MILLIMETER WAVE GUNN DIODE OSCILLATORS

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ABSTRACT

MILLIMETER WAVE GUNN DIODE OSCILLATORS

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This thesis presents the design and implementation of a millimeter-wave Gunn diode oscillator operating at 35 GHz (Ka (R) 26.5-40 GHz Band). The aim of the study is to produce a high frequency, high power signal from a negative resistance device situated in a waveguide cavity by applying a direct current bias. First the physics of Gunn diodes is studied and the requirements that Gunn diode operates within the negative differential resistance region is obtained. Then the best design configuration is selected. The design of the oscillator includes the design of the waveguide housing, diode mounting and the bias insertion network. Some simulation tools are used to predict, approximately, the behaviour of the oscillator and the bias coupling circuit. For tuning purposes, a sliding backshort and a triple-screw-tuner system is used. For different bias values and different positions of the tuning elements oscillations are observed. A much more stable and higher magnitude oscillations were obtained with the inclusion of "resonant disc" placed on top of the diode. 15 dBm power was measured at a frequency of 28 GHz. Laboratory measurements have been carried out to determine the oscillator frequency, power output and stability for different bias conditions.

Keywords: Gunn Diode, Millimeter-Wave Oscillator Design, Diode Mounting, Resonant Disc

ÖZ

MİLİMETRİK DALGA GUNN DİYOT OSİLATÖRLER

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Bu tezde 35GHz'de çalışan bir milimetrik dalga Gunn diyot osilatörün tasarımı, gerçekleştirilmesi ve üzerinde yapılan ölçüm çalışmaları anlatılmaktadır. Tezin amacı, bir doğru akım besleme uygulayarak, milimetrik dalga kılavuzu içerisinde yer alan kavite içindeki bir negatif direnç aygıtından, yüksek frekanslı ve güçlü bir sinyal üretmektir. İlk olarak Gunn diyotun fiziği üzerinde durulmuş ve Gunn diyotun negatif diferansiyel direnç alanında çalışması için gerekli koşullar saptanmıştır. Daha sonra en iyi tasarım konfigürasyonu seçilmiştir. Osilatörün tasarımı, dalga kılavuzunun yerleşim, diyotun takılma ve öngerilim besleme devresinin tasarımını içermektedir. Osilatörün davranışını yaklaşık olarak tahmin etmek için bazı simülasyon araçları kullanılmıştır. Ayar işlemleri için bir kayar kısa devre ve üçlü ayar vidası sistemi kullanılmıştır. Farklı besleme gerilimleri ve ayar elemanlarının farklı pozisyonları için osilasyonlar gözlenmiştir. Çok daha kararlı ve güçlü osilasyonlar, diyotun üzerine yerleştirilen rezonans diskinin eklenmesiyle elde edilmiştir. 28 GHz frekansında 15 dBm güç ölçülmüştür. Farklı besleme gerilimleri için osilatör frekansı, çıkış gücü ve kararlılığı belirlemek amacıyla laboratuar ölçümleri yapılmıştır.

Anahtar kelimeler: Gunn Diyot, Milimetrik Dalga Osilatör Tasarımı, Diyot Yerleşimi, Rezonans Diski

To My Dear Family

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ADS	Advanced Design System
CdTe	Cadmium Telluride
FMCW	Frequency Modulated Continuous Wave
GaAs	Gallium Arsenide
GaN	Gallium Nitrade
IBM	International Business Machines Corporation
InP	Indium Phosphide
GaN	Gallium Nitrade
MVDS	Microwave Video Distribution and Systems
PCB	Printed Circuit Board
PSU	Power Supply Unit
SMA	SubMiniature version A
TED	Transfer Electron Devices
TEO	Transfer Electron Oscillators

CHAPTER 1

INTRODUCTION

The Gunn diode is a complex electronic device, which can operate in a region known as the negative differential resistance region. When the device is operating within this region it exhibits negative resistance characteristics as the input voltage increases the current through the diode decreases. This phenomenon is due to the band structure of Gunn diodes, which cause electrons to move to higher energy bands as the voltage across the diode is increased, resulting in the electrons gaining a higher relative mass and moving at a slower speed. When the Gunn diode is operated in this region, it can be made to produce a high frequency oscillating signal due to the production of domains that propagate internally across the diode.

The diode must be operated within the negative differential resistance region to produce an RF output signal. The diode is maintained in this region of operation by the bias voltage, which is applied to the diode along a path known as choke circuitry or radial line transformer.

Conventional Gunn diodes are usually made on GaAs or InP substrates and are limited with respect to their power generation capability. Recently, it has been postulated that nitrides are very promising materials for high power, high temperature and high frequency semiconductor devices. But so far, GaN-based Gunn diodes showed severe limitations linked to electromigration and high bias voltage operation. Gunn diodes usually produce an output signal frequency between about 10 GHz and 3000 GHz and even higher as the technology progresses. To achieve this high frequency, a cavity type of structure is used to couple the negative resistance of the diode to the load which is usually the characteristic impedance of a transmission line or a waveguide system. Gunn diodes consume a large amount of power, but they have low energy efficiency, so much of this power is dissipated as heat, resulting in the output power of the Gunn diode being relatively small compared to the DC power consumed.

The Gunn diodes are used to generate RF signals in the region of 100 mW – 5 W producible directly from DC. The low voltage requirements make them suitable for a wide range of applications and allow them to be used in a variety of different environments. The devices are currently being used in many systems including car radar and terahertz imaging. Gunn diodes are being used in terahertz (10^{12} Hz or 1000 GHz) radiation systems. Terahertz imaging is a technology similar to that of X-rays, used to produce an internal image of an object from measurements acquired by non-intrusive processes [1], in security screening systems (e.g. recognition of explosives and hazardous materials), genetic engineering, pharmaceutical quality control and medical imaging.

Gunn diodes are also used in systems such that intrusion alarms, automobile safety equipment, police radar, tanker docking radar and other types of traffic control including radar for pleasure boats [2].

Other systems which use Gunn diodes include frequency modulated continuous wave (FMCW) radar sensor heads, local oscillators/carrier generators for microwave video distribution and systems (MVDS), point to point links or other communication applications [3].

Within the scope of this thesis, originally a millimeter-wave waveguide type Gunn diode oscillator operating at 35 GHz is designed and implemented. During the design stage the design approaches are examined according to the requirements.

After the decision of the best design configuration, the simulation of the design is carried out to give an insight into the operation of filter circuit that is included in the oscillator design. After the design is completed, drawing programs are used to help the implementation of the oscillator. High grade brass is used as manufacturing material because it can be machined to a close tolerance giving near-net shapes, this is critical for the accurate measurements required. Finally the laboratory measurements are carried out.

In Chapter 2, an introduction to the Transfer Electron Devices (TEDs), such as Gunn diodes, is given. The advantages and disadvantages of the TEDs over microwave transistors are discussed. The fundamentals of the Gunn diode are introduced and the characteristics of Gunn diodes and the reasons behind their behaviour are described. At the end of the chapter two types of high power oscillator circuits, namely waveguide and planar, are compared.

In Chapter 3, the theory of one port negative resistance oscillators is investigated to explain the oscillation conditions of a one-port negative resistance oscillator like a Gunn diode oscillator. Equivalent circuits of the Gunn diode, waveguide and the choke circuitry are examined and used to construct the equivalent circuit of the Gunn diode oscillator. The simplified theory of the "resonant disc" which is used to obtain proper and stable oscillations is also provided.

In Chapter 4, the mechanical design and the construction of the Gunn diode oscillator is given. Firstly, properties of the waveguide, that is used to propagate the signal, are examined. After that the design and the simulation of the filter circuit are given. The filter itself with a post constitutes a choke circuitry that is used to bias the Gunn diode. The drawings of the oscillator parts are shown that are carried out using some drawing programs called Proengineer and AutoCAD.

In Chapter 5, the measurement setup is introduced and the results of the measurements are given. First, the DC characteristic of the Gunn diode is examined. Later, frequency and power of the oscillations are measured using the equipment of the millimeter-wave laboratory. The measurement results are given in tabulated and graphical formats.

In Chapter 6, conclusions are given including the comparison of the simulations and the practical measurements of the Gunn diode oscillator. The probable future design aspects and relevant measurements of the oscillator as a part of the microwave system are described briefly.

CHAPTER 2

OWERVIEW OF THE GUNN DIODES AND HIGH POWER OSCILLATOR CIRCUITS

2.1. Transferred Electron Devices (TEDs)

The common characteristic of all active two-terminal solid-state devices is their negative resistance. The real part of their impedance is negative over a range of frequencies. In a positive resistance the current through the resistance and the voltage across it are in phase. The voltage drop across a positive resistance is positive and a power is dissipated in the resistance.

Positive resistances absorb power (passive devices), negative resistances generate power (active devices). In a negative resistance, the current and voltage are out of phase by 180°. The voltage drop across a negative resistance is negative, and a power is generated by the power supply associated with the negative resistance.

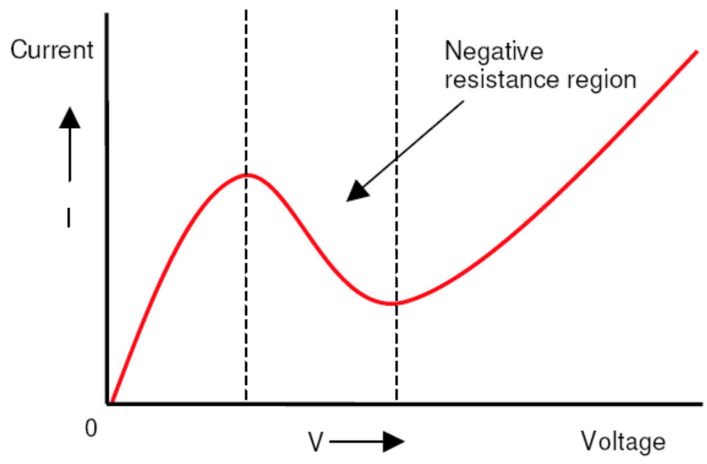


Figure 2.1: Negative Resistance

Figure 2.1 shows the negative resistance region, where as the voltage is increased the current falls.

Transferred electron devices (TEDs) such as Gunn diodes are semiconductor devices which have been used in a variety of applications as microwave generators. They comprise a piece or region of n-type semiconductor material having an appropriate energy band structure, and two electrodes, the anode and the cathode, attached to the active material for the purpose of applying a high electric field across the active material with the cathode biased negatively. Transferred electron devices operate by the transferred electron effect by which the state of some free electrons in the active material is transferred from a conduction band region of low energy and high mobility to one or more conduction band regions of high energy and low mobility by the application of a high electric field equal to or greater than a threshold level. Electrical current oscillations in the active material result, and these can be converted into electro-magnetic microwaves in a conventional microwave cavity.

The differences between microwave transistors and transferred electron devices (TEDs) are fundamental. Transistors operate with either junctions or gates, but TEDs are bulk devices having no junctions or gates. The majority of transistors are fabricated from elemental semiconductors, such as silicon or germanium, whereas TEDs are fabricated from compound semiconductors, such as gallium arsenide (GaAs), indium phosphide (InP), or cadmium telluride (CdTe). Transistors operate with "warm" electrons whose energy is not much greater than the thermal energy of electrons in the semiconductor, whereas TEDs operate with "hot" electrons whose energy is very much greater than the thermal energy. Because of these fundamental differences, the theory and technology of transistors cannot be applied to TEDs [4].

2.1.1. Gunn-Effect Diodes

Gunn-effect diodes are named after J.B. Gunn, [5] who in 1963 discovered a periodic fluctuation of current passing through the n-type gallium arsenide (GaAs) specimen when the applied voltage exceeded a certain critical value. This type of device is a bulk device in the sense that microwave amplification and oscillation are derived from the bulk negative resistance property between two different semiconductors rather than from the junction negative resistance property between two different semiconductors, as in the tunnel diode.

After inventing the transistor, Shockley suggested in 1954 that two-terminal negative-resistance devices using semiconductors may have advantages over transistors at high frequencies [6]. In 1961 Ridley and Watkins described a new method for obtaining negative differential mobility in semiconductors [7]. The principle involved is to heat carriers in a light-mass, high-mobility subband with an electric field so that the carriers can transfer to a heavy-mass, low-mobility, higher-energy subband when they have a high enough temperature. Ridley and Watkins also mentioned that Ge-Si alloys and some III-V compounds may have suitable subband structures in the conduction bands. Their theory for achieving negative differential mobility in bulk semiconductors by transferring electrons from high-mobility energy bands to low-mobility energy bands was taken a step further by Hilsum in 1962 [8]. Hilsum carefully calculated the transferred electron effect in several III-V compounds and was the first to use the terms transferred electron amplifiers (TEAs) and oscillators (TEOs).

It was not until 1963 that J. B. Gunn of IBM discovered the so-called Gunn effect from thin disks of n-type GaAs and n-type InP specimens while studying the noise properties of semiconductors. Gunn did not connect—and even immediately rejected—his discoveries with the theories of Ridley, Watkins, and Hilsum. In 1963 Ridley predicted [9] that the field domain is continually moving down through the crystal, disappearing at the anode and then reappearing at a favored nucleating center, and starting the whole cycle once more. Finally, Kroemer stated [10] that the origin of the negative differential mobility is Ridley-Watkins-Hilsum's mechanism of electron transfer into the satellite valleys that occur in the conduction bands of both the n-type GaAs and the n-type InP and that the properties of the Gunn effect are the current oscillations caused by the periodic nucleation and disappearance of traveling space-charge instability domains. Thus the correlation of theoretical predictions and experimental discoveries completed the theory of transferred electron devices (TEDs).

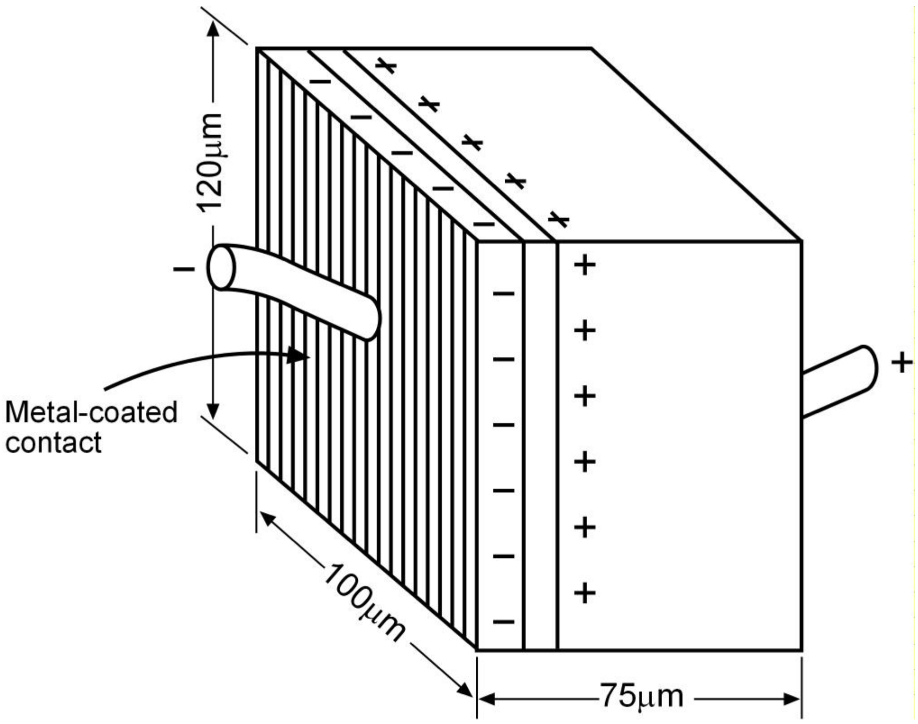


Figure 2.2: Schematic Diagram Of A Gunn Diode With Ohmic Contacts At The End Surfaces

A schematic diagram of a uniform n-type GaAs diode with ohmic contacts at the end surfaces is shown in Figure 2.2. Gunn stated in his first paper that:

- Above some critical voltage, corresponding to an electric field of 2000-4000 volts/cm the current in every specimen became a fluctuating function of time. In the GaAs specimens, this fluctuation took the form of a periodic oscillation superimposed upon the pulse current.
- The frequency of oscillation was determined mainly by the specimen, and not by the external circuit.
- The period of oscillation was usually inversely proportional to the specimen length and closely equal to the transit time of electrons between the

electrodes, calculated from their estimated velocity of slightly over 107 cm/s.

