INTERNATIONAL INTERCOMPARISON OF POWER AT 15 GHz

IN WAVEGUIDE R 140

GT-RF 75-A1

Final Report of the Pilot Laboratory

by

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Summary

This is the detailed final report of the international intercomparison GT-RF 75-A1 "Microwave power in waveguide R 140 at 15 GHz" sponsored by the RF Working Group of the "Comité Consultatif d'Electricité (CCE)" in the "Bureau International des Poids et Mesures" and decided on at its 4th meeting (19.5. to 21.5. 1975) in Sèvres. The following institutes LCIE (France), NBS (United States of America), NRC (Canada), RSRE (England) and PTB (Federal Republic of Germany) participated, the latter as pilot laboratory. Three different pairs of transfer standards, two of the barretter type and one of the thermistor type circulated. The quantity to be measured was the effective efficiency. A good agreement within ± 0.0015 could be stated for the results of 4 participants, only in one case was a systematic deviation ≦ 0.005 obvious. The results of one special pair of barretters (Type PTB-2.22-460) have not been included for the further evaluation and interpretation, because instabilities occured in the course of the cycle. Possible reasons for this effect are discussed. All measurement results as reported by the participants to the pilot laboratory are given in the appendix.

1. INTRODUCTION

At the 4th meeting of the Radiofrequency Working Group of the "Comité Consultatif d'Electricité" at the "Bureau International des Poids et Mesures" in Sèvres which was held from May 19th to May 21st, 1975, it was decided to run an international intercomparison of microwave power in the waveguide R 140 at the 15 GHz frequency.
The following national institutes agreed to participate:

1. Laboratoire Central des Industries Electriques (LCIE), Fontenay-aux-Roses, France
2. National Bureau of Standards (NBS), Boulder (Colorado), U.S.A.
3. National Research Council (NRC), Ottawa, Canada
4. Royal Signals and Radar Establishment (RSRE), Great Malvern, England
5. Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Federal Republic of Germany

The PTB acted as pilot laboratory for this cycle. Three different pairs of transfer standards were circulated, two of them were barretter mounts and one pair consisted of thermistor mounts. The intercomparison run started in August 1978 and was completed in June 1982.

2. THE INTERCOMPARISON SCHEME

The intercomparison scheme is illustrated in Fig. 1. In the course of this cycle one pair of transfer standards was damaged and became unstable. It was removed and replaced by another identical pair of barretter mounts, manufactured in the PTB. With these two mounts a second run (II) was started after the main run (I) was completed. But a flange distortion also occured in these transfer mounts and an instability of the measurement results was ascertained. A discussion of this problem is given in the conclusion (Section 7).

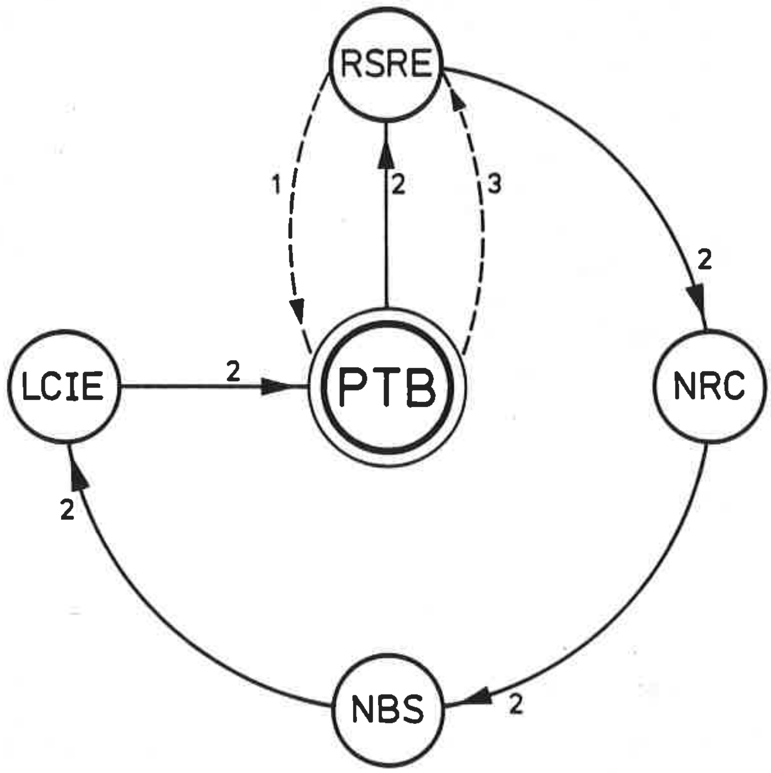
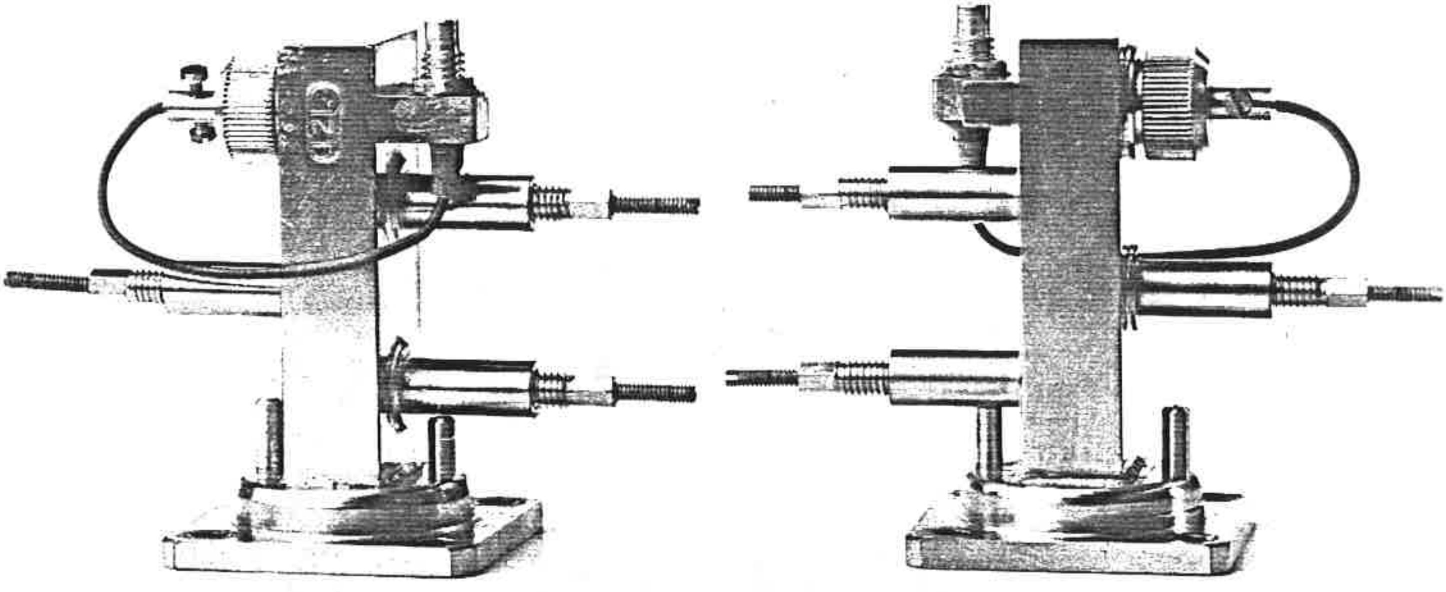
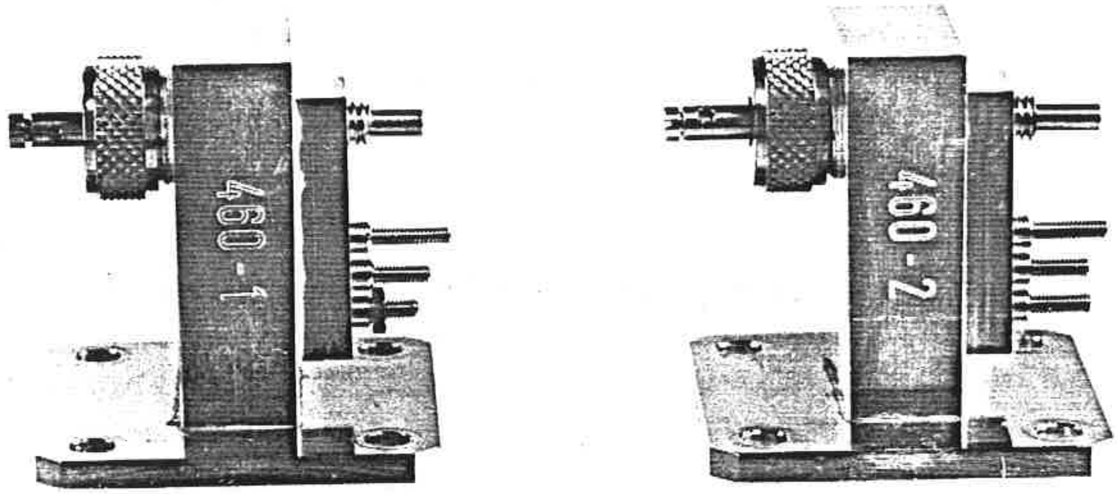


Fig. 1 Intercomparison pattern for the international intercomparison Gt-RF 75-A 1 (microwave power of about 10 mW in waveguide R 140 at the frequency 15 GHz). This pattern refers to cycle I. Cycle II is identical, only omitting the pattern pathes (1) and (3) , which only exist for the British transfer standards UK- J 21 and UK- J 22 of cycle I.

