CAVITY STABILIZED GUNN OSCILLATOR DESIGN

A DISSERTATION

submitted in partial fulfilment of the requirements for the award of the degree

of

MASTER OF ENGINEERING

in

ELECTRONICS AND COMMUNICATION ENGINEERING

(With Specialization in Solid State Electronics)

By

MANOJ KUMAR

DEPARTMENT OF ELECTRONICS AND COMPUTER ENGINEERING
UNIVERSITY OF ROORKEE
ROORKEE-247 667 (INDIA)

FEBRUARY, 1996

CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the dissertation entitled **"CAVITY STABILIZED GUNN OSCILLATOR DESIGN"** in partial fulfilment of the requirements for the award of the Degree of **Master of Engineering** in Electronics and Computer Engineering with specialization in **Solid State Electronics** of the University of Roorkee, Roorkee, in an authentic record of my own original work carried out for a period of seven months from July 95 to February 96 under the guidance of **Dr. R.P. Agarwal**, Professor, and **Dr. S. Sarkar**, Professor, Department of Electronics and Computer Engineering, University of Roorkee, Roorkee.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree or diploma so far.

Dated: 22 Feb.,96

Manoj Kr
(MANOJ KUMAR)

This is to certify that the above statement made by the candidate is correct to the best of our knowledge.

23/2/96
(Dr. R.P.AGARWAL)
Professor
Department of Electronics and
Computer Engineering,
University of Roorkee,
Roorkee-247 667 (U.P.)
INDIA

(Dr.S.SARKAR)
Professor
Department of Electronics and
Computer Engineering,
University of Roorkee,
Roorkee-247 667 (U.P.)
INDIA

ACKNOWLEDGEMENT

I wish to express my deep sense of gratitude to **Dr. R.P. Agarwal**, Professor, and **Dr. S. Sarkar**, Professor, Department of Electronics and Communication Engineering for suggesting the problem and for their keen interest, constant encouragement and invaluable guidance throughout the progress of the work.

I express my sincere thanks to the laboratory staff members and the workshop technicians of the Department of Electronics & Compurter Engineering, U.O.R. Roorkee and the staff members of the New Computer Facility, U.O.R., Roorkee, who helped me at various stages for completing the task.

I should not forget to thank my friends and colleagues whose comeradian spirit helped me in keeping my head in level in moments of anxiety and despair. I thank one and all those who have directly or indirectly taken interest and helped me in completing this work.

Manoj Kr.
(MANOJ KUMAR)

ABSTRACT

This dissertation systematically presents the design of a Cavity Stabilized Gunn Oscillator circuit operating in X band range of the frequency spectrum. The theoretical study has been done to find the proper mode of oscillation and proper dimension of the cavity to get the stabilization of the oscillator as large as possible.

CONTENTS

INTRODUCTION

Microwave signal sources with a high degree of short and long term frequency stability find application in systems for radar and FM Communications such as telephone and television. A requirement for the FM noise of the oscillalor is set by the CCIR recommendations, which. for example, for an 1800 channel telephone microwave link specify that, measured in a 3.1 KHz band at baseband frequencies from 10 KHz to 10 MHz, the noise level is 80 dB below the level of a 140 KHz rms deviation test tone and an output signal level of at most 50 mW, which is free from harmonics and spurious frequencies. Longterm variations of frequency, in particular those caused by temperature range, are required to be within ± 10 ppm (± 1 x $10^{-5}/^{o}C$) for ambient temperature from $0^{o}C$ to $50^{o}C$.

Gunn diodes and IMPATT diodes are used to generate the desired microwave frequencies. The frequency of oscillation of these sources depends upon bias voltage, load impedance and ambient temeprature. The frequency varies with the effective capacitance of the diodes, which is a function of the bias voltage and ambient temeprature. The temperature coefficient of these devices is only $10^{-3}/^{o}C$ for ambient temperature from $0^{o}C$ to $50^{o}C$. So, to meet the strict requirements with respect to FM noise and long term stability a stability factor of more than 100 is required. Two well known methods are employed to achieved this purpose. The first method being the injection locking to a master oscillator and the second one being the cavity stabilization. Then the Gunn oscillators become stable oscillators with low noise performance, reasonable power and efficiency., They become reliable enough to be used as a stable pump source of the parametric amplifier.

Cavity stabilization is a very simple method as compared with the complex injection locking method. In this method a high quality factor cavity is coupled to the Gunn oscillator. The cavity works as a big energy reservoir and provides for the Gunn diode circuit the necessary impedance for satisfying the condition of maximum power output and desired oscillation frequency.

Depending on the oscillator structures, coupling network and stabilizating cavity there are three types of cavity stabilization, viz., reflections type, reaction type and transmission type of cavity stabilization. The study of the three types of cavity stabilized Gunn oscillators has given the following results :

1. Transmission type cavity : It has the maximum stabilization range, the minimum power ripple, large loaded quality factor but small output power.

2. Reaction-type cavity : It has the maximum loaded quality factor, large output power but the minimum stabilization range.

3. Reflection-type cavity : It has the maximum output power, large stabilization range, small output power ripple with a relatively small loaded quality factor.

So a transmission-cavity is used for the loaded quality factor and stabilization range being the crucial points. A reaction-cavity is used when a large quality factor and output power are required. A reflection type cavity is used when the output power is the crucial point.

In this dissertation a methodology for the design of a reflection-type Cavity Stabilized Gunn Oscillator has been developed. Emphasis has been given on the stabilization range, interfering modes, quality factor and stabilization factor. The thesis is divided into four chapters. Chapter I is a review of past work carried out in the area of cavity stabilized oscillators. In Chapter II an analytical study of cavity stabilization is given. The Chapter III deals with the oscillator design. The Chapter IV presents the result and discussion of the design method developed.

CHAPTER I

REVIEW

Microwave solid state oscillators such as Gunn and IMPATT Oscillators produce power at microwave and millimetre wave ranges of electromagnetic spectrum. But these high frequency sources are noisy, producing AM and FM noise. In communication systems, to make the optimum use of the electromagnetic spectrum high frequency sources are needed with a high degree of accuracy and stability.

The noise performance of Gunn oscillators is comparable to Klystron and IMPATT Oscillators. Since it is a low power device operating at very high frequencies its FM noise reduction is more important than AM noise reduction.

Using discriminator of phase locked loop system [19] efforts have been made by several authors to stabilize the oscillator frequency through electronic methods. Robert Adler [13] and Kurokawa [6] have studied injection locking of microwave oscillators and have discussed graphically and mathematically noise, locking range, large and small signal injection and locking stability.

R. Knochelt and K. Schunemann [1] have discussed about the diffeent cavity stabilization techniques with respect to their quality factor, stabilization range, output power and power ripple.

Nagano [12] et al have studied a directly coupled stabilizing cavity of a very small size and studied frequency stability against temperature variation from 0^{o} to 50^{o}C. They have reduced rms noise deviation by a factor of 50 at the sacrifice of only 0.4 dB of power.

F. Bernard and Heyden [4] have derived mathematically the relationship between efficiency, input and output coupling factors, quality factor and stabilizing factor. They have also discussed machanical compensation and temperature compensation of the cavity and the effect of humidity on the performance of the cavity.

Yukio Ito et al [5] have designed an X band cavity (TE_{011} mode) stabilized Gunn oscillator with a temperature coefficient of less than-7 x $10^{-7}/^{o}C$ and a low FM noise of 8 Hz per 1 KHz BW at 100 KHz from the carrier. They ahve also described characteristics such as cavity pulling bandwidth, hysteresis phenomena peculiar to mechanical tuning, bias voltage and temperature and load-impedance variations.

Yukio Ito et al [2] have also designed a K band high-power IMPATT oscillator stabilized by hybrid-coupled cavities which has the advantage of being free from mode jumping. But it has the disadvantage of being bulky as it employs two cavities for stabilization technique.

There is also some [17] effort in the direction of making superconducting cavity stabilized oscillator of very high stability (drift of less than 1.3 x 10^{-12}/hour) using super conducting niobium (Nb) material for cavity and using injection locking.

CHAPTER II

THEORY

The Cavity Stabilized Gunn Oscillator Circuit consists of a Gunn diode mounted by a post in a reduced height waveguide at a distance of one guide wavelength (λ_g) from a properly designed high quality factor cylindrical cavity as shown in fig.2.1. The power output of the Gunn diode is coupled to a full height tapered waveguide transformer. The effective length of the cavity is varied by a metallic piston. The coupling between the reduced height waveguide is made through an iris. There is also a tuning screw near the cavity to slightly change the effective electrical distance of the cavity from the Gunn Oscillator by introducing some susceptance.

OSCILLATION CONDITIONS FOR A GUNN OSCILLATOR CIRCUIT [6].

The circuit diagram of fig.2.1 may be transformed into an equivalent circuit for a negative resistance of oscillation as shown in fig. 2.2. which contains:-

(a) A circuit load impedance $Z(w) = R(w) + jX(w)$

This is an inductive impedance which is provided by cavity external load, tuner etc.

(b) A negative impedance of device

$-\overline{Z(i)} = -R(i) - jX(i)$, which is a non-linear capacitive impedance depending upon the r.f. current (i) amplitude but independent of the frequency to a first approximation [6] and which is provided by the diode chip and the parasitics of its package.

For steady state oscillation condition, the total circuit impedance is zero or the load line Z(w) and device line $\overline{Z(i)}$ must intersect or

$$Z(w)-\overline{Z(i)} = 0 \tag{2.1}$$

In fig.2.3 the intersection point A corresponds to an oscillation point required by eqn. (2.1).

TYPES OF STABILITY

There are two types of stability in negative resistance devices:-

(a) Drift Stability: It refers to the basic changes in the load line by temperature and in the device line by temperature or bias current and with ageing of the semiconductor material.

(b) perturbation stability: It refers to the inclusion of an additional small voltage (e) into the circuit, such as noise produced by the active device, or a reflected wave from a distant mismatch to the oscillator output port.

