CHAPTER 5

AM SIDEBAND NOISE MEASUREMENT

5.1 Introduction

The output power spectrum of a practical oscillator departs from an ideal spectral-line due to the presence of noise. To facilitate noise measurement it is convenient to treat the effect of noise as a modulation of the oscillator output frequency (carrier) by a broadband modulating signal (noise). This results in the generation of noise sidebands. Noise sidebands may be split-up into amplitude modulation (AM) and frequency modulation (FM) components (Ondria, 1968). AM noise of oscillators is usually expressed as a ratio of the power in the noise sideband in a fixed bandwidth to the carrier power at a particular modulation frequency. FM noise is generally given as a root mean square frequency deviation measured in a fixed bandwidth at a modulation frequency away from the carrier.

For modulation frequencies close to the carrier, both FM and AM noise are important, while for frequencies far away from the carrier (>10 MHz) AM noise usually predominates (Ashley et al, 1968). The AM sideband noise of a local oscillator can be eliminated by the use of a balanced mixer. In a balanced mixer, the lower noise-sideband is 180° out of phase with the upper noise-sideband at the IF port and therefore they cancel each other (Ondria, 1968). However, at millimetre wavelengths, the realization of balanced mixers is quite difficult.

As pointed out in chapter 1, millimetre-wave radio astronomy receivers usually employ Schottky diode mixers of single-ended design with intermediate frequency of 1.4 GHz. Therefore, AM sideband noise of local oscillator at 1.4 GHz away from the carrier affects receiver performance. This is illustrated in figure 5.1. The sideband noise power contained in the receiver bandwidth Δf at 1.4 GHz away on both sides of the local oscillator frequency gets converted to the IF by the action of the single-ended mixer thereby worsening receiver noise performancce. The local oscillator sideband-noise may be particularly serious in ultra low-noise cooled receivers where it may be the dominant source of noise. An accurate measurement of AM sideband noise of the local oscillator source at the intermediate frequency (1.4 GHz away from the carrier) is therefore necessary to evaluate its effect on receiver performance and to take corrective measures.

AM noise measurement of millimetre-wave oscillators is generally carried out by directly detecting the oscillator signal with a square-law detector and analyzing the output with a low frequency wave analyzer (Weller, 1973). This method is quite satisfactory for AM noise measurements for modulation frequencies between 10 Hz and 10 MHz. However, AM noise measurement at modulation frequencies above 10 MHz is best carried out by heterodyne detection.

The AM sideband noise measurement of millimetre wave Gunn oscillators and klystrons at 1.4 GHz away from the carrier using a millimetre-wave low-noise mixer and a calibrated IF radiometer

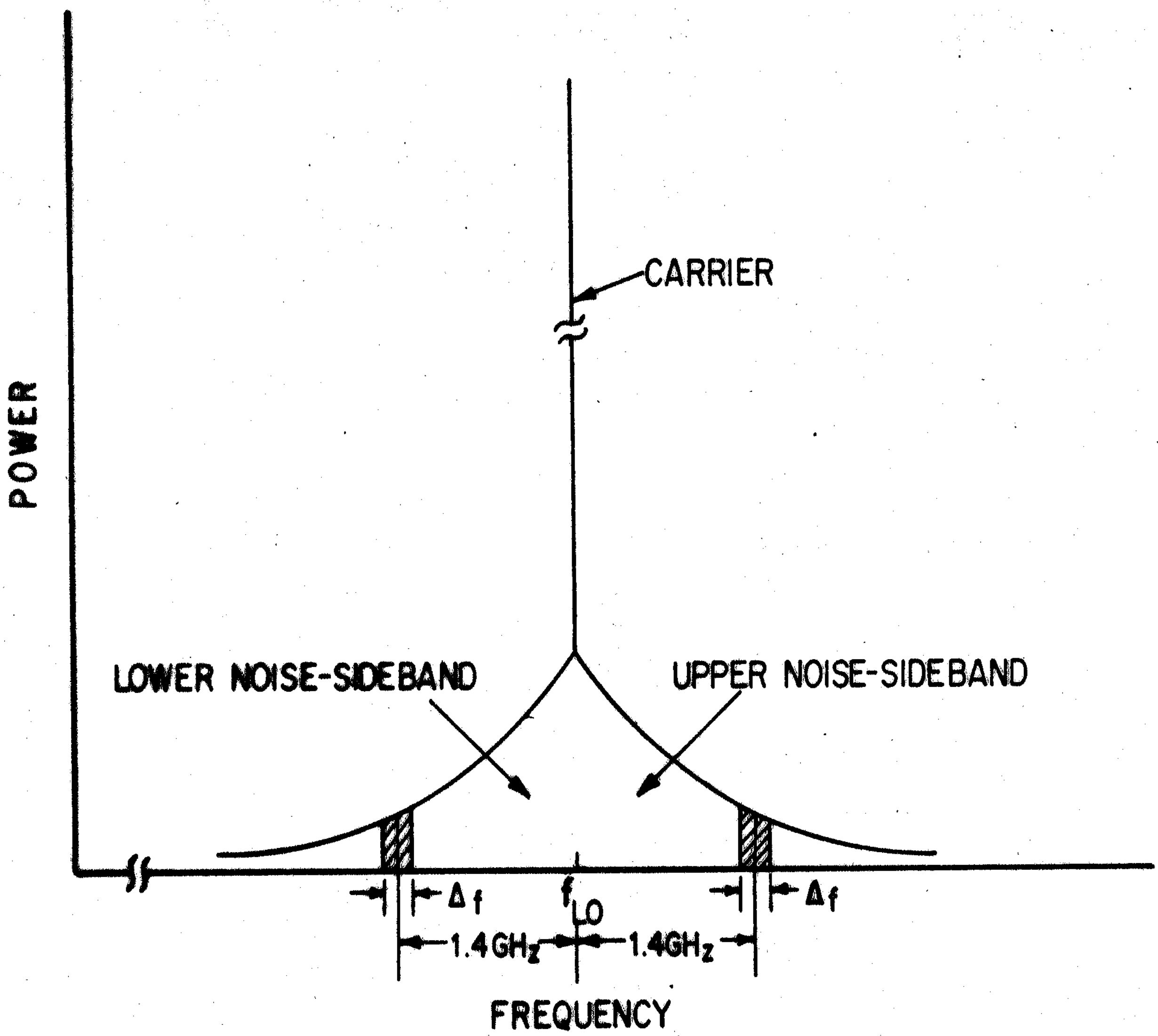

FIG. 5.1 TYPICAL OUTPUT POWER SPECTRUM OF A MILLIMETRE-WAVE OSCILLATOR.

is described in this chapter. The method used here is similar to the one employed by Cong and Kerr (1979).

5.2 Noise measurement set-up

The noise measurement setup is shown in figure 5.2. It consists of a low-noise millimetre-wave mixer and an IF (1.4 GHz) radiometer calibrated to give the IF noise temperature directly in degrees Kelvin. Noise powers are usually expressed as equivalent noise temperatures in radioastronomy for convenience. Noise power can be readily obtained from the equivalent noise temperature by the following expression:

$$P_N = k\ T_N\ B \qquad (5.1)$$

where P_N is the noise power in watts.

T_N is the noise temperature in degrees Kelvin.

B is the bandwidth in Hertz

and k is the Boltzmann constant in watts per degree Kelvin per Hertz.

The millimetre-wave mixer used for noise measurement is similar to the one used in a radio astronomy receiver. It consists of a whisker contacted Schottky barrier diode mounted in a metal waveguide of appropriate dimensions. The mixer is of single-ended design and has only one waveguide input port, Local oscillator power from a low-noise millimetre-wave reflex klystron is coupled to the mixer through a resonant-ring diplexer of a design similar to that developed by Davis (1977). The diplexer also acts as a bandpass filter and reduces the AM sideband noise of the klystron at 1.4 GHz away from the carrier by at least 20dB. A horn connected to the RF port of the diplexer couples the noise power from hot-cold calibrating loads to the mixer input.

The I.F. radiometer at 1.4 GHz is a low-noise receiver of a design similar to that used by Weinreb and Kerr (1973). It is calibrated to read the IF noise temperature directly in degrees Kelvin. The radiometer also has a provision to determine the mismatch of the mixer IF output with respect to the radiometer input impedance of about 50 ohms. It does this by injecting noise power from a noise-diode (contained in the radiometer) into the IF port of the mixer and measuring the reflected power. The IF noise temperature can therefore be corrected for the mismatch. However, residual mismatches within the IF radiometer limit the overall accuracy to about 10%.

5.3 System calibration

The unknown parameters in the noise measurement setup shown in figure 5.2 are the mixer input noise temperature T_M and the mixer conversion loss L (greater than unity). These are determined by placing hot-cold loads at the input of the horn and measuring the mixer IF output noise temperature. Since there are two unknowns (T_M and L), two calibrated input noise sources are required for determining them. Eccosorb, a microwave absorber at room temperature (295K) and dipped in liquid nitrogen (77K) provide the two calibrated noise sources. The local oscillator power level is adjusted to 2mW

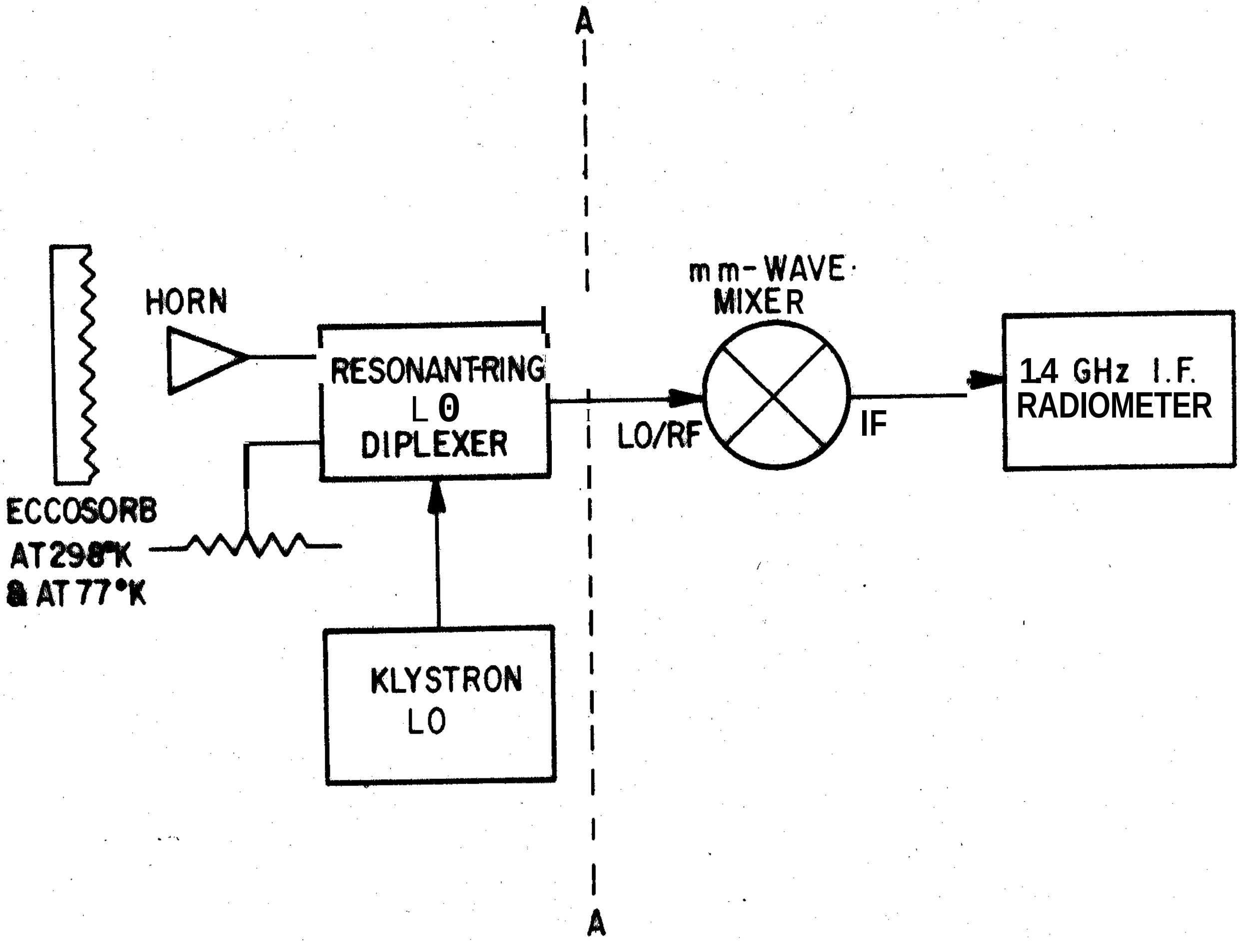

FIG. 5.2 AM SIDEBAND NOISE MEASUREMENT SETUP - SYSTEM CALIBRATION.

at the plane AA [refer figure 5.2) during this measurement. A forward d.c. bias of 0.6V is also applied to the mixer for optimum performance. Once T_M and L are known, the measurement of AM sideband noise of oscillators is relatively simple.