Fig 2 : The circulated transfer standards

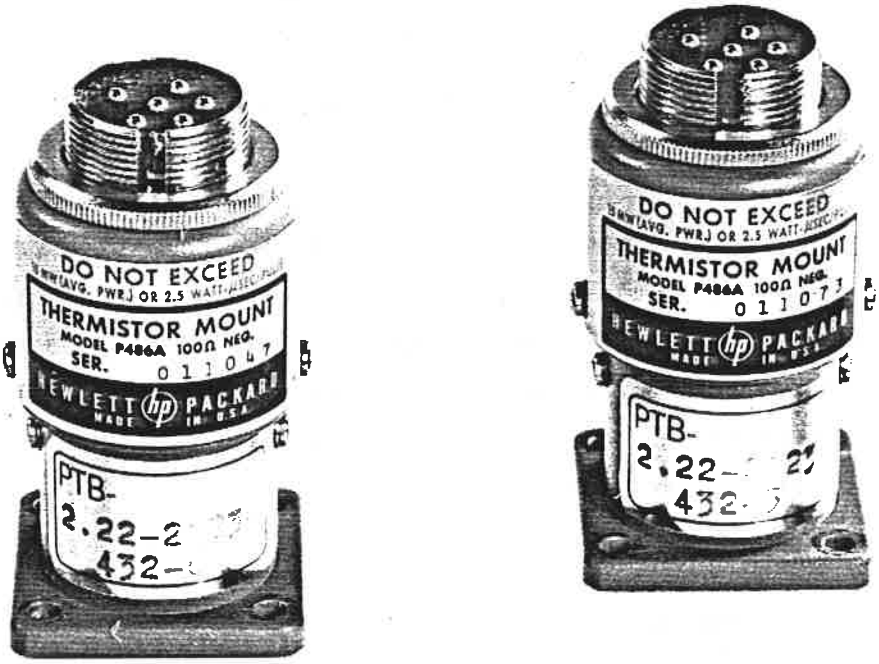


a) the baretter mounts UK- J 21 and UK- J 22, developed at the RSRE



b) the barretter mounts PTB-2,22-460-1 and PTB-2.22-460-2 developed at the PTB. (The mounts 460-3 and 460-4 are of identical construction).

Fig 2, continued



c) the thermistor mounts PTB-2.22-432-5 and PTB-2.22-432-6, made available by the PTB.

3. THE TRANSFER STANDARDS

Three pairs of transfer standards were made available by the participants:

1. Two tuned barretter mounts developed and manufactured at the RSRE; designated as UK-J 21 and UK-J 22.
2. Two tuned barretter mounts developed and manufactured at the PTB and designated as PTB-2.22-460-1 and PTB-2.22-460-2. For a second run they were replaced by the identical mounts PTB-2.22-460-3 and PTB-2.22-460-4.
3. Two commercial untuned thermistor mounts, type hp 486 A, designated as PTB-2.22-432-5 and PTB-2.22-432-6.

The PTB barretter mounts (No.2) were constructed with rather small masses combined with thin flanges which were soldered on the waveguide body in the case of 460-1 and 460-2. The flanges of 460-3 and 460-4 were fastened by applying a special adhesive. By this means a low heat capacity and therefore a good temperature response was achieved. Photographs of the transfer standards described are shown in Fig. 2

4. THE MEASURING METHODS

The quantity to be measured is the effective efficiency of the bolometer mounts, defined by

$$(1) \qquad \eta_{eff} = \frac{\text{DC substitution power, effecting the same heat response as the substituted RF power in the bolometer element}}{\text{Total RF power absorbed within the bolometer mount}}$$

The standard device with which RF power is related to DC power and thus traced to the national standards of voltage and resistance is in all cases a microcalorimeter system, as was first described by MacPherson and Kerns [1] and refined by Engen [2] . The transfer standards were not always directly calibrated within the microcalorimeter but instead were compared with a laboratory working standard which was calibrated in a microcalorimeter. In these cases the comparison of the transfer standard with the working standard was performed by means of an auxiliary device, e.g. a bolometer coupler or a sixport system.

4.1 The RSRE measuring devices

At the RSRE, two different devices were used for calibrating barretter and thermistor mounts. The effective efficiency of each barretter mount was determined using a microcalorimeter immersed in a water bath at + 24.5 ^{o}C. Microwave power was incident on the mount for alternate one hour periods. At the end of each one-hour period the temperature of the barretter mount, sensed by a thermopile and the dc power dissipation in the element, were recorded. The effective efficiency η_{eff} was calculated from (1) , where the total microwave power was calculated from the dc substitute power and the temperature increase of the mount on the application of microwave power. Corrections were applied to the calculated efficiency to compensate for

a) heating of the waveguide input mount,

b) variation in sensitivity of the thermopile between localised dc heating of the mount in the plane of the bolometer and localised plus distributed heating of the mount with dc and microwave dissipation,

c) thermopile offset voltage, i.e. thermopile output for zero dc and microwave dissipation.

A crushable waveguide shim was used between the bolometer flange and the microcalorimeter measurement flange in all calibrations. It should be mentioned that the first measurements of the standards UK-J 21 and UK-J22 at the RSRE were performed applying a water bath of 20^{o}C.

To determine the effective efficiency and the reflection coefficient of a thermistor mount, it was biased with a Hewlett-Packard 432 A power meter and connected to the measurement plane of a tuned reflectometer (Fig. 3). Calibration constants of the reflectometer were calculated from measurements with a short circuit and national standard 15 GHz bolometer (J 9) connected succesively to the measurement plane. These constants and subsequent power meter readings enabled the forward-going power at the measurement plane to be calculated and compared with the power absorbed and reflected at the thermistor mount. Four hp 432 A power meters were used successively to bias each mount and the value of the mount efficiency resulting from the reflectometer measurement was corrected for deviations from 100 Ω operation in each power meter bridge.

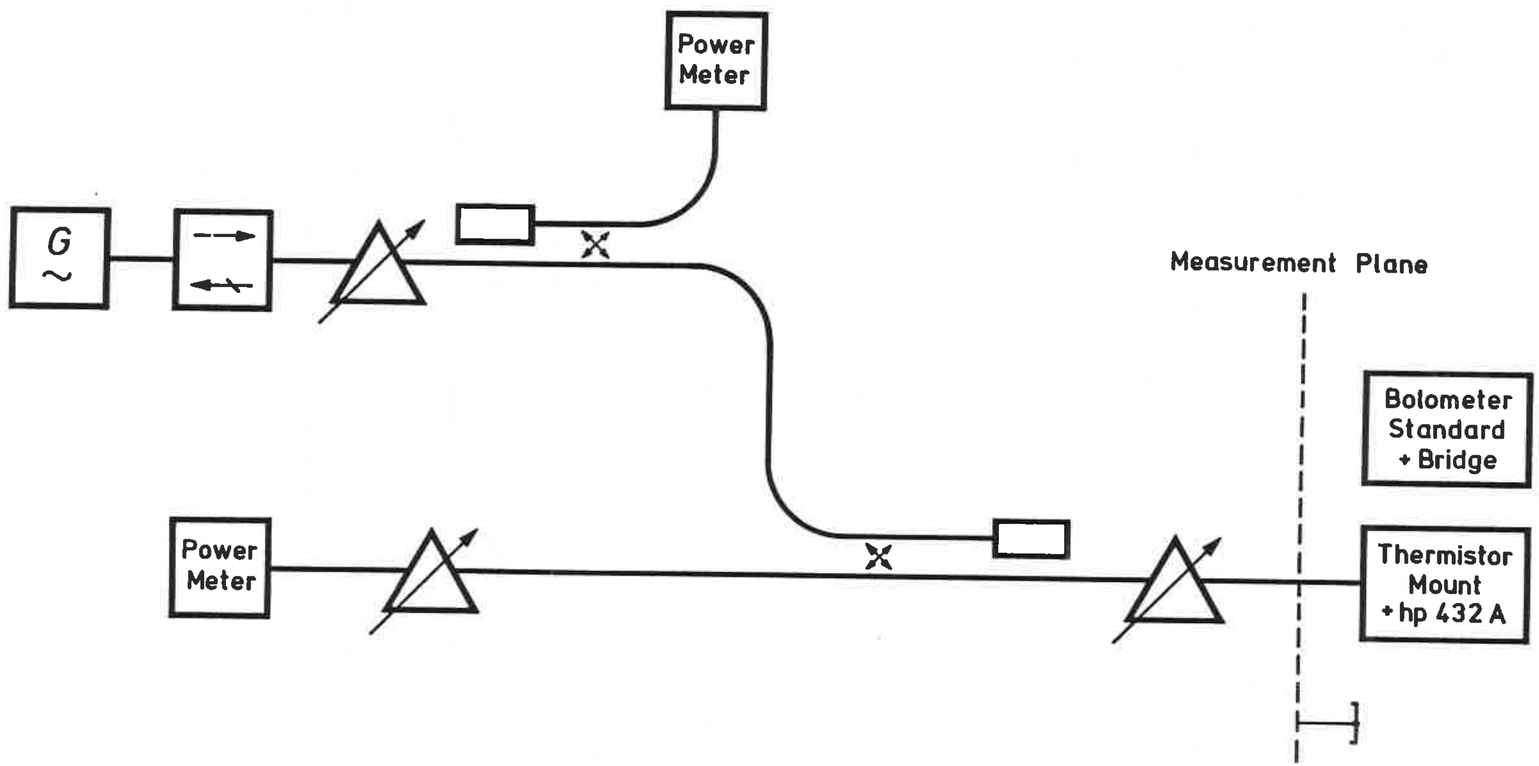


Fig. 3 Circuit diagram for determining the effective efficiency of thermistor mounts by comparing them with a national standard bolometer mount in a tuned reflectometer device (applied by the RSRE)

4.2 The NRC measuring device

At the National Research Council (NRC) a semiautomatic calorimeter was used. The response time of this calorimeter is about 1.5 min for a representative thermistor mount. Theory, construction details and the measuring procedure are described by Clark [3] .

4.3 The NBS measuring device

At the NBS a sixport system was used for comparing the bolometer transfer mounts to be calibrated, with a working standard calibrated in a microcalorimeter of the Engen type.

The theory, circuit design and the application of automated six-port devices have been published in numerous papers (e.g. [4] , [5] ,[6] ,[7] , [8]).

4.4 The LCIE measuring device

The device and the method applied by the LCIE is also derived from the refined microcalorimeter technique developed by Engen. A detailed description of the French power standard is given in [9] , [10] , [11] .

