CHAPTER 3

POST-COUPLED GUNN OSCILLATORS FOR 33-50 GHz BAND

3.1 Introduction

As pointed out in Chapter 1, the 33-50 GHz frequency band is a low-absorption atmospheric window region for ground based radio astronomical observations. The rotational lines of several astrophysically important molecules e.g. methyl alcohol (CH_3OH-36.169 GHz), silicon monoxide (SiO-43.122 GHz), carbon monosulphide (CS-48.991 GHz) lie in this frequency range. Low-noise receivers built for spectroscopy of these molecules are of superheterodyne design generally employing a klystron local oscillator source. The klystron, although having good noise performance, has a very limited operating life. Moreover, it requires an expensive and bulky high voltage regulated power supply. The need for a reliable solid-state alternative to the klystron local oscillator has been felt for a long time. With the commercial availability of millimetre-wave GaAs Gunn diodes (Kramer, 1976), solid-state local oscillator sources for low-noise receivers can now be realized. These Gunn diodes are capable of yielding tens of milliwatts of CW power and have shown excellent noise characteristics at millimetre wavelengths.

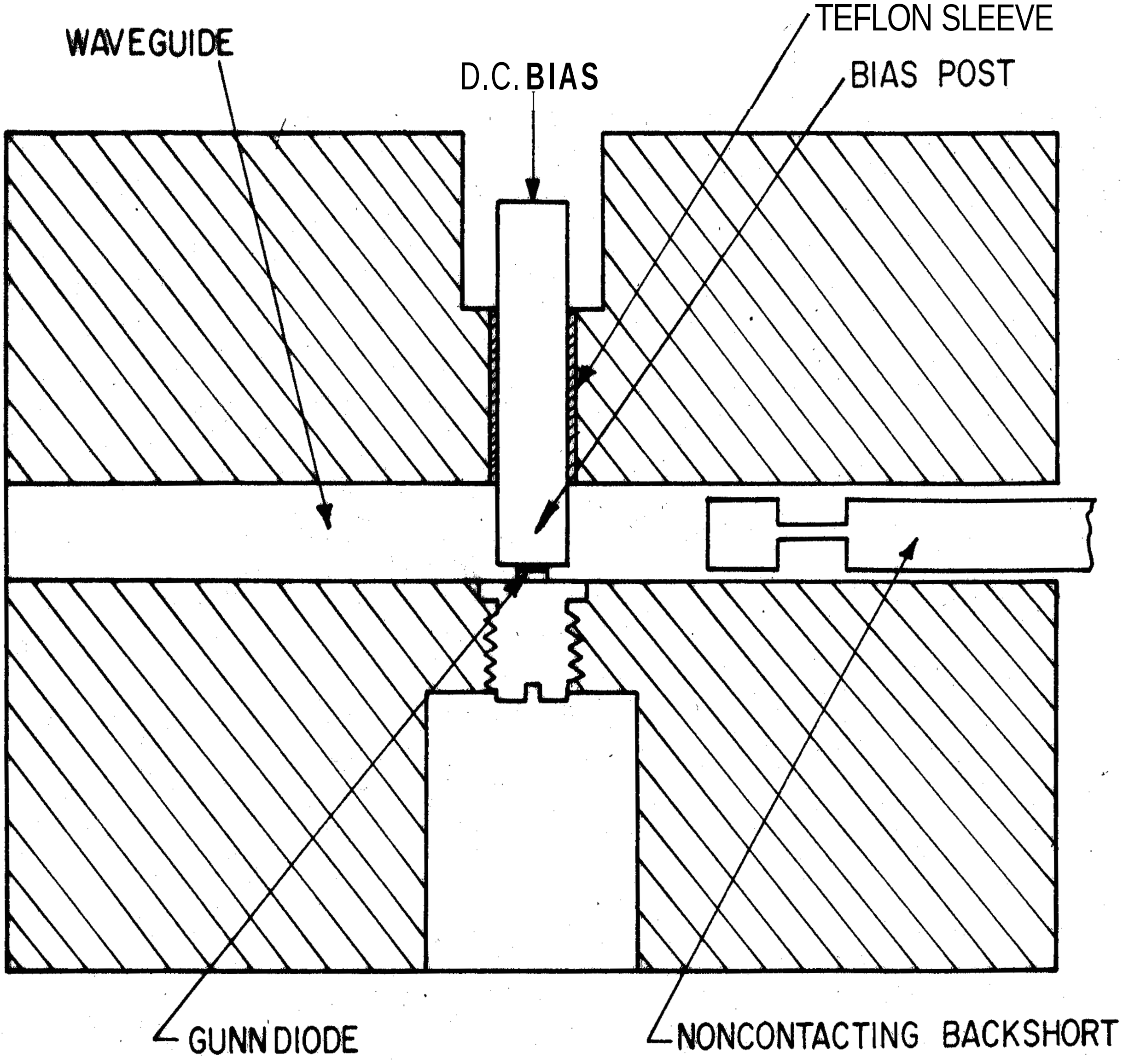
Gunn oscillators for the 33-50 GHz frequency band have been realized in the past in a number of different oscillator circuit configurations (Ruttan, 1974; Ondria, 1981). A waveguide Gunn oscillator circuit which has found widespread application due to its constructional simplicity and good performance is the post-coupled oscillator. In this design, the Gunn diode is mounted in a section of a waveguide and the power is coupled to the load by means of a metal-post which contacts the diode spanning the waveguide. A movable backshort is also provided in the waveguide for oscillator tuning.

Post-coupled Gunn oscillators developed for local oscillator use in low noise millimetre-wave radioastronomy receivers are described in this chapter. The effect of various circuit parameters on the oscillator performance has been investigated experimentally. A new Gunn oscillator design of simpler construction using circular waveguide has been developed. A discussion on the analysis of the observed circuit behaviour of various Gunn oscillators is also included.

3.2 Post-coupled Gunn oscillator in a standard rectangular waveguide

3.2.1 Design and construction

A cross-sectional view of the Gunn oscillator is shown in figure 3.1 and a photograph of the oscillator is given in figure 3.2. This oscillator is constructed in a split-block. The waveguide is formed by milling a rectangular channel of 5.7 x 2.8mm dimension in a brass block and covering it on the top by a flat polished surface of another brass block. The Gunn diode package is threaded into the bottom wall of the waveguide. A metal post passing through a hole on the top block is made to rest on the Gunn diode. The metal post is electrically isolated from the top brass block by a thin teflon



I 3.1 **CROSS-SECTIONAL VIEW OF THE STANDARD RECTANGULAR WAVEGUIDE** GUNN 'OSCILLATOR" FOR THE 33-50 GHz. **FREQUENCY BAND.**

