Chapter 2

Wide-band Local Oscillator

2.1 Millimeter-Wave Receivers

Fortunately for astronomers, the millimeter wave part of the electromagnetic spectrum is not used for radio communication and most transmitters have low power and narrow beams thus reducing drastically the problem of man made interference. But the millimeter wave astronomers have to contend with the problem of ***atmospheric absorption*** especially due to water vapour and oxygen. As seen in figure 2.1, the atmospheric attenuation over the millimeter wave range shows some windows of low attenuation which the ground based telescopes utilise. The amount of absorption is strongly dependent on the geographical location, and season, through the atmospheric water vapour content. Over the past two decades, better and better receivers have been developed for operation over these low attenuation bands.

The block diagram of a typical millimeter wave receiver is shown in figure 2.2. These are of super-heterodyne design. The first element is a mixer, either of a cryogenic Schottky or superconductor-insulator-superconductor junction design, because low-noise amplifiers at these frequencies have not yet become available. The IF signal is amplified by a cooled low-noise GaAs or HEMT amplifier. Since the mixer is a lossy device, the IF amplifier should have very low noise temperature. The AM side band noise of the LO at the signal and image frequencies also contributes to the receiver noise. The IF signal is then fed to spectrometers after further amplification and down conversion. In this chapter we describe the development of an ultra wide-band Gunn oscillator tunable over the 3-mm atmospheric transmission window for use as local oscillator at the 10.4m millimeter wave radio telescope at the Raman Research Institute, Bangalore. Rotational transitions of many astrophysically important molecules including CO fall in this range.

2.2 Local Oscillator Requirements

The power output requirement of the LO depends on the type of mixer used. Cryogenically cooled mixers using metal-semiconductor junctions (Schottky barrier diodes) as the non-linear element typically require 0.25 mW of CW power for efficient operation. The SIS mixers which are fast replacing the Schottky mixers require less than a microwatt. With the development of quasi-optical diplexers (Erickson 1977) which couple the LO power to the mixer with an insertion loss <1dB, an LO power output of 0.5 mW is adequate. An output of 1 mW will be sufficient to operate a dual polarisation receiver. Low AM sideband noise at the signal and image frequencies will be an advantage, though the diplexers can be designed to have nulls

