The emissivity measurement for microwave blackbody of FY-3

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Abstract

FY-3 series is the new generation meteorological satellites under launching. Three microwave radiometers, including imaging sounder and temperature sounder together with humidity sounder, will fly on FY-3 and be hoped to meet the operational weather prediction requirements of china and the global change research. Two types of blackbodies are designed to calibration the three microwave radiometers. Emissivity measurements for above ultra wideband microwave blackbodies in free space are presented in this paper. Owing to the limitations of presently available calibration standards and techniques, pyramid microwave blackbody usually has to be carried on without full space calibration. The paper describes the space method with moving device under test that does not need space calibration. Measurement data finished by BIRMM (Beijing Radio Institute of Metrology and Measurement) and VNIIFTRI (All Russia scientific research institute for physical technical and radio technical measurement) respectively are presented. Those data came from same blackbody sample and were obtained with different measurement procedure. The paper also discusses the influences arising from no ideal waveguide port.

1. Introduction

In 2005, BIRMM became the technical leader of FY-3 microwave radiometer pre-launch thermal-vacuum calibration and carried out the corresponding measurement and calibration for many parameters such as linearity and sensitivity etc. Now BIRMM has constructed the 10GHz-200GHz microwave radiometer laboratory and vacuum calibration system by cooperation and self-development. The three microwave radiometers in FY-3 cover a wide frequency range from 10.65GHz to 183GHz. To meet the request coming from frequency range and emissivity, BIRMM have designed two types wide aperture radiator. The emissivity of the calibration targets is required to be at least 0.999. This is necessary in order to keep radiation which unavoidably emitted from the radiometer's local oscillators through the antenna and reflected back off the calibration target to a minimum.

Two types of targets (their diameters are 300mm and 500mm respectively) all take the form of an array of pyramids, 3.5x mm high with bases x mm wide. They are constructed from a spark-eroded aluminum alloy substrate covered in a 1mm or 2mm layer microwave absorber CF-114.

In order to monitor the temperature of the target, some PRTs are embedded in the substrate of each. Because the temperature of blackbody is variable, the thickness of microwave absorber is usually less than 2mm in order to avoid temperature gradient. The metal base and pyramid with spark machining in one-piece aluminum ensures that temperature gradients across the targets are minimal, while the absorbing coating ensures that the emissivity is close to one. To improve emissivity measurement accuracy, The BIRMM (namely author's address) and the VNIIFTRI (All Russia scientific research institute for physical technical and radio technical measurement) finished together an international comparison measurement with same sample. Fig. 1 presents the metal aluminum target and two types of final blackbodies that used in the international comparison measurement of emissivity.

Figure 1. Aluminum target (left), 300mm diameter radiator (middle), 500mm diameter radiator (right)

Fig. 2 presents the actual calibration targets used in thermal-vacuum can, and the arc orbit used in backward voltage reflection coefficient measurement and scattering factor measurement of emissivity. The left figure in Fig. 2is a 500mm cold target, and the middle figure is the back of a 300mm cold target.

The computation formula of emissivity has been presented in [1-3].

Figure 2. Actual targets and measurement orbit of emissivity

2. Space Method with Moving Blackbody

The measurement modeling can be expressed in following signal flow figure (SFF), as shown in Fig. 3. The total signal flow figure can be divided into two figures, namely SFF in network analytical and SFF in free space.

The S parameters in network analyzer express the system errors including directivity, frequency response error, source match error etc. Those errors can be calibrated well with some calibration modeling (SOLT or TRL) and kit. The type of error encountered in free space measurement of blackbody reflectivity depends upon the measurement configuration employed. The [4, 5] presented calibration modeling that can work at plane absorber. Different from the computation and measurement of general plane absorbing material, the emissivity measurement of pyramid microwave blackbody need consider near field effect, scattering effect and influence coming from measurement system reflection. Hence the measurement modeling of the former can not work well at measuring the emissivity of the latter.

Accordingly, tracing to other metrology standards (such as antenna standard, attenuator standard and power standard etc) is more convenient than designing some calibration modeling used in space. Based on accurate analytical formula, space method replaces building calibration modeling in free space with tracing to microwave parameter standard.

The S parameters in free space express the errors including space attenuation, multi-reflection between antenna and blackbody and VSWR existing in antenna aperture and other waveguide piece. It is easy to prove that all time-independent signals coming from reflection and leakage can be separated from reflection brought by moving blackbody. When observing the S_{11} parameter in polar mode, we find the chart can be expressed with a fixed vector and a variable vector.

Fig. 4 gives another measurement chart that can explain the fig 3. In fig. 4, we measure the reflectance form blackbody when antenna having different VSWR. The variable VSWR is obtained by adding different mismatch waveguide piece (Including VSWR=1.4 and VSWR=2.0) between antenna and match waveguide.

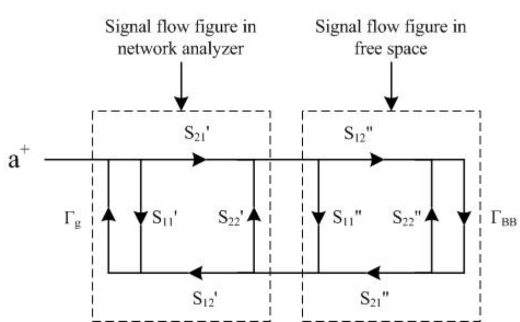

Figure 3. Signal flow figure of space method

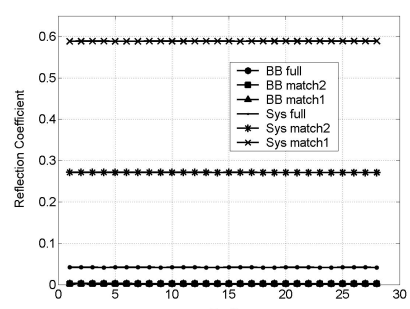

Figure 4. System reflectance and blackbody reflectance

Six charts including system reflectance and blackbody reflectance in 89GHz are plotted in fig. 4. BB full expresses the reflectance is measured with a full calibration network analytical. BB match2 denotes the reflectance is measured when a mismatch piece with VSWR = 1.4 was inserted between two WR-10 waveguide sections. BB

match1 denotes the reflectance is measured when a mismatch piece with VSWR = 2 is inserted between two WR-10 waveguide sections. The x axial is the distance range of blackbody corresponding to a reference position.

The results show blackbody reflectance is independent on system reflectance and can be separated by moving blackbody and the system reflectance is independent on measurement distance between antenna aperture and blackbody.

3. Measurement Data

Measurements were performed in the Beijing Radio Institute of Metrology and Measurement anechoic chamber last year, whose dimensions between outer walls are 8m× 5m× 3m. A calibrated vector network E8363B was connected to the waveguide input of the antenna below 40GHz. In WR-15, WR-10, WR-06, WR-05 band, scalar network, Signal generator and antenna receiver-transmitter system are used to extend the frequency range. The corrugate lens antennas were used in the band below WR-15 and corrugate antennas for above.

The emissivity values are measured with above equipments, and the reflections from the target are separated from the much larger VSWR in the horn, coaxial to rectangular waveguide adapter and rectangular to circular waveguide transition by moving the calibrator relative to the horn.

The Fig. 5 presents the measurement equipments above 40GHz. The left figure is a scalar network analyzer working in WR-15. The middle figure is a scalar network analyzer working in WR-10. In WR-06 and WR-05 band, the transmitter-receiver antenna system that uses a WR-42 oscillator is used to extend the frequency range. The emissivity measurement below 40GHz is finished by E8363B.

Figure 5. Measurement equipments above 40GHz.

Two blackbody samples, as shown in fig. 1, were measured by BIRMM and VNIIFTRI within half a year. Their diameters are 300mm and 500mm respectively. The 300mm blackbody with 120mm high and 30mm wide is designed to meet calibration from 10.65GHz to 90GHz and the 500mm blackbody with 35mm high and 10mm wide is expected to finish the calibration of WR-06 and WR-05 band.

The emissivity measurement can be divided into backward voltage reflectance and scattering factor. In first measurement, VNIIFTRI uses direct method and BIRMM uses indirect method. In the scattering factor measurement, VNIIFTRI uses signal generator plus radiator and BIRMM uses the S_{21} or receiver mode.

Fig. 6 gives a set of original data of backward voltage reflectance. The data is the S_{11} parameter measured by port one. From the chart, we can find the variation coming from the synthesis of a fixed stable wave and a variably stable wave. The chart in fig. 7 is the distribution of scattering field and can be used to compute the scattering factor of emissivity. BB is the abbreviation of blackbody and locates at the bottom of the figure.

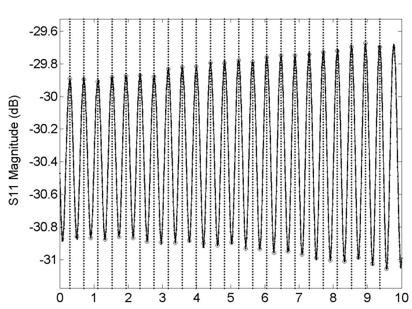

Figure 6. S_{11} parameter measured by VNA

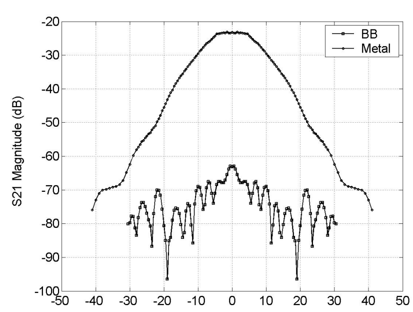

Figure 7. Distribution of scattering field

Table I gives the measurement data of BIRMM and VNIIFTRI. From the data provided by BIRMM and

VNIIFTRI, we can find direct method and indirect method can replace each other in well controlled experiment. In fact, the emissivity of 300mm blackbody is more than 0.9994 from 10GHz to 200GHz. Compared with 300mm blackbody, the emissivity of 500mm blackbody decreases to 0.9982 when it is measured in 10.65GHz.

TABLE I
EMISSIVITY of 300mm BLACKBODY and 500mm BLACKBODY

Emissivity Measurement Data Presented by BIRMM and VNIIFTRI											
f (GHz)	10.65	18.7	23.8	36.5	50.3	53.6	89	150	180	183	183.31
Diameter of radiator (mm)	300							500			
Emissivity of BIRMM	0.9996	0.9999	0.9999	0.9994	0.9999	0.9999	0.9992	0.9999	-------	0.9998	0.9998
Emissivity of VNIIFTRI	0.9998	0.9998	0.9998	0.9994	0.9995	0.9997	0.9999	0.9992	0.9994	0.9993	-------

4. Conclusion

From table I, we can find the emissivity data has a 0.07% difference in 89GHz and 150GHz. A probable reason is the imperfect system calibration. The different antenna also leads to the difference in final emissivity in a manner especially in scattering factor measurement.

Based on applications of microwave radiometer remote sensing, the 1.4GHz microwave radiator that detecting seawater salinity is the lowest frequency now. Hence designing the microwave blackbody that working from 1.4GHz to 200GHz with emissivity 0.999 is our further aim.

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6. References

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