

Calibration History of Waveguide Thermistor Power Standards in the U.K.

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1. Abstract

The efficiencies of, widely used, commercial waveguide thermistor sensors have been measured periodically from 1981 to the present day to provide the U.K.'s national standard for waveguide power. Prior to this date in-house tuned bolometer sensors were used for this purpose. The effective efficiency of the thermistor sensor is measured using waterbath microcalorimeters in waveguide sizes IEC R100 (WG16), R140 (WG18), R220 (WG20), R320 (WG22) covering the frequency range 8.2 GHz to 40 GHz and have typical uncertainties of $\pm 0.6\%$ to $\pm 0.8\%$ (at 95% confidence interval).

The raw data from these measurements has been re-analysed to give the long-term stability of this type of power sensor at a range of frequencies across each waveguide band and the repeatability of our waterbath microcalorimeter systems in the three laboratories that they have been situated in during this period. The data shows the thermistor sensors have good long-term stability with generally good consistency between the three laboratories.

2. Introduction

The UK's national standards for waveguide power in the frequency range 8.2 to 40GHz are HP486A thermistor sensors. Standards are also provided in the range 40 to 110GHz but these have not been included in this review. The previous standards were tuned bolometer sensors but these were replaced in the mid 1980's because although the measurement uncertainties associated with the bolometer sensors were slightly lower than those of the thermistors, they were also very slow to use since a separate sensor was needed for each frequency. The thermistor sensors have the advantage of covering the entire waveguide band and are also very linear and repeatable.

The efficiency of the thermistor sensors is measured in waterbath microcalorimeters [1] over several weeks. It would be impractical to measure all sensors with this method so once the thermistor sensors have been characterised in the microcalorimeter they can then be used to calibrate a multistate reflectometer [2], with which measurements of the efficiency of other waveguide sensors can rapidly be made.

The waterbath calorimeter consists of an input waveguide, a thinwall waveguide section (for thermal isolation) and a multi-junction thermopile. The sensor to be measured is connected to the end of the thinwall waveguide section. An efficiency measurement entails applying RF power to the sensor and finding the temperature rise for a given meter response. A short circuit is then placed between the sensor and the thinwall section and the temperature rise measured for a given RF power. From this data the power lost as heat in the walls of the sensor can be calculated and hence the sensor efficiency.

Due to the long time constant of the calorimeter and the very low temperature changes involved (mK), the RF power must be cycled on and off every few hours. This makes the apparatus sensitive to changes in the ambient lab temperature in that time. The lab temperature is controlled to $(23 \pm 1)^\circ\text{C}$.

In order to get a better contact between the sensor and the waveguide flange a crushable shim is generally used. This improves the repeatability but can change the measured efficiency (e.g. by $\sim 0.2\%$ in WG16 compared to a measurement without a shim). Shims were not used for calibrations between 1997 and 1999, shims have been used since 1999 and were used prior to 1997.

3. Calibration History

Waveguide Size	16	18	20	22
Calibration History	20 years	17 years	16 years	17 years

Table 1 Maximum length of time for which calibration data exists for UK microwave power standards in four waveguide sizes

The sensors were measured in the water bath calorimeters several times in their first few years of use to establish their repeatability and short-term stability. The sensors have then been re-measured every 2 to 3 years. Originally the thermistor sensors were only measured at about four frequencies in each waveguide band, corresponding to the frequencies of the individual tuned bolometer sensors, but these have gradually been extended to now cover ten to fifteen frequencies per band. The number of sensors of each waveguide size that are calibrated in the waterbath calorimeter has also gradually increased meaning that some of the sensors have much longer calibration histories than others.

4. Uncertainties

The measurement uncertainty (at 95% confidence level) on our efficiency measurements is approximately 0.6% in waveguide sizes 16 and 18 and 0.8% in waveguide sizes 20 and 22. These values have not changed in the 20 years the calorimeters have been operational. The largest contributors to the uncertainty budget in these waveguide sizes are the flange connection repeatability, the microwave power source stability and the laboratory temperature stability. In smaller waveguide sizes the thinwall waveguide heating uncertainty begins to dominate the uncertainty budget.

