

## CHAPTER 1

### INTRODUCTION

#### 1.1 Historical Background

The science of radio astronomy was born in 1932 when Karl **Guthe** Jansky, a radio engineer at Bell Telephone Laboratory, while investigating the effect of thunderstormson shortwave radio communication discovered an extra-terrestrial source of radio noise in the Milky Way by observing the sidereal nature of its periodicity (Jansky, 1932, 1933, 1935). This discovery, however, did not invoke great enthusiasm at that time and the subject was not pursued further. Some years later, Grote Reber, an amateur radio engineer at Illinois (USA) constructed a 31-foot parabolic dish antenna at his private expense to study Galactic radio noise. Reber first tried to detect this radiation at a much shorter wavelength of 9.7 cm. He argued that if the Galactic radio emission was of thermal origin obeying **Planck's** radiation law, more flux would be obtained at shorter wavelengths. But he could not detect any celestial radiation at 9.7 cm. He finally succeeded in detecting Galactic radio emission at a much larger wavelength of 1.9m (160 MHz) (Reber, 1940). Reber also prepared the first systematic maps of the radio sky at 160 MHz (Reber, 1944) and 480 MHz (Reber, 1948). It is now known that the Galactic radio **continuum** emission detected by Jansky and Reber is produced by relativistic electrons spiralling in Galactic magnetic fields by a mechanism called synchrotron

radiation (Shklovsky, 1960). This radiation has a steep frequency spectrum, the strength of radiation falling off with increasing frequency.

Following the work of Reber, J.H. Oort at **Leiden** Observatory asked one of his young students, Van de Hulst, to investigate the possibility of obtaining line radio emission from the Galaxy. Van de Hulst, purely from theoretical considerations, predicted the possibility of detecting line radiation at 21 cm wavelength (1420 MHz) from the neutral hydrogen so widely distributed in the Galaxy (Van de Hulst, 1945). Van de Hulst's prediction of the 21 cm hydrogen line could not be immediately verified due to the non-availability of sensitive receivers at this wavelength at that time. 21 cm line radiation from the Galaxy was finally **detected** in 1951 by Ewen and Purcell (1951) at Harvard and **later** by **Muller** and Oort (1951) at **Leiden**. The detection of the 21 cm hydrogen line opened up a new window for the study of Galactic structure. Radial velocities of interstellar clouds could now be obtained by observing the doppler shift of the hydrogen line. The study of hydrogen line profiles also yielded **valuable** information about several physical parameters like column density **and** temperature. Moreover, the portions of the Galaxy which were obscured to optical observations by the intervening dust became transparent since radio waves penetrate through the dust clouds. Spiral structure of our galaxy was mapped for the first time using the 21 cm line as a probe.

As the interest in radio astronomy grew, the need for radio telescopes with higher resolution and better sensitivity was felt. The resolution of a telescope is determined by its size. Large size telescopes which are difficult to build, are required for achieving high resolutions. To circumvent this difficulty, radio interferometers were developed to study radio sources of small angular extent (Bolton and Stanley, 1948). The resolution of an interferometer is determined by the spacing (baseline) between the antennas and is not limited by antenna size (Kraus, 1966). Several radio interferometer systems operating at various frequencies have since been built all over the world, the largest among them being the Very Large Array (VLA) in New Mexico and Multi-Telescope Radio Linked Interferometer (MTRLI) in England. These instruments provide angular resolutions of a few arc seconds for observations at centimetre wavelengths. Very Long Baseline Interferometers (VLBI) with inter-continental baselines have also been used to provide angular resolutions of milli-arc seconds (Redhead, 1979), a resolution unimaginable in optical observations.

In addition to radio interferometers, several large steerable parabolic single dish antennas were built all over the globe for radio astronomical observations. Prominent among this type of radio telescope are the 250-foot diameter parabolic dish at Jodrell Bank, England, the 210-foot telescope at Parkes, Australia, and the 100-metre parabolic antenna at Effelsberg, West Germany.

Along with the development of high resolution radio telescope antennas, receivers were also improved for obtaining better sensitivity. The earliest post-World War radio astronomy receivers were of superheterodyne design and employed germanium point-contact diodes as frequency converters. The sensitivity of these receivers was limited by the noise generated in these diodes which formed the first stage of the receiving system. With the development of masers and cooled parametric amplifiers in the mid-sixties, ultra-low noise receivers with noise temperatures of the order of 50K were realized at centimetre wavelengths.

The availability of an efficient antenna along with ultra low-noise cooled receivers and the development of absolute calibration techniques led to a very important astronomical discovery. Penzias and Wilson, while calibrating their cooled receiving equipment at Bell Telephone Labs in 1965 found an excess in the system noise temperature of about 3K which they subsequently identified as an isotropic microwave background radiation (Penzias and Wilson, 1965). This microwave background radiation is now believed to be a relic of the big bang explosion at the beginning of the universe 10-20 billion years ago.

Over the past three decades, several remarkable astronomical objects have been discovered by observations with ground based radio telescopes. Prominent among them are 'Quasars' (Quasi-Stellar Radio Sources) and 'Pulsars' (Pulsating Radio Sources).

Quasars are the farthest known star-like objects receding at relativistic speeds and releasing enormous amount of energy in the form of radio radiation. Pulsars are extremely compact Galactic objects emitting radio radiation in the form of pulses with incredibly precise time intervals.)

The 21 cm hydrogen line was the only celestial line radiation known to radio astronomers for more than a decade after its first detection in 1951. Several types of radio spectrometers were developed during this time to study the line radiation. One of the earlier designs was based on the splitting of the input frequency band into a large number of narrow-band contiguous filter channels whose outputs were detected and integrated separately to obtain the power spectrum. With the advent of digital techniques, autocorrelation type spectrometers were developed. These spectrometers were based on the Fourier-transform relationship between the autocorrelation function and the power spectral density. Using this type of spectrometer, a molecular line of the hydroxyl-radical (OH) was discovered in interstellar space at 18 cm wavelength (Weinreb et al, 1963). Discovery of this molecular line led to an intense effort for finding line emission from other molecules. Molecular lines of ammonia and water were soon discovered around 1.3 cm wavelength (Cheung et al, -1968; 1969).

(With the availability of low-noise receivers at millimetre wavelengths in the early seventies, a large number of organic and

inorganic molecules were identified in the interstellar medium through **observations** of their rotational transitions which fall in the millimetre-wave band of the electromagnetic spectrum (Rank et al, 1971; Zuckerman and Palmer, 1974).

The study of these molecular lines at millimetre wavelengths has assumed great importance over the past decade due to their relevance for understanding the physical mechanism of star formation (Elmegreen and Lada, 1977). These molecules have generally been found to be associated with giant molecular clouds which are believed to be the sites where star formation is taking place today.