4.5 The PTB measuring device

For determining the effective efficiency of barretter and thermistor mounts in the PTB, a universal microcalorimeter system with interchangeable insets was manufactured for coaxial and waveguide systems in the frequency range between 1 MHz and 40 GHz [12], [13] , [14] . These measurements were carried out by inserting the combined waveguide arrangement for the frequency bands 8.2 GHz to 12.4 GHz and 12.4 GHz to 18.0 GHz; the masses of both systems were symmetrically arranged with regard to the medium calorimeter reference plane. Corrections were made for the heat effect of the input waveguide and for the power dissipation within the bolometer mount outside the RF power-receiving bolometer element.

The effective efficiency is calculated applying the equation (2)

(2) $$\eta_{eff} = \frac{1}{K} \frac{1 - \left(\frac{I_2}{I_1}\right)^2}{\frac{e_2}{e_1} - \left(\frac{I_2}{I_1}\right)^2} \pm \Delta\eta_{eff}$$

with

- K Correction factor considering the different behaviour of DC and RF power with regard to the power absorption,
- I_1 bolometer bridge current, when only DC is fed to the bolometer element,
- I_2 bolometer bridge current, when DC and RF power is fed to the bolometer element and the bridge balance is maintained,
- e_1 thermopile output voltage (for measuring the temperature rise of the mount), when only DC is applied,
- e_2 thermopile output voltage, when DC and RF power is applied

5. MEASURING CONDITIONS

The ambient conditions inside the different measuring rooms were not homogeneous. The room temperature varied between $(20 \pm 0.75)^{\circ}C$ (RSRE) and $(23 \pm 0.3)^{\circ}C$ (PTB). The values of the room relative humidity were also different. The NRC reported about 15 %, and the RSRE (50 ± 10) %. The relative uncertainty of the measuring frequency (15 GHz) was between $7 \cdot 10^{-5}$ (NRC) and $3 \cdot 10^{-7}$ (RSRE). In nearly all cases the RF power fed into the transfer standards was about 10 mW. The number of single measurements within one measuring period varied between 4 (NBS) and 20 (RSRE). The estimated random and systematic uncertainty was related to a confidence level of 95 % ($\simeq 2\sigma$).

6. MEASUREMENT RESULTS

Table I shows a survey of the mean values for the effective efficiencies as they were reported by the participants to the pilot laboratory. A complete arrangement of all reported data is given in the annex of this report.

On the history of this intercomparison cycle and the measurement results as presented in Table I, the following comment is made:

TABLE I

The measured mean values of η_{eff} as reported by the participating laboratories

Measuring device (laboratory)	Measured mean values $\overline{\eta_{eff}}$ (from n single measurements)							
	Designation of the transfer standards							
	UK-J21	UK-J22	PTB-2.22-432-5	PTB-2.22-432-6	PTB-2.22-460-1	PTB-2.22-460-2	PTB-2.22-460-3	PTB-2.22-460-4
RSRE	0.9907	0.9909	-	-	-	-	-	-
PTB	0.9907	0.9909	0.9792	0.9806	0.9912	0.9911	0.9894	0.9917
RSRE	0.9899	0.9909	0.9802	0.9818	0.9915	0.9916	0.9886	0.9919
NRC	0.9901	0.9882	0.9795	0.9809	0.9869	-	0.9870	0.9877
NBS	0.989	0.989	0.980	0.982	0.987	-	0.9868	0.9874
LCIE	0.9841	0.9860	0.9757	0.9726	-	-	0.9845	0.9853
PTB	0.9891	0.9889	0.9805	0.9814	-	-	0.9852	0.9858

The original cycle was performed with three pairs of transfer standards: UK-J 21, UK-J 22; PTB-2.22-460-1, PTB-2.22-460-2; PTB-2.22-432-5 and PTB-2.22-432-6. After the arrival of the transfer standards at the NRC (Canada), this laboratory reported to the pilot laboratory that the transfer mount PTB-2.22-460-1 could not be measured because the flange was distorted. The Canadian and the US measurement values on the mount PTB-2.22-460-2 were considerably lower than the former values measured by the RSRE and the PTB. However, the values measured by the NRC and the NBS were in agreement, as previously the values of the RSRE and PTB agreed with each other. The NBS reported that they had ascertained a slight flange distortion of mount PTB-2.22-460-2. After the NBS had performed several measurements on this mount, the barretter opened up and all further measurements on this mount had to be discontinued. To repeat these measurements, two new barretter mounts - identical in their construction with 460-1 and 460-2 - were manufactured at the PTB. They were designated as PTB-2.22-460-3 and PTB-2.22-460-4. With this pair, a second intercomparison cycle was started after the first one had been completed. A change in the measurement values was also observed in these two mounts, again, particularly between the results at the RSRE and the NRC (at the same position as in cylce A!). The values of the RSRE and the PTB were in good agreement. A flange distortion of this second pair was observed when they were returned to the pilot laboratory.

A further comment on these statements will be given in Section 7.

6.1 The weighted mean value

To calculate the most probable true measurement value for each transfer standard and in an attempt to eliminate unknown systematic deviations within the measurement values reported by the participating laboratories, a weighting factor g_i was assigned to each result [15] .

With the normalized weighting factor

(3) $$G_i = \frac{g_i}{\sum_{j=1}^{m} g_j}$$

and

(4) $$\sum_{i=1}^{m} G_i = 1$$

the weighted mean value is calculable from

(5) $$(\overline{\eta_{eff}})_w = \sum_{i=1}^{m} (\eta_{eff})_i \; G_i$$

and its confidence interval

(6) $$(\Delta\eta_{eff})_w = \sqrt{\sum_{i=1}^{m} (\Delta\eta_{eff})_i^2 \; G_i^2}$$

In those cases where the measurement value apparently contains an unknown systematic deviation and the reported uncertainty is inconsistent with the weighted mean value calculated, the uncertainty $(\Delta\eta)_{eff}$ was enlarged to $(\Delta\eta)'_{eff}$ for consistency. In a first order correction

(7) $$(\overline{\eta_{eff}})'_w = \sum_{i=1}^{m} (\eta_{eff})_i \; G_i'$$

and

(8) $$(\Delta\eta_{eff})'_w = \sqrt{(\Delta\eta_{eff})'_i \; G_i'^2}$$

were calculated as the most probable true measurement value and its confidence interval.

The weighting factor g_i was chosen *)

(9)
$$g_i = \frac{1}{(\Delta\eta_{eff})_i \, d_i} \, e^{-\frac{d_i}{d_{min}} \left(1 + \frac{(\Delta\eta_{eff})_i}{\overline{\Delta\eta_{eff}}}\right)}$$

with

$(\Delta\eta_{eff})_i = t_p \, \sigma_i$ — Confidence interval of the measured mean value $(\eta_{eff})_i$

$\sigma_i^2 = \sum_{j=1}^{m} \sigma_j^2$ — Total variance evaluated from the single contributions σ_j for the random and systematic uncertainties

t_p — Constant factor, related to the same confidence level P for all measurement results under consideration

$d_i = \sum_{j=1}^{m} |(\eta_{eff})_i - (\eta_{eff})_j|$ — Sum of the magnitudes of all distances between the measurement result i and all other results (j)

m — The number of measurement results to be compared

d_{min} — Smallest value of d_i for all values (i = 1,2,3...m)

$\overline{\Delta\eta_{eff}} = \frac{1}{m} \sum_{i=1}^{m} (\Delta\eta_{eff})_i$

Applying this formalism to the measured values given, yields the weighted mean values in Table II.

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*) Paper to be published (in preparation)

TABLE II

The calculated weighted mean values $(\overline{\eta_{eff}})_{ws}$ for the transfer standards UK-J 21, UK-J 22, PTB-2.22-432-5, PTB-2.22-432-6

Transfer standard	Weighted mean value $(\overline{\eta_{eff}})_{ws}$	Confidence interval
UK-J 21	0.9900	± 0.0010
UK-J 22	0.9894	± 0.0010
PTB-2.22-432-5	0.9800	± 0.0009
PTB-2.22-432-6	0.9814	± 0.0009

The measured mean values and their uncertainties - as reported by the participating laboratories - and their distances with respect to the calculated weighted mean value are represented in Fig. 4. A weighted mean value was not calculated for the PTB transfer standards 460-1 to 460-4 because of the distortions and instabilities occuring in these devices.

6.2 Mean deviations of the devices and transfer standards [16]

The expression

(10) $$|\overline{(\Delta\eta_{eff})_l}| = \frac{1}{n}\left(\sum_{s=1}^{n} |(\eta_{eff})_{ls} - (\overline{\eta_{eff}})_{ws}|\right)$$

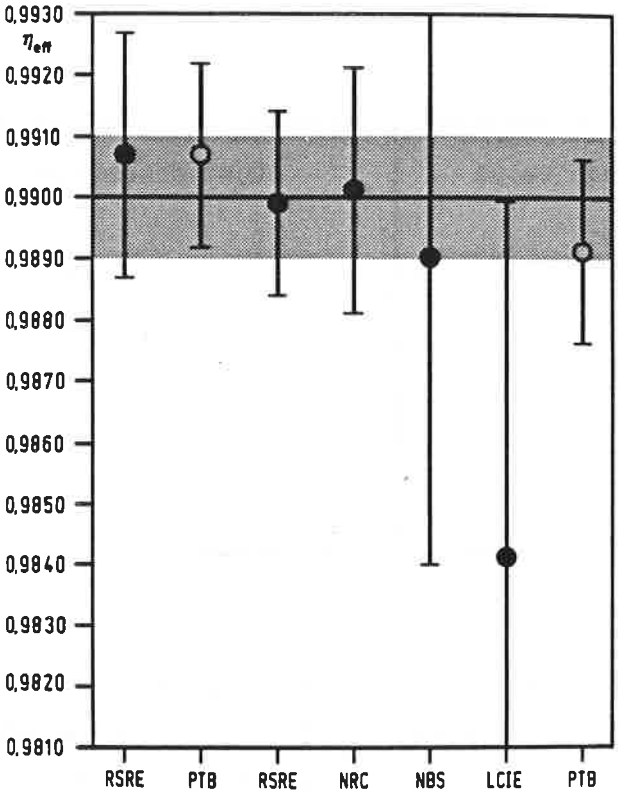
gives a mean value for the stability of the measuring devices relative to each other. The mean systematic deviations of the measuring devices are