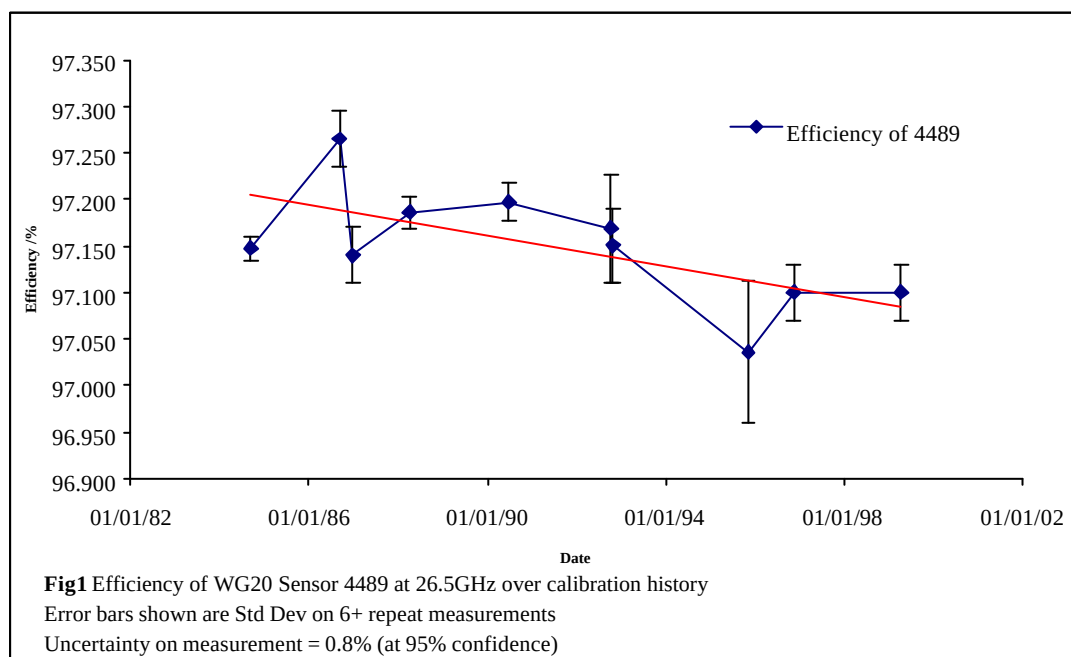
5. Analysis of Data

The efficiency of the thermistor power sensor is generally measured six to ten times without reconnection. This data is processed to give the mean and the standard deviation of these efficiency measurements. From this the following can be calculated:

Average standard deviation on all sets of waterbath measurements taken during a year - this indicates the temperature stability of the laboratory during that year.

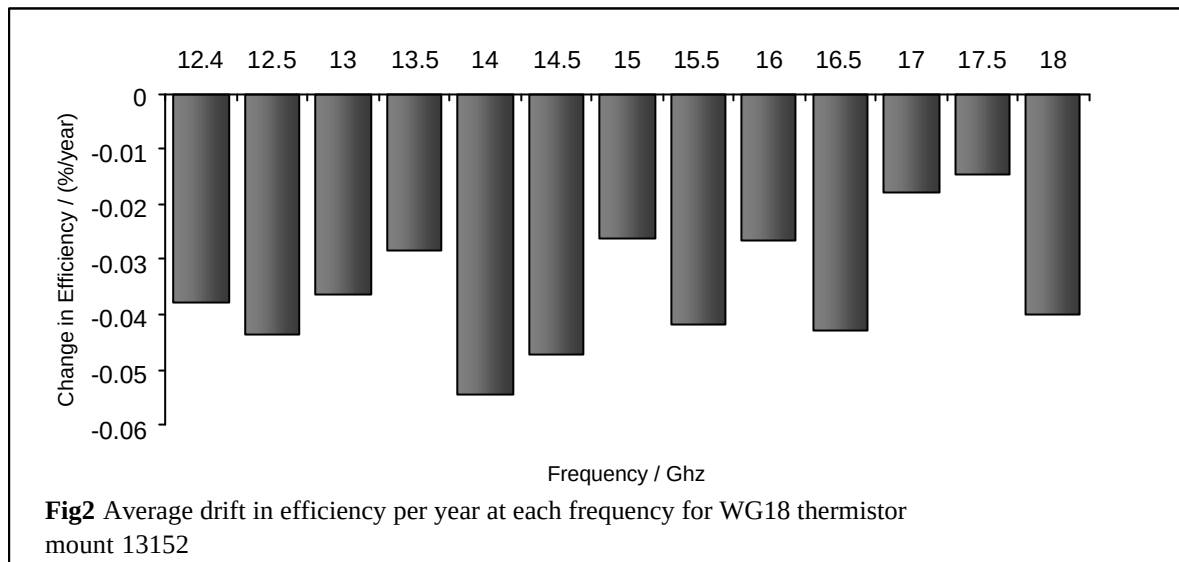
Average standard deviation for a waveguide size - this indicates how repeatable measurements on a particular type of sensor are expected to be, and is mainly due to physical characteristics of that waterbath and calorimeter. For example, it is known WG16 is less stable which may be due to the large waveguide size and the relatively greater amount of heat that is conducted into the calorimeter via this path.