From Gunn's observation the carrier drift velocity is linearly increased from zero to a maximum when the electric field is varied from zero to a threshold value. When the electric field is beyond the threshold value for the n-type GaAs, the drift velocity is decreased and the diode exhibits negative resistance. This situation is shown in Figure 2.3.

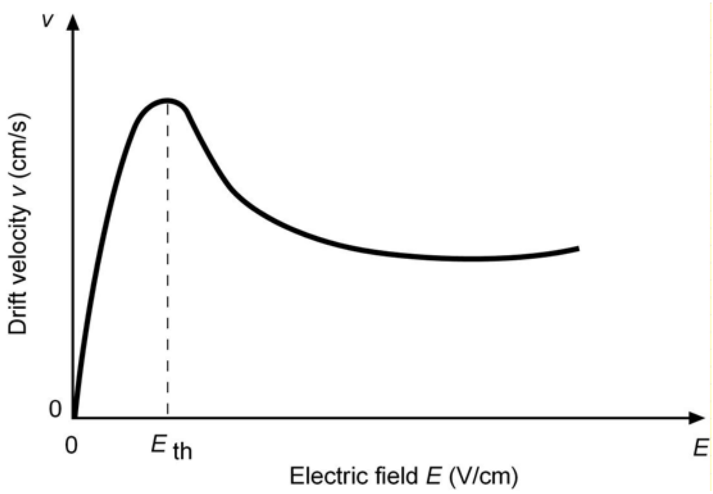


Figure 2.3: Drift Velocity of Electrons in n-type GaAs Versus Electric Field

Gunn diodes produce periodic fluctuations on the current passing through them when the applied voltage exceeded a certain critical value. The current fluctuations are shown in Figure 2.4.

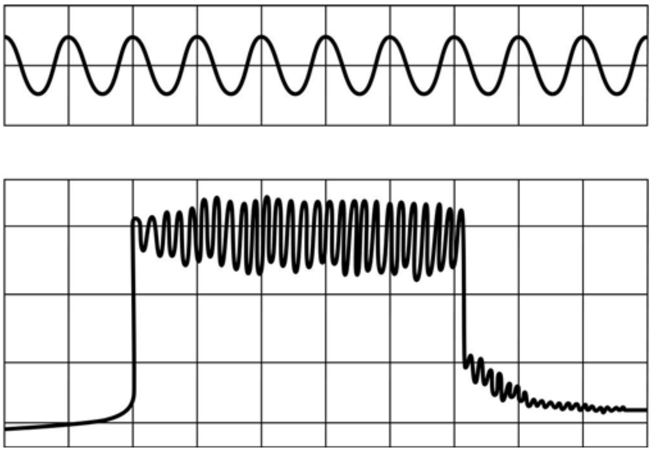


Figure 2.4: Current Waveform of n-type GaAs Reported by Gunn

Gunn also discovered that the threshold electric field E_{th} varied with the length and type of material. He developed an elaborate capacitive probe for plotting the electric field distribution within a specimen of n-type GaAs of length L=210µm and cross-sectional area $3.5 \times 10^{-3} cm^2$ with a low field resistance of 16Ω. Current instabilities occurred at specimen voltages above 59V, which means that the threshold field is

$$E_{th} = \frac{V}{L} \tag{2.1}$$

$$Eth = \frac{59}{210 \times 10^{-6} \times 102} = 2810 \ \ volts/cm$$

The fundamental concept of the Ridley-Watkins-Hilsum theory is the differential negative resistance developed in a bulk solid state when either a voltage (or electric field) or a current is applied to the terminals of the sample. There are two modes of negative-resistance devices: voltage-controlled and current-controlled modes.

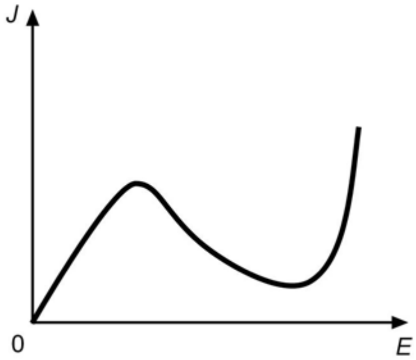


Figure 2.5: Voltage-controlled Mode

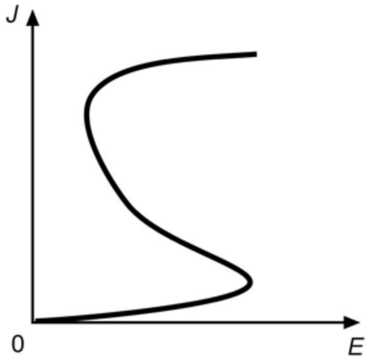


Figure 2.6: Current-controlled Mode

In the voltage-controlled mode as shown in Figure 2.5, the current density can be multivalued, whereas in the current-controlled mode the voltage can be multivalued as shown in Figure 2.6. The major effect of the appearance of a differential negative-resistance region in the current-density-field curve is to render the sample electrically unstable. As a result, the initially homogeneous sample becomes electrically heterogeneous in an attempt to reach stability. In the voltage-controlled negative-resistance mode high-field domains are formed, separating two low-field regions. The interfaces separating low and high-field domains lie along equipotentials; thus they are in planes perpendicular to the current direction as shown in Figure 2.7. In the current-controlled negative-resistance mode splitting the sample results in high-current filaments running along the field direction as shown in Figure 2.8.

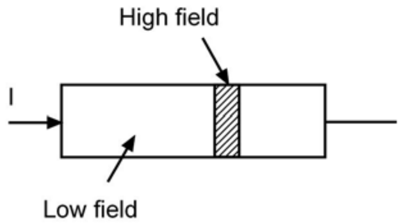


Figure 2.7: High-Field Domain

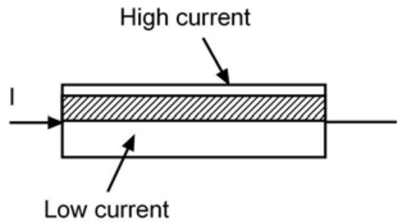


Figure 2.8: High-Current Filament

If an electric field E0 (or voltage V0) is applied to the sample, for example, the current density J0 is generated. As the applied field (or voltage) is increased to E2 (or V2), the current density is decreased to J2. When the field (or voltage) is decreased to E1 (or V1), the current density is increased to J1. These phenomena of the voltage-controlled negative resistance are shown in Figure 2.9. Similarly, for the current-controlled mode, the negative-resistance profile is as shown in Figure 2.10.

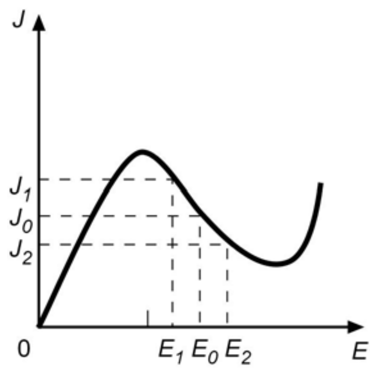


Figure 2.9: Voltage-controlled Mode-2

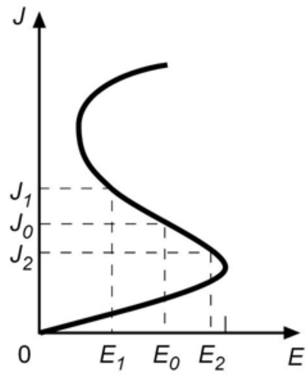


Figure 2.10: Current-controlled Mode-2

2.2. High Power Oscillator Circuits

Waveguide and planar structures can be used for the implementation of negative resistance oscillators. The waveguide configuration has low attenuation losses and acts as a heat sink for the diode, so is the chosen circuit configuration in this thesis. Figure 2.11 shows an example for waveguide based structures.

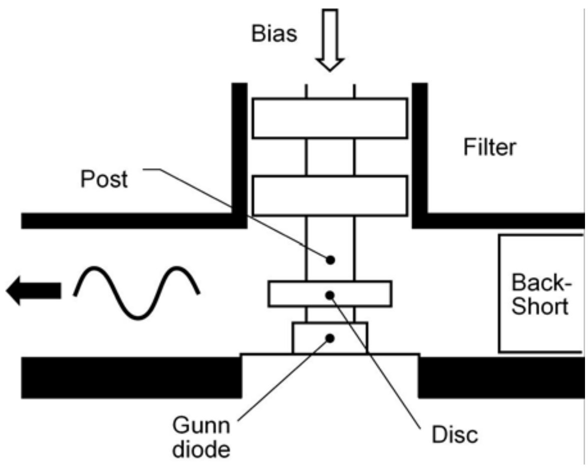


Figure 2.11: Typical Waveguide Oscillator Cross Section

A packaged Gunn diode on a heatsink with a disc above the diode package, a post connecting the disc and bias-line filter and finally the bias-line filter itself are seen on the Figure 2.11 [11].

The waveguide circuit configuration is a 3-dimensional circuit. The Gunn diode sits inside a hollow metal cavity inside of which the microwave signal propagates. The

metal walls of the cavity constrain the microwave signal by reflecting it, enabling the signal to propagate freely in the desired direction.
The advantages of the waveguide circuit are that the quality factor (Q) is high; the power losses of the output signal are low since the walls of the waveguide are metal, which is a very low attenuation medium and reflects most of the signal. The waveguide acts as a heat sink and efficiently dissipates most of the heat from the Gunn diode. The waveguide circuit allows some tuning of the frequency of the output signal by altering a number of components, including moving the sliding backshort.

The disadvantages of the waveguide are that the waveguide is costly to manufacture; it is a metal box that is more expensive to purchase and machine than a PCB, though as the desired frequency of the output signal increases the magnitude of the box decreases.

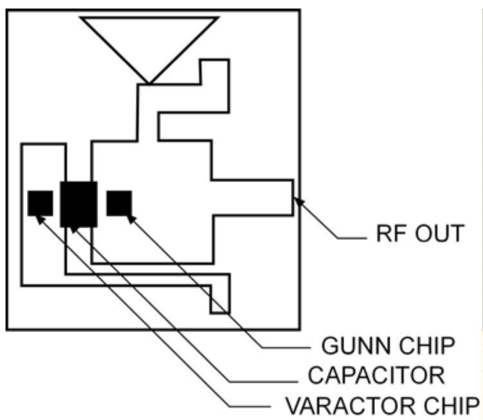


Figure 2.12: Planar Gunn Diode Oscillator

A microwave microstrip oscillator as shown in Figure 2.12 includes a thin dielectric substrate, a Gunn diode mounted within the thickness of the substrate, an annular conductive resonator lying on the surface of the substrate and at least partially surrounding the Gunn diode, and a varactor diode associated with the Gunn diode for controlling the frequency of oscillation of the Gunn diode. A microstrip circuit coupled to the Gunn diode extracts an output power signal at a desired microwave frequency [12].

There are advantages and disadvantages of using the planar circuit configuration. The advantages are that the planar circuit is low cost when mass manufactured, so the configuration is suitable for system of which many are built. The circuit is small and light since it is a printed circuit board (PCB).

The disadvantages of the planar circuit are that the quality factor (Q) of the circuit is low; this means that the power losses of the output signal are high and the signal degrades quickly because of attenuation, which is absorption of the signal. Microwave signals are attenuated by many mediums, including air, water and water vapour. The planar circuit is heavily affected by changes in external conditions including temperature changes. The Gunn diode dissipates a huge amount of heat; the planar circuit is a poor heat sink. The planar circuit does not allow any tuning of the frequency of the output signal.

CHAPTER 3

EQUIVALENT CIRCUIT OF GUNN DIODE OSCILLATOR

In this chapter the basic theory of one-port (two-terminal) negative resistance oscillators are given. The equivalent circuit of Gunn diodes is used to obtain the input impedance as a function of frequency. Equivalent circuit of the complete oscillator is obtained. At the end the simplified theory of the resonant disc is given.

3.1. Theory of One Port Negative Resistance Oscillators

A microwave oscillator converts DC power to RF power, and so is one of the most basic and essential components in a microwave system. A solid-state oscillator uses an active device, such as a diode or transistor, in conjunction with a passive circuit to produce a sinusoidal steady-state RF signal. At startup, however, oscillation is triggered by transients or noise, after which a properly designed oscillator will reach a stable oscillation state. This process requires that the active device be nonlinear. In addition, since the device is producing RF power, it must have a negative resistance. Because of this active and nonlinear element, the complete analysis of oscillator operation is very difficult and is usually carried out by numerical methods.

Here the operation and design of one port negative resistance oscillators are discussed. Such circuits represent oscillators that use Gunn diodes, tunnel diodes, IMPATT diodes etc. which are all two terminal devices and exhibit differential negative resistance under suitably applied DC bias.

Figure 3.1 shows the canonical RF circuit for a one port negative resistance oscillator, where

$$Z_{in} = R_{in} + jX_{in} \tag{3.1}$$

is the input impedance of the active device (e.g., a biased diode). In general, this impedance is current (or voltage) dependent, as well as frequency dependent, which can be indicated as

$$Z_{in}(I, j\omega) = R_{in}(I, j\omega) + jX_{in}(I, j\omega) \tag{3.2}$$

The device is terminated with a passive load impedance,

$$Z_L = R_L + jX_L \tag{3.3}$$

Applying Kirchoff's voltage law gives

$$(Z_L + Z_{in})I = 0 \tag{3.4}$$

Starting condition for oscillation is obtained when $(Z_L + Z_{in}) = 0$. This gives

$$R_L + R_{in} = 0 \tag{3.5}$$

$$X_L + X_{in} = 0 \tag{3.6}$$

Since the load is passive, $R_L > 0$ and $R_{in} < 0$. Thus, while a positive resistance implies energy dissipation, a negative resistance implies an energy source. The condition of (3.6) controls the frequency of oscillation.

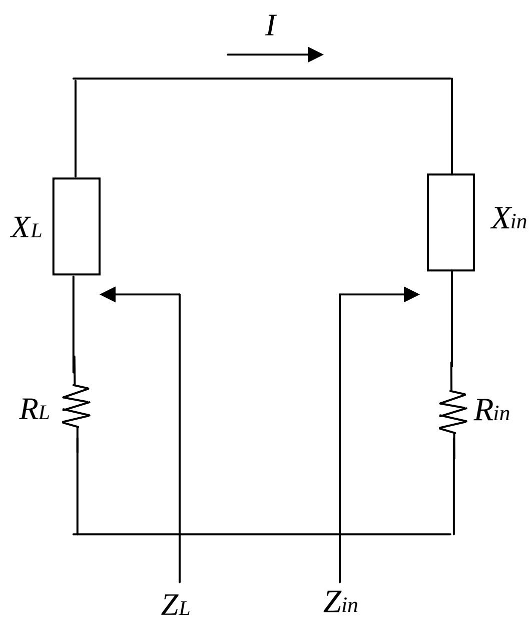


Figure 3.1: Circuit For a One Port Negative Resistance Oscillator

The process of oscillation depends on the nonlinear behavior of Z_{in}, as follows. Initially, it is necessary for the overall circuit to be unstable at a certain frequency, that is, $R_{in}(I, j\omega) + R_L < 0$. Then any transient excitation or noise will cause an oscillation to build up at the frequency, ω. As I increases, $R_{in}(I, j\omega)$ must become less negative until the current I_0 is reached such that $R_{in}(I_0, j\omega_0) + R_L = 0$, and $X_{in}(I_0, j\omega_0) + X_L(j\omega_0) = 0$. Then the oscillator is running in a stable state. The final frequency, ω_0, generally differs slightly from the startup frequency because X_{in} is current dependent, so that $X_{in}(I, j\omega) \neq X_{in}(I_0, j\omega_0)$.

