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RADIOMETER HARDWARE AND CALIBRATION TECHNIQUE

2.1. Introduction :

Radiometers, at microwaves and millimeterwaves are highly sensitive receivers capable of measuring very low level of thermal emissions from atmospheric gases and also from any material media. Unlike radars, they can measure noiselike incoherent signal expressed in terms of 'brightness temperature' of the scene within antenna main beam. Since both water vapour and oxygen are having emission lines in the microwave and millimeter band, they contribute significant attenuations to the millimeter-wave communication, particularly when the frequency coincides with the resonance lines. To decide the fade margin, measurement of these two gases under widely varying weather conditions are extremely important. Such radiometers are, therefore, excellent tools for wave propagation studies as well as for remote sensing of atmospheric gases. Both space-borne and ground-based radiometers are found to be quite useful for studying dynamic variation of these parameters in the atmosphere continuously except for some brief periods during heavy rains when antenna temperature approaches room temperature used as a reference. Such problems can be partially avoided by absorption mode of measurement using sun as a source, when rain attenuation upto about 15 dB can be sensed by the radiometer.

Satellite borne earth looking radiometers can provide vital information on earth's surface feature, soil moisture, vegetation, sea surface temperature and also imaging on a large scale basis. In practice, radiometers can operate within a small band of frequency with higher accuracy and each frequency band has it's own merit in terms of information that can be extracted from the scene under observation. Therefore, sometimes, a multifrequency system is preferred to a single frequency system in order to collect comprehensive information of the target being sensed.

2.2. Radiometer Concept :

All material media including gases radiate thermal noise above absolute zero. Such noise power increases with physical temperature (T) of the source and is governed by the Nyquist's theorem as,

$$P = kTB \tag{2.1}$$

where k is the Boltzman constant and B is often called noise bandwidth. The radiated noiselike power can be measured with radiometers as brightness temperature when the emitted power is considered as noise power produced by a resistor equal to the radiation resistance of the antenna. The antenna temperature, T_a is related to the brightness temperature of the source $T(\theta,\phi)$ as given by,

$$T_a(\theta,\phi) = \frac{1}{4\pi}\int_{4\pi} T(\theta,\phi)G(\theta,\phi)d\Omega \qquad (2.2)$$

where $G(\theta, \phi)$ is the antenna gain expressed as a function of θ and ϕ, in the orthogonal planes of r, θ, ϕ co-ordinate system. If the source is broader than the antenna beam width and the temperature distribution $T(\theta,\phi)$ slowly varying across the planes θ and ϕ, then the Eqn.(2.2) may be modified as,

$$T_a(\theta,\phi) = \frac{T(\theta,\phi)}{4\pi}\int_{4\pi} G(\theta,\phi)d\Omega \qquad (2.3)$$

$$= T(\theta,\phi)$$

since, $\frac{1}{4\pi}\int_{4\pi} G(\theta,\phi)d\Omega = 1$, by the definition of antenna gain

In case, the source width is less than the antenna beam width, a part of the beam will be filled up by the source and the 'beam fill factor' would be less than unity. In such cases, the apparent temperature of the source should be lowered by a factor $(\theta_c/\theta_b)^2$ when $\theta_c << \theta_b$. If the source be the sun, which has angular width 0.5° and the antenna beam width is 22°, then the apparent solar brightness temperature should be reduced by a factor,

$$\left(\frac{0.5}{22}\right)^2 = \frac{0.25}{484} \approx \frac{1}{2000}$$

Assuming temperature of sun being 6000 K, the apparent temperature will be 6000x1/2000 = 3K. This dilution of the brightness temperature of an antenna beam broader than that of source is, therefore, utilised to compensate the effect of sun when emission mode of measurement is done by a zenith looking radiometer. It may be mentioned here that, if θ_c is comparable to θ_b then the integral in Eqn.(2.2) has to be worked out. This technique is called emission mode of measurement.

