Transfer Radiation Thermometer
With Temperature Range Of 0 °C To 3,000 °C
At 8 µm To 14 µm

O. Struss[1], H-P. Vietze[2]

[1] *HEITRONICS Infrarot Messtechnik GmbH, Wiesbaden, Germany*
E-mail: ortwin.struss@heitronics.com
[2] *HEITRONICS Infrarot Messtechnik GmbH, Wiesbaden, Germany*
E-mail: hans-peter.vietze@heitronics.com

Abstract. The paper will present the performance, specification and design of the Transfer Radiation Thermometer IV.82 (TRT IV.82) which covers a temperature range of 0 °C to 3,000 °C in one temperature range. It has a spectral response of 8 µm to 14 µm. More and more Infrared Thermographic Cameras and Infrared Radiation Thermometers are used in industry for manufacturing, inspection and improvement of the product quality. Today those instruments cover the temperature ranges from -50 °C up to 3,000 °C. Their spectral responses are typically 3 to 5 µm or 8 to 14 µm. For high level calibration Transfer Radiation Thermometers are needed that cover those temperatures. The TRT IV.82 has been designed and developed to improve the accuracy in long wave spectral band and high temperatures. The size of source effect (SSE) is optimized for the spectral range of 8 µm to 14 µm. It can be used as a Transfer Standard Radiation Thermometer (TSRT) for the transfer of radiation temperatures in VTBB scheme [1]. It will be calibrated against high grade blackbody radiators (BBR) according to ITS 90 and it is capable to transfer radiation temperatures between black body radiators (BBR). The instrument has an industrial design with the benefits and means of ruggedness, transportation and handling and the performance of a transfer standard. The construction of the thermometer and the test performed to characterize it are described. General specifications, spectral response, temperature resolutions, influence of ambient temperature and humidity as well as size of source effects (SSE) are investigated and presented in this paper.

Keywords: Transfer Radiation Thermometer, High temperature, 8 µm to 14 µm, calibration

INTRODUCTION

More and more Infrared Thermographic Cameras and Infrared Radiation Thermometers are used in industry for manufacturing, inspection and improvement of the product quality.

Today those instruments cover the temperature ranges from -50 °C up to 3,000 °C. Their spectral responses are typically 3 to 5 µm or 8 to 14 µm.

For high level calibration Transfer Radiation Thermometers are needed that cover those temperatures. The Transfer Radiation Thermometer IV.82 (TRT IV.82) has been designed and developed to improve the accuracy in long wave spectral band and high temperatures. The size of source effect (SSE)[2] is optimized for the spectral range. It can be used for the transfer of radiation temperatures in the VTBB scheme [1].

DESIGN

The TRT IV.82 has an industrial design, it is based on the Transfer Radiation Thermometer II (TRT II) [3] The optical design, the electronics and the software of the instrument were modified to higher performances than the industrial version, e.g. NETD (Noise Equivalent Temperature Difference), SSE (Size of Source Effect) and thermal drift.

The operating principle is based on the chopped radiation method. In this instrument a pyroelectric detector is used.

The TRT IV.82 covers temperature ranges from -50 °C up to 3,000 °C (in four different temperature ranges) on blackbody sources. Outputs are provided either in temperature or radiance equivalent values. Emissivity value can be set between 0.100 and 1.000.

The instrument provides a field of view (FOV) of approximately 6.8 mm @ 380 mm.

For calibration the minimum spot size has to be positioned at the opening of the calibration source. A built-in laser-marker facilitates aiming on the center of the field of view.

For convenient operation the TRT IV.82 has three outputs, which can be individually configured:

- a display at the rear side of the instrument, which indicates the value in temperature. (It can be configured in °C, °F and K.)

- a the serial interface RS232C for readouts in temperature or radiance values.
- an analog output for the readout signal (mA or Volt) which can be configured either in temperature or in radiance values.

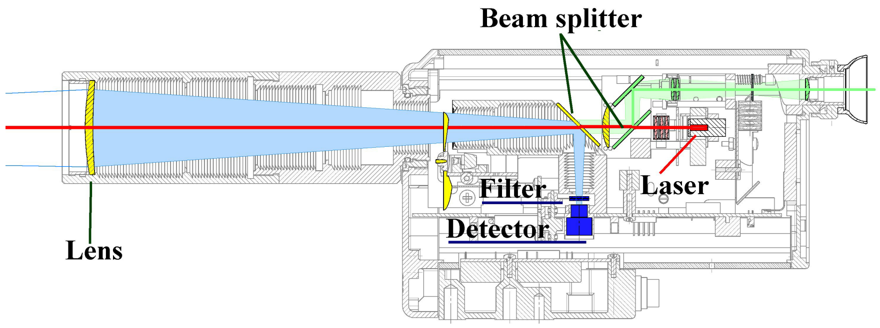

FIGURE 1. Design of the TRT IV shows the layout of the instrument with optical path for the measurement, the through the lens sighting and the laser beam for marking the field of view.

TEMPERATURE AND DYNAMIC RANGES

The first TRT has been designed and developed in the TRIRAT project [4]. It covers the temperature range from -50 °C up to 300 °C with a spectral range from 8 µm to 14 µm. To expand the temperature ranges up to 3,000 °C creates the need of a much higher (radiance) dynamic range. While the temperature range up to 300 °C means a dynamic range of 660:1, the temperature range up to 3,000 °C means a dynamic range of 13,460:1 (see fig.2)

The TRT IV.82's are available in four different versions with temp. ranges of -50 °C to 1,000 °C up to 0 °C to 3,000 °C. The different temperature ranges means different gain settings of the instruments. The wider temperature ranges have also the meaning of a slightly higher NETD at higher temperatures.

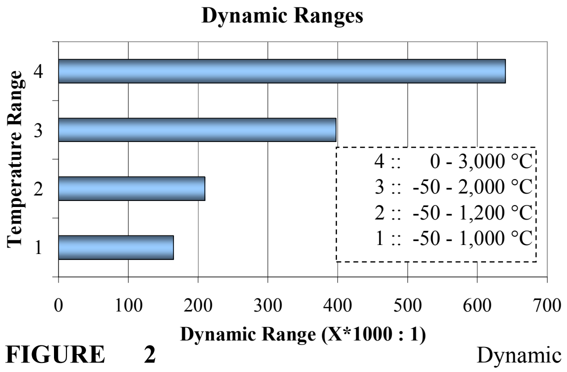

FIGURE 2 Dynamic Ranges for the Temperature Ranges 1 to 4

NOISE EQUIVALENT TEMPERATURE DIFFERENCE (NETD) VERSUS TEMPERATURE

The NETD has been measured in front of blackbodies providing temperatures up to 2,000 °C

The TRT was photoelectric aligned in front of the blackbodies in the horizontal and vertical plane. The measurement values were acquired with the aid of the serial interface over a period of approx. 2 minutes for each temperature value.

The NETD values are measured from 39 °C to 2,000 °C.

During the measurement the response time is set to 3 sec. The NETD stated in the table is the expanded NETD of the measurement obtained by multiplying the standard value by the coverage factor k=2. The temperature fluctuation of the BBR was smaller than the registered NETD

TABLE 1. Noise Equivalent Temperature Difference (NETD) vs Blackbody Temperature for TRT IV.82

Black body radiator Temp. / °C	NETD for 3 s response time /K	Black body radiator Temp. / °C	NETD for 3 s response time /K
39	0.04	1000	0.03
150	0.03	1150	0.03
300	0.04	1700	0.09
650	0.04	2000	0.25

SSE IMPROVEMENT

The instrument provides a field of view of 6.8 mm @ 380 mm for 99 % collected radiation. The SSE graph shows improvable values for diameters between the nominal diameter and 30 mm.

To improve this diameter range to a higher SSE value has been the part of the work to achieve higher performance.

The layout of the inner optical path is redesigned. Field stop diameter and positions where adjusted and optimized to shift this diameter range to a SSE level of 0.998 or higher.

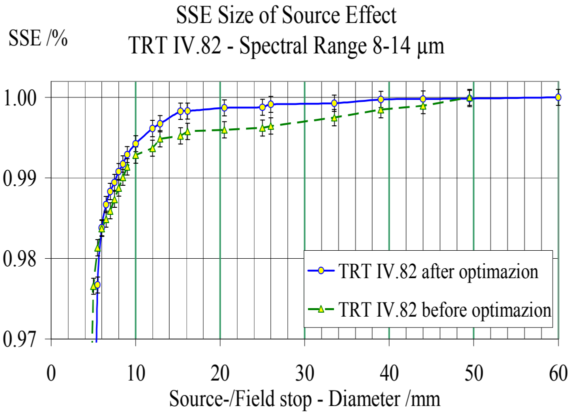

FIGURE 3 SSE diagram

SSE DETERMINATION

It is recommended to use calibration sources that provide an aperture of 8 mm or more to minimize Size of Source Effects. Functions for correction of SSE are measured for different apertures. The lens of the instrument is designed for a wide spectral range (3 µm to 15 µm). It is a ZnSe meniscus. For calibration the minimum spot size has to be positioned at the opening of the calibration source. A built-in laser-marker is aiming on the center of the field of view. The instrument also provides through the lens sighting

The SSE is determined on the instrument before calibration. The incorporated aiming device, a focus laser, is aligned to the measuring field.

The arrangement to determine the SSE consists of the following components:

- Optical rail system
- Variable aperture (3…60 mm)
- Deflection mirror
- Stabilized Black Body Radiator (BBR) (±0.1 °C)

The BBR is made from a 210 mm x 450 mm aluminum plate with a pyramid structure on the emitting surface. The emitting surface is coated with high temperature paint [Nextel].

The BBR is placed at an angle of approximately 25° to the rail system to avoid multiple reflections between the BBR and the variable aperture. The TRT IV.82 is positioned at a distance of 650 mm to the BBR. Its optical axis is roughly aligned to the rail system using the built-in focus laser.

After the rough alignment the aperture is moved to the minimal field of view (FOV) (the actual displacement is usually less than a few tenth of a millimeter in xy-direction and less than 5 mm along the z-axis).

The actual measurement is carried out starting with a fully open aperture and recording the radiation values (RAD) for 60 seconds. To eliminate the background (e.g. temperature radiation coming from the aperture) the deflecting mirror is placed between the BBR and the variable aperture. This procedure is repeated several times by reducing the aperture opening down to 3 mm in steps. Then the aperture is removed and the 100 % RAD value is measured The background in this case is determined placing the deflecting mirror directly in front of the TRT IV.82 objective.

FIELD OF VIEW

The field of view diagram shows the diameter of the measurement area versus the distance from the front edge of the lens (Objective). It is required to use the TRT IV.82 at the focal distance. For this distance the SSE is measured.

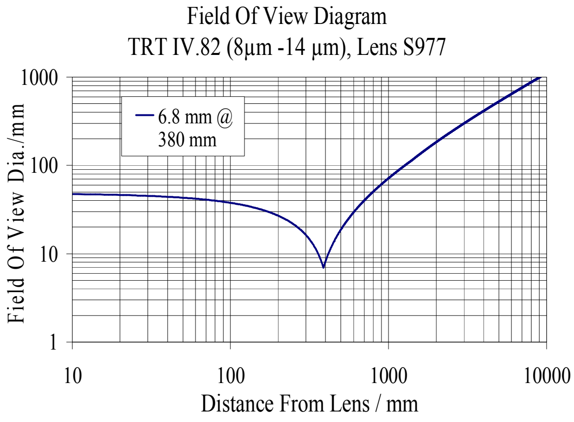

FIGURE 4 Field of View Diagram

MEASUREMENT UNCERTAINTY

The uncertainties are calculated as described in reference [1], it has been taken according the VTBB calibration scheme [1]. The uncertainty budget incorporates the Blackbodies, the Ambient Conditions, the Radiation Thermometer and the "In-Use"-Effects like drift. In case of the Radiation Thermometers it incorporated the Size-of-Source-Effect, the Ambient Temperature, the Atmospheric Effect and the NETD. (Conditions see TABLE 2).

Calibration was performed on high-grade heat-pipe blackbodies of PTB. The radiation temperatures $t_{s,90}$ at the calibration points from -39 °C to 960 °C were adjusted by means of standard platinum resistance thermometers, taking into account correction values. For the radiation temperatures $t_{s,90}$ from 1,200 °C to 2,000 °C the calibrations were accomplished with the help of the High-Temperature Blackbody (HTBB). The TRT has been photoelectric aligned in front of the blackbodies in the horizontal and vertical plane. The measurement values of calibration were acquired with the aid of the serial interface over a period of approx. 2 minutes for each temperature value. Later, the arithmetic means of the measurement values stored were calculated. The reading of TRT, and the uncertainty stated in TABLE 3 and TABLE 4 are valid for the measurement conditions (TABLE 2).

At the moment of calibration, the analysis of the PTB heat-pipe blackbodies furnished the values stated in TABLE 3 and TABLE 4.

The uncertainty stated is the expanded uncertainty of the measurement obtained by multiplying the standard uncertainty by the coverage factor k=2. The stated uncertainty considers the uncertainty in the realization of the radiation temperatures of the blackbodies, the realization of the measurement conditions in combination with the SSE of the radiation thermometer and the short term stability of the radiation thermometer under calibration. The uncertainties are valid for the applied measurement conditions. Long term drifts of the instrument are not considered. The uncertainty has been determined in accordance with the "Guide to the Expression of Uncertainty in Measurement". Normally, the value of the measurand lies with a probability of approximately 95 % within the attributed interval of values.

The temperature values stated in this calibration certificate are in accordance with the International Temperature Scale of 1990.

TABLE 2. Measurement conditions

Measurement distance of TRT to the aperture stops:	380 mm
Setting of emissivity:	1.000
Setting of response time:	3 s
Ambient temperature:	23 °C +/- 2 °C
Relative air humidity:	(22 – 38) % +/- 2 %

TABLE 3. Measurement uncertainty

TRT IV.82	***8-14 µm***	***-50 °C – 2,000 °C***
Year of Calibration: 2009		
Black Body	**Radiation**	**Uncertainty**
Aperture Diameter / mm	**Temperature $t_{s,90}$ / °C**	**U / K**
20	0.03	0.05
20	350.0	0.3
20	500.0	0.5
20	900.0	0.9
20	1175.4	1.5
20	1509	2.1
20	2005	3.2

The calibration is done up to 2,000 °C and calculated up to 3,000 °C. The uncertainties given in TABLE 3 are taken in 2009 [5].

The calibration setup has improved in 2010 which will lead to smaller uncertainties (see TABLE 4) [7]. The uncertainties for the higher temperatures from 1,000 °C up to 2,000 °C will be taken with the new setup and published later.

TABLE 4. Measurement uncertainty

TRT IV.82	***8-14 µm***	***-50 °C – 1,000 °C***
Year of Calibration: 2011		
Black Body	**Radiation**	**Uncertainty**
Aperture Diameter / mm	**Temperature $t_{s,90}$ / °C**	**U / K**
40.0	-39.008	0.070
40.0	0.032	0.063
40.0	30.029	0.063
40.0	155.99	0.15
40.0	232.05	0.16
40.0	300.01	0.20
40.0	420.02	0.12
40.0	660.03	0.18
40.0	810.03	0.23
40.0	960.01	0.30

ATHMOSPHERIC EFFECTS

The influences of atmospheric effects by humidity were determined by placing the instrument at the working distance of 380 mm from the opening of a BBR, measured through a climatic chamber with variable humidity. Measurements were made from 20 % to 95 % relative humidity. For the 8-14 µm range a small effect was measured that should be corrected. Figure 5 shows the results of these measurements. Functions for correction will be provided with the instrument.

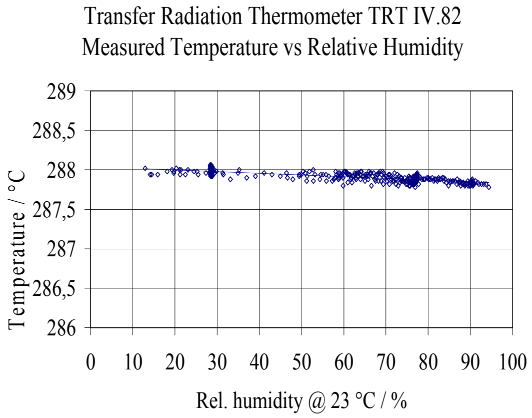

FIGURE 5 Effect of humidity for TRT IV.82 (8 - 14 µm)

AMBIENT TEMPERATURE AND WARM UP EFFECTS

The effect of ambient temperature variations was investigated by placing the instrument in front of a BBR at a working distance of 380 mm in a climatic chamber. The ambient temperature was changed and the effect was registered. The ambient temperature was determined by the internal reference temperature of the TRT IV.82 (Figure 7). The effect is within the instrument compensated by calculation.

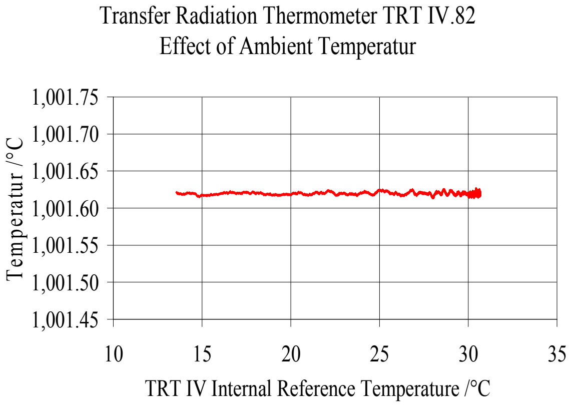

FIGURE 7. Effect of ambient temperature

Figure 8 shows the warm up effect in measuring operation. The temperature drift of the TRT IV.82 is recorded versus time while the instrument was continuously viewing at a 1,000 °C source at 380 mm distance.

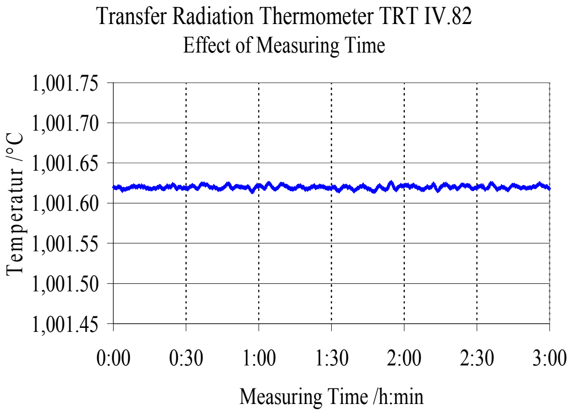

FIGURE 8. Effect of time in front of a Black body

TECHNICAL SPECIFICATION

Table 5

Technical Specification of TRT IV.82

Value	**TRT IV.82 (8 - 14 µm)**
Temperature measuring ranges	0 °C – 3,000 °C -50 °C – 2,000 °C -50 °C – 1,200 °C -50 °C – 1,000 °C
Spectral response	8 - 14 µm
Field of view	6.8 @ 380 mm
Measuring field marking	Laser marker and through-the-lens-sighting
Lens	S977 (Zinc Selenide)
Detector	Pyroelectric
Analog output (selectable by programming)	0 ... 20 mA, 4 ... 20 mA, 0... 1 V, 0 ... 10 V The output signal is linear to the measured temperature or linear to the measured radiation, depends on setting
Resolution of the analog output	12 bit
Digital interface (RS232C)	9,600 -115,200 bps
Resolution of serial output	0.010 °C
Response time (90 %) (selectable by programming)	0.05; 0.10; 0.03, 0.1, 0.3, 1, 3 and 10 s
Uncertainty	Given by calibration laboratory
Permissible ambient temperature	23 °C ± 3 °C
Storage temperature	- 20 ... + 70 °C
Operating voltages	24 VAC +/- 10 %, 48-400 Hz, 22-30VDC
Power requirements	200 mA RMS
Housing dimensions	See above
Weight	1.5 kg
Type of protection	IP65 (NEMA4 equivalent)

CONCLUSION

HEITRONICS has improved the performances of the TSRT and designed the TRT IV.82, an advanced, commercially available instrument which is suitable to be used as a Transfer Radiation Thermometer up to 3,000 °C on long wavelength (8 – 14 µm). It provides high stability and excellent temperature resolution for calibrations at Calibration Laboratories as well as on industrial level. The instrument has to be calibrated against high grade Radiation Sources. It can be used in the VTBB scheme. It combines the benefits in handling and features of an industrial infrared thermometer with the performance of a TRT.

ACKNOWLEDGEMENTS

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