Design Philosophy of Microwave Gunn Oscillator

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Abstract: **-In the microwave field, Gunn diode oscillators have important role in the development of communication systems because of its low noise behavior and medium power. The primary application of Gunn diode is as a local oscillator in microwave receivers. At higher microwave frequencies, transistors cannot generate required low noise power, suitable for receivers. The Gunn diode is two-terminal solid-state negative impedance device, where the real part of the impedance is negative over a range of frequencies. This paper introduces Design Philosophy of high-frequency Gunn Oscillators and discusses the design and implementation steps to produce the oscillator. For example the Waveguide Cavity Gunn Oscillator at 94 GHz frequency, which consists of a packaged Gunn device mounted in WR-10 waveguide, and tuning plunger is used to tune the desired frequency. The matching circuit is a post mounting network and a waveguide – height transformer.**

Keywords: **Gunn oscillator, Waveguide cavity, Tuning Plunger, Voltage regulator circuit, Low Pass Filter.**

I. INTRODUCTION

After Second World War semiconductor devices came into light to develop microwave oscillators and amplifiers, due to its reliability, ruggedness, and better characteristics. In the late 1970s, Gunn oscillators and Avalanche diodes oscillators had been used extensively to produce microwave power [1]. IMPATT (Impact Avalanche Transit Time) and Gunn diodes are the two terminal devices which work at frequencies higher than the Ka frequency band (26-40 GHz) up to D-band (110-170GHz).

They can be tuned mechanically or electrically. The theory of how Gunn devices oscillate has been covered in other literature [2]. The brief concept of Gunn Effect is as follows;

- Gunn device consists of GaAs compound semiconducting material. On application of an electric field in the material at threshold level, the mobility of electrons decrease as the electric field is increased; this in turn produces negative resistance.
- This device can generate microwave/millimeter wave (30 -300 GHz). In 1963 Scientist J.B. Gunn invented the Gunn Effect.
- Gunn Effect can be explained by two valley theory of Ridley Watkins- Hilsum (RWH) theory or the transferred electron mechanism. The mechanism involved in the operation of bulk n-type GaAs devices is the transfer of electrons from lower valley to upper valley in the conduction band.
- The electron in the lower valley has a smaller effective mass ($m1 = 0.072\ m0$) than one in the upper valley ($m2 = 1.2m0$). The different effective masses mean different mobilities for the lower valley ($\mu 1 = 0.5 m2/volt\ sec$) and the upper valley ($\mu 2 = 0.1 m2/volt\ sec$) respectively.
- The ratio of the density of states in the upper valley to that in the lower valley is about 60. Thus the upper valley has a very high density of states compared with $k = 0$ location. On increasing applied field, the electrons gain energy from it and move upward in the upper valley.
- As the electrons transfer to this upper valley, their mobility decreases and the effective mass is increased thus decreasing the current density and hence the negative differential conductivity.
- There is a certain threshold field, approximately 3.3kV/cm above which this inner valley transfer (population inversion) of charges from lower valley to the upper valley or the electron transfer effect takes place [3]. The transfer of electrons from lower valley to upper valley in the conduction band has been illustrated in Figure 1.

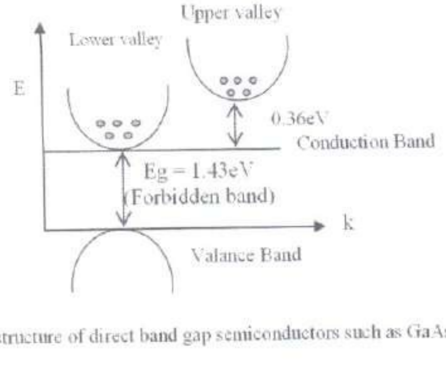

Fig. 1 Band structure of direct band gap semiconductors such as GaAs

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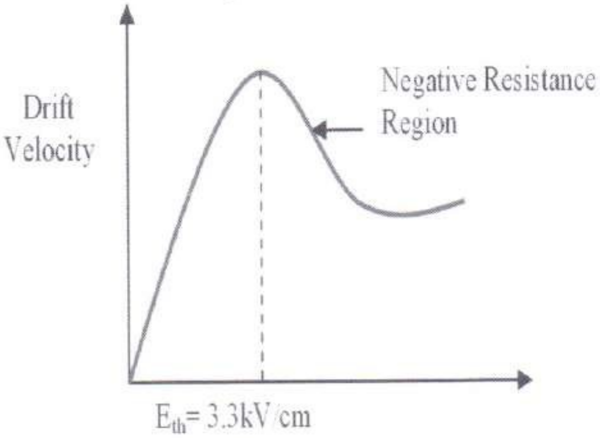
- Mobility of electrons implies conductivity, it means as the mobility slows down due to population inversion the velocity of electrons or current decreases with an increase in applied electric field after a threshold value Eth as shown in Figure 2.



