Noise Temperature Measurement System of Normal and High Temperature Load Method

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Abstract. Microwave receiver is a special equipment used to receive radio signals in radio telescope. The noise temperature of receiver is an important target to test sensitivity. The lower the noise temperature is, the higher the sensitivity is. Therefore, the measurement of noise temperature is very important. The classical cold and ambient load method can measure noise temperature well, but it can not be carried out during observation. In addition, the performance of microwave devices is not unchanged, and noise temperature will vary with the ambient temperature and test equipment, so real-time measurement of noise temperature is important. We set up a noise temperature measurement system based on normal and high temperature load method. Through this system, noise temperature can be calculated by measuring the radiation power and temperature of blackbody at normal temperature and after heating to 150℃. Compared with results of the cold and ambient load method, the maximum test error is 12.3% in five tests, and the other test errors are less than 10%. The results can confirm that the normal and high temperature load method could be hopeful to satisfy the normal test requirements of centimeter-band normal temperature receiver.

1. Introduction

Radio astronomy is a subject which observes radio waves from cosmic objects with radio telescope[1]. The microwave receiver is a device which collects electromagnetic wave signals from telescope[2]. For example, original radio signals are reflected once by main reflector of antenna and twice by the secondary reflector to the feed of receiver[3,4], then it is transmitted to the data backend through the receiver's ortho-mode transducer[5], low noise amplifier and filter. As shown in figure 1.

![Figure 1. Signal transmission link of microwave receiver.](image)

The main technical target of receiver is sensitivity. The higher the sensitivity is, the stronger the ability to detect weak signals is. When original radio signals entrance receiver, the noise of receiver will be added to the signals, resulting in the weak signals can not be detected. Generally, the thermal...
noise which generated by the receiver itself is called the equivalent noise temperature of the receiver. The lower the noise temperature is, the higher the sensitivity of the receiver is\[6\].

It is particularly important to test the noise temperature of the receiver. As we know, even if the microwave devices of receiver are tested under the same environment and test platform, there will be some differences in different time. If the noise temperature measured in the laboratory is directly applied to the antenna and receiver system of the observation, it will be inappropriate, because different environments and test systems will make some differences of receiver noise temperature measurement\[7\]. Some microwave devices of 1.3 cm band receiver are shown in figure 2.

![Figure 2. The feed and OMT of 1.3 cm band receiver.](image)

The classical cold and ambient load method can accurately test the noise temperature of the receiver, because the cold load test can not be carried out in antenna observation, the using conditions are very limited. The conventional method is to adjust the antenna elevation to 90 degrees before each observation, and to calibrate the receiver manually by operating the cold and ambient load\[8\]. How to test the noise temperature of the receiver in real time is the key of system calibration. After this step, the noise temperature of the receiver can be applied to radio observation, so that the observed radio source can be further calibrated, and finally the flow density of the radio source can be calculated.

2. Design idea of normal and high temperature load method

2.1. The classical test method of cold and ambient load

For the measurement of noise temperature, the most common and classical method is cold and ambient load (Y factor) method. This method uses two broad-band radiation sources with different physical temperatures (such as cold and ambient blackbody) to place in front stage of the first stage amplifier or mixer of the receiver, so that the radiation can be injected into the feed or waveguide of the receiver.

In the actual cold and ambient load test, the ambient load usually uses the blackbody at normal temperature. The cold load also uses blackbody which is placed in foam containers filled with liquid nitrogen, so the blackbody temperature is reduced to the liquid nitrogen temperature. Finally we place them in the front feed stage of the receiver respectively. As shown in figure 3, the corresponding blackbody temperature and intensity output needs to be recorded.

![Figure 3. The cold and ambient load covers the receiver feed interface.](image)

Because of the inconvenience of providing cold load in antenna observation, noise temperature measurement generally adjusts the antenna elevation to 90 degrees before observation, and then receiver engineers do relevant testing specially, but it can not be carried out in process of observation.
Equation 1 is the "Y factor" for the classical cold and ambient load method, it is the power response ratio of the receiver when the cold and ambient (normal temperature) loads are placed in the front stage of the feed. When the cold and ambient loads cover the feed surface of the receiver respectively, record the low temperature load temperature $T_{cold}$, the ambient (normal temperature) load temperature $T_{amb}$, the cold load intensity output $V_{cold}$ and the ambient (normal temperature) load intensity output $V_{amb}$. According to equation 2, the noise temperature of the receiver $T_{rec1}$ can be calculated, that is the equivalent temperature value of the receiver's own strength response by classical cold and ambient load method.