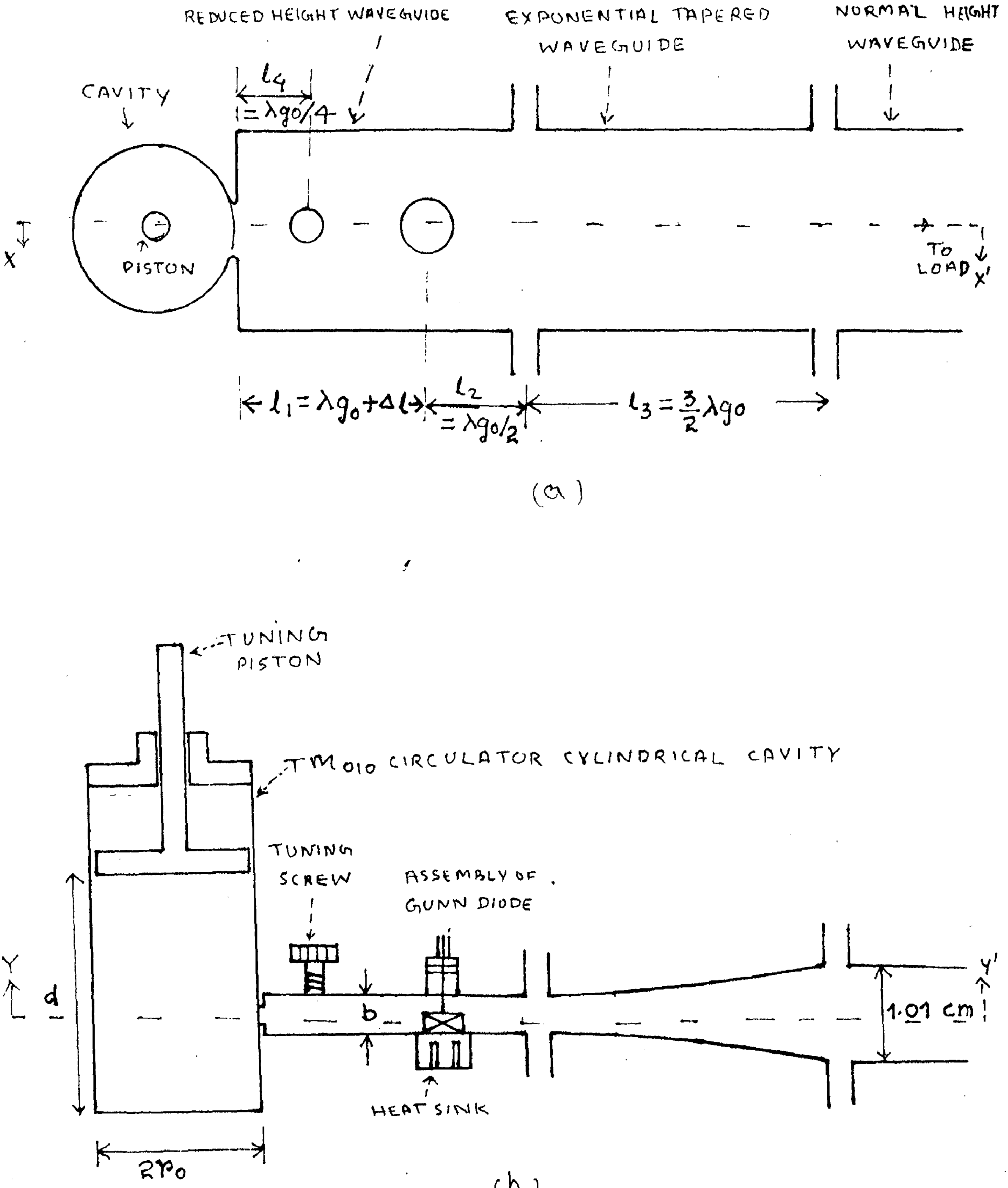

Fig.2.1 : Cross sectional view of a cavity stabilized Gunn Oscillator operating in TM_{010} mode for (1) X-X' (b) Y-Y'.

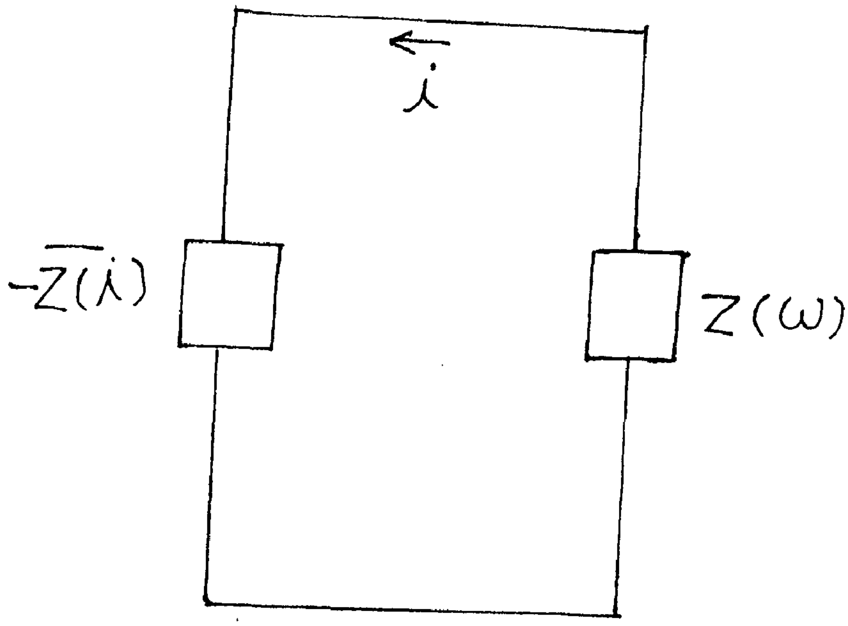

Fig.2.2 : Equivalent Circuit of a Negative Resistance Oscillator.

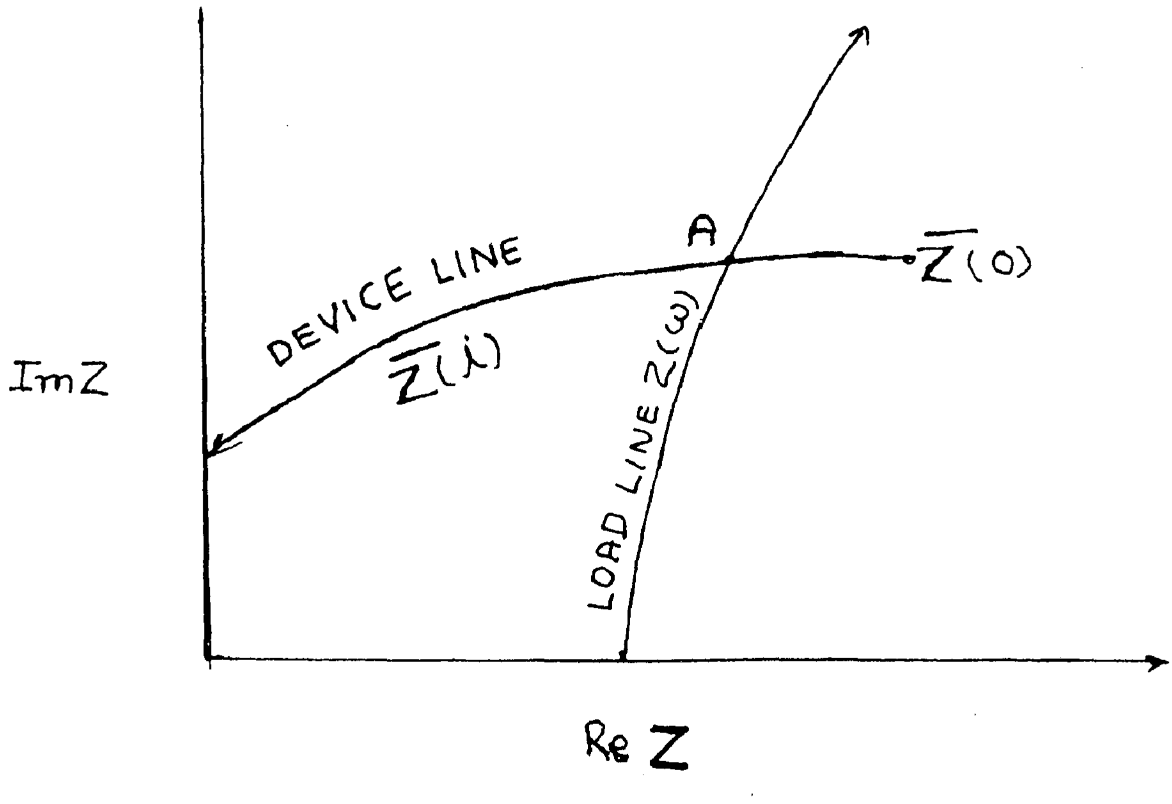

Fig.2.3 : Oscillation Condition of a Negative Resistance device in the Impedance Plane Z .

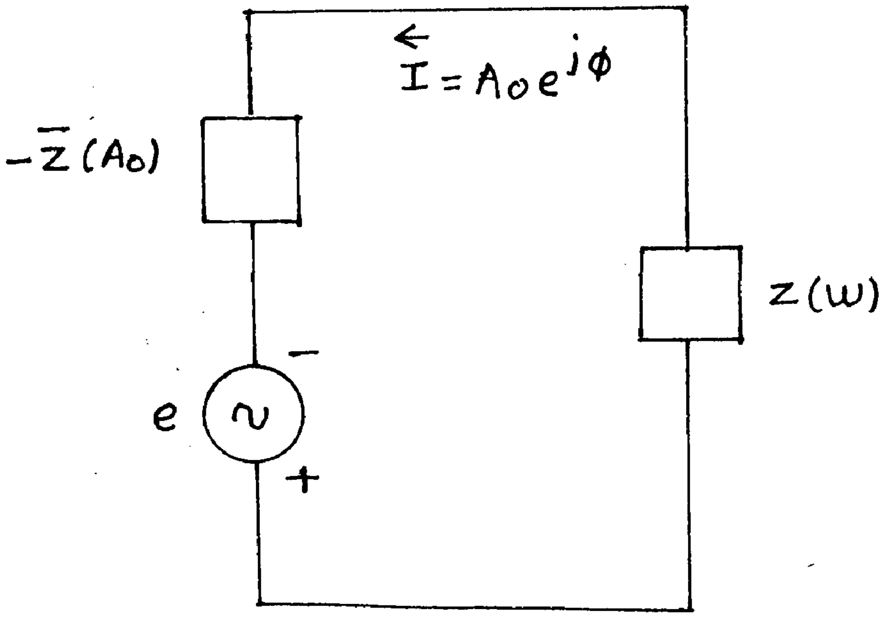

Fig 2.4 : Equivalent Circuit of a Noisy free-running Oscillator.

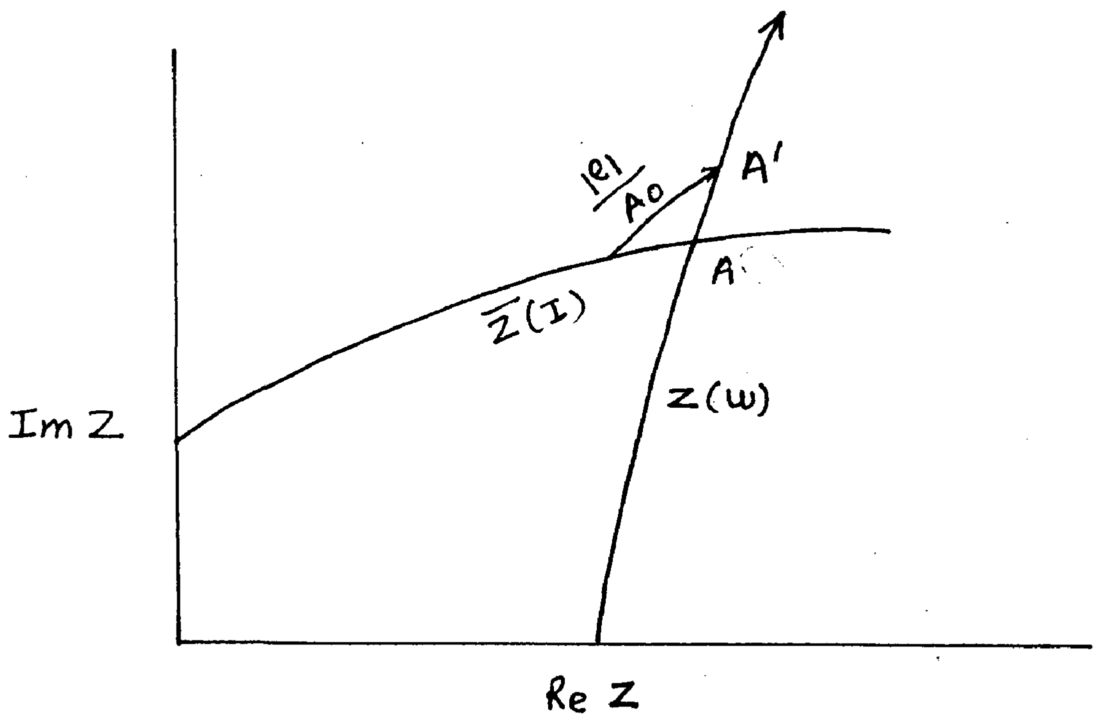

Fig.2.5 : Relation between the noise Vector Impedance Locus Z, and Device Line.

In such a case eqn. (2.1) is modified as shown in fig.2.4.

$$[Z(w) - Z(i)]\, I = e \qquad (2.2)$$

Where I is the noise free oscillation current amplitude Ao with a phase factor of $e^{j\phi}$.

Thus as shown in fig. 2.5, $Z(w) = Z(I) + \frac{e}{I}$

$$= Z(A_0) + \left(\frac{e}{A}\right) e^{-j\phi} \qquad (2.3)$$

Since the vector (e) is a random vector whose direction as well as magnitude changes randomly with time, both frequency and current amplitude change randomly producing FM and AM noise components. While FM noise is a major contribution to random shift in oscillation frequency, the change in oscillator cavity dimensions with ambient temperature variations also adds to the frequency fluctuations. In order to minimize the frequency shift at varying ambient temperatures the cavity is made from a material having a very low temperature coefficient of expansion. One such material is specially heat-treated silver-plated invar with a stable thermal expansion of about $1.5 \times 10^{-6}/^{o}C$. For this, invar is first heated at $830^{o}C$, followed by a quenching procedure, after machining, annealing at $315^{o}C$ removes the stresses and finally ageing at $95^{o}C$ for 48 hours stabilizes the material. The cavity is provided with a circular output iris covered by a glass window to remove the undesired effects of moisture in the cavity.

The temperature coefficient of the cavity stabilised Gunn Oscillator is [5] mechanically compensated for as shown by

$$\delta f = -\alpha_1 + (\alpha_2 - \alpha_1)\frac{d}{f}\frac{\delta(f)}{\delta(d)} \qquad (2.4)$$

Where α_1 = Temperature coefficient of material of cavity.

α_2 = Temperature coefficient of material of short plunger.

d = length of the cylindical cavity,

So, if a proper material is taken for short plunger the temperature coefficient of the cavity of a proper length can be controlled as low as to the range of $-7 \times 10^{-7}/^{o}C$.

STABILISATION FACTOR (S)

The short frequency stability, as characterised by the output FM noise, is determined by the inherent noise of the diode, reduced by the circuit stabilisation factor S. The stabilisation factor is given by the energy storage and loss in the oscillator, stabilising cavity and the external load. It can be defined as the ratio of the frequency deviations caused by perturbing the unstabilized oscillator to the frequency deviation produced by the same perturbation of the stabilized oscillator. It has been shown [18] that

$$S = 1 + \frac{Q_{cav}}{Q_{osc}} \qquad (2.5)$$

where Q_{cav} = the quality factor of cavity

Q_{osc} = **The quality factor of the Gunn oscillator.**

This stabilization factor may be also defined [4] as the ratio of the frequency derivatives of the susceptance at resonance, when looking, into a reference plane near the diode, into the cavity and the generator parts of the circuit. From eqn. (2.5) it is evident that the stabilization factor depends mainly on the quality factor of the cavity.

CYLINDRICAL RESONATOR.

A cylindrical resonator is a section of cylindrical waveguide of length d and radious r_o, with two plane conducting plates perpendicular to the axis of the cylinder. The modes in a cylindrical cavity are denoted as transverse electric TE_{nml} (or H_{nml}) and transverse magnetic TM_{nml} (or E_{nml}). The indices n, m and l indicate the number of half period variations of the microwave field along the azimuthal, the number of zeros of the electric field intensity in the radial direction, and the number of half period variations in the longitudinal direction respectively. Defining the cut off wavenumber K_c determined from the root of the bessel functions $J'_n(K_c r_o) = 0$ and $J_n(K_c r_o) = 0$ for TE_{nml} and TM_{nml} modes respectively we get from [appendix A] that $K_c r_o = P_{nm}$ for TM mode

$$= p'_{nm} \text{ for TE mode} \qquad (2.6)$$

The cavity designed for an angular frequency of w_0 has to satisfy the condition that

$$w_0^2 \mu \varepsilon = \beta_g^2 + K_c^2 \tag{2.7}$$

Where $\beta_g = \frac{l\pi}{d}$, a constant of propagation (2.8)

μ = Permeability of the medium of cavity.

ε = Permittivity of the medium of the cavity.

UNLOADED QUALITY FACTOR (Q_C) OF A CYLINDRICAL RESONATOR.

The unloaded quality factor Q_c of the cavity arises primarily from the finite wall conductivity losses in the cavity and a low dielectric loss in the air or gas filled in the cavity. It is defined as.

$$Q_c = w_0 \frac{W_s}{P_L} \tag{2.9}$$

Where W_s = The energy stored in the resonator

P_L = The time averaged power loss

The quality factor of the cavity depends upon [18] its dimensions, resonating frequency and mode and its material. It is given by

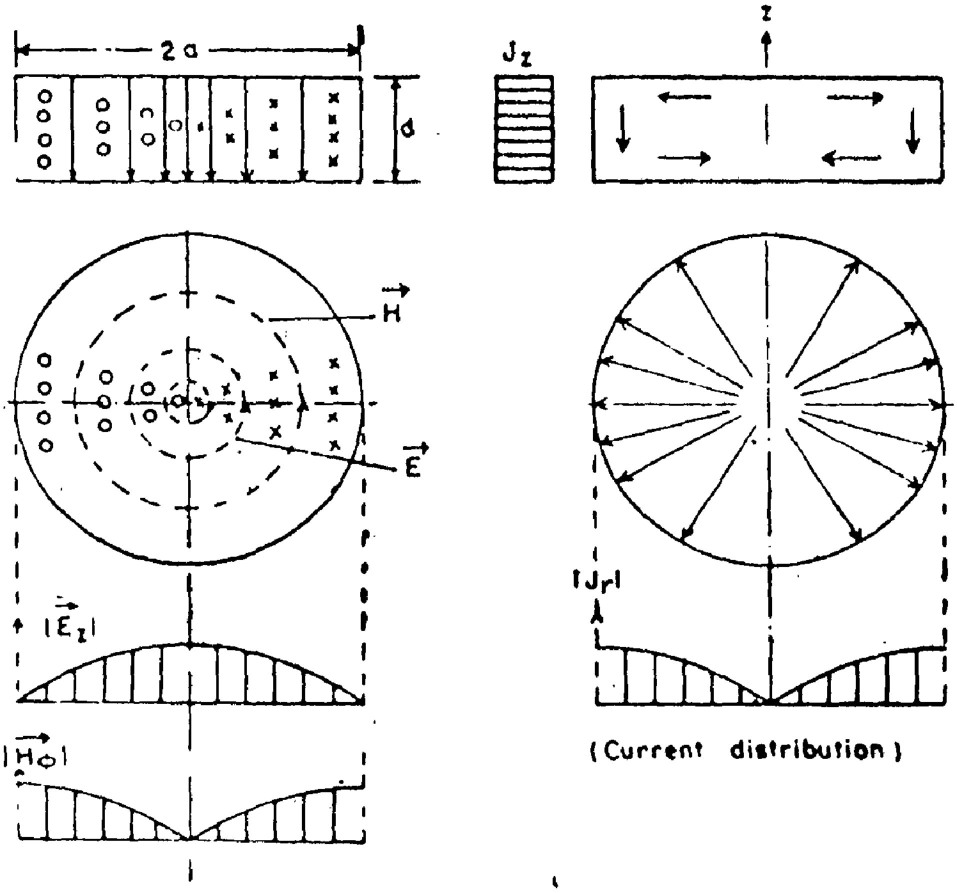

Fig.2.6 Field pattern and current distribution in a cylindrical resonator at TM_{010} resonant mode.

$$Q_c(TM_{nml}) = \frac{\lambda_o}{\delta} \frac{\left\{ p^2_{nm} + \left(\frac{l\pi a}{d}\right)^2 \right\}^{1/2}}{2\pi\,(1 + \frac{2a}{d})} \qquad \text{for } l \neq 0$$

$$= \frac{\lambda_o}{\delta} \frac{p_{nm}}{2\pi(1 + \frac{a}{d})} \qquad \text{for } l = 0 \qquad (2.10)$$

and $Q_c(TE_{nml}) =$

$$\frac{\lambda_o}{\delta} \frac{\left\{1 - \left(\frac{n}{p'_{nm}}\right)^2\right\} \left\{(p'_{nm})^2 - \left(\frac{l\pi a}{d}\right)^2\right\}^{3/2}}{2\pi\left\{(p'_{nm})^2 + \frac{2a}{d}\left(\frac{l\pi a}{d}\right)^2 + \left(1 - \frac{2a}{d}\right)\left(\frac{n l \pi a}{p'_{nm} d}\right)^2\right\}}$$

(2.11)

Where δ = skindepth of the material coated in the inner side of the cavity.

λ_o = resonant wavelength

STUDY OF MODES IN A CYLINDRICAL RESONATOR

The lowest modes in a cylindrical waveguide in TM series are the TM modes in which there is no variation of the electric field in the azimuthal (ϕ) direction and in the axial direction. Hence the lowest, dominant resonant mode in a cylindrical resonator will be TM_{010} for which eqn. (2.7) gives

$$\lambda_o\ (TM_{010}) = 2.62r_o \tag{2.11}$$

The resonant wavelength λ_o is the same as cut-off wavelength of the propagating TM_{01} mode in a cylindrical waveguide and is independent of the length of the cavity. The field pattern and current distribution of this mode are depicted in fig. 2.6. the unloaded quality factor Q_c for this mode is given by eqn. (2.10) as

$$Q_c = \frac{\lambda_o}{\delta} \frac{p_{01}}{2\pi(1+(a/d))}$$

$$= \frac{\lambda_o}{\delta} \frac{2.405}{2\pi(1+(a/d)} \tag{2.12}$$

Thus the unloaded quality factor approaches zero for very small cavity length ($d \to 0$), while for infinite cavity length it approaches a constant value of $\frac{\lambda_o}{\delta} \frac{2.405}{2\pi}$.

The next higher mode in the TM series is TM_{011}, whose field distribution is depicted in fig. 2.7. As seen from eq. (2.7) this mode has always a shorter resonant wavelength as compared to TM_{010}. However, at considerable cavity length, the resonant wavelengths of these two modes can come quite close to each other, which is an undesirable effect and must be avoided in practise by limiting the cavity length.

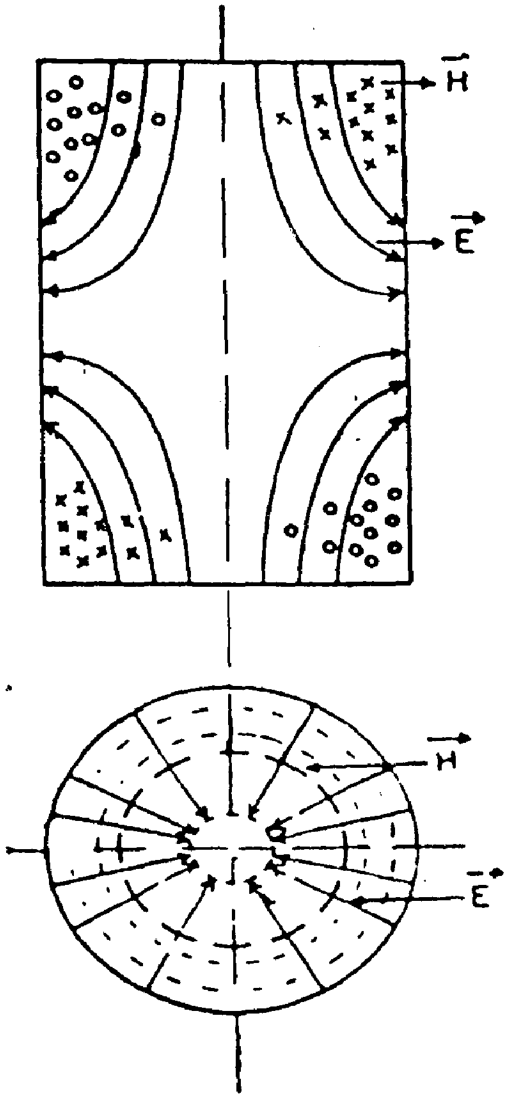

Fig.2.7 Field distribution in a cylindrical cavity at TM_{011} resonant mode.

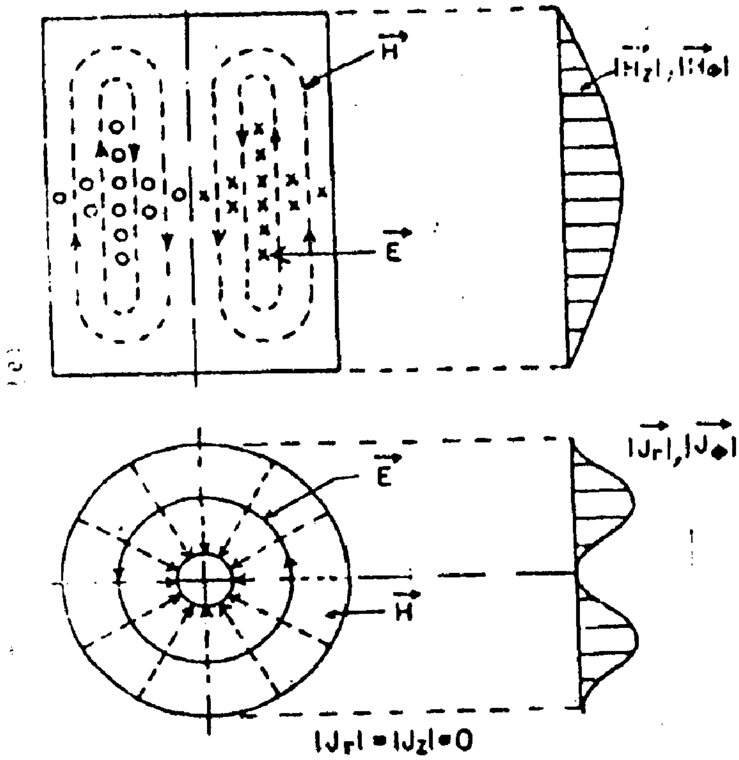

Fig2.8 Field pattern and current distribution in a cylindrical resonator at TE_{011} resonant mode.

The dominant magnetic mode in a cylindrical waveguide is TE_{11}. So the resonant mode of interest in this series in a cylindrical resonator is TE_{111} which has a resonant wavelength which is shorter than the TM_{010} resonant wavelength for a sufficiently short cavity length. However, as cavity length increases the difference between the two wavelengths goes on decreasing and at a critical condition ($d = 2.1r_0$), degeneracy occurs.

There after ($d = 2.1a$) TE_{111} resonant mode has longer resonant wavelength than TM_{010}. Thus, the dominant resonant mode may correspond to the TM_{01} propagation mode despite the fact that in a circular waveguide the dominant propagation mode is TE_{11}.

The nearest higher mode in a cylindrical resonator is TE_{011} whose field pattern and current distribution are shown in fig. 2.8. Since there are no axial currents in this mode, the end plates of the cavity can be free to move to adjust the cavity length d for tuning purposes without introducing any significant loss, i.e. the gap between the circular end plate and the cylinder wall is parallel to current flow lines. As it has a higher value of quality factor than TE_{111} and TM_{010} modes, it is used in designing high resolution wavemeters, echoboxes, spectrum analyzers, etc. However, the TE_{011} mode in not a dominant mode, hence care must be exercised to choose a coupling scheme that doesnot excite a mode other than TE_{011} or mode suppressors be used to suppress spurious resonances.

CHAPTER III

DESIGN CONSIDERATONS

The complete waveguide diagram of the cavity stabilized Gunn Oscillator circuit of Fig. 2.1 can be represented by an equivalent electrical diagram as shown in Fig. 3.1a. Here the stabilizing cavity is represented by a series R_o-L_o-C_o circuit whose resonant angular frequency w_o is given by

$$w_o = \frac{1}{(L_o C_o)^{1/2}} \quad (3.1)$$

and the quality factor Q_c is given by

$$Q_c = \frac{w_o \; L_o}{R_o} \quad (3.2)$$

Where R_o is given by the loss in the cavity wall. The Gunn diode is coupled to the cavity through a slot in the reduced height waveguide. The characteristic impedance of the waveguide is given by

$$Z_o = \frac{b}{a} \frac{120\,\pi}{\left[1 - \left(\frac{\lambda_o}{2a}\right)^2\right]^{1/2}} \tag{3.3}$$

where b = height of the reduced height waveguide

a = width of the waveguide.

= 2.28 cm

λ_o = resonant wavelength.

The equivalent circuit of the Gunn diode is a parallel R_d-C_d circuit where R_d is the negative resistance and C_d is the capacitance of the Gunn diode as shown in Fig. 3.1a. The reduced height waveguide terminates in an exponentially tapered waveguide. This couples the oscillator to a full height waveguide which in turn is terminated by a load impedance equal to its characteristic impedance. Thus the load seen by the reduced height waveguide is almost equal to its characteristic impedance, that is,

$$n_2^2 \, R_L = Z_o \tag{3.4}$$

Where n_2 is the transformer voltage ratio of the load side.

Here we have assumed for the sake of simplicity that no mismatch or discontinuity exists at the flange joints of the exponential transformer although there is some mismatch in the actual case.

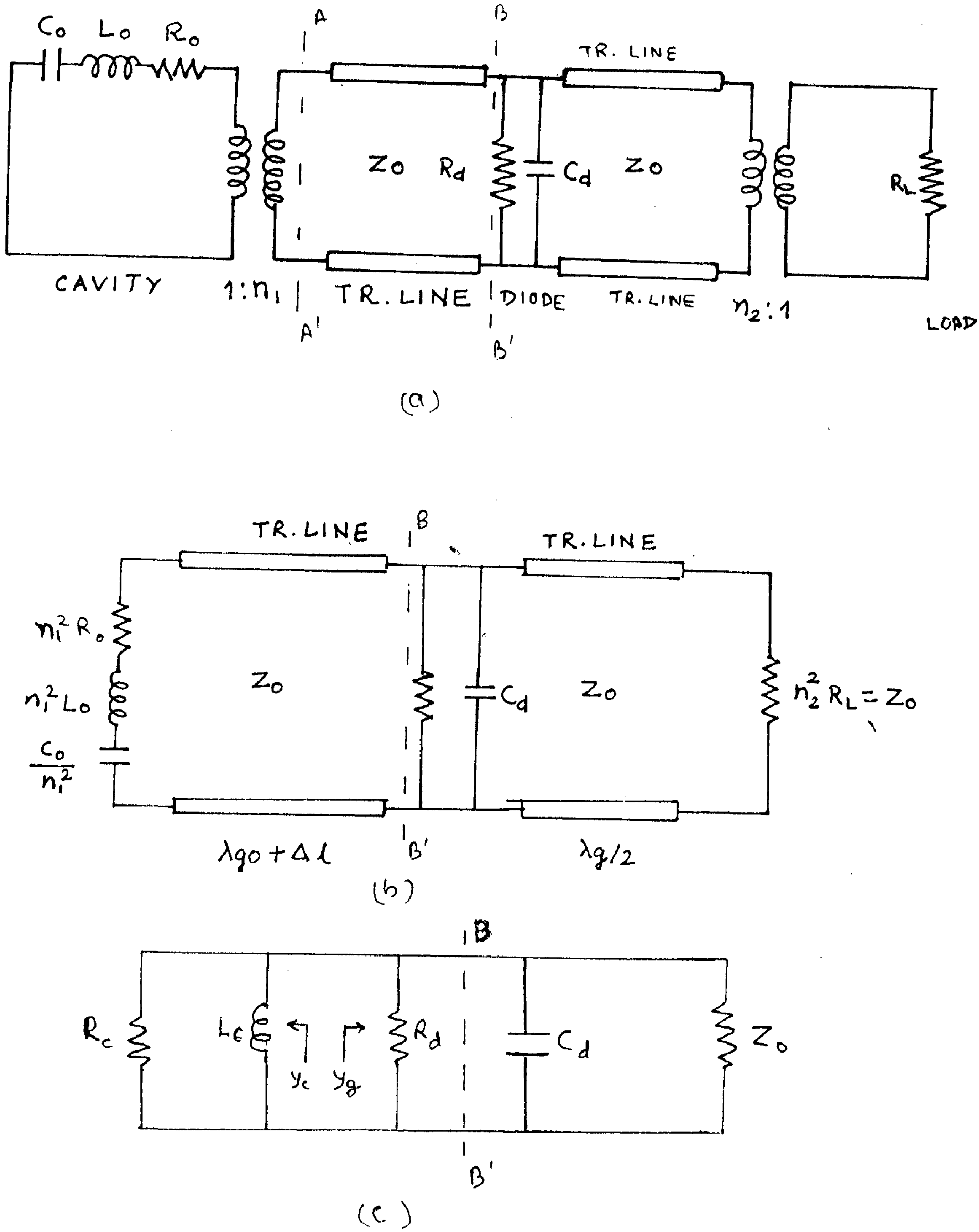

Fig 3 1 : (a) Equivalent circuit diagram of the cavity stabilized Gunn Oscillator . (b) & (c) are simplified forms of (a).

In Fig. 3.1b the impedance Z_A at the point A is given by

$$Z_A = n_1^2 R_o + j \left[\left(w L_o n_1^2 - \frac{n_1^2}{wC_o} \right) \right.$$

$$= n_1^2 R_o \left[1 + Q_c \left(\frac{w}{w_o} - \frac{w_o}{w} \right) \right] \qquad (3.5)$$

Where n_1 is the transformer voltage ratio of the cavity side

$$Z_A = n_1^2 R_o \quad \text{at} \quad w = w_o \qquad (3.6)$$

The distance between the points A and B is $l_1 = \lambda_{g_o} + \Delta l$ (3.7)

Where λ_{g_o} is the guide wavelength of the designed frequency and Δl is a very small distance as compared to λ_{g_o}.

The normalized admittance y_c seen by the Gunn diode in the cavity side is

$$y_c = \frac{y_A + j \tan \beta l_1}{1 + j y_A \tan \beta l_1} \qquad (3.8)$$

where $y_A = \frac{Z_o}{Z_A}$ the normalized admittance at point A.

Assuming $y_A >> 1$ and $y_A \tan \beta l_1 >> 1$ eqn. (3.7) reduces to

$$y_c = \frac{1 + \tan^2 \beta l_1}{y_A \tan^2 \beta l_1} - j \frac{1}{\tan \beta l_1} \qquad (3.9)$$

The normalized admittance y_g seen in the generater side of the circuit of Fig. 3.1b is given by

$$Y_g = 1 + \frac{Z_o}{R_D} + j\, WC_D\, Z_o \qquad (3.10)$$

In Fig. 3.1c the cavity coupling factor β_1 and the load coupling factor β_2 are given by the normalized admittance of the cavity and the load respectively, that is,

$$\beta_1 = \frac{1 + \tan^2 \beta l_1}{y_A \tan^2 \beta l_1} \qquad (3.11)$$

$$\beta_2 = \frac{Z_o}{n_2^2 R_L} = 1 \quad \text{(From (3.4))} \qquad (3.12)$$

From equation (2.1) the required condition for the circuit to oscillate with an angular frequency of w_o is

$$y_c + y_g = 0 \qquad (3.13)$$

taking from equations (3.9) and (3.10), eqn. (3.13) gives

$$\frac{1 + \tan^2 \beta l_1}{y_A \tan^2 \beta l_1} + 1 + \frac{Z_o}{R_D} + j\left(w_o C_D Z_o - \frac{1}{\tan \beta l_2}\right) = 0 \qquad (3.14)$$

This gives $\tan\beta l_1 = \frac{1}{w_o C_D Z_o} = \frac{1}{Q_o}$ (3.15)

Where $Q_o = w_o C_D Z_o$ (3.16)

is the quality factor of the reduced height waveguide with the diode capacitance.

using eqn. (3.7) in eqn. (3.15) we get

$$\frac{2\pi\Delta l}{\lambda_{g_o}} = \frac{1}{Q_o} \qquad (3.17)$$

With equations (3.1) and (3.15), eqn. (3.14) gives

$$\frac{Z_o}{-R_D} = 1 + \beta_1 \qquad (3.18)$$

Taking from (3.5) and (3.11), (3.9) gives the value of y_c at an angular frequency of w as

$$y_c = \beta_1 \left[1 + j\, Q_c \left(\frac{w}{w_o} - \frac{w_o}{w} \right) \right] - \frac{j}{\tan \beta l_1} \qquad (3.19)$$

the susceptance part of y_c is b_c and differentiating it we get

$$\left(\frac{\partial b_c}{\partial w} \right)_{w=w_o} = \frac{2}{w_o} \left[\beta_1 Q_c + \frac{\left(1 + Q_o^2\right)\left(2\pi Q_o + 1\right) \left(\frac{\lambda_g}{\lambda_o} \right)^2 \pi}{2\pi Q_o} \right] \qquad (3.20)$$

from eqns. (3.10) and (3.15) b_g, the normalized susceptance part of y_g, is given as

$$\left(b_g \right) = \frac{Q_o}{w_o} w$$

Differentiating it with respect to w at the angular frequency of w_o: we get

$$\left(\frac{\partial b_g}{\partial w} \right)_{w=w_o} = \frac{Q_o}{w_o} \qquad (3.21)$$

The circuit stabilization factor S is defined as the ratio of the frequency derivatives of the susceptances at resonance when looking, in reference plane B-B′ of fig. 3.1 b, into the cavity and the generator parts of the circuit respectively, that is

$$S = \left(\frac{d\, b_c}{dw}\right) / \left(\frac{d\, b_g}{dw}\right) \qquad \text{at } w = w_o \tag{3.22}$$

Taking from equations (3.20) and (3.21) and using appropriate approximations the equation (3.22) simplifies to

$$S = 2\left[\beta_1 \frac{Q_c}{Q_o} + Q_o\, \pi \left(\frac{\lambda_g}{\lambda_o}\right)^2\right] \tag{3.23}$$

$$\text{guide wavelength } \lambda_g = \frac{\lambda_o}{\left[1 - \left(\frac{\lambda_o}{2a}\right)^2\right]^{1/2}} \tag{3.24}$$

using eqn. (3.18) get equation (3.23) as

$$S = 2\left(-1 - \frac{R_o}{R_D}\right)\left(\frac{Q_c}{Q_o}\right) + \frac{2\pi\, Q_o}{1 - \left(\frac{\lambda_o}{\lambda_c}\right)^2} \tag{3.25}$$

The oscillator effeciency η is defined as

$$\eta = \frac{\text{Power going to the load side}}{\text{Total power generated in the diode}}$$

$$= \frac{\beta_2}{\beta_1+\beta_2} = \frac{1}{\beta_1+1}$$

$$\eta = -\frac{R_D}{Z_o} \qquad \text{using (3.18)} \qquad (3.26)$$

From equation (3.25) it is clear that for a high value of efficiency the diode negative resistance should be large and characteristic impedance of waveguide should be low.

Putting eqn. (3.26) into eqn. (3.25) we get

$$S = 2\left[\left(\frac{1}{\eta} - 1\right)\left(\frac{Q_c}{Q_o}\right) + \frac{\pi\, Q_o}{1-\left(\frac{\lambda_o}{\lambda_c}\right)^2}\right] \qquad (3.27)$$

As shown by eqns. (3.26) , (3.25) and (3.27) it is not possible to increase η and S simultaneously. To increase the efficiency the characteristic impedance of the waveguide should be low. The reduced height waveguide is used, as given by equation (3.3), has low value of characteristic impedance.

To get a high value of S we should choose a resonant mode of oscillation which gives a large quality factor and at the same time there

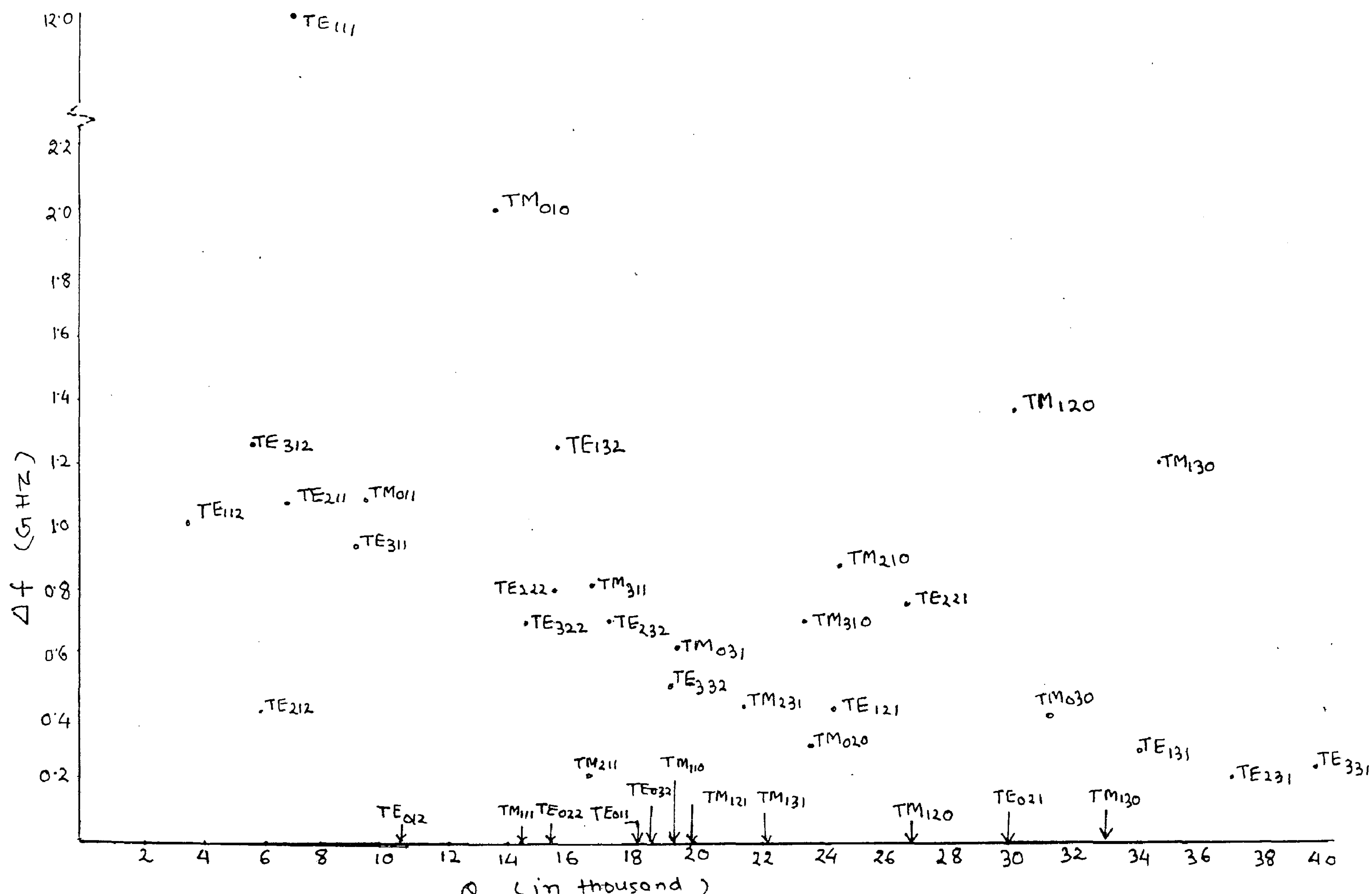

FIG 32: CHART SHOWING THE UNLOADED QUALITY FACTOR (Q_c) OF CAVITY AND THE DIFFERENCE BETWEEN TWO INTERFERRING FREQUENCIES (Δf) OF THE CAVITY DESIGNED IN VARIOUS MODES.

TABLE I

Design Frequency = 10.0 GHz

Length of Cavity = 4.0 cm

Radius (cm) of the cavity required is as given

TE_{nm1}

m | n	0	1	2	3
1	1.97	0.95	1.57	2.16
2	3.61	2.75	3.45	4.13
3	5.24	4.40	5.13	5.84

TE_{nm2}

m | n	0	1	2	3
1	2.77	1.33	2.20	3.03
2	5.06	3.85	4.84	5.79
3	7.34	6.16	7.20	8.19

TM_{nm0}

m | n	0	1	2	3
1	1.148	1.83	2.45	2.39
2	3.45	3.35	4.02	
3	4.13	4.86	5.94	

TM_{nm2}

m | n	0	1	2	3
1	1.24	1.97	2.64	2.58
2	3.35	3.61	4.33	
3	4.46	5.24	5.98	

is sufficient noise immunity from the adjacent interferring modes of oscillation frequencies.

With the designed frequency of 10 GHz (λ_o = 3 cm) and taking the cavity length of 4.0 cm, the radii required for various TE_{nml} and TM_{nml} modes have been calculated and put in a tabular form [Table 1]. Fig. 3.2 shows the quality factor and the difference between the two adjacent interferring frequencies for each mode of oscillation. It is seen that the higher order modes give high quality factor but the noninterferring frequency range is very low. So higher order modes are not preferred. TE_{011} mode gives larger quality factor than TM_{010} or TE_{111} but it is degenerate with TM_{111} mode. If TE_{011} mode is used then the need to suppress TM_{111} mode arises. Also the coupling iris has to be at the point which doesnot couple TM_{111} mode energy. TE_{111} mode gives the maximum range of noninterferring frequency but quality factor obtained will be low. Also coupling the energy from a TE_{111} mode cavity is difficult to achieve.

The TM_{010} mode has sufficiently large quality factor and the non-interfering frequency range as seen in Fig. 3.3(b). So the TM_{010} mode has been taken for the designed cavity.

Taking from eqn. (2.11)

$$\text{radius } \gamma_o = 1.483 \text{ cm} \tag{3.28}$$

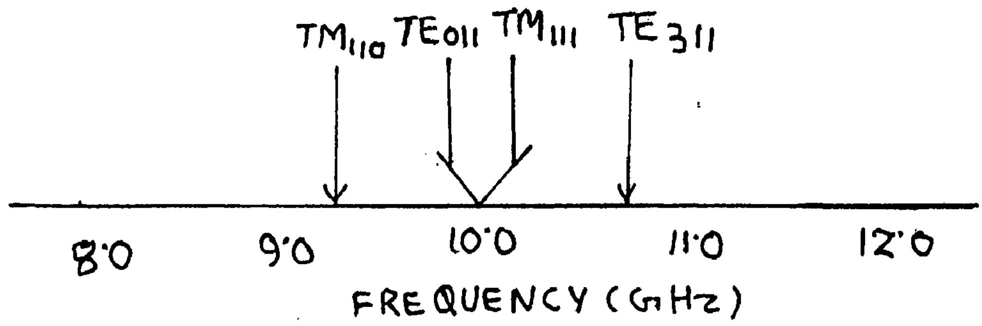

Fig. 3.3(a) : Resonant Frequencies for Cavity radius r_o = 1.97 cm and Cavity Length d=4.0 cm

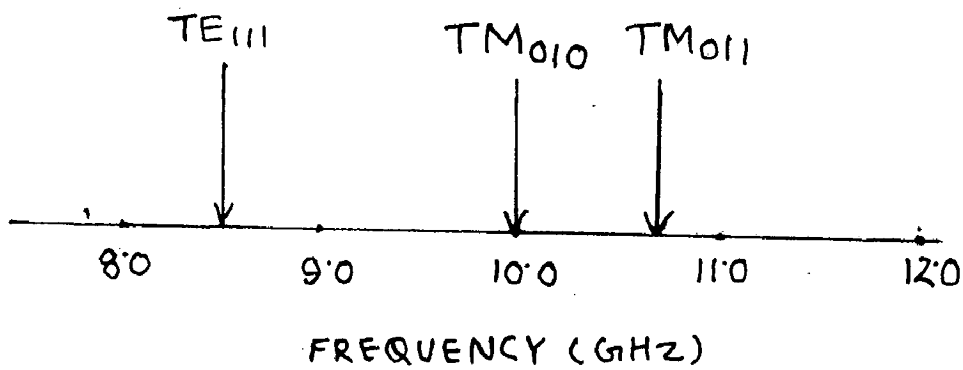

Fig. 3.3(b) : Resonant Frequencies for Cavity radius r_o = 1.148 cm, and Cavity Length d=4.0 cm.

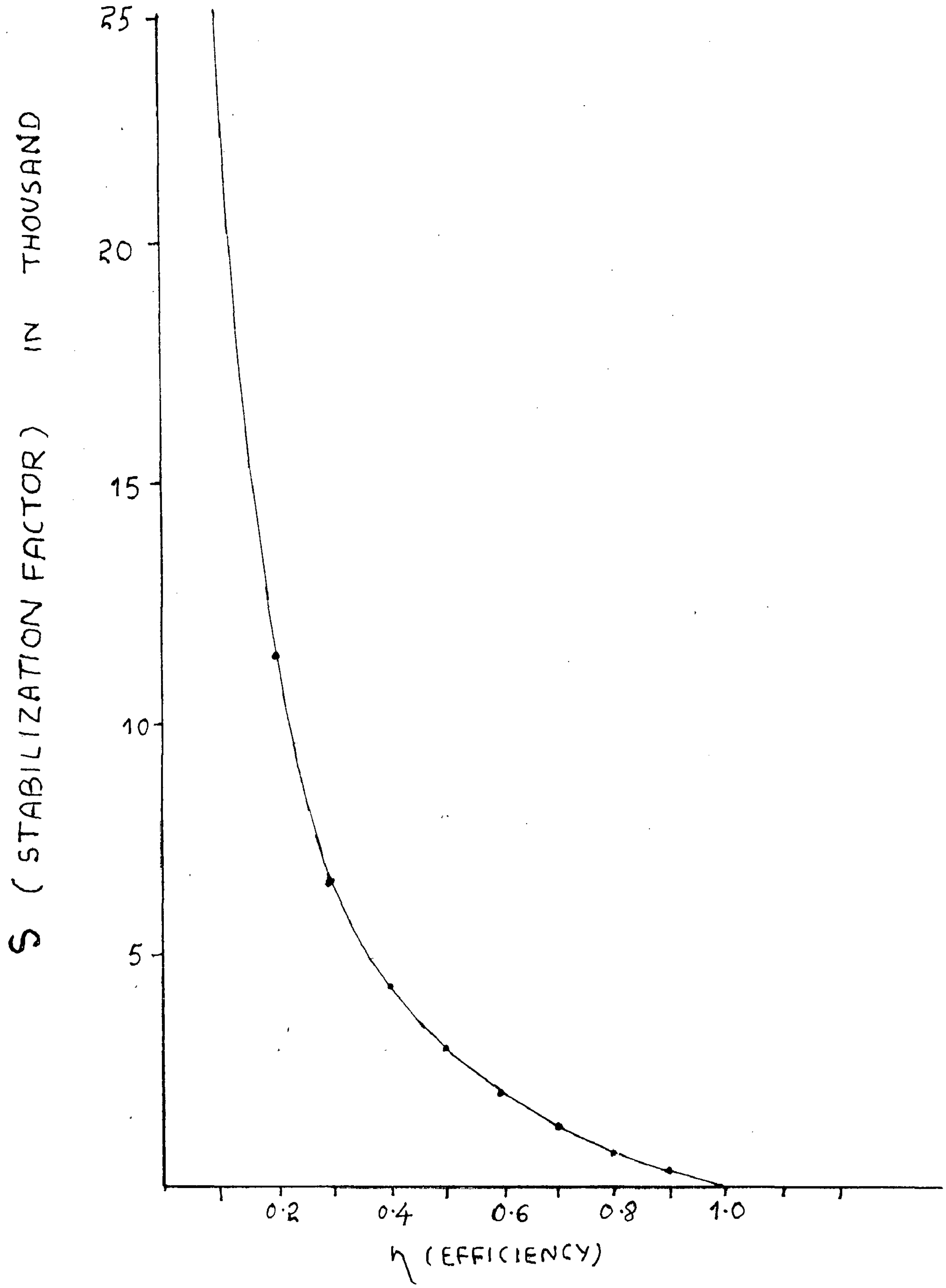

Fig.3.4: Relation Between Stabilization Factor(S) and Efficiency (η) of the Circuit. The Parameter Q_o has a value of 10.

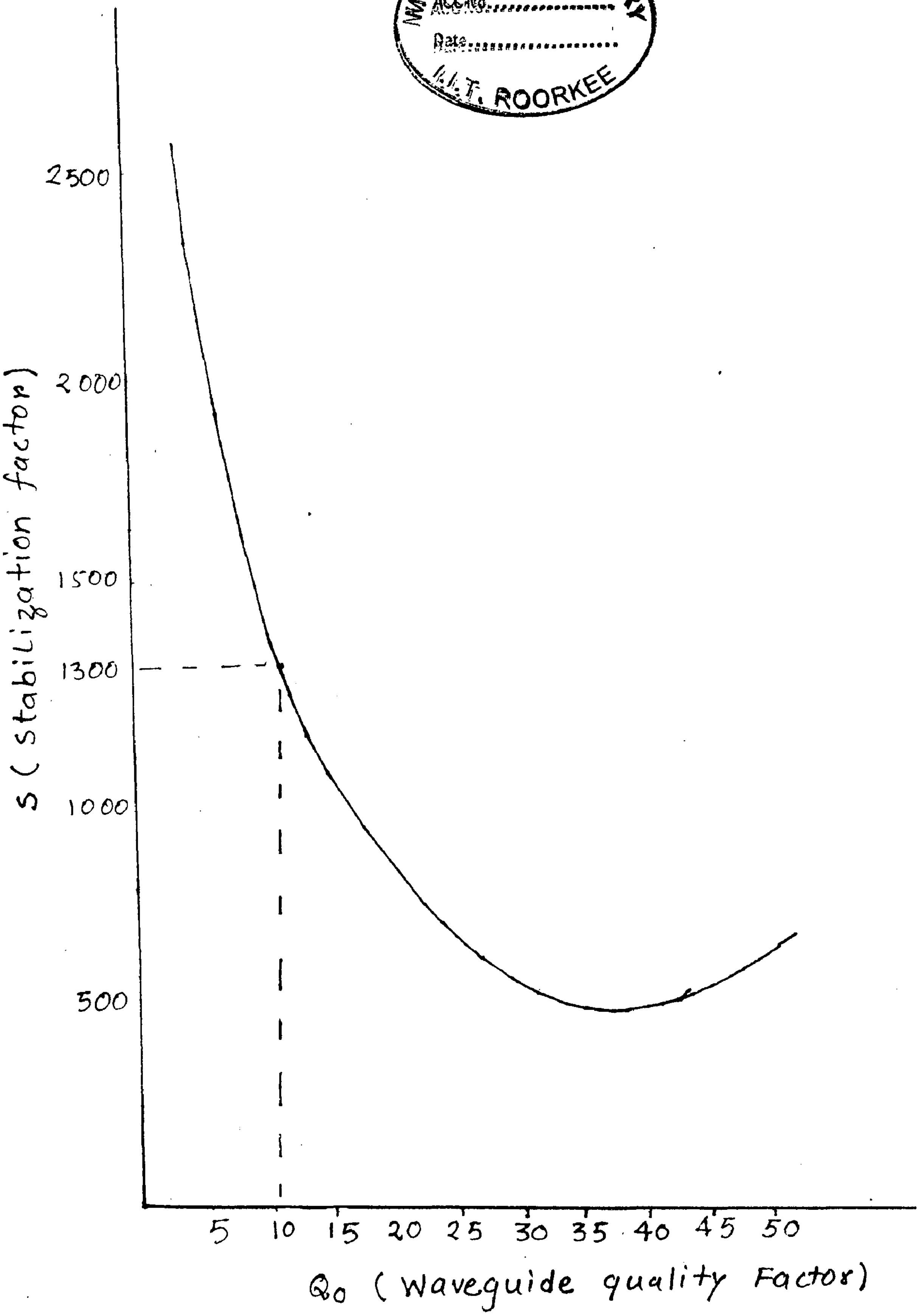

Fig.3.5 : Relation Between Stabilization Factor(S) and Waveguide Quality Factor(Q_o) with Cavity Quality Factor (Q_c = 14000)

Diode resistance R_D = -30 Ω from [22] (3.29)

Taking height of the reduced height waveguide as 2 mm the characteristic impedance Z_o is calculated from Eq. (3.3) as

$$Z_o = 43.7\ \Omega \tag{3.30}$$

Fig. 3.4 shows the relation between efficiency (η) and stabilization factor (S). From eqns. (3.28), (3.29) and (3.26) we get

$$\eta = 68.65\% \tag{3.31}$$

Using eqn. (3.24)

$$\lambda_g = 4.0\ \text{cm} \tag{3.32}$$

Using eqn. (2.12)

$$Q_c = 14000 \tag{3.33}$$

Putting these values into eqn. (3.27), we get

$$S = \left[\frac{6400}{Q_o} + 5.527\ Q_o\right] \tag{3.34}$$

Fig. 3.5 shows the relation between stabilization factor (S) and quality factor (Q_o) of the reduced height waveguide. Now taking C_D = 3pf, we have from eqn. (3.16),

$$Q_o = 10 \tag{3.35}$$

Putting the values obtained from (3.31) and (3.35) into eqn. (3.27), we get

$$S = 2\left[0.0457\ Q_c + 55.17\right] \tag{3.36}$$

As we know that TM_{010} mode is independent of the length of the cavity. To get the proper length, the length is varied with the plunger and the quality factor (Q_c) and stabilization factor (S) are calculated as shown in fig. 3.6. For the length of 4.0 cm the Q_c and S obtained are high but TM_{011} mode resonant frequency is quite close to the designed TM_{010} center frequency as shown in fig. 3.7. If the length is lower than 1.0 cm then the interference from TE_{111} is very low but the Q_c and S values obtained are also very low. If the length is between 2.0 and 3.0 cm then the Q_c and S increase but the TE_{111} mode resonant frequency comes quite close to the designed frequency. For d = 3.25 cm, we find good quality factor and stabilization factor and almost symmetrical distances of the TE_{111} mode and TM_{011} mode resonant frequencies from the designed frequency as shown in figs. 3.8(a), (b) and (c). So the length of the cavity has to be about 3.25 cm.

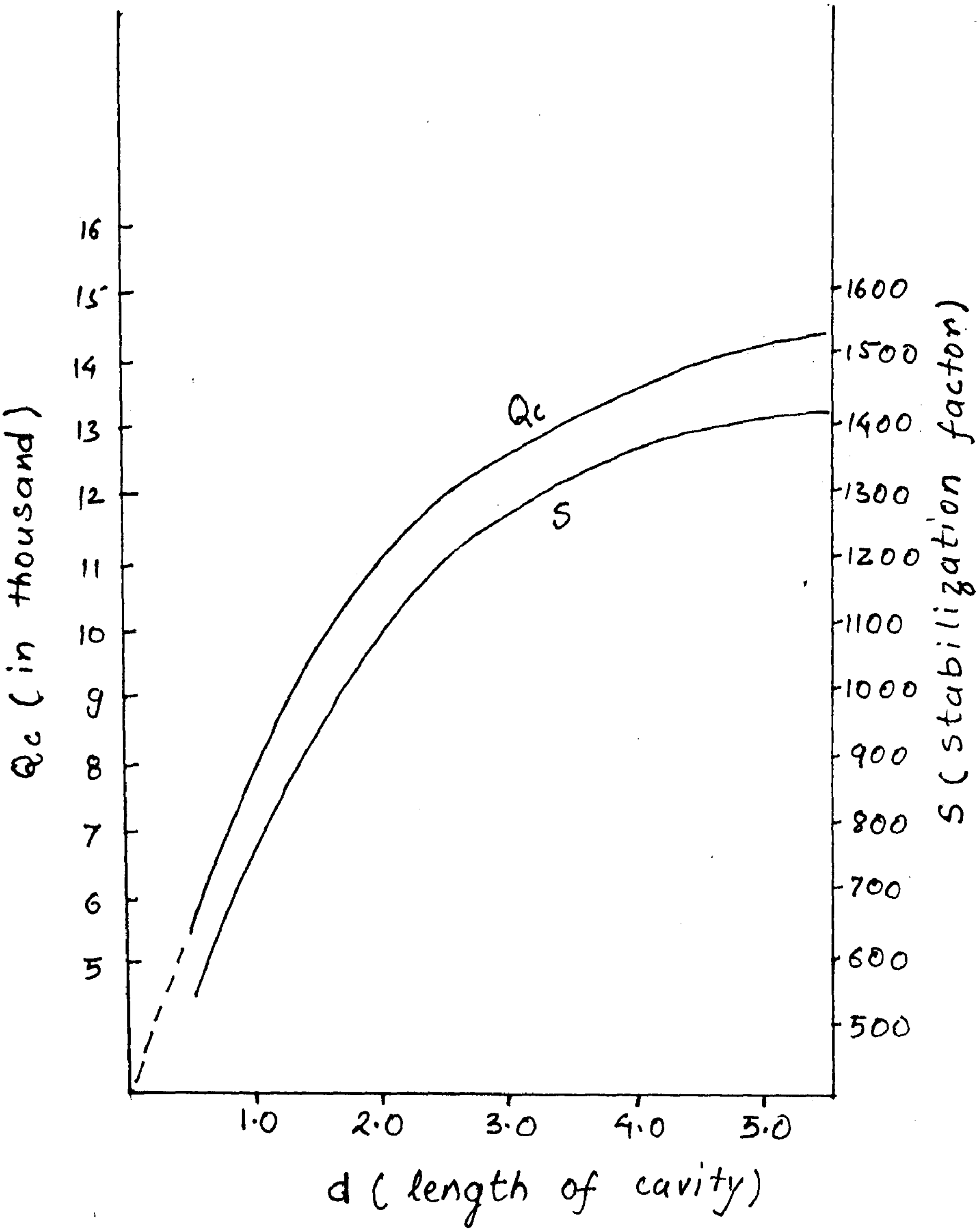

Fig.3.6 : The stabilization factor(S) and quality factor(Q_c) vs. length of cavity (TM_{010} mode)

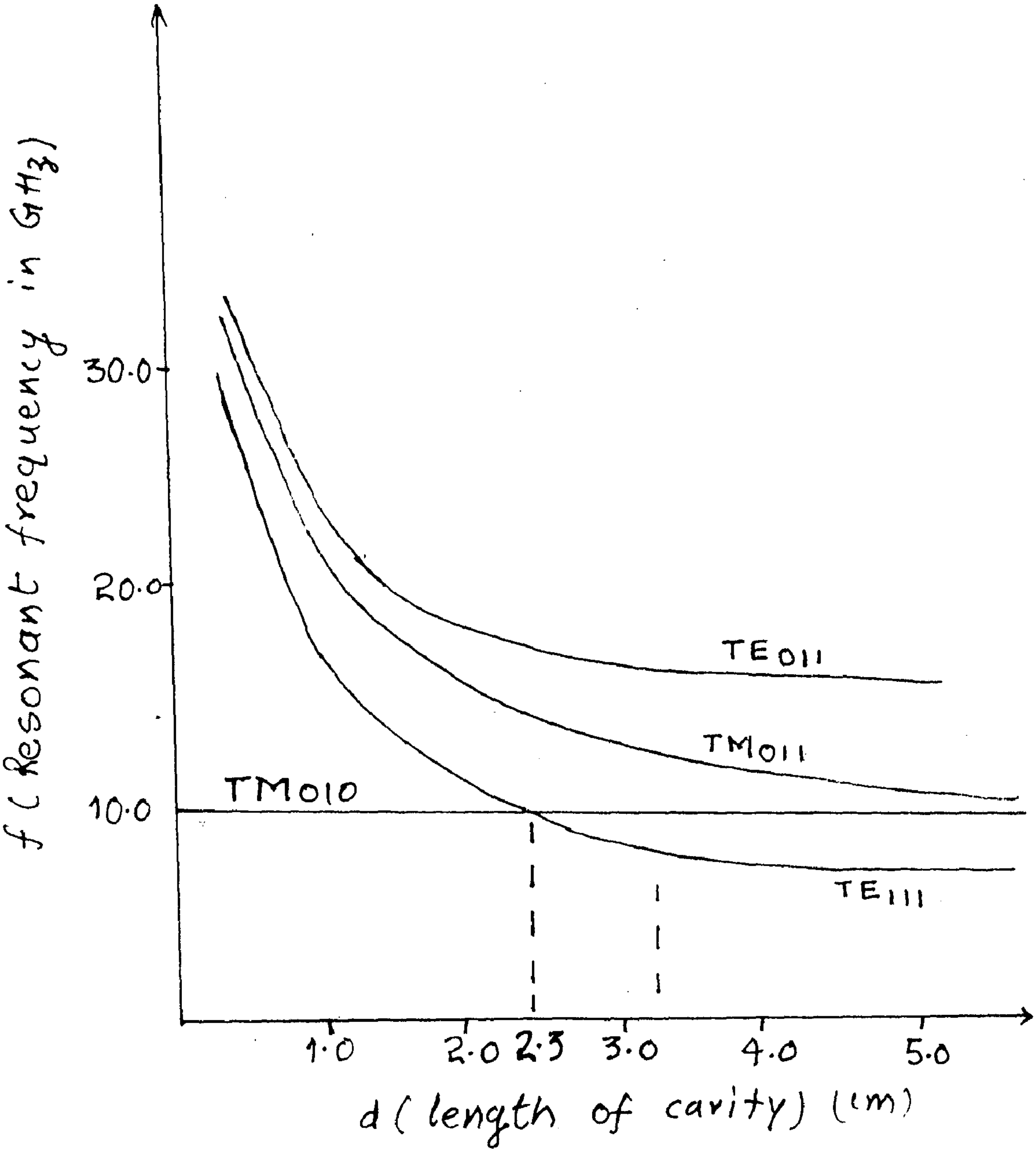

Fig. 3.7 : Nearest Interferring Frequencies vs. length of Cavity (d) designed in TM_{010} mode operating at 10 GHz. (radius r_o = 1.148 cm)

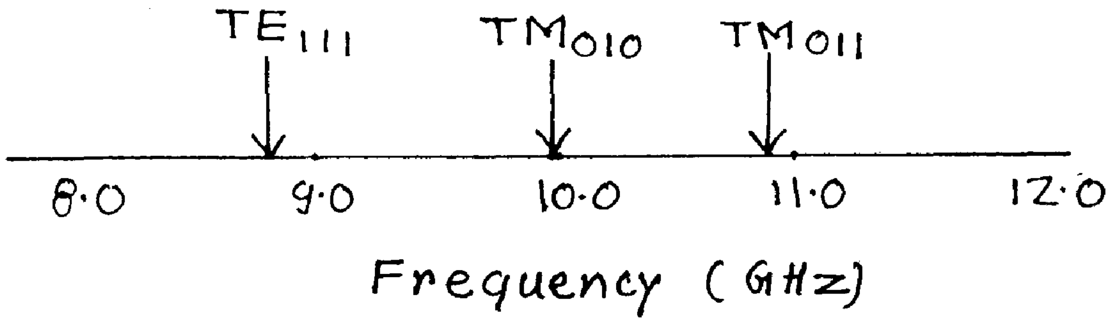

Fig.3.8(a) : Resonant Frequencies for r_o = 1.1483 cm
d = 3.5 cm.

