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Mechanical Tuning Properties of Waveguide-mounted Resonant-cap IMPATT Oscillator at Ka-band

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ABSTRACT

The paper describes the studies of the tuning properties of an indigenously developed resonant-cap continuous wave IMPATT oscillator at Ka-band by changing circuit susceptance through mechanical tuning. It was observed that output power of a resonant-cap IMPATT oscillator passes through a maximum at a particular frequency for a given diode with an optimum combination of cap diameter and cap height. An empirical relation has been found between cap diameter and wavelength of the optimised oscillator, which agrees with the theoretical relation. The effect of sliding short tuner position on the oscillator at optimised condition and the phenomenon of frequency jump in certain positions of sliding short have been studied.

Keywords: Mechanical tuning, resonant-cap, IMPATT oscillator, Ka-band, cavity tuning, sliding short tuner, frequency jump

I. INTRODUCTION

IMPATT diodes have emerged in twenty-first century as very powerful solid-state sources of microwaves/millimeter waves, covering a wide frequency spectrum. The vast frequency range and high-power output makes the IMPATT a highly suitable device for meeting the ever increasing communication needs of the world. IMPATTs have been used in microwave and millimeter wave digital and analog communication systems and in radar and missile for defence systems. The achievable bandwidth is very crucial, since it dictates the total system design. Many researchers have already investigated the tunable bandwidth of microwave/ millimeter wave IMPATT oscillators[1-8]. Inspite of considerable work reported in the field of resonant-cap IMPATT oscillators, there remains a scope for detailed and coherent study of their tuning properties, specially at Ka-band. Among all the window frequencies, Ka-band has become very useful in present age due to its wide applications in civil, industrial, medical, and strategic fields. In this paper, a detailed and systematic study of the tuning properties of resonant-cap IMPATT oscillator at Ka-band has been presented by varying the cap diameter, the cap height, and the sliding short tuner position.

2. DESIGN OF Ka-BAND OSCILLATOR

The cross-sectional view of IMPATT oscillator has been shown in Fig. 1. The resonant-cap waveguide mount consists of a resonant-cap structure under which the diode has been embedded and the two together have been mounted in a rectangular waveguide. The cap and broad surface of the waveguide forms a localised radial cavity around the diode. The millimeter wave power generated

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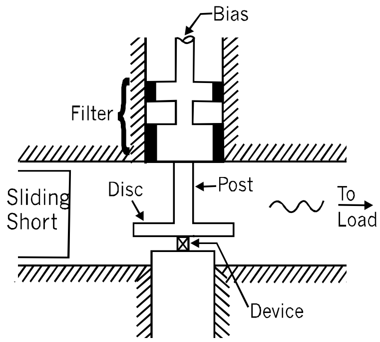

Figure 1. Cross-sectional view of the IMPATT oscillator.

by the diode is coupled to the main rectangular waveguide cavity through the vertical open edges of the radial cavity. The resonant cap can be approximated as a radial transmission line which acts like an impedance transformer between the device and the load. Experimental studies of the tuning characteristics of resonant-cap oscillators have been carried out by using silicon Ka-band SDR IMPATT diodes having the following specifications:

Frequency range (f) = 35 - 42 GHz

Breakdown voltage [$(V_B)_{Max}$] = 45 V

Maximum current (I_{Max}) = 150 mA

Power output (P_{Max}) = 100 mW

An indigenously developed Ka-band IMPATT oscillator and a typical spectrum achieved at Ka-band are shown in the Figs 2 and 3, respectively.

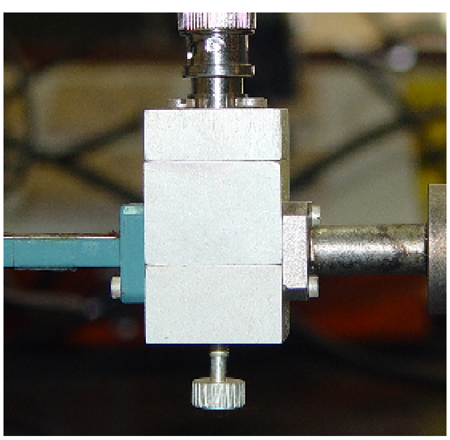

Figure 2. Hardware of Ka-band IMPATT oscillator.