Drift - The efficiency measurements for each sensor have been collated and at each frequency for which data exists that spans five or more years a drift rate has been estimated. The drift is based on a linear fit of the data using least squares linear regression to give a best-fit equation of the form: $Eff = Eff_0 + gradient \times date$



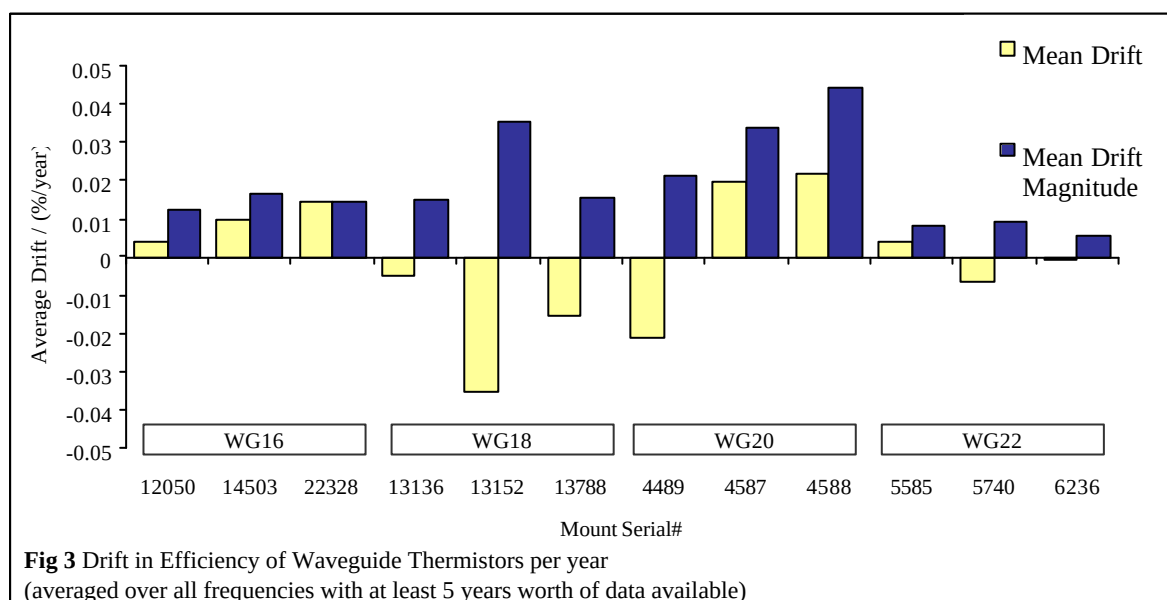
The gradient of the line can be taken to be the average drift per year at that frequency for that sensor. An average drift for the sensor is obtained by averaging the magnitudes of the drifts at every frequency for which sufficient data exists. [Fig1] above shows an example straight line fit for a WG20 sensor at a single frequency.

Any drift that is occurring is at a much smaller level than the calculated measurement uncertainty but over many years of measurements even a small drift should be noticeable. (Note the uncertainty on calibration date is relatively small and may be assumed to be zero). It is useful to compare the drifts at individual frequencies for all the sensors in a waveguide size to check that they do not all exhibit the same characteristics. If it was found that they did then that would be good evidence that the drift was due to a change in the properties of the calorimeter and not those of the power sensor.