Thus it can be seen that the conditions of (3.5) and (3.6) are not enough to guarantee a stable state oscillation. In particular, stability requires that any perturbation in current or frequency will be damped out, allowing the oscillator to return to its original state. A high-Q circuit will result in maximum oscillator stability. Cavity and dielectric resonators are often used for this purpose [13].

3.2. Gunn Diode Oscillators

Solid state microwave sources can be categorized as two-terminal devices (diodes) or three terminal devices (transistor oscillators). An equivalent circuit for a Gunn diode is represented by a negative resistance $-R$ in parallel with a capacitance C_j, as shown in Figure 3.2.

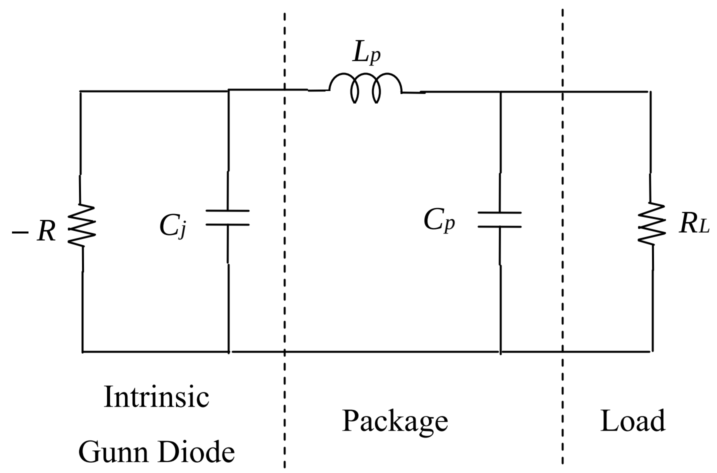


Figure 3.2: Equivalent Circuit For a Packaged Gunn Diode

The negative resistance $-R$ has a value that typically lies in the range -5Ω to -20Ω. C_p is the package capacitance and L_p is the package inductance. Figure 3.3 shows how the total resistance of the Gunn diode and the cavity with the external load depends on the voltage across the diode. The cavity used for the resonator must generally have an impedance transforming property in order to reduce the high impedance of the output waveguide to the appropriate low value required by the Gunn diode [14].

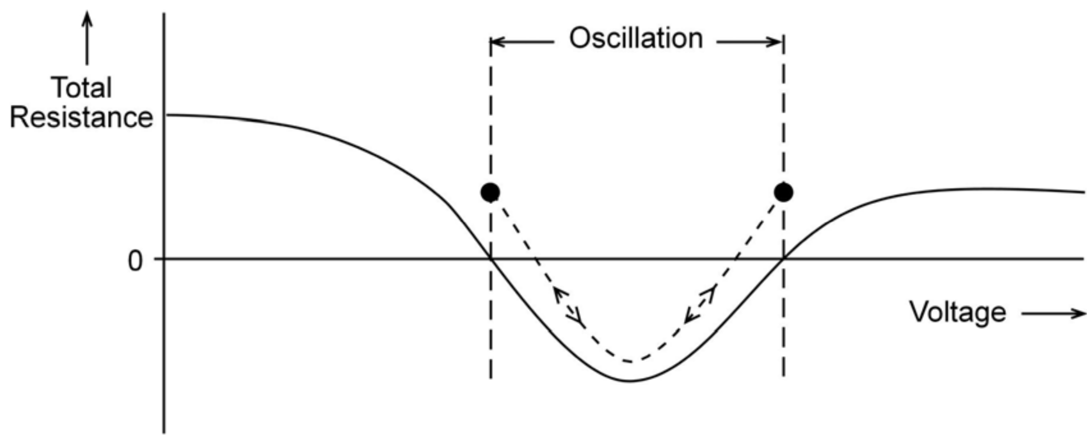


Figure 3.3: Total Resistance Behaviour

A simple cavity structure is shown in Figure 3.4. The Gunn diode is located under a choke circuitry, which is a combination of a filter circuit, a post and a resonant disc, in a rectangular waveguide. The cavity is resonated at the desired frequency by adjusting the diameter of the resonant disc and the position of the sliding backshort. The DC bias voltage is applied to the top of the choke circuitry and the filter circuit is used to protect the bias voltage supply from the RF energy. Fine tuning of the cavity can be obtained by means of a triple-screw-tuner system.

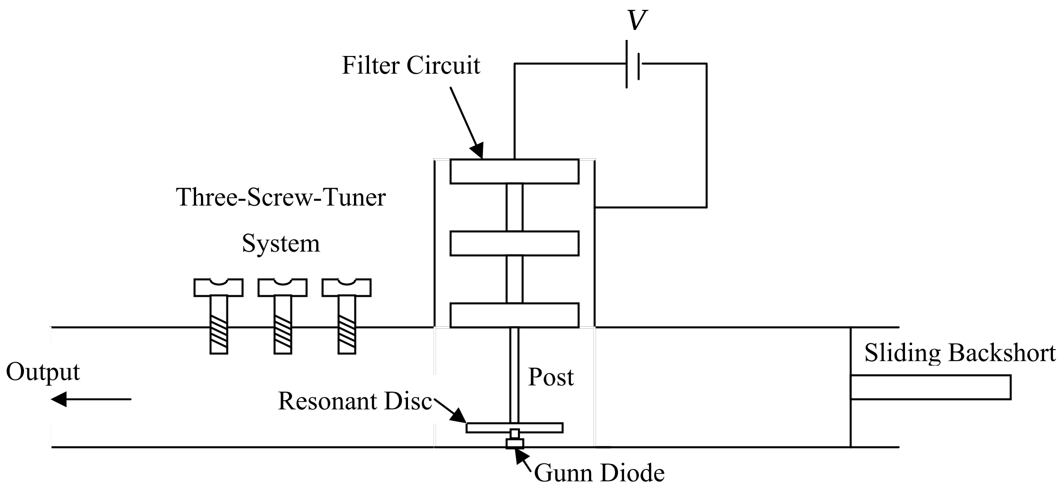


Figure 3.4: Gunn Diode Oscillator with a Waveguide Cavity

3.3. Circuit Analysis of the Gunn Diode Oscillator

A simple equivalent circuit of the Gunn diode oscillator is presented in this section. The oscillator circuit impedance is combined from diode impedance, post impedance and the waveguide impedance. The equivalent circuit of the Gunn diode is determined first and after that the post impedance and the waveguide impedance are examined.

3.3.1. Equivalent Circuit of Gunn Diode

Figure 3.5 is a picture of a Gunn diode which is packaged in a ceramic package that is mounted to a copper heat sink with threaded base [15]. The equivalent circuit of the Gunn diode is shown in Figure 3.6. Three dimensional drawing of the Gunn diode can be seen in Appendix C.

Figure 3.5: Picture of a Packaged Gunn Diode Mounted on a Heat Sink

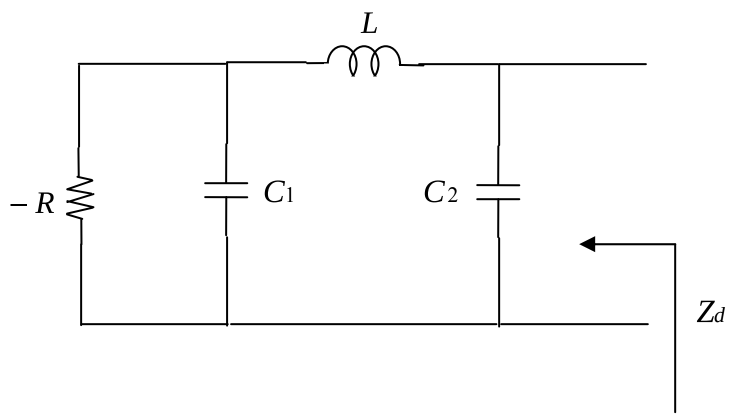


Figure 3.6: Equivalent Circuit of the Gunn Diode

The diode itself is comprised from $-R$, the negative resistance of the Gunn diode, and C_1, the diode capacitance. L and C_2 are the package inductance and the package capacitance respectively. Z_d is the diode impedance. All parameters depend on frequency except negative resistance. The circuit analysis of Figure 3.6 is as follows.

$$Z_d = \frac{R + j2\pi fL - 4\pi^2 f^2 C_1 LR}{1 + j2\pi fR(C_1 + C_2) - 4\pi^2 f^2 LC_2 - j8\pi^3 f^3 C_1 C_2 LR} \tag{3.7}$$

The characteristics of the Gunn diode that is used in this thesis is listed in Table 3.1.

Table 3.1: Characteristics of the Gunn Diode

Threshold Voltage	1.58 V
Operating Voltage	5.72 V
Threshold Current	1060 mA
Operating Current	768 mA
Package Capacitance	0.18 pF
Package Inductance	0.10 nH

The negative resistance of the Gunn diode, $-R$, can be calculated using the operating and threshold values. It is obtained as -14Ω, approximately. The intrinsic capacitance can be taken as 0.18 pF.

After putting the values in (3.7) Z_d is found as related with frequency and the real and imaginary parts of the diode impedance are plotted versus frequency as in Figure 3.7 and Figure 3.8. In these figures, the starting value for the negative resistance is taken as the ratio of the voltage difference between the operating and threshold values to the corresponding current differences.

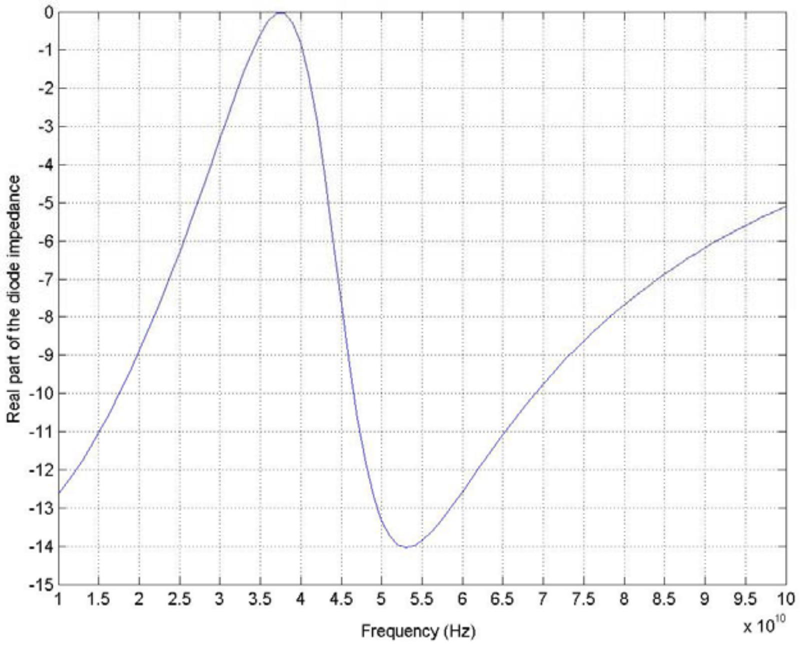


Figure 3.7: Variation of the Gunn Diode Resistance Versus Frequency

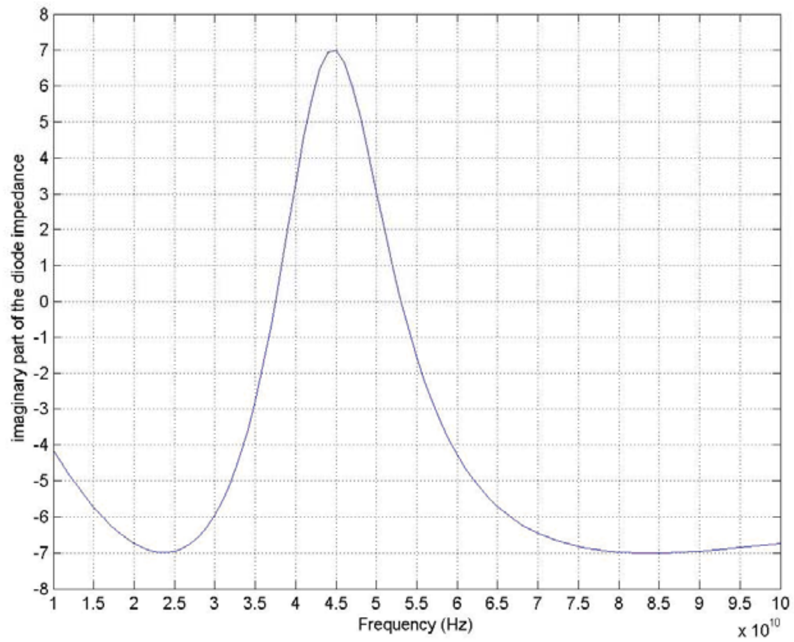


Figure 3.8: Variation of the Gunn Diode Reactance Versus Frequency

3.3.2. Equivalent Circuit of Post

The post that is used in Gunn diode oscillator is shown in Figure 4.12. The height of the post is 2.67 mm and the diameter is 0.86 mm. The equivalent circuit of a post in a waveguide is shown in Figure 3.9 [16] .

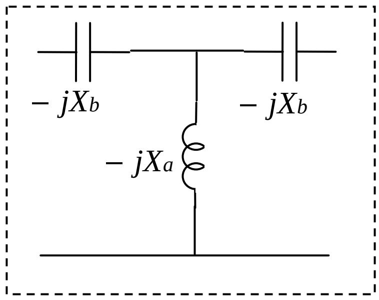


Figure 3.9: Equivalent Circuit of the Post

The equivalent circuit consists of a series capacitive reactance and shunt inductive reactance. The formulae obtained from variational method to calculate these reactances are as follows [17].

$$X_b = \frac{a}{\lambda_g} \frac{\left(\frac{\pi d}{a}\right)^2}{1 + 2g^2\left(S + \frac{3}{4}\right)} \tag{3.8}$$

$$X_a = \frac{X_b}{2} + \frac{a}{2\lambda_g\left[S - g^2 - \frac{5}{8}g^4\left(S - \frac{2S\lambda_0{}^2}{\lambda_g{}^2}\right)^2\right]} \tag{3.9}$$

$$S = \ln\frac{4a}{\pi d} - \frac{5}{2} + \frac{11}{3}\left(\frac{\lambda_0}{2a}\right)^2 - \left(\frac{\lambda_0}{a}\right)^2 t \tag{3.10}$$

$$t = \sum_{m=3,5,..}^{\infty} m\left\{\sqrt{1-\left(\frac{2a}{m\lambda_0}\right)} - 1 + 2\left(\frac{a}{m\lambda_0}\right)^2\right\} \tag{3.11}$$

$$g = \frac{\pi d}{2\lambda_0} \tag{3.12}$$

After many calculations are evaluated X_b and X_a are found as 0.09 and 0.33 respectively.

3.3.3. Total Equivalent Circuit

The characteristic impedance of the waveguide can be calculated as, [18],

$$Z_0 = 377\frac{\lambda_g}{\lambda_0} \tag{3.13}$$

$$Z_0 = 472\Omega$$

and the waveguide impedance is shown in (3.14). ℓ is the distance between the sliding backshort and the Gunn diode axis.

$$Z_s = jZ_0 \tan \beta\ell \tag{3.14}$$

By using the equation (3.14) waveguide impedance can be found as j28.

The total equivalent circuit can be seen in Figure 3.10. The transformer is used to describe the triple-screw-tuner system.

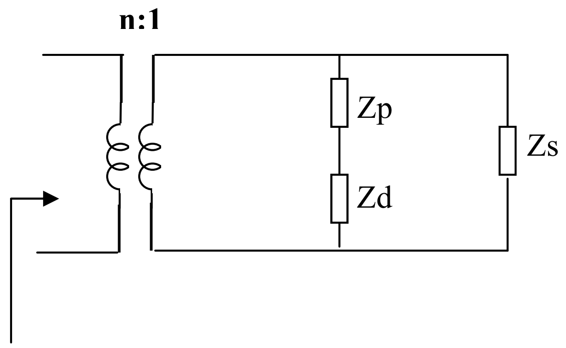


Figure 3.10: Equivalent Circuit of the Gunn Diode Oscillator

The equivalent circuit formed from lumped elements is shown in Figure 3.11.

