6.1. Introduction

The resonant-cap structures normally used in practice have circular shaped disc or cap which forms a localised resonant cavity around the diode. In the previous two chapters we have presented studies of the effect of variation of the size of the normal resonant-cap cavity on the performance of IMPATT diode oscillators and amplifiers. It has been found by the author that certain modifications of the geometry of the resonant-cap cavity can lead to significant improvement of the performance of IMPATT oscillators and the same will be described in this chapter. The modification consists of incorporation of circumferential slots on the disc of the resonant-cap. The presence of appropriately sized slots on the circumference of the disc causes considerable increase of the power output and electronic tunability of the oscillator over those available from the same device oscillating in normal resonant-cap cavity.

We have seen in chapter IV that both the cap-diameter and the cap-height have significant effects on the frequency and power output of IMPATT oscillators. Thus it appeared to us that some modification in the geometry (either in cap-diameter or cap-height or in both) of the resonant-cap cavity may be
introduced to bring about meaningful effect on the oscillator performance characteristics. Further, it was found by Lee and Standley\textsuperscript{86} that tunability of IMPATT oscillator may be improved by providing more than one resonant circuit for the oscillator. It was also found by Swan\textsuperscript{128} that improvements in both the power output and the tunability can be obtained by providing an idler resonance at twice the transit-time frequency. We have introduced appropriate geometrical modifications on the shape of the resonant-cap by incorporating very narrow circumferential slots on the disc of the resonant-cap structure thereby providing two resonant circuits for the oscillator which resulted in considerable improvement of oscillator performance.

In this chapter extensive experimental investigations on IMPATT oscillator performance with various geometries of the modified cap cavities have been presented. The variations in the geometry of the modified cap cavity were brought about by varying the number and also the dimensions of the circumferential slots. The oscillator performance for various modified cap cavities have been studied in terms of the microwave power output and the electronic tunability. An optimum geometry of the modified cap cavity was obtained from the experimental studies which leads to maximum increase of the power output and electronic tunability. A qualitative understanding of the results in the light of the device-circuit interaction has also been included in this chapter.
6.2. Experimental Studies, Results and Discussion

Experimental investigations were carried out to study the performance of IMPATT oscillators with the device embedded in resonant-cap cavities having various geometric modifications. The IMPATT diodes used in these investigations were the same type silicon SDR diodes (Type No : HP 5082-0432). The experimental arrangement and the techniques of measurement for studying the oscillator performance are similar to that discussed in section 4.2.

The studies on the effect of modification of cap geometry on the properties of resonant-cap IMPATT oscillators have been carried out with a view to improve the oscillator performance. As seen from the Fig. 6.1 the modification consists of the incorporation of circumferential slots on the disc of the resonant-cap. Various geometries of this type of modified cap have been designed by varying the number and the dimensions of the slots (as shown in Fig. 6.1). It was observed that circumferential slots of proper dimensions four in number and placed in quadrature on the disc of the resonant-cap structure gives maximum improvement of electronic tunability and microwave power output.