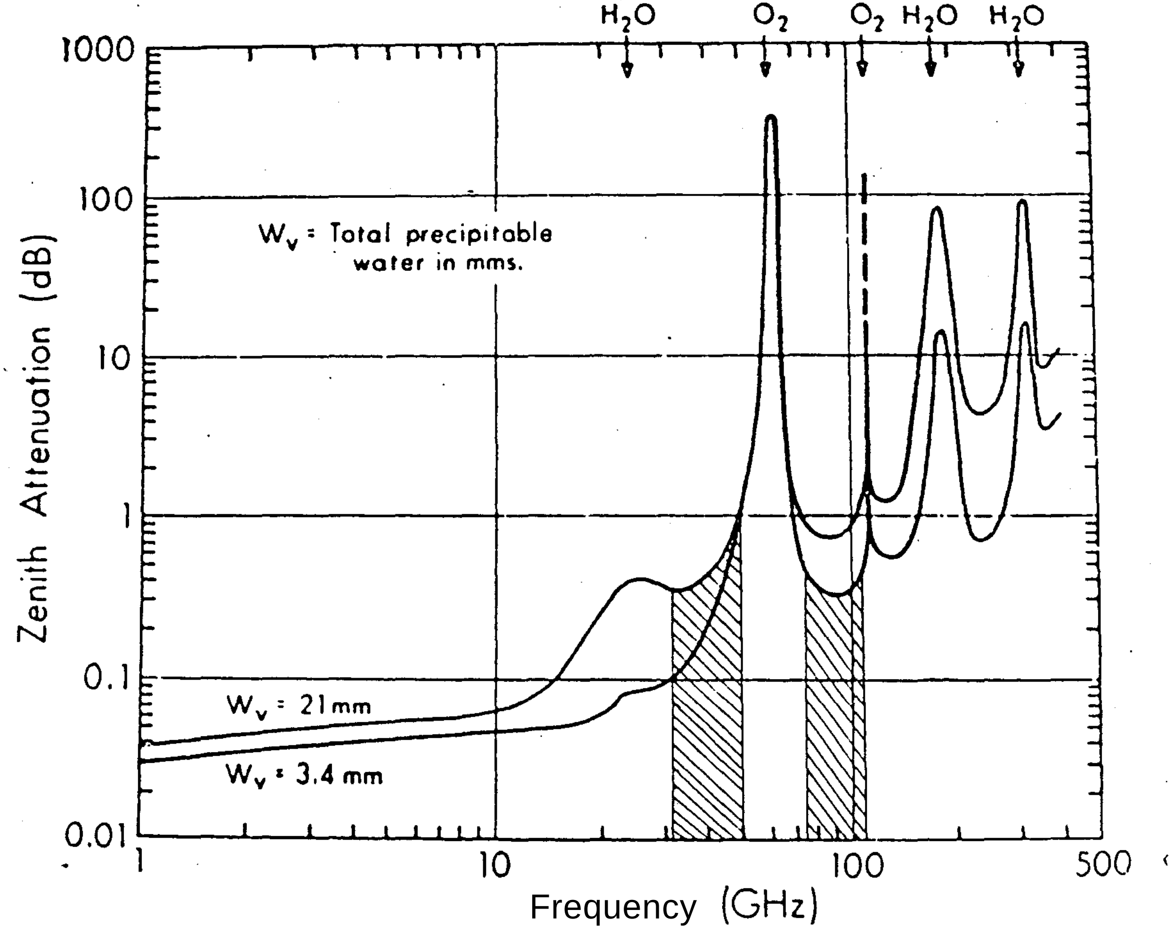


Figure 2.1: Atmospheric attenuation over the millimeter-wave region of the electromagnetic spectrum. The hatched regions are used by ground based telescopes (adapted from Penzias and Burrus 1973).

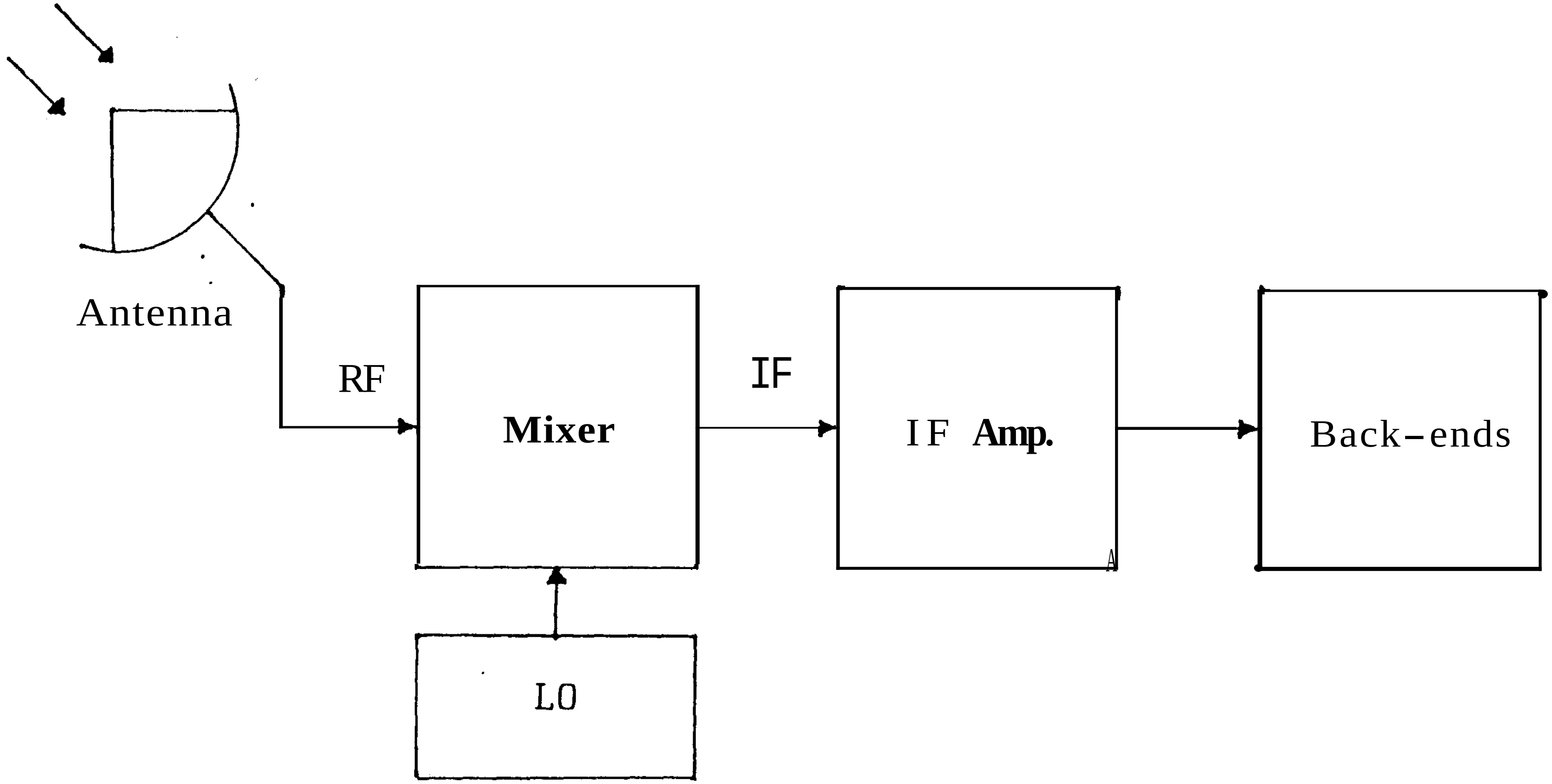


Figure 2.2: **A** block diagram of a typical millimeter-wave receiver.