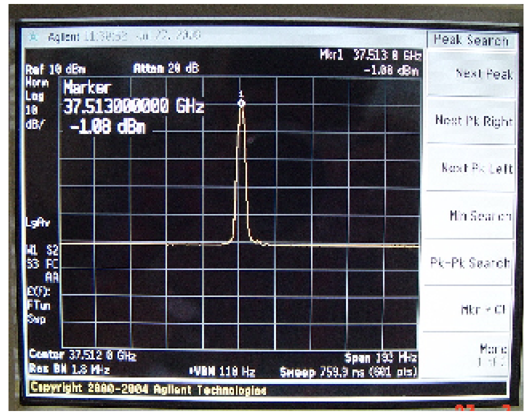

Figure 3. Typical spectrum achieved at Ka-band.

3. MECHANICAL TUNING

Mechanical tuning of a resonant-cap IMPATT oscillator can be achieved by means of cavity tuning and by varying the sliding short positions. The cap dia and cap height have been varied for tuning the cavity. The dependence of the oscillation frequency and output power on the cap dia and cap height has been investigated and the results have been shown in Tables 1 and 2 and in Figs 4 and 5. The

Table 1. Variation of cap diameter

Cap diameter (D= $\frac{ë}{2} \pm x$) (mm)	Output power (mW)	Frequency (GHz)
λ/2 - 0.6	46.34	37.70
λ/2 - 0.4	66.78	37.44
λ/2 - 0.2	81.85	37.07
λ/2 = 4.0	89.41	36.80
λ/2 + 0.2	83.74	36.40
λ/2 + 0.3	76.45	36.24
λ/2 + 0.5	58.74	36.00

Table 2. Variation of cap height

Cap height (mm)	Output power (mW)	Frequency (GHz)
1.0	52.84	35.84
1.2	67.57	36.18
1.4	82.02	36.53
1.6	88.97	36.86
1.8	85.19	37.18
2.0	72.56	37.14

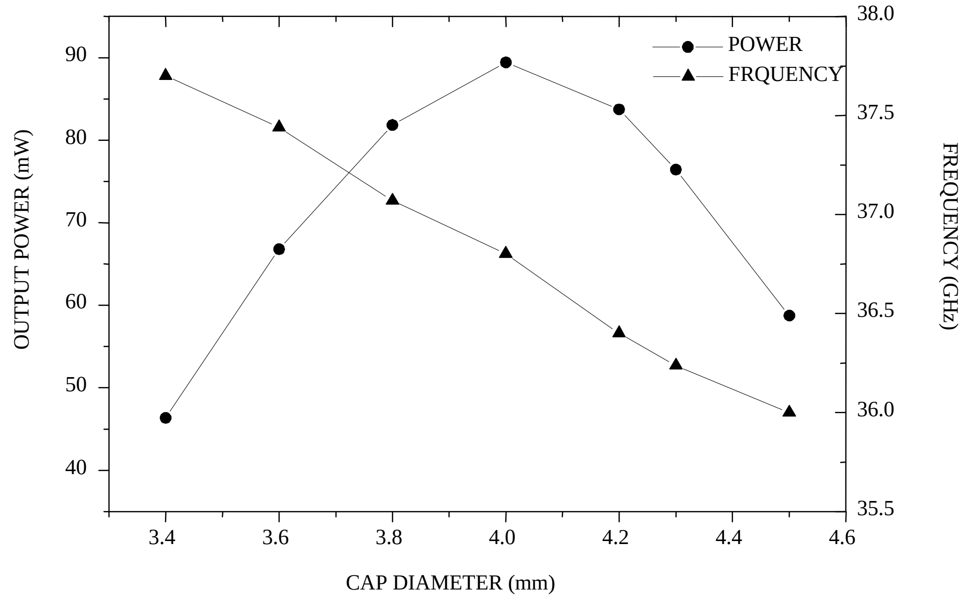

Figure 4. Variation of output power and frequency with cap diameter.