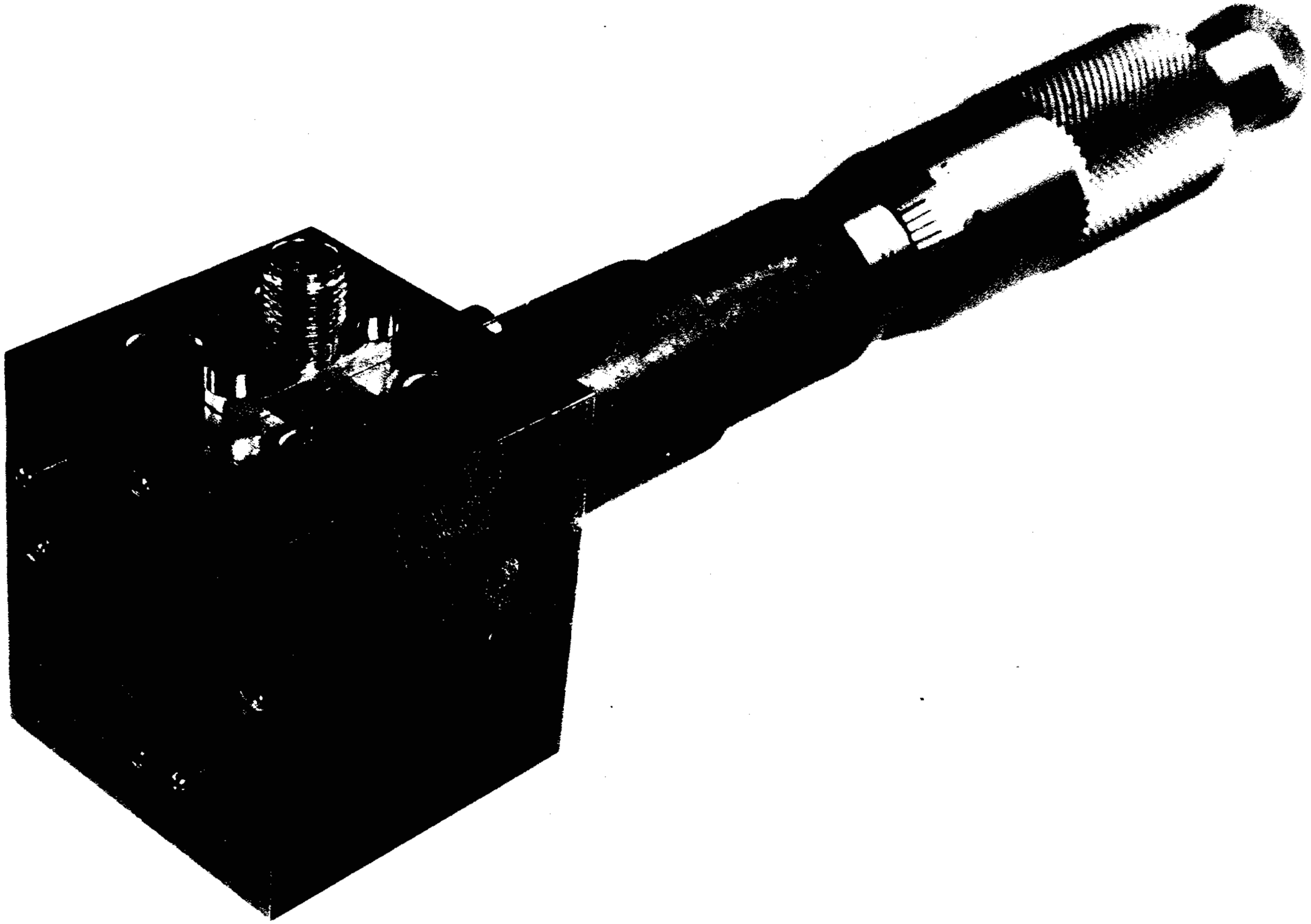


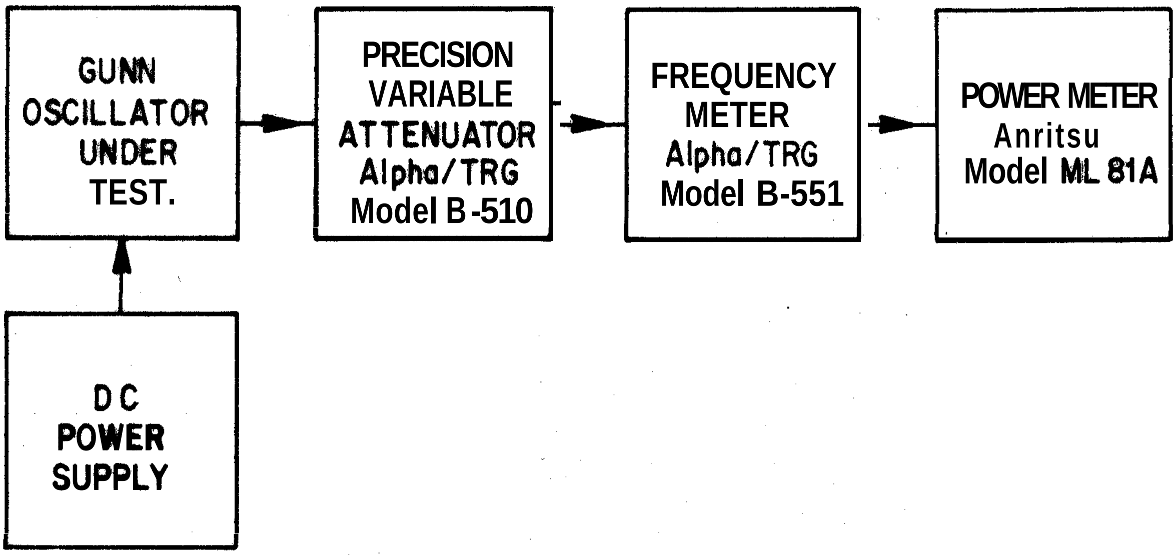
FIG. 3.2 PHOTOGRAPH OF THE RECTANGULAR WAVEGUIDE GUNN OSCILLATOR FOR THE: 33-50 GHz FREQUENCY BAND.

sleeve. D.C bias to the Gunn diode is applied through this metal post which also acts as a co-axial low-pass filter for RF choking. A vernier driven sliding backshort is provided in the waveguide section behind the Gunn diode. The metal post couples the Gunn diode RF energy to the waveguide.

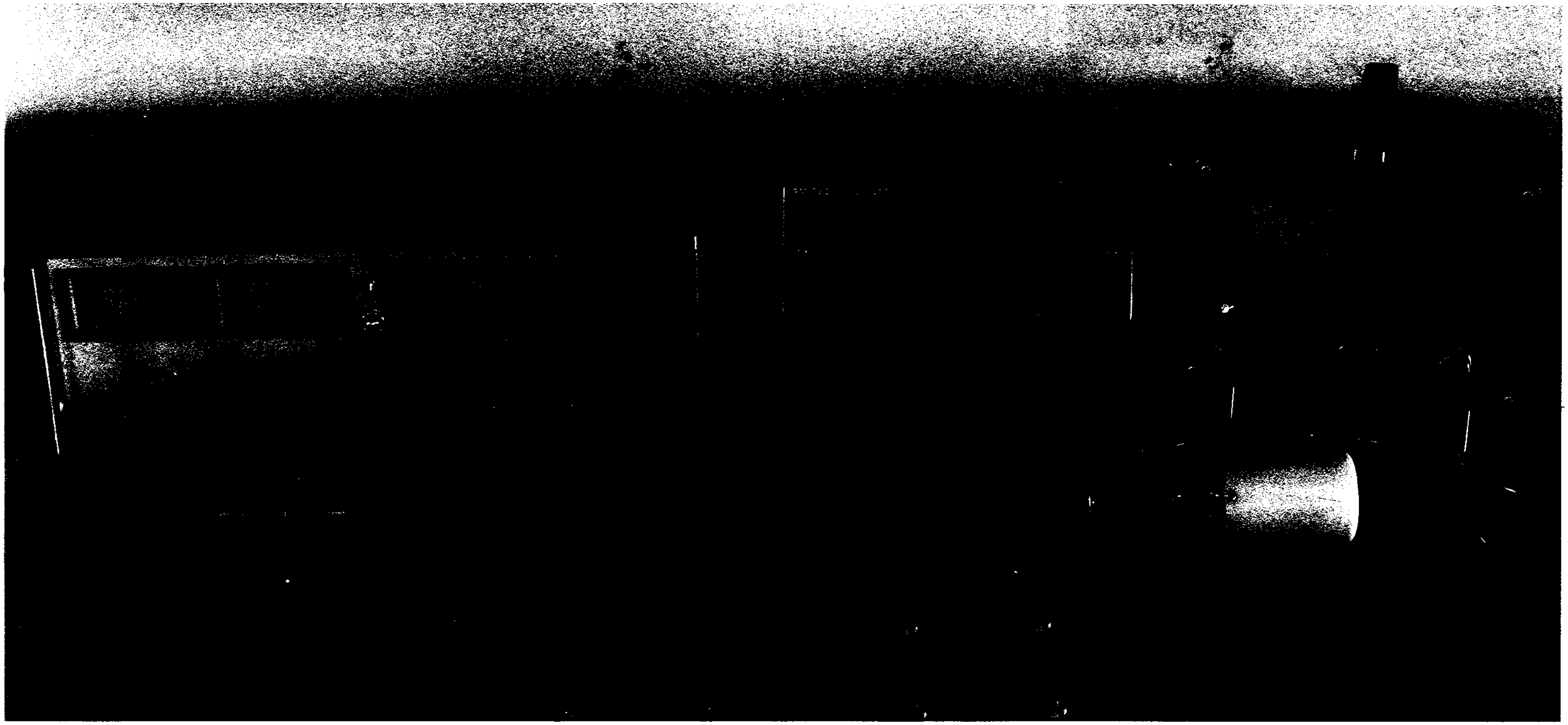
3.2.2 Oscillator performance

Performance of the Gunn oscillator is evaluated in a standard 33-50 GHz rectangular waveguide measuring system. A block diagram of the measurement setup is given in figure 3.3 while a photograph is shown in figure 3.4. It consists of a rotary vane type precision variable attenuator, a waveguide-cavity type frequency meter and a power meter employing a thin film thermocouple as the power sensor. The oscillator is connected directly to the measurement system without any isolator or E-H tuner. The procedure adopted for measurement consists in noting down power output and frequency of the oscillator at various positions of the sliding backshort. This measurement is repeated for several metal posts of different diameters.