Most of the early millimetre wave observations were carried out using the NRAO 11-metre radio telescope at Kitt-Peak, Arizona (U.S.A). A number of millimetre-wave telescopes have since been installed and some more are under development in several countries. These are much bigger in size (Nobeyama - 45m, RAM - 30m) and of greater surface accuracy (Caltech - 10m) for obtaining higher sensitivity and resolution.

The presence of water-vapour and oxygen in the earth's atmosphere contributes to the absorption of the incoming millimetre-wave radiation. Fig. 1.1 shows two typical atmospheric absorption curves for radio waves of 1-500 GHz frequency range, passing vertically down through the atmosphere for a dry (precipitable water vapour  $W_v = 3\text{mm}$ ) and a comparatively humid ( $W_v = 21\text{mm}$ ) atmosphere (Penzias and Burrus, 1973). Several low-absorption window regions are

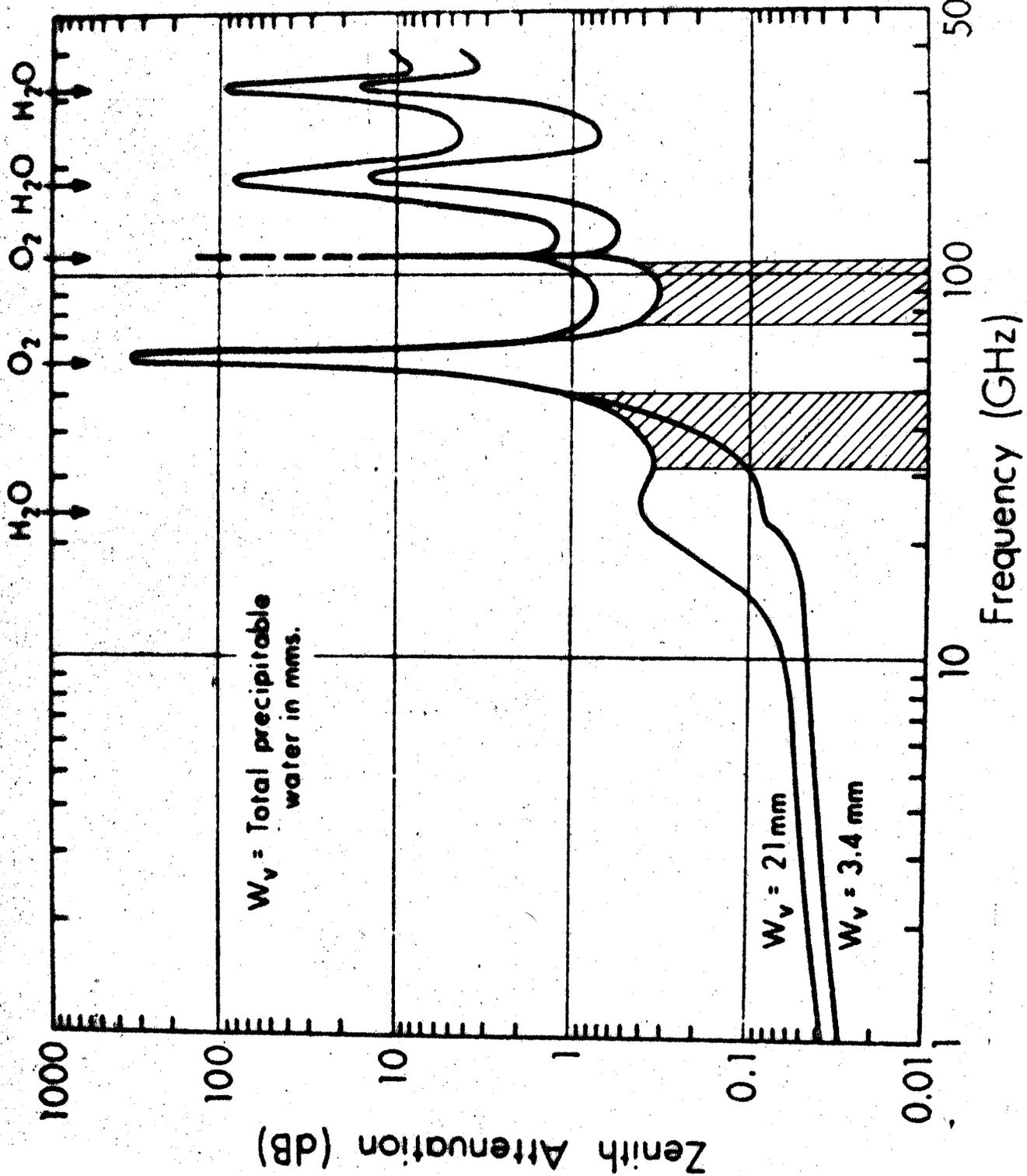


FIG 1.1 ATMOSPHERIC ABSORPTION OF MILLIMETRE-WAVES. (after Penzias and Burrus, 1973)

clearly discernible in the figure. Ground based millimetre-wave radio telescopes are designed to exploit these window regions of the radio spectrum. Two of these windows (shown shaded in Fig. 1.1) located between 33-50 GHz and 75-110 GHz bands are of particular interest for molecular spectroscopy since the rotational transitions of several astrophysically important molecules lie in these frequency bands.

### 1.2 Millimetre-wave radio, astronomy receivers ✓

Receivers for millimetre-wave radio astronomy are of super-heterodyne design in which the incoming radiation is first down-converted to an intermediate frequency (IF) signal by multiplying it with a strong signal from a local oscillator (LO). The electronic device used for this frequency conversion is called the mixer. Metal semiconductor junctions (Pt on GaAs) of extremely small area ( $\sim 2-4 \mu\text{m}^2$ ) are commonly employed as millimetre-wave mixers (Penzias and Burrus, 1975). More recently, superconducting tunnel junctions have also been used with excellent results (Phillips and Woody, 1982). The IF signal is amplified in a low-noise amplifier before further processing. The back-end of these receivers generally consists of a spectrometer of filter-bank or acousto-optic design.

The sensitivity of millimetre-wave receivers is mainly determined by the noise performance of the mixer and the IF amplifier. Therefore, these two are mostly operated at cryogenic temperature's to minimize their noise contribution. The millimetre-wave mixer is a lossy device which enhances the noise contribution of the .

**subsequent stages** of the **receiver**. For this reason, the IF amplifier has to be of **high gain** and **ultra** low-noise design. An IF of around 1.4 GHz is generally chosen for convenience of low-noise amplifier realization. Since this IF is much smaller than the LO frequency, both the signal ( $LO + IF$ ) and the image ( $LO - IF$ ) bands get converted to the IF yielding a double **sideband** (DSB) receiver. However, for molecular spectroscopy work, a single sideband (SSB) receiver response is required. In a real-life situation, it is very hard to filter out the **image** response; therefore, most practical millimetre-wave receivers are of **DSB design**. The SSB receiver noise temperature for these receivers, which is the real quantity of interest for spectral line work, is a factor of two worse than the measured **DSB** value, **assuming** equal response at the signal and image frequencies.

