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Design and Characterization of Microstrip IMPATT Oscillator

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Abstract: In this work an IMPATT oscillator circuit at Ka band has been designed using inverted microstrip circuit. Using microstrip Impatt ocsillator as sources, the transreceiver becomes extremely light and compact. The performance of IMPATT diode is thermally limited and it suffers from parametric and bias oscillation. It is a relatively noisy device due to avalanche ionization. These limitations were considered in the design and minimized the effects. The Design of the oscillator consist of an active element (IMPATT) which converts dc power to RF power and a passive element with the electronic circuits for dc bias for the device to operate, providing the em environment at the device terminal to initiate oscillation and optimizes the oscillators output power and efficiency. The observed frequency of oscillation is 36.4 GHz with a maximum output 0f 1.472 mW.

INTRODUCTION

The IMPATT diode is basically a p-n junction diode that operates when it is reverse-biased to avalanche breakdown condition. IMPATT diodes have emerged at the end of the 20th Century, as most powerful solid-state sources of microwave and millimeter-wave, covering a wide range of frequency spectrum. The reported frequency range of IMPATT oscillators extends from below X Band (6 GHz) to the sub millimeter wave region. IMPATT is an acronym for IMPact Avalanche Transit Time (IMPATT) diode, which reflects the mechanism of its operation. In its simplest form IMPATT is a reverse-biased p-n junction diode, in which an avalanche of electron-hole pair is produced in the high-field region of the device depletion layer by impact ionization. The transit of carriers through the depletion layer leads to generation of microwaves and millimeter waves when the device is tuned in a microwave or millimeter wave cavity. The vast frequency range and high-power output should make the IMPATT a highly suitable device to meet the ever increasing communication needs of the world. IMPATTs have been used in microwave and millimeter wave digital and analog communication systems and in Radars, missile seekers for defence systems. Si IMPATT diode is designed on the basis of a generalized computer method for DC and current profiles in IMPATT devices starting from the field maximum in the depletion layer. The field-maximum method is suitable for any arbitrary doping profile and involves the determination of the location and magnitude of the maximum field position. In recent years, solid state microwave oscillators and amplifiers are becoming increasingly important in microwave, millimeter wave and submillimeter wave frequency ranges. Theses power devices find their application primarily in communication and radar system. The three terminal solid state power devices (MESFET, HEMT,HBT) dominates power applications upto 30 GHz. while the two terminal devices , Impact Avalanche Transit Time Diode (IMPATT) has the advantage of delivering high power at microwave and millimeter wave frequencies. Because of their low cost, small size, high reliability, solid state devices have replaced traditional microwave devices such as Klystron, Magnetron and TWT in most medium power applications.

DESIGN

Design of Microstrip Impatt Oscillator

Microstrip oscillator circuit generally consists of an impedance matching network and a resonant circuit for stabilizing the oscillations. The resonant circuit can be a metal resonant cap (1), Impatt diode resonant line section (2) or a dielectric resonator(3), resonant cap mounting of Impatt diodes for oscillations in one of the simple low cost techniques. The active devices used here was a GaAs IMPATT diode with its frequency of operation in the Ka band.

The diode specifications are listed below:

Diode part number - IMPATT F14-DI-350-420

Maximum Current - 200mA

Output power - 511 mW

Oparating frequency - 35.2 GHz.

GaAs diode has several advantage above silicon IMPATT diode, IMPATT diode made from GaAs have efficiencies roughly twice that of their Si counterparts. GaAs exhibits a nonlinear velocity versus electric field characteristics. The dc to RF conversion efficiency of commercially available GaAs IMPATT is Typically 15-20%.For a Si diode , an increase in dc current produces an increase in dc voltage, if the device is mounted in an optimum RF circuit, the RF power increases until the IMPATT's thermal limits are reached. On the other hand, as dc bias current applied to a GaAs IMPATT increases, the operating voltage increases to a threshold value and then begins to decrease with increasing current. This reducing voltage phenomenon with increasing current and RF power results in higher dc to RF conversion efficiency. The details of the substrate used are given below:

Material: RT duriod 5880

Permittivity: 2.2

Tanδ: 0.0009

Thickness: 10 mil

The 10 mil substrate was chosen considering mounting on the diode. As seen from the case style of the diode, with a 10 mil (0.254 mm) substrate the diode chip can easily be mounted on the substrate and will be flushed with the substrate, giving a smooth surface finish.