5.4 Noise Measurement

The oscillator under test is connected to the measurement setup through a precision variable attenuator as shown in figure 5.3. The oscillator power level is adjusted to 2mW at the plane A-A using the precision variable attenuator and the IF noise temperature is noted. In this case, the carrier of the oscillator signal acts as the local oscillator while the noise sidebands behave as the RF signal to'be converted to IF. The IF noise temperature T_{IF} is, therefore, related to the AM sideband noise of the oscillator by the following expression:

$$T_{IF} = \frac{1}{L} (T_M + 2T_{N(LO)}) \qquad (5.2)$$

where $T_{N(LO)}$ is the noise temperature in each AM noise sideband of the oscillator at 1.4 GHz away from the carrier. Rearranging equation 5.2 gives

$$2T_{N(LO)} = (LT_{IF} - T_M) \qquad (5.3)$$

Equation 5.3 gives the AM sideband noise temperature $T_{N(LO)}$ as measured at the plane A-A. To determine the AM sideband noise temperature $T_{N(O)}$ as seen at the oscillator output port, the attenuation setting of the precision variable attenuator must be known. If X is the attenuation factor (> 1) between the oscillator and the mixer,

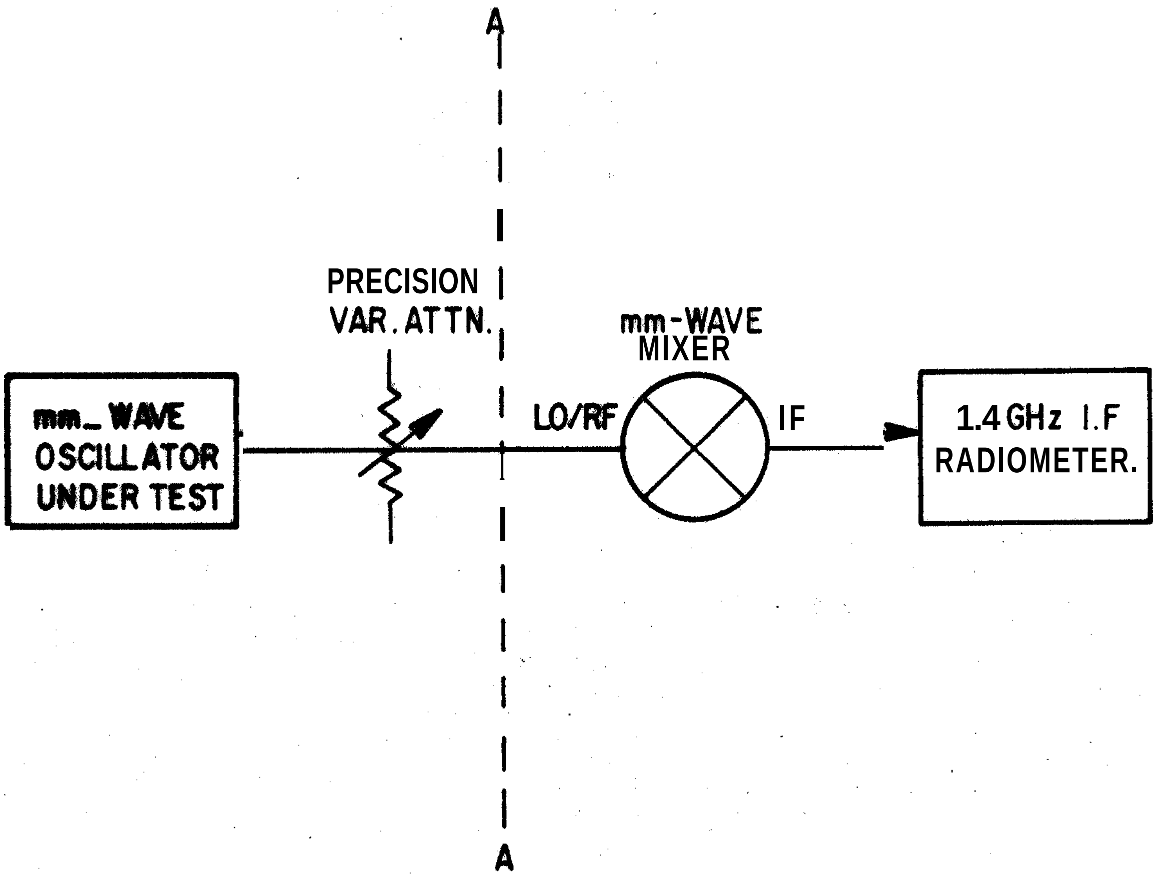

FIG. 5.3 AM SIDEBAND NOISE MEASUREMENT SETUP - NOISE MEASUREMENT.

then

$$2T_{N(O)} \quad 2T_{N(LO)} X - 2(X-1) T_o \qquad (5.4)$$

where T_o is the ambient temperature (295K). The noise temperature obtained from equation 5.4 is converted to sideband-noise power in a 1 KHz bandwidth by using equation 5.1. Since the oscillator output power is also known, DSB AM sideband noise-to-carrier ratio is determined and expressed in the standard decibel notation.

Table 5.1 summarizes the results obtained from AM sideband noise measurements carried out on a number of millimetre-wave Gunn oscillators as well as klystrons. The results clearly indicate that the AM noise performance of Gunn oscillators is better than that of the best available klystrons at these wavelengths. The DSB AM sideband noise to carrier ratio for Gunn oscillators in 1 KHz bandwidth at 1.4 GHz away from the carrier is found to be around -145dBc. This is 6dB less than that of the Varian klystron and 12dB less than that of the