A plot of the oscillation frequency versus the backshort position for various post diameters is given in figure 3.5. Theoretical half-wave cavity modes of the waveguide cavity formed between the post and the backshort are also plotted in the same figure for comparison. The oscillation frequency characteristics show two distinct regions - in one, the oscillation frequency is practically independent of the backshort position (frequency saturation effect)



I 3.3 BLOCK DIAGRAM OF THE MEASURING SETUP FOR THE 59-50 GHz FREQUENCY BAND GUNN OSCILLATORS.



FIG, 3.4 PHOTOGRAPH OF THE MEASURING SETUP FOR THE 33-50 GHz FREQUENCY BAND GUNN OSCILLATORS.

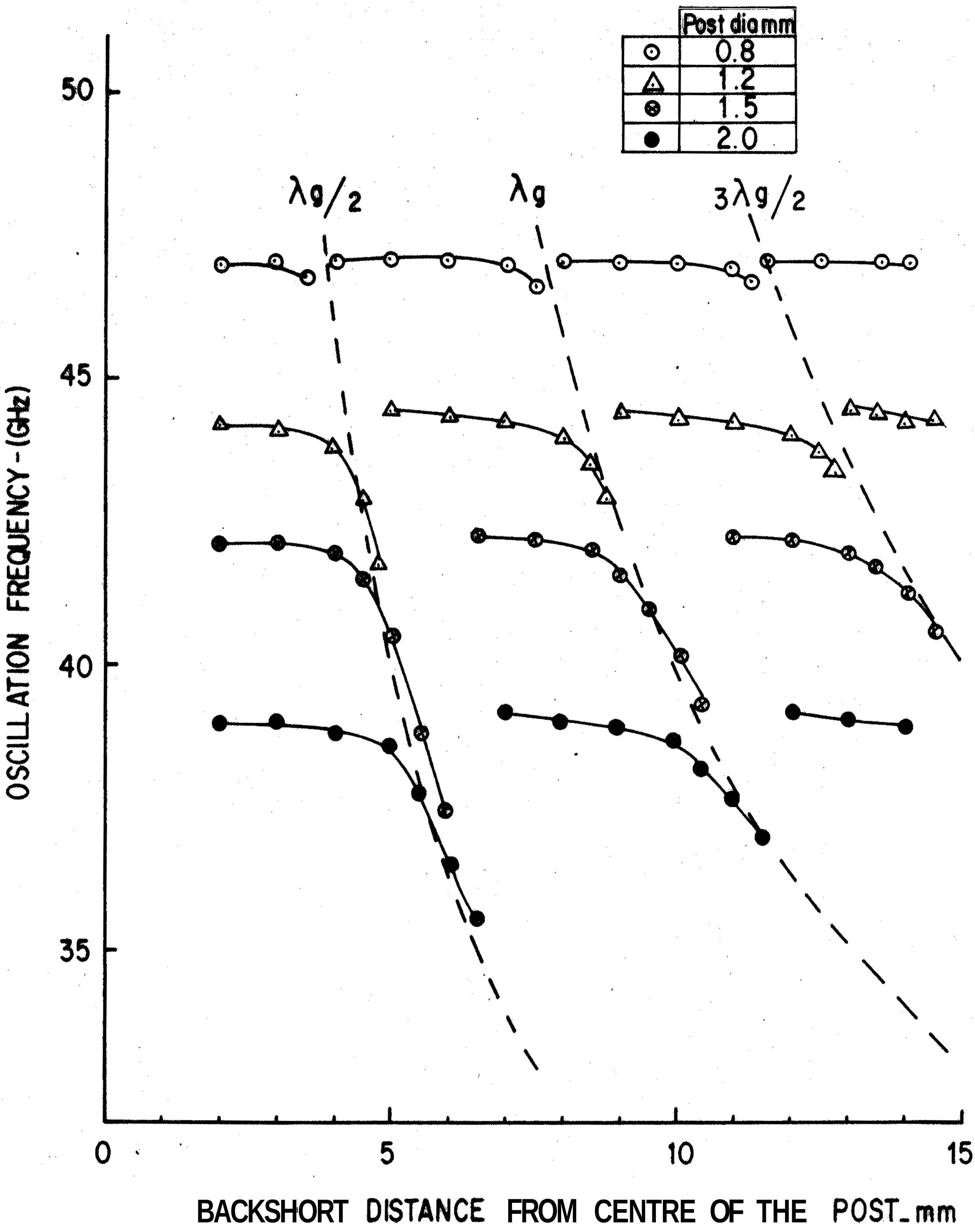


FIG. 3.5 OSCILLATION FREQUENCY vs. BACKSHORT POSITION FOR THE STANDARD RECTANGULAR WAVEGUIDE GUNN OSCILLATOR.

while in the other the frequency variation with backshort position closely corresponds to the half-wave cavity modes. The Gunn oscillator frequency could also be varied by about 100 MHz by changing the d.c. bias voltage from 3.5 to 4.5 volts.

This circuit employing a Varian Gunn diode type VSQ 9219S4, which is specified for 75mW output at 43 GHz, has yielded 100mW of CW power at 33 GHz, 80mW at 43 GHz and about 60mW at 47 GHz. Bias-post diameter has been optimized at each frequency for obtaining these results. Mechanical tuning of these oscillators by varying the position of the backshort, commonly employed at lower microwave frequencies, is limited due to the frequency saturation effect of the bias-post. However, 2-3 GHz mechanical tuning range with the backshort has been obtained, particularly with larger diameter posts.

3.2.3 Effect of the post diameter

It has been found that the post diameter has a major effect on the oscillation frequency and the power output. A number of posts with diameters varying from 0.8mm to 2.0mm were fabricated for a systematic experimental investigation. The oscillation frequency was found to be a well behaved function of the post diameter indicating that the Gunn diode is oscillating in a post-circuit controlled mode. In this mode of operation, the oscillation frequency is practically independent of the backshort position. A plot of the oscillation frequency versus the post diameter for a fixed position of the backshort (backshort distance-2.0mm) is shown in figure 3.6.