(11) $$(\overline{\Delta\eta_{eff}})_l = \frac{1}{n}\left(\sum_{s=1}^{n} (\eta_{eff})_{ls} - (\overline{\eta_{eff}})_{ws}\right)$$

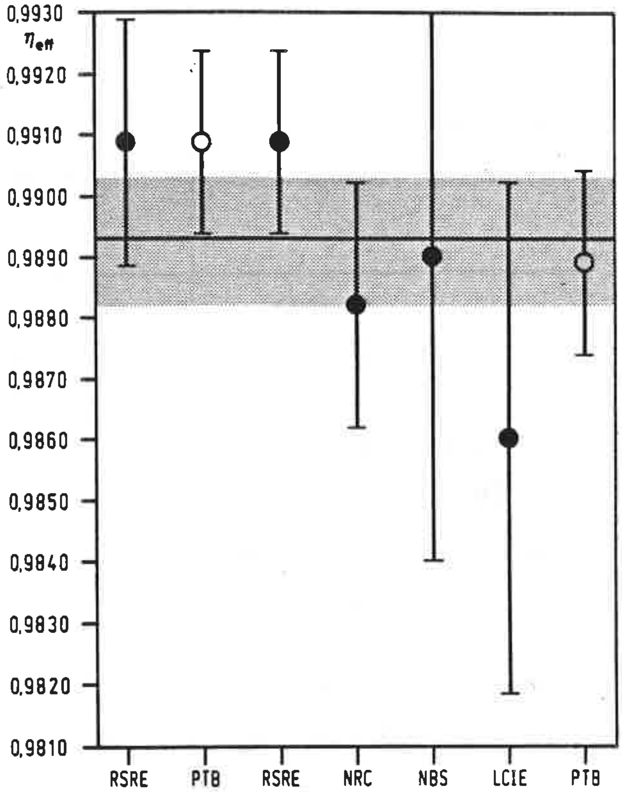
n being the number of the transfer standards considered, in this case n = 4.

Fig. 4 Measurement results for all circulated transfer standards.

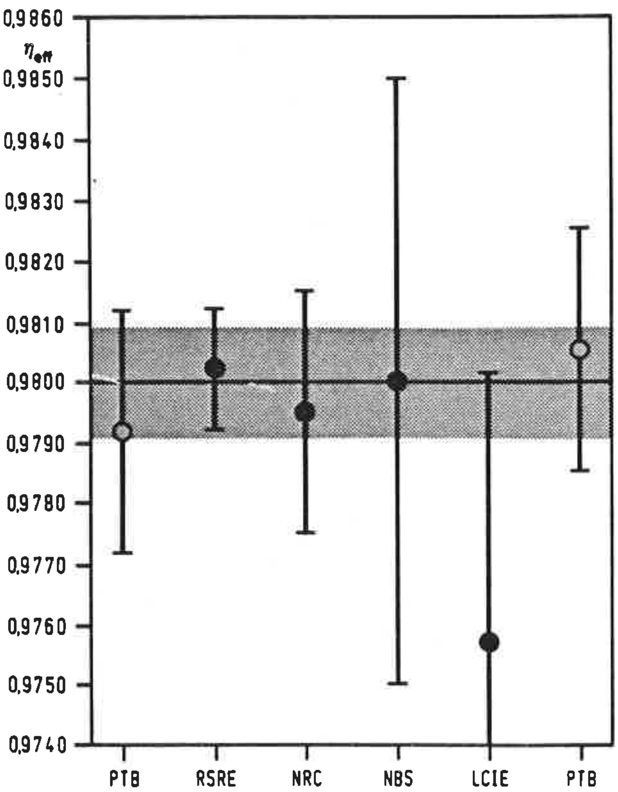
(A slight drift cannot be excluded for the standards UK-J 21 and UK-J 22; with regard to the mounts PTB-2.22.460-1 to -4, see section 7)
The weighted mean values and their confidence intervals are marked for the standards UK-J 21, UK-J 22, PTB-2.22-432-5 and PTB-2.22-432-6.