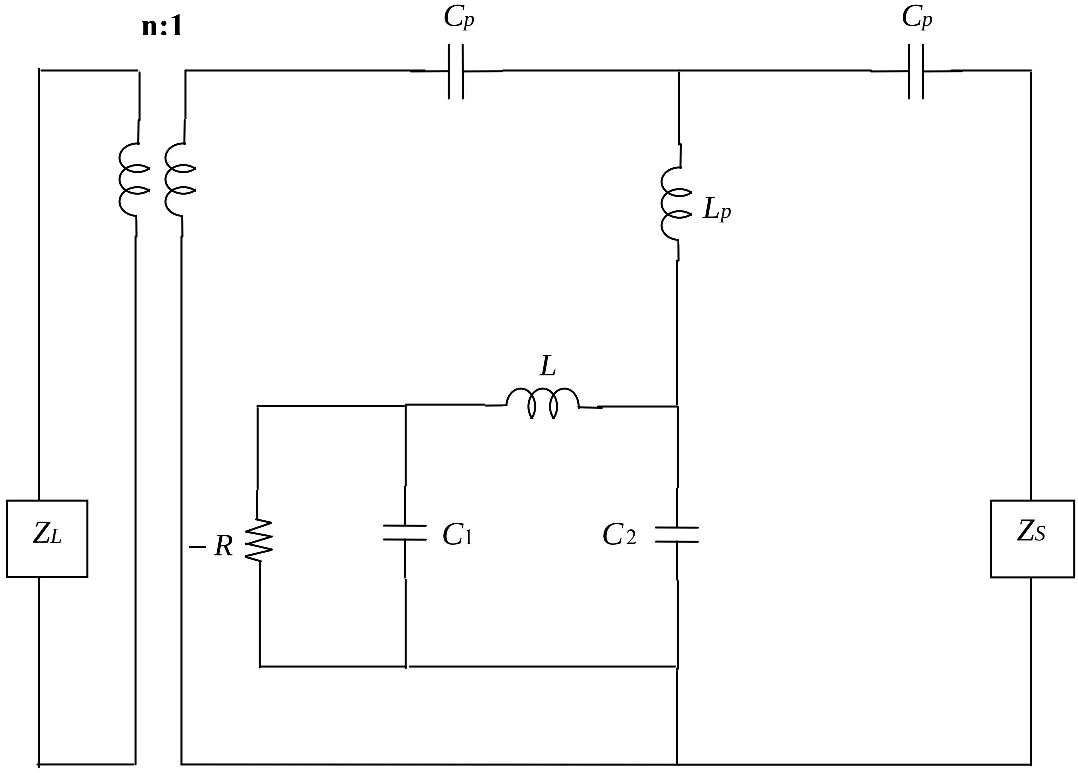


Figure 3.11: Equivalent Circuit of the Gunn Diode Oscillator With Lumped Elements

C_p =Post Capacitance

L_p =Post Inductance

$-R$ =Gunn Diode Negative Resistance

C_1 =Gunn Diode Capacitance

L =Package Inductance

C_2 =Package Capacitance

Z_S =Waveguide Impedance

Z_L =Load Impedance

3.4. Resonant Disc

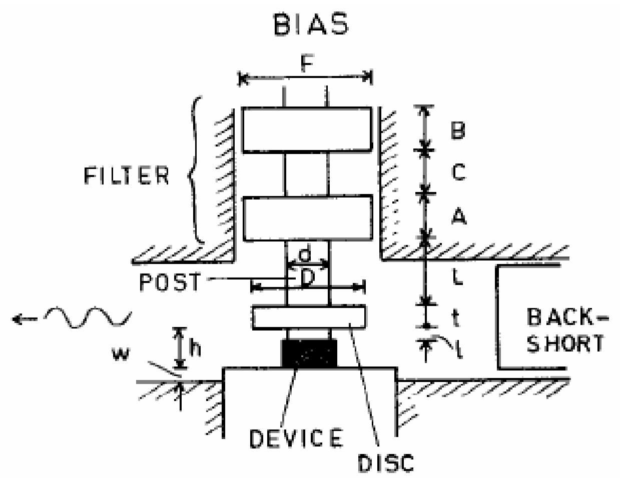


Figure 3.12: Gunn Diode Oscillator With Resonant Disc on top of the Gunn Diode

A resonant disc on top of the Gunn diode is seen in Figure 3.12 [19]. The disc diameter "D" and the thickness "t" affect the frequency of the oscillator. The disc diameter, d inches, can be calculated as equation (3.15), by using equation (3.14) [20].

$$D = \frac{6.922}{f} \text{ in inches} \tag{3.14}$$

At 35 GHz D is calculated as

$$D = 0.198 \text{ inches}$$

or

$$D = 5 \text{ mm} \tag{3.15}$$

The thickness of the disc reduces the frequency as it increases [19]. So the thickness is chosen as small as possible. The thickness of the disc of our oscillator is 0.2 mm. And the diameter is 5 mm. The oscillator gives an oscillation at 28 GHz with these dimensions.

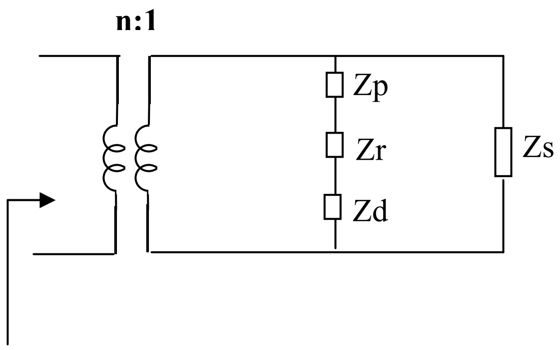


Figure 3.13: Equivalent Circuit of the Gunn Diode Oscillator With Resonant Disc

Figure 3.13 shows the equivalent circuit of a Gunn diode oscillator with resonant disc. Zr is the impedance of the resonant disc.

CHAPTER 4

DESIGN AND CONSTRUCTION OF THE GUNN DIODE OSCILLATOR

In this chapter the design and the construction of the Gunn diode oscillator operating at 35 GHz is given. The waveguide based structure which is comprised of post mounted diode, sliding backshort and triple-screw-tuner is described. Three dimensional and two dimensional drawings of the Gunn diode oscillator including the waveguide, the filter circuit and the diode mounting are shown in Figure 4.1 and Figure 4.3. All mechanical drawings of the Gunn diode oscillator are included as Appendix C.

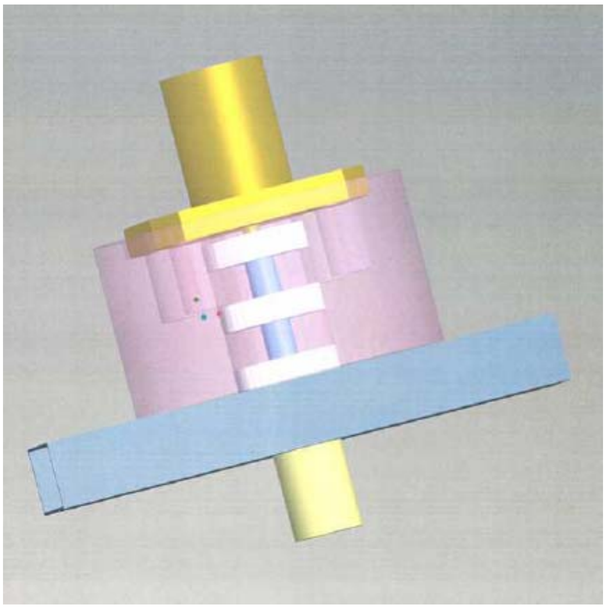


Figure 4.1: Three Dimensional Drawing of Waveguide Based Gunn Diode Oscillator

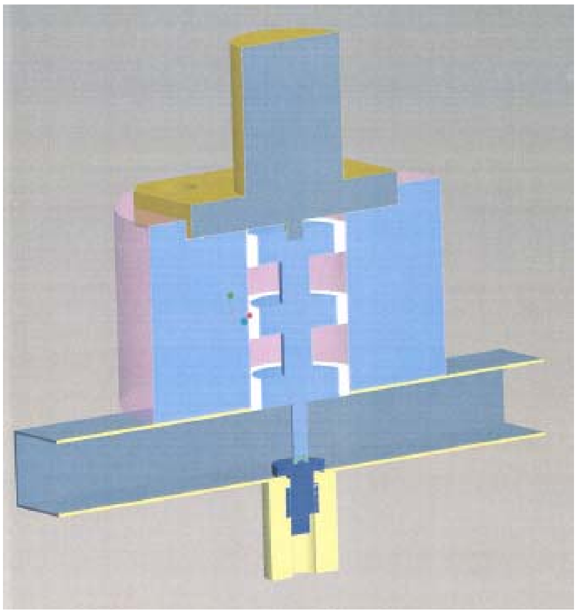


Figure 4.2: The Cross Section of Waveguide Based Gunn Diode Oscillator

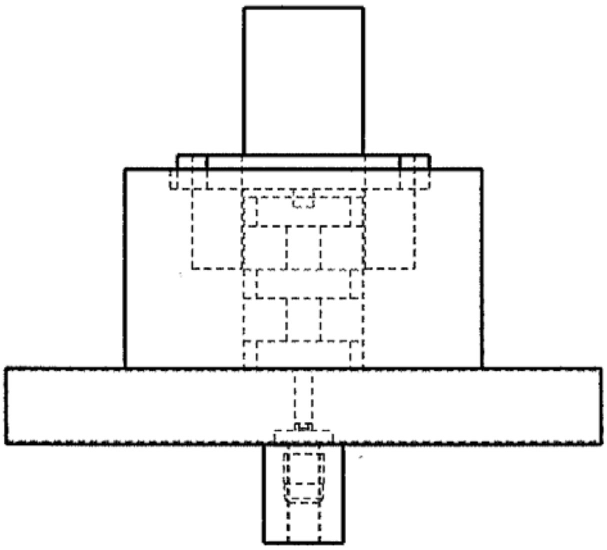


Figure 4.3: Two Dimensional Drawing of Waveguide Based Gunn Diode Oscillator

4.1. Waveguide

As the design configuration, a waveguide based structure is chosen because of the power loss and heat sink considerations. In this type of design, the Gunn diode is mounted inside the waveguide. To operate at 35 GHz a Ka-Band waveguide is used. The properties of the waveguide are listed in Table 4.1.

Table 4.1: Ka-Band Waveguide Properties

Band	Inside Dimensions inches	Outside Dimensions inches (typ)	Standard Freq Range, GHz	Cutoff Freq GHz
Ka	0.280, 0.140	0.360, 0.220	26.5 to 40.0	21.08

4.2. Filter Circuit

The filter circuit comprises of a succession of quarter-wave lines; a low pass filter. The aim of the low pass filter circuit is to apply DC current into the Gunn diode while stopping any RF energy leaking out of the oscillator. The filter circuit is designed and simulated using the quarter-wave lines technique. The oscillator must operate at 35 GHz so the quarter wavelength in free space is 2.14 mm. The thin high characteristic impedance lines have these lengths. The characteristic impedance of high characteristic impedance lines is 75 Ω. For low characteristic impedance lines the lengths are 1.48 mm each as the dielectric substrate teflon is used. The characteristic impedance of these lines is 10 Ω. The “a” dimensions of the components are calculated by using the equation (4.1).

$$Z_0 = \frac{60}{\sqrt{\varepsilon_r}} \ln \frac{b}{a} \tag{4.1}$$

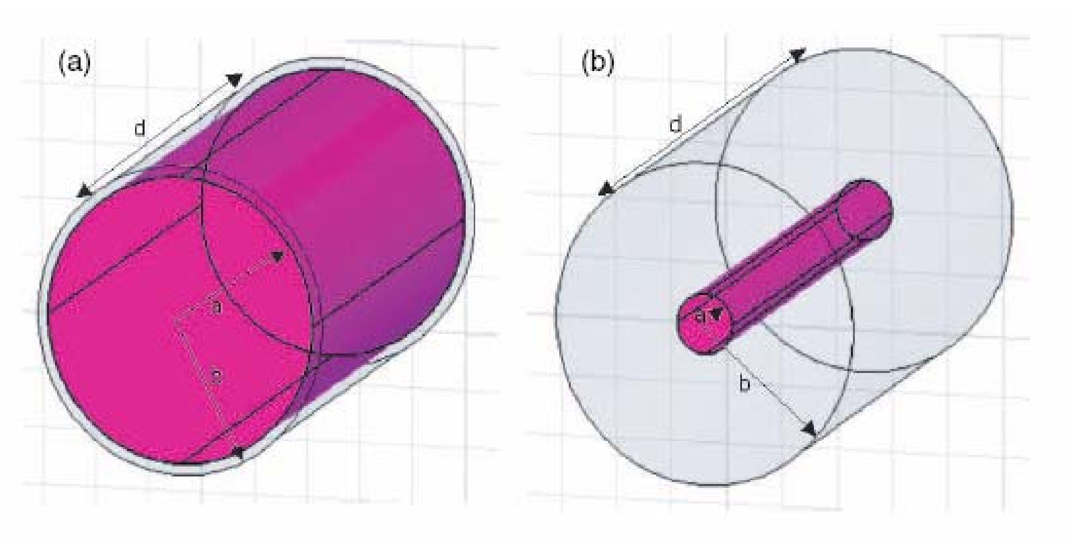


Figure 4.4: Schematic View for the Low and High Characteristic Impedance Lines

The dimensions for the filter circuit are given in Table 4.2.

Table 4.2: Filter Circuit Dimensions

Component	a (mm)	b (mm)	d (mm)
Line 1	2.36	3.00	1.48
Line 3	2.36	3.00	1.48
Line 5	2.36	3.00	1.48
Line 2	0.86	3.00	2.14
Line 4	0.86	3.00	2.14

Once the dimensions of the filter have been determined, the values are entered into a simulation package called Advanced Design System (ADS). ADS contains, among other things, a circuit simulator intended primarily for the designs of RF/microwave frequency systems. Figure 4.5 shows a screenshot from ADS, of the components.