Experimental results showing the oscillator performance for modified resonant-cap cavities having four slots of narrow cut on the circumference (fixed at 32 mils each) and having different lengths of cuts in the radial direction of the disc
Fig. 6.1. Modified resonant-cap of various geometries (plan view) realised by varying the number and dimensions of the slots.
have been presented in Figs. 6.2 to 6.6. In all these cases the cap-diameter (D) and the cap-height (h) are kept same as that for the optimized normal cap oscillator using the same device. It is found that a cut of approximately 7.5% (i.e. 16 mils for cap radius of 225 mils) in the radial direction produces an electronic tuning bandwidth which is almost double that of a corresponding oscillator with normal resonant-cap. The maximum power output of the modified cap oscillator improves from 120 mW to 140 mW (i.e. approximately 18% improvement) while the operating frequency of the oscillator increases to 9.621 GHz from 9.588 GHz. It is also observed that the microwave oscillation starts at a lower value of d.c. bias current (in this instance: 17 mA) for a modified cap oscillator compared to the corresponding normal resonant-cap oscillator. Further, the d.c. bias current that may be allowed to flow through the diode while remaining in the safe region of the oscillator operation (as discussed in section 4.3) is almost 50% more than that of the normal resonant-cap oscillator (i.e. 65 mA compared to 45 mA in the normal case). By increasing the cut in the radial direction from 7.5% to approximately 15% (i.e. 32 mils for cap radius of 225 mils) further improvement of oscillator performance have been observed as shown in Fig. 6.3. It may be seen that the electronic tuning bandwidth improves further, but at a slower rate, and becomes approximately 2.5 times the bandwidth of the normal cap oscillator. The power output also improved by 50% (180 mW compared to 120 mW in the case of normal
Fig. 6.2. Electronic tuning characteristic of IMPATT oscillator using modified resonant-cap with circumferential slots on the cap having the length of cut in radial direction \( r \approx 16 \text{ mils} \) and with a fixed cut on the circumference \( c = 32 \text{ mils} \).
Modified Resonant-cap:
- \( D = 450 \) mils
- \( h = 100 \) mils
- \( c = 32 \) mils
- \( r = 32 \) mils

Diode type: HP 5082-0432

Fig. 6.3. Electronic tuning characteristic of IMPATT oscillator using modified resonant-cap with circumferential slots on the cap having the length of cut in radial direction \( r = 32 \) mils and with a fixed cut on the circumference \( c = 32 \) mils.
Fig. 6.4. Electronic tuning characteristic of IMPATT oscillator using modified resonant-cap with circumferential slots on the cap having the length of cut in radial direction \( r = 64 \text{ mils} \) and with a fixed cut on the circumference \( (c = 32 \text{ mils}) \).
Fig. 6.5. Electronic tuning characteristic of IMPATT oscillator using modified resonant-cap with circumferential slots on the cap having the length of cut in radial direction $r = 80$ mils and with a fixed cut on the circumference ($c = 32$ mils).
Fig. 6.6. Electronic tuning characteristic of IMPATT oscillator using modified resonant-cap with circumferential slots on the cap having the length of cut in radial direction $r = 100$ mils and with a fixed cut on the circumference ($c = 32$ mils).
cap oscillator) while the operating frequency shifts further upwards to $9.653$ GHz. Best performance for the modified resonant-cap oscillator has been obtained with a radial cut of nearly 30% (i.e. 64 mils for cap radius of 225 mils) as shown in Fig. 6.4. It may be observed that the electronic tuning bandwidth of this optimally modified cap oscillator is almost 4 times that of the normal resonant-cap oscillator (i.e. 96 MHz compared to 25 MHz in the normal case). Also the power output is nearly doubled compared to the normal case (i.e. 210 mW compared to 120 mW in the case of normal cap oscillator) and the operating frequency is increased further upwards to $9.716$ GHz. The threshold current for microwave oscillation for this modified cap oscillator is 14 mA and the highest safe limit of d.c. bias current that may be allowed to flow through the diode is nearly 70% more than that in the case of a normal cap oscillator (i.e. 80 mA in the optimally modified cap oscillator compared to 45 mA for normal cap oscillator). With further increase of the length of the cut of the slots in the radial direction of the disc the power output and the electronic tunability of the modified cap oscillator deteriorates and the results are shown in Figs. 6.5 and 6.6 for 80 mils and 100 mils length slots. But the frequency of oscillation shifts upward with increasing length of cut while the threshold current for oscillation decreases. The power output of the oscillator saturates at a lower value of d.c. bias current than that in the case of a normal cap oscillator. Further, the electronic
tunability of the modified cap oscillator for larger cuts (i.e. 80 mils and 100 mils) does not show any significant improvement over that of the corresponding normal resonant-cap oscillator.