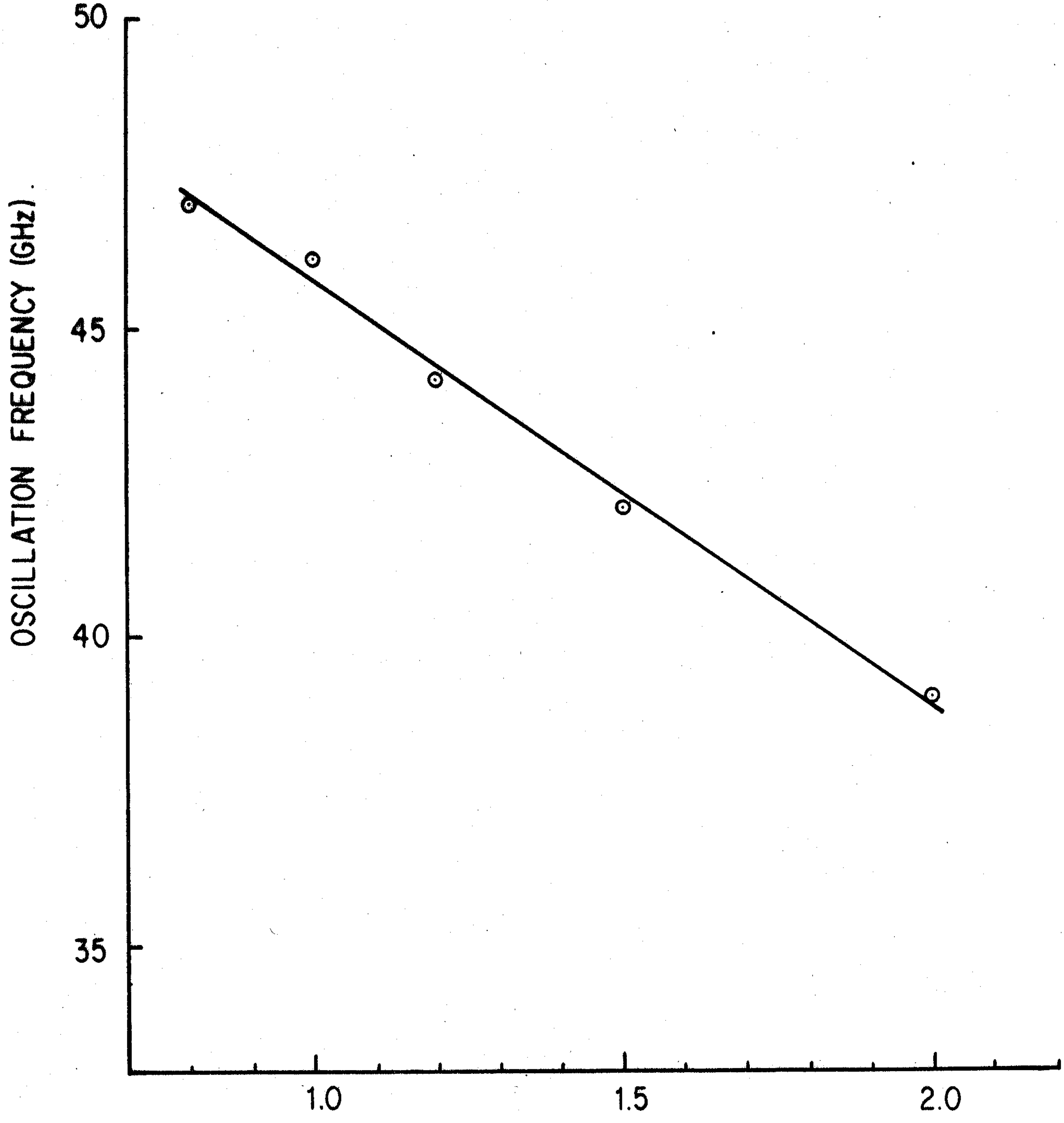


FIG. 3.6 OSCILLATION FREQUENCY vs. POST-DIAMETER FOR THE STANDARD RECTANGULAR WAVEGUIDE GUNN OSCILLATOR FOR A FIXED BACKSHORT POSITION.

The oscillation frequency monotonically decreases with increasing post diameter.

Effect of the post diameter on the RF power output is shown in figure 3.7. The curves of figure 3.7 have been obtained by plotting the output power as a function of frequency for various posts 'as the backshort position is varied. For each post, maximum power is obtained at a specific frequency which decreases as the post diameter is increased.

3.3 Reduced-height waveguide Gunn oscillator

This oscillator circuit was developed to minimize the effect of the bias-post which results in a saturation of the oscillation frequency with backshort tuning as observed in the standard waveguide circuit described above.

3.3.1 Design and construction

In this design shown in figure 3.8, the waveguide height is reduced from the standard 2.8mm to 0.7mm (quarter-height) which is just a little more than the height of the Gunn diode package (0.5mm). This height reduction is carried out by means of a linear taper extending over several guide-wavelengths to achieve broadband impedance match between the reduced height waveguide section and the standard waveguide output. The Gunn diode is mounted in the reduced-height section which also contains a vernier driven sliding backshort. D.C.bias for the Gunn diode is applied in a manner similar to that of the standard waveguide oscillator circuit already described in section 3.2.1.