2.2.1. Absorption mode radiometry :

Absorption mode of measurement is done through tracking the sun with a narrow beam radiometer so that it can accommodate sun to its maximum extent. The emission noise of the sun reaches the earth after being attenuated by the earth's atmosphere. Therefore, the apparent temperature as received by a ground based radiometer will be somewhat less than the true brightness temperature of the sun. If the sun could be precisely tracked with a narrow beam radiometer antenna throughout the day, then from radiometer output atmospheric attenuation can be found out as a function of zenith angle. A simple formula can be used for this purpose,

$$\alpha = 10 log_{10} \frac{T_m}{T_m - T_a} \tag{2.4}$$

where T_a is the antenna temperature in the emission mode and T_m is the mean atmospheric temperature which is a function of location, season and time of the day. For temperate latitude, T_m may be assumed to be 275 K and for tropical latitude $T_m = 280$ K would be reasonably accurate.

2.2.2. Absorption mode of measurement during rain :

During heavy rain absorption mode of radiometric observation may pose some problems due to the fact that the mean atmospheric temperature T_m

tends to increase somewhat. *Zhang et al.* [1985] have studied the increase of mean atmospheric temperature with rain rate. Besides this, radiometric sensing becomes inaccurate as rain rate goes high. An alternative method suggests the use of satellite based high power noise transmitter instead of sun as a source. The transmitter power is deliberately maintained at high level so that the noise power transmitted through the rain medium may be well above the emission noise of the rain medium. To achieve this, a broad band noise source may be used in the transmitter covering the bandwidth of the radiometer. Alternatively, a satellite up-link or down-link may be used to measure the rain attenuation with unmodulated carrier transmission and a narrow band receiver for the transmission, avoiding the radiometer.

2.3. Dicke type radiometer :

In 1946, R.H. Dicke proposed a unique way for solving the gain instability problems in radiometers [Dicke, 1946]. In this method the radiometer antenna output is constantly switched between some known reference temperature and the scene under measurement. By this process the sensitivity of the measurement to gain and noise temperature instability is greatly reduced.

A Dicke type radiometer is basically a highly sensitive superheterodyne receiver in which slow variability of gain can not affect the measurement due to Dicke switching which constantly switches between the receiver input and a reference load kept at a particular temperature (fixed temperature noise source). The switching rate is chosen carefully so that it is higher than the highest significant spectral component in the gain fluctuation in spectrum. The schematic block diagram is shown in Fig.2.1. The predetection section consists of the RF amplifier, mixers and IF amplifier. A synchronous detector is placed in between the square law detector and the low pass filter (integrator). A synchronous detector consists of a switch that operates in synchronism with the input Dicke switch followed by two unity gain amplifiers (in parallel) with opposite polarity followed by an integrator and an amplifier. The unity gain amplifier and the radiometer output is obtained as a dc voltage and is proportional to the difference between antenna temperature and reference load temperature but independent of receiver noise temperature.