The output spectrum of the optimally modified cap IMPATT oscillator was investigated by using Tektronix 492 spectrum analyzer and the photographs of the same have been shown in plate 5. The three photographs of the output spectrum have been taken corresponding to three different settings of the d.c. bias current to the diode. The photograph in the middle (i.e. Ph.5 I) shows the output spectrum of the oscillator corresponding to a bias current of 60 mA. The photograph on the top (i.e. Ph.5 II) and that at the bottom (i.e. Ph.5 III) shows the output spectrum corresponding to bias current settings of 40 mA and 78 mA respectively. The output spectrum of the optimally modified resonant-cap IMPATT oscillator for various bias current to the diode thus clearly shows an electronically tunable (i.e. bias current tuned) bandwidth of nearly 95 MHz centered at 9.711 GHz. A comparison of the spectrums shown in plates 4 and 5 indicates a nearly 4 fold improvement of electronic tuning bandwidth of the optimally modified cap IMPATT oscillator when compared with the corresponding normal cap oscillator.

A full quantitative theoretical understanding of the phenomena associated with the modified resonant-cap IMPATT oscillator which have been experimentally studied will be extremely involved. It requires a large-signal analysis of the
PLATE 1

Photograph of the IMPATT oscillator/amplifier mount.
Photograph showing the experimental arrangement used for studying the properties of IMPATT oscillator.
PLATE 4
Photograph showing the experimental arrangement used for studying the properties of IMPATT amplifier.
Photographs of the output spectrum of IMPATT oscillator fitted with normal resonant-cap of optimum size for the diode.
Photographs of the output spectrum of IMPATT oscillator fitted with modified resonant-cap of optimum size for the diode.

Ph. 5 I
\( I_{dc} = 40 \, mA \)

Ph. 5 II
\( I_{dc} = 60 \, mA \)

Ph. 5 III
\( I_{dc} = 78 \, mA \)
system including the device as well as the microwave circuit represented by the modified resonant-cap. However, a simple qualitative understanding of the important properties of the modified resonant-cap IMPATT oscillator may be obtained as follows.

The incorporation of circumferential slots on the disc of the resonant-cap structure in effect leads to two values for the radius of the cap as seen by the device. This is because the microwave source (i.e. the device) is placed along the axis of the resonant-cap cavity and the microwave energy within the cavity moves radially outward (since the resonant-cap cavity can be approximated as a radial transmission line: vide section 4.3). Thus the source would effectively see two different values for the radius of the cap, one corresponding to the rim of the cap and the other corresponding to the inner circumferential line sections produced by the slots. Since the slots are very narrow in circumferential direction we can consider the circumference and also the radius corresponding to the outer circle of the modified cap practically equal to that of the unslotted disc of the normal cap. In the experimentally studied X-band normal resonant-cap oscillator this frequency of oscillation was 9.588 GHz (vide section 4.3). But the inner radius is effective only over the narrow regions of the inner circumferential line sections corresponding to the slots of the modified resonant-cap. The frequency due to an inner radius corresponding to these inner circumferential line sections may be calculated in terms
of the inner radius $R_i$, the number of slots $n$, the length of cut in the circumferential direction $c$, the length of cut in the radial direction $r$ and the rate of change of frequency with radius $\frac{df}{dR}$ (please see Fig. A of appendix I). For the optimally modified cap which produced the best results (Fig. 6.4) the frequency corresponding to the inner circle (which is effective only at the inner circumferential line sections corresponding to the slots of the modified cap) is found to be $9.928$ GHz (where $R_i = 161$ mils, $n = 4$, $c = 32$ mils, $r = 64$ mils and $\frac{df}{dR} \approx 42$ MHz/mil).