$$Y_1 = \frac{V_{amb}}{V_{cold}}$$

$$T_{rec1} = \frac{T_{amb} - Y_1 T_{cold}}{Y_1 - 1}$$

2.2. The test method of normal and high temperature load

On the basis of classical cold and ambient load method, we only design a heated blackbody load with chopper function, which can be a normal temperature load when not heated. The cold load which is difficult to realize can be replaced by the high temperature load after heating, so as to complete the measurement of receiver noise temperature. Specific operation, first we put the non-heating blackbody (i.e. normal temperature load) at the front stage of the receiver feed, record the temperature of blackbody and corresponding intensity value of power meter output. Then heat the blackbody to 150℃, after the temperature is stable, record the temperature of heated blackbody and corresponding intensity value of power meter output. The noise temperature of the receiver can be calculated by using the corresponding values of normal and high temperature load. Because the normal and high temperature load method can test the receiver's noise temperature at different elevation angles of the antenna, it can get rid of the dependence of the original low temperature load on liquid nitrogen and container. In addition, because of the chopper function of the system, the blackbody needed for the test can be removed from the feed surface during the observation, which greatly improves the observation efficiency.

Equation 3 is the "Y factor" for the normal and high temperature load method, $V_{cold}$ is the high temperature load intensity output and $V_{amb}$ is the ambient (normal temperature) load intensity output. According to equation 4, the noise temperature of the receiver $T_{rec2}$ can be calculated, that is the equivalent temperature value of the receiver's own strength response by the normal and high temperature load method, $T_{amb}$ is the ambient (normal temperature) load temperature and $T_{hot}$ is the high temperature load temperature.

$$Y_2 = \frac{V_{hot}}{V_{amb}}$$

$$T_{rec2} = \frac{T_{hot} - Y_2 T_{amb}}{Y_2 - 1}$$

3. Realization of normal and high temperature load measurement system

3.1. System establishment

Because the normal and high temperature load method can measure the receiver noise temperature during antenna observation, it is simpler and easier than the classical cold and ambient load method. For this reason, we have built a 1.3 cm band ambient temperature receiver in the laboratory, and tried these two kinds of noise temperature measurement methods to carry out and compare.

The 1.3 cm band ambient temperature receiver is composed of a feed (22-24.2 GHz), an orthomode transducer, a waveguide coaxial converter and a low noise amplifier (noise figure 3, gain 30 dB), as shown in figure 4. The signal amplified by LNA is measured directly by a power meter.
Figure 4. The measurement system of 1.3 cm band receiver.

The flat blackbody is chosen as the test load. The reflection coefficient of vertical incidence of the blackbody is 30 dB (@18 GHz), 35 dB (@40 GHz), which fully satisfies the test requirements of 1.3 cm band.

The blackbody of the cold and ambient load method is shown in figure 5 on the left and the blackbody of normal and high temperature load method is shown in figure 5 on the right.

Figure 5. Blackbody loads for measurement.

In the design of normal and high temperature load method, the heating resistor wire is evenly arranged in a 25*20 cm heating plate (figure 6 on the left), a temperature sensor is installed in the middle of the heating plate, and an LED digital monitor (figure 6 on the right), the 18*18 cm blackbody is attached to the bottom of the heating plate, together with the chopper wheel installed in rotation axis, so it is convenient to remove the test blackbody from the feed surface after the calibration test is completed. Initially, the heating function is turned on, then the LED digital monitor shows the current temperature of the heating plate. Set the heating to 150℃ and stop heating, when the temperature of the heating plate drops to 145℃, the heating function will be restarted. After heating to 150℃, the heating will stop, so as to circulate. When the calibration is completed or the heating function is turned off, the heating plate restores itself to normal temperature.

Figure 6. Heating plate and high temperature load.

The total power test method is used for power acquisition. The power meter is a HP E4419B and E4413A (50 MHz-26.5 GHz) is used for power probe. The composition of the test device is shown in figure 7.
3.2. System measurement

In the laboratory environment, we have carried out five groups of tests, each of which has the same testing process. The field measurement of the normal and high temperature load method on 1.3 cm band receiver is shown in figure 8.

Figure 8. Operating state of the normal and high temperature load method.

First, we need to preheat the power meter and supply power of the low noise amplifier, and test the receiver by cold and ambient load method to determine the noise temperature of the receiver in the current state, which is used as the comparison standard. Secondly, we test the receiver at normal temperature and record the temperature and power, and then the heating module is turned on, it can be seen that the temperature of the heating plate begins to rise slowly from room temperature, and the power meter reading also increases. When the heating plate is heated to 150°C, the heating plate stops heating, the temperature begins to drop to 145°C, and the power meter reading begins to decrease slightly, then the heating plate is reheated to 150°C, the maximum reading of the power meter is basically locked after three processes of cooling and heating, reading the current reading of the power meter at 150°C, and the whole heating process is about 10 minutes, so as to calculate the noise temperature of the normal and high temperature load method finally. Two kinds of noise temperature measurement methods and their comparison errors are shown in table 1.

|   | Tcold (°C) | Vcold (nW) | Tamb (°C) | Vamb (nW) | Trec1 (K) | Tamb (°C) | Vamb (nW) | Thot (°C) | Vhot (nW) | Trec2 (K) | Error (%) |
|---|-----------|------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| 1 | -194      | 96         | 21.2      | 124.4     | 648.3     | 21.1      | 133.3     | 151       | 152.2     | 621.9     | 4.1       |
| 2 | -194      | 96.1       | 20.5      | 124.6     | 644.1     | 37        | 131.7     | 150       | 146.1     | 723.3     | 12.3      |
| 3 | -194      | 96.4       | 19.6      | 124.9     | 643.3     | 19        | 128.2     | 150       | 145.9     | 656.7     | 2.1       |
| 4 | -194      | 96.6       | 19.8      | 125.1     | 645.5     | 34        | 127.8     | 151       | 142.6     | 703.2     | 8.9       |
| 5 | -194      | 96.9       | 18.5      | 125.4     | 643.4     | 26        | 123.8     | 151       | 140.3     | 638       | 0.8       |

4. Conclusions

Five groups of noise temperature tests and comparisons of 1.3cm band receiver are carried out by using cold and ambient load method and normal and high temperature load method. One group of test errors is 12.3%, the other four groups of test errors are less than 10%. To analyze the biggest test error,
the difference between the normal and high temperature blackbody radiation power value is the smallest, and the reduction of the difference will directly affect the test accuracy. Because the accuracy is related to the error, the lower the accuracy is, the greater the error is. Therefore, in the future testing of normal and high temperature load method, it is necessary to wait until the blackbody temperature drops to normal temperature, and the blackbody radiation stabilizes before heating again for calibration, so as to expand the power and temperature difference and reduce the uncertainty of noise temperature test. In addition, for the precise calibration, if the error needs to be further reduced, it is necessary to fabricate the constant temperature cavity for the high temperature load.

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References
[1] N. Wang. Xinjiang Qitai 110 m radio telescope(in Chinese). Sci Sin-Phys Mech Astron. 2014, 44(8):783-794.
[2] M. Z. Chen, Q. LIU, J. Ma, et al. Ultra-wideband receiver technology development for radio astronomical large aperture telescope (in Chinese). Sci Sin-Phys Mech Astron. 2017,47(5):35-47.
[3] C. S. Wang, L. Xiao, B. B. Xiang, et al. Development of active surface technology of large radio telescope antennas (in Chinese). Sci Sin-Phys Mech Astron. 2017, 47(5):19-34.
[4] B. B. Xiang, C. S. Wang, W. Wang, et al, Adjustment method of subreflector position of reflector antennas based on electromechanical couple theory, Systems engineering and electronic technology. 2018, 40(3):489-497.
[5] M. Z. Chen, J. Ma, L. Qin, et al. Design of a Q Band Orthomode Transducer Based on the Ridged Waveguide Connection, Journal of University of Electronic Science and technology of China. 2018, 47(2): 178-182
[6] K. Wang, M. Z. Chen, J. Ma, et al. Aerating System of Keeping Dry for Vacuum Window of Cryogenic Receiver, Hydraulic and pneumatic. 2016,(12) :31-36.
[7] K. Wang, M. Z. Chen, J. Ma, et al. The Amplitude Calibration of Radio Astronomy Millimeter Wave Receiver, ACTA ASTRONOMICA SINICA. 2018, 59(5):1-14.
[8] Penzias A A, Burrus C A. Millimeter-Wavelength Radio-Astronomy Techniques[J]. Annual Review of Astronomy & Astrophysics, 1973, 11(1):51-72.