In **addition** to the noise contributions of the mixer and the IF amplifier, there is yet another source of receiver noise. The AM sideband **noise** of the local oscillator at the signal and image frequencies is also converted to the IF along with the input signal thus **worsening** the signal-to-noise ratio at the IF port. Therefore, only oscillators with low sideband noise are chosen for LO application in these receivers.

The power requirement of the LO source depends on the type of **the** mixer used. Metal semiconductor junction (Schottky barrier diode) mm-wave mixers operating at cryogenic temperatures typically **require** 0.25-1.0mW of CW power for efficient operation. The LO

source must, however, be **capable** of providing 5-10mW of CW power to account for the **losses** in the LO injection device. Millimetre wave mixers generally have only one waveguide input port, therefore a method of supplying LO power to the mixer is required. A waveguide directional filter for LO injection in millimetre wave mixers has been developed (Davis, '1977). It provides good isolation between LO and signal ports while introducing negligible loss in the signal path and gives about 6-7dB loss between the LO and mixer ports. The LO injection device also acts as a **bandpass** filter giving about 20dB rejection for AM sideband noise at 1.4 GHz away from the LO frequency. LO injection devices based on quasioptical techniques (Erickson, 1977) give only 0.5-1dB loss in the LO to mixer path, thus greatly reducing the power requirement on the local oscillator.

The LO frequency must also be precisely known for measuring the frequency of the incoming line radiation for identifying the molecular species. **Since** the inherent frequency stability of a millimetre-wave source is not good enough, some **form** of external frequency stabilization is needed to meet the LO requirement.

**Millimetre-wave** reflex klystrons which are phase-locked to a highly stable signal derived from a VHF frequency synthesizer are presently being used as local oscillators in low noise millimetre-wave radio astronomy receivers. The limited operating life ( $\sim 500$  hrs) and bulky high voltage supplies required for these klystron tubes have been serious disadvantages. With the **recent** availability of

solid-state millimetre-wave devices like Gunn and IMPATT diodes, the search for finding a suitable solid-state alternative to the klystron LO has assumed great importance. IMPATT diodes, however, have been found to be too noisy for LO applications, but the Gunn diodes have shown good noise performance at millimetre-wave frequencies (Tully et al, 1978). The CW power capability of mm-wave Gunn diodes, although limited to a few tens of milliwatts, is adequate for most local oscillator applications. Moreover, with the recent development of superconducting tunnel junction mixers for mm-wave frequencies which require extremely low local oscillator powers (a few tens of nanowatts) the interest in solid-state local-oscillator<sup>a</sup> sources has increased considerably.

### 1.3 Scope of present work

The present work is concerned with the development of solid-state local oscillator sources for millimetre-wave radio astronomy receivers for the 33-50 GHz and 75-110 GHz atmospheric transmission window bands. Post-coupled Gunn oscillators operating in a fundamental mode have been designed and built for the 33-50 GHz frequency range. Resonant-cap Gunn oscillators operating in a harmonic extraction mode have been constructed for the 75-110 GHz frequency range. A new design for millimetre wave Gunn oscillators using circular waveguide has been developed. Circular waveguide Gunn oscillator mounts are comparatively simple to construct at these wavelengths. A detailed experimental investigation of the effects of the various oscillator circuit parameters has been carried out. The large amount

of experimental data thus obtained has been analyzed and interpreted based on a phenomenological model of oscillator behaviour.

AM sideband noise measurement of the Gunn oscillators (at 1.4 GHz away from the carrier) has been carried out and compared with that of the klystrons to ascertain their suitability for local oscillator application in low-noise radio astronomy receivers.

A versatile phase-lock system has been developed for the frequency stabilization of millimetre-wave oscillators; this is required for local oscillator application in receivers designed for molecular spectroscopy. The system has been used to phase-lock several millimetre-wave Gunn oscillators as well as klystrons to a highly stable signal derived from a VHF frequency synthesizer.

CHAPTER 2  
THE GUNN DIODE

### 2.1 Introduction

Since the first experimental observation of microwave current instabilities in bulk samples of n-type GaAs and InP by J.B. Gunn in 1963, The Gunn diode has become a very important solid-state active device. Gunn diodes have found widespread application in the realization of solid-state sources for several system applications in radar, communications and radioastronomy. Gunn diodes are now commercially available for operation over a broad range of frequencies from 1 to 100 GHz giving CW powers from a few watts at the lower end to a few tens of milliwatts at the higher end of the microwave spectrum. The low-noise characteristics of these devices make them an ideal choice for local oscillator application in radio astronomy receivers. The extremely compact size, low voltage operation and high reliability are some of the advantages of Gunn oscillators in local oscillator application as compared to the traditional klystrons. In this chapter, the principle of operation of Gunn diodes is discussed and the various oscillation modes of these devices are described. Practical device and oscillator circuit considerations are also presented.

### 2.2 Principle of operation of Gunn diodes

Operation of the Gunn diode is based on the transferred electron effect observed in some III-V semiconductors like GaAs and InP. The mechanism of the transferred electron effect was explained by

Ridley and Watkins (1961) and independently by Hilsum (1962) well before the experimental observations of microwave oscillations in samples of GaAs and InP by J.B. Gunn (1963). Herbert Kroemer (1964) was among the first researchers to point out that the current instabilities observed by Gunn in samples of n-GaAs and InP were actually a manifestation of the transferred electron effect.

Transferred electron effect is a consequence of the satellite-valley structure of the conduction band of III-V semiconductors. The satellite valleys of GaAs and InP are shown in the energy-band diagram of figure 2.1. The carrier mobility in the satellite valley is much lower compared to that in the main valley. The minimum energy separation of the satellite valley from the main valley for GaAs is 0.36eV while for InP it is about 0.53eV.

When the voltage applied across a sample of GaAs or InP is zero, the average energy of carriers (electrons for n-type samples) is equal to the thermal energy,  $kT$ , where  $k$  is the Boltzmann constant and  $T$  the ambient temperature. The magnitude of this energy at room temperature, approximately 0.025eV, is much lower than the minimum energy gap between the main and the satellite valley. Therefore, in the absence of externally applied electric field, most carriers reside in the high mobility main valley. When an external voltage is applied, the average carrier velocity and hence their energy increases. At sufficiently high values of applied electric voltage, most carriers acquire enough energy to get scattered to the low mobility satellite valley. Any further