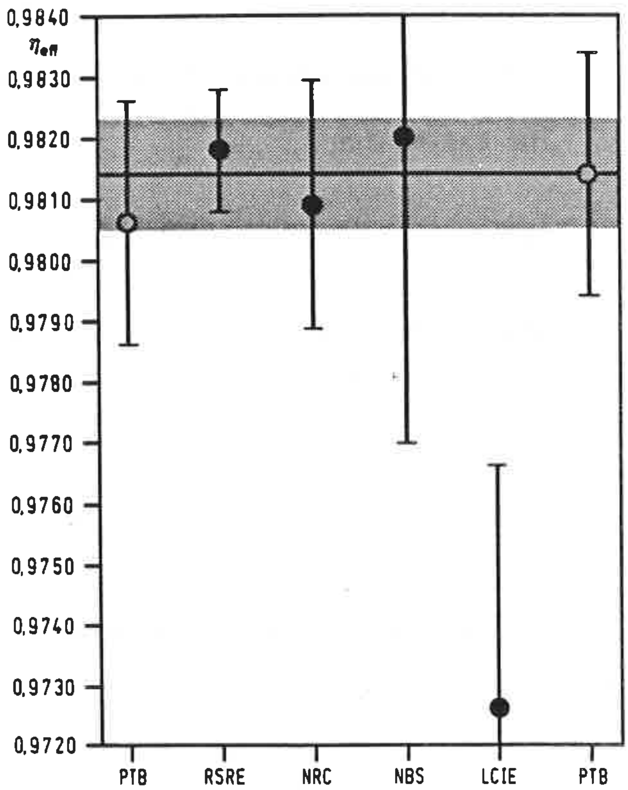
a) UK J-21



b) UK-J 22

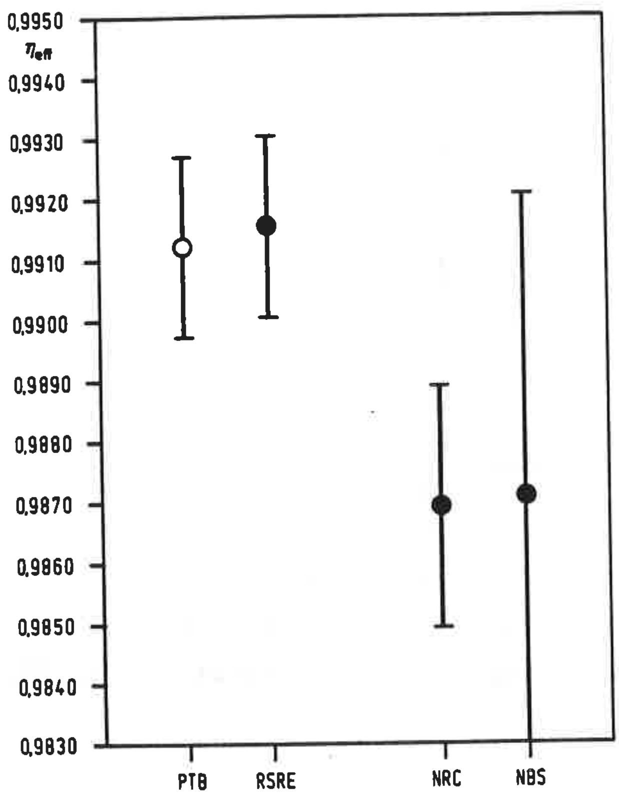


c) PTB-2.22-432-5

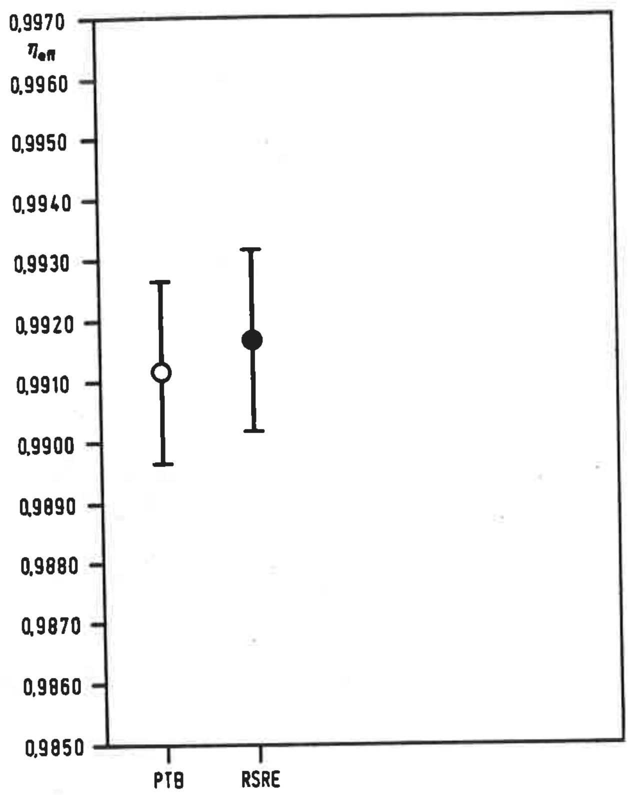


d) PTB-2.22-432-6

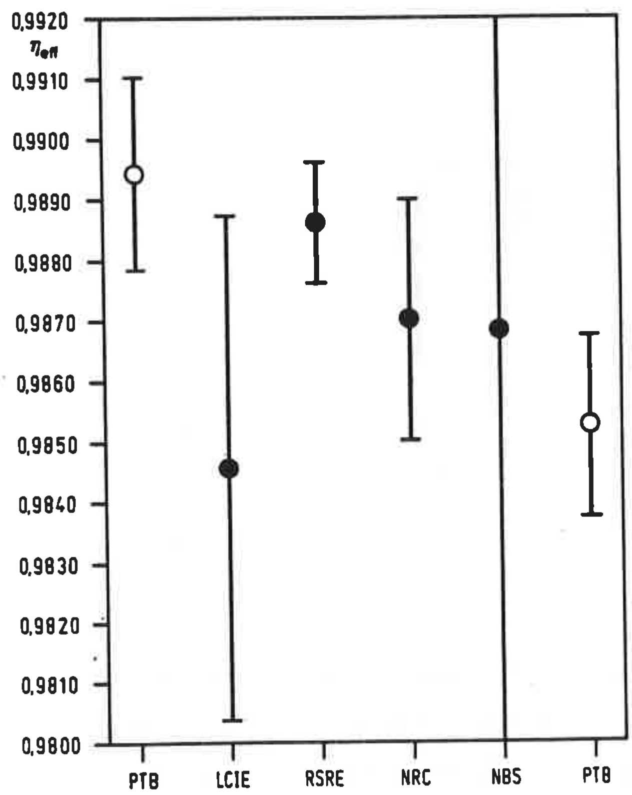
Fig. 4, continued



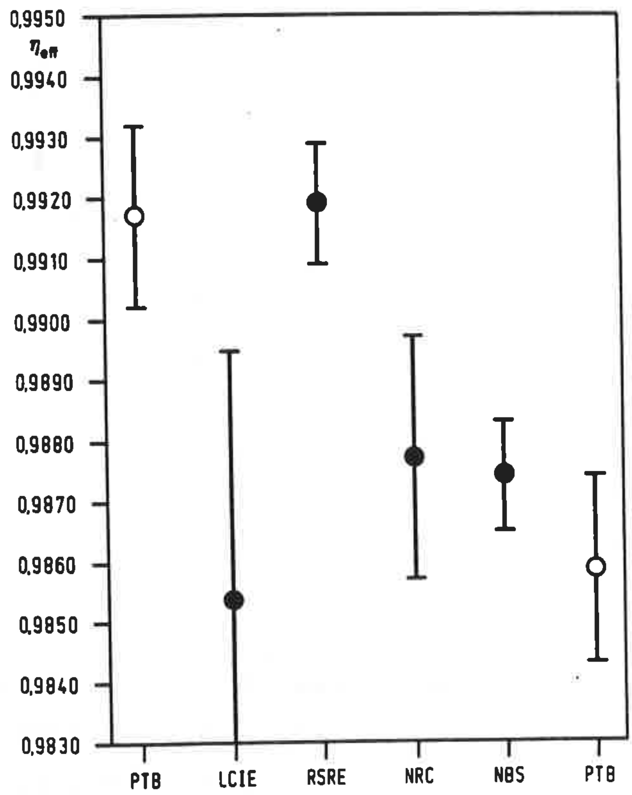
e) PTB-2.22-460-1



f) PTB 2.22-460-2



g) PTB-2.22-460-3



h) PTB-2.22-460-4

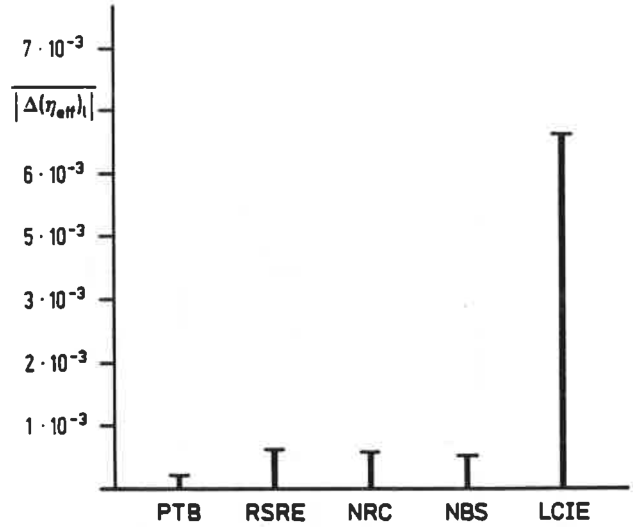


Fig.5 Mean values of the magnitudes of the deviations of the measured values from the weighted mean values, averaged over the results for the four stable transfer standards (equ.10)

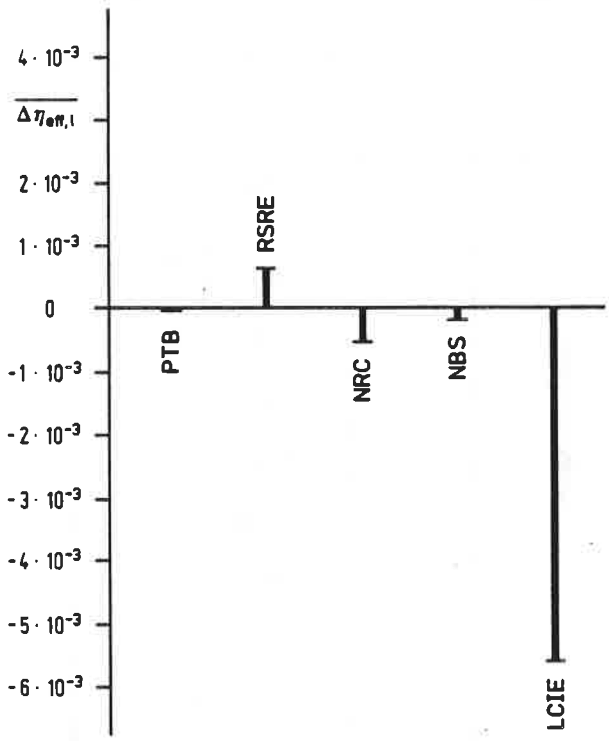


Fig. 6 Mean deviations of the measured values from the weighted mean values averaged over the four stable transfer standards and considering also the sign of the deviation (equ.11)

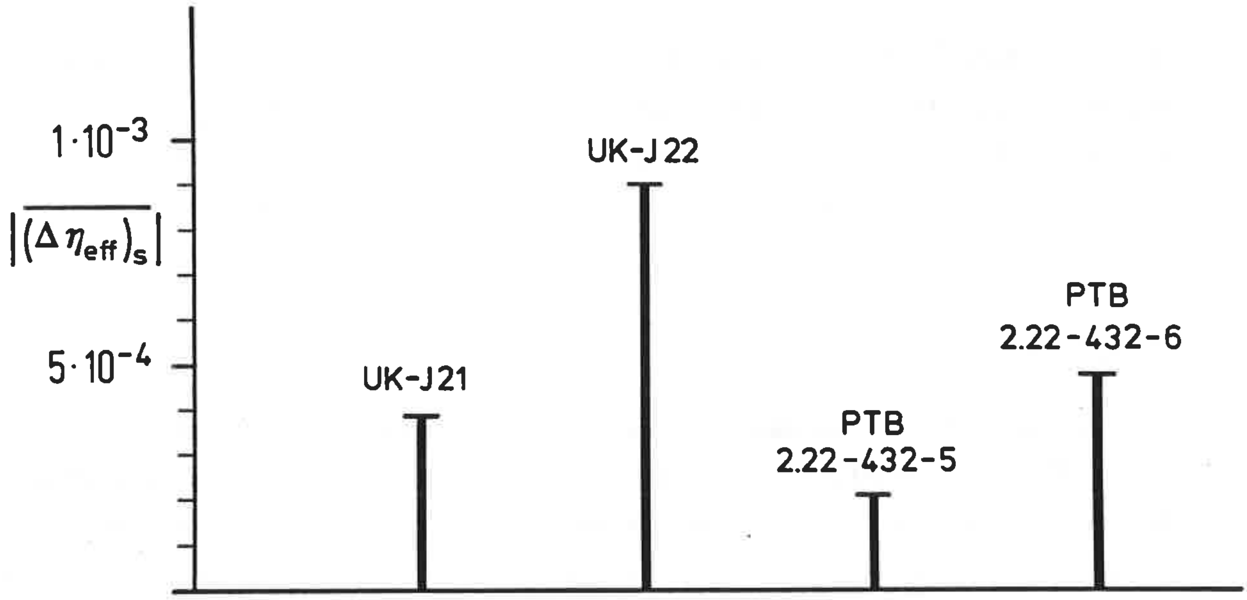


Fig. 7 Mean values of the magnitudes of the deviations of the measured values from the calculated weighted mean values, averaged over the measuring values of all laboratories for each transfer standard (equ. 12)

The results of (10) and (11) - averaged over the 4 transfer standards UK-J 21, UK-J 22, PTB-2.22-432-5 and PTB-2.22-432-6 - are given in the diagrams of Fig. 5 and Fig. 6.

Averaging the differences between the measured values and the calculated weighted mean value over the results of all participating laboratories for each transfer standard, deviations are caused particularly by the differing degrees of stability of the transfer standards.

(12) $$|\overline{(\Delta\eta_{eff})}_s| = \frac{1}{m}\left[\sum_{l=1}^{m} |(\eta_{eff})_{ls} - \overline{(\eta_{eff})}_{ws}|\right]$$

m is the number of the measurement values to be compared, corresponding to the number of participating laboratories; in this case m = 4 (the values measured by the LCIE were omitted on account of their systematic deviations, for the pilot laboratory the mean value of its two measurements was inserted).

7. CONCLUSION

First, comment will be made on the unstable behaviour of the barretter mounts PTB-2.22-460-1 to PTB-2.22-460-4. With regard to transfer standard PTB-2.22-460-2, the NRC (Mr. R.S. Clark) reported to the pilot laboratory on Febr. 26th, 1980, as follows: "I am sorry to report that I found the flange of your barretter mount 460-2 was distorted, so I did not calibrate it." The NBS as the measuring laboratory next-in-line reported on April 8th, 1980, :" We did not make measurements on 460-2 as Mr. R. Clark of Canada noticed the flange was not flat. It appeared to me that the flange on 460-1 was also not quite flat. I did try to measure 460-1 at 9 mW power level and noticed some instability. After several measurements the barretter opened up."