WG Size	Model Number	Certificate Uncertainty	Average Magnitude of Drift per year (%)	Average Standard Deviation on measurements
16	X486A	0.60%	0.014	0.077
18	P486A	0.60%	0.022	0.026
20	K486A	0.80%	0.033	0.029
22	R486A	0.80%	0.008	0.035

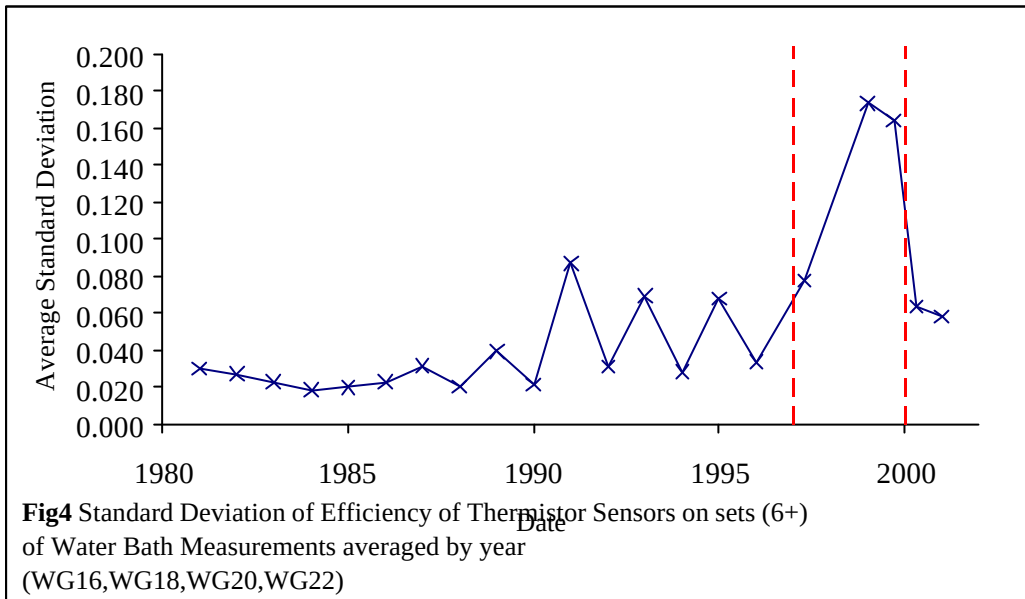
Table 2 Summary of Waveguide Power Sensor Efficiency Drift



WG16 [Tab2] shows a large average standard deviation on measurements. This is probably partly due to waveguide conduction of heat into calorimeter and partly because a relatively large number of measurements were taken in the lab with poor temperature control. The measured drift is low [Fig3] and may just be artefact of the high standard deviation. The WG18 results show a small average drift dominated by drift on sensor 13152.

The small average standard deviation is probably mainly because few measurements were made in the lab with poor temperature control. The WG20 results show the largest average drift per year. The physical properties of these sensors seem to have changed over the calibration history. WG22 shows a very small average drift and a small standard deviation. These sensors appear to be the most stable.

The waterbath measurements from the early eighties show very low standard deviations [Fig4]. As these measurements were the first ones of the thermistor sensors they had to be very accurate due to the lack of a calibration history on these items. The slight increase in Standard Deviations up until 1997 is probably because it was realised the measurements were agreeing well with the original data and that measurements could be made slightly more quickly without adversely affecting the results. The high average standard deviations in 1991, 1993 and 1995 are due to the large proportion of WG16 calibrations performed in these years.



In 1997 the Power Section moved from DERA at Malvern to temporary accommodation on the NPL site at Teddington. This lab had significantly worse temperature control than previously and this is particularly illustrated by the large increase in Standard Deviation for the WG16 measurements.

In July 2000 the Power Section moved to new accommodation on the Teddington site with much better temperature control and the standard deviation on measurements decreased to the pre-1997 levels. It will hopefully be possible to reduce the temperature variability in the current laboratory and enable the measurement standard deviations to be further reduced.

6 Conclusions

The average magnitude of the drift in efficiency of a waveguide thermistor sensors at any frequency per year has been found to be always less than 0.05% (0.02% is a typical value). This is very much smaller than the measurement uncertainty with these sensors so in most cases it can be assumed that the long term sensor drift is effectively zero. Sensors do not always show the same size or direction of drift at all frequencies across the waveguide band but in general the drifts are reasonably consistent. The physical characteristics of the calorimeters do not seem to be changing significantly and producing an apparent drift for all the sensors in that waveguide size.

The standard deviation of the efficiency measurements is very dependent on the laboratory temperature stability, especially in WG16. Laboratory temperature stability has recently improved following a period when the waterbath calorimeters were housed in temporary accommodation with poorer temperature control.

7 References

1. Engen G.F., 'A Refined X-Band Microwave Microcalorimeter', J. Research NBS, 63C, 77-82, July-Sept 1959
2. Oldfield L.C., Ide J.P., Griffin E.J., 'A Multistate Reflectometer', IEEE Trans. IM-34, No. 2, 198-201, June 1985