OKI klystron. Although the absolute value of AM noise to carrier ratio may be subject to the inaccuracies of the measuring system, the relative comparison of the noise performance of various oscillators is quite accurate. These results also invite comparison with the measurement of Tully et al (1978) where they reported DSB AM, sideband noise to carrier ratio of -140dBc in 1 KHz bandwidth at 1 GHz away from carrier for a 94 GHz Gunn oscillator.

5.5 Discussion

The AM sideband noise temperature as seen by the mixer ($2T_{N(LO)}$)

TABLE 5.1: RESULTS OF AM SIDEBAND NOISE MEASUREMENTS ON VARIOUS MILLIMETRE-WAVE OSCILLATORS

Sl. No.	OSCILLATOR TYPE	f_o GHz	P_o mW	T_M K	L ratio	T_{IF} K	$2T_{N(LO)}$ K	X ratio	$2T_{N(O)}$ K	DSB noise to carrier ratio in 1 KHz BW 1.4 GHz from carrier dB_c
1.	GUNN OSC.-I	83.4	11.3	1116	5.1	360	727	5.7	2737	-145
2.	GUNN OSC.-II	87.5	6.6	1041	5.1	390	956	3.3	2476	-143
3.	GUNN OSC.-III	92.4	15.9	911	5.1	317	712	8.0	3611	-145
4.	OKI KLYSTRON MODEL 90V11	85.5	15.0	1254	5.4	1556	7148	7.5	51696	-133
5.	VARIAN KLY-STRON MODEL VRB-2113B	90.0	5.5	1031	4.9	650	2141	2.8	5372	-139

for Gunn oscillators has been found to be of the order of 1000K for 2mW power levels (refer table 5.1). This will add directly to the receiver noise temperature, if no filter is provided in the local,oscillator path. However, the resonant-ring LO diplexer employed in millimetre-wave radio astronomy receivers gives about 20dB rejection.for the 'noise sidebands. Therefore, the net contribution of the LO sideband noise to receiver noise temperature reduces to about 10K. This may be acceptable'for the cooled Schottky diode illimetre-wave receivers which give SSB receiver noise temperatures of the order of 150K (Raisanen et al, 1981). Additional filtering of LO may be required for superconducting tunnel junction receivers giving receiver noise temperatures of about 50K (Pan et al, 1983).

It is also seen from table 5.1 that the sideband noise contribution of the Gunn oscillators is much less than that of the klystrons. Therefore Gunn oscillators can provide a reliable solid-state alternative to the klystrons for local oscillator application in low-noise millimetre-wave fadio astronomy receivers.