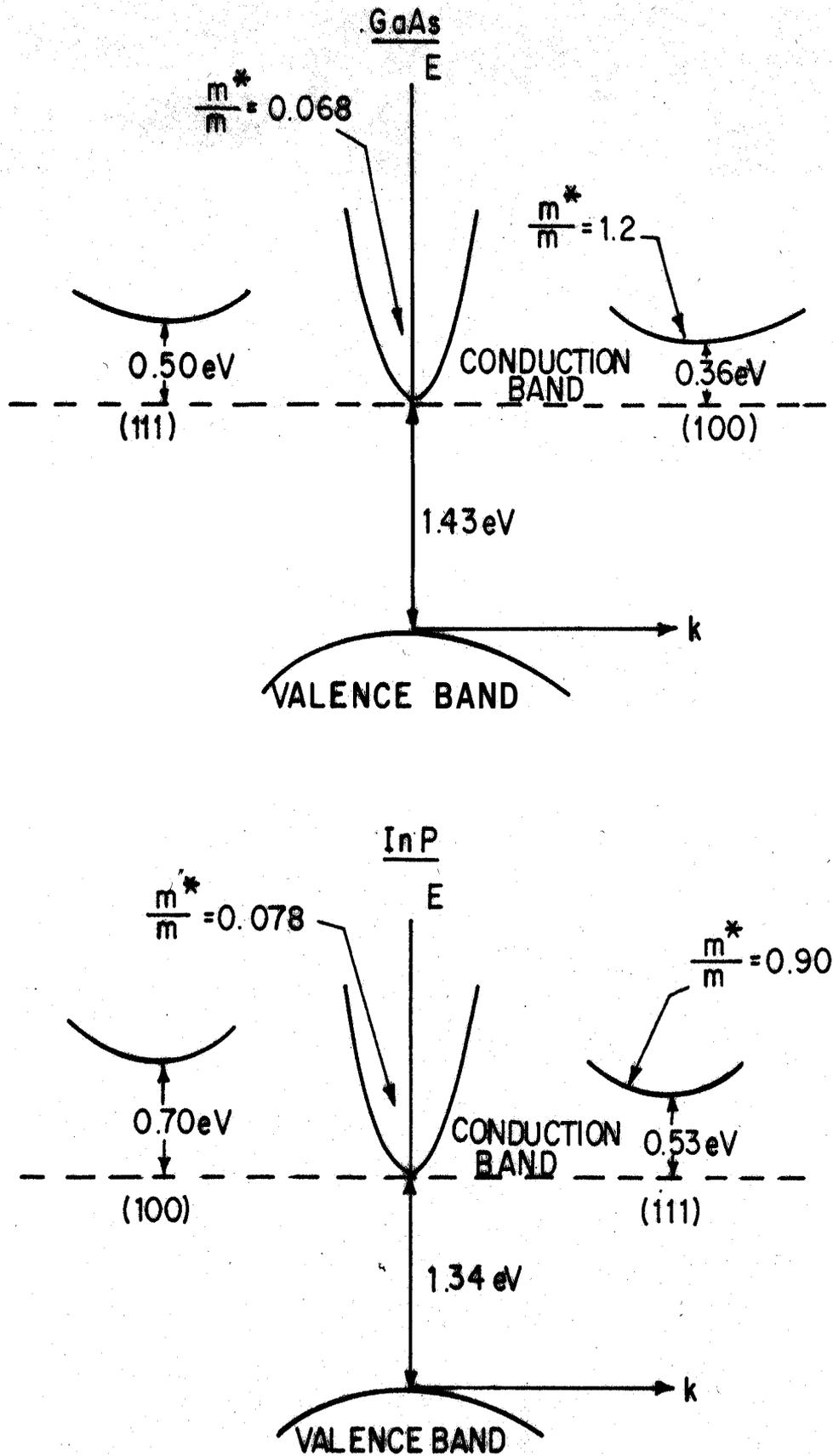


FIG. 2.1 CONDUCTION BAND STRUCTURE OF GaAs AND InP.

(after Eastman, 1976)

increase of voltage actually results in a decrease of carrier velocity since most carriers by now are residing in the satellite valley where carrier mobilities are lower.

The carrier velocity vs. electric field characteristics of samples of GaAs and InP are shown in figure 2.2. A region of negative differential mobility is clearly discernible in the figure above a certain minimum value of applied electric field. Since the electric field is proportional to the terminal voltage and the carrier velocity determines the external circuit current, figure 2.2 can also be taken to represent the V-I characteristic of the device. The negative differential resistance property of these devices gives rise to oscillations when placed in a suitable resonant cavity..

### 2.3 Modes of oscillation of Gunn diodes

The Gunn diode can oscillate in a number of different modes (Narayan and Sterzer, 1970) depending on the device and circuit parameters. Some of the crucial device parameters are the carrier doping density,  $n$ , the length of the active layer  $\ell$  and the circuit resonant frequency  $f$ . A mode-chart showing the different regions of various modes on a  $n\ell$  vs.  $f\ell$  diagram is shown in figure 2.3. A brief description of the various modes is given below.

#### 2.3.1 Transit-time mode

This is the classical mode discovered by Gunn (1963). For this mode to occur, the Gunn device is operated in a low Q resonant circuit just above the threshold voltage. Stable dipole domains