at these frequencies. Frequency stability is a vital consideration. In other words, it should be possible to easily phase-lock the oscillator to a stable reference. Another important consideration is tunability. Since there are many rotational transitions of a vareity of molecules spread over the 3 mm window, a single oscillator tunable over the W-band will avoid changing local oscillators every time a new line is to be observed. Klystrons, IMPATTS and Gunns are some of the devices used as LOs. We briefly discuss the advantages and disadvantages of these methods of generating LO power.

2.2.1 Klystrons

Until recently millimeter wave reflex klystrons, phase locked to a highly stable reference source, were used as LOs. The limited life time (*500* hours) and the bulky high voltage power supplies and cooling systems required are their main drawbacks. High power output and wide tunability were their main attractions. Only klystrons can give enough power to pump multipliers used to generate sub-mm LO power.

2.2.2 IMPATTS

Local oscillators made using IMPATT diodes are capable of power outputs and tunability comparable to klystrons. They are also cheaper than klystrons and being solid state devices require only low voltage power supplies and no cooling. The main disadvantage of IMPATT oscillators, however, is their excessive noise. Low AM sideband noise can be acheived only over a limited frequency range making a wide band tunable oscillator difficult to realise.

2.2.3 Gunn device

Also called the *transferred electron device*, it exhibits low AM sideband noise comparable to klystrons. It is possible to have tunability over a wide frequency range without any change in the noise level. Like the IMPATT, being a solid state device it requires only low voltage power supplies and no cooling. Electronic tunability of upto 500 MHz is possible by varying the bias voltage with easy phase locking. The main disadvantage of Gunn oscillators is their low power output, but it is enough to operate cryogenic mixers. In adition availability of InP Gunn devices higher power output has become possible.

Clearly the Gunn oscillators meet the requirements of an LO for a mm-wave radio telescope. In the rest of this chapter, we will discuss in more detail the Gunn device and the construction of oscillators using the Gunn device.

2.3 The transferred electron effect

The Gunn diode falls under the general class of devices called negative conductance devices. The device is simply a piece of bulk semiconductor such as GaAs or InP and has no junction. The negative conductance arises due the trasferred electron mechanism operative over a certain range of the voltage applied across this piece of semiconductor. It is called the Gunn diode after 5.13. Gunn who first demonstrated in 1963 one form of oscillation in these devices. The theory of this effect had already been proposed by Ridley and Watkins(1961), and Hilsum(1962).

To understand the origin of negative conductance we refer to figure **2.3** which shows simplified energy band digrams for the widely used III-V semiconductors, GaAs and InP. The conduction band consists of a central valley (primary minimum) and satellite valleys (secondary minima) at energies about half an eV higher than the central valley. Since at room temperature this energy difference is much larger than $k_B T$, the conduction electrons are in the central valley and the satellite valleys are unoccupied. If the material is subjected to an electric field above some critical field of about 3000 Vcm^{-1}, the electrons in the central valley gain enough energy from the field and get scattered into the higher energy satellite valley. The important point now is that the effective mass of an electron in the upper valley is almost 20 times its value in the main valley. making the mobility in the upper valley 20 times less. Therefore the electrons move slower, thus reducing the current. In other words as the applied voltage on a sample of GaAs or InP is increased, the current increases till the field in the sample reaches a critical value, and then begins to decrease with increase in the applied voltage and one has negative differential conductance. The carrier velocity versus electric field characteristics for GaAs and InP plotted in figure 2.4 show clearly the negative conductance region. By scaling the X-axis by the length of the sample used one gets the V-I characteristic. This negative conductance gives rise to sustained oscillations when the device is placed in a suitable cavity.