To repeat these measurements, two identical barretter mounts were manufactured at the PTB. They were measured in a second cycle following the first one after its completition. The measurement results on these transfer standards 460-3 and 460-4 did not prove satisfactory either. Apart from larger deviations, the pilot laboratory again ascertained flange distortions on both mounts after their return.

Fig. 8a shows a photograph of an original flat flange taken before the standards left the pilot laboratory. Fig. 8b shows a distorted flange after the cycle was completed.

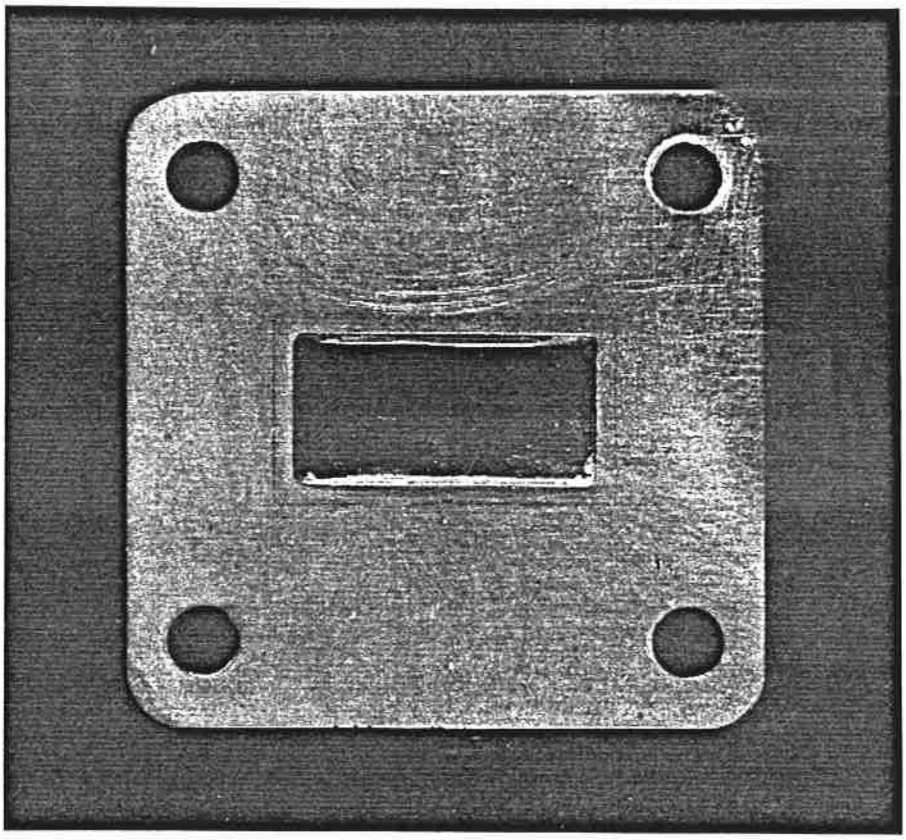
In Table III after the measurement results for 460-1, 460-3 and 460-4, the differences between two succeeding measurements are listed.

TABLE III

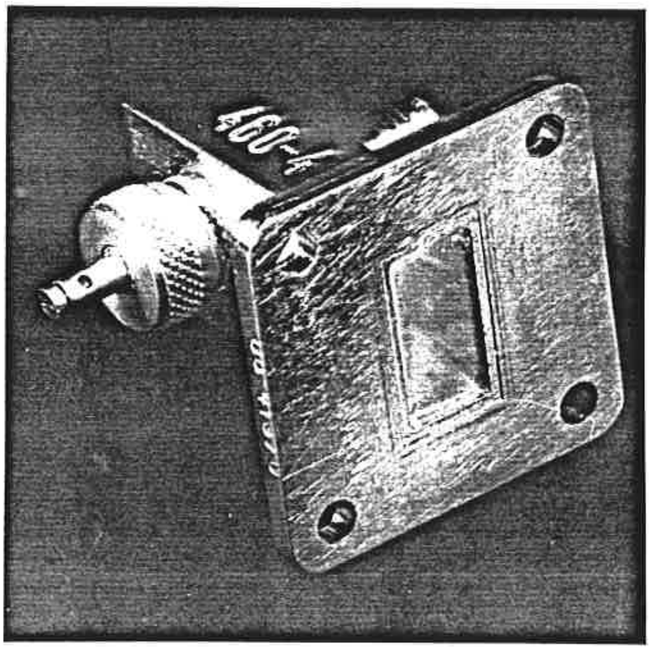
TRANSFER STANDARDS

Measuring device (laboratory)	PTB-2.22-460-1		PTB-2.22-460-3		PTB-2.22-460-4	
	η_{eff}	$(\Delta\eta_{eff})_{n,n+1}$	η_{eff}	$(\Delta\eta_{eff})_{n,n+1}$	η_{eff}	$(\Delta\eta_{eff})_{n,n+1}$
PTB	0.9912		0.9894		0.9917	
		+ 0.0003		- 0.0008		+ 0.0002
RSRE	0.9915		0.9886		0.9919	
		- 0.0046		- 0.0016		- 0.00042
NRC	0.9869		0.9870		0.9877	
		+ 0.0001		- 0.0002		- 0.0003
NBS	0.9870		0.9868		0.9874	
						- 0.0016
LCIE	-		-		-	
				- 0.0016		
PTB			0.9852		0.9858	

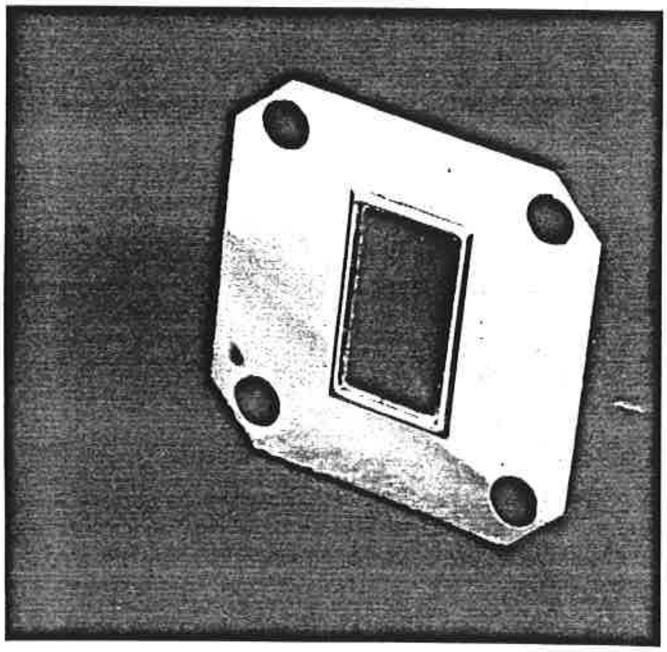
Fig. 8 Flange distortions on the barretter mount PTB-2.22-460-4



a) original form of the flange before entering into the cycle (the bright strips parallel to the waveguide broad side have been caused by optcal reflections from the teflon foil inserted.



b) flange distortion on the same mount returned from the cycle (the waveguide body is shifted against the flange plane.



c) crushable shim which was inserted between the flanges of the standard and those of the measuring device in one case.

If the measured values of the RSRE, NRC, NBS and PTB are averaged for each transfer standard circulated, the differences are small compared with $1 \cdot 10^{-3}$ and the mean deviation from the weighted mean value are also smaller than $1 \cdot 10^{-3}$. The transfer standard UK-J 22 has a somewhat larger mean deviation than the others. As Table IV indicates, a recognizable discrepancy in the measurement results can be established between the values of the RSRE and the NRC, at the same position where the measurement results for PTB-2.22-460-1 to 460-4 changed their numerical value.

TABLE IV

	η_{eff}	$(\Delta\eta_{eff})_{n+1,n}$
RSRE	0.9909	
PTB	0.9909	0.0000
RSRE	0.9909	0.0000
NRC	0.9882	- 0.0027
NBS	0.9890	+ 0.0008

Slight inhomogeneity in the measurement results for transfer standard UK-J 22.

On examination of all the reported measured values, it can be asserted that the deviations from the calculated weighted mean values are in all cases smaller than 0.0015, usually smaller than 0.0010. Considering that the total uncertainties given are between 0.0010 and 0.0050, this is a good result. It may be supposed that in some cases the actual uncertainties are smaller than the reported values, e.g. for the NBS.

Concluding the pilot laboratory thanks all participants for their good cooperation and their excellent measuring work, by which the good agreement between the standard measuring devices could be confirmed.
Especially we thank the responsible scientists and engineers:
Mr. R.F. Clark (NRC, Canada), Mr. L. Erard (LCIE, France), Dr. L.C. Oldfield and Mr. P.J. Skilton (RSRE, England), Mr. M.P. Weidman (NBS, United States of America) and Mr. R. Honigbaum (PTB, Federal Republic of Germany).

Inspecting the measurement results for PTB-2.22-460-3 only, we consider that a drift causes by continuous alterations of the barretter cannot be excluded [1], but together with the results for PTB-2.22-460-1 and PTB-2.22-460-4, the remarkable discrepancy between the RSRE results and those of the NRC is obvious. Comparing the distortions in the flange area with the shape of the "crushable shims" as applied by the RSRE, the PTB assumes that the distortions were caused by pressuring the shims between the flanges when applying a torque of about 0.1 Kg.m. The flanges of the PTB mounts were affixed to the waveguide body by a special adhesive and this mounting was not completely resistant to external pressures acting on it. The RSRE comments as follows: "In view of the apparent drift[1] disclosed by the attached graphs it seems doubtful if the crushable shims produced an effect of this kind, I think that it would be desirable to conduct experiments before official mention is made of any mechanical damage to your standards by RSRE."
In any case inference would be that the manufacturing method applied for the barretter mounts PTB-2.22-460 is rather susceptible to actions of pressures and forces and is therefore not suitable for transfer standards in world wide cycles.

On examination of the measurement results for the other four transfer standards which had not suffered any recognizable distortion, a good agreement between the results of the RSRE, NRC, NBS and PTB is found. All the measurement results of the LCIE seem to have been affected with a mean systematic deviation of about $5 \cdot 10^{-3}$.