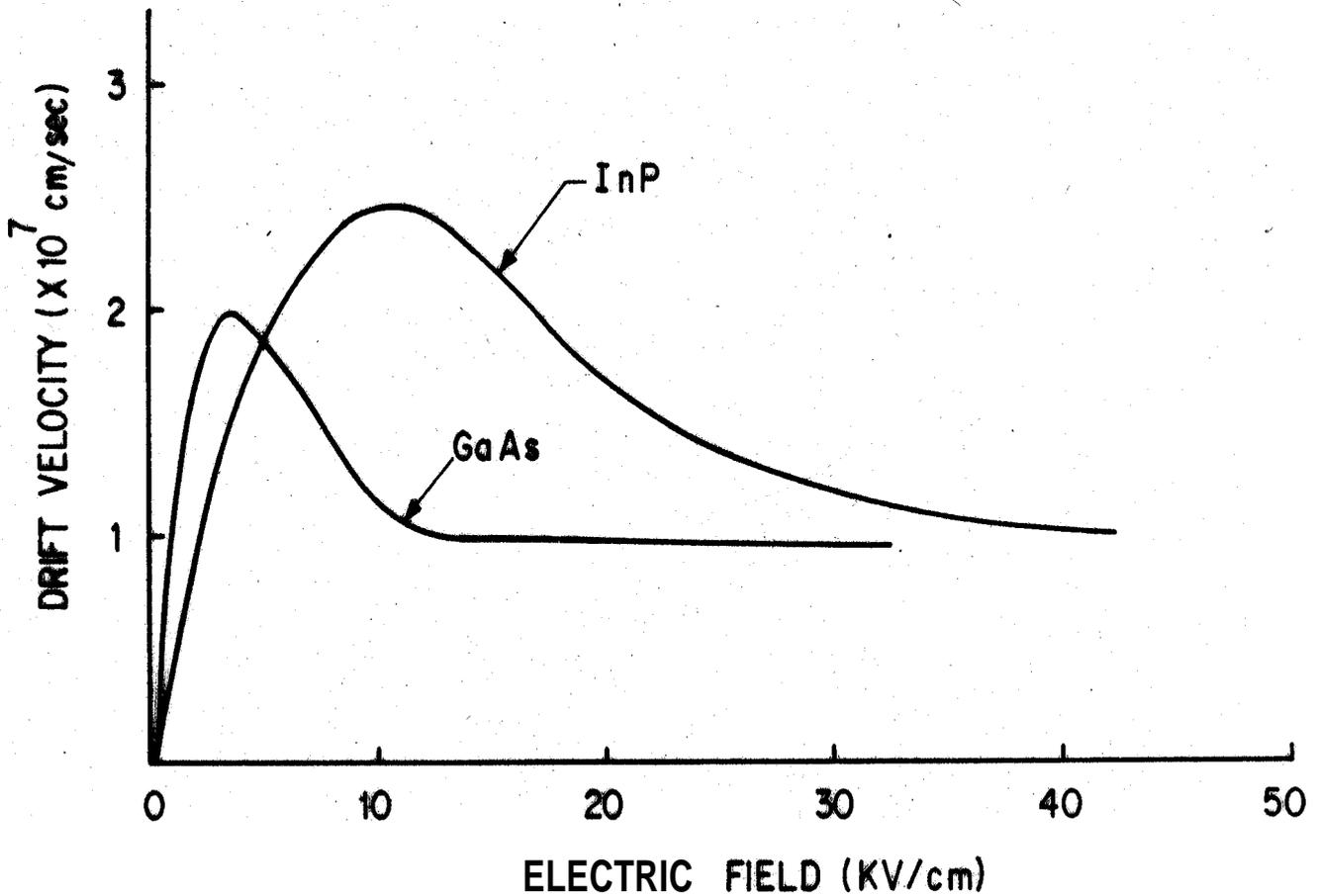


FIG. 2.2 VELOCITY-FIELD CHARACTERISTICS OF GaAs AND InP.  
(after Kuno, 1981)

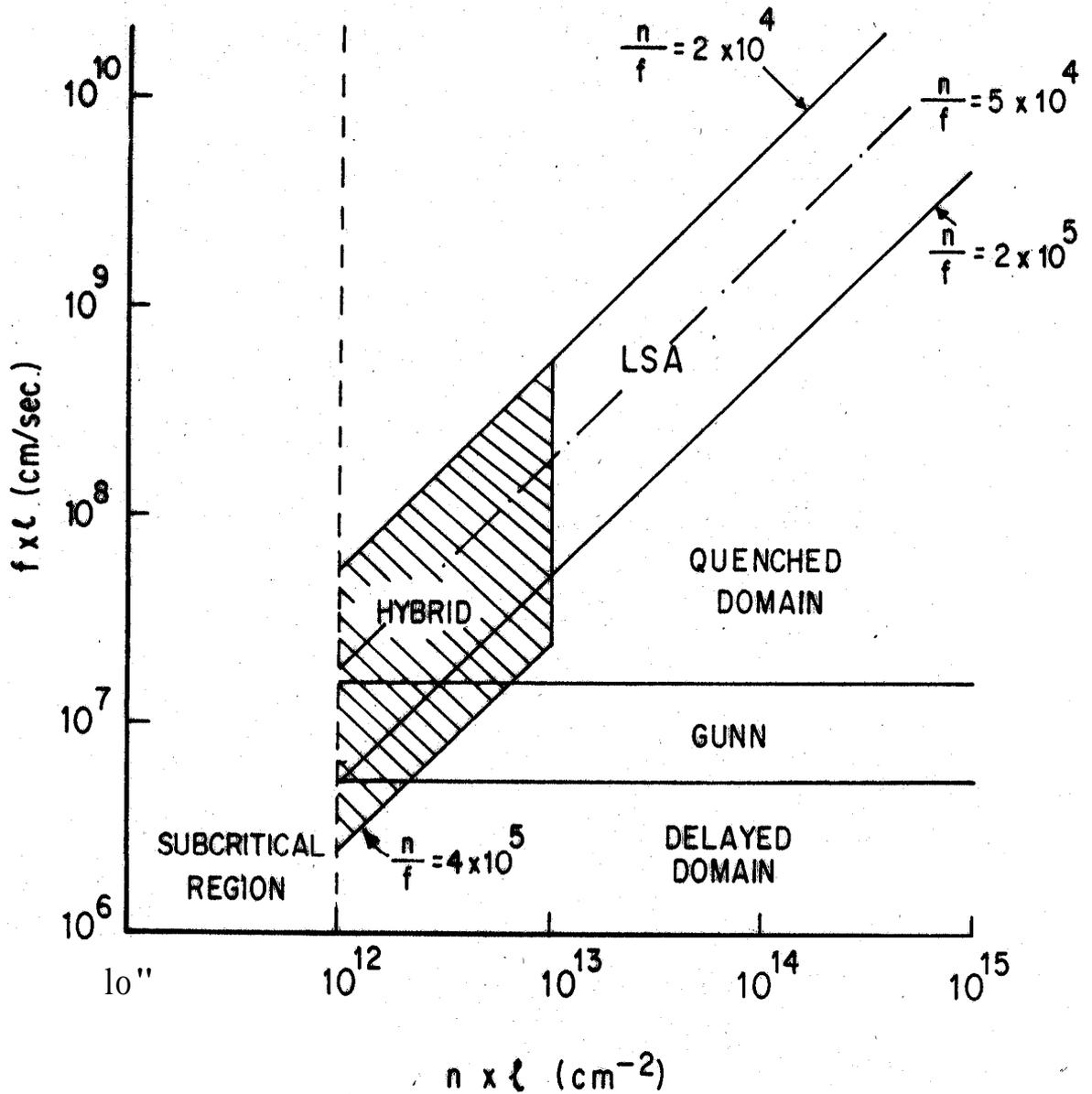


FIG. 2.3 OSCILLATION MODES OF A GUNN DIODE.  
(after Narayan and Sterzer, 1970)

are formed when the device is biased into the negative differential mobility regime. The oscillation frequency of a device operating in this mode is therefore directly determined by the time taken by these domains to transit the length of the device and is given by:

$$f = \frac{v}{\ell} \quad (2.1)$$

where  $f$  is the oscillation frequency in GHz,  $v$  is the saturated carrier velocity in km/sec. and  $\ell$  is the length of the device active layer in micrometres.

### 2.3.2 Quenched and delayed-domain modes

When the device is placed in a high Q resonant circuit and biased into the negative differential mobility regime, the instantaneous voltage across the device, which is the sum of dc bias and the RF voltage can swing both above and below the threshold voltage. If device and circuit parameters are so adjusted that the domain has sufficient time to mature near the cathode but the voltage across the device goes below threshold before the domain can reach the anode, the quenched domain mode of operation results. That is, the domain is quenched before reaching the anode. The life time of the domain is a function of d.c. bias, RF voltage swing (circuit Q), the device length and the circuit resonance frequency.