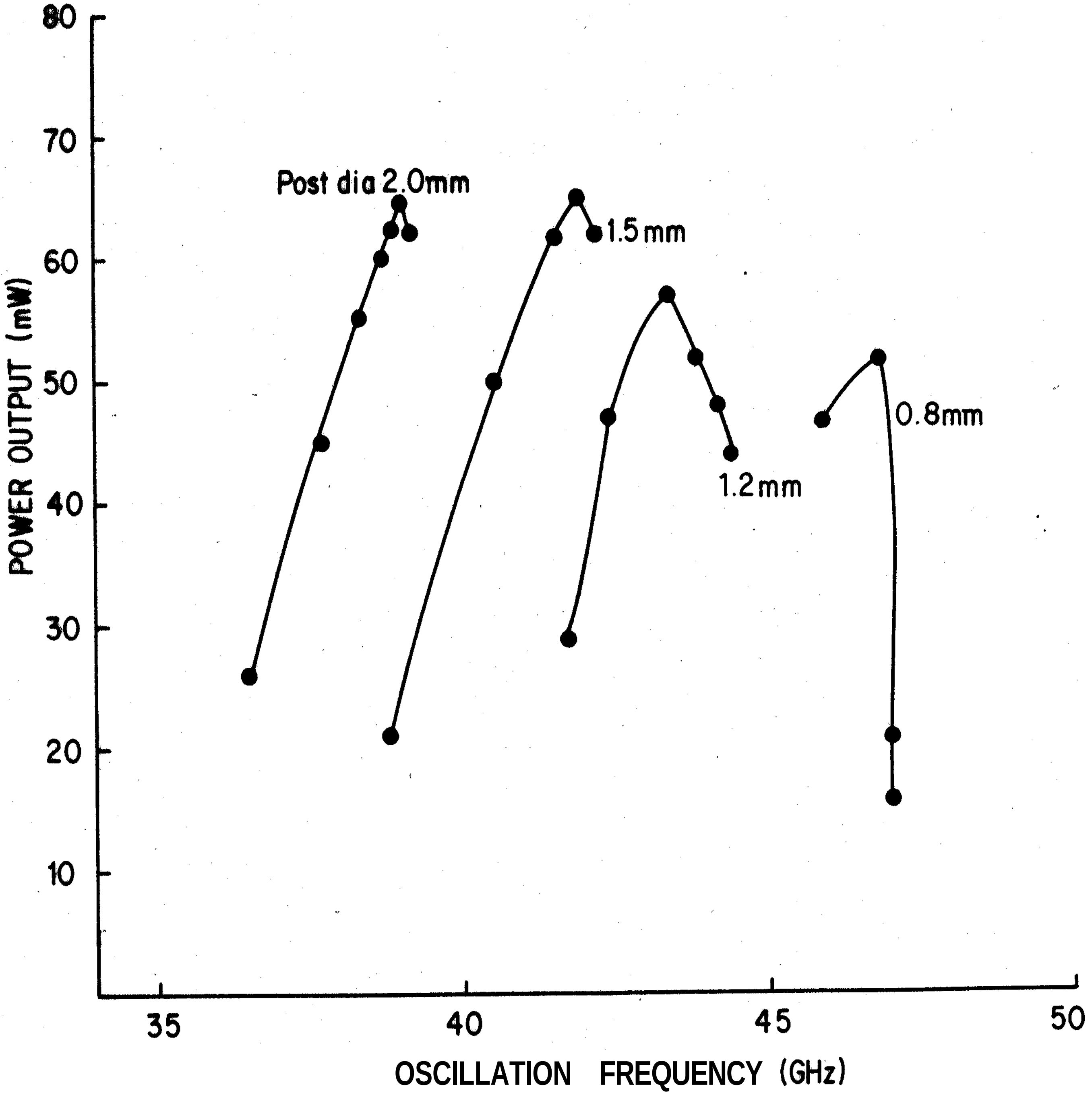


FIG. 3.7 POWER vs. FREQUENCY CHARACTERISTICS OF THE STANDARD RECTANGULAR WAVEGUIDE GUNN OSCILLATOR*

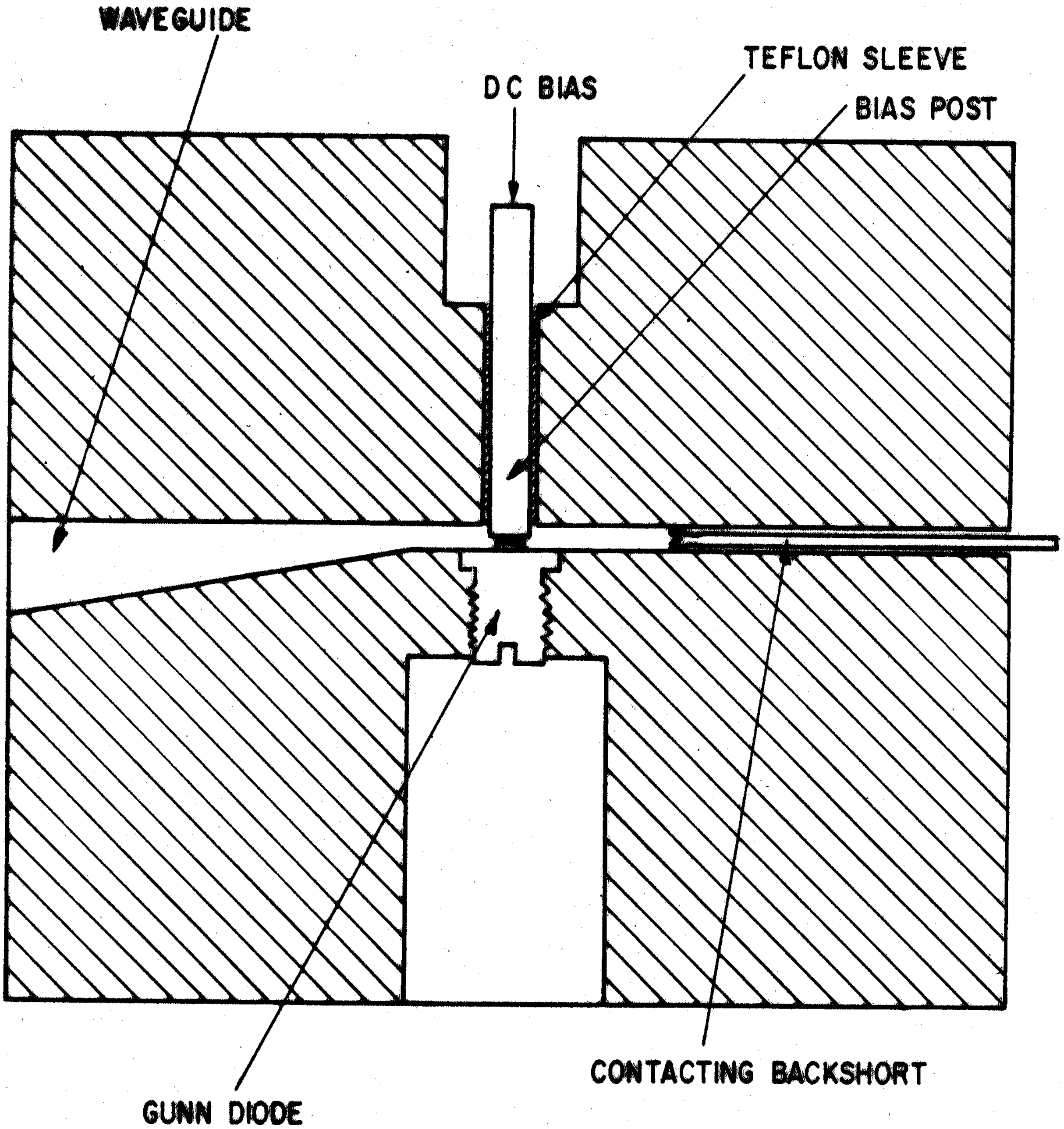


FIG. 3.8 CROSS-SECTIONAL VIEW OF THE REDUCED-HEIGHT WAVEGUIDE GUNN OSCILLATOR FOR THE 33-50 GHz FREQUENCY BAND.

3.3.2 Oscillator performance

Oscillation frequency obtained with the reduced-height waveguide design as a function of the backshort position is plotted in figure 3.9. Waveguide cavity-mode resonances are also plotted in the same figure for comparison. Unlike the previous case, frequency saturation is not observed for this design. The oscillator frequency seems to closely follow the waveguide cavity modes with a characterstic mode-jump point at a backshort distance which is a multiple of approximately one-half the guide wavelength.

Frequency versus power characteristics of this oscillator are shown in figure 3.10. Using the Varian Gunn diode type VSQ9219S4 in this oscillator mount, about 80mW of CW output power was obtained at 41.5 GHz. A mechanical tuning range of about 6 GHz with slightly more than 3dB power variation is observed by varying the position of the backshort. Bias-tuning of about 100 MHz is obtained for this oscillator also by changing the d.c. bias voltage from 3.5 to 4.5V.

3.4 Post-coupled Gunn oscillator in a circular waveguide

The realization of rectangular waveguide Gunn oscillator mounts for 33-50 GHz frequency range involves a number of precise milling operations. A new design using a circular waveguide is described here which is simpler in construction.

The use of circular waveguides is generally avoided due to overmoding problems in a broadband design. However, in this particular case the presence of the Gunn diode-bias post assembly inside the

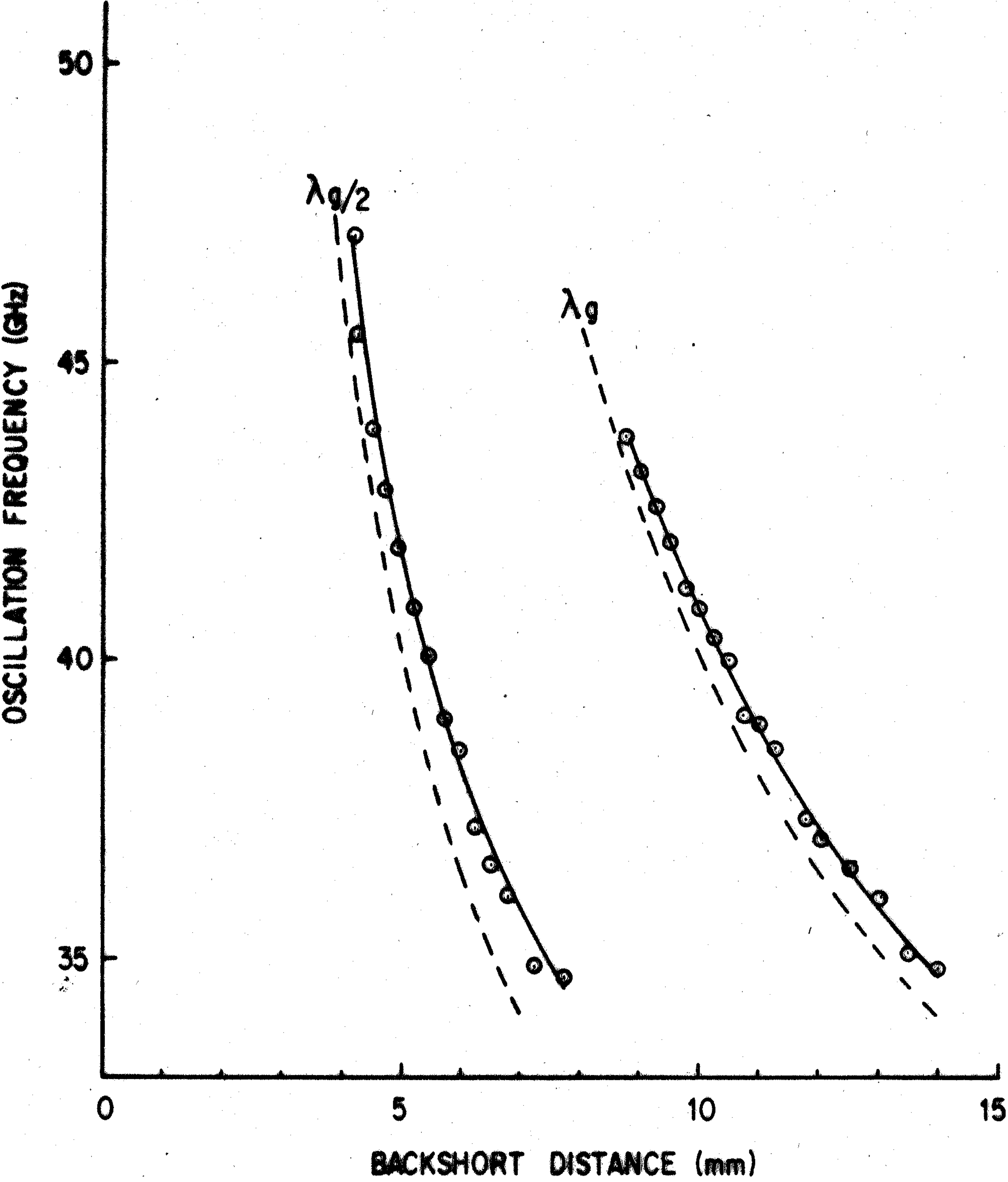


FIG. 3.9 OSCILLATION FREQUENCY vs. BACKSHORT POSITION FOR THE REDUCED-HEIGHT WAVEGUIDE GUNN OSCILLATOR.

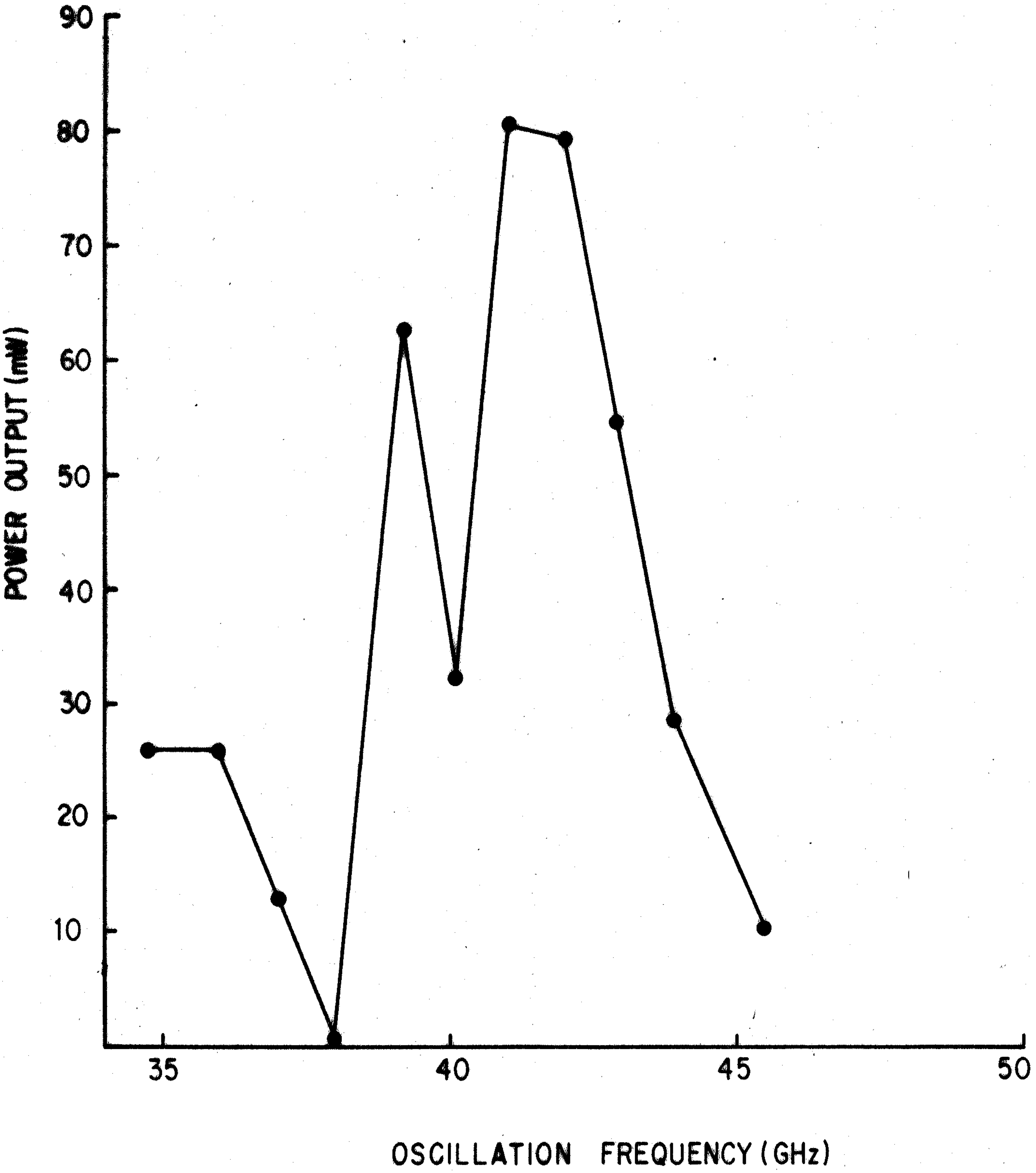


FIG. 3.10 POWER vs. FREQUENCY CHARACTERISTICS OF THE REDUCED-HEIGHT WAVEGUIDE GUNN OSCILLATOR.

waveguide actually helps in exciting only the dominant (TE_{11}) mode and inhibits the excitation of the next higher order mode (TM_{01}). Therefore, wideband single mode operation is obtained.

3.4.1 Design and construction

A cross-sectional view of this oscillator is shown in figure 3.11 and a photograph of the oscillator in figure 3.12. A 5mm diameter hole is drilled in a solid brass block which forms a circular waveguide with a cutoff frequency of about 40 GHz for the dominant mode (TE_{11}). The Gunn diode is mounted on a copper plug and inserted into the circular waveguide through a 3mm diameter hole drilled across the waveguide. DC bias is provided in the usual manner through a metal bias-post. A noncontacting backshort is provided for oscillator tuning. Most of the constructional steps in the realization of this oscillator mount involve only drilling and turning operations which are much simpler than the precise milling operations needed for rectangular oscillator mounts. This oscillator can be used in a standard rectangular waveguide system using a commercially available circular to rectangular waveguide transition.

3.4.2 Oscillator performance

Oscillation frequency versus backshort position for this oscillator using three different post diameters is shown in figure 3.13. These characteristics are somewhat similar to those obtained with the standard rectangular waveguide circuit except for the fact that the frequency saturation region is not as well defined.

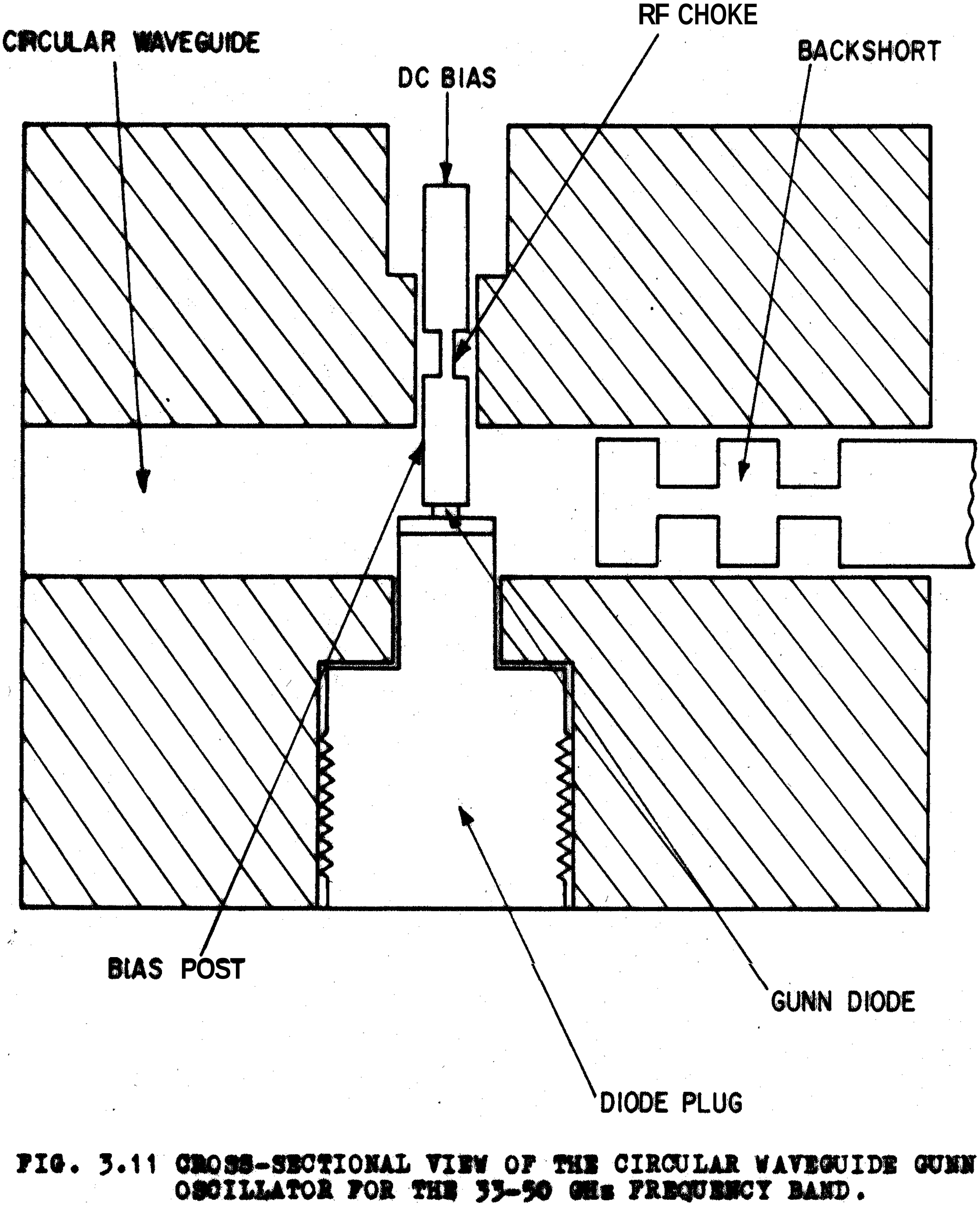


FIG. 3.11 CROSS-SECTIONAL VIEW OF THE CIRCULAR WAVEGUIDE GUNN OSCILLATOR FOR THE 33-50 GHz FREQUENCY BAND.