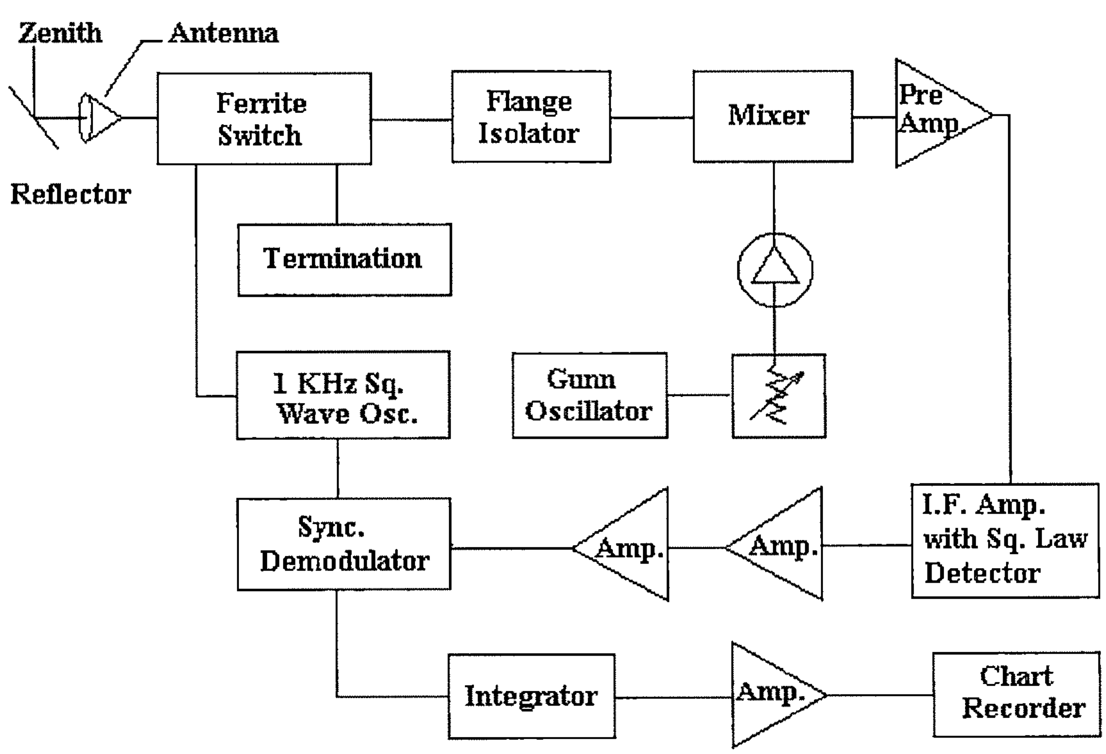

Fig. 2.1 A typical 22.235 GHz radiometer block diagram

A 22.235 GHz radiometer is in operation at the Institute of Radiophysics and Electronics (IRPE), Calcutta University, since 1984. The radiometer has been designed and developed by Space Application Centre (SAC), Ahmedabad as a part of the collaboration programme with the IRPE under the Indian Middle Atmospheric Programme (IMAP). Similar prototypes were flown to Indian Remote Sensing Satellite Bhaskara I & II. The detail radiometer specification is given in Table 2.1.

Table 2.1 : The 22.235 GHz radiometer specification

Parameters	**Values**
Frequency	22.235 GHz
Antenna	Corrugated horn lens
Beam width	22°
R. F. bandwidth	250 MHz
I. F. bandwidth	10-110 MHz
Pre amp. Gain	30 dB
I. F. Gain	30 dB
Stability of local oscillator	1 MHz / $^{\circ}$ C
Noise figure of mixer	8.5 dB
Radiometer sensitivity	1 K
Post detection time constant	1 Sec.

2.3.1. Physical configuration :

The Dicke type radiometer, with all its associated electronics, are mounted within a 43 x 24 x 15 cm^3 enclosure and is kept inside a temperature controlled room with antenna beam facing outside through a window on the wall. The window is covered with a material called 'Mylar', which is transparent to the radiometer operating frequency and is also effective in maintaining room temperature as a thermal insulator. A flat anodised aluminium sheet used as a reflector outside the room is fixed at 45° to the ground in front of antenna beam. The reflector surface is chosen unpolished without any paint cover to prevent beading and formation of rivulets during rain which may affect reflector efficiency [*Blevis*, 1965]. The total arrangement, as shown in Fig.2.2 and Fig.2.3, is such that the atmospheric noise emissions can be sensed by the radiometer without much loss through reflection. Atmospheric thermal emission, as picked up by the radiometer antenna is then compared periodically with the noise power from a matched load at the room reference temperature, at a fast rate of 1 KHz and then fed to a low noise microwave amplifier with a Gunn source serving as a local oscillator at 22.235 GHz. The noise band of about 100 MHz centred around the local oscillator frequency, i.e. 22.235 GHz, is amplified by the IF amplifier chain having a bandwidth of 10-100 MHz. The output of the IF amplifier is detected by a square law detector and then amplified at the switching frequency of 1 KHz by a low noise amplifier. The output is then detected by a phase sensitive detector acting as a synchronous demodulator and further integrated to record on a chart paper recorder.

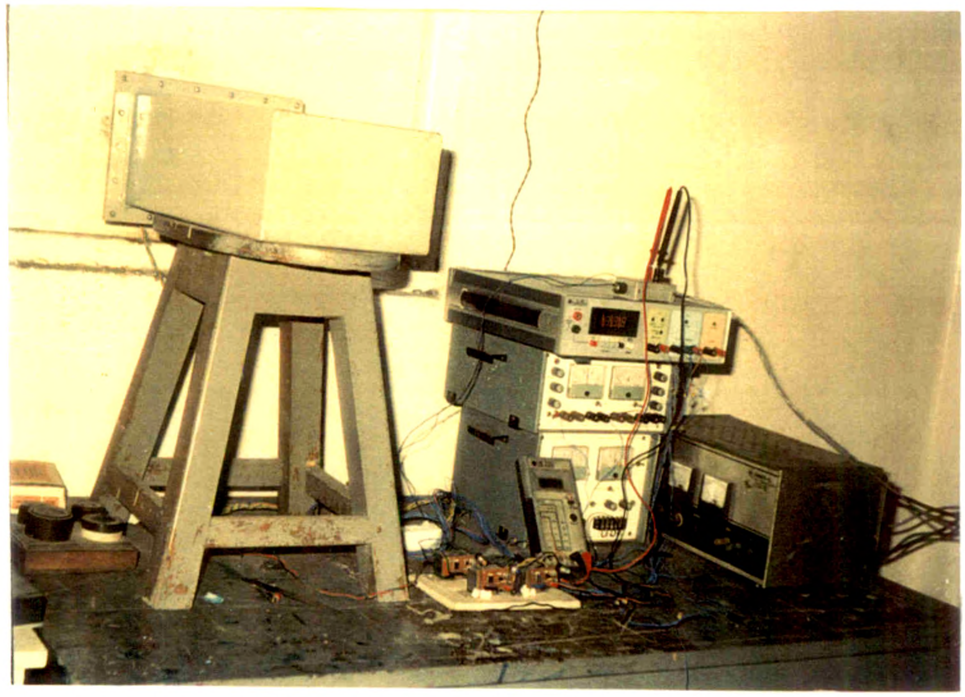

Fig.2.2 The radiometer system with antenna facing towards a metallic reflector kept outside the room.

Fig.2.3 The metallic reflector kept at 45° inclined to the ground outside the room.

The sensitivity of the radiometer is 1K which implies that the radiometer is capable of sensing a change in atmospheric thermal emission as low as 1K. The complete arrangement of radiometer and its reflector can be seen in the Fig.2.2 and Fig.2.3.

2.3.2. Calibration technique :

The radiometer output is the contribution of following components;

- Energy received by the antenna main beam
- Energy received by the antenna beam sidelobe
- thermal energy due to the antenna structure itself

To achieve a very high degree of measurement accuracy with radiometer, the side lobe level is minimised by controlling the field distribution across the mouth of the horn with the help of the lens. and by reducing the load in the antenna structure. Besides these, the radiometer should pass through a calibration technique before putting into actual operation.

Linear response of output with brightness temperature makes it easy to calibrate a radiometer, and only two calibration points may be sufficient to find out any unknown brightness temperature in between [*Ulaby* 1981]. Two reference output values are recorded with their known temperatures. One reference temperature is taken as the room temperature, the other being the liquid nitrogen load to which antenna beam is directed. For propagation studies, liquid nitrogen load is sufficient as zenith temperature always lies in the range between room temperature and liquid nitrogen temperature.

A calibration set-up is shown in Fig.2.4(a), where the antenna main beam with all its sidelobes is made to look into a flask containing liquid nitrogen. Some 'ecosorb' absorbers are placed at the bottom of the flask so that there is no reflections from the bottom for a radio wave incident on the source, which ensures the source to behave as a perfect blackbody source at liquid nitrogen temperature. In atmospheric emission noise measurement, the radiometer is mounted with its beam axis horizontal to the ground. A suitable reflector should be used to sense brightness temperature of liquid nitrogen kept in a Dewar as shown in Fig.2.4(b). A concave reflector may be used in place of flat reflector as shown in Fig.2.4(c) to ensure that the antenna beam looks into the liquid nitrogen exclusively.

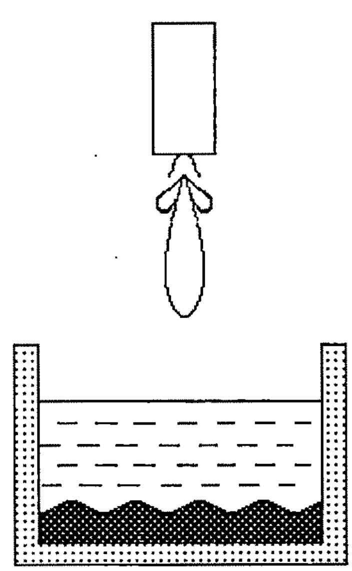

Fig. 2.4(a) Radiometer is directly sensing liquid nitrogen in the flask

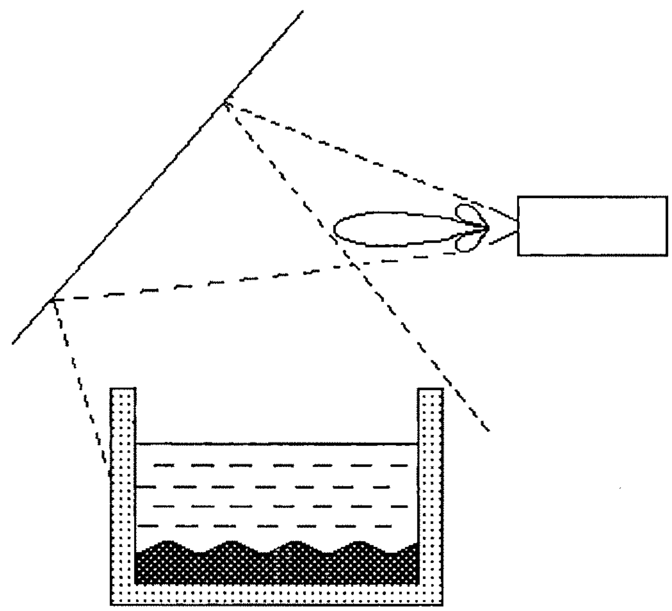

Fig. 2.4(b) Radiometer is sensing liquid nitrogen emission through a flat metal reflector

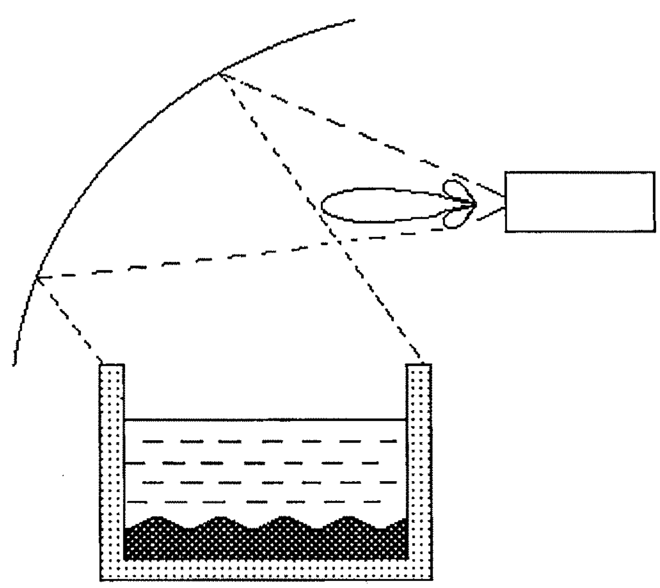

Fig. 2.4(c) Radiometer is made to sense liquid nitrogen emission through a parabolic metal reflector

The radiometer was initially calibrated at Space Application Centre, ISRO, Ahmedabad, using a liquid nitrogen immersed matched load coupled with radiometer receiver input through a precision attenuator. As a matter of fact, a Dicke type radiometer truly records the difference between two temperatures. One is the reference load temperature T_r and the other is antenna temperature T_a. If the reference load temperature T_r is made constant, then the radiometer output i.e. the antenna temperature will be a linear function of T_r-T_a. If load temperature is changed then the radiometer output values can be changed even though there is no variation in antenna temperature. Therefore, it is important to keep the reference load temperature fixed at a point during radiometric measurements. In practice, a temperature sensor was incorporated to monitor the reference load temperature.

With a particular reference load temperature, a pair of two radiometric output values were recorded at two known temperatures, one at room temperature and the other at liquid nitrogen temperature. A set of values were taken at different reference load temperatures. Calibration curves were drawn with temperature (T_r-T_a in K) along in X-axis and radiometer output (in volts) along the Y-axis as shown in Fig.2.5. A second calibration curve is drawn with reference temperature of matched load against the sensor output as obtained. This is shown in Fig.2.6. With these calibration curves, any atmospheric radiometric observation can easily be converted into equivalent brightness temperature. For propagation studies, liquid nitrogen load is good enough considering atmospheric brightness temperature lies between room temperature and liquid nitrogen temperature.

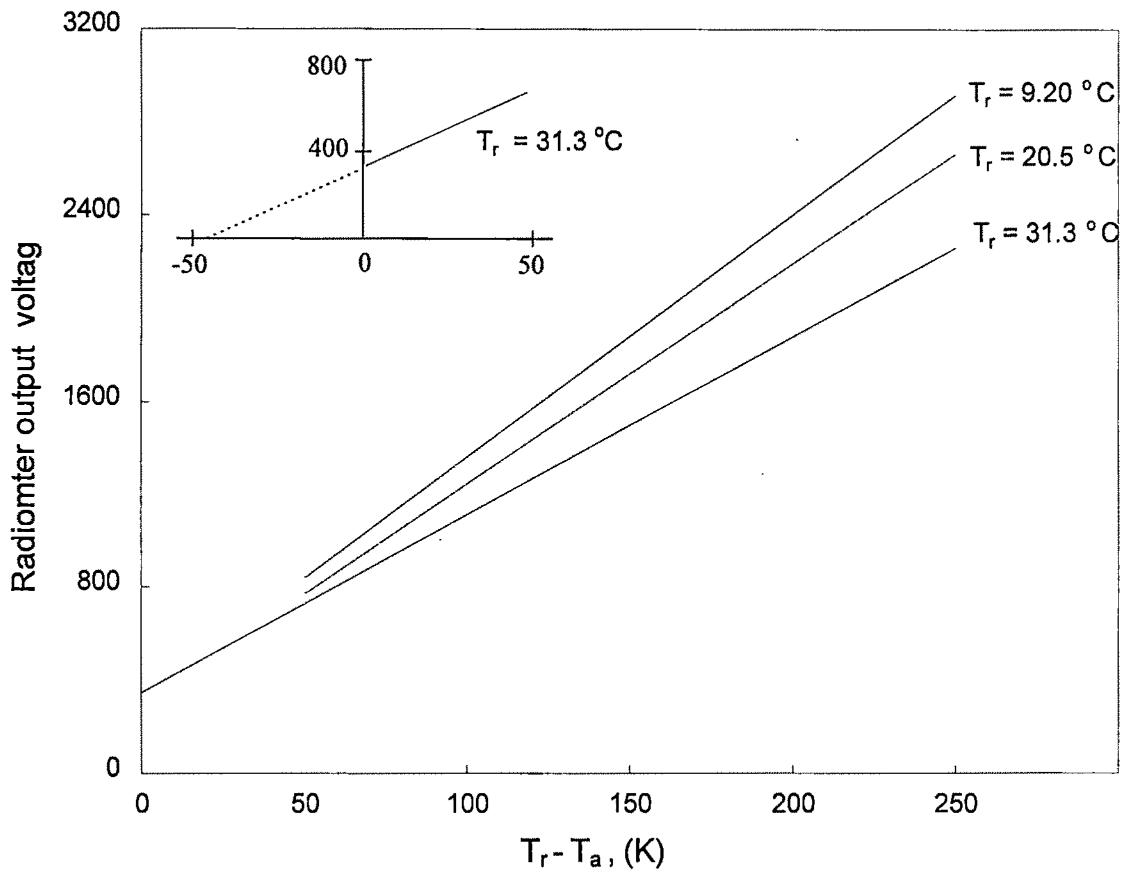

Fig. 2.5 Calibration curves showing the plot of ($T_r - T_a$) with radiometer output voltage at different reference temperatures of the matched load

