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INTERNATIONAL INTERCOMPARISON OF ATTENUATION IN WAVEGUIDE R 140 AT 15 GHz

Final Report
by
H. Bayer

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INTERNATIONAL INTERCOMPARISON OF ATTENUATION IN WAVEGUIDE R 140 AT 15 GHz

GT-RF 75-A 3

Final report of the pilot laboratory

by

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S U M M A R Y

This is the final report about the results of the international intercomparison GT-RF 75-A 3 decided by the RF working group of the "Comité Consultatif d'Électricité" in the "Bureau International des Poids et Mesures" at its 4th meeting (may 1975) in Sèvres. Five national institutes (IENGF, Italy; NBS, USA; OMH, Hungary; RSRE, United Kingdom and PTB, Federal Republic of Germany) decided to participate, the latter one as pilot laboratory.

The quantity to be measured was the attenuation in waveguide R 140 (WG 18, WR 62) at the frequency 15 GHz. Five transfer standards - having the nominal attenuation values 0.01 dB; 0.1 dB; 10 dB; 20 dB; 40 dB - were made available by the participants. All transfer standards were switchable between the minimum insertion loss (zero position) and the nominal value of attenuation to be measured. The principles of the design of the transfer standards and the measuring methods applied by the participants are described.

The measurement results are given in several tables and diagrams. For each transfer standard a weighted mean value is calculated. The mean deviations are evaluated for each measuring device. All total uncertainties varied between 0.0002 dB at 0.01 dB to nearly 0.1 dB (worst value at 40 dB) Apart from one case (10 dB) all transfer standards were of good repeatability and long-term stability. All data and measuring results - as reported by the participating laboratories - are presented in the appendix.

1. INTRODUCTION

This international intercomparison of the radiofrequency quantity "attenuation in waveguide R 140 (WG 18, WR 62) at the frequency 15 GHz" was decided at the 4th meeting of the Radio Frequency Working Group of the "Comité Consultatif d'Électricité" which was held from May 19th to May 21st, 1975 at the International Bureau of Weights and Measures (BIPM) in Sèvres. The official designation of this comparison is GT-RF 75-A 3. The attenuation values to be compared were 0.01 dB, 0.1 dB, 10 dB, 20 dB and 40 dB. The following national institutes participated:

1. Istituto Elettrotecnico Nazionale Galileo Ferraris (IENGF, Torino, Italy);
2. National Bureau of Standards (NBS, Boulder, Colorado,USA);
3. Országos Mérésügyi Hivatal (OMH, Budapest, Hungary);
4. Royal Signals and Radar Establishment (RSRE,Great Malvern, United Kingdom)
5. Physikalisch-Technische Bundesanstalt (PTB,Braunschweig, Federal Republic of Germany)

The PTB acted as pilot laboratory. Five transfer standards with the nominal attenuation values mentioned above were developed and made available by the NBS (0.1 dB), the OMH (10 dB), the RSRE (20dB) and the PTB (0.01 dB and 40 dB). The measurement cycle was started in June 1980 and was completed in January 1984.

2. THE INTERCOMPARISON SCHEME

First, NBS, OMH and RSRE measured the attenuation values of the standards developed at their own laboratories which were then sent to the pilot laboratory (PTB). The cycle of the further run can be seen in Fig. 1. After the conclusion of these comparison measurements the transfer standards were sent back to their home laboratories, where at OMH and at RSRE a final re-measurement was done.

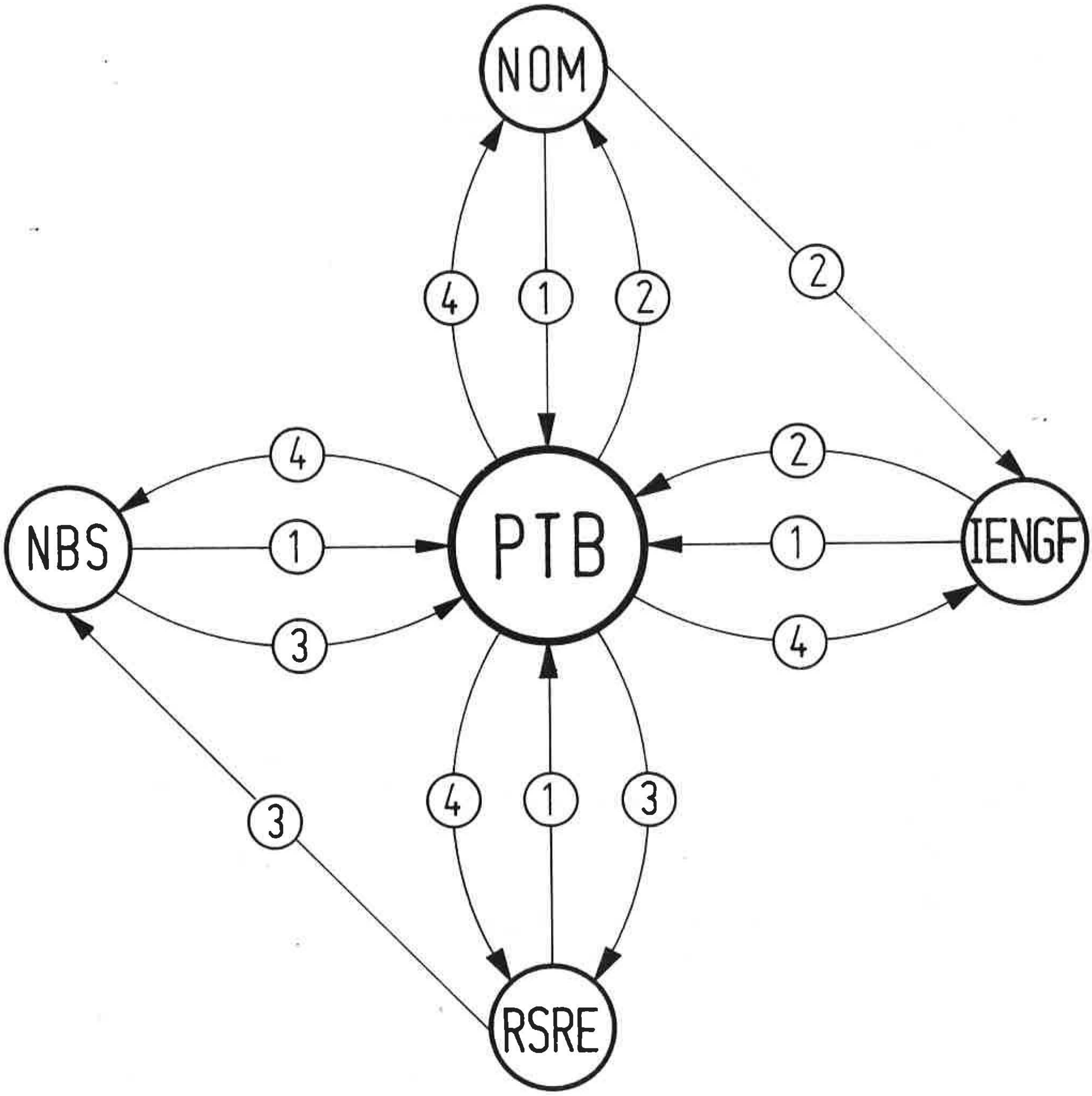
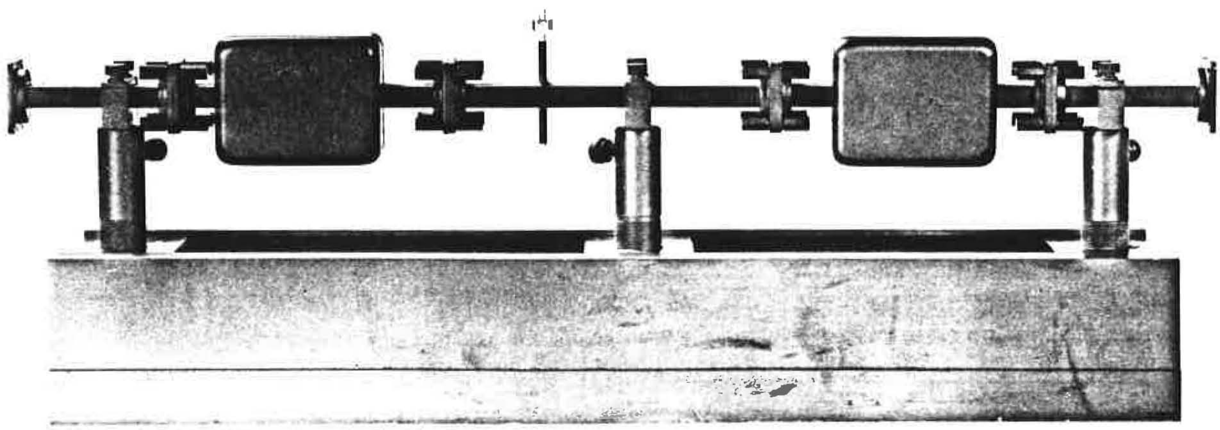


Fig 1 Intercomparison pattern for the international intercomparison GT-RF 75-A 3 (Attenuation in waveguide R 140 at 15 GHz)

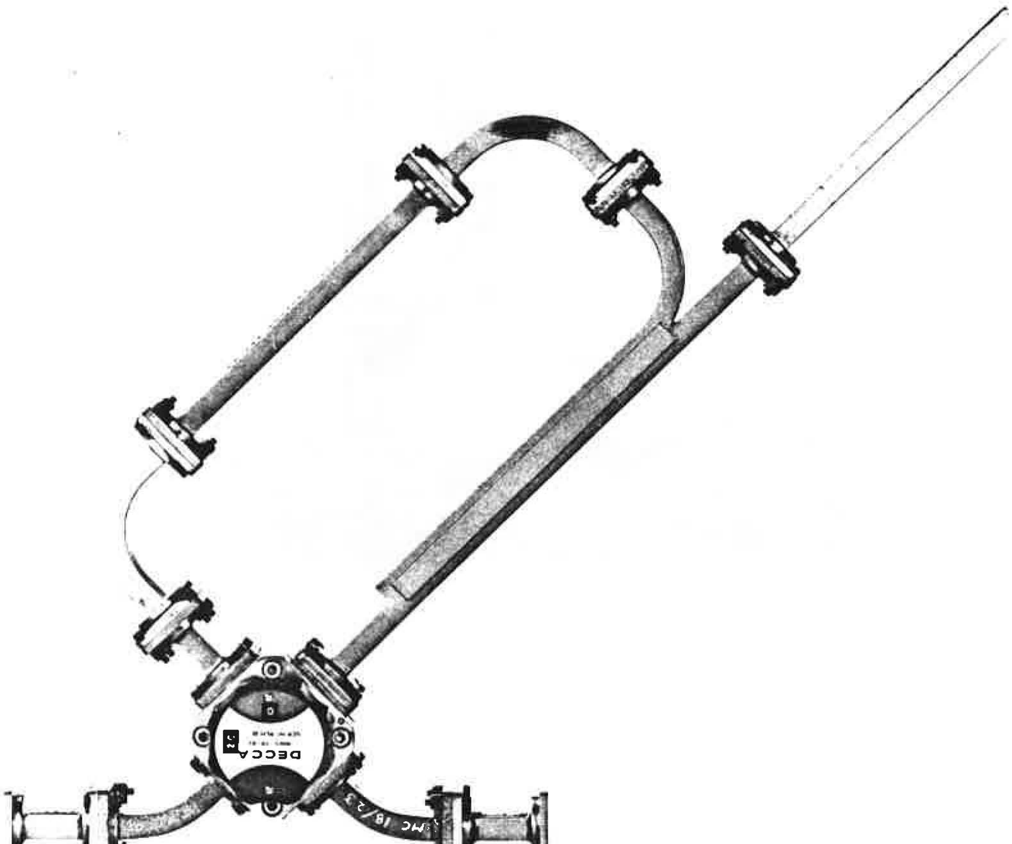
Fig. 2 Photographs of all transfer standards:

a) Transfer standard PTB-2.22-481 (0.01 dB)

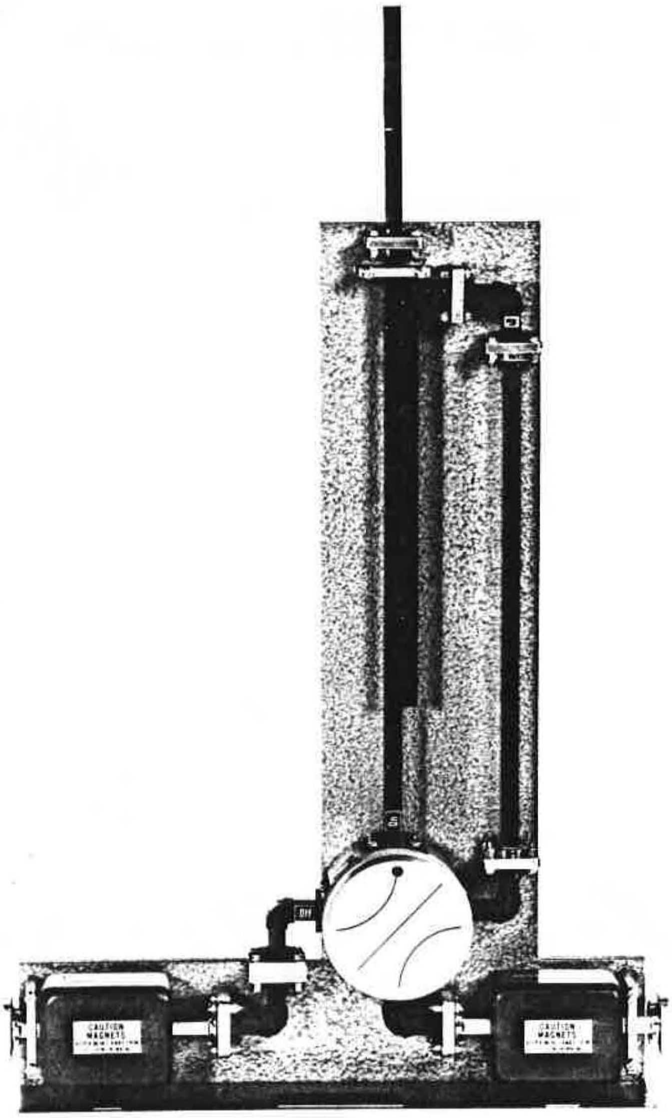


b) Transfer standard NBS-0.1 (0.1 dB)

c) Transfer standard OMH-10-01 (10 dB)



d) Transfer standard UK-18-S2 (20 dB)



e) Transfer standard PTB-2.22-311 (40 dB)

In the course of the entire run the attenuation values of all transfer standards were measured three times in the pilot laboratory to check their stability. The first of these measurements was carried out at the beginning of the run, the second one when the half circle was passed and the last one when all other participants had measured the standards.

3. The transfer standards

All circulated transfer standards were switchable ones, meaning that they remain in the guide system of the measuring devices during the operation; the attenuation value to be measured is the difference of the attenuation value at switch position "on" and the attenuation value at switch position "off" (zero position). Fluctuations and instabilities with regard to an imperfect connector repeatability need not therefore to be considered. Photographs of all the transfer standards are presented in Figs. 2 a to 2e

3.1 Transfer standard PTB-2.22-481 (0.01 dB)

The principle design is shown in Fig. 3

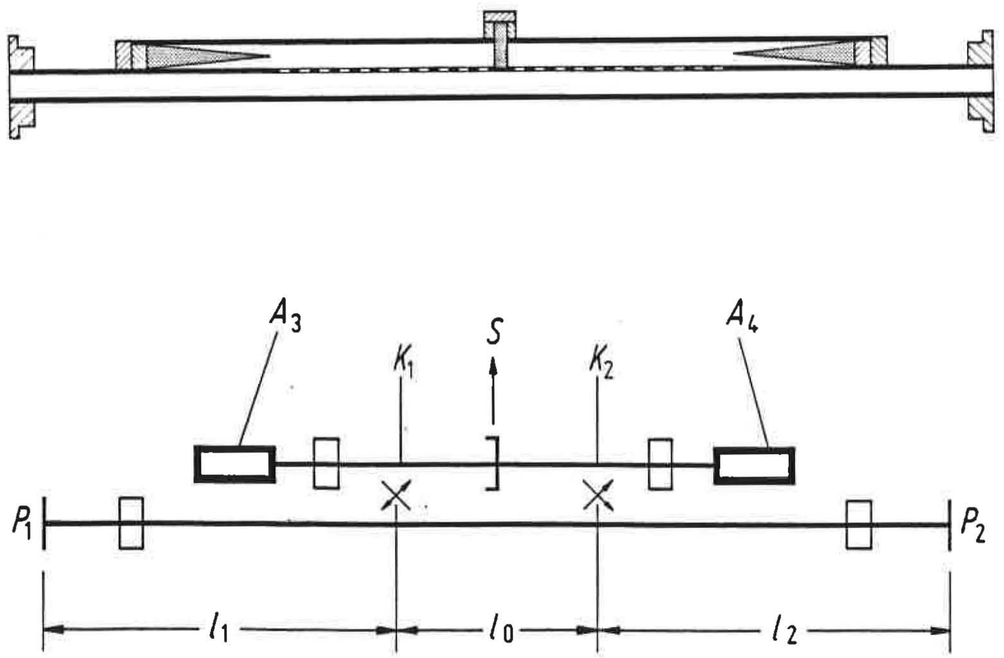


Fig.3 Construction scheme (a) and circuit diagram (b) of the transfer standard PTB-2.22-481 (0.01 dB) P_1,P_2 Input and output port, K_1,K_2 coupling holes, A_3,A_4 matched loads, S movable short

A small fraction of the electromagnetic power entering the main guide is coupled through the coupling holes K_1 into the side guide which has a larger side in common with the main guide. The side-arm is separated in two sections by a movable short S in the middle of it. If the short is "in", the fraction of power coupled into the side-arm is reflected from the short and mainly absorbed at the matched termination A_3. If the short is in the "out"-position, the power coupled into the side-arm is partially coupled back to the main guide through the coupling holes K_2; the power remaining in the side-arm is absorbed at the matched termination A_4. The process of inserting and removing the short results in an attenuation difference of the wave leaving the main guide. As can be shown [1] ΔA is given by

$$\Delta A = 20 \cdot \log \frac{1 - \zeta^2}{1 - 2\zeta^2} \qquad (1)$$

with $\zeta = 10^{-C/20}$; C being the coupling coefficient in dB. To achieve A = 0.01 dB, C must be 29.4 dB.

3.2 TRANSFER STANDARD NBS-0.1 (0.1 dB)

The assembly consists of a section of R 140 (WG 18, WR 62) waveguide with a hole bored through the broad wall and tubes soldered on each side to serve as guide for a rexolite pin which is inserted through the whole waveguide. This section of the guide is isolated with two nominal 40 dB ferrite isolators. Each isolator has a small section of guide attached which serves as the connecting port to the measurement apparatus. The complete assembly is rigidly mounted on an aluminium base.

The attenuation step is accomplished by inserting the rexolite pin totally through the guide so that it protrudes approximately one centimeter beyond the end of each tube. Although the manufacturing laboratory was unable to detect any variation in attenuation with an axial displacement or rotation of the pin, the pilot laboratory marked the pin to enable it to be always inserted in the same coaxial position.

3.3 TRANSFER STANDARDS OMH-10-01, UK-18-S2, PTB-2.22-311 (10 dB, 20 dB, 40 dB)

All three transfer standards are of the same design. A waveguide directional coupler is used for producing the desired attenuation differences. The attenuation value to be measured is in good approximation defined by the coupling coefficient C of the device

$$\Delta A = 20 \log \frac{1}{|S_{31}|} = C \qquad (2)$$

A waveguide switch must be positioned that the wave is propagated directly between input and output port of the switch in one position and then - in the other position of the switch - into the main guide of the coupler, passing the coupling device to the side arm and from here to the output of the switch. The circuit is presented in Fig. 4. In the case of the transfer standard PTB-2.22-311 two waveguide ferrite isolators are inserted just beyond the input port and in front of the output port [1]

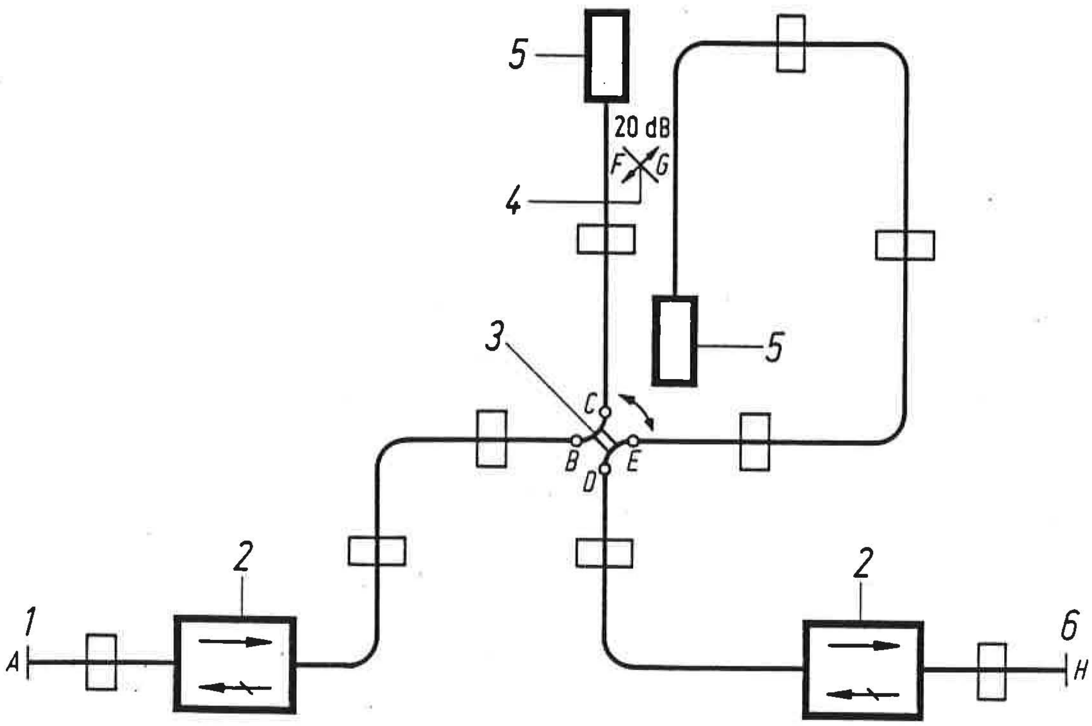


Fig. 4 Circuit diagram for transfer standard PTB-2.22-311 (40 dB)

(1) input port, (2) isolators, (3) waveguide switch, (4) directional coupler, (5) terminating loads, (6) output port.
Power flow when attenuation pad is removed: ABDH;
power flow when attenuation pad is inserted: ABCFGEDH

4. THE QUANTITY TO BE MEASURED

To measure the attenuation of the transfer standards, the device to be measured is inserted between the source output and the load (absorbing detector) input at the insertion point. The source may be protected by an integrated isolator to ensure stable operation. When the switch is actuated by changing its position from "off" to "on", the difference in insertion loss between these two positions is given by [2], [3]

$$L_I = 10 \cdot \log \frac{|(1 - S_{11}\Gamma_G)(1 - S_{22}\Gamma_L) - S_{12}S_{21}\Gamma_G\Gamma_L|^2 \; |S'_{21}|^2}{|(1 - S'_{11}\Gamma_G)(1 - S'_{22}\Gamma_L) - S'_{12}S'_{21}\Gamma_G\Gamma_L|^2 \; |S_{21}|^2} \qquad (3)$$

The S-matrix is related to the operation point of the attenuator, in which the loss-pad is inserted, the S' matrix is related to the zero position. Γ_G and Γ_L are the complex reflection coefficients with regard to the generator and load side of the measuring device, measured at the insertion point. After the system has been matched, so that $\Gamma_G \approx \Gamma_L \approx 0$, the quantity to be measured and compared is defined by

$$A = 10 \cdot \log \left|\frac{S'_{21}}{S_{21}}\right|^2 \qquad (4)$$

The measuring uncertainty resulting from an imperfect matching of the measuring device $(\Gamma_G, \Gamma_L \neq 0)$ is in the worst case (with regard to the phase relations) expressed by [3], [4]

$$\Delta A_{max} = 20 \cdot \log \frac{1 + |S_{11}\Gamma_G| + |S_{22}\Gamma_L| + |\Gamma_G\Gamma_L|(|S_{12}S_{21}| + |S_{11}S_{22}|)}{1 - |S'_{11}\Gamma_G| - |S'_{22}\Gamma_L| - |\Gamma_G\Gamma_L|(|S'_{12}S'_{21}| + |S'_{11}S'_{22}|)} \qquad (5)$$

For $|S_{11}|, |S_{22}| \ll 1$; $|\Gamma_G|, |\Gamma_L| \ll 1$
the simplified approximation

$$\Delta A_{max} \approx 2 M' \{ |\Gamma_G|(|S_{11}| + |S'_{11}|) + |\Gamma_L|(|S_{22}| + |S'_{22}|) + |\Gamma_G\Gamma_L|(|S_{12}S_{21}| + |S'_{12}S'_{21}|) \} \qquad (6)$$

with $M' = 10 \log e$ is valid. To reduce these uncertainties to an extent where they are negligible , great care must be taken to achieve a sufficiently good match of the system's source and load side.

5. THE MEASURING METHODS

The different methods used by the participants in this inter-comparison are as follows:

1. The power ratio method (PTB; IENGF and OMH partly),
2. the audio-frequency substitution method (OMH),
3. the modulated subcarrier method (RSRE),
4. the parallel IF substitution method (IENGF, NBS partly)
5. the voltage ratio method (RSRE),
6. the RF substitution method (NBS)

In the following a brief description of the basic principles of each method will be given; for a more detailed presentation including the theory and constructional refinements the references should be referred to.

5.1 THE POWER RATIO METHOD

The amplitude of the microwave power fed to the input of the attenuator to be measured is stabilized by applying a feed-back circuit: A portion of this power is coupled out from the main guide via a directional coupler terminated by a sufficiently sensitive and stable bolometer mount the absorbing bolometer-element of which being integrated in a bolometer bridge circuit with a built-in potentiometer compensating the bridge current. The error voltage resulting from the bridge imbalance caused by the microwave power fluctuations is fed back to a power controlling device in the main guide (PIN diode, ferrite modulator or modulation-input of the source). Two tuners, one in front and one behind the insertion point are used for matching the source and load side of the measuring system. The main guide power is received in a thermally stabilized bolometer mount (barretter or thermistor element). By determining the bolometer bridge voltages (once with attenuation pad inserted and once with it

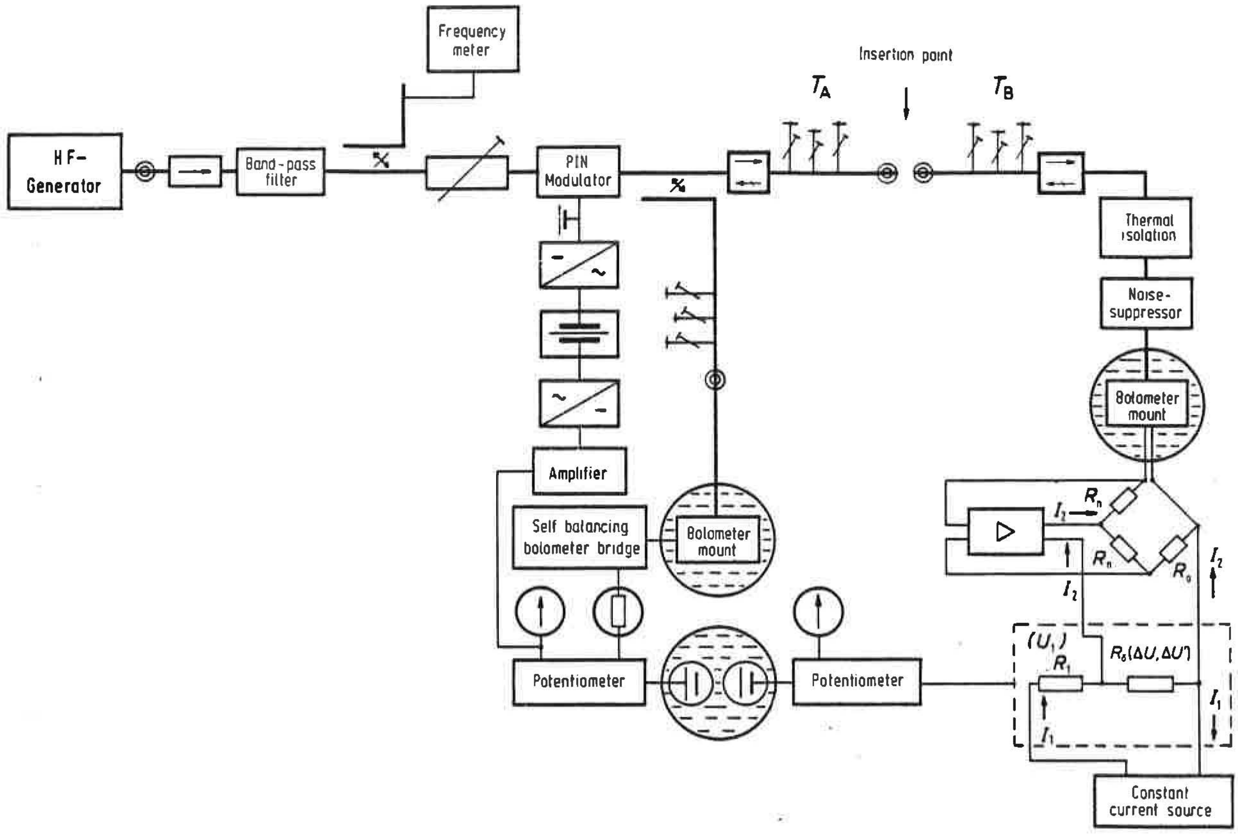


Fig. 5 Circuit diagram of the power ratio measuring equipment as establshed at PTB

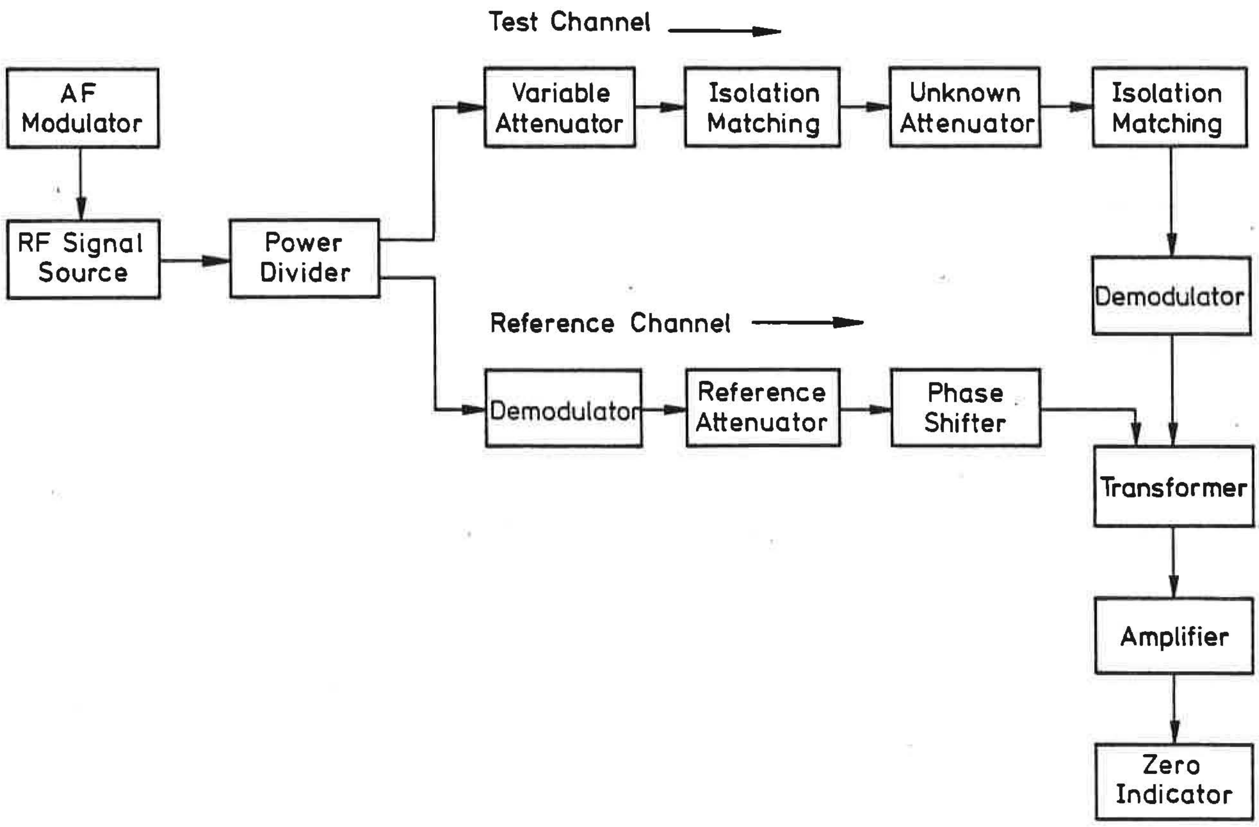


Fig. 6 Block diagram of the audio frequency substitution method as applied at OMH . The transformer is an inductive voltage divider (IVD)

removed) the power ratio P_s'/P_s is determined. (P_s' power absorbed by a non-reflecting terminating load with attenuation pad removed, P_s the corresponding value with attenuation pad inserted) The attenuation value under consideration is then received by

$$A = 10 \log \frac{P_s'}{P_s} \qquad (7)$$

[3],[4] . A block diagram of the circuit is presented in Fig. 5

5.2 AUDIO FREQUENCY SUBSTITUTION METHOD

The microwave source is modulated by an audio-frequency signal (e.g. at the frequency 1 kHz). The microwave power guiding system is split into two branches, both terminated by a well-matched barretter mount. The input power is controlled by a variable level-set attenuator, two matching pads and the attenuator to be measured are inserted in the test-channel. An audio-frequency voltage is received by demodulation of the barretter's output signal. The reference channel is supplied with a reference attenuator and an AF phase shifter for balancing the two audio-frequency voltage signals in amplitude and phase. The balance of both channels is observed in a sensitive zero-indicator. The attenuation difference to be measured is expressed by the voltage ratio of an inductive voltage divider (IVD) when the attenuation pad has been inserted once and removed once. [5]. A block diagram of the principle circuit is given in Fig.6

5.3 MODULATED SUBCARRIER TECHNIQUE

As in the audio-frequency substitution method an AC modulation (e.g. at 1 kHz) is used in this case. The microwave power supplied by the source is again split into two branches, but only one of them - the subcarrier branch - is modulated , e.g. by feeding the modulating AC voltage to the field coil of a ferrite modulator which has been inserted. The signals of both branches are recombined in a linear balanced mixer with a phase difference θ.

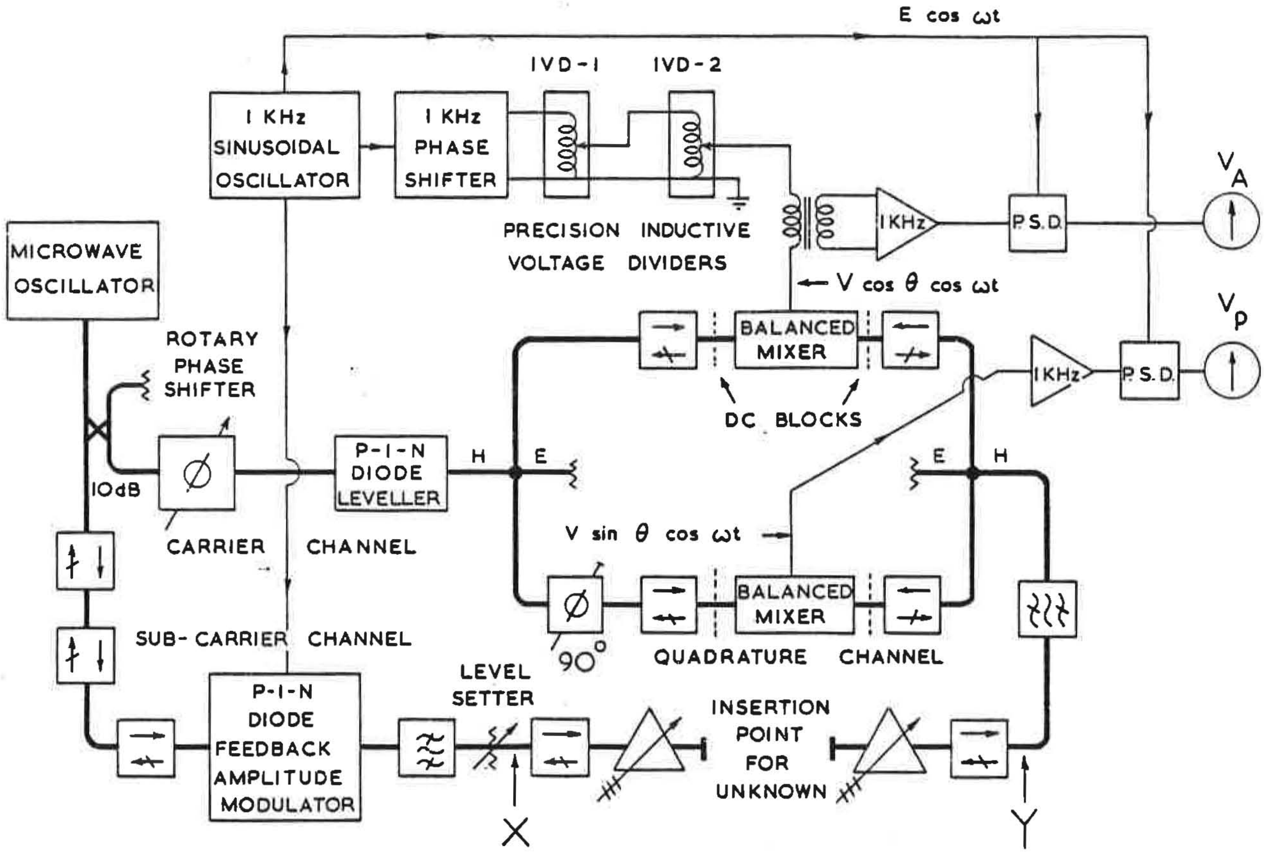


Fig.7 Circuit diagram of the modulated subcarrier technique as established at RSRE (drawn from WARNER, HERMAN and JEFFS)

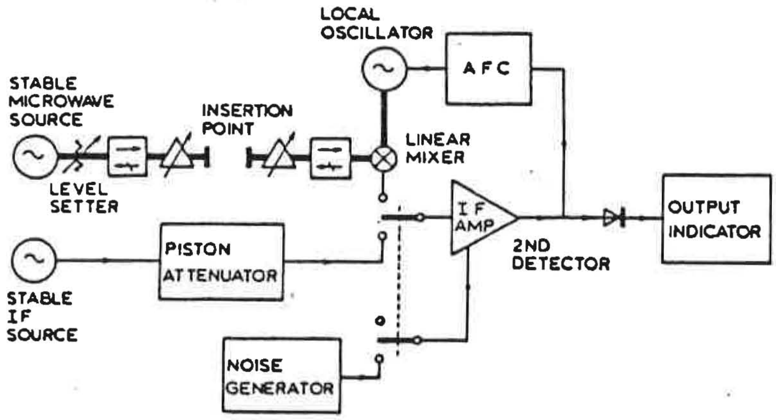


Fig. 8 Simplified circuit diagram of the IF parallel substitution method, applied e.g. at IEN (drawn from WARNER [3])

This phase difference is changed to zero by the corresponding setting of a rotary vane phase shifter inserted in the unmodulated channel. The demodulated AC signal (1 kHz) emerging from the mixer and that of 1 kHz sinussoidal frequency-stabilized oscillator are combined in a sensitive 1 kHz null detector. To balance the bridge circuit a precise IVD is used. The difference in the attenuation to be measured can be calculated from the two settings of the IVD, when the bridge is balanced - once with attenuation pad inserted and once with it removed. The refined circuit -as applied at RSRE - is presented in Fig. 7 [3], [6], [7]

5.4 PARALLEL IF SUBSTITUTION METHOD

This method is favoured for measuring higher attenuation differences. The attenuator to be measured is inserted in the microwave circuit which follows the stable microwave source; both sides from the insertion point are well matched with regard to the wave impedance of the guide system. After passing the attenuator under test, the microwave signal is fed into a linear mixer which also takes up the local oscillator power the frequency of which shifted by $(\Delta\nu)_{IF}$ against the frequency of the microwave source supplying the microwave power to the test circuit. A parallel circuit is fed by a stable intermediate frequency (IF) source to whose frequency the frequency shift $(\Delta\nu)_{IF}$ emerging from the linear mixer is locked. This parallel circuit contains the variable standard attenuator, e.g. a precise waveguide below cutoff (WBCO) piston attenuator. The output voltages of the linear mixer and the IF parallel circuit are compared by actuating an electronic or waveguide switch between both outputs and receiving the combined output signal of both channels in a synchronous detector followed by a sensitive null detector. The two parallel circuits are balanced by setting the variable standard attenuator (e.g. the WBCO) for a zero indication in the null detector. The attenuation to be measured is given by the difference in the setting of the standard attenuator when the attenuation pad to be measured is once inserted and once removed. The different noise behaviour of the two parallel circuits may be equalized by adding an appropriate noise contribution (from a noise generator) to the IF parallel circuit's output power. A block diagram of the simplified circuit is presented in Fig. 8 [3], [8], [9], [10]

5.5 VOLTAGE RATIO METHOD

This comparatively new method was firstly investigated and proposed by F.L.WARNER and P. HERMAN [11] [12] It is particularly suitable for computer-controlled automatic measuring devices of high precision. After having passed the attenuator to be measured, the microwave signal is fed to a linear mixer which also takes up the local oscillator's (L.O.) signal, frequencyshifted by $\Delta\nu$, e.g. 50 kHz. Both oscillators (source and L.O.) are locked to the same crystal, ensuring that their difference frequency is highly stable. The voltage of the IF signal emerging from the mixer is measured - via a stable IF amplifier - by a precision digital voltmeter. The non-linearity in the IF-amplifier and the DVM can be checked and corrected by switching over to a stable IF oscillator combined with an IVD. The attenuation of the unknown device to be measured is then [11]

$$A_x = 20 \cdot \log \frac{U_o}{U_x} + C \qquad (8)$$

(U_o voltage indication of the zero setting of the unknown attenuator, U_x corresponding voltage indication at the attenuation level A_x to be measured, C Correction value) .
The block diagram - including a gauge block system for enlarging the dynamic range up to 90 dB - is presented in Fig. 9 [12]

5.6 RF SUBSTITUTION TECHNIQUE

In this method the attenuator to be measured is compared with a variable standard attenuator in the microwave measuring circuit. Similiarly as in the IF substitution technique the unknown and the standard attenuator can be inserted in series (RF series substitution) or in parallel (RF parallel substitution). As variable attenuation standard a precise rotary vane attenuator or a waveguide below cutoff may be used. At NBS the measurements were performed using the RF series substitution technique . The microwave standard was a modified rotary vane attenuator . The modifications involve a precision gearing system with a resolution of 0.001 degree. Corrections have been made for eccentricity, vane angle and gearing errors based on the analysis of WILBUR F. LARSON [13], [14], [3]

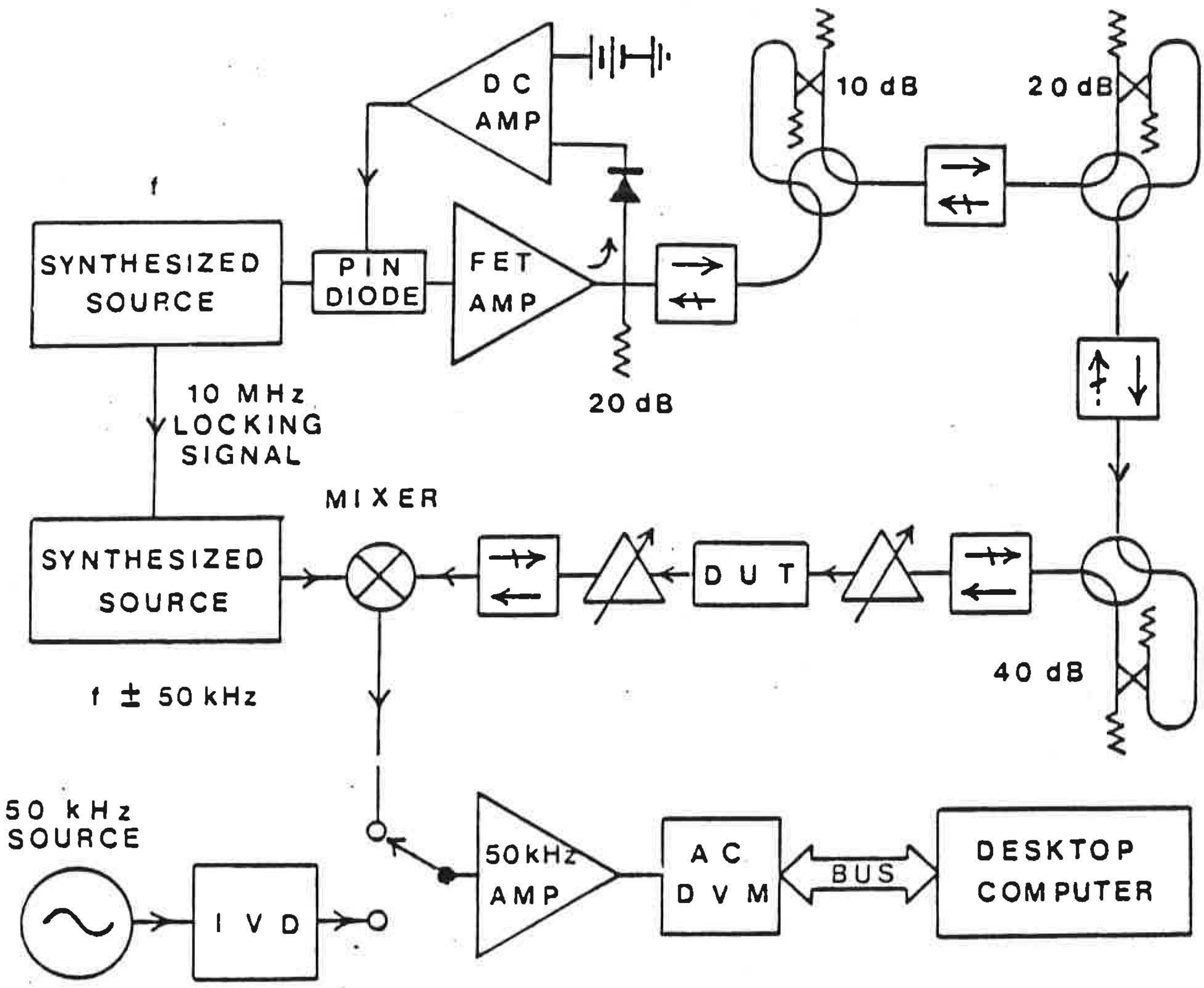


Fig. 9 Circuit diagram of the voltage ratio method including gauge blocks for enlarging the measuring range (drawn from WARNER and HERMAN |12|)

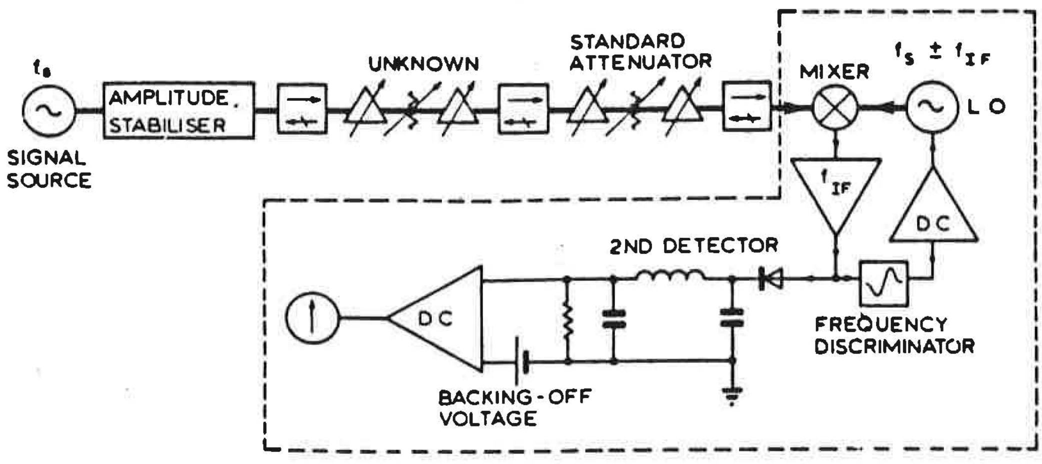


Fig. 10 Simplified circuit diagram of the RF series substitution technique partly applied at NBS (drawn from WARNER [3])

6. MEASUREMENT RESULTS AND DISCUSSIONS

6.1 AMBIENT AND MEASUREMENT CONDITIONS

The ambient conditions in the measuring rooms of the participating laboratories were sufficiently homogenous. The room temperature was in almost all cases +23^0 C, only the RSRE carried out the measurements at +21^0 C. The room relative humidity was about 50 % with the exception of IENGF (70 %) and RSRE (40 %). The relative uncertainty of the measuring frequency varied between $1 \cdot 10^{-4}$ and $1 \cdot 10^{-8}$, in most cases it was about $1 \cdot 10^{-6}$. The number of single measurements, from which each participant calculated its mean value to be reported, was between 10 and 50, the majority performed 10 single measurements for one run.

6.2 MEASURED MEAN VALUES

The mean values calculated from the n single measurements which each participant performed during one measuring period, are given in table I. In the case of the RSRE which has applied two different measuring methods and has reported the results for each of them, the mean value of both measurements is presented as the mean measured value in table I. A detailed list of all single measurement values - as reported by the participants - is given in the appendix.

6.3 DETERMINATION OF A WEIGHTED MEAN VALUE

For a critical examