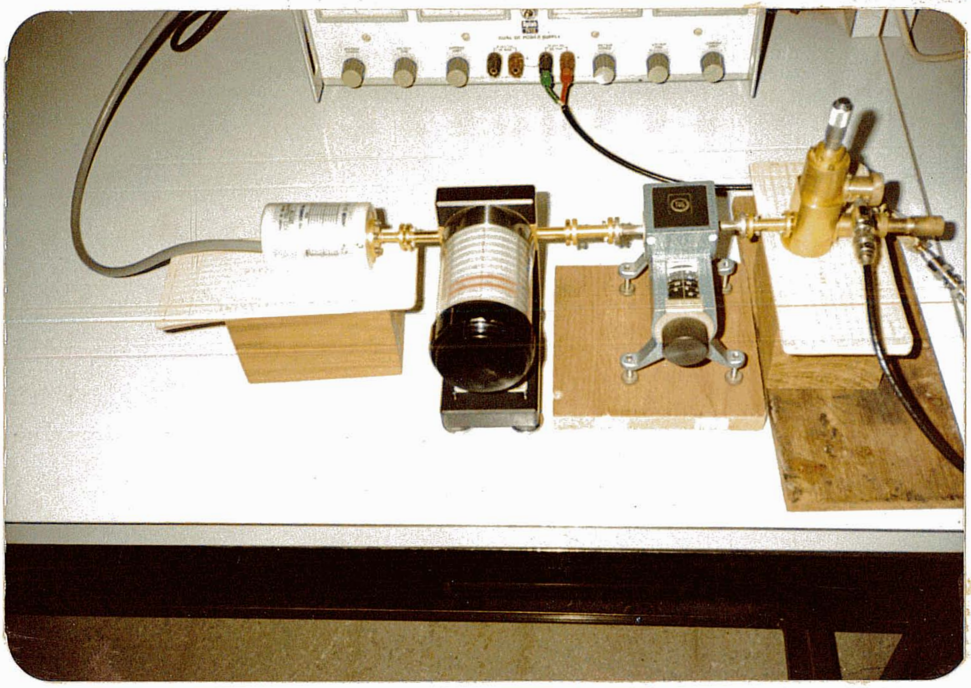
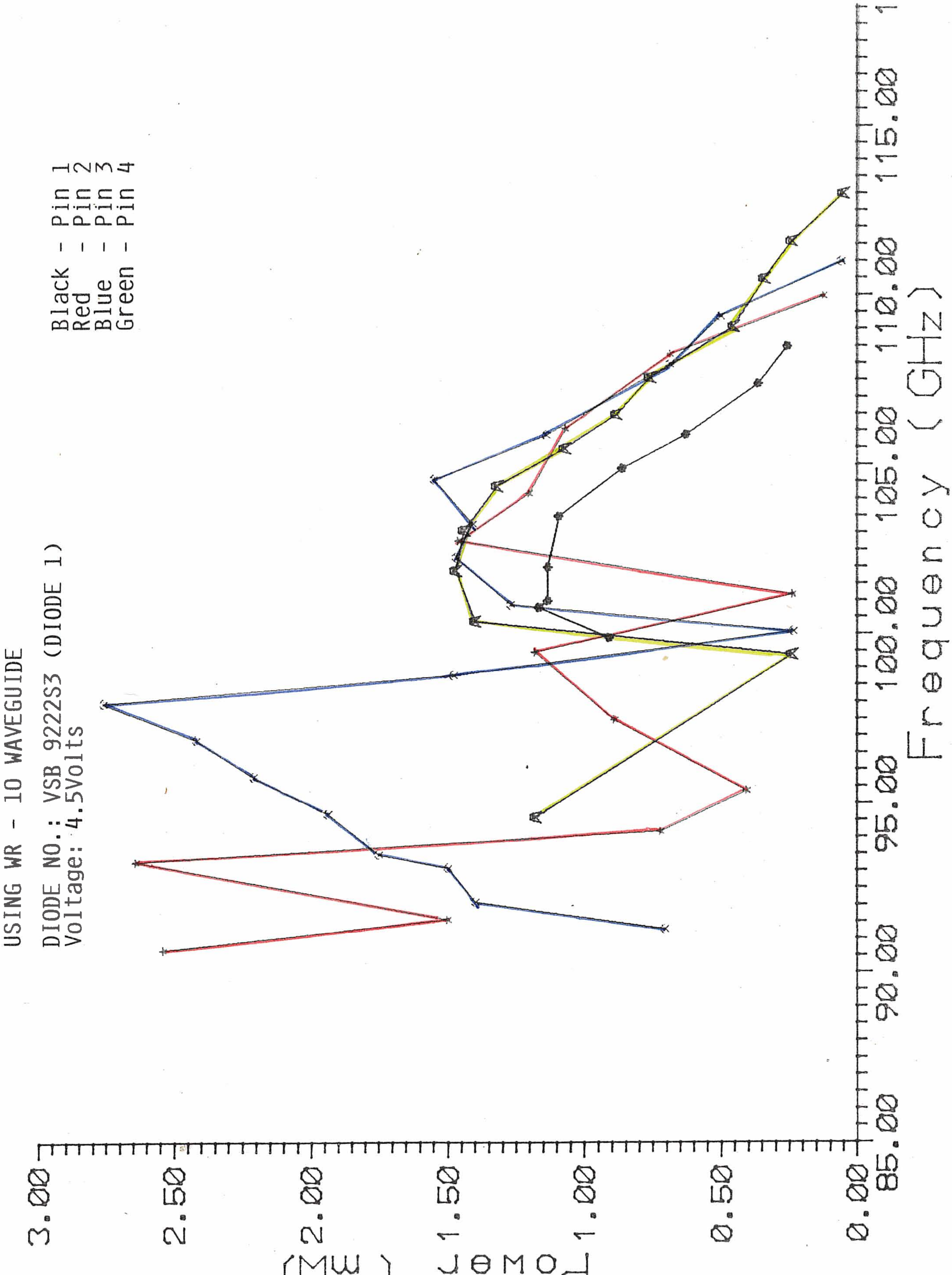


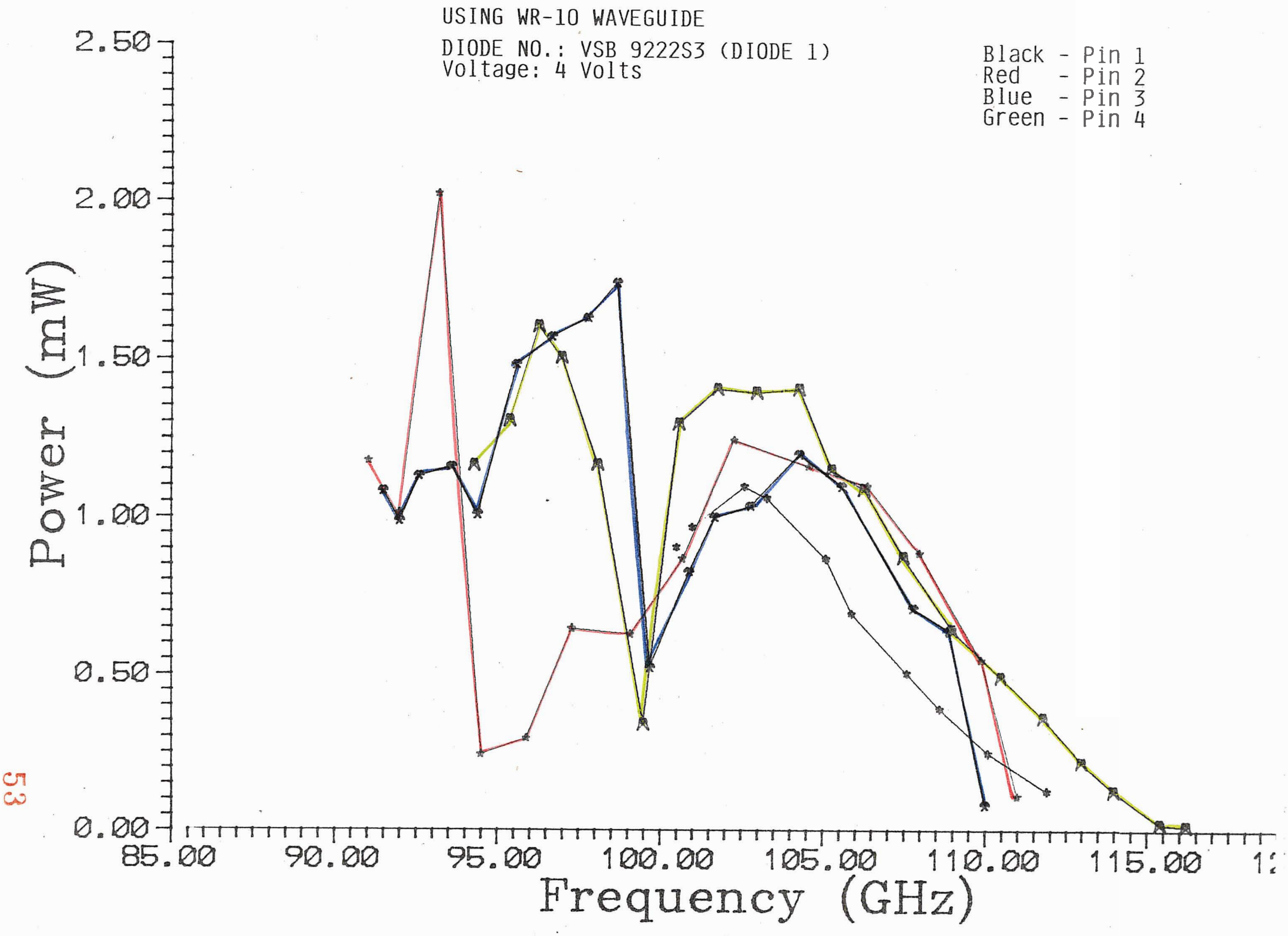
Fig 5.2 PHOTOGRAPH OF THE MEASURING SET UP FOR THE 85-115 GHz FREQUENCY BAND GUNN OSCILLATORS.

reflections of microwave oscillations from the measuring system back into the oscillator due to load mismatches. It also provides thermal isolation.

The output of the attenuator is then fed to a frequency meter using a standard waveguide. The frequency meter consists of a resonant cavity which absorbs power at its resonant frequency. By tuning this resonant cavity, at resonance the oscillations produced by the oscillator are absorbed by the resonant cavity of the meter thus producing a dip in the output power which is indicated by a 'kick back' of the pointer in the power meter. The tuning of the frequency meter is achieved by changing the size of the resonant cavity by means of a calibrated rotary scale on the frequency meter.

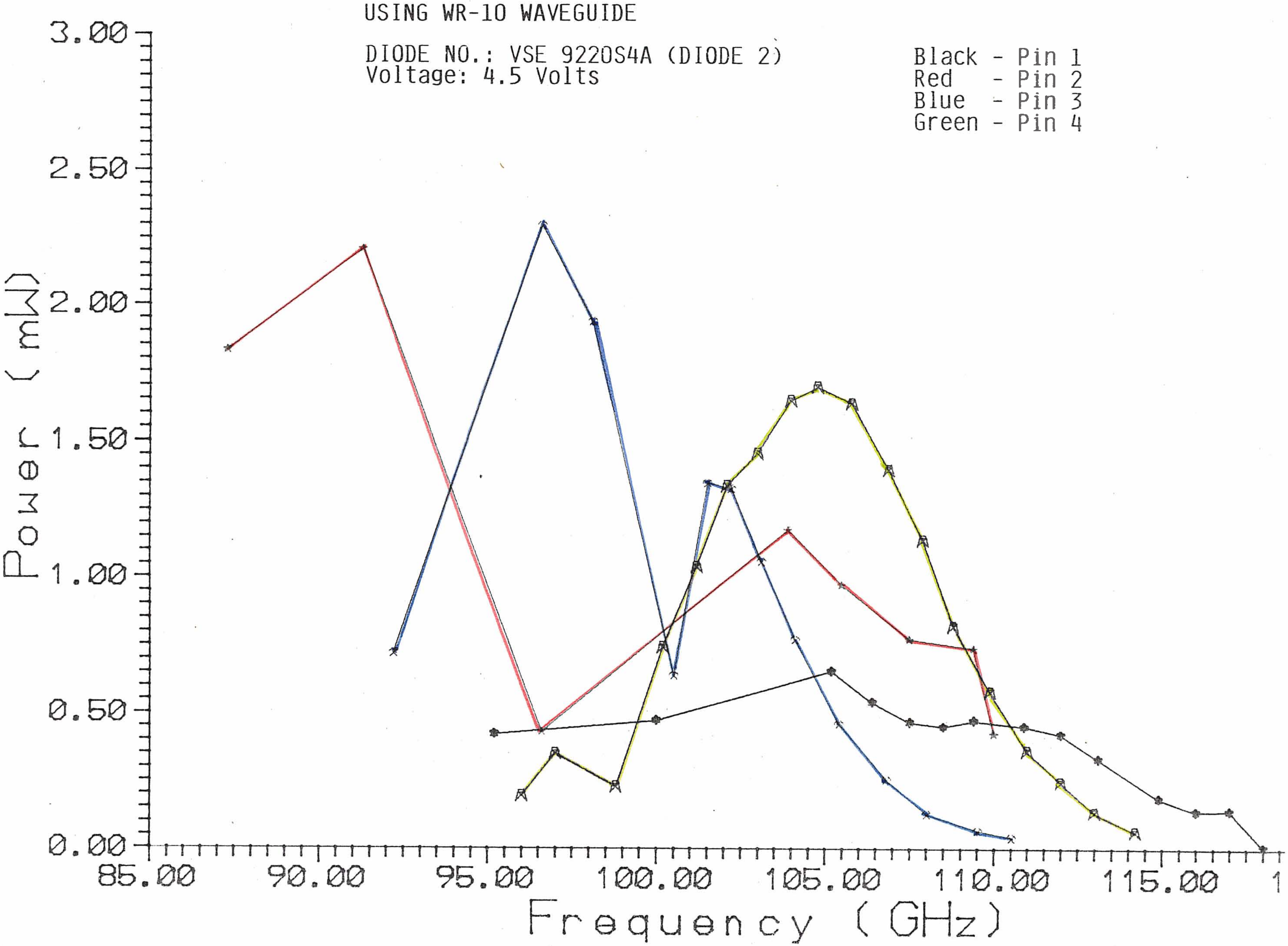
The output of the frequency meter is coupled to the power head of a power meter. The power head consists of a thin film thermocouple which acts as a power sensor. Here the power is used to heat the thermocouple. The heat produced in the thermocouple gives a corresponding d.c. voltage which is amplified and displayed, (with the option to correct for known loses in the waveguides.) The procedure adopted for measurement was to select a particular resonant cap and a diode. The oscillation frequency and power output as the cap position is varied inside the waveguide was noted. The backshort position was adjusted each time to maximize the power output. The

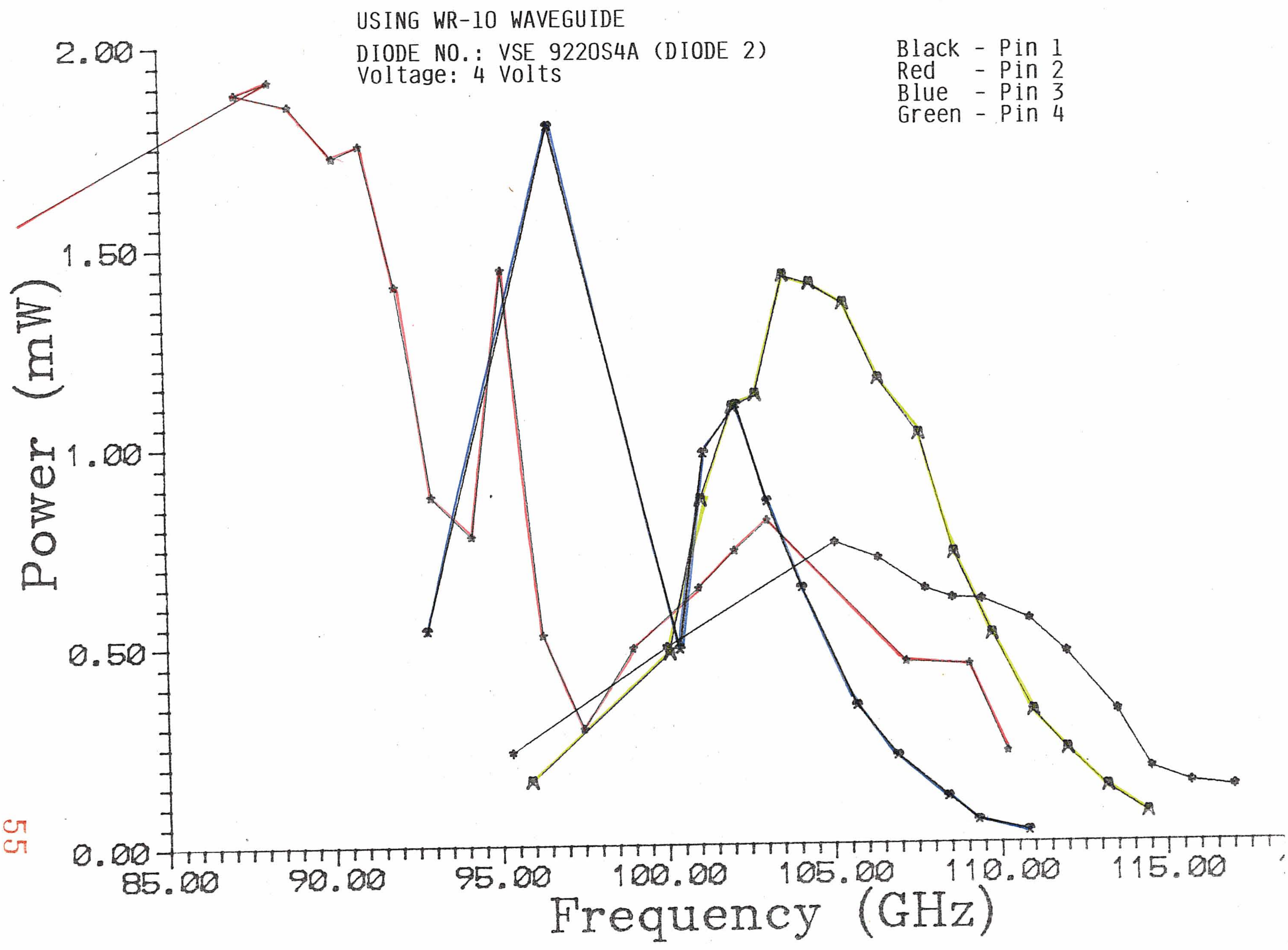

USING WR - 10 WAVEGUIDE
DIODE NO.: VSB 9222S3 (DIODE 1)
Voltage: 4.5Volts
Black - Pin 1
Red - Pin 2
Blue - Pin 3
Green - Pin 4
Power (mW)
0.00
0.50
1.00
1.50
2.00
2.50
3.00
85.00
90.00
95.00
100.00
105.00
110.00
115.00
1
Frequency (GHz)



USING WR-10 WAVEGUIDE

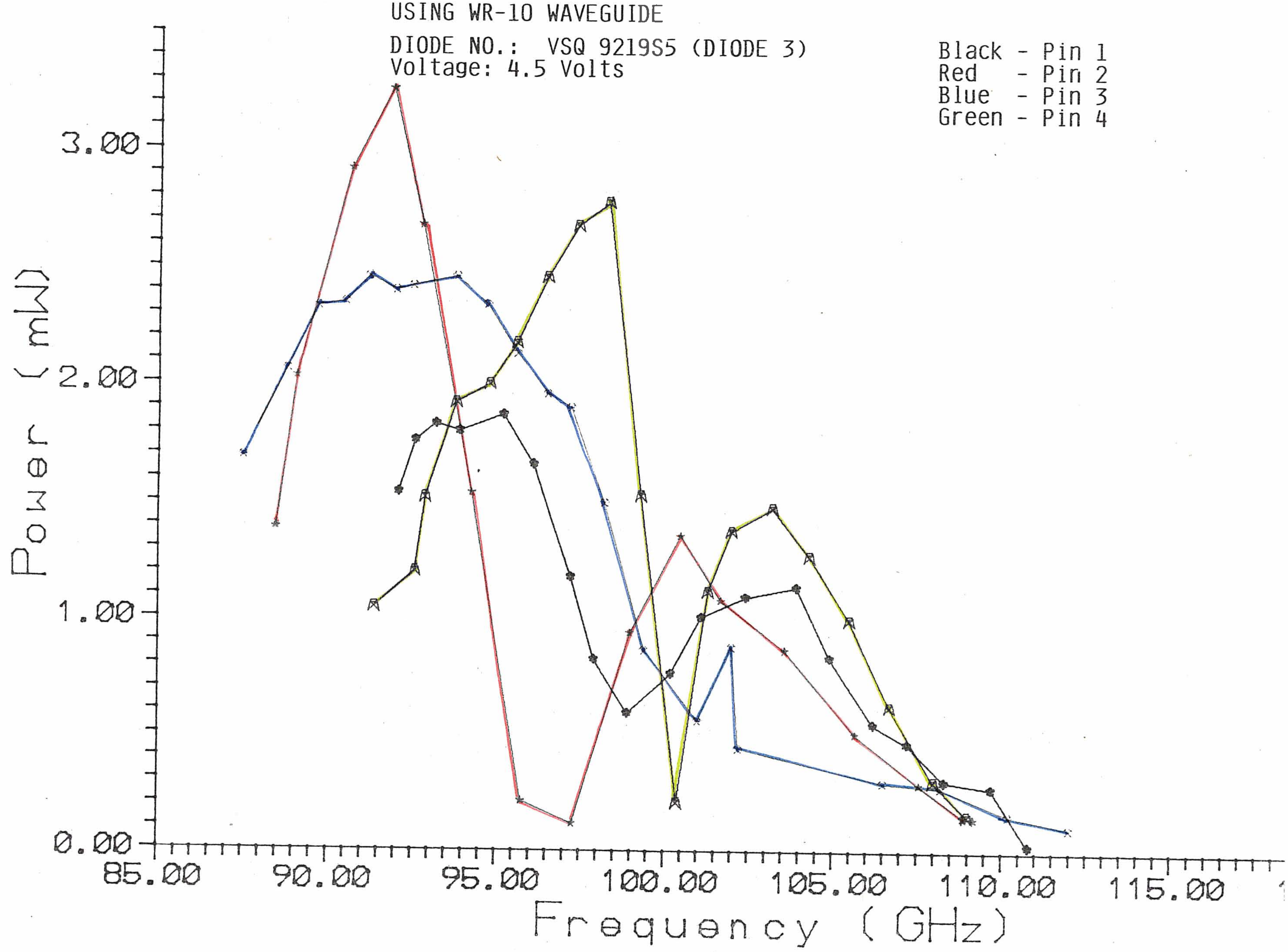
DIODE NO.: VSB 9222S3 (DIODE 1)
Voltage: 4 Volts

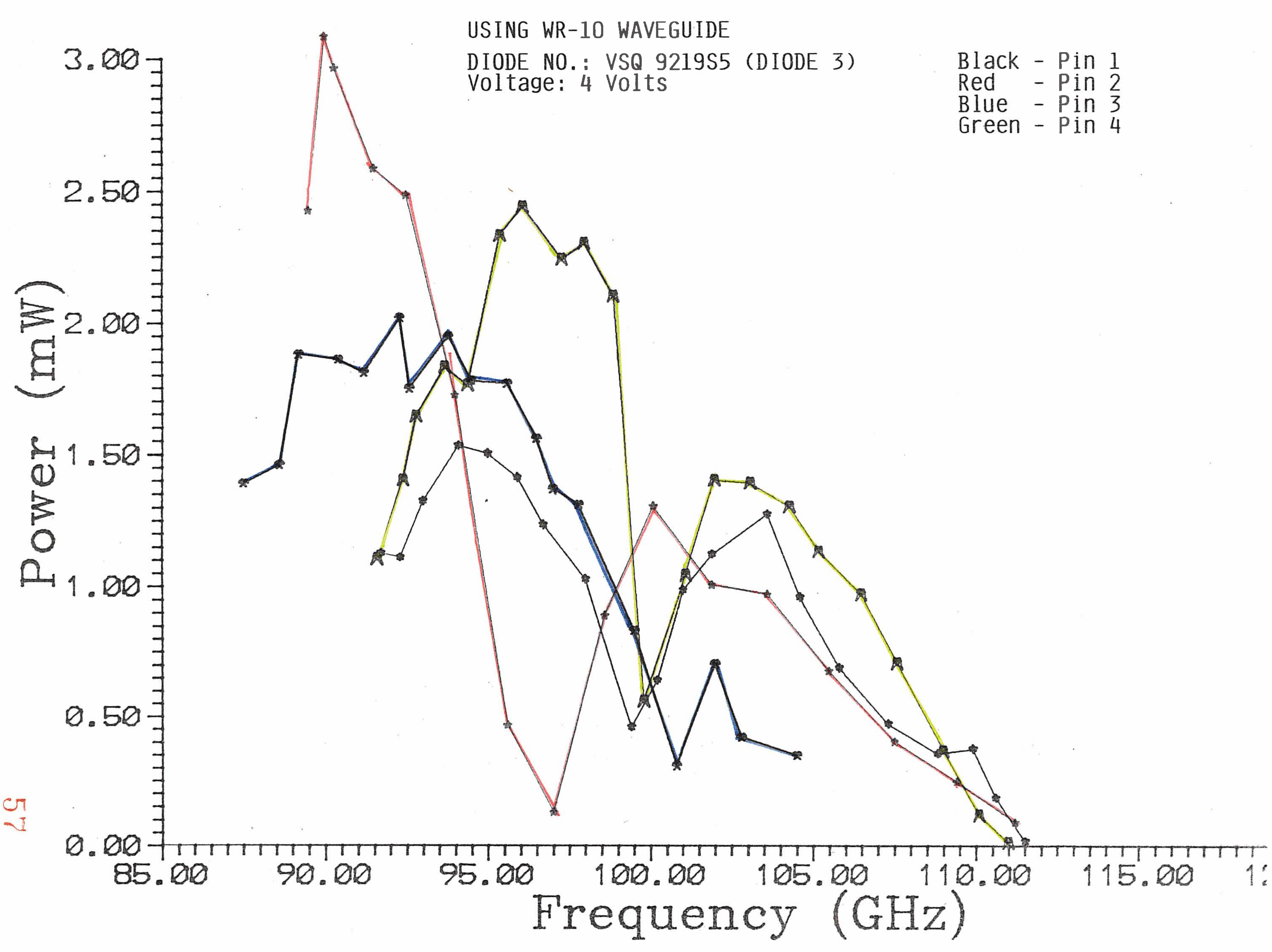

USING WR-10 WAVEGUIDE
DIODE NO.: VSE 9220S4A (DIODE 2)
Voltage: 4.5 Volts
Black - Pin 1
Red - Pin 2
Blue - Pin 3
Green - Pin 4
Power (mW)
3.00
2.50
2.00
1.50
1.00
0.50
0.00
85.00
90.00
95.00
100.00
105.00
110.00
115.00
1
Frequency (GHz)

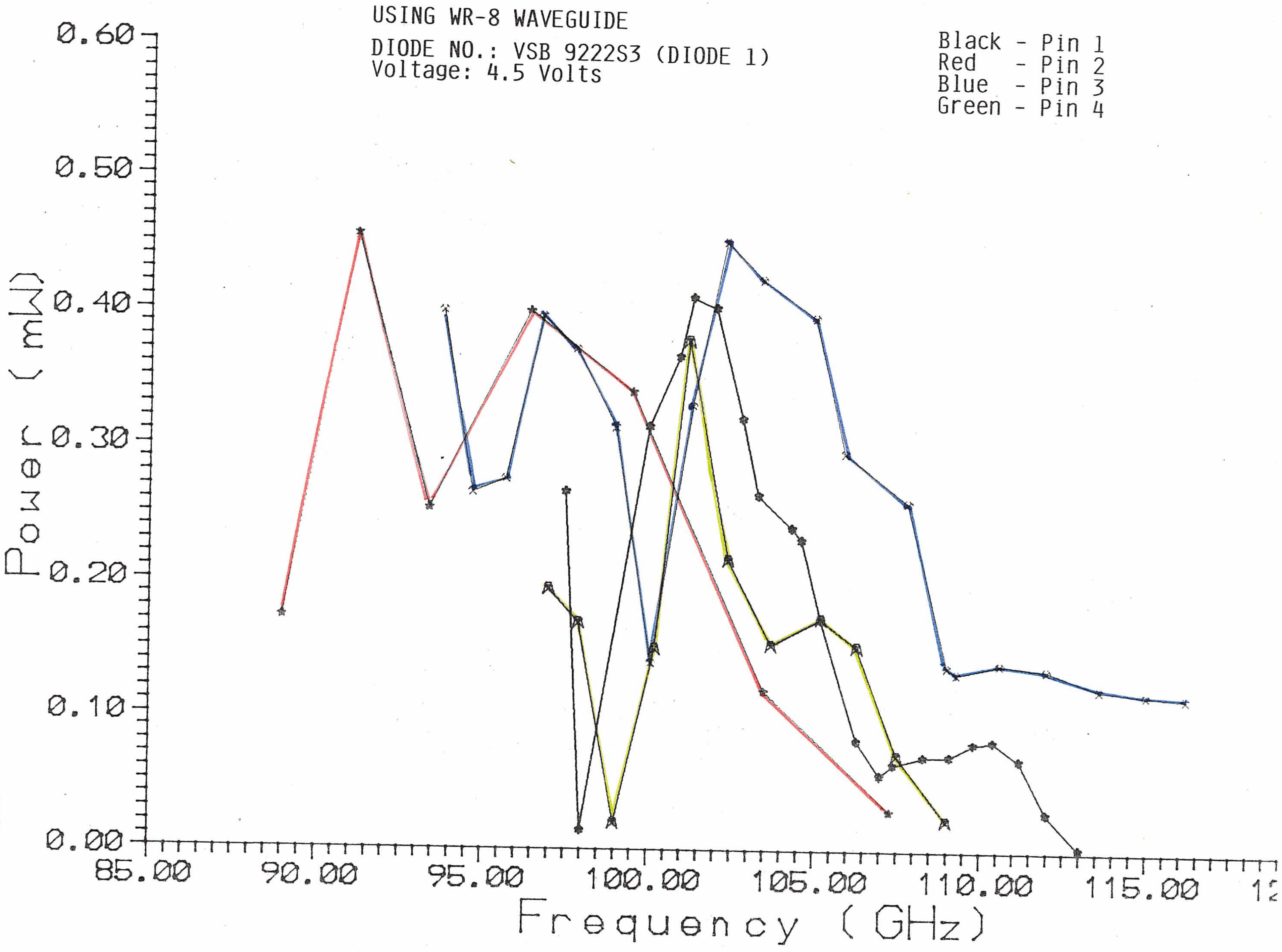


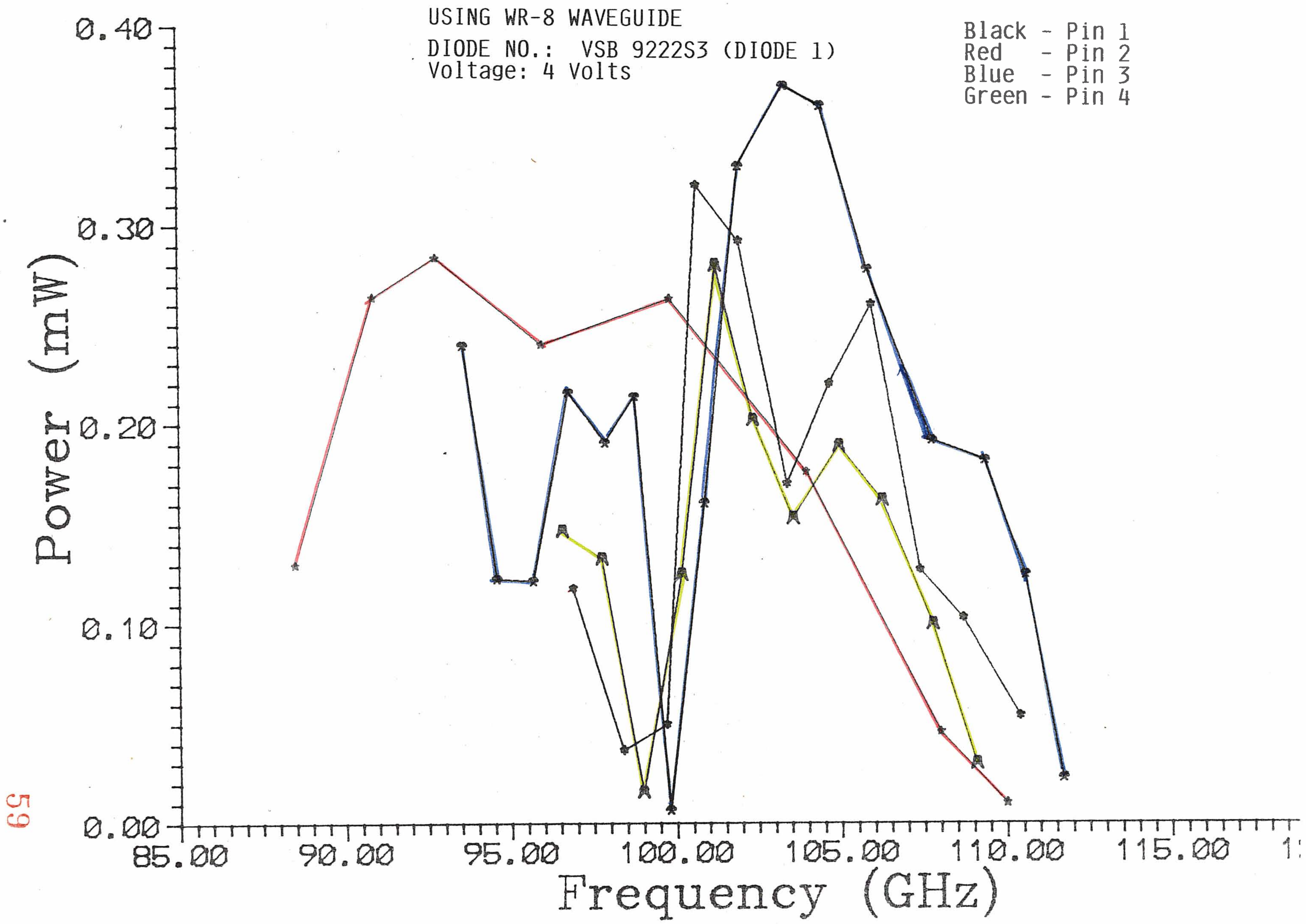
USING WR-10 WAVEGUIDE

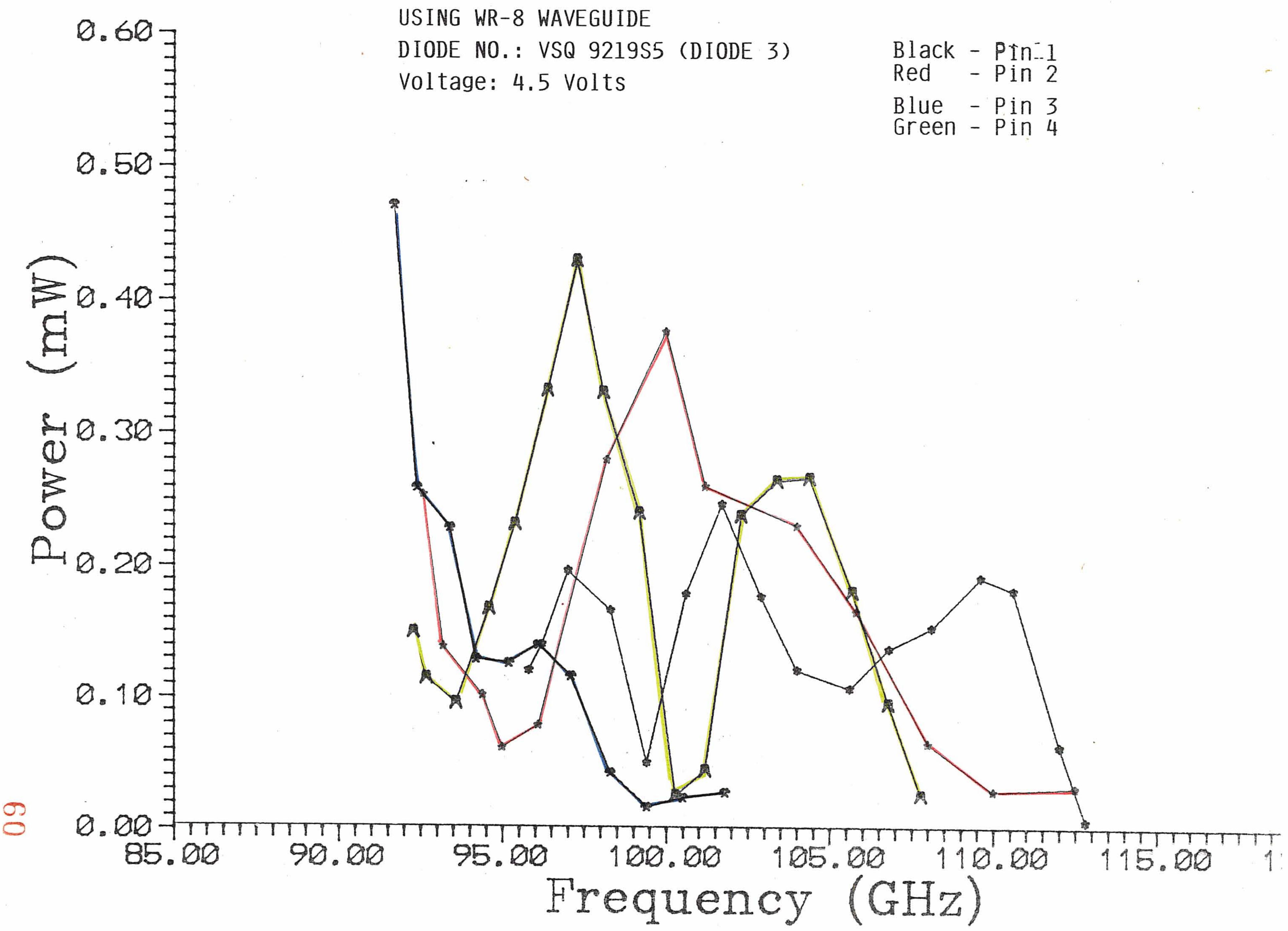
DIODE NO.: VSE 9220S4A (DIODE 2)
Voltage: 4 Volts


USING WR-10 WAVEGUIDE
DIODE NO.: VSQ 9219S5 (DIODE 3)
Voltage: 4.5 Volts
Black - Pin 1
Red - Pin 2
Blue - Pin 3
Green - Pin 4
Power (mW)
0.00
1.00
2.00
3.00
Frequency (GHz)
85.00
90.00
95.00
100.00
105.00
110.00
115.00


USING WR-10 WAVEGUIDE
DIODE NO.: VSQ 9219S5 (DIODE 3)
Voltage: 4 Volts
Black - Pin 1
Red - Pin 2
Blue - Pin 3
Green - Pin 4
Power (mW)
3.00
2.50
2.00
1.50
1.00
0.50
0.00
85.00
90.00
95.00
100.00
105.00
110.00
115.00
Frequency (GHz)


USING WR-8 WAVEGUIDE
DIODE NO.: VSB 9222S3 (DIODE 1)
Voltage: 4.5 Volts
Black - Pin 1
Red - Pin 2
Blue - Pin 3
Green - Pin 4
Power (mW)
0.60
0.50
0.40
0.30
0.20
0.10
0.00
85.00
90.00
95.00
100.00
105.00
110.00
115.00
Frequency (GHz)


USING WR-8 WAVEGUIDE
DIODE NO.: VSB 9222S3 (DIODE 1)
Voltage: 4 Volts
Black - Pin 1
Red - Pin 2
Blue - Pin 3
Green - Pin 4
Power (mW)
0.40
0.30
0.20
0.10
0.00
85.00
90.00
95.00
100.00
105.00
110.00
115.00
Frequency (GHz)



USING WR-8 WAVEGUIDE
DIODE NO.: VSQ 9219S5 (DIODE 3)
Voltage: 4.5 Volts

backshort position was found to have little effect on the oscillation frequency.

The results are present in the graphs as follows which gives the oscillation frequencies and the output powers obtained for a large number of resonant caps of varying dimensions and different diodes.

More than 1 mW CW power was achieved uptill 105 GHz in several cases and around 0.5 mW over the entire frequency range using various types of Gunn diode packages (Varian) in the WR-10 (2.54 x 1.27 mm) waveguide. A power of 0.1 mW and more was achieved using the WR-8 waveguide (2.32 x 1.02 mm).

In the course of experimental study a steady d.c. bias voltage required for maximum power varied between 4 and 5 volts depending on the oscillation frequency - higher frequencies requiring lower voltage.

The variation of oscillation frequency with bias voltage can be utilised for frequency stabilization of the Gunn oscillator using a Phase lock loop (PLL).

5.2 GRAPHS

The graphs plotted with various resonant cap dimensions and with different diodes have been plotted as follows. The data for these curves is present in this project at the APPENDIX-I.

CHAPTER VI

CHAPTER VI

CONCLUSION

We have attempted the characterisation of a low noise Gunn oscillator for local oscillator application in millimeter wave radio astronomy.

We have used commercially available packaged GaAs Gunn diodes for the purpose of developing this oscillator, and the oscillator is of a Resonant cap design and a second harmonic output is got.

Experimental investigation of the various cap parameters on the oscillator frequency showed the dependance of parameters to the frequency and power of the oscillator. The second harmonic was tapped out thus making the resonant cap Gunn oscillator to operate in a harmonic extraction mode.

The various resonant cap and disks used and their results are given in the APPENDIX-I.

The variations of frequency due to the bias voltage makes this oscillator well suited for electronic tuning using a phase lock loop which is a pre-requisite for a local oscillator in millimeter wave radio astronomy.

The work carried out here was to optimize power over a 30 GHz band width from approximately 85 to 115 GHz and get a power output of more than 0.5 mW over this range.

However, we achieved a power output of only 0.3 mW using a WR-8 waveguide and a power of about 1 mW using the WR-10 waveguide. This may be due to the frequency limitation of the GaAs packaged Gunn diodes used in this oscillator.

Higher outp[ut power beyond 120 GHz might be possible with the same circuit using better quality Gunn diodes.

The data base accumulated was analysed and the various dependencies on power and frequency were brought out. (i.e., oscillator performance when changes were made in resonant cap dimensions, diode packages, bias voltages and waveguides).

This information is useful for :

1) Stabilization of existing oscilltor block at the RRI Radio Telescope.

2) Designing a new oscillator block for higher frequencies.

3) Studying the limitations of Gunn Oscillator.

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APPENDIX - I

PIN SPECIFICATIONS

PIN NO. & TYPE	OUTER CAP DIAMETER	RIDGE CAP DIAMETER	PIN DIAMETER	CAP THICKNESS	TOTAL CAP THICKNESS
1[with cap ridge]	1.61mm	1.20mm	0.77mm	0.155mm	0.26mm
2[with cap ridge]	1.97mm	1.35mm	0.78mm	0.177mm	0.28mm
3[without cap ridge]	1.70mm	--------	0.79mm	--------	0.17mm
4[without cap ridge]	1.60mm	--------	0.79mm	--------	0.09mm

DIODE SPECIFICATIONS

DIODE 1: VSB 922283 [VARIAN]
DIODE 2: VSE 9220S4A [VARIAN]
DIODE 3: VSQ 9219S5 [VARIAN]
DIODE 4: VSB 9222S2 [VARIAN]

A detailed Diode specification sheet is enclosed in APPENDIX-III.

NOTE:

L mm
F GHz
P mW

USING WR-10 WAVEGUIDE (OLD BLOCK)

DIODE:VSB 922253 (DIODE 1)

VOLTAGE- 4.5 volts

PIN: 1			PIN:2			PIN:3			PIN:4		
L	F	P	L	F	P	L	F	P	L	F	P
7.0	99.9	0.908	7.0	90.7	2.54	7.5	91.3	.708	7.5	94.6	1.178
6.9	100.8	1.164	6.9	91.6	1.50	7.4	92.1	1.40	7.0	99.4	.240
6.8	101.0	1.130	6.8	93.3	2.64	7.3	93.1	1.50	6.9	100.4	1.40
6.7	102.0	1.130	6.7	94.2	0.722	7.2	93.5	1.75	6.8	101.9	1.47
6.6	103.5	1.09	6.6	95.4	0.406	7.1	94.7	1.94	6.7	103.1	1.44
6.5	104.9	0.860	6.5	97.5	0.890	7.0	95.8	2.21	6.6	104.4	1.32
6.4	105.9	0.628	6.4	99.5	1.180	6.9	96.9	2.42	6.5	105.5	1.070
6.3	107.4	0.364	6.3	101.2	0.238	6.8	98.0	2.76	6.4	106.5	.884
6.2	108.5	0.258	6.2	102.8	1.46	6.7	98.8	1.48	6.3	107.6	.760
			6.1	104.2	1.20	6.6	100.1	.238	6.2	109.1	.456
			6.0	106.1	1.066	6.5	100.9	1.27	6.1	110.5	.344
			5.9	108.3	0.686	6.4	102.3	1.47	6.0	111.6	.244
			5.8	110.0	0.127	6.3	103.3	1.41	5.9	113.0	.056
						6.2	104.6	1.55			
						6.1	105.9	1.138			
						6.0	108.0	0.69			
						5.9	109.4	.504			
						5.8	111.0	.064			

VOLTAGE-4.0 volts

PIN:1			PIN:2			PIN:3			PIN:4		
L	F	P	L	F	P	L	F	P	L	F	P
7.0	100.5	0.900	7.0	91.05	1.174	7.5	91.5	1.08	7.5	94.30	1.160
6.9	101.0	0.964	6.9	92.0	1.010	7.4	92.0	.986	7.4	95.4	1.30
6.8	102.6	1.092	6.8	93.2	2.02	7.3	92.6	1.128	7.3	96.3	1.60
6.7	103.3	1.056	6.7	94.5	0.238	7.2	93.6	1.158	7.2	97.0	1.50
6.6	105.1	0.864	6.6	95.9	0.290	7.1	94.4	1.006	7.1	98.1	1.162
6.5	105.9	0.690	6.5	97.3	0.642	7.0	95.6	1.48	7.0	99.5	.336
6.4	107.6	0.500	6.4	99.1	0.624	6.9	96.7	1.57	6.9	100.6	1.29
6.3	108.6	0.386	6.3	100.7	0.864	6.8	97.8	1.63	6.8	101.8	1.40
6.2	110.1	0.244	6.2	102.3	1.24	6.7	98.7	1.74	6.7	103.0	1.39
6.1	111.9	0.124	6.1	104.6	1.156	6.6	99.7	.520	6.6	104.3	1.40
			6.0	106.4	1.094	6.5	100.9	.826	6.5	105.3	1.146
			5.9	108.0	0.882	6.4	101.7	.998	6.4	106.3	1.084
			5.8	109.9	0.544	6.3	102.8	1.034	6.3	107.5	.870
			5.7	111.0	0.108	6.2	104.3	1.198	6.2	109.0	.638
						6.1	105.6	1.096	6.1	110.5	.488
						6.0	107.8	.710	6.0	111.8	.358
						5.9	108.9	.640	5.9	113.0	.214
						5.8	110.0	.082	5.8	114.0	.124
									5.7	115.4	.020

DIODE:VSE 922084A [DIODE-2]

VOLTAGE-4.5 volts

PIN:1			PIN:2			PIN:3			PIN:4		
L	F	P	L	F	P	L	F	P	L	F	P
7.5	95.2	0.420	7.5	87.3	1.83	7.5	92.2	0.72	7.5	96.0	0.19
7.0	100.0	0.472	7.0	91.3	2.21	7.0	96.6	2.30	7.4	97.0	0.35
6.5	105.2	0.654	6.5	96.6	0.430	6.8	98.1	1.94	7.2	98.8	0.22
6.4	106.4	0.540	6.0	103.9	1.178	6.5	100.5	0.63	7.0	100.2	0.74
6.3	107.5	0.466	5.9	105.5	0.972	6.4	101.5	1.35	6.9	101.2	1.04
6.2	108.5	0.450	5.8	107.5	0.772	6.3	102.2	1.33	6.8	102.1	1.34
6.1	109.4	0.472	5.7	109.4	0.738	6.2	103.1	1.06	6.7	103.0	1.46
6.0	110.9	0.45	5.6	110.0	0.424	6.1	104.1	0.77	6.6	104.0	1.65
5.9	112.0	0.42				6.0	105.4	0.46	6.5	104.8	1.70
5.8	113.1	0.330				5.9	106.8	0.25	6.4	105.8	1.64
5.7	114.9	0.184				5.8	108.0	0.12	6.3	106.9	1.40
5.6	116.0	0.137				5.7	109.5	0.06	6.2	107.9	1.14
5.5	117.0	0.140				5.6	110.5	0.04	6.1	108.8	0.82
5.4	118.0	0.006							6.0	109.9	0.58
									5.9	111.0	0.36
									5.8	112.0	0.24
									5.7	113.0	0.13
									5.6	114.2	0.06

VOLTAGE-4.0 volts

PIN:1			PIN:2			PIN:3			PIN:4		
L	F	P	L	F	P	L	F	P	L	F	P
7.5	95.3	0.230	7.3	88.3	1.910	7.5	92.80	0.540	7.5	95.90	0.15
7.0	100 .0	0.492	7.5	87.3	1.880	7.0	96.70	1.800	7.0	100.1	0.47
6.5	105 .1	0.752	7.2	88.9	1.850	6.5	100.4	0.490	6.9	101.1	0.86
6.4	106 .4	0.712	7.1	90.2	1.720	6.4	101.2	0.980	6.8	102.1	1.09
6.3	107 .8	0.634	7.0	91.0	1.750	6.3	102.2	1.100	6.7	102.8	1.12
6.2	108 .6	0.610	6.9	92.0	1.400	6.2	103.1	0.860	6.6	103.7	1.42
6.1	109 .5	0.606	6.8	93.0	0.874	6.1	104.1	0.642	6.5	104.5	1.40
6.0	110 .9	0.556	6.7	94.2	0.774	6.0	105.7	0.346	6.4	105.5	1.35
5.9	112 .0	0.472	6.6	95.2	1.440	5.9	106.9	0.220	6.3	106.5	1.16
5.8	113 .5	0.326	6.5	96.3	0.524	5.8	108.4	0.116	6.2	107.7	1.02
5.7	114 .5	0.182	6.4	97.5	0.290	5.7	109.3	0.056	6.1	108.7	0.72
5.6	115 .7	0.145	6.3	99.0	0.490	5.6	110.8	0.029	6.0	109.8	0.51
5.5	117 .0	0.133	6.2	101.0	0.640				5.9	111.0	0.32
			6.1	102.1	0.734				5.8	112.0	0.23
			6.0	103.1	0.810				5.7	113.2	0.13
			5.8	107.2	0.452				5.6	114.4	0.07
			5.7	109.1	0.444						
			5.6	110.2	0.225						

DIODE:VSQ 921985 [DIODE-3]

VOLTAGE-4.5 volts

PIN:1			PIN:2			PIN:3			PIN:4		
L	F	P	L	F	P	L	F	P	L	F	P
7.5	92.1	1.54	7.0	88.5	1.39	7.5	87.5	1.69	7.5	91.4	1.04
7.4	92.6	1.76	6.9	89.1	2.03	7.4	88.8	2.06	7.4	92.6	1.20
7.3	93.2	1.83	6.8	90.7	2.92	7.3	89.7	2.33	7.3	92.9	1.52
7.2	93.9	1.80	6.7	91.9	3.26	7.2	90.5	2.35	7.2	93.8	1.92
7.1	95.2	1.87	6.6	92.8	2.68	7.1	91.2	2.46	7.1	94.8	2.00
7.0	96.1	1.66	6.5	94.3	1.54	7.0	92.0	2.40	7.0	95.6	2.18
6.9	97.2	1.17	6.4	95.8	0.21	6.9	92.5	2.42	6.9	96.5	2.46
6.8	97.9	0.82	6.3	97.3	0.11	6.8	93.8	2.46	6.8	97.4	2.68
6.7	98.9	0.59	6.2	99.0	0.94	6.7	94.7	2.34	6.7	98.3	2.78
6.6	100.2	0.76	6.1	100.5	1.36	6.6	95.6	2.13	6.6	99.3	1.53
6.5	101.1	1.00	6.0	101.7	1.08	6.5	96.5	1.96	6.5	100.4	0.20
6.4	102.4	1.09	5.9	103.6	0.86	6.4	97.2	1.90	6.4	101.3	1.11
6.3	103.9	1.13	5.8	105.7	0.50	6.3	98.2	1.50	6.3	102.0	1.38
6.2	104.9	0.83	5.7	107.6	0.28	6.2	99.4	0.86	6.2	103.2	1.48
6.1	106.2	0.54	5.6	108.9	0.15	6.1	101.0	0.56	6.1	104.3	1.27
6.0	107.2	0.46	5.5	109.2	0.14	6.0	102.0	0.88	6.0	105.5	0.99
5.9	108.3	0.30				5.9	102.2	0.44	5.9	106.7	0.62
5.8	109.7	0.27				5.8	106.5	0.29	5.8	108.0	0.30
5.7	110.8	0.02				5.7	108.2	0.27	5.7	109.0	0.15
						5.6	110.2	0.15			
						5.5	112.0	0.10			

VOLTAGE:4.0 volts

PIN:1			PIN:2			PIN:3			PIN:4		
L	F	P	L	F	P	L	F	P	L	F	P
7.5	91.7	1.12	7.0	89.5	2.42	7.5	87.5	1.39	7.5	91.6	1.10
7.4	92.3	1.10	6.9	90.0	3.08	7.4	88.6	1.46	7.4	92.4	1.40
7.3	93.0	1.32	6.8	90.3	2.96	7.3	89.2	1.88	7.3	92.8	1.64
7.2	94.1	1.53	6.7	91.5	2.58	7.2	90.4	1.86	7.2	93.7	1.83
7.1	95.0	1.50	6.6	92.5	2.48	7.1	91.2	1.81	7.1	94.4	1.76
7.0	95.9	1.41	6.5	94.0	1.72	7.0	92.3	2.02	7.0	95.4	2.33
6.9	96.7	1.23	6.4	95.6	0.46	6.9	92.6	1.75	6.9	96.1	2.44
6.8	98.0	1.02	6.3	97.0	0.12	6.8	93.8	1.95	6.8	97.3	2.24
6.7	99.4	0.45	6.2	98.6	0.88	6.7	94.5	1.78	6.7	98.0	2.30
6.6	100.2	0.63	6.1	100.1	1.30	6.6	95.6	1.77	6.6	98.9	2.10
6.5	101.0	0.98	6.0	101.9	1.00	6.5	96.5	1.56	6.5	99.8	0.55
6.4	101.9	1.11	5.9	103.6	0.96	6.4	97.0	1.37	6.4	101.1	1.04
6.3	103.6	1.27	5.8	105.5	0.67	6.3	97.8	1.31	6.3	102.0	1.40
6.2	104.6	0.95	5.7	107.5	0.39	6.2	99.5	0.83	6.2	103.1	1.39
6.1	105.8	0.68	5.6	109.4	0.24	6.1	100.8	0.30	6.1	104.3	1.30
6.0	107.3	0.46	5.5	111.2	0.08	6.0	102.0	0.70	6.0	105.2	1.13
5.9	108.8	0.35				5.9	102.8	0.41	5.9	106.5	0.96
5.8	109.9	0.36				5.8	104.5	0.34	5.8	107.6	0.70
5.7	110.6	0.17							5.7	109.0	0.36
5.6	111.5	0.01							5.6	110.1	0.11

USING WR-8 WAVEGUIDE(new block)
DIODE: VSB 9222S3 [DIODE-1]

VOLTAGE-4.5 volts

PIN:1

L	F	P
7.5	97.5	0.266
7.4	98.0	0.014
7.3	100.0	0.314
7.25	100.9	0.366
7.2	101.3	0.410
7.15	102.0	0.402
7.10	102.8	0.320
7.05	103.3	0.264
7.00	104.3	0.240
6.95	104.6	0.231
6.90	105.2	0.172
6.85	106.3	0.082
6.80	107.0	0.056
6.75	107.4	0.064
6.70	108.3	0.070
6.65	109.1	0.070
6.60	109.8	0.080
6.55	110.4	0.082
6.50	111.2	0.068
6.45	112.0	0.029
6.40	113.0	0.003

PIN:2

L	F	P
3.9	91.2	0.456
3.8	93.4	0.254
3.7	96.4	0.400
3.6	99.5	0.340
3.5	103.5	0.119
3.4	107.3	0.030

PIN:3

L	F	P
7.5	93.8	0.400
7.4	94.7	0.266
7.3	95.7	0.276
7.2	96.8	0.396
7.1	97.8	0.372
7.0	99.0	0.314
6.9	100.1	0.140
6.8	101.3	0.330
6.7	102.3	0.452
6.6	103.4	0.424
6.5	105.0	0.396
6.4	105.9	0.296
6.3	107.8	0.260
6.2	109.0	0.138
6.1	109.3	0.133
6.0	110.6	0.140
5.9	112.0	0.136
5.8	113.6	0.122
5.7	115.0	0.118
5.6	116.2	0.116

PIN:4

L	F	P
7.5	97.0	0.19
7.4	97.9	0.16
7.3	99.0	0.02
7.2	100.2	0.15
7.1	101.2	0.37
7.0	102.4	0.21
6.9	103.7	0.15
6.8	105.2	0.17
6.7	106.3	0.15
6.6	107.5	0.07
6.5	109.0	0.02

VOLTAGE-4.0 volts

PIN:1

L	F	P
7.5	96.9	0.118
7.4	98.4	0.037
7.3	99.7	0.050
7.2	100.7	0.320
7.1	102.0	0.292
7.0	103.4	0.170
6.9	104.7	0.220
6.8	106.0	0.260
6.7	107.4	0.127
6.6	108.7	0.103
6.5	110.4	0.054

PIN:2

L	F	P
4.0	88.5	0.13
3.9	90.9	0.26
3.8	92.8	0.28
3.7	96.0	0.24
3.6	99.9	0.26
3.5	104.0	0.17
3.4	108.0	0.04
3.3	110.0	0.01

PIN:3

L	F	P
7.5	93.6	0.24
7.4	94.6	0.12
7.3	95.7	0.12
7.2	96.8	0.21
7.1	97.9	0.19
7.0	98.8	0.21
6.9	99.8	0.00
6.8	100.9	0.16
6.7	102.0	0.33
6.6	103.4	0.37
6.5	104.5	0.36
6.4	105.9	0.27
6.3	107.8	0.19
6.2	109.4	0.18
6.1	110.6	0.12
6.0	111.7	0.02

PIN:4

L	F	P
7.5	96.6	0.14
7.4	97.8	0.13
7.3	99.0	0.01
7.2	100.2	0.12
7.1	101.3	0.28
7.0	102.4	0.20
6.9	103.6	0.15
6.8	105.0	0.18
6.7	106.3	0.16
6.6	107.8	0.10
6.5	109.1	0.03

USING WR-8 WAVEGUIDE {new block}
DIODE:VSQ 921955[DIODE-3]

VOLTAGE-4.5 volts

PIN:1			PIN:2			PIN:3			PIN:4		
L	F	P	L	F	P	L	F	P	L	F	P
7.5	95.8	0.12	7.0	92.6	0.25	7.5	91.7	0.47	6.0	92.3	0.15
7.4	96.2	0.14	6.9	93.2	0.13	7.4	92.4	0.26	5.9	92.7	0.11
7.3	97.0	0.19	6.8	94.4	0.10	7.3	93.4	0.23	5.8	93.6	0.09
7.2	98.3	0.16	6.7	95.0	0.06	7.2	94.2	0.13	5.7	94.6	0.16
7.1	99.4	0.05	6.6	96.1	0.07	7.1	95.2	0.12	5.6	95.4	0.23
7.0	100.6	0.17	6.5	98.2	0.28	7.0	96.1	0.14	5.5	96.4	0.33
6.9	101.7	0.24	6.4	100.0	0.37	6.9	97.1	0.11	5.4	97.3	0.43
6.8	102.9	0.17	6.3	101.2	0.26	6.8	98.3	0.04	5.3	98.1	0.33
6.7	104.0	0.12	6.2	104.0	0.23	6.7	99.4	0.01	5.2	99.2	0.24
6.6	105.6	0.10	6.1	105.8	0.16	6.6	100.5	0.02	5.1	100.3	0.02
6.5	106.8	0.13	6.0	108.0	0.06	6.5	101.8	0.02	5.0	101.2	0.04
6.4	108.1	0.15	5.9	110.0	0.02				4.9	102.3	0.23
6.3	109.6	0.19	5.8	112.5	0.03				4.8	103.4	0.26
6.2	110.6	0.18							4.7	104.4	0.26
6.1	112.0	0.06							4.6	105.7	0.18
6.0	112.8	0.00							4.5	106.8	0.09
									4.4	107.8	0.02

VOLTAGE-4.0 volts

PIN:1			PIN:2			PIN:3	PIN:4		
L	F	P	L	F	P		L	F	P
7.4	96.1	0.11	7.3	89.5	0.40		6.0	92.5	0.09
7.3	97.3	0.14	7.2	90.0	0.46		5.9	93.2	0.07
7.2	98.0	0.10	7.1	92.0	0.51		5.8	93.8	0.06
7.1	100.0	0.03	7.0	93.1	0.29		5.7	94.7	0.10
7.0	101.0	0.22	6.9	94.8	0.10		5.6	95.6	0.16
6.9	102.4	0.10	6.8	96.5	0.05		5.5	96.6	0.20
6.8	103.2	0.11	6.7	98.1	0.19		5.4	97.5	0.21
6.7	104.8	0.06	6.6	99.9	0.27		5.3	98.4	0.16
6.6	106.1	0.11	6.5	101.8	0.30		5.2	99.4	0.12
6.5	107.5	0.13	6.4	103.3	0.17		5.1	100.2	0.00
6.4	109.0	0.20	6.3	105.3	0.06		5.0	101.2	0.02
6.3	110.4	0.20	6.2	107.8	0.03		4.9	102.3	0.11
6.2	111.5	0.14	6.1	109.8	0.06		4.8	103.4	0.12
6.1	112.8	0.05	6.0	111.0	0.03		4.7	104.6	0.11
							4.6	105.8	0.08