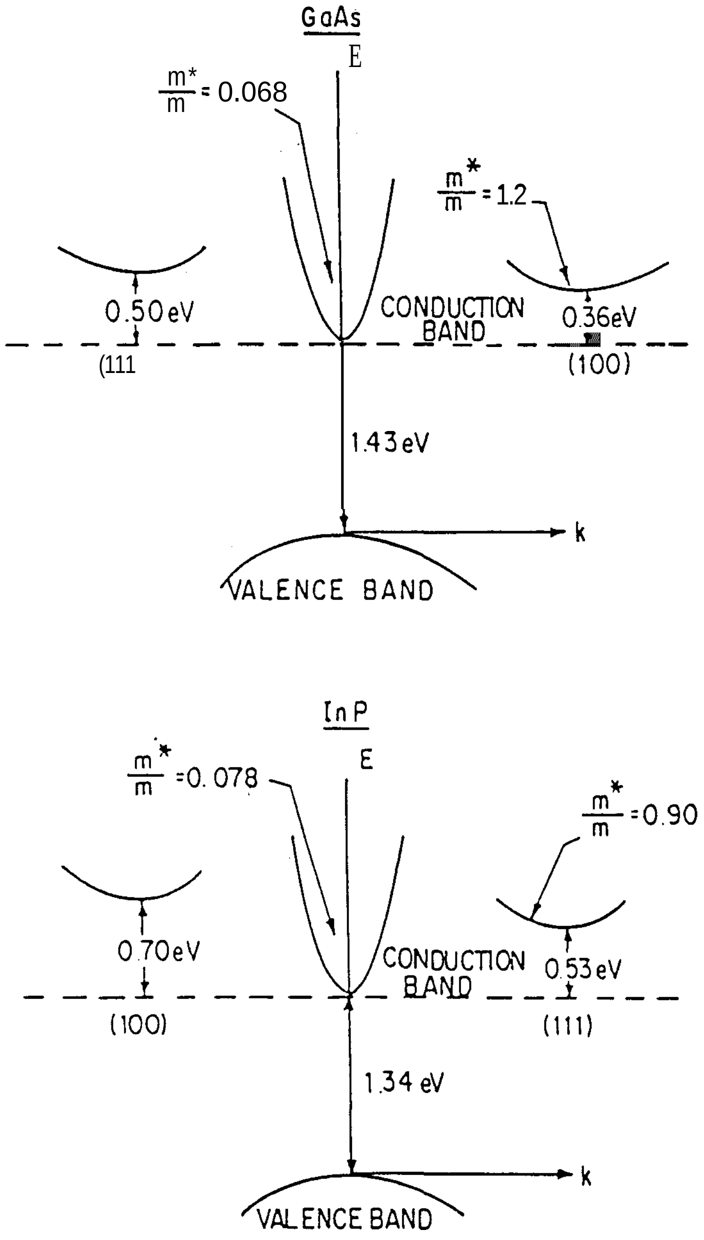


Figure 2.3: Energy band diagrams for GaAs and InP (after Eastman 1976).

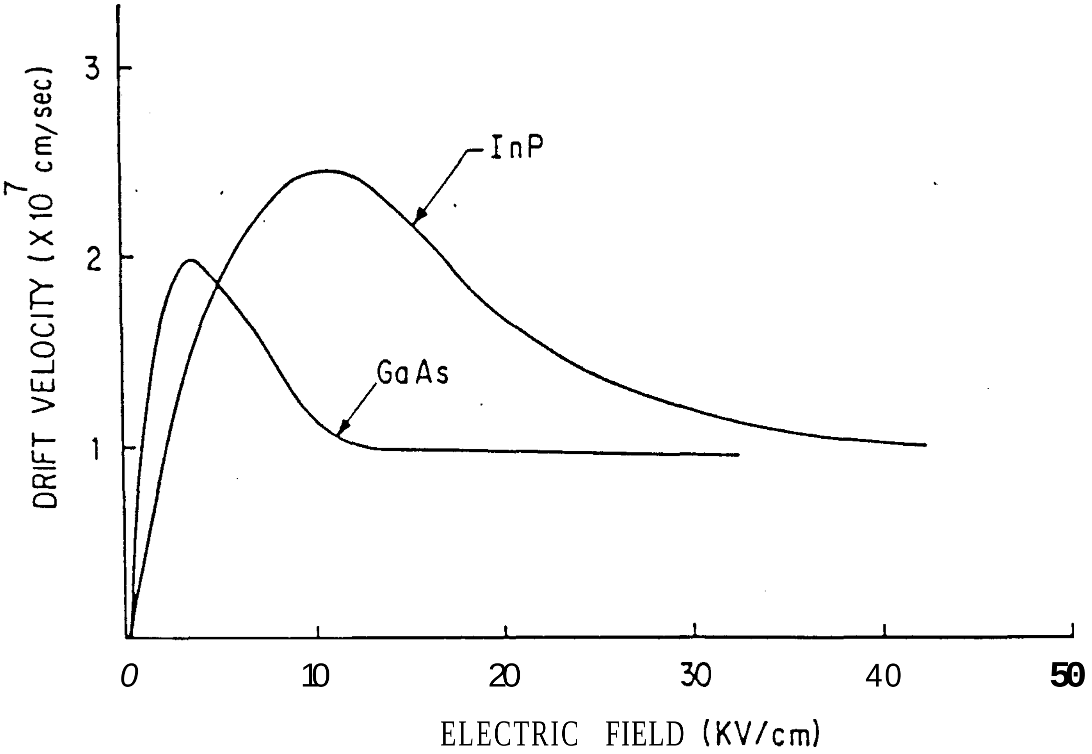


Figure 2.4: Electric field versus drift velocity characteristics for GaAs and InP (after Kuno 1981).