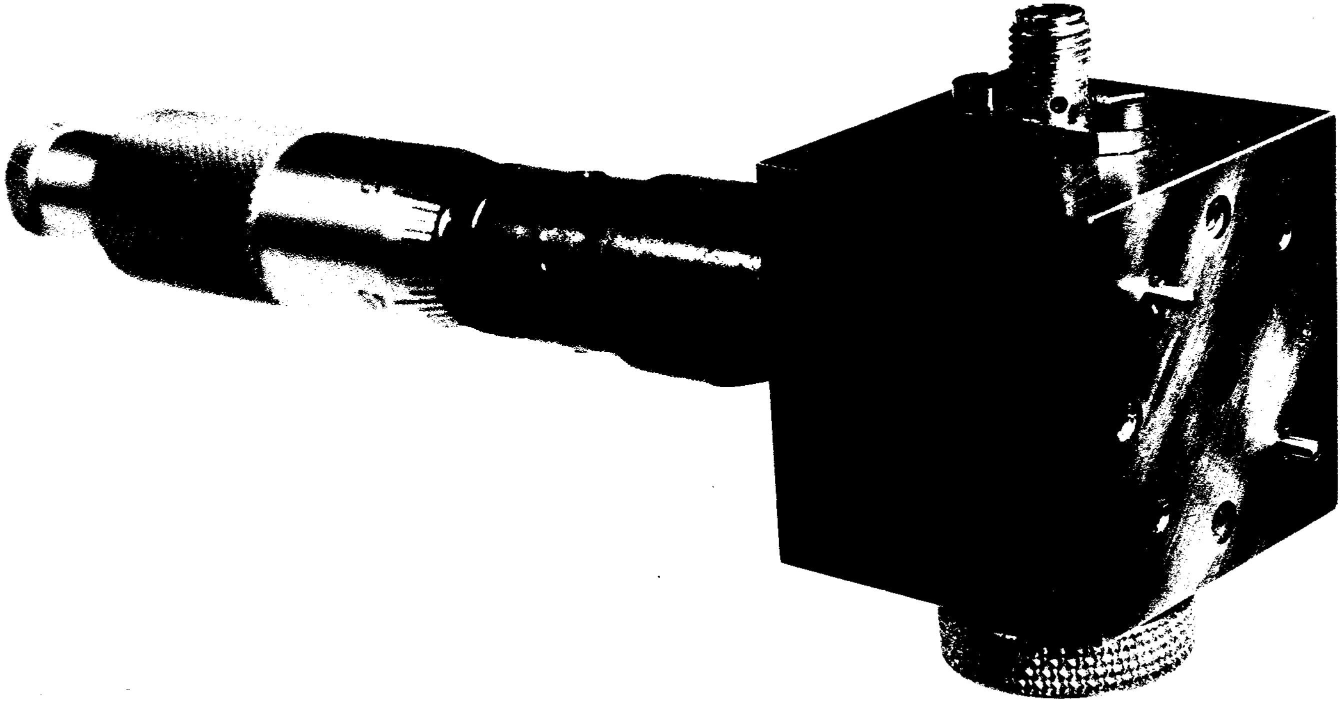


FIG. 3.12 PHOTOGRAPH OF THE CIRCULAR WAVEGUIDE GUNN OSCILLATOR FOR THE 33-50 GHz FREQUENCY BAND.

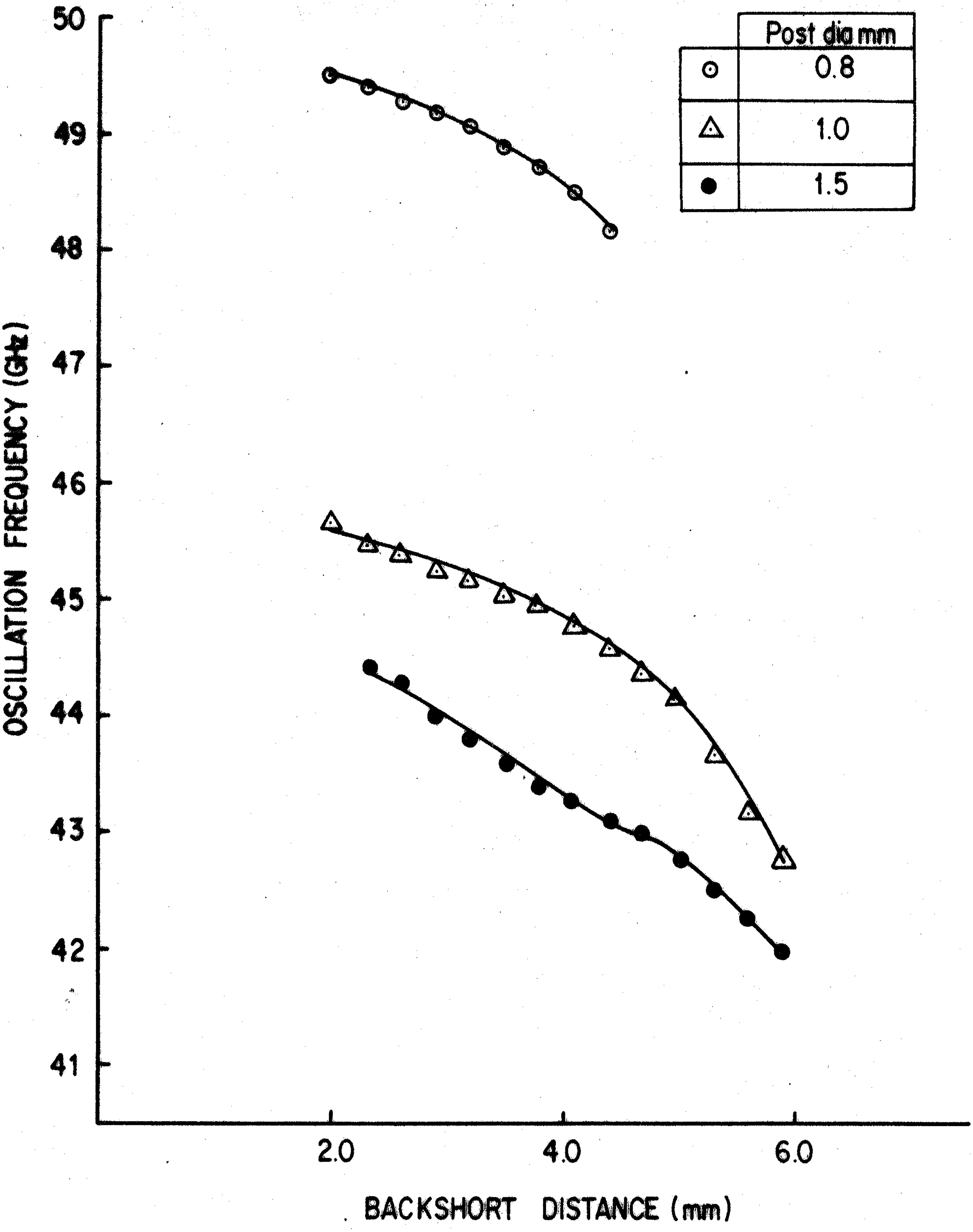


FIG. 3.13 OSCILLATION FREQUENCY vs. BACKSHORT POSITION FOR THE CIRCULAR WAVEGUIDE GUNN OSCILLATOR.

Frequency versus power characteristics of this oscillator are plotted in figure 3.14. Maximum power output of more than 100mW at 43.4 GHz is obtained with this circuit using a Varian Gunn diode type VSQ 921985 specified for 100mW output at 45 GHz. About 3 GHz backshort frequency tuning with less than 3dB power variation is obtained. Bias tuning sensitivity of about 100 MHz/volt is observed for this oscillator also.

The performance of this oscillator improves significantly when a second backshort is added in an orthogonal direction. This was done by drilling another 5mm diameter hole in a direction perpendicular to the first hole near the Gunn diode assembly. With two backshorts, there is greater flexibility of circuit optimization. This results in higher power output and an increased backshort tuning range.

3.5 Discussion

The development of various post-coupled Gunn oscillator circuits for the 33-50 GHz frequency range has been described in the foregoing sections. A theoretical understanding of the oscillator circuit behaviour requires a precise knowledge of the diode and circuit impedances presented at the diode package terminals inside the waveguide.