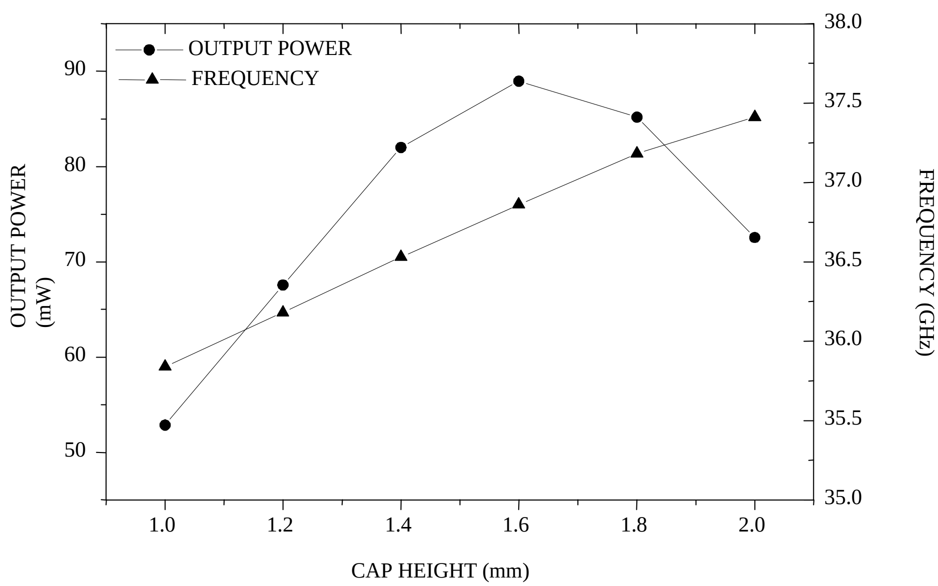

Figure 5. Variation of output power and frequency with cap height.

cap dia has been varied from 3.4 mm to 4.5 mm and correspondingly height from 1 mm to 2 mm to optimise the oscillator.

It was observed that output power attained a maximum of 90 mW from 46 mW and again it decreased to 60 mW level with diameter variation from 3.4 to 4.5 mm and correspondingly frequency was found to vary from 36.0 GHz to 37.75 GHz. For height variation from 1 mm to 2 mm in steps of 0.2 mm, it was observed that power level increased from 52 mW and attained a maximum of 88 mW with a height of 1.6 mm and again it decreased to a power level of 72 mW at 2 mm and correspondingly frequency changed from 36.0 GHz to 37.5 GHz. All the studies have been carried out at the current level of 145 mA with breakdown voltage of 30.5 V.

It was observed that the oscillation frequency decreased with increase of the cap dia and reverse happened for cap height variation. The rate of decrease of oscillation frequency with increasing cap dia for a Ka-band IMPATT oscillator was found to be 1.5 GHz/mm. For increasing cap height the oscillation frequency increases at the rate of approx. 1.57 GHz/mm. It was further observed that maximum output power at desired frequency of 36.5 GHz was obtained with the cap dia range from 3.8 mm – 4.2 mm corresponding to height of 1.4 mm – 1.8 mm range. More precisely, cap dia and cap height combination of 4.0 mm and 1.6 mm, respectively, resulted in maximum output power of 90 mW at desired frequency of 36.5 GHz. Thus the output power of a resonant-cap IMPATT oscillator was found to pass through a maximum at a particular frequency for a given diode with an optimum combination of cap dia and cap height.

The experimental results of optimised condition of oscillator obtained can be approximated by the relation:

$$D = \frac{\lambda}{2} \tag{1}$$

where λ is the operating wavelength and D is the cap dia. Thus, for developing a resonant-cap IMPATT oscillator, the dia of the cap may be taken half of the wavelength of desired frequency of the oscillator for optimum operation.