- The process of electrons travelling from lower valley to upper valley is called the transferred electron effect, and the device is so called 'Transfer Electron Device (TED)".
- Thus the Transfer Electron device i.e. Gunn diode behaves as negative resistance device over a range of applied voltages and can be used in microwave oscillators [4].

II. Basic Structure of Gunn diode

- The basic configuration of a Gunn diode has been shown in Figure 3; it consists of a slab of N-type GaAs (Gallium Arsenide) or InP (Indium Phosphide) contacted on both sides by low resistance ohmic contacts.

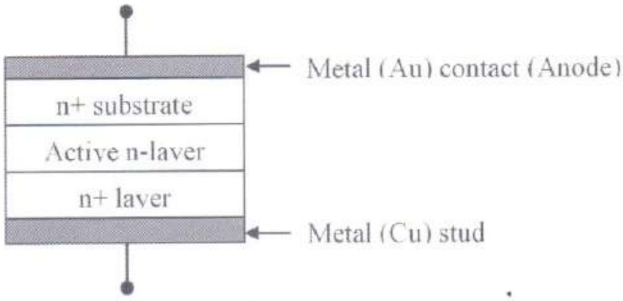


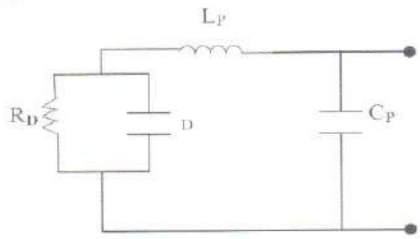
Fig. 3 Gunn diode structure

- Thus it is a two terminal device called Gunn diode but has no junctions. It has a negative-resistance region where drift velocity decreases with increased voltage and in turn results a concentration of free electrons called a domain.

III. Equivalent Circuit:

- The equivalent circuit diagram of Gunn diode has been shown in Figure 4.

Where;



RD = Gunn diode negative resistance

CD = Diode capacitance

LP = Package inductance

CP = Package capacitance

IV. Design criteria of Gunn Oscillator

Gunn Oscillator is one of the most important solid state millimeter wave sources. It exhibits low AM and FM noise and a wide operating frequency range. Therefore it is being used as a transmitter and as well as a local oscillator. The Gunn diode is a complex electronic device, which can operate in a region known as the negative differential resistance region (NDRR).When the device operates in negative resistance region; it produces a high frequency oscillating signal.

- For oscillation to occur, the following conditions need to be satisfied

Imaginary part of (Z_D) +

Imaginary part of $(Z_C) = 0$ .... (1)

And $|\mathrm{Re}(Z_D)| \geq \mathrm{Re}(Z_C)$ .... (2)

Where Z_D is the device impedance and Z_C is the transformed load impedance, as shown in the equivalent circuit of Figure 5.

In a waveguide transmission medium at higher frequency microwave R_L is the impedance of the full height waveguide, which is around 300 to 400 Ω.

- The matching circuit is a post mounting network and a waveguide – height transformer. The hardware is designed to meet the conditions in equation (1) and (2) at the desired frequency.

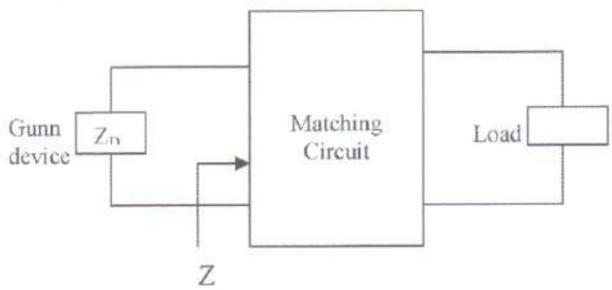


Fig 5. Simplified circuit for Gunn Oscillator

- The device impedance is a function of frequency and DC bias current and temperature. The circuit impedance is a function of frequency only. Hence we have

$$Z_D = -R_D + jX_D \quad (3)$$

$$Z_C = R_C + jX_C \quad (4)$$

Where; Z_D is the diode impedance, and Z_C is the circuit impedance.