APPENDIX - II

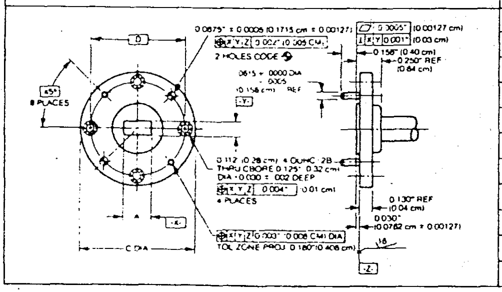
Waveguide Specifications and MIL Specification Cross Reference

Band Designation	Frequency (GHz)	MIL-W-85/ X-XXX (Silver)①	Waveguide Specifications: Inside Dimensions (inches (cm)) a x b	tol ±	Outside Dimensions (inches (cm)) a x b	tol ±	Flange Specifications: MIL-F-3922/ XX-XXX (Brass)①	UG-XXX/U Equivalent (REF)	Remarks
K	18-26.5	1-106 (WR-42)	0.420 x 0.170 (1.07 x 0.43)	0.0020 (0.0051)	0.500 x 0.250 (1.27 x 0.635)	0.0030 (0.0076)	54-001 67-004	UG-595/U —	Square② Round
Ka	26 5-40	3-006 (WR-28)	0.280 x 0.140 (0.711 x 0.356)	0.0015 (0.0038)	0.360 x 0.220 (0.914 x 0.559)	0.0020 (0 0051)	54-003 68-002 67B-005	UG-599/U — UG-381/U	Square Square③ Round
Q	33-50	3-010 (WR-22)	0.224 x 0.112 (0.57 x 0.28)	0.0010 (0.0025)	0.304 x 0.192 (0.772 x 0.488)	0.0020 (0.0051)	67B-006	UG-383/U	Round
U	40-60	3-014 (WR-19)	0.188 x 0.094 (0.48 x 0.24)	0.0010 (0.0025)	0.268 x 0.174 (0.681 x 0.442)	0.0020 (0.0051)	67B-007	UG-383/U Mod	Round
V	50-75	3-017 (WR-15)	0.148 x 0.074 (0.38 x 0.19)	0.0010 (0.0025)	0.228 x 0.154 (0.579 x 0.391)	0.0020 (0.0051)	67B-008	UG-385/U	Round
E	60-90	3-020 (WR-12)	0.122 x .061 (0.31 x 0.15)	0.0010 (0.0025)	0.202 x 0.141 (0.513 x 0.356)	0.0020 (0.0051)	67B-009	UG-387/U	Round
W	75-110	3-023 (WR-10)	0.100 x 0.050 (0.254 x 0.127)	0.0010 (0.0025)	0.180 x 0.130 (0.458 x 0.330)	0.0020 (0.0051)	67B-010	UG-387/U Mod	Round
F	90-140	3-026 (WR-8)	0.08 x 0.040 (0.232 x 0.102)	0.0005 (0.0013)	0.160 x 0.120 (0.406 x 0.305)	0.0015 (0.0038)	— 74-001	UG-387/U Mod	Round Pin Contact
D	110-170	3-029 (WR-6)	0.065 x 0.0325 (0.17 x 0.083)	0.0005 (0.0013)	0.145 x 0.1125 (0.368 x 0.2858)	0.0015 (0.0038)	— 74-002	UG-387/U Mod	Round Pin Contact
G	140-220	3-032 (WR-5)	0.051 x 0.0255 (0.130 x 0.0648)	0.0005 (0.0013)	0.131 x 0.1055 (0.333 x 0.2680)	0.0015 (0.0038)	— 74-003	UG-387/U Mod	Round Pin Contact

① All waveguide and flange assemblies are gold plated per MIL Spec MIL-G-45204 ② Also available with #4-40 threaded holes instead of through holes ③ Threaded holes

OUTLINE AND MOUNTING DRAWINGS

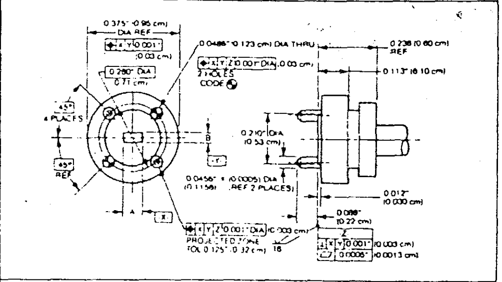
Round



DIMENSIONS (inches (cm))

BAND	A	B	C dia	D dia
K	0.420 (1.07)	0.170 (0.43)	1.125 (2.86)	0.9375 (2.38)
Ka	0.280 (0.71)	0.140 (0.36)	1.125 (2.86)	0.9375 (2.38)
Q	0.224 (0.57)	0.112 (0.28)	1.125 (2.86)	0.9375 (2.38)
U	0.188 (0.48)	0.094 (0.24)	1.125 (2.86)	0.9375 (2.38)
V	0.148 (0.38)	0.074 (0.19)	0.750 (1.91)	0.5625 (1.43)
E	0.122 (0.31)	0.061 (0.15)	0.750 (1.91)	0.5625 (1.43)
W	0.100 (0.25)	0.050 (0.13)	0.750 (1.91)	0.5625 (1.43)
F	0.080 (0.23)	0.040 (0.10)	0.750 (1.90)	0.5625 (1.43)
D	0.065 (0.17)	0.0325 (0.083)	0.750 (1.90)	0.5625 (1.43)
G	0.051 (0.13)	0.0255 (0.064)	0.750 (1.90)	0.5625 (1.43)

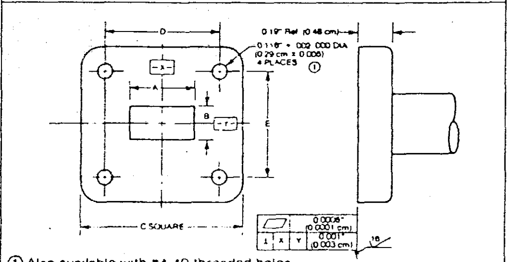
Pin Contacts



DIMENSIONS (inches (cm))

BAND	A	B
F	0.080 (0.20)	0.040 (0.10)
D	0.063 (0.16)	0.0325 (0.083)
G	0.051 (0.13)	0.0255 (0.065)

Square



① Also available with #4-40 threaded holes.

DIMENSIONS (inches (cm))

BAND	A	B	C	D	E
K	0.420 (1.07)	0.170 (0.43)	0.875 (2.22)	0.640 (1.63)	0.670 (1.70)
Ka	0.280 (0.71)	0.140 (0.36)	0.750 (1.91)	0.500 (1.27)	0.530 (1.35)

APPENDIX - III

GENERAL CHARACTERISTICS

ELECTRICAL—High Frequency Gunn Diodes

FREQUENCY COVERAGE (GHz)	MINIMUM OUTPUT POWER^3 (mW)	MAXIMUM BIAS VOLTAGE^1 (Vdc)	BIAS CURRENT (mAdc) Operating Typ	Operating Max	Threshold Typ	Threshold Max	Type NUMBER^2
18.0-26.0	50	8	350	450	500	700	VSK-9204S3
	75		400	550	550	750	VSK-9204S4
	100		500	650	600	800	VSK-9204S5
	150		600	850	750	900	VSK-9204S6
	200		700	1100	1200	1400	VSK-9204S7
26 - 40	50	7	600	1000	900	1100	VSA-9210S3
	75		700	1200	1100	1400	VSA-9210S4
	100		300	1300	1150	1400	VSA-9210S5
	150		1000	1300	1150	1400	VSA-9210S6
	200		1000	1300	1200	1500	VSA-9210S7
40 - 50	10	6.5	500	700	650	850	VSQ 9219S1
	25		500	700	650	850	VSQ-9219S2
	50		850	1000	1000	1200	VSQ 9219S3
	75		1000	1200	1100	1400	VSQ 9219S4
	100		1000	1200	1100	1400	VSQ-9219S5
	125		1000	1500	1200	1600	VSQ-9219S6
50 - 60	10	6	500	700	800	850	VSE-9220S1
	25		500	800	600	900	VSE-9220S2
	50		1000	1200	1100	1400	VSE-9220S3
	75		1000	1200	1100	1400	VSE-9220S4
	100		1000	1500	1200	1600	VSE-9220S4A
60 - 75	25	5.5	550	800	700	1000	VSE-9220S5
	50		700	950	900	1200	VSE 9220S6
	75		1000	1200	1200	1500	VSE-9220S7
75 - 95	5	5	550	800	700	1000	VSB-9222S1
	10		700	950	900	1200	VSB-9222S2
	20		1000	1200	1200	1500	VSB-9222S3

NOTES:

1. Voltage specified is the maximum voltage required for operation within the frequency band specified. Bias voltage generally decreases as frequency increases and may vary from diode to diode.
2. The suffix "S1", "S2", etc. denotes power output. The suffix "N34", etc. denotes diode case style. They are used for quoting and ordering purposes. When an order is received at Varian, e.g. VSK-9204S1N34, a two-letter suffix is assigned, e.g. VSK-9204AP to identify the customer and the exact requirements.
3. Power output is measured in a Varian Critically Coupled Cavity at a heat sink temperature of 25°C at a specified center frequency. Exact operating frequency must be specified at time of order.