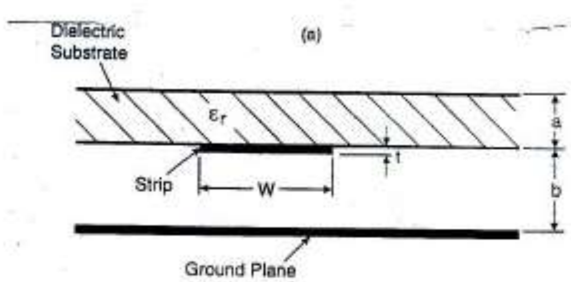

Fig 1. Cross section of Inverted Microstrip Lines

Inverted microstrip line has been chosen due to following advantages: Inverted microstrip lines achieve a lower loss (or higher Q) than possible with microstrip line. Further this lines have a much lower effective dielectric constant (compared with that of a microstrip line), thus leading to their performance being less sensitive to dimensional tolerances at high frequencies. Further, the wide range of impedance values achievable using these lines makes them particularly suitable in realizing filters. The inverted microstrip retains the advantage of the suspended microstrip in terms of achieving larger strip dimensions and lower dissipative losses. Furthermore, it reduces the radiation loss in contrast to that in an open suspended microstrip.
The resonator should be designed that it matches the diode impedance and it should not radiate rather than guide the power to 50 Ω line. Using PCADD (software package) and Microfil (standard line length calculator) and considering the effective dielectric constant to be 1.01 for inverted configuration, the following results have been obtained:

Radius of the resonator: 4.09 mm
Length 0f 20Ω line: 4.41 mm
Width of 20Ω line: 4.96 mm
Gap for surface
mount capacitor: 0.3 mm
Length of 50 Ω line: 3.0 mm
Width of 50Ω line: 1.56 mm

Taper section

Initial Width: 4.96 mm
Final Width: 1.56 mm
Length: 2.24 mm

Low pass filter

1st section
Width: 8.0 mm
Length: 1.5 mm

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2nd section
Width: 0.2mm
Length: 2.4 mm

SIMULATION

The microstrip circuit which is designed using inverted microstrip configuration is simulated using HP Advanced Design Software. The results ensure the correctness of the design logic. The four section alternate low and high impedance line filter has been simulated for S parameters over 1-45 GHz. frequency range. The result [Fig 4.] shows the cutoff frequency as 11 Ghz and an insertion loss 0f -35 dB over the required band. The return loss at the cutoff frequency is -20 dB. The resonator, impedance matching circuit and coupling line section has been simulated and the result [Fig. 6.] shows a return loss of above -40 dB at the design frequency of 36 GHz. The entire design including the biasing circuit, rf coupling capacitor and 50 ohm termination is simulated. An isolation of -42 dB of the dc bias from millimeterwave power port and a good return loss at the design frequency (-25 dB) is observed.

The designed circuit is shown below:

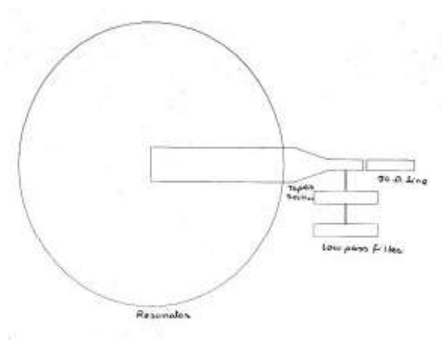

Fig 2. Schematic Layout of the PCB

Fig. 3. Actual Layout of the PCB

FABRICATION & TESTING

The Impatt Oscillator is driven by a constant current source [Fig. 5.]. Since the Impatt diode has low efficiency, it needs to be driven by a large source and highly regulated power supplies. The oscillator circuit is fabricated and shown in Figure 7.The tested result of the device shows oscillations at the biasing voltage level of 25 Volt. The frequency of oscillation was 36.34 GHz [Figure8.]. The current vs. power plot is shown in Figure 9.It was observed that at the minimum voltage (32.4V) across the diode, the current drawn was 142.4 mA with a power output of 472 mW.

CONCLUSION

In this work a challenging work of design, development and evaluation of microstrip based Impatt oscillator in inverted configuration has been performed. After a lot of research, a simple design methodology has been implemented with the above mentioned design parameters. The diode and the substrate were mounted properly in the mechanical package and placed in the test set up. The frequency of oscillations obtained is 36.34 GHz. which is in close agreement with the designed value of 36 GHz. The maximum output power is 1.472 mW. The air gap between the ground plane and the microstrip line can be varied to obtain the optimized power output and more power output is possible by preventing soldering loss. The efficiency of the diode was 2% against the rated value of 15%. This may be due to absence of temperature compensation and tuning mechanism. Further miniaturization can be achieved using alumina substrate and modifying the taper section into step discontinuity. However the performance and efficiency can be improved by adopting different design methodology. But

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considering the fabrication tolerance inverted microstrip configuration in Millimeterwave frequency is useful due to increased circuit area. Design techniques in microstrip configurations are much smaller than the waveguide counterparts and further miniaturization can be possible using:

a. Alumina substrate, where circuit dimensions reduce considerably.

b. Modifying the filter circuit layout, by bending the inductive line the circuit layout can be reduced.