Fig. 5 and Fig. 6 indicate that the mean values of the magnitudes of the deviations from the weighted mean values as well as the mean systematic deviations from these mean values - averaged over the four transfer standards UK-J 21, UK-J 22, PTB-2.22-432-5 and PTB-2.22-432-6 - are smaller than $1 \cdot 10^{-3}$ for the RSRE, NRC, NBS and PTB.

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[1] A re-measurement of these mounts two years later (1984) has shown, that the last measurement value of 1982 was exactly reproduced. A drift over the last two years could not be stated.

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A P P E N D I X

Results of the international intercomparison GT-RF 75 A-1

(Power in waveguide R 140 at 15 GHz)

Numerical values reported by the participating laboratories

POWER IN WAVEGUIDE R 140

AT 15 GHz

(Effective efficiency of bolometer mounts)

I.1. **Results for the first measurement of the British transfer standards in their home laboratory (RSRE)**

Pilot laboratory: P T B

ROOM TEMPERATURE (^{o}C)	:	20.5 ± 0.75
ROOM RELATIVE HUMIDITY (%)	:	50 ± 10
APPLIED MEASURING METHOD	:	Microcalorimeter
MEASURING FREQUENCY (GHz)	:	15.000 000 ± 0.000 005

Designation of the standard	I 21		I 22		
Input reflection coefficient of the standard	negligible		negligible		
RF power fed into the standard *)	(1) 11.0	(2) 10.7	(3) 10.0	(4) 10.9	(5) 9.4
Number of measurements	20	12	11	14	17
Mean value of effective efficiency	0.9908	0.9905	0.9908	0.9910	0.9910
Standard deviation	0.00022	0.00029	0.00011	0.00025	0.00034
Standard deviation of mean	0.000005	0.00008	0.00003	0.00007	0.00008
Minimum measured value	0.9904	0.9899	0.9906	0.9905	0.9907
Maximum measured value	0.9914	0.9910	0.9911	0.9916	0.9905
Estimated system. uncertainty (95 %)	± 0.002		± 0.002		

*) Measuring dated (1) 25.8.78 (3) 1.9.78 (5) 13.11.78
(2) 25.11.78 (4) 19.9.78

Measuring period: August to Nov.1978

POWER IN WAVEGUIDE R 140

AT 15 GHz

(Effective efficiency of bolometer mounts)

I.2. Results for the first measurement of all circulating transfer standards in the pilot laboratory (PTB)

Pilot laboratory: P T B

ROOM TEMPERATURE (°C)	:	23.0 ± 0.3
ROOM RELATIVE HUMIDITY (%)	:	50 ± 5
APPLIED MEASURING METHOD	:	Microcalorimeter
MEASURING FREQUENCY (GHz)	:	15.000 000 ± 0.000 001

Designation of the standard	UK - J 21	UK-J 22	PTB-2.22-460-1	PTB-2.22-460-2	PTB-2.22-432-5 Ser.Nr. 011073	PTB-2.22-432-6 Ser.Nr. 011047
Input reflection coefficient of the standard	< 0.005	< 0.005	< 0.005	< 0.005	0.052 ± 0.001	0.087 ± 0.001
RF power fed into the standard (mW)	10.0	10.0	10.0	10.0	9.6	10.0
Number of measurements	10	6	8	6	6	7
Mean value of effective efficiency	0.9907	0.9909	0.9912	0.9911	0.9792	0.9806
Standard deviation	0.00022	0.00027	0.00034	0.00019	0.00015	0.00014
Standard deviation of mean	0.00007	0.00011	0.00012	0.00008	0.00007	0.00005
Minimum measured value	0.9903	0.9906	0.9907	0.9909	0.9790	0.9805
Maximum measured value	0.9910	0.9912	0.9917	0.9914	0.9795	0.9809
Estimated systematical uncertainty	± 0.0015	± 0.0015	± 0.0015	± 0.0015	± 0.002	± 0.002

Measuring period: March to May 1979

I.3. Results of the measurement of all circulating transfer-standards at the RSRE (England)

BIPM - 75 A - 1

POWER IN WAVEGUIDE R 140

AT 15 GHz

(Effective efficiency of bolometer mounts)

Pilot laboratory: PTB

ROOM TEMPERATURE (°C)	: 20.5 ± 0.75	(21 ± 1)+)
ROOM RELATIVE HUMIDITY (%)	: 50 ± 10	
APPLIED MEASURING METHOD	: Microcalorimeter,	(Tuned reflectometer for comparison with national standard 15 GHz bolometer)+)
FREQUENCY (GHz)	: 15.0000 ± 0.0002	(15.000000 ± 0.000005)+)

Designation of the standard	UK - J21	UK - J22	PTB 2.22-460-1	PTB 2.22-460-2	PTB 2.22-432-5+) (Ser.Nr.011073)	PTB 2.22-432-6+) (Ser.Nr.011047)
Input reflection coefficient of the standard	-	-	-	-	0.054	0.091 0.092 0.091 0.089
RF power fed into the standard (mW)	9.4 9.9	9.6 10.1	9.9 9.8	9.9 9.8	4.8	4.8
Number of measurements	12 18	20 15	16 15	19 15	5	5
Mean value of effective efficiency	0.9898 0.9900	0.9909 0.9909	0.9915 0.9915	0.9916 0.9916	0.9802 0.9803 0.9801 0.9801	0.9818 0.9820 0.9818 0.9817
Standard deviation	0.00019 0.00013	0.00016 0.00020	0.00020 0.00011	0.00016 0.00010	0.00007 0.00008 0.00009 0.00013	0.00006 0.00014 0.00011 0.00014
Standard deviation of the mean	0.00005 0.00003	0.00004 0.00005	0.00005 0.00003	0.00004 0.00003	0.00003 0.00004 0.00004 0.00006	0.00003 0.00006 0.00005 0.00006
Minimum measured value	0.9896 0.9898	0.9906 0.9905	0.9911 0.9914	0.9914 0.9914	0.9801 0.9802 0.9800 0.9799	0.9817 0.9819 0.9817 0.9815
Maximum measured value	0.9902 0.9902	0.9912 0.9913	0.9919 0.9917	0.9919 0.9918	0.9803 0.9804 0.9802 0.9802	0.9819 0.9822 0.9820 0.9819
Estimated systematical uncertainty (95%)	0.0015	0.0015	0.0015	0.0015	0.001	0.001

+) These statements relate to the columns 5 and 6

Measuring period: October 1979

I.4. Results of the measurement of all circulating standards at the NRC (Canada)

BIPM - 75 A - 1

POWER IN WAVEGUIDE R 140

AT 15 GHz

(Effective efficiency of bolometer mounts)

Pilot laboratory: PTB

ROOM TEMPERATURE (^{o}C)	:	22 ± 2
ROOM RELATIVE HUMIDITY (%)	:	15 %
APPLIED MEASURING METHOD	:	Semiautomatic micro-calorimeter
FREQUENCY (GHz)	:	15.000 ± 0.001

Designation of the standard	UK - J 21	UK - J 22	PTB 2.22-460-1	PTB 2.22-460-2	PTB 2.22-432-5 (Ser.Nr.011073)	PTB 2.22-432-6 (Ser.Nr.011047)
RF power fed into the standard (mW)	10.0 ± 0.2	10.0 ± 0.2	10.0 ± 0.2	10.0 ± 0.2	10.0 ± 0.2	10.0 ± 0.2
Number of measurements	9	9	9	9	9	9
Mean value of effective efficiency	0.9901	0.9882	0.9869	Not measured because flange was distorted.	0.9795	0.9809
Standard deviation	0.00022	0.00024	0.00020		0.00015	0.00019
Standard deviation of the mean	0.00007	0.00008	0.00007		0.00005	0.00006
Minimum measured value	0.9897	0.9877	0.9865		0.9793	0.9807
Maximum measured value	0.9903	0.9886	0.9871		0.9797	0.9811
Estimated systematical uncertainty	±0.002	± 0.002	±0.002		±0.002	±0.002

Measuring period: January, February 1980

I.5. Results of the measurement of all circulating standards at the NBS (Boulder, USA)

BIPM - 75 - A1

Pilot laboratory: PTB

POWER IN WAVEGUIDE R 140

AT 15 GHz

(Effective efficiency of bolometer mount)

ROOM TEMPERATURE (^{o}C)	:	≈ 23^{o}
ROOM RELATIVE HUMIDITY	:	≈ 40%
APPLIED MEASURING METHOD	:	Microcalorimeter, 6-port measuring system
FREQUENCY (GHz)	:	15.0

Designation of the standard	UK - J 21	UK - J 22	PTB 2.22 - 460-1*)	PTB 2.22 - 460-2	PTB 2.22 - 432-5 (S/N 011073)	PTB 2.22-432-6 (S/N 011047)
RF power fed into the standard (mW)	9	9	9	9	9	9
Number of measurements	4	4	4	Not measured because flange was distorted.	4	4
Mean value of effective efficiency	0.989	0.989	0.987		0.980	0.982
Standard deviation	0.0002	0.0002	0.0002		0.0002	0.0002
Standard deviation of mean	0.0001	0.0001	0.0001		0.0001	0.0001
Estimated systematical uncertainty	±0.005	± 0.005	± 0.005		± 0.005	± 0.005

*) The barretter of mount 2.22 - 460-1 opened up, after having finished some measurements. Therefore the mounts PTB 2.22 - 460-1 and PTB 2.22 - 460-2 cannot be used furtheron in this intercomparison before being repaired.