The Gunn diode impedance is, in general, a non-linear function of the oscillation frequency and amplitude, However, a simplified lumped equivalent circuit similar to the one shown in figure 2.6

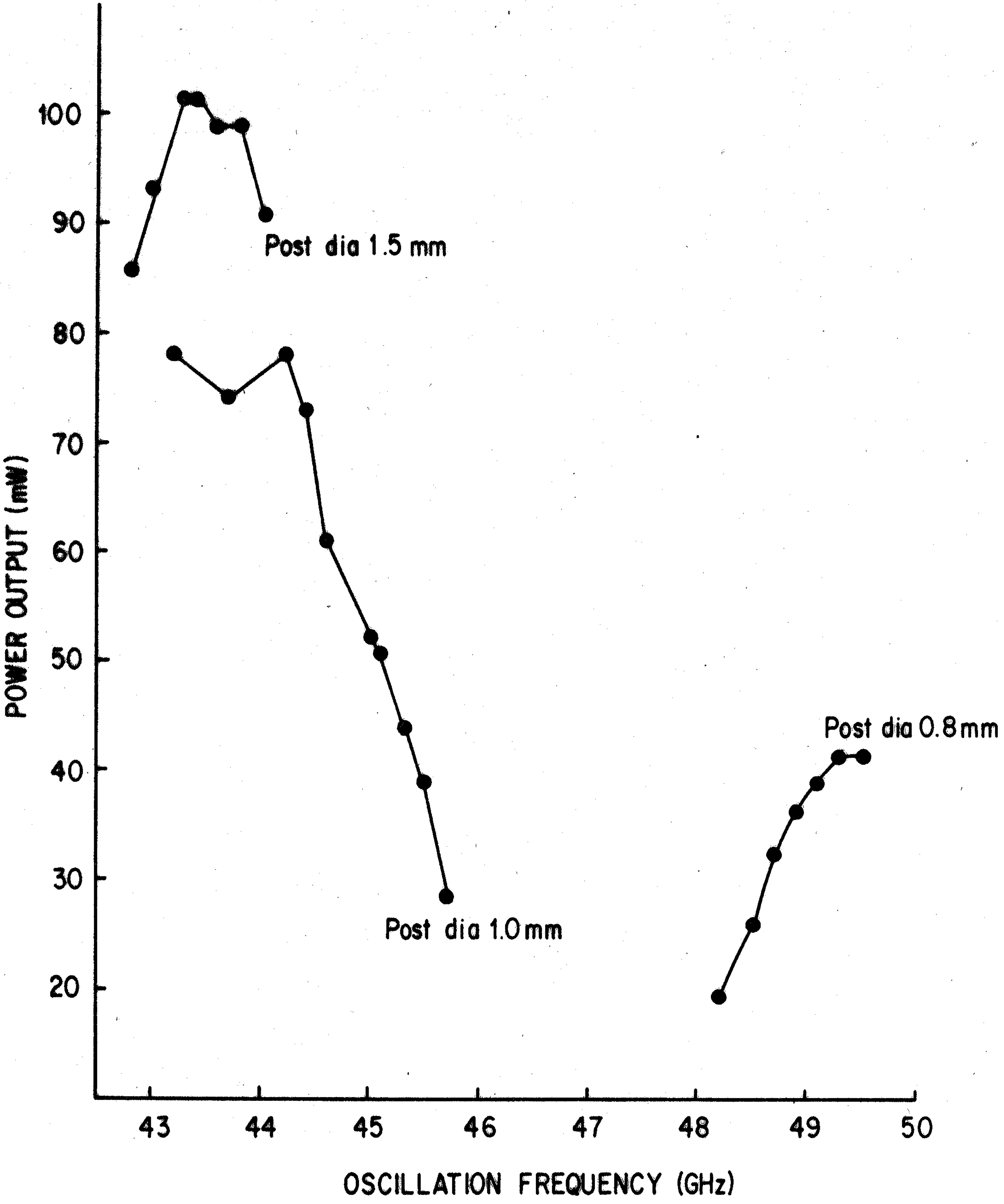


FIG. 3.14 POWER vs. FREQUENCY CHARACTERISTICS OF THE CIRCULAR WAVEGUIDE GUNN OSCILLATOR.

is sometimes employed for an approximate linear analysis (Bischoff, 1979; Solbach et al, 1983a). The Gunn diode is represented by a negative conductance G_N shunted by the parallel plate capacitance C_G between the diode terminals with GaAs dielectric. The package parasitics are accounted for by a series inductance L_s of the gold ribbon leads and a shunt capacitance C_P mainly due to the use of a ceramic ring insulator in the Gunn diode package. Typical values for these elements measured by Bischoff (1979) for a Varian millimetre-wave Gunn diode are, G_N = 38 millimhos, C_G = 0.28pF, L_s = 0.08nH and C_P = 0.09pF.

The circuit impedance presented at the diode package terminals inside the waveguide is generally unknown. Theoretical calculation of this impedance is highly complex involving the solution of a dyadic Green's function. Analysis of a waveguide mounting structure formed by a metal strip partially extending into a rectangular waveguide has been carried out and an equivalent circuit obtained (Eisenhart and Khan, 1971). The gap impedance thus obtained has been used for explaining the oscillation frequency behaviour of some post-coupled Gunn oscillators for the 12-18 GHz band (Eisenhart and Khan, 1972). However, the waveguide mounting structure analyzed by Eisenhart and Khan using a thin metal strip is not a true representation of the actual geometry of Gunn oscillator mounts which use solid round metal posts for biasing of the Gunn diode in the waveguide. Moreover, the restrictions imposed on post and gap size for convenience of analysis are generally violated in practical Gunn oscillator circuits.

In view of these constraints, the Eisenhart and Khan equivalent circuit cannot be used directly for the determination of the circuit impedance presented at the diode terminals. The measurement of this circuit impedance at millimetre wavelengths is also quite difficult. Therefore, in practice, a number of circuit variables are provided for the experimental optimization of circuit impedance for best oscillator performance.

The circuit variables in the case of post-coupled Gunn oscillators are the diameter of the bias post and the position of the backshort. It has been shown that the post-diameter has a strong influence on the oscillator performance. The presence of the post inside the waveguide is also seen to give rise to a kind of frequency saturation in oscillator backshort tuning. Frequency saturation phenomenon in post-coupled Gunn oscillators has also been observed by Taylor et al (1970) in connection with 12-18 GHz and 26-40 GHz Gunn oscillators. Taylor et al attribute the frequency saturation phenomenon to the resonance of a co-axial line resonator formed by the bias post along with the sidewalls of the waveguide and of a length equal to the waveguide height. Eisenhart and Khan (1972), however, believe that the saturation is caused by the combined effect of the coupling of the higher order waveguide modes to the gap impedance. This coupling gives rise to a series resonance right across the Gunn diode. In any case, it is clear that the saturation is caused by the bias-post spanning the waveguide height. This is confirmed by reducing the waveguide height to be nearly equal to the height of the Gunn diode package so that the bias-post protrusion into the waveguide is minimized. As expected, the reduced-height waveguide Gunn oscillator does not show any frequency saturation in backshort tuning. However, the output powers obtained with the reduced-height waveguide Gunn oscillator are slightly lower than those obtained with the standard waveguide circuit, perhaps due to the lower quality factor (Q) of the reduced-height waveguide cavity.

The circular waveguide oscillator mount, which is employed because of its simpler construction, also seems to show a circuit behaviour similar to that of the standard rectangular waveguide oscillator. The deteriorating effect of the higher order modes, usually the inhibiting factor in the use of circular waveguides, has not been observed. It is belived that the presence of the Gunn diode assembly inside the circular waveguide results in a preferential excitation of the dominant (TE_{11}) mode.

The choice of Gunn oscillator circuit depends on the system requirements. Standard rectangular waveguide or the circular waveguide oscillator circuits yield the highest powers for fixed frequency applications. On the other hand, wideband mechanically tuned Gunn oscillators may be realized with the reduced-height waveguide oscillator circuit. More than 50mW of CW power has been obtained with post-coupled Gunn oscillators in the 33-50 GHz band which is adequate for most local oscillator applications in radio astronomy receivers. Moreover, the bias-tuning sensitivity of about 100 MHz/volt observed in these Gunn oscillators is well suited for the automatic frequency control of these oscillators by the phase-lock system described in chapter 6.