When the domain transit-time is less than the period of oscillation of the high-Q cavity, the domain can reach the anode before the instantaneous device voltage falls below the threshold

value. If the phase of the RF signal is properly adjusted, the next domain can be quenched before it is fully formed and no more domains will be formed till the voltage again goes above the threshold value. This essentially delays the formation of the next domain, therefore this mode of operation is called the delayed-domain mode.

Using the quenched and delayed-domain modes, Gunn diode operation above and below the transit-time frequency is possible.

### 2.3.3 Limited space-charge accumulation (LSA) mode

In the LSA mode of operation, discovered by Copeland in 1966 (Copeland, 1966) the device is placed in a resonator tuned to a frequency several times the transit-time frequency. The device is also biased to several times the threshold voltage. As the voltage swings above threshold, the space-charge starts building up at the cathode, but the voltage swings below threshold before a domain can form. The accumulated space-charge drains in a very small fraction of RF cycle. The device spends most of the time in the negative mobility regime, but the space-charge is not allowed to build up. This mode requires the following condition to be met:

$$2 \times 10^4 < \frac{n}{f} < 2 \times 10^5 \text{ s.cm}^{-3} \quad (2.2)$$

The LSA mode of operation is not limited by the device length, and is truly a bulk phenomenon which can be used for yielding high powers at millimetre-wave frequencies. However, the practical application of this mode is rather limited due to the severe constraint imposed by equation 2.2.

#### 2.3.4 Hybrid mode

This mode is half-way between the domain and LSA modes of operation. For operation in this mode, device and circuit parameters are so adjusted that mature domains are allowed to exist over part of the RF cycle. This mode was discovered by Huang and Mackenzie (1968) and has the advantages of the LSA mode without having the constraint of equation 2.2.

In addition to the domain modes described above, the Gunn diodes can also operate simply as a two terminal negative resistance device like tunnel diodes. Oscillations are produced by overcoming the circuit losses by the device negative resistance. Supercritically doped ( $n_d > 10^{12} \text{ cm}^{-2}$ ) samples of GaAs have been found to show negative resistance over several octaves of frequency without any travelling high-field domains being present.

#### 2.3.5 Harmonic mode operation of Gunn diodes

Fundamental frequency operation of GaAs Gunn diodes is limited to about 60 GHz due to the 'cutoff' of the transferred electron effect in GaAs [Bosch and Thim, 1974]. However, GaAs Gunn devices are capable of yielding useful CW powers even upto 100 GHz by operating as efficient harmonic generators. Harmonic operation of Gunn diodes was first discovered by Eddison and Brookbanks (1981) in connection with W-band (75-110 GHz) resonant-cap Gunn oscillators. In the harmonic mode of operation, the resonator is tuned to the fundamental frequency while the power is delivered to the load at the harmonic frequency.

## 2.4 Gunn diode structure and packaging

Although the Gunn diode is based on the bulk property of semiconductors, the small device lengths required for transit-time operation at frequencies of 10 GHz and above are best realized epitaxially. There are two main processes for the epitaxial growth of GaAs layers for Gunn diodes (Eastman, 1976). One is called vapour phase epitaxy (VPE) and uses pure arsenic trichloride and gallium as chemical sources. The other method, called liquid phase epitaxy (LPE), employs pure gallium saturated with GaAs as the chemical source. Molecular beam epitaxy (MBE) has also been used recently for the fabrication of extremely thin (1-2µm active layer lengths) Gunn devices (Haydl et al, 1980). Most of the commercially available Gunn diodes use GaAs material for their construction, since GaAs epitaxial processes are fully developed. A few experimental Gunn devices have also been made with InP and have given higher powers and efficiencies at 90 GHz as compared to GaAs devices (Crowley et al, 1980). However, several epitaxial growth problems of InP remain to be solved before practical devices based on InP become commercially available.

The structure of a typical millimetre-wave Gunn device is shown in figure 2.4. It consists of an  $n^+$  GaAs substrate of about 25 micrometre thickness on which an  $n^+$  buffer layer and an  $n$ -active layer are grown epitaxially. A  $n^+$  contact layer is then grown on the active layer and metal contacts are evaporated on this contact layer as well as on the  $n^+$  substrate. An alloy of gold-indium-

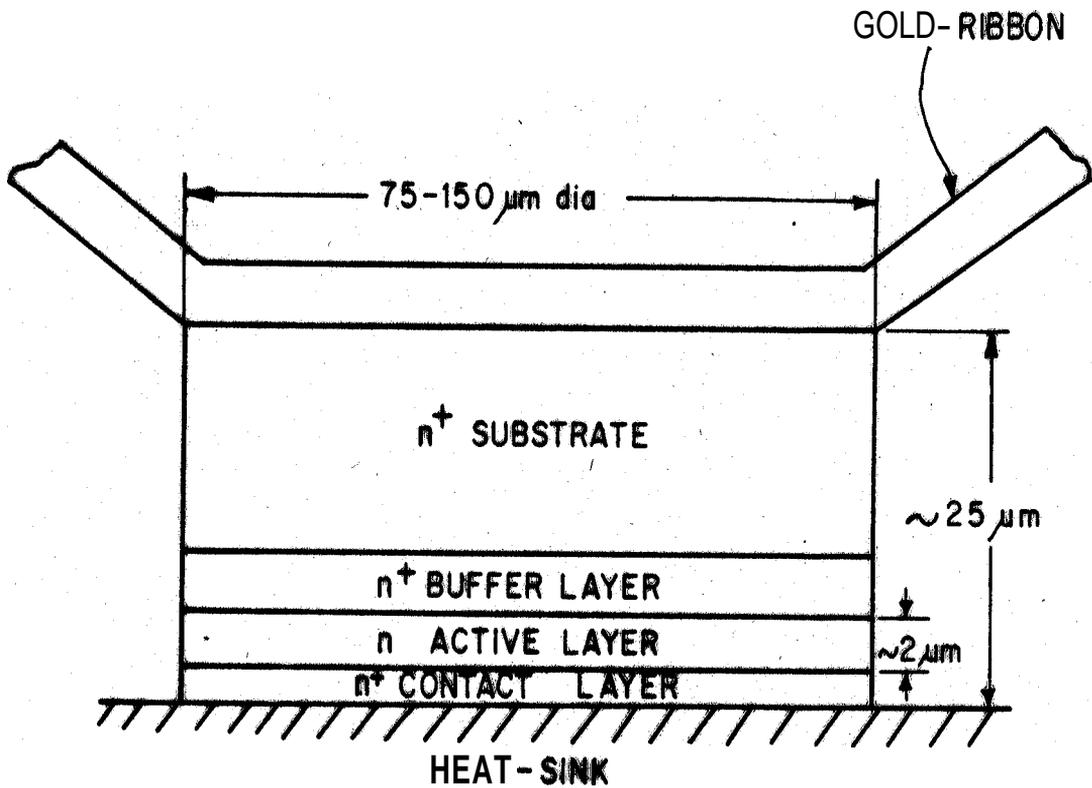


FIG). 2.4 STRUCTURE OF A TYPICAL MILLIMETRE WAVE GUNN DEVICE  
(after Kramer, 1976)

germanium is usually employed for metal contacts.