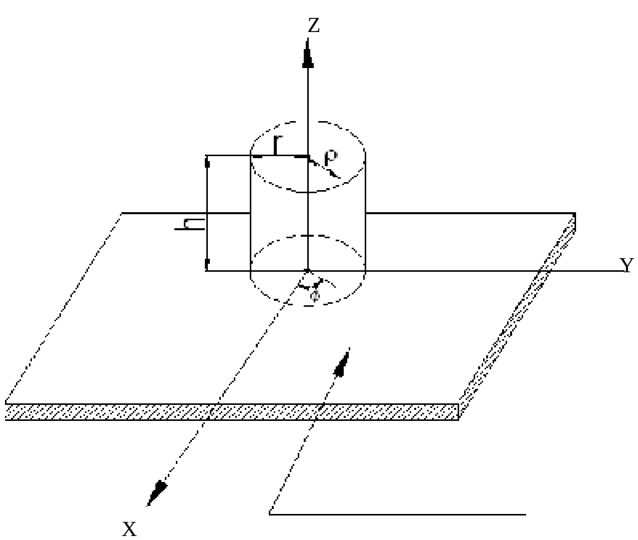

Figure 6. Schematic diagram showing the resonant-cap cavity formed between the disc of the resonant-cap structure and the lower broad face of the waveguide.

The experimental results obtained can be explained by considering the electromagnetic fields within the resonant-cap cavity. The resonant-cap cavity is formed between the disc of the resonant-cap structure and the lower broad face of the waveguide as shown in Fig. 6. Such a cavity can be approximately modelled as a cylindrical cavity, bounded at its top and bottom by electric walls and on its sides by a magnetic wall[9-11]. The electric field within the resonant-cap cavity has essentially only a z-component, and the magnetic field has essentially x- and y-components. Because $h << \lambda_g$ (guided-wavelength), the fields do not vary along the z direction, and the component of the current normal to the edge of the cap approaches zero at the edge. This implies that the tangential component of the magnetic field at the edge is vanishingly small.

With these assumptions, the resonant-cap can be modelled as a cylindrical cavity, bounded at its top and bottom by electric walls and on its sides by a magnetic wall. Thus the fields within the resonant-cap cavity, corresponding to TM_{nm} modes, may be determined by solving a cavity problem. The fields corresponding to TM_{nm} modes within the cavity are given by[10]

$$E_z = E_0 J_n(k\rho) Cos(n\phi) \tag{2}$$

$$H_\rho = -\frac{j\omega\varepsilon n}{k^2\rho} E_0 J_n(k\rho) Sin(n\phi) \tag{3}$$

$$H_\phi = -\frac{j\omega\varepsilon}{k} E_0 J_n'(k\rho) Cos(n\phi) \tag{4}$$

where, K is the propagation constant, J_n is the Bessel function of the first kind and order n.

The open circuited edge condition requires that $J_n'(kr) = 0$, where r is the radius of the disk and the prime indicates differentiation wrt the argument. Thus for each mode of configuration, a radius may be found that will result in resonance corresponding to zeros of the derivative of the Bessel function. For any given frequency, the dominant mode has $n = m = 1$ and it corresponds to the minimum radius of the disc for resonance. The root of $J_n'(kr) = 0$ for dominant mode is kr = 1.841, but $k = 2\pi/\lambda$ and $2r$ = D.

Diameter of the disc is given by

$$\frac{D}{\lambda} = 0.58 \qquad (5)$$

The theoretical relation[3] shows that the operating wavelength λ and the disc dia D of the resonant-cap are directly proportional and the constant of proportionality is 0.58. The empirical relation [Eqn (1)] derived[4] from our experiments has similar form as the theoretical relation [Eqn (5)] and is found to be a close approximation to relations derived by Misawa and Kenyon[2]; Qwartz[5], *et al*.; and Cachier[12], *et al*.

4. TUNING BY SLIDING SHORT

The dependence of the oscillation frequency and output power on the sliding tuning short position has been studied and the results have been shown in Table 3 and Fig. 7. Sliding tuning short position has been varied from 0 mm to 9.7 mm in steps of 0.5 mm and it has been noticed that power level varied from 0 mW to 88 mW and frequency varied from 34.50 GHz to 37.75 GHz. It has been observed that the mechanical tuning is characterised by an initial frequency jump and a sharp fall and then a subsequent rise of output power with change of the position of the sliding short. A smooth mechanical