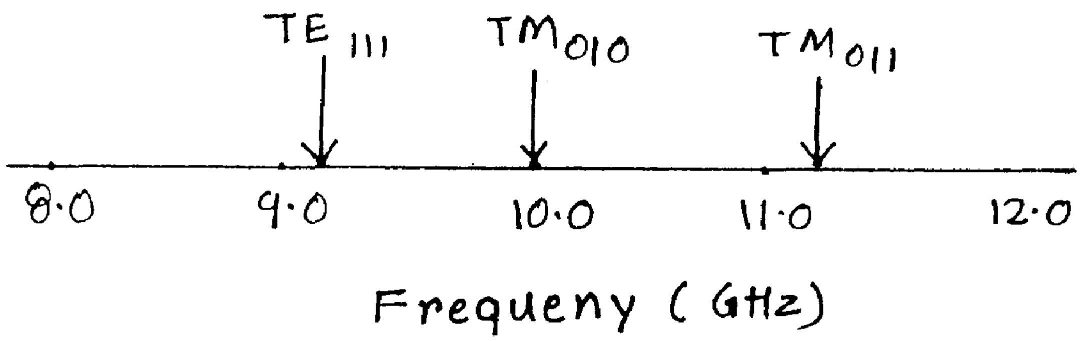

Fig.3.8(b) : Resonant Frequency for r_o = 1..1483 cm
and d=3.0. cm

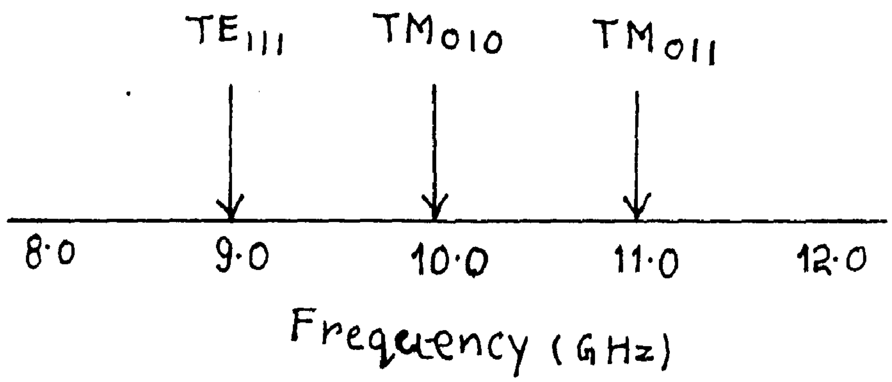

Fig.3.8(c): Resonant Frequency for radius r_o=1.1483 cm. and d = 3.25 cm.

Other dimensions are calculated as

$$l_1 = \lambda g_o + \frac{\lambda g_o}{2\pi} \cdot \frac{1}{Q_o} \text{ [using (3.7) and (3.17)]}$$

$$= 4.0 + \frac{4.0}{2\pi} \times \frac{1}{10} = 4.06 \text{ cm} \quad (3.36)$$

$$l_2 = \lambda g_o/2 = 2.0 \text{ cm} \quad (3.37)$$

$$l_3 = 3\lambda g_o/2 = 6.0 \text{ cm} \quad (3.38)$$

$$l_4 = \lambda g_o/4 = 1.0 \text{ cm} \quad (3.38)$$

$$Q_c = 13000 \quad (3.39)$$

$$S = 1280 \quad (3.40)$$

CHAPTER IV

RESULTS & DISCUSSION

1. CAVITY SPECIFICATIONS

1. Resonant Frequency	:	10 GHz
2. Material	:	Invar
3. Dominant Mode	:	TM_{010}
4. Inner Cavity Dimensions	:	Radius 1.148 cm Length 6.0 cm
5. Effective Length of Cavity	:	3.25 cm
6. Coupling Iris Dimension	:	2mm x 1mm
7. Piston Dimensions	:	Radius 1.148 cm Thickness 0.8 cm
8. Piston Material	:	Brass
9. Calculated Quality Factor	:	13000
10. Calculated Stabilization Factor	:	1280
11. Skin Depth δ	:	6.6×10^{-7} meter

2. REDUCED HEIGHT WAVEGUIDE SPECIFICATIONS

1. Material	:	Brass
2. Cross Sectional Dimension	:	2.28 cm x 0.2 cm
3. Dominant Mode	:	TE_{10}

4. Distance of the Gunn Diode from the Cavity Wall : 4.0 cm

5. Distance of the Gunn Diode amount from the Tapered Waveguide : 2.0 cm

6. Distance of the Tuning Screw from the Cavity : 1.0 cm

3. EXPONENTAIL TAPERED WAVEGUIDE SPECIFICATIONS

1. Material : Brass
2. Length of the Tapered Section : 6.0 cm

The designed cavity stabilized Gunn oscillator has a very good quality factor and frequency stability and it can easily limit the frequency fluctuations of a standard Gunn oscillator in the range of $10^{-6}/^{o}C$ for ambient temperature from $0^{o}C$ to $50^{o}C$. The obtained theoretical value of stability factor is much more than the miniumum value of stabilization factor required for a Gunn diode to be used in a microwave communication system. Thus the circuit gives a good performance even if the actual value of the quality factor and the stabilization factor is quite less than the theoretical value. The result will be better if the cavity is outgassed in vacuum and nitrogen gas is filled inside it.

APPENDIX - A

FIRST FEW ROOTS OF BESSEL FUNCTIONS

$J'_n(K_c r_o)$ and $J_n(K_c r_o)$

	P'_{mn}(TE Modes)		
Values of m	P'_{om}	P'_{1m}	P'_{2m}
1.	3.832	1.840	3.054
2.	7.016	5.331	6.706
3.	10.174	8.536	9.970
4.	3.334	11.706	13.170

	P_{nm} (TM Modes)		
	P_{om}	P_{1m}	P_{2m}
1.	2.405	3.832	5.135
2.	5.520	7.016	8.417
3.	8.654	10.174	11.602

REFERENCES

1. R. KNOCHEL & K. SCHUNEMANN, "Design of Cavity Stabilised Microwave Oscillators", Electronics Letters, Vol. 17, August 1975, pp. 405-406.
2. KITO YUKIO et. al. "K Band Single Tuned IMPATT Oscillator Stabilized by Hybrid Coupled Covities", MTT-20, No. 12 Dec. 1972, pp. 799-805.
3. S. NAGANO & S. OHNAKA, "Highly Stabilized IMPATT Oscillators at Millimeter Wavelengths", MTT-21 No. 11 Nov. 1973, pp. 491-492.
4. F. BERNARD & VARNDER HEYDEN, "Design of Stable, Very Low Noise, Cavity-Stabilized IMPATT Oscillators for C Band", MTT-25 No. 4, April 1977, pp. 318-323.
5. ITO YUKIO et. al. "Cavity Stabilized X and Band Gunn Oscillator", MTT-18 No. 11, Nov. 1970, pp. 894-96.
6. K. KUROKAWA, "Injection Locking of Microwave Solid State Oscillators", Proc. of IEEE. Vol. 61, Oct. 1973, pp. 1386-1405.
7. D.V. MORGAN & M.J. HOWES, "Microwave Solid State Devices and Application".
8. S. SARKAR & O.P. GUPTA, "Dependence of the Multiple Device Oscillator Injection Locking Range on the Number of Constituent Devices", IEEE. Microwave Theory Tech., Vol. MTT-34, July 1986, pp. 839-840.
9. P.S. KOOI & D. WALSH "Novel Technique for Improving the Frequency Stability of Gunn Oscillators", Electronics Letters, Vol. 6, Feb. 1970, pp. 84-85.

10. K. KOHIYAMA, "A New Type of Frequency Stabilized Gunn Oscillator", Proceedings of IEEE, Oct. 1971, pp. 1532.33.

11. S. NAGANO & S. OHNKA, "A Highly Stabilized Ka Band Gunn Oscillator", MTT-20, pp. 174-176.

12. NAGANO & KONDO, "Highly Stabilized Half-Watt IMPATT Oscillator", MTT-18 No. 11, Nov. 1970, pp. 885-890.

13. ROBERT ADLER, "A Study of Locking Phenomena in Oscillator", Proceedings of IEEE, No. 10, Vol. 61, Oct. 1973, pp. 1381-1410.

14. J. GONDA & SCHROEDER, "IMPATT Diode Circuit Design for Parametric Stability", MTT-25 No. 5, May 1977 pp 343-350.

15. NAGANO & OHNAKA "A Low Noise 80 GHz Silicon IMPATT Oscillator Highly Stabilized with a Transmission Cavity", MTT-22, No. 12, Dec. 1974, pp. 1152-60.

16. COHEN & GILDEN, "Temperature Stability of an MIC Gunn Effect Oscillator", MTT-21, Feb. 1973, pp 115-116.

17. R. STEN "Superconducting Cavity Stabilized Oscillator of High Stability", Electronics Letter No. 13 Vol. 18, June 1972, pp. 321-322.

18. M.L. SISODIA & G.S. RAGHUVANSHI "Microwave Circuits and Passive Devices" Wiley Eastern Ltd., India.

19. B. GLANCE, W.W. SWELL "A Discriminator Stabilized Microstrip Oscillator", IEEE MTT-24, Oct. 1976, pp. 648-659.

20. B. SCHIEK "Noise of Negative Resistance Oscillators at High Modulation frequencies", MTT-20 No. 10, Oct. 1972, pp. 635-642.

21. K. SCHUNEMANN "Comparison Transmission and Reaction-Cavity Stabilized Oscillators", Electronics Letters, No. 20, Vol. 7, Oct. 1971, pp. 618-619.

22. LIAO SAMUEL "Microwave Devices & Circuits", Prentice Hall, 1990.