2.4 Oscillator designs for W-band

Nearly all the designs reported in the literature consist of a Gunn diode embedded in a resonator whose fundamental frequency is in the range 30-60 GHz with the second harmonic being coupled out through a waveguide which is below cut-off for the fundamental. The differences are in the design of the fundamental frequency resonator. Tuning is done by mechanically changing the resonance frequency of this resonator. The resonator may be a waveguide cavity tuned by a backshort (Lazarus et *al.* 1981; Barth 1981; Bester, Jacobs and Vowinkel 1983) or a disk and post co-axial arrangement tuned either by inserting a tuning rod near the disk giving a small tuning range (Ruttan 1975; Haydl 1981) or by changing the resonator position resulting in a wider tuning range (Ondria 1979; Arora and Sarma 1984) or by mechanically changing the post length giving the largest tuning range reported so far (Haydl 1983; Carlstrom, Plambeck and Thornton 1984). A second backshort is incorporated in the second harmonic guide which helps improve the power output. Crossed waveguide oscillators with separate waveguides for the fundamental and second harmonic frequencies have been built but with limited tunability (Bester, Jacobs and Vowinkel 1983). The oscillator with a mechanically adjustable post length was chosen for fabrication in view of its excellent performance. Being a second harmonic extraction oscillator, its frequency is not very sensitive to loading because the fundamental is not coupled to the output. This gives enough isolation that there is no need to provide a separate isolator between the LO arid the mixer.

2.5 Wide-band oscillator design

The design of the oscillator described below is the same as that of Carlstrom, Plambeck and Thornton(1985) but for modifications to do away with the miniature linear bearing as described below. Figure 2.5 shows the cross sectional view of the oscillator. It consists of a half-height W-band waveguide with a taper to full-height on one side. The Gunn diode is mounted in a hole drilled in the half-height portion. The lower impedence of the reduced height waveguide improves the matching to the low impedence Gunn diode. A co-axial cavity whose central conductor supplies the bias voltage to the diode, intersects the guide directly above the diode. The bias choke which forms the top wall of the cavity can be moved vertically. The central conductor has a thin disk at the end where it contacts the diode. The motion of the choke changes the length of the cavity giving frequency tuning.

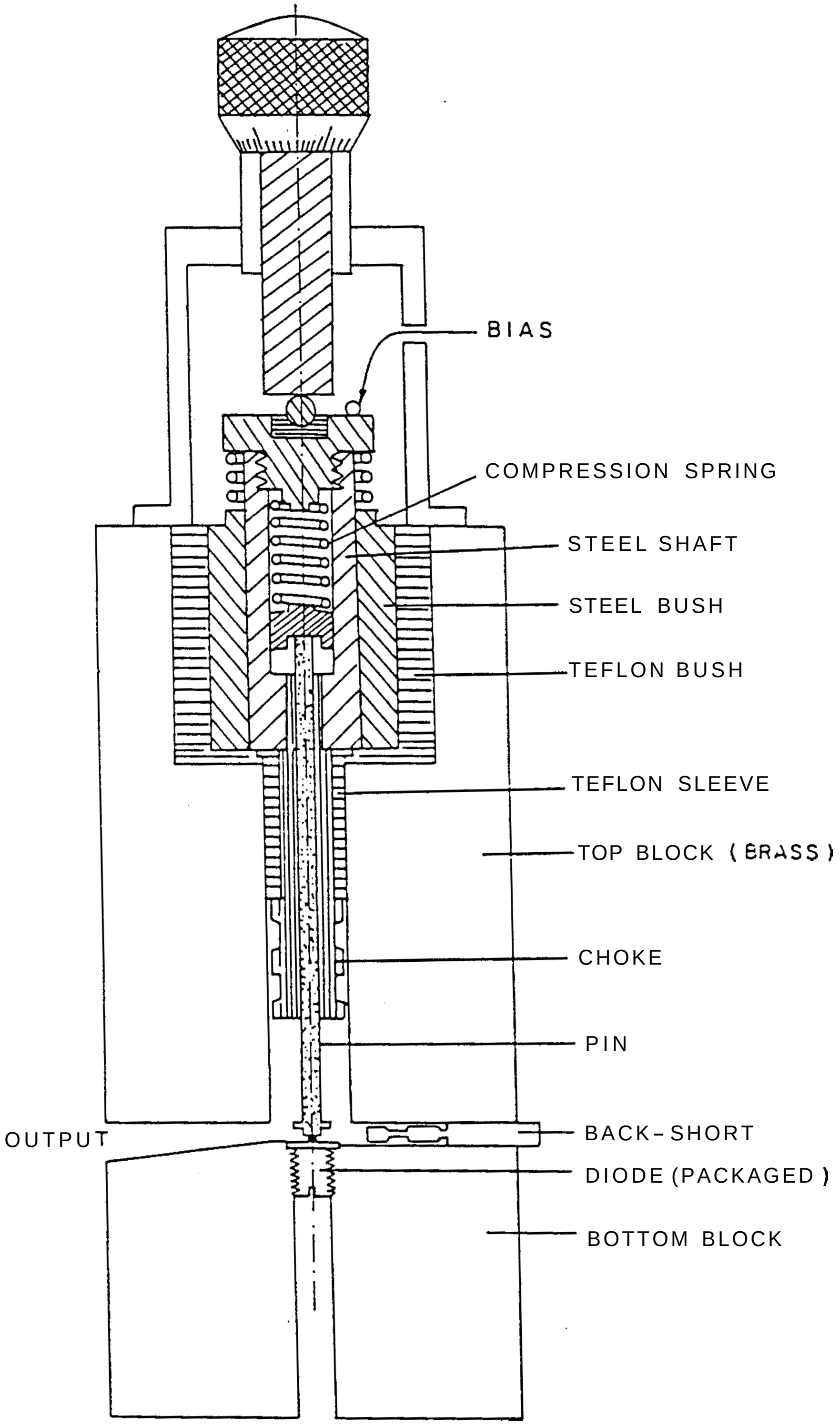


Figure 2.5: Cross-sectional view of the tunable Gunn oscillator (not to scale).

If the diode is placed in the negative conductance region by applying a suitable bias voltage, oscillations build up at the resonance frequency of the circuit formed by the co-axial cavity, the disk, the post and the diode. The parameters are such that this frequency is half the desired output frequency. The oscillations are confined to the cavity because the waveguide is below cut-off for this frequency. But the non-linearity of the diode V-I characteristic results in fields oscillating at the second (and higher) harmonic freequency which the guide propagates. The disk now acts as a radial line transformer helping to match the guide impedance to the diode. The reactive part of the diode impedance is tuned out by the non-contacting backshort provided.

2.6 Fabrication

The fabrication of the oscillator requires extreme care, especially because the choke sections with small airgap ~ 50 micron (crucial for the output power level) should be able to move without touching the outer wall. The oscillator is fabricated as a split block in brass. First two cylindrical brass blocks are fixed together with screws and dowels in the bottom block. The diode mounting hole is drilled first extending upto the top block. The bottom block is then removed and the hole in the top block is reamed to 2.95mm to form the outer wall of the co-axial cavity. This ensures that the co-axial cavity is centered above the diode. The outer surface of the block and the hole are machined in one setting and hence are concentric. Then the top face of the top block is bored to receive the teflon bush, with the outer diameter of the block dialled to ensure concentricity. Then the teflon bush is press fitted to this hole and bored to receive the steel bush. The steel bush is made out of oil hardening non-shrinking steel (OHNS), hardened and made smooth by grinding and lapping the inner surface. Hardening is necessary to acheive low wear. This steel bush is press fitted into the teflon bush.

The next operation is to mill the waveguide in the bottom block with the taper on one side. The steel shaft which carries the choke is seperately machined out of OHNS, ground, lapped and hardened. It has a central hole to accomodate the compression spring. Its outer diameter is such that it makes a smooth sliding fit to the steel bush. An over-sized teflon sleeve and brass rod are assembled together and press fitted to the steel shaft. The brass rod is then machined to form the choke after dialling the steel shaft to ensure concentricity. This should be done accurately to avoid the choke shorting while tuning. Finally a central hole is drilled through the choke for the pin and lapped. The pin is separately machined out of brass to make a snug fit to this hole. A wire is soldered to the steel bush and brought out for bias supply. We have shown if figures 2.6 a,b,c and d the fully assembled oscillator and split views.

2.7 Performance

The oscillator was tested in a set-up consisting of an attenuator, a wavemeter and a power-head. Pins with different disk diameters were tried and the one that gave the best performance was chosen and different diodes were tried. It was found that even diodes of the same type from the same batch gave markedly different power outputs and tuning ranges. It became clear that every time a new diode is to be used some experimentation is necessary with the pin before one gets optimum performance. The way the characterictics of the oscillator would change with pin dimensions is predictable to a large extent based on previous work and is also understood phenomenologically (see, for expample, Arora 1984).

A 35 GHz diode made by Microwave Associates (MA49713) performed best. Its tuning and power curves are shown in figure 2.7. The phase lock system described by Arora(1984) was used to lock the oscillator using the bias tuning property of the Gunn oscillators.

2.8 Conclusion

An ultra wide-band mechanically tunable Gunn oscillator of simplified construction based on a design by Carlstrom, Plambeck and Thornton(1985) has been fabricated for use as local oscillator with low-noise receivers for the 3 111111 atmospheric transmission window. It gives a CW power output of at least 1 mW which is more than adequate for pumping a low-noise Schottky mixer, covering the frequency range 75-115 GHz. It has been successfully phase-locked to a highly stable VHF reference source using the bias tuning property of the oscillator.

Figure 2.6 (a): A fully assembled Gunn oscillator.

Figure 5.2 (b) A pseudo color image of the kinetic temperature distribution over CG22-Blob-1. The scale is in units of Kelvin.

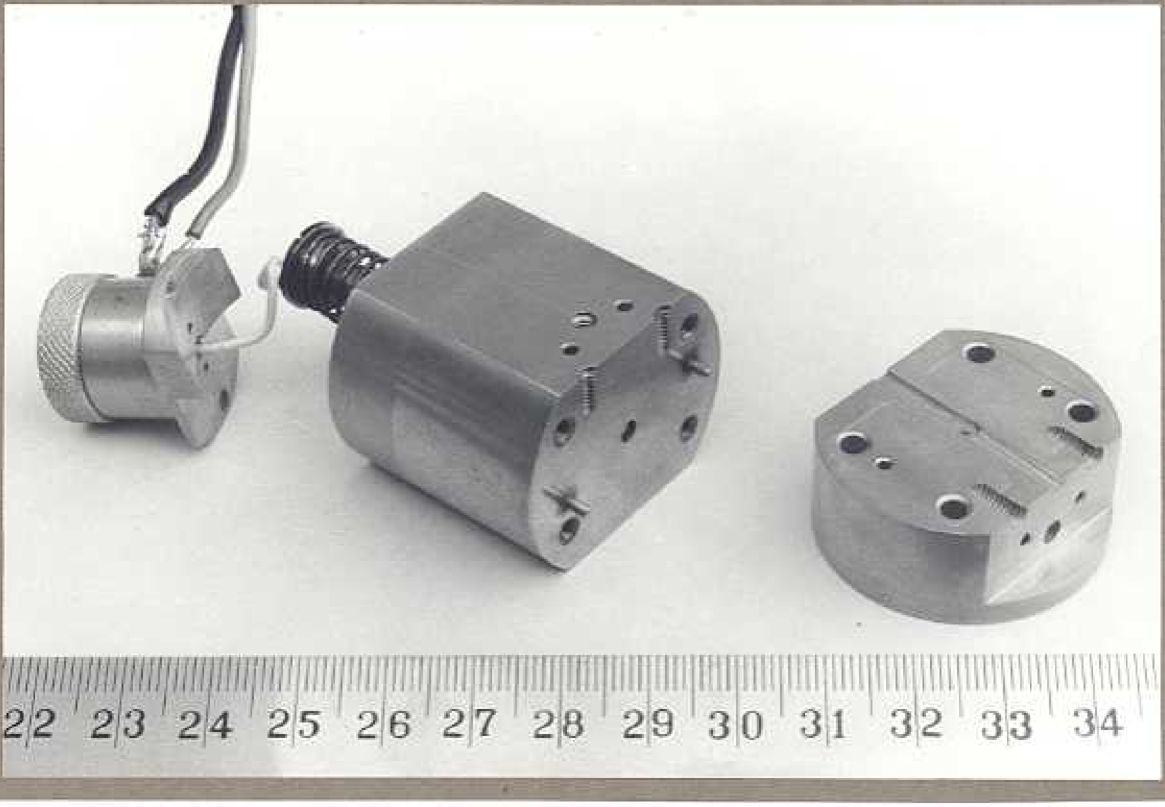


Figure 2.6 (c): Split view of the Gunn oscillator showing the Gunn diode mounted in the waveguide.

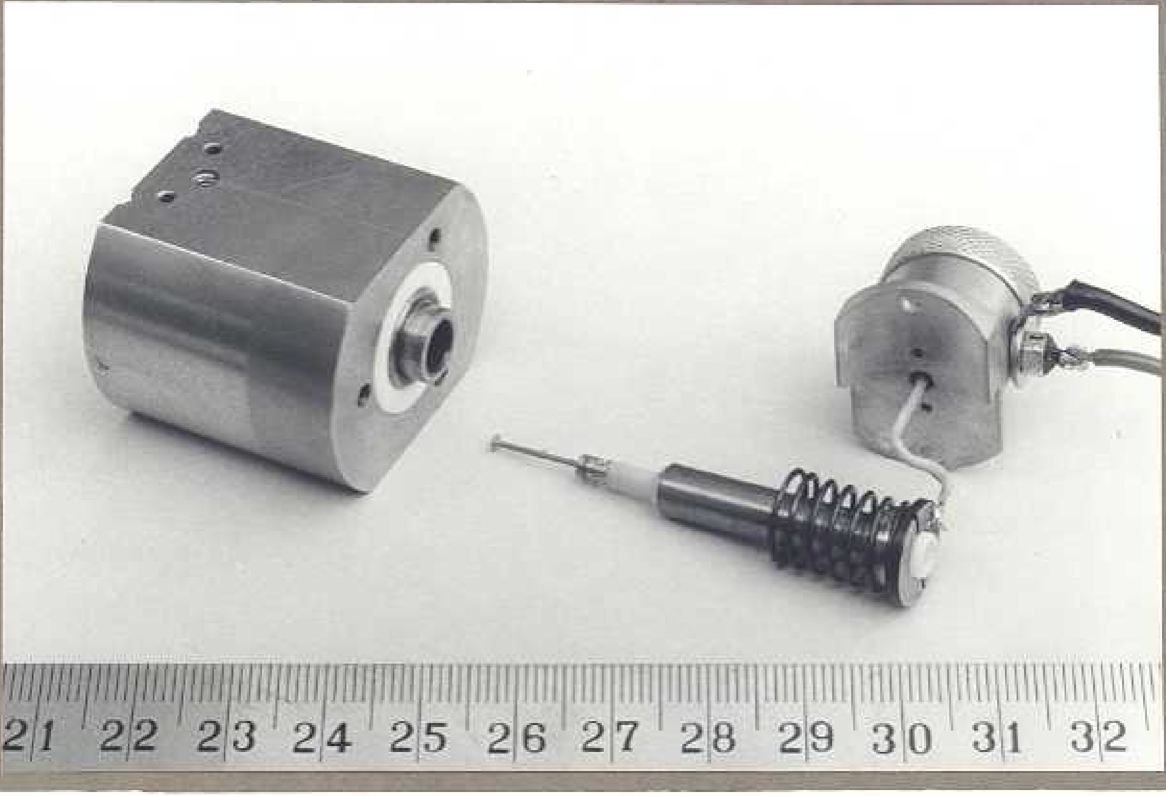
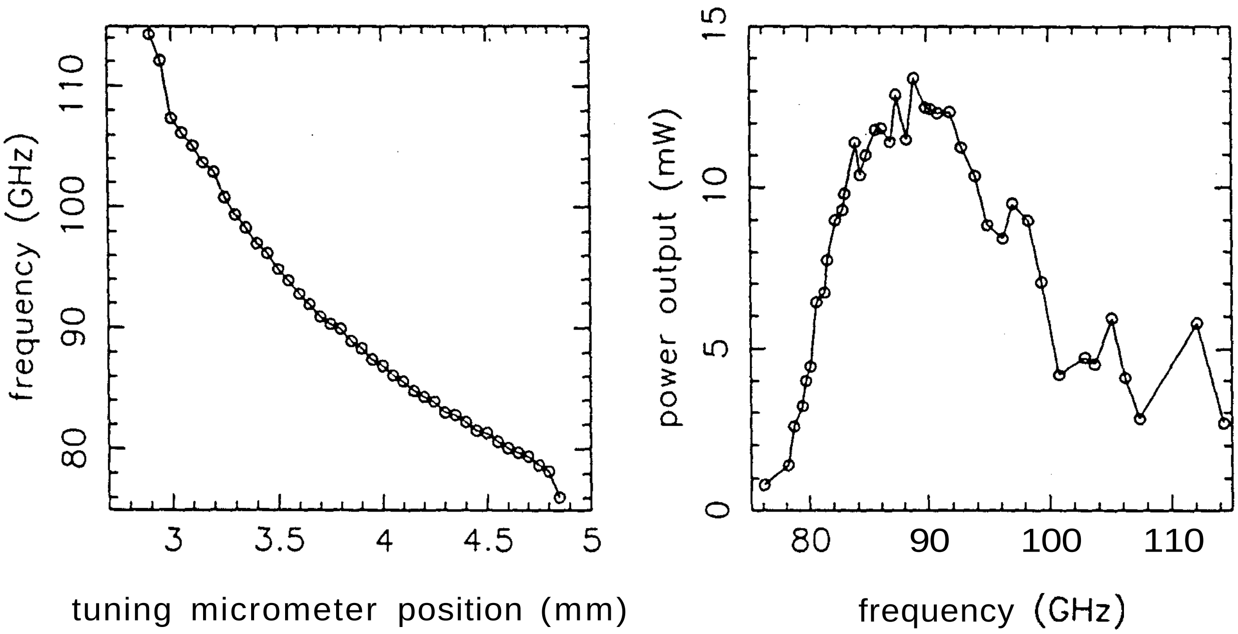


Figure 2.6 (d): Split view of the Gunn oscillator showing bias choke mounted on the movable steel shaft and the pin.



(a) (b)

Figure 2.7: (a) Tuning curve of the tunable oscillator. The tuning micrometer position is with respect to an arbitrary reference. (b) Power output of the oscillator. The tuning backshort and the bias voltage were optimised to get maximum power output.

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