Maximum CW power obtainable from Gunn diodes is mainly limited by the device temperature rise due to heat dissipation. The temperature rise of the active layer reduces the peak to valley current ratio, the parameter determining power efficiency (Eastman, 1976), thus reducing the device output power. An important factor which governs the device temperature rise is its thermal resistance. GaAs by itself is a poor thermal conductor. In addition, the contact layers and the solder joints of the device to the package also add to the overall thermal resistance. Thus a major design consideration for CW Gunn diodes is the efficient heat-transfer from the device to the surroundings.

Some kind of device packaging is required for convenient handling and circuit mounting of these devices. The package must also provide for heat transfer from the diode chip to the surroundings. A sealed package which has found widespread use for Gunn diodes is shown in figure 2.5. The diode chip is soldered on top of a gold plated copper screw and surrounded by a miniature ceramic ring. A pair of crossed gold ribbons is thermocompression bonded to the top metallization of the chip, with the ceramic ring acting as an insulator. A metal cap is now brazed on to the ceramic ring to seal the package. This package has been found to be sufficiently rugged for easy circuit replacement and has operated quite well for frequencies upto 100 GHz.

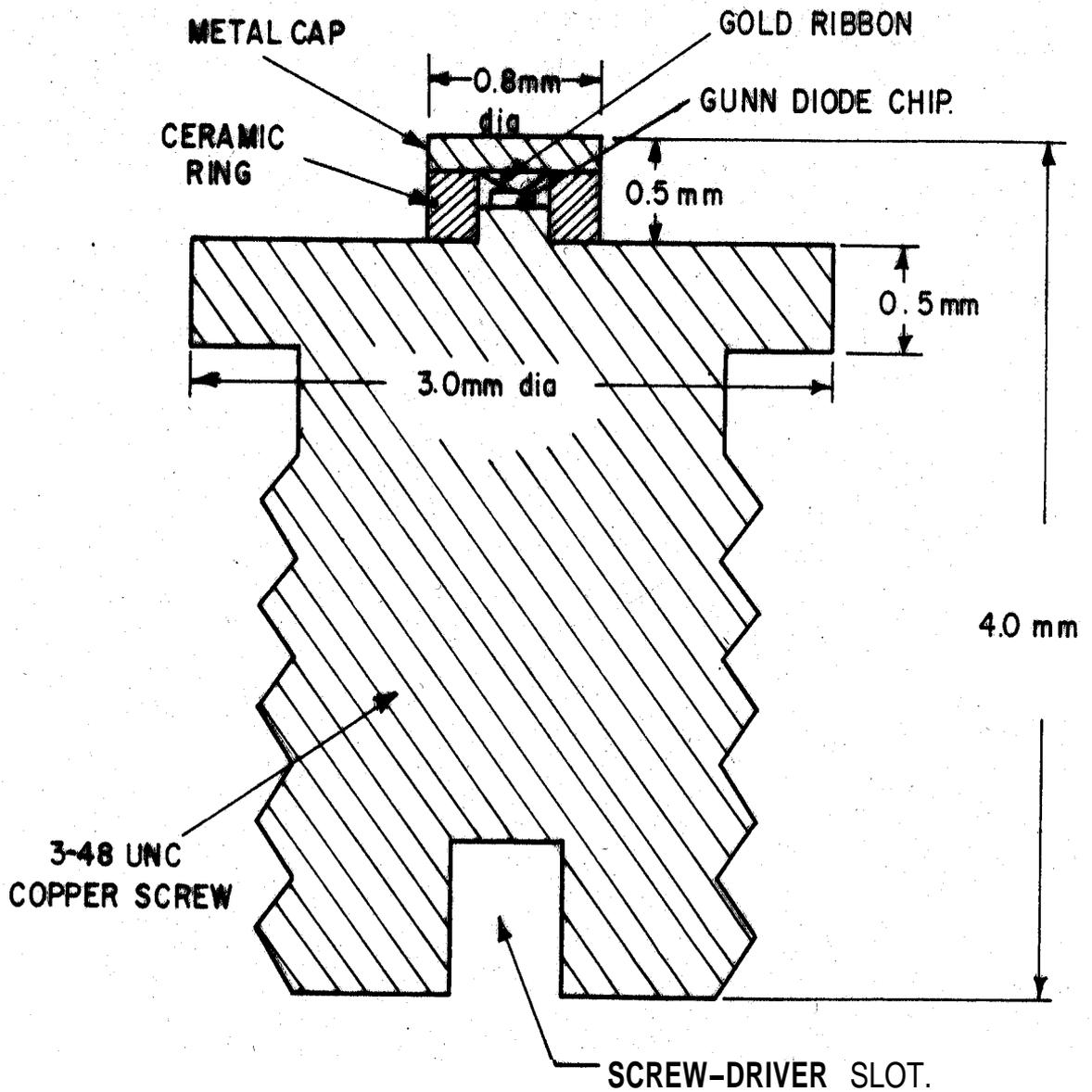


FIG. 2.5 MILLIMETRE-WAVE GUNN DIODE PACKAGE.

A **simplified** lumped equivalent circuit of a millimetre-wave Gunn diode is shown in **figure 2.6**. The device is represented by a negative conductance  $G_N$  in shunt with the **GaAs** dielectric capacitance  $C_G$ . The package **parasitics** are represented by the series inductance  $L_s$  and the shunt capacitance  $C_p$ .

### 2.5 Oscillator design considerations

Gunn diodes are two **terminal** negative resistance devices which require a suitable resonant circuit for generation of microwave power. Oscillation conditions for negative resistance oscillators have been worked out in detail by Kurokawa (1969). These conditions are:

$$R_{\text{diode}}(f) + R_{\text{circuit}}(f) = 0 \quad (2.3)$$

$$X_{\text{diode}}(f) + X_{\text{circuit}}(f) = 0 \quad (2.4)$$

$$\text{and } \frac{\partial X_{\text{total}}}{\partial f} > 0 \quad (2.5)$$

where  $R$  and  $X$  represent resistance and reactance respectively and  $f$  is the oscillation frequency. Oscillation frequency is determined by eq. 2.4 which states that the total reactance at the oscillation frequency must be zero. Equation 2.5 represents a stability criterion. Use of these equations for determining the oscillation frequency of **Gunn** oscillators in practice is rather limited, since both diode and circuit impedances are usually unknown. Therefore, the design of Gunn oscillators is mostly carried out empirically providing a sufficient number of circuit variables. The performance of the