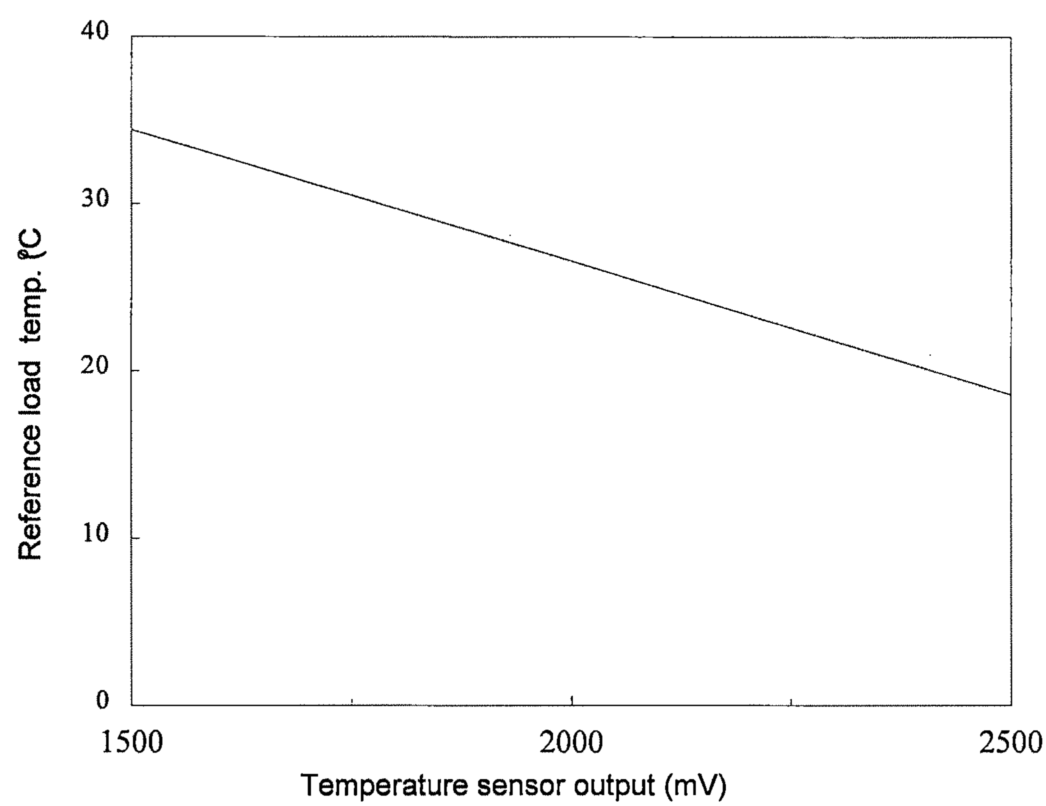

Fig. 2.6 Calibration curve showing reference temperature of matched load with sensor output voltage.

2.3.3. An alternative method of calibration at room temperature :

An alternative method of calibration may be achieved by disconnecting the antenna and a matched termination immersed in a liquid nitrogen bath is connected directly to the receiver input. If the antenna efficiency were unity, the deflection of the radiometer, would correspond to the brightness temperature of liquid nitrogen. In the presence of antenna losses one has to incorporate some correction in the result.

The matched load cooled to 77 K may be connected through a direct reading precision attenuator instead of connecting it directly to the receiver input as shown in Fig.2.7. With a setting A(ratio) of the attenuator, the noise power input to the radiometer is given by,

$$KT_a B = KT_N Be^{-A} + KTB(1- e^{-A}) \qquad (2.5)$$

From Eqn.(2.5), we note that, if $A=0, T_a=T_N$ while with $A=\infty$, $T_a=T$. Between these two limits of T_N and T one can find out any intermediate calibration mark.

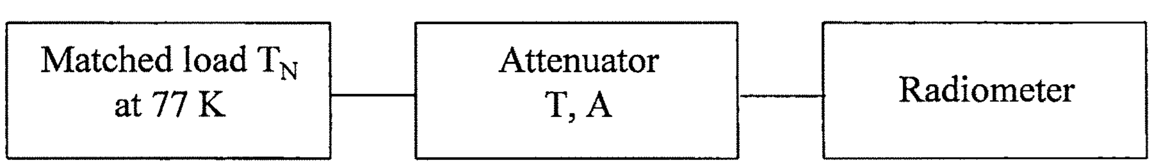

Fig. 2.7 Matched load cooled to 77 K connected through a direct reading precision attenuator to the radiometer input.

Thus there can be calibration points at intervals of 1 K at 77, 78, 79, 80, 90, 300 K (room temperature), depending on the setting of the attenua-tor. Calibration marks at a closer spacing of 0.1K or even 0.01K may be obtained if the attenuator setting is reliable to that degree of resolution and the sensitivity of the radiometer be of that order.

2.4. Discussion :

In course of radiometric studies, radiometers were calibrated from time to time to ensure the accuracy of measurement. It is important to note that the method of direct calibration with a parabolic reflector proved to be a quick calibration method. The use of parabolic dish made the calibration easy and convenient as it avoided any movement of radiometer system. The method is specially convenient considering a number of radiometers in a row are to be calibrated within a short interval of time. The method has been found to provide consistently good calibration results.

Radiometers , however, are not without their drawbacks, for example a limited dynamic range and the fact that, in general, they measure only the absorption, and not the scattering component of attenuation. But till today, the Dicke principle has been proven to be very useful, and Dicke radiometers are the most commonly found radiometer type, though the sensitivity is poorer than for the total power radiometer.