As will be seen in the next chapter dealing with modified resonant-cap IMPATT amplifiers the system has indeed two resonant frequencies: a lower resonant frequency ($f_{\text{out}}$) determined by the outer radius (corresponding to the rim of the cap) and an upper resonant frequency ($f_{\text{in}}$) determined in terms of the inner radius produced by the slots. These resonant frequencies have been experimentally found in the gain-frequency characteristics of the modified cap amplifier (vide Figs. 7.1 - 7.5) where the diode embedded in the cavity is excited by an external microwave source. In the oscillator mode the system however oscillates at a single frequency which may be taken as the average of the two resonant frequencies of the system. The operating frequency ($f_{\text{op}}$) of the modified cap IMPATT oscillator may thus be obtained as:

$$f_{\text{op}} = \frac{f_{\text{out}} + f_{\text{in}}}{2}.$$  

For the optimally modified X-band IMPATT oscillator (vide Fig. 6.4) the frequency of oscillation should accordingly be:

$$f_{\text{op}} = \frac{9.588 + 9.928}{2} = 9.758 \text{ GHz}.$$
This empirically calculated result agrees fairly well with the experimental results of \( f_{op} = 9.716 \text{ GHz (from graph)} \) and 9.711 GHz (from spectrum). Similar calculations carried out for other modified caps also showed fairly good agreement between the theoretically calculated and the experimentally measured results.

It was observed experimentally that the modified resonant-cap IMPATT oscillator has a much wider electronic tuning bandwidth than that of the normal cap oscillator. The reason for this may be understood qualitatively in the light of the device-circuit interaction. The IMPATT diode is basically a broadband device but the microwave circuit corresponding to a normal resonant-cap has a narrow bandwidth. Thus the device-circuit interaction results in a narrow-band oscillator performance for the IMPATT diode embedded in a normal resonant-cap cavity. But in case of the modified resonant-cap oscillator the circuit conductance matches the device negative conductance over a wide frequency range because of the broadband nature of the double-resonant circuit corresponding to the modified cap. Also the microwave power delivered by an IMPATT diode (having a characteristic broadband negative conductance) to the modified cap circuit is therefore appreciably larger than the power delivered by the same broadband IMPATT diode to a narrow-band circuit corresponding to a normal unslotted resonant-cap.
Further, it was noted that the efficiency remaining almost same as that of the normal cap oscillator the microwave power output of the modified resonant-cap oscillator increases substantially. The higher r.f. power output at the same efficiency is possible only if the modified cap oscillator draws more input power from the bias supply. In our experimental studies we have found that the increased r.f. power output of the modified cap oscillator is actually accompanied by a proportionately increased flow of d.c. bias current. It has also been found that the increased r.f. output power at the cost of larger input bias current is accompanied by an extension of the highest safe limit of d.c. bias current which can flow through the diode and this is seen from a comparison of Fig. 4.3 for normal resonant-cap with Figs. 6.2 - 6.4 corresponding to modified resonant caps.

6.3. Conclusion

Experimental investigations on the performance of IMPATT oscillators with the device mounted in modified resonant-cap cavities have been carried out. The modified cap cavity has been realised through incorporation of circumferential slots on the disc of the resonant-cap structure. It has been found that a significant improvement of the microwave power output and the electronic tunability of the IMPATT oscillator can be realised with appropriately sized slots on the disc of the resonant-cap.
A microwave power output of $\sim 210$ mW at 9.71 GHz and electronic tuning bandwidth of $\sim 100$ MHz has been obtained with the IMPATT diode embedded in an optimally designed modified cap cavity. The same IMPATT diode produced only 120 mW of microwave power at 9.588 GHz and electronic tuning over only 25 MHz when the device was mounted in normal resonant-cap cavity under optimum condition. A semiquantitative understanding of the observed properties of the modified resonant-cap oscillator has been obtained in terms of the two values of the radius of the cap as seen by the active device situated at the centre of the cavity. The theoretically calculated values of oscillation frequency shows good agreement with experimentally measured values. The modified resonant-cap IMPATT oscillator reported in this chapter is thus expected to be a powerful source of microwave energy with wide electronically tunable bandwidth and may be useful for communication and radar systems.