Measuring period: March 1980

I.6. Results of the measurement of all circulating standards at LCIE

INTERNATIONAL INTERCOMPARISON
BIPM - 75 A-1
POWER IN WAVEGUIDE R 140
AT 15 GHz
(Effective efficiency of bolometer mounts)

ROOM TEMPERATURE (^{o}C)	: 20 ± 0,2
ROOM RELATIVE HUMIDITY (%)	: ≈ 50
APPLIED MEASURING METHODS	: Microcalorimeter
MEASURING FREQUENCY (GHz)	: 15.000 00 ± 0.000 15

Designation of the standard	UK - J 21	UK - J 22	PTB-2.22-460-3 +)	PTB-2.22-460-4 +)	PTB-2.22-432-5	PTB-2.22-432-6
RF power fed into the standard (mW)	10	10	10	10	10	10
Number of measurements	4	7	5	4	7	5
Mean value of effective efficiency	0.9841	0.9860	0.9845	0.9853	0.9757	0.9726
Standard deviation	0.003	0.0014	0.001	0.0006	0.0014	0.0005
Standard deviation of mean	0.0015	0.0005	0.0005	0.0003	0.0005	0.0002
Minimum measured value	0.9801	0.9838	0.9834	0.9848	0.9729	0.9722
Maximum measured value	0.9881	0.9879	0.9855	0.9859	0.9772	0.9727
Estimated systematical uncertainty	±0.004	±0.004	±0.004	±0.004	±0.004	±0.004

+) These measurements were made after the pilot laboratory has measured the mounts 460-3 and 460-4 (see II.1), replacing the damaged mounts 460-1 and 460-2

Measuring period: January 1981 and June 1981

I.7. Results of the last re-measurements of the 4 transfer standards UK-J21, UK-J22, PTB-432-5, PTB-432-6 in the pilot laboratory

Pilot laboratory: PTB

INTERNATIONAL INTERCOMPARISON

BIPM 75 - A1

POWER IN WAVEGUIDE R 140

AT 15 GHz

(Effective efficiency of bolometer mounts)

ROOM TEMPERATURE (^{o}C)	:	23.0 ± 0.3
ROOM RELATIVE HUMIDITY (%)	:	50 ± 5
APPLIED MEASURING METHOD	:	microcalorimeter
MEASURING FREQUENCY (GHz)	:	15.000 00 ± 0.000 01
RF POWER FED INTO THE INPUT OF THE STANDARD (mW)	:	~ 10

Designation of the standards	UK - J 21	UK - J 22	PTB-2.22-432-5	PTB-2.22-432-6
Number of single measurements	7	15	6	6
Mean value of effective efficiency	0.9891	0.9889	0.9805	0.9814
Standard deviation	0.0003	0.0007	0.00015	0.0002
Standard deviation of mean	0.00011	0.00018	0.00006	0.00008
Minimum measured value	0.9887	0.9880	0.9803	0.9812
Maximum measured value	0.9897	0.9903	0.9807	0.9817
Estimated system. uncertainty	±0.0015	±0.0015	±0.002	±0.002

Measuring period: Oct./Nov. 1981

II-1 1. measurement of the replacement bolometer mounts PTB-460-3 and PTB-460-4, replacing the damaged mounts PTB-460-1 and PTB-460-2 in the pilot laboratory

INTERNATIONAL INTERCOMPARISON

BIPM 75 A -1

POWER IN WAVEGUIDE R 140

AT 15 GHz

(Effective efficiency of bolometer mounts)

ROOM TEMPERATURE (^{o}C)	: 23.0 ± 0.3
ROOM RELATIVE HUMIDITY (%)	: 50 ± 5
APPLIED MEASURING METHOD	: microcalorimeter
MEASURING FREQUENCY (GHz)	: 15.000 00 ± 0.000 01
RF POWER FED INTO THE INPUT OF THE MOUNTS (mW)	: ~ 10
NUMBER OF SINGLE MEASUREMENTS	: 6

Designation of the transfer-standard	PTB - 2.22 - 460 - 3	PTB - 2.22 - 460 - 4
Mean value of effective efficiency	0.9894	0.9917
Standard deviation	0.00043	0.0002
Standard deviation of mean	0.00017	0.00008
Minimum measured value	0.9888	0.9914
Maximum measured value	0.9899	0.9919
Estimated system. uncertainty	±0.0015	±0.0015

Measuring period: May 1981

II. 2. Second measurement of the transfer mounts PTB-460-3 and PTB-460-4 at the LCIE (see also I.6)

INTERNATIONAL INTERCOMPARISON

BIPM-75-A1

POWER IN WAVEGUIDE R 140

AT 15 GHz

(effective efficiency of bolometer mounts)

ROOM TEMPERATURE (°C) :	20 ± 0.2
ROOM RELATIVE HUMIDITY (%) :	≃ 50
APPLIED MEASURING METHOD :	microcalorimeter
MEASURING FREQUENCY (GHz) :	$15.000\,00 \pm 0.000\,15$

Designation of the transfer standard	PTB - 2.22 - 460-3	PTB - 2.22 - 460-4
RF power fed into the transfer standard (mW)	10	10
Number of measurements	5	4
Mean value of effective efficiency	0.9845	0.9853
Standard deviation	0.001	0.0006
Standard deviation of mean	0.0005	0.0003
Minimum measured value	0.9834	0.9848
Maximum measured value	0.9855	0.9859
Estimated systematical uncertainty	$\pm$ 0.004	$\pm$ 0.004

Measuring period: June 1981

II. 3. Third measurement of the transfer mounts PTB-460-3 and PTB-460-4, measured at the RSRE

INTERNATIONAL INTERCOMPARISON

BIPM 75 A -1

POWER IN WAVEGUIDE R 140

AT 15 GHz

(Effective efficiency of bolometer mounts)

Pilot laboratory PTB

ROOM TEMPERATURE (^{o}C)	: 20.00 ± 0.75
ROOM RELATIVE HUMIDITY (%)	: 50 ± 10
APPLIED MEASURING METHOD	: microcalorimeter (immersed in a water bath at 24,8^{o}C)
MEASURING FREQUENCY (GHz)	: 15.0000 ± 0.0002
MICROWAVE POWER FED INTO THE INPUT OF THE TRANSFER STANDARD (mW)	: 10.1
NUMBER OF SINGLE MEASUREMENTS	: 12

Designation of the transfer standard	PTB-2.22-460-3	PTB-2.22-460-4
Mean value of effective efficency	0.9886	0.9919
Standard deviation	0.00013	0.00009
Standard deviation of mean	0.00004	0.00003
Minimum measured value	0.9884	0.9918
Maximum measured value	0.9888	0.9921
Estimated systematical uncertainty (95% confidence level)	± 0.001	± 0.001

Measuring period: 9.9.1981 and 12.9.1981.

II.4 Fourth measurement of the transfer mounts PTB-460-3 and PTB-460-4 at the NRC

INTERNATIONAL INTERCOMPARISON

BIPM - 75-A1

POWER IN WAVEGUIDE R 140

AT 15 GHz

(effective efficiency of bolometer mounts)

Pilot laboratory: PTB

ROOM TEMPERATURE (^{o}C)	:	21.4 ± 1
ROOM RELATIVE HUMIDITY (%)	:	≈ 25%
APPLIED MEASURING METHOD	:	Microcalorimeter
MEASURING FREQUENCY (GHz)	:	15.000 ± 0.001
MICROWAVE POWER FED INTO THE INPUT OF THE TRANSFER STANDARD (mW)	:	10 ± 0.5
NUMBER OF SINGLE MEASUREMENTS	:	11

Designation of the standard	PTB - 2.22 - 460 - 3	PTB - 2.22 - 460 -4
Mean value of effective efficiency	0.9870	0.9877
Standard deviation	0.00027	0.00027
Standard deviation of mean	0.00008	0.00008
Minimum measured value	0.9866	0.9872
Maximum measured value	0.9875	0.9881
Estimated systmatic uncertainty	± 0.002	± 0.002

Measuring period: January 1982

II.5. Fifth measurement of the transfer mounts PTB-460-3 and PTB-460-4 at the NBS

Pilot laboratory: PTB

INTERNATIONAL INTERCOMPARISON

BIPM - 75 A-1

POWER IN WAVEGUIDE R 140

AT 15 GHz

(effective efficiency of bolometer mounts)

ROOM TEMPERATURE (^{o}C)	:	23
ROOM RELATIVE HUMIDITY (%)	:	40
APPLIED MEASURING METHOD	:	sixport system
MEASURING FREQUENCY (GHz)	:	15
MICROWAVE POWER FED INTO THE INPUT OF THE TRANSFER STANDARD (mW)	:	5
NUMBER OF SINGLE MEASUREMENTS	:	4

Designation of the standard	PTB - 2.22 - 460 - 3	PTB - 2.22 - 460 - 4
Mean value of effective efficiency	0.9868	0.9874
Standard deviation	0.0005	0.0005
Standard deviation of the mean	0.00035	0.00035
Minimum measured value	-	-
Maximum measured value	-	-
Long term random error (95%)	0.005	0.005
Estimated total uncertainty (95%)	± 0.009	± 0.009

Measuring period: February 1982

II.6. Results of the last re-measurement of the two transfer standards PTB - 2.22-460-3 and PTB - 2.22-460-4 in the pilot laboratory

INTERNATIONAL INTERCOMPARISON

BIPM 75 A-1

POWER IN WAVEGUIDE R 140

AT 15 GHz

(Effective efficiency of bolometer mounts)

Pilot laboratory: PTB

ROOM TEMPERATURE (^{o}C)	: 23.0 ± 0.3
ROOM RELATIVE HUMIDITY (%)	: 50 ± 5
APPLIED MEASURING METHOD	: microcalorimeter
MEASURING FREQUENCY (GHz)	: 15.000 00 ± 0.000 01
RF POWER FED INTO THE INPUT OF THE MOUNTS (mW)	: ≃ 10
NUMBER OF SINGLE MEASUREMENTS	: 6

Designation of the transfer-standard	PTB - 2.22 - 460 - 3	PTB - 2.22 - 460 - 4
Mean value of effective efficiency	0.9852	0.9858
Standard deviation	0.0002	0.0003
Standard deviation of mean	0.0001	0.0001
Minimum measured value	0.9849	0.9855
Maximum measured value	0.9855	0.9863
Estimated system. uncertainty	± 0.0015	± 0.0015

Measuring period: May/June 1982