Table 3. Tuning short position from diode plane

Position of tuning short x_2 (mm)	Output power (mW)	Frequency (GHz)
0.0	80.87	37.71
0.5	63.28	36.38
1.0	50.50	36.20
1.5	47.14	35.20
2.0	37.82	35.18
2.5	22.66	34.83
3.0	6.31	34.60
3.5	67.37	37.73
4.0	67.81	37.43
4.4	80.48	37.08
4.7	86.63	36.90
5.0	84.78	36.71
5.5	70.57	36.44
6.0	55.87	36.14
6.5	51.48	35.82
7.0	46.11	35.47
7.5	33.84	35.10
8.0	20.60	34.82
8.5	6.70	34.61
8.75	1.01	34.58
9.0	67.59	37.37
9.5	74.02	37.20
9.7	81.22	36.90

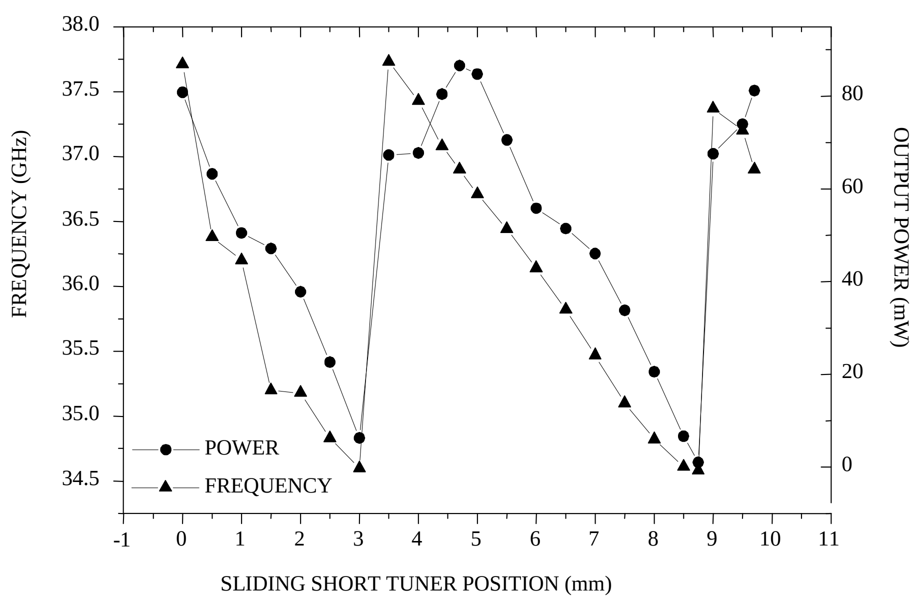

Figure 7. Variation of frequency and output power with sliding short tuner position.

tuning range of 3.15 GHz with centre frequency at 36 GHz has been obtained for a change of sliding short position over a range of $\lambda/2$. It has been further observed that frequency jumped approximately 3 GHz and sudden power gain of 70 mW occurred nearly at $\lambda/2$ and λ distance between the sliding short position and the diode plane. This experimental observation was found to agree well with the studies of Musawa and Kenyon[2], and Kenyon[4].

5. CONCLUSIONS

In this paper, three different methods of mechanical tuning of waveguide-mounted resonant-cap Ka-band IMPATT oscillator have been brought out. A wide tunable range of 3.15 GHz has been achieved by sliding short and 1.75 GHz and 1.5 GHz by varying cap dia and cap height around the centre frequency 36 GHz of Ka-band. For design and development of mm wave (Ka-band) IMPATT oscillator using resonant-cap waveguide structure, cap dia and cap height have a very crucial role in deciding the output power as well as frequency.

The authors have found an approximate relation between cap dia and wavelength at optimised condition, i.e., $D = \lambda/2$ which is very close to the theoretical relation D/λ = 0.58. The dependency of output power and frequency with the sliding short position has been demonstrated. To achieve optimum condition, the sliding short position has to be tuned very multiples of $\lambda/2$. In this paper, it has been demonstrated that in course of tuning by sliding short, there was sudden frequency jump in certain positions with high power gain. Utmost care has to be taken for tuning the oscillator by sliding short to avoid burn out phenomenon of mm wave IMPATT diode which is very frequent in practical situations.

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