V. Waveguide cavity Gunn oscillator

- The Gunn Oscillator consists by coupling the Gunn diode to a load through tuning and matching elements, which optimize the load impedance as seen at the diode terminals.
- The circuit will resonate, and oscillations will build up at a frequency where the total susceptance of diode and circuit is zero.
- As RF level increases the negative resistance of the Gunn diode will decrease. A stable state reaches when load resistance presented to the diode is equal to or less than the negative resistance of the diode.
- The structure of Waveguide Cavity Gunn Oscillator (shown in Figure 6) consists of;
  1) Full height waveguide,
  2) Tuning plunger
  3) Low pass bias filter
  4) Impedance transformer/output coupling
  5) Tuning screw,

1) Full height waveguide

- It is a high Q rectangular waveguide cavity. High Q is requirement for minimum losses in the oscillator circuit and better stability, low FM and AM noise.
- At W-Band frequency (75-110GHz) WR-10 full height rectangular waveguide is used.

2) Tunable plunger:

- In a fundamental mode, cavity impedance is changed by changing the position of tuning plunger and thus frequency tuning is accomplished by adjusting the position of the tuning plunger.
- However when the diode is working in second harmonic mode, a position of the plunger or back short has no effect on frequency.
- The frequency of such oscillator is independent of back short position, and in such cases, back short is used to optimize output power of Gunn oscillator.

3) Low pass bias filter:

Low pass filter at bias voltage prevents transmission of energy at desired frequency through bias circuit.

- Low Pass Filter (LPF) is a coaxial filter having low impedance and high impedance element. But such filter also works as band stop filters because of anomalous resonance in stop band region.
- The practical filter should exhibit stop bands at fundamental frequency 94GHz and at a second harmonic frequency at 188 GHz frequency. The choice of diameters of inner and outer conductors depends on the following considerations.
- The cut-off wavelength of the lowest order non- TEM mode

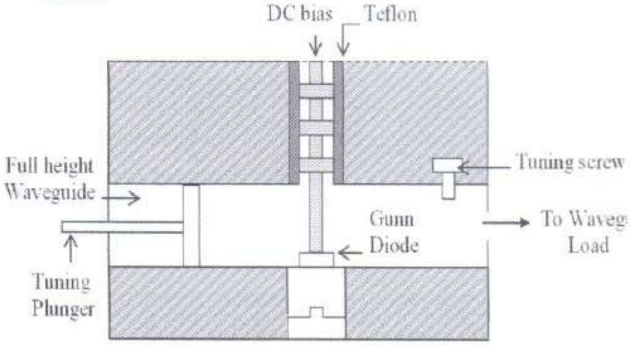


Fig. 6 Cross sectional view of waveguide Gunn Oscillator circuit

TE11 of a coaxial line is given by:

$$\lambda_{cTE11} = \frac{\pi}{2}(d + D) \quad (5)$$

Where d and D are the diameters of inner and outer conductor respectively

4. Impedance transformer/output coupling:

Iris coupling is best option at the output for impedance matching to the waveguide load.

5. Tuning screw:

Tuning is used for slight changes in the output impedance and small frequency drift of Gunn oscillator.

All above elements are responsible for tuning exact frequency and maximization of the output power of the oscillator.

VI. Gunn Power Supply

- A well-stabilized power supply is used to bias the diode. This power supply module consists of a low noise voltage regulator to maintain constant DC bias voltage on the Gunn diode and reduce power supply ripple and noise.

- The regulated power supply also provides protection against the inadvertent application of potentially destructive over voltage of the Gunn diode.
- This regulated voltage has been obtained by a regulator circuit which is consists of LM317 regulator ICs as illustrated in Figure 7.

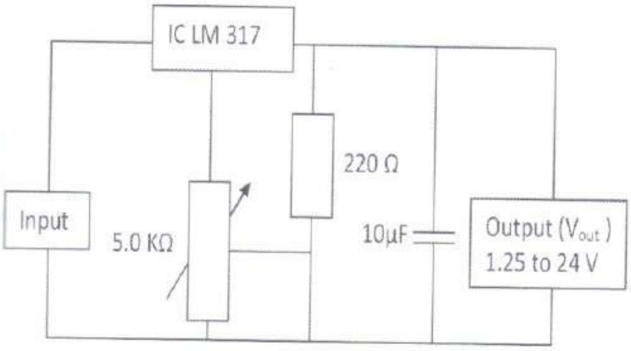


Fig. 7 Voltage regulator circuit

- It is better to bias Gunn oscillator at peak power voltage for stability and less noise. Operating voltage should be Voperating = 3.5V threshold for the highest power level and efficiency at W-Band frequency.

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