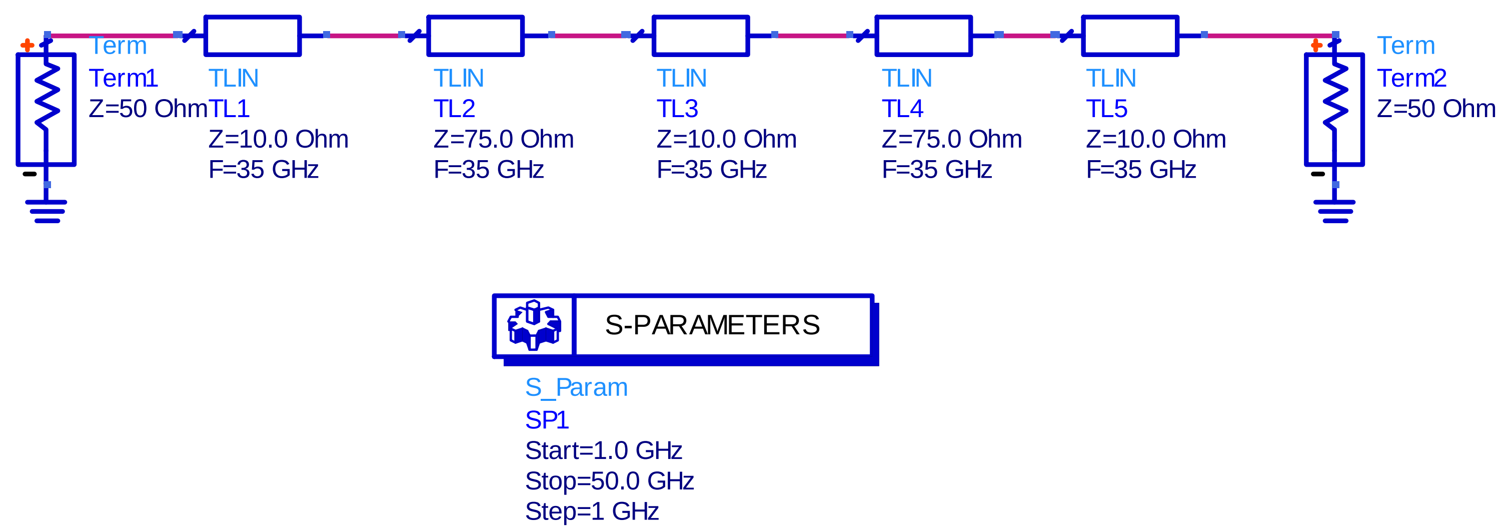
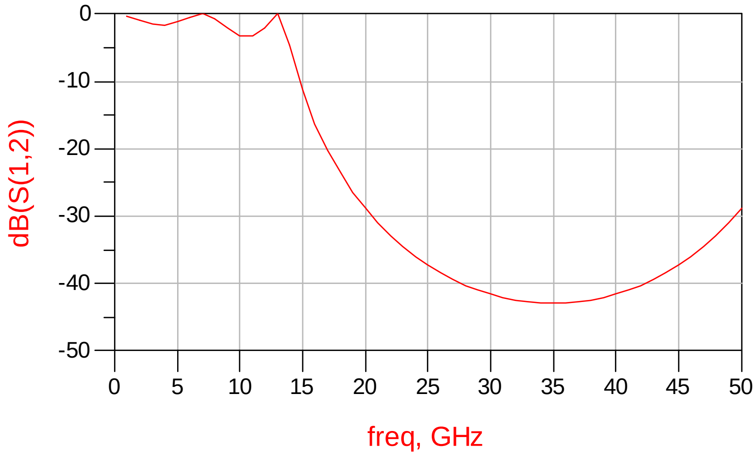


Figure 4.5: Screenshot of Components from ADS

The S-parameters were set up so that the results could be seen across a range of 1 GHz to 50 GHz, which includes the frequency of interest; 35GHz. The circuit was simulated and the results can be seen in Figure 4.6. The filter circuit is symmetric that means S(1,2) parameters of the filter is the same as the S(2,1) parameters of the filter. Also S(1,1) is the same as S(2,2) in the same manner. On the S(1,2) plot a sharp roll off can be seen easily between 10 GHz and 15 GHz. It is desired that there should be enough rejection at the 35 GHz. It is less than about -40 dB at 35 GHz which satisfies the requirements for all load resistances except for 3 Ω where the isolation is approximately 30 dB.



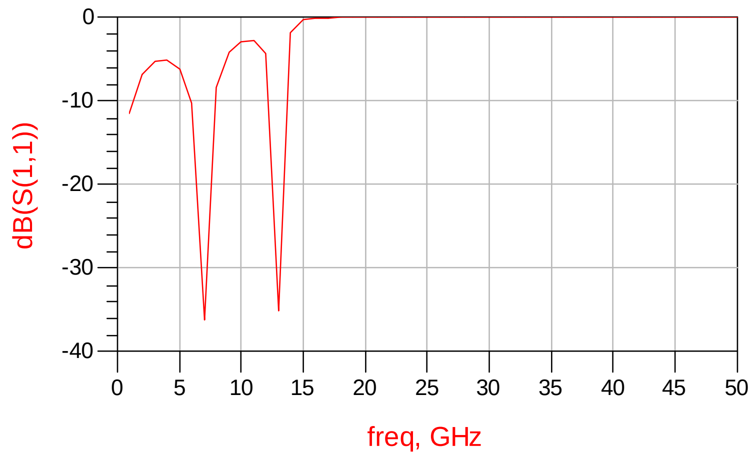
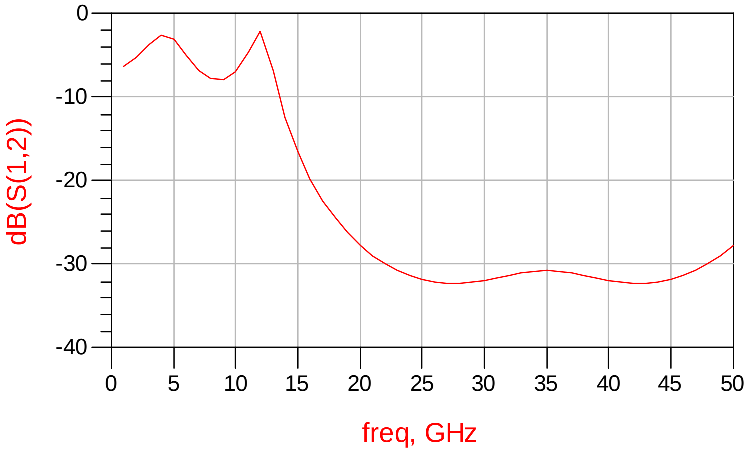


Figure 4.6: S Parameter Plots of Filter Circuit With 50Ω Load Impedance

The behavior of the filter circuit does not depend on the load impedance. The circuit is simulated with different load impedances. The S parameter plots with different load impedances are shown in Figure 4.7, Figure 4.8, Figure 4.9 and Figure 4.10.



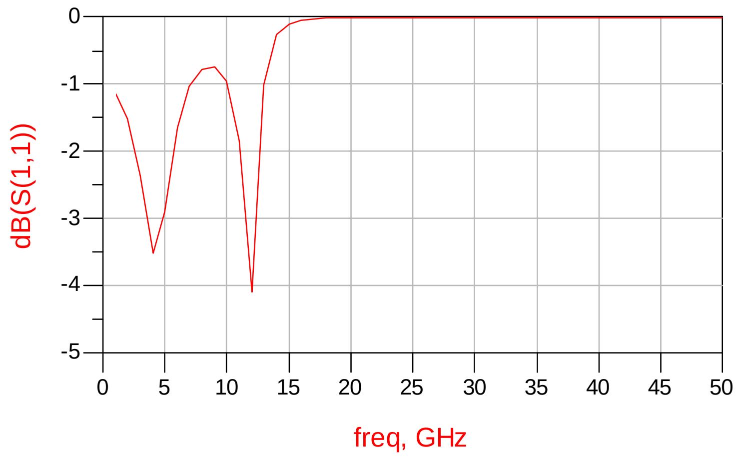


Figure 4.7: S Parameter Plots of Filter Circuit With 3Ω Load Impedance

Figure 4.8: S Parameter Plot of Filter Circuit With 100Ω Load Impedance

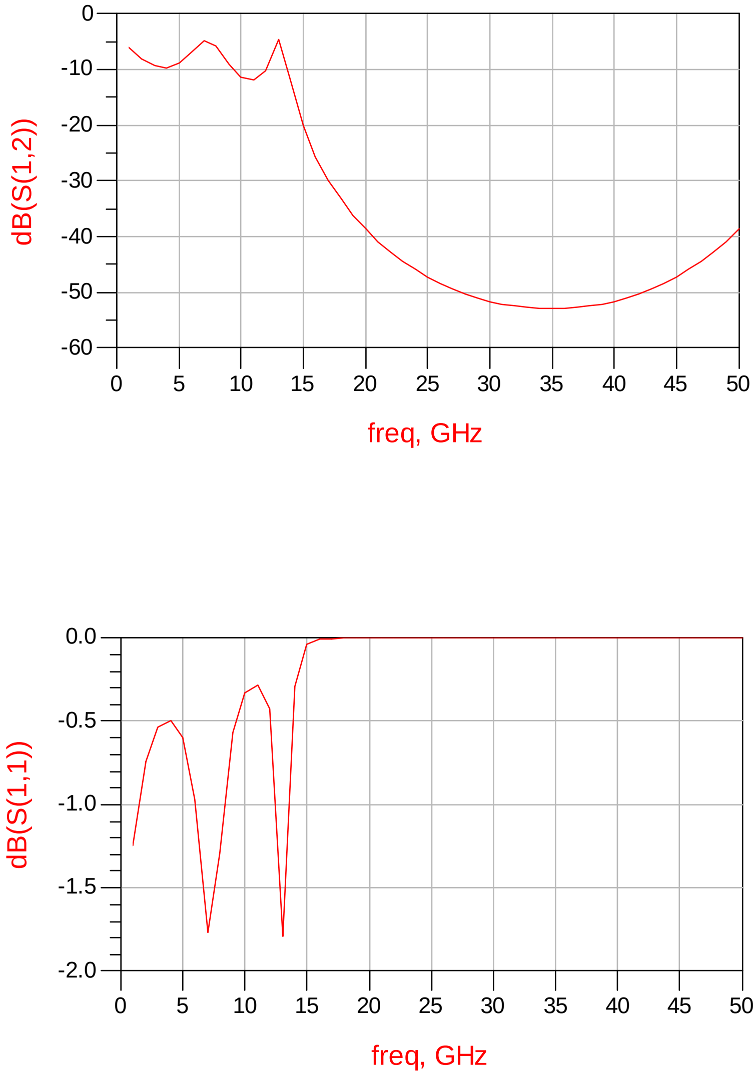


Figure 4.9: S Parameter Plots of Filter Circuit With 500Ω Load Impedance

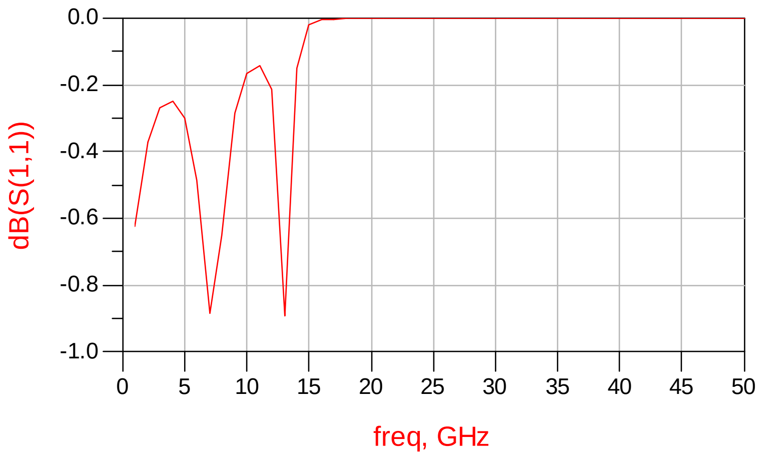


Figure 4.10: S Parameter Plots of Filter Circuit With 1kΩ Load Impedance

After simulation process using ADS is completed two and three dimensional drawings are carried out using some drawings programs as Proengineer and AutoCAD. The drawings of the filter circuit with post are shown in Figure 4.11 and

Figure 4.12. The photograph of the constructed filter circuit can be seen in Appendix D.

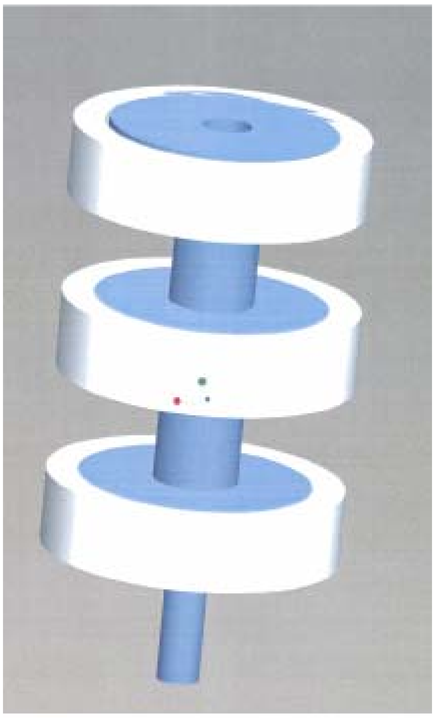


Figure 4.11: Three Dimensional Drawing of Filter Circuit with Post

The top of the filter is used for placing the SMA connector to couple the DC bias.

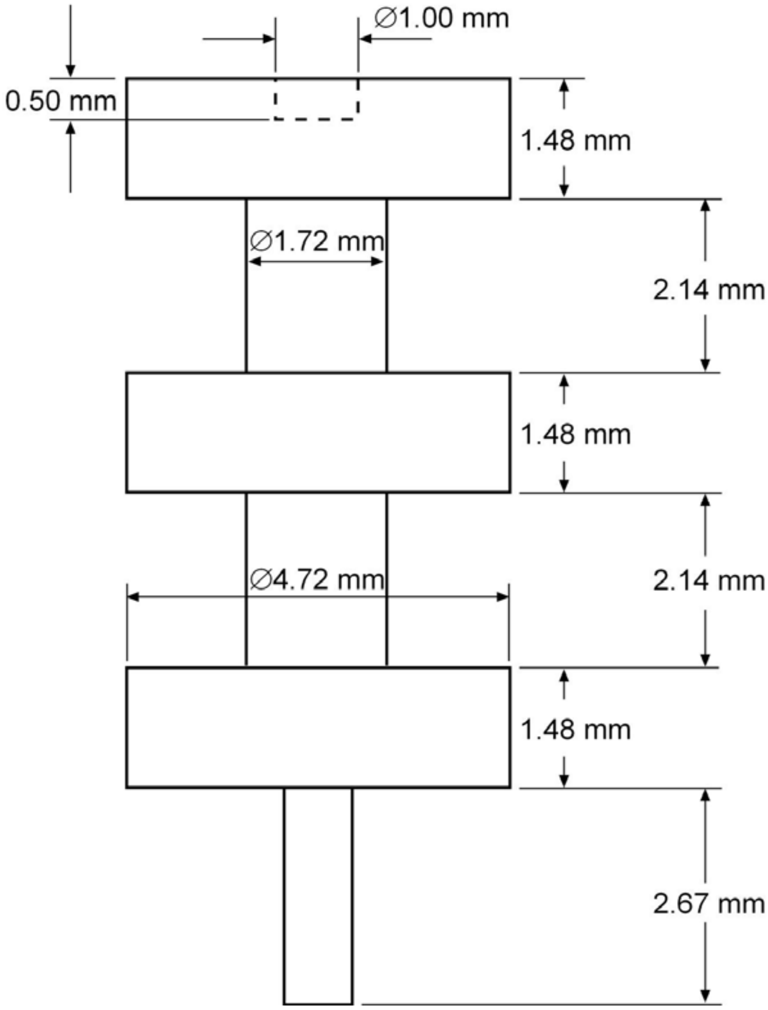


Figure 4.12: Two Dimensional Drawing of Filter Circuit with Post

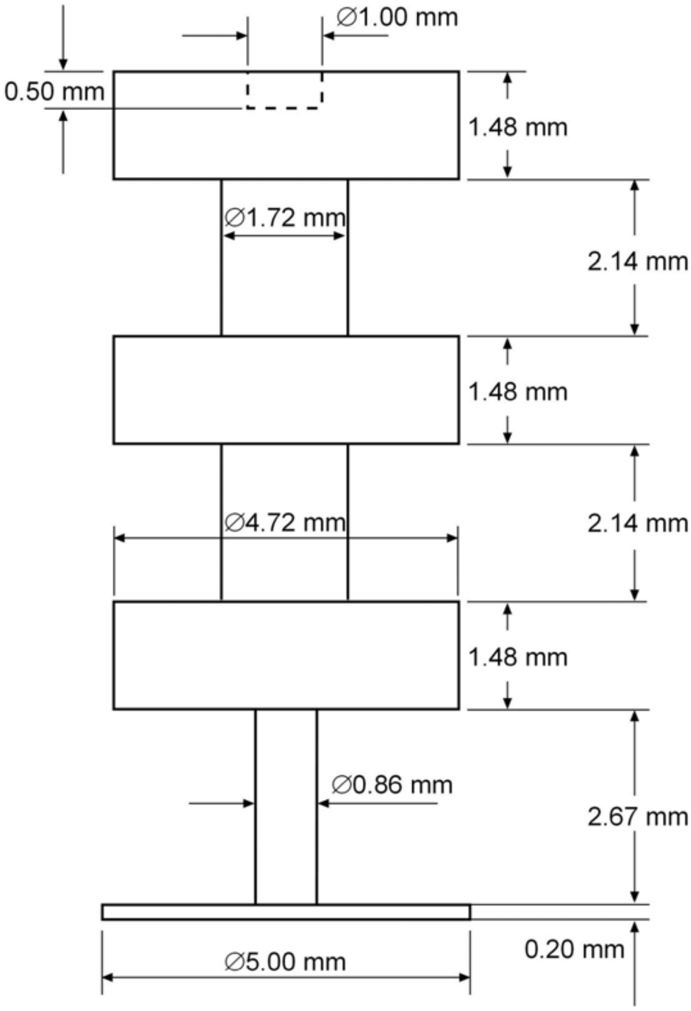


Figure 4.13: Two Dimensional Drawing of Filter Circuit with Post and Resonant Disc

Figure 4.13 shows a two dimensional drawing of the filter circuit with post and a resonant disc of diameter 5.00 mm and the thickness of the disc is 0.20 mm.

4.3. Sliding Backshort

Sliding backshort makes the oscillator easily tunable. The frequency of oscillations in the cavity is determined by two variables which are the size and the shape of the cavity. In fact having a smaller cavity gives a higher frequency. Having the backshort in the correct position causes the electromagnetic wave to reflect back and forth along the backshort cavity and introduces correct reactance across the diode.

The backshort component is vital to the operation of the device. In this thesis a commercial micrometer controlled sliding backshort is used to adjust the cavity. It is shown in Figure 4.14.

Figure 4.14: TS-28 Dorado Company Tunable Short

4.4. Triple-Screw-Tuner System

Figure 4.15 shows a triple-screw-tuner system used for impedance matching for the Gunn diode oscillator design within this thesis.

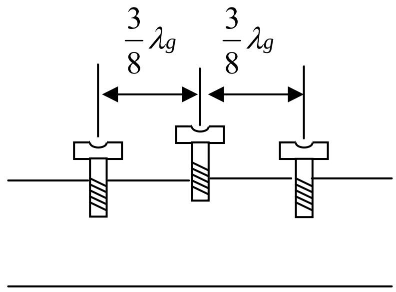


Figure 4.15: Triple-Screw-Tuner

The screws in triple-screw-tuner system are variable-depth screws that can penetrate into the guide through a centered narrow slot in the broad wall of the guide. This slot is cut along the current flow lines so that it has a negligible perturbing effect on the internal field. The penetration of screws does not need to be so great that it behave as an inductive element. Three variable-depth screws spaced a fixed distance of about $\frac{3}{8}\lambda_g$ apart as in Figure 4.15 can match a large variety of loads [21].

The distance between the variable-depth screws is calculated as 4 mm for the Gunn diode oscillator operating at 35 GHz.

4.5. Mounting

After all components of the Gunn diode oscillator are designed and constructed, mounting of these parts is needed. First triple-screw-tuner system is mounted to the waveguide. Afterwards the Gunn diode is mounted. The diode is enclosed in a small cylindrical package with a screw thread. The screw based package allows the diode to be mounted extremely easily into its target environment and acts as a heatsink and dissipates the heat to the brass walls of the waveguide. This heatsink casing screwed into a nut so the Gunn diode sits just above the waveguide surface. Additionally the choke circuitry is mounted on the top of the Gunn diode and the SMA connector is screwed into the brass that covers the filter circuit and sits above the upper side of the waveguide. The mounted Gunn diode oscillator is shown in Figure 4.16.

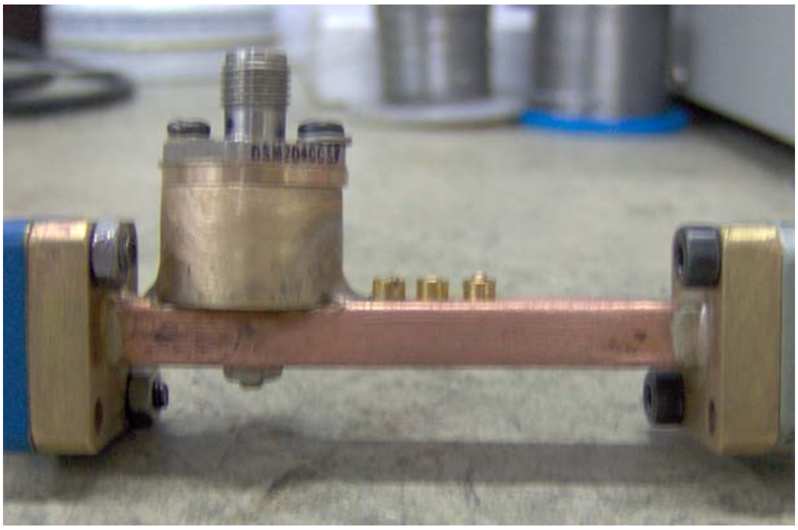


Figure 4.16: Mounted Gunn Diode Oscillator

CHAPTER 5

MEASUREMENTS

This chapter is related with the measurements that are performed after the Gunn diode oscillator has been built. Since the structure is one complete system, it was not possible to carry out measurements on individual parts. The measurements that are performed on the completed oscillator include measurements on diode characteristic, spectrum of oscillations and power output.

5.1. Equipment Used

The equipment used to perform the measurements of the Gunn diode oscillator is shown Figure 5.1.

The list of used equipment and their technical specifications is given below.

1. HP 70000 Series Hewlett Packard Spectrum Analyser
   a. HP 70001A Mainframe
   b. 70004A Display
   c. 70902A IF Section, RBW 10 Hz to 300 kHz
   d. 70900B Local Oscilator
   e. 70906A RF Section 50 kHz to 26,5 GHz
   f. 70907B External Mixer Interface

g. 70601A Preselector

2. HP 11974 Hewlett Packard External Ka Band Mixer for Spectrum Analyser

3. E3648A Agilent Dual Output DC Power Supply

4. TS-28 Dorado Company Tunable Short

5. 2-28-250 M/A-COM Isolator

6. MFR-06351 Waveguide to Coaxial Converter

7. 2PS-145ATW-240-2PS 02891 Insulated Wire

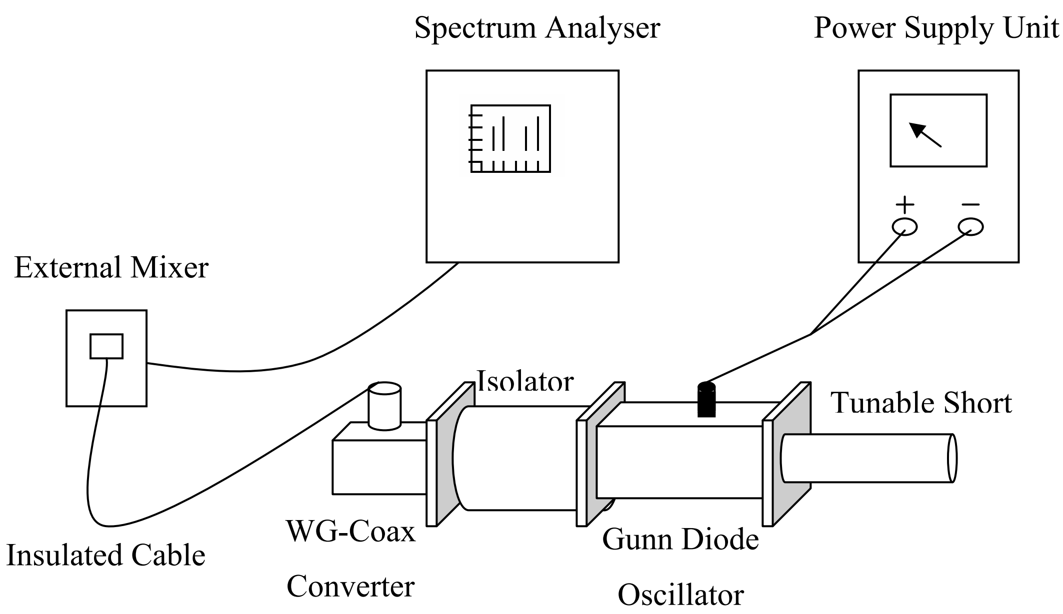


Figure 5.1: Block Diagram of the Equipment Used

The procedure used for the measurements is as follows: First DC power supply unit (PSU) output is set to 0V and its current limit to about 1.3 A. Then the positive terminal is connected to the inner conductor of the filter circuit and the negative supply is connected to the ground. After PSU connections are completed the spectrum analyser is connected to the waveguide output port of the Gunn diode oscillator. A isolator, to isolate the oscillator from the other equipment, is connected between the output port and the coaxial-waveguide transition unit. The total insertion loss of the components between the oscillator and the input terminal of the spectrum analyser, was measured. This loss was found to be 6 dB. A mixer unit was employed just before the spectrum analyser to extend the frequency coverage from 26.5 GHz to 40 GHz.

5.2. Measurements

5.2.1. Diode Characteristics Measurements

A Gunn diode is a two terminal device. Just like a normal diode they exhibit non linear I/V behaviour, but have a negative resistance characteristic. The current versus voltage measurements in Table 5.1 shows the negative resistance characteristic of the diode, where as the voltage is increased the current falls above a threshold value.

Table 5.1: Results of the Current versus Bias Voltage Measurements

Bias Voltage (V)	Current (mA)
0.1	158
0.2	310
0.3	450
0.5	720
0.6	840
0.7	950
0.8	1030
0.9	1090
1.0	1130
1.1	1150
1.2	1160
1.3	1170
1.4	1170
1.5	1110
1.6	1100
1.7	1090
1.8	1080
2.0	1070
2.1	1060
2.2	1056
2.3	1050
2.5	1038
2.6	1030
2.7	1026
2.8	1020
3.0	1010

Table 5.1 (cont'd)

Bias Voltage (V)	**Current (mA)**
3.1	1000
3.2	990
3.3	990
3.4	980
3.5	980
4.0	920
4.2	910
4.4	910
4.6	900
4.8	890
5.0	890
5.3	880
5.4	880
5.5	880

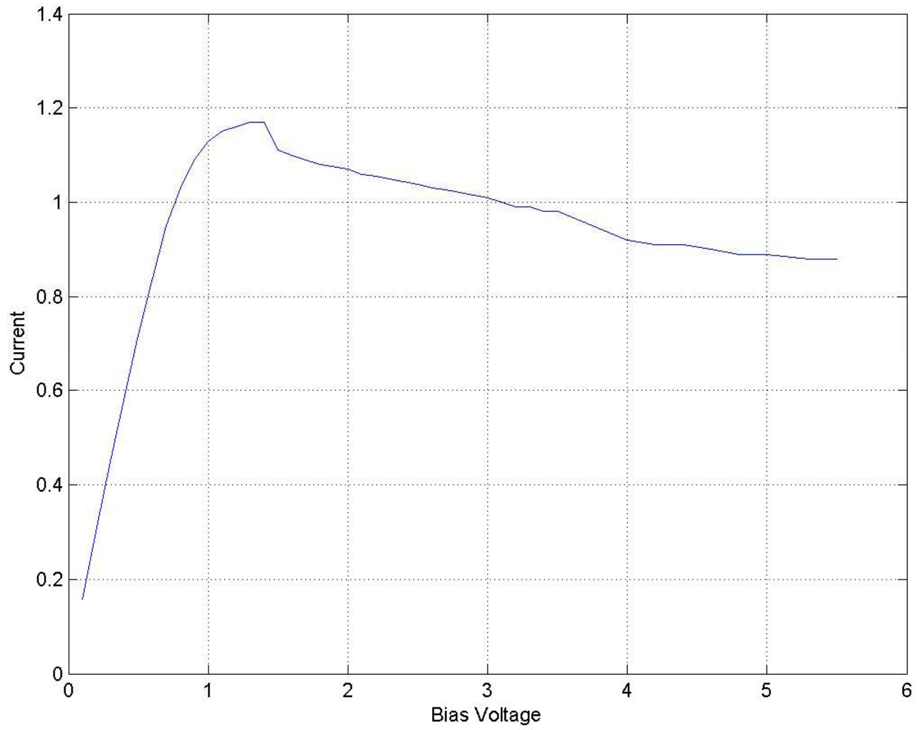


Figure 5.2: DC Characteristic of the Gunn Diode

According to the results in Table 5.1 the DC characteristic of the Gunn diode is obtained as in Figure 5.2. The irregularities observed in the negative resistance region are due to the oscillations already taking place within the system and hence distorting the appearance of the graph. This is usual for all negative diode oscillators.

5.2.2. Frequency and Power Measurements Without Resonant Disc

First measurements are carried out without the use of a resonant disc. In this configuration the post of the choke filter touches the diode directly. By biasing the choke circuitry of the oscillator above some threshold, the Gunn diode enters its negative differential resistance region of operation. Whilst the Gunn diode is biased in the negative differential resistance region the diode oscillates at a frequency determined by the Gunn diode, the geometry of the waveguide, the choke circuitry and position of the backshort. Provided the bias voltage maintains the diode within this mode of operation, any variations in the bias will also cause variations in the oscillation frequency. As the geometry of the oscillator at these frequencies is very small, inconsistencies in dimensions are almost unavoidable. By varying the bias voltage, fine tuning of the frequency may be achieved without the need for such accurate machining and mechanical adjustments.

Measurements start with turning the PSU and raising the voltage slowly until oscillation is detected by spectrum analyser. The bias voltage is increased to get a better signal and the tunable short is used to get a higher power. The results are given in Table 5.2.

Table 5.2: Results of the Frequency and Power Output versus Bias Voltage

Bias Voltage (V)	Operating Frequency (GHz)	Power Output (dBm)
2.93	32.90	-11.00
2.93	33.88	-11.00
2.93	34.37	-14.00
2.93	34.61	-3.00
2.99	34.58	-4.00
2.99	34.37	-4.15
2.99	34.26	-7.00
2.99	34.23	-6.40
2.99	34.19	-5.00
3.23	34.19	-4.51
4.03	34.19	-4

Figure 5.3 shows the frequency voltage characteristic of the Gunn diode oscillator obtained from results in Table 5.2.

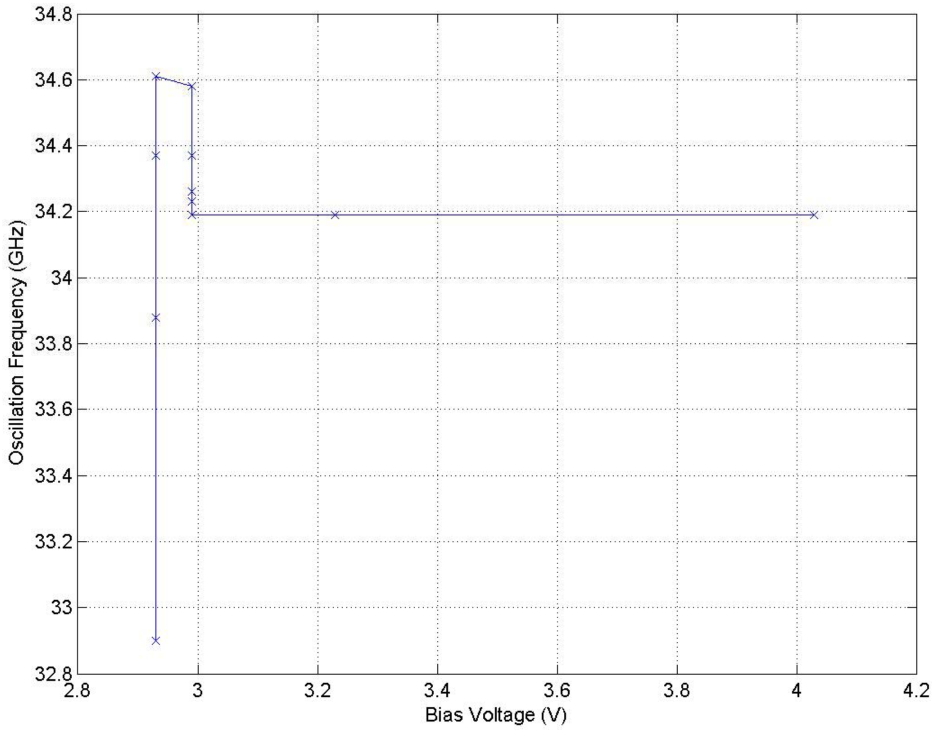


Figure 5.3: Frequency – Voltage Characteristic Without Resonant Disc

Figure 5.4 shows measured power values of the Gunn diode oscillator without a resonant disc. It can be seen that the output power is very low.

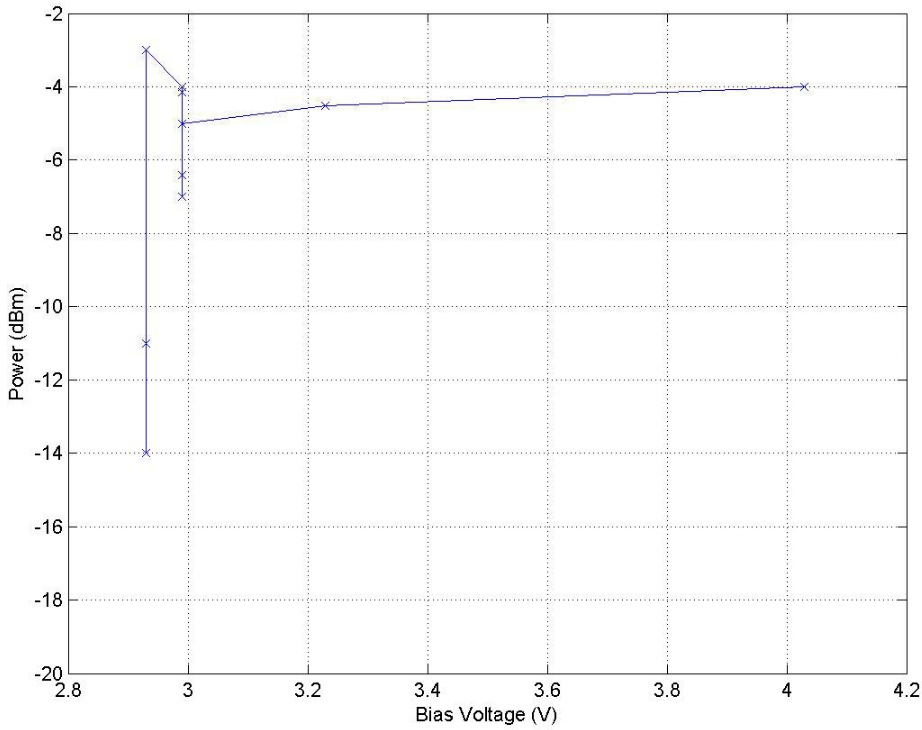


Figure 5.4: Measured Power Without Resonant Disc

The power output of a Gunn diode oscillator depends on the frequency at which the diode is oscillating. As the frequency is dependent on the bias voltage, it follows that the power output is also dependent on the bias voltage. In order to measure the power output of an oscillator the spectrum analyser can be used. The measurements obtained are shown in Table 5.2. The loss of the isolator and the isolated cable is 6 dB so the signal power output is 6 dB high than the measured power. In these measurements it is seen that the power obtained at the desired frequency is very low. The spectrum of the oscillations shows that other frequencies are also present. The given results show the values obtained at the highest output frequency. It can be concluded that these observations are the result of oscillations at a lower frequency which can not be displayed in the 26.5-40 GHz band. What is observed, most probably, are the higher harmonics.

5.2.3. Frequency and Power Measurements With Resonant Disc

The measured power outputs using the first design are very low so a change in the design is needed. A resonant disc that is used to resonate at the desired frequency is added to the design. The simplified resonant frequency of this type of resonant disc is given in Chapter 3. A resonant disc having a 5 mm diameter is positioned between the Gunn diode and the post. Voltage, current, power and frequency measurements with resonant disc are given in Table 5.3. Again a 6 dB loss of cable and isolator are taken into the consideration. Measurements with the resonant disc show oscillations at the fundamental frequency because no other frequencies are present in the spectrum. The power is higher and the oscillations are stable. The disc seems to control the frequency of oscillations primarily, although the position of the backshort circuit and the triple-screw-tuners affect the frequency to some extent.

Table 5.3: Measurements Performed With a 5 mm Resonant Disc

Voltage (V)	Current (mA)	Frequency (GHz)	Power (dBm)
3.13	1030	27.40	8.14
5.50	800	27.59	14.45
5.55	870	28.30	15.28
5.55	870	28.44	10.24

Figure 5.5 shows the frequency voltage characteristic of the Gunn diode oscillator with a 5 mm resonant disc. It can be seen from the plot that the oscillation frequency increases with the increasing bias voltage.

Figure 5.6 shows measured power values of the Gunn diode oscillator with a 5 mm resonant disc. The output power is higher than the output power obtained without a resonant disc.

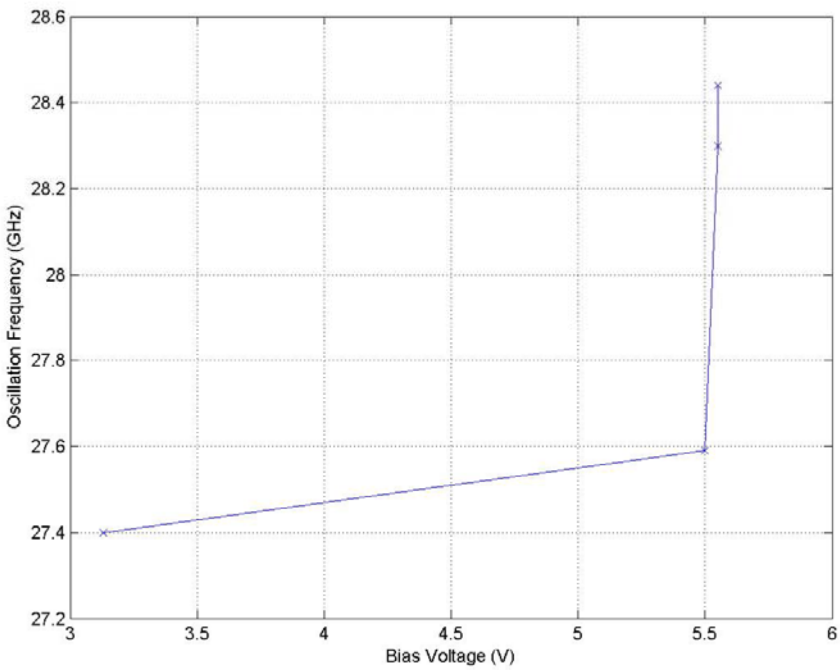


Figure 5.5: Frequency – Voltage Characteristic With Resonant Disc

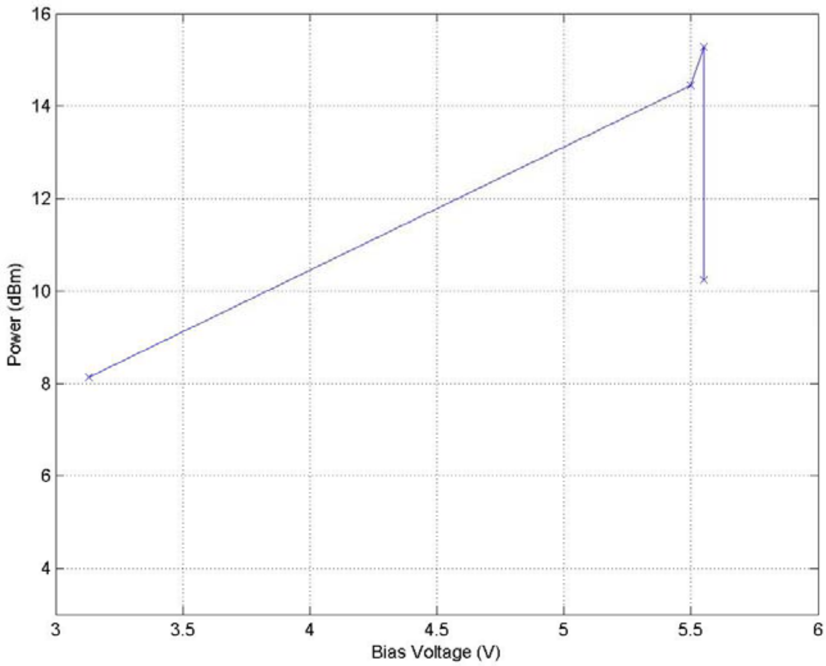


Figure 5.6: Measured Power With Resonant Disc

During practical tests undertaken in the laboratory it was noted that the brass waveguide becomes hot. Due to the small size of the Gunn diode and the power that is involved, the diode can became very hot. If this heat is not dissipated the diode will overheat causing it to fail. If the oscillator was implemented using planar techniques the heat dissipation would be an even greater problem.

CHAPTER 6

CONCLUSIONS

In this thesis, the design and the implementation of a Gunn diode oscillator that is operating at around 35 GHz are given.

The content of the thesis includes research about Gunn diode oscillators, design of the Gunn diode oscillator, the simulation and the computer aided drawings of the designed parts, the construction of the oscillator and finally the measurements.

The thesis is initiated with researching Gunn diodes, their physics, uses and previous research and designs, as well as looking at housings and diode mounting. The findings are evaluated and planar housing is eliminated because of power loss and heat sink considerations.

It is decided that the Gunn diode is placed inside a waveguide housing and research about waveguide housing is continued. The requirements of the oscillator system are first determined to begin the design of the Gunn diode oscillator. The system is designed to operate at 35 GHz.

As the design process progresses the use of the some simulation tools as ADS and Matlab to simulate the filter circuit and to determine the diode impedance characteristic approximately according to the frequency variation. It is determined that whilst simulation is very useful in the design of such systems, it cannot model the system completely.

To manufacture the Gunn diode oscillator avoiding inconsistencies in dimensions a three dimensional drawing program called Proengineer is used. The mechanical parts of the oscillator are drawn and processed separately. Mounting of the separated parts is executed and the mechanical design is tuned by the simulation of the mechanical mounting. Commercial companies generally use a drawing program to construct the mechanical parts called AutoCAD. So the drawings in Proengineer are transferred to the AutoCAD environment. These drawings are all given to a commercial constructor and briefly explained that the dimensions and tolerances are very important. After the construction is completed it was seen that the tolerances are far away from expected and the dimensions are not consistent. Lots of modifications are carried out in the laboratory to improve the mechanical construction.

The oscillator includes a sliding backshort and a triple-screw-tuner system so the errors of the mechanical construction can be tolerated. Tests of the Gunn diode oscillator have illustrated that the position of the backshort and the triple-screw-tuner system affects the performance of the system. The design of the oscillator includes the design of the waveguide housing, diode mounting and the bias insertion network. Some simulation tools are used to predict, approximately, the behaviour of the oscillator and the bias coupling circuit. For tuning purposes, a sliding backshort and a triple-screw-tuner system is used. For different bias values and different positions of the tuning elements oscillations are observed. A much more stable and higher magnitude oscillations were obtained with the inclusion of "resonant disc" placed on top of the diode. 15 dBm power was measured at a frequency of 28 GHz. Measurements have been carried out to determine the oscillator frequency, power output and stability for different bias conditions.

The advantages of the designed and fabricated waveguide mounted Gunn diode oscillator described in this thesis, are its high power output and robust structure to handle heat dissipation relative to planar based Gunn diode oscillators. Use of waveguide based structure is much more difficult than the use of the planar based structure. However, its heat dissipation properties are better.

Future work in this area could be a Gunn diode oscillator using multiple Gunn diodes in the same housing, to provide power combining and achieve the high power output signal. Power can be combined within a section of waveguide with diodes carefully spaced.

The design approach used in this thesis is a typical waveguide housed oscillator. Other design configurations also exist in the literature. Some these configurations include radial line couplers to the waveguide. These type of oscillators can also be tested provided that high precision mechanical facilities are available.

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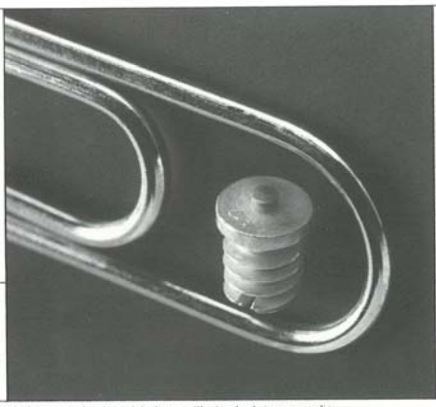
APPENDIX A

INFORMATION ABOUT HUGHES GUNN DIODES

Gunn Diodes



Diode mounted on heatsink shown with standard size paper clip

Hughes 4720xH series of GaAs Gunn Diodes are available for operation at any specified frequency between 26.5 and 95 GHz. Power output levels range from 20 mW at 95 GHz to 350 mW at 40 GHz. Their low noise characteristics make them ideally suited for receiver applications such as paramp pumps and local oscillators.

The diodes are packaged in a 0.035-inch diameter ceramic package which is mounted to a copper heat sink with threaded base.

Every diode is tested at the specified frequency for output power, threshold voltage and current and operating voltage and current in a critically coupled cavity.

POWER OUTPUT AVAILABLE*

Frequency (GHz)	26-40	40-60	60-75	75-95
Power Output	**350 mW**	**150 mW**	**80 mW**	**50 mW**

*Higher power outputs are available at lower end of frequency ranges (consult factory).

GUNN DIODE SPECIFICATIONS

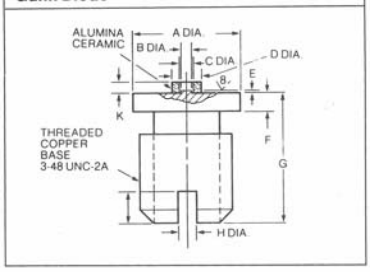
	FREQUENCY BAND (of test circuit in GHz)					
	Ka (26.5-40)	Q (33-50)	U (40-60)	V (50-75)	E (60-90)	W (75-95)
Power Output Available (mW min)	250, 350	from Table	100, 150	from Table	from Table	20, 50
Bias Voltage (V typ)	6.5	6.0	5.0	4.0	5.5	5.0
Bias Current (A typ)	1.10	1.0	1.0	1.0	1.0	1.0
Threshold Current (A typ)	1.3	1.3	1.3	1.3	1.3	1.3
Package Capacitance (pF typ)	0.18	0.18	0.18	0.18	0.18	0.18
Package Inductance (nH typ)	0.10	0.10	0.10	0.10	0.10	0.10

NOTE: Each diode is supplied with the following data: frequency, output power, threshold current and voltage, and operating current and voltage. Diodes are designed to operate over a temperature range of −30°C to +75°C. Storage temperature range is −54°C to +125°C.

NOTE: All specifications apply at 25°C ambient temperature.

OUTLINE AND MOUNTING DRAWINGS

Gunn Diode



DIM.	INCHES MIN.	INCHES MAX.	MILLIMETERS MIN.	MILLIMETERS MAX.
A	0.114	0.116	2,90	2,95
B	0.011	0.013	0,28	0,33
C	0.014	0.018	0,36	0,46
D	0.030	0.034	0,76	0,86
E	0.003	0.005	0,08	0,13
F	0.019	0.021	0,48	0,53
G	0.140	0.144	3,56	3,66
H	0.015	0.025	0,38	0,64
J	0.030	0.040	0,76	1,02
K	0.020	0.024	0,25	0,36

HOW TO ORDER GUNN DIODES

Gunn Diode Model Number 4720xH-04xx

Test Circuit Frequency Band

1: Ka
2: Q
3: U
4: V
5: E
6: W

Power Output (Gunn Diodes)

02: 20mW
05: 50mW
08: 80mW
10: 100mW
15: 150mW
25: 250mW
35: 350mW

APPENDIX B

GUNN DIODES DATA SHEETS

Data Sheet For Gunn Diode Having the Serial No: 2322A-12

Model No	47201H-0425
Serial No	2322A-12
Date	02.12.1991
Sales Order No	I-44008S
Center Frequency	35.4 GHz
Output Power	265 mW
Operating Voltage	5.72 V
Threshold Voltage	1.58 V
Operating Current	768 mA
Threshold Current	1060 mA
Production	T.W. Bell

Data Sheet For Gunn Diode Having the Serial No: 2322B-3

Model No	47201H-0425
Serial No	2322B-3
Date	02.12.1991
Sales Order No	I-44008S
Center Frequency	35.7 GHz
Output Power	-
Operating Voltage	5.53 V
Threshold Voltage	1.69 V
Operating Current	895 mA
Threshold Current	1160 mA
Production	T.W. Bell

APPENDIX C

PROENGINEER DRAWINGS

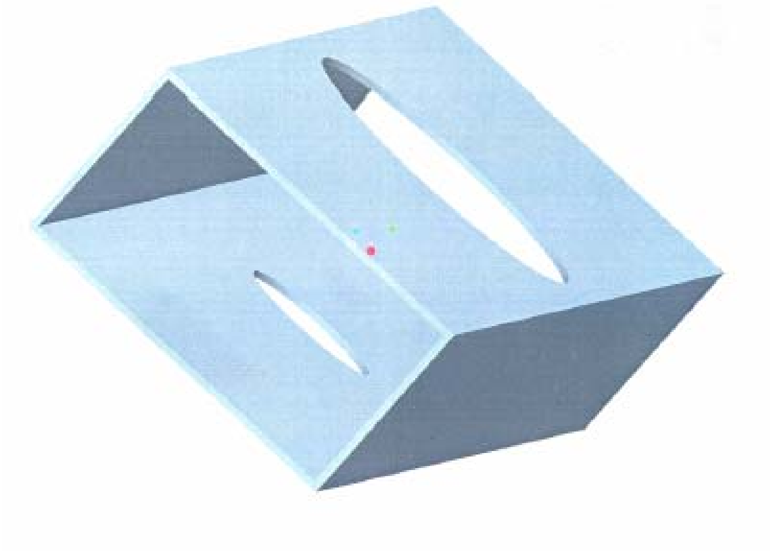


Figure C.1: Ka-Band Waveguide

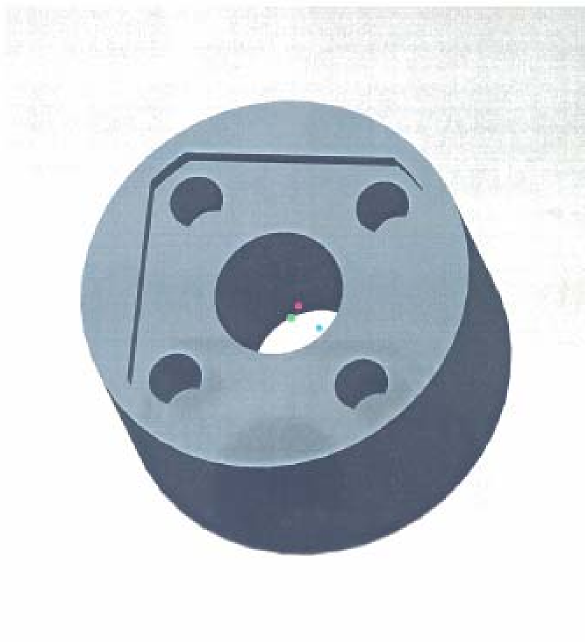


Figure C.2: Top Cylinder That Covers the Filter Circuit

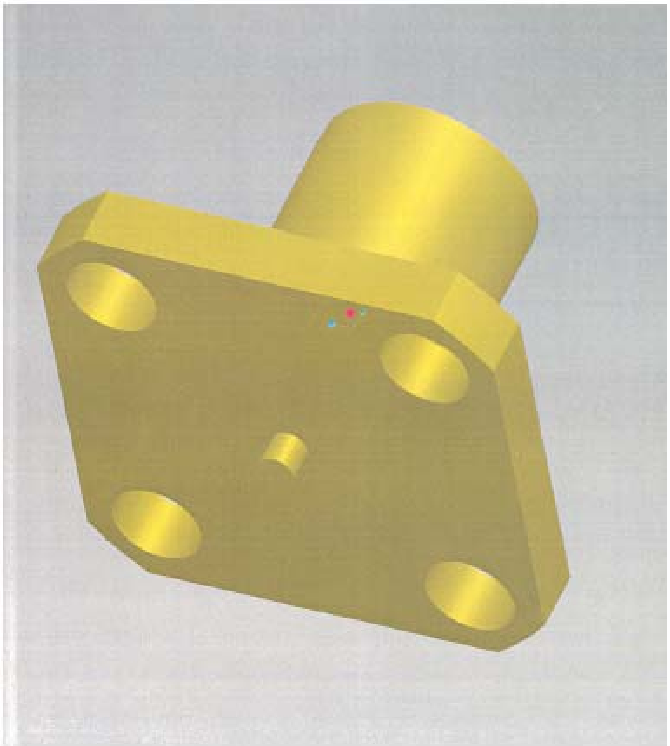


Figure C.3: SMA Connector

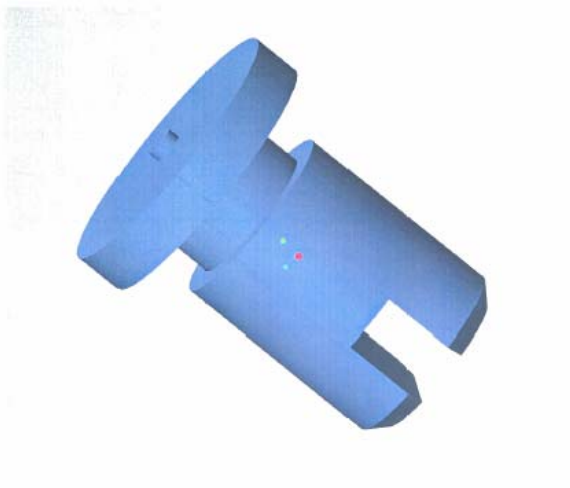


Figure C.4: Gunn Diode

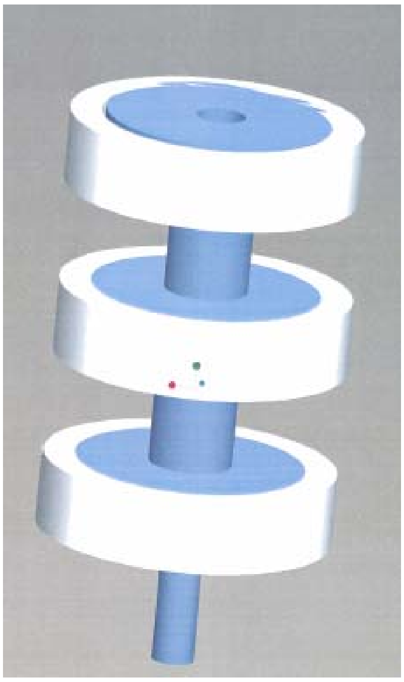


Figure C.5: Filter Circuit with Post

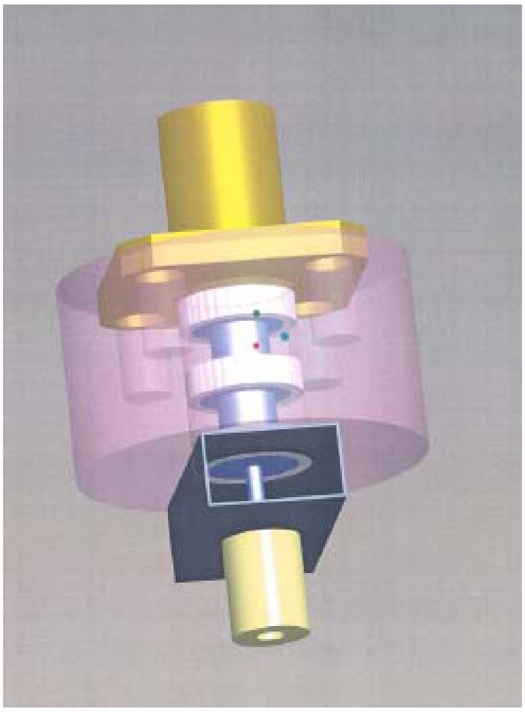


Figure C.6: Mounted Gunn Diode Oscillator

APPENDIX D

PHOTOGRAPHS OF THE CONSTRUCTED OSCILLATOR

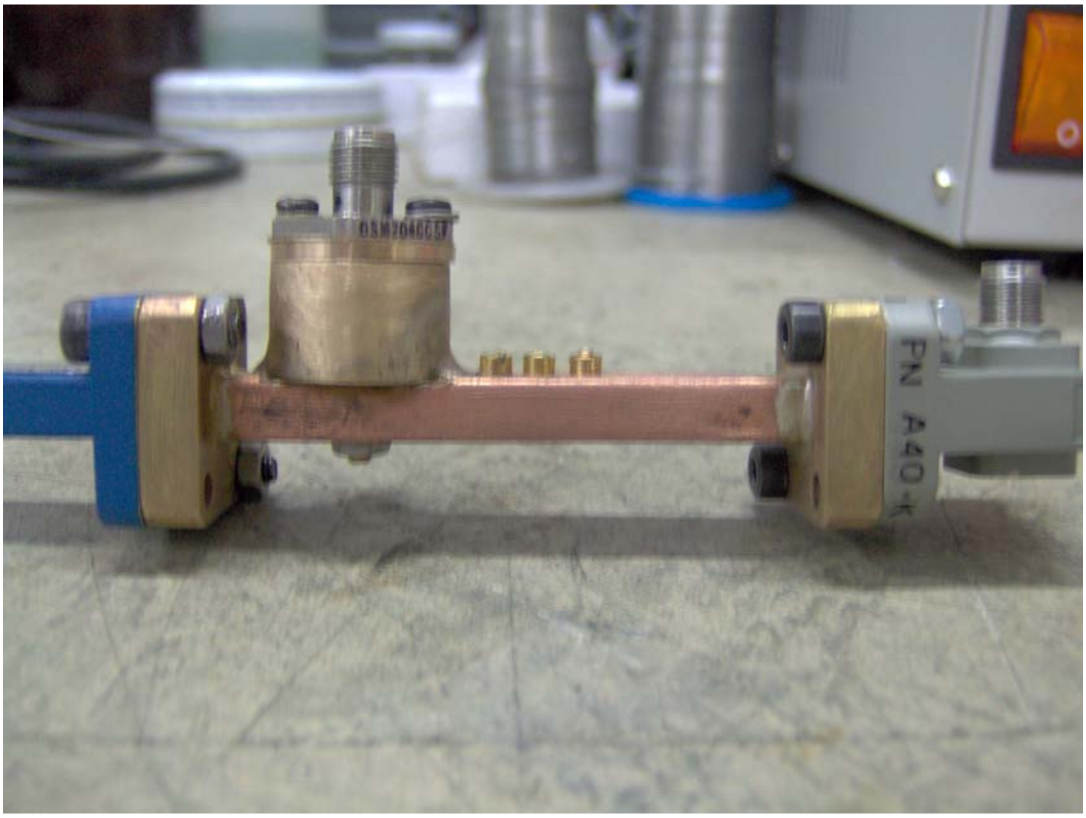


Figure D.1: Gunn Diode Oscillator

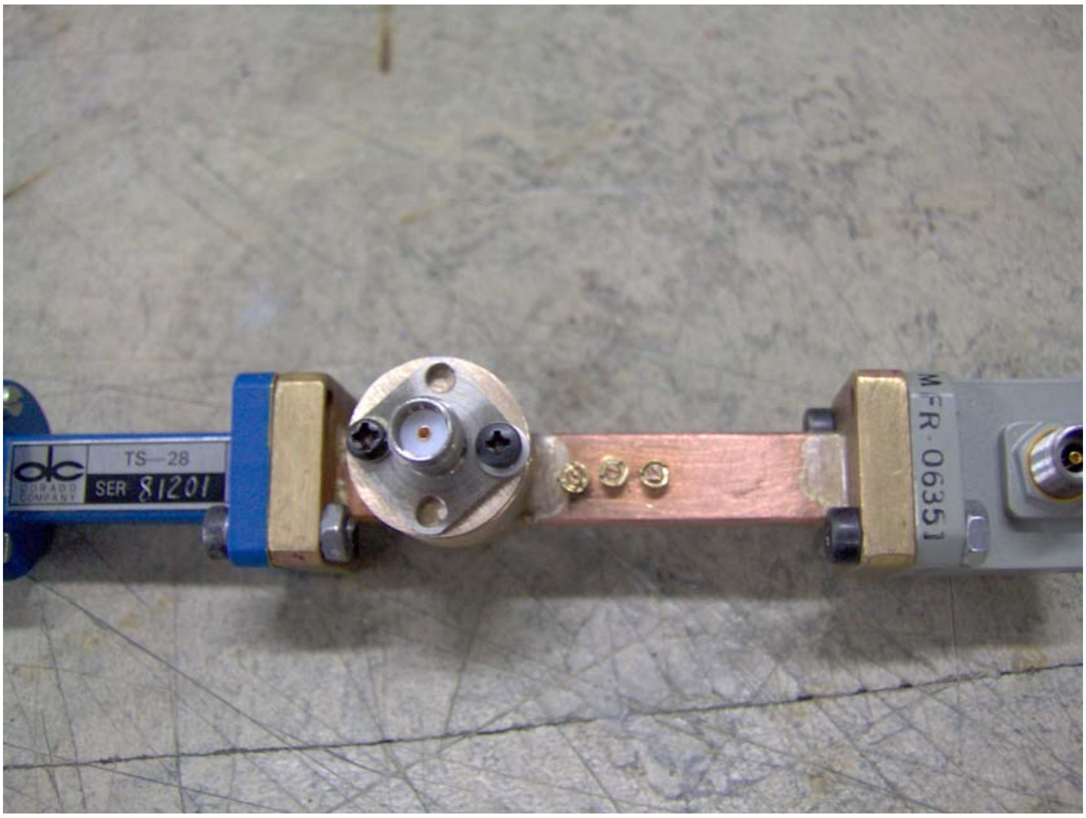


Figure D.2: Gunn Diode Oscillator Top Wiev

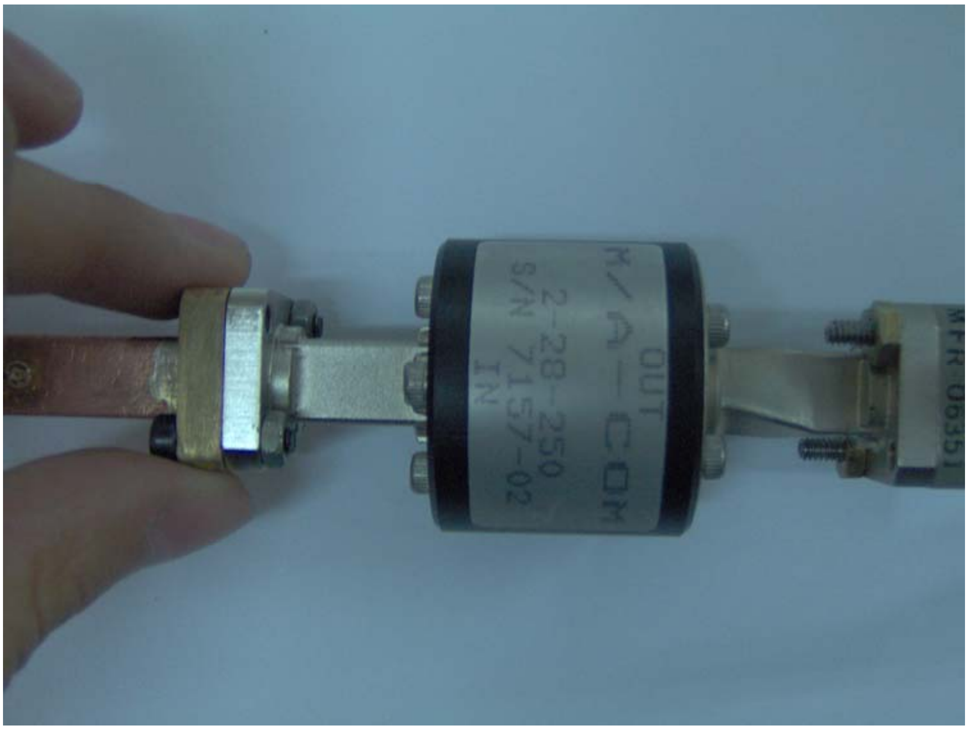


Figure D.3: Isolator

Figure D.4: Resonant Disc

Figure D.5: Filter Circuit With Post and Resonant Disc

Figure D.6: Gunn Diode

Figure D.7: Setup Used For Measurements