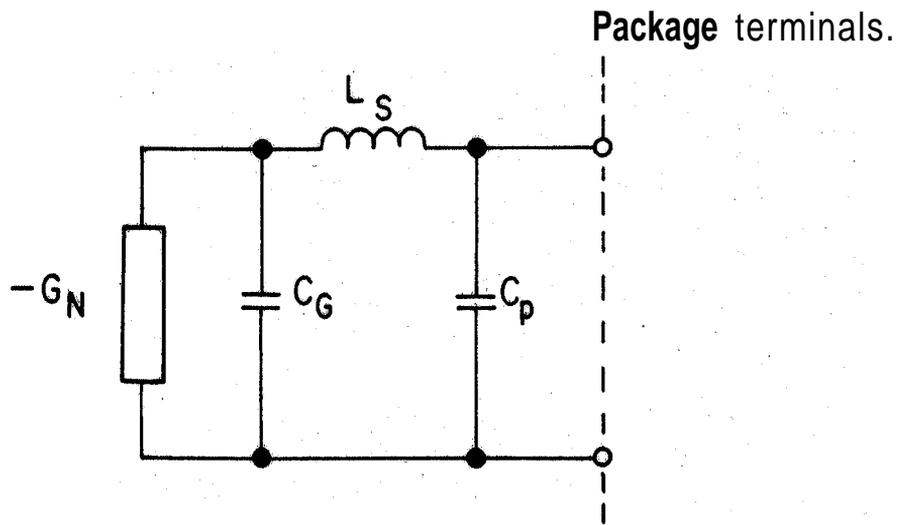


FIG. 2.6 SIMPLIFIED LUMPED EQUIVALENT CIRCUIT OF A PACKAGED GUNN DIODE. (after Bischoff, 1979)

Gunn oscillator is then optimized by experimentally observing the effect of various circuit parameters.

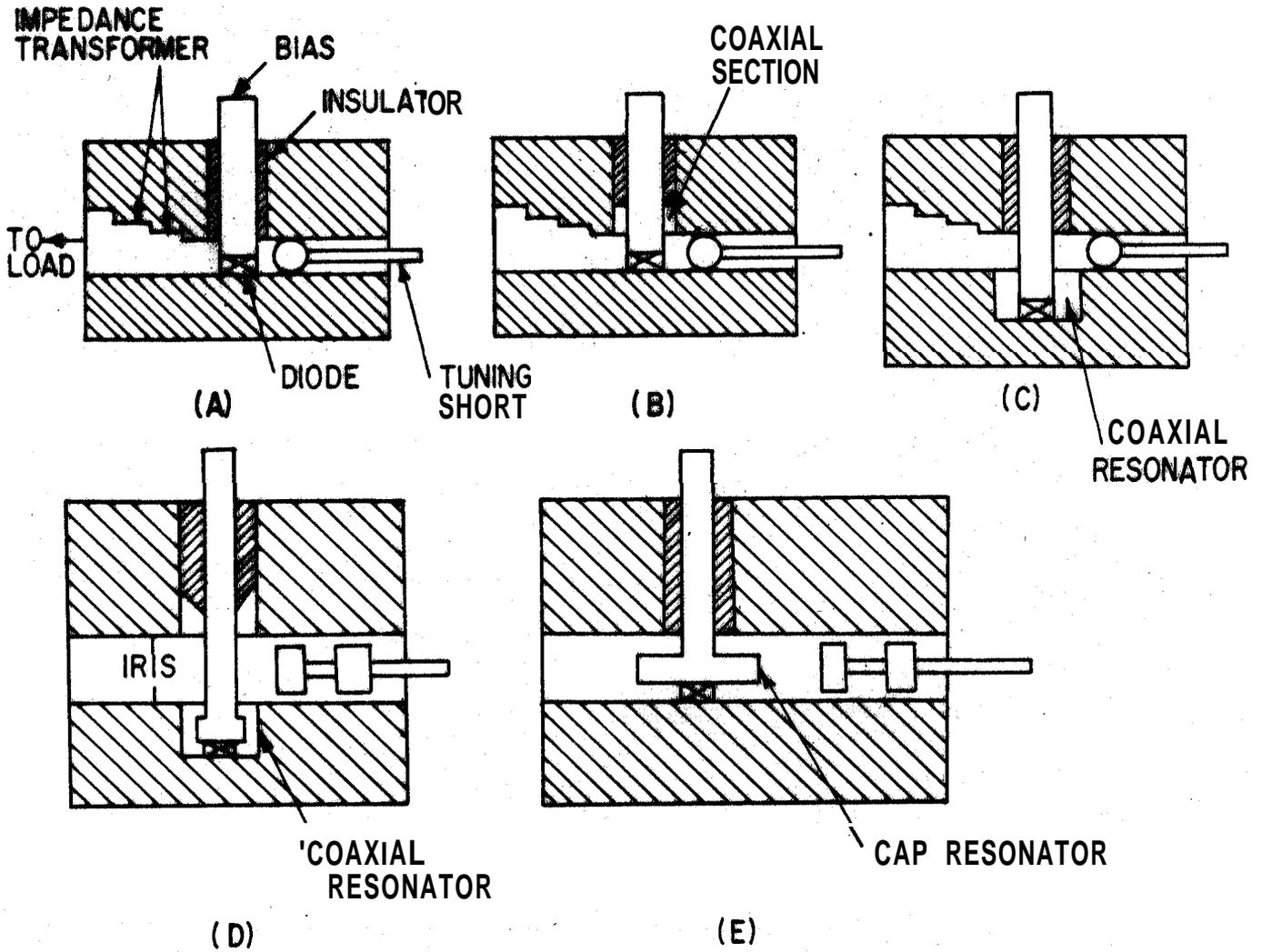
## 2.6 Oscillator circuits

A number of waveguide oscillator circuits have been developed for Gunn and IMPATT diodes at millimetre wavelengths (Kuno, 1981). Some of the popular designs are shown in figure 2.7. The inductive post-coupled circuit of 2.7 (A) has been used extensively for both Gunn and IMPATT diodes. The diode is mounted in a reduced-height section of waveguide and matching to standard waveguide output is achieved by a waveguide step transformer. About 10-20% mechanical tuning of oscillation frequency can be obtained with this circuit by the variable backshort.

In another configuration, given in figure 2.6 (B), a co-axial section is added to the circuit of Fig. 2.6 (A). The co-axial section provides a series impedance to the Gunn diode while the backshort provides a shunt impedance. This helps in better circuit optimization.

In yet another configuration given in figure 2.7 (C), the oscillation frequency is determined by the quarterwave co-axial resonator while the backshort is used for optimization of output power.

An inductive iris is used for output matching in figure 2.7 (D) in place of the step transformer used in 2.7 (C). This results in



**FIG. 2.7 TYPICAL GUNN DIODE OSCILLATOR CIRCUITS.**  
 (after Kuno, 1981)

a better matching of the oscillator output to the load.

The configuration of figure 2.7 (E) has found widespread application for the realization of harmonic mode Gunn oscillators in the 75-110 GHz frequency range (Barth, 1981; Haydl, 1983). The cap along with the bias-post provides a resonator at the fundamental frequency and also acts as a radial line transformer for efficient coupling of the harmonic power to the waveguide output.