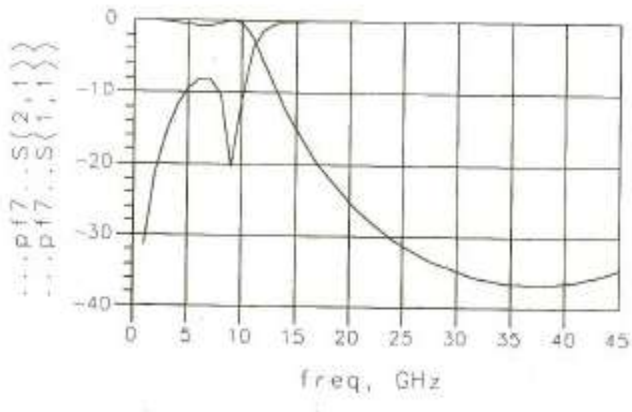

Fig. 4 Simulation result of the LP Filter

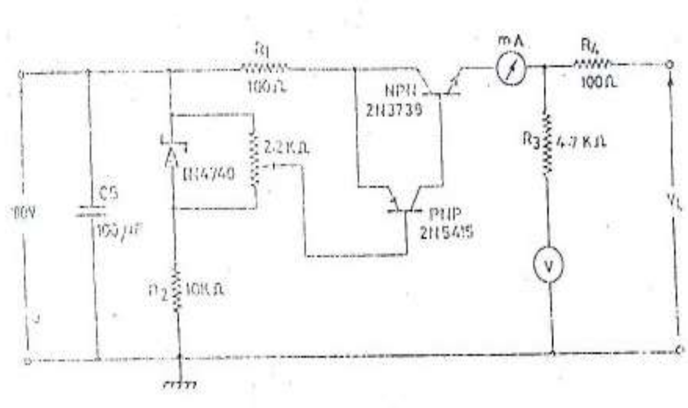

Fig. 5. Constant current bias supply used in the experimental studies

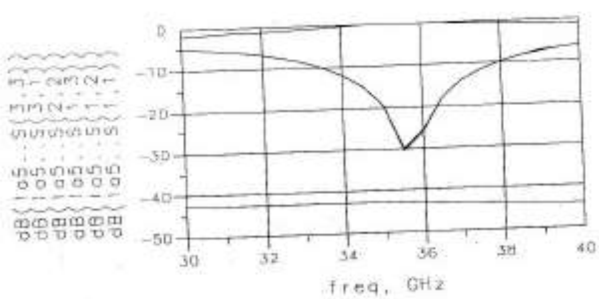

Fig.6. Resonator Simulation result

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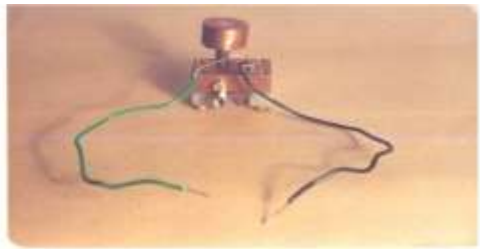

Fig. 7. Hardware of Fabricated Impatt Oscillattor

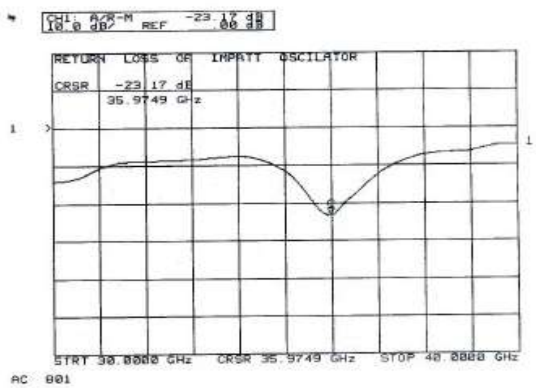

Fig. 8. Return Loss of Impatt Oscillator

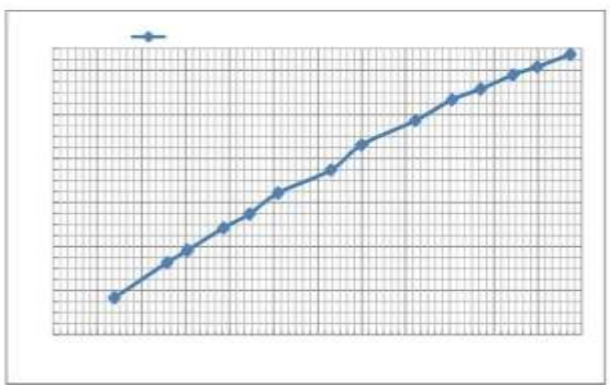

Fig. 9. Current Vs Power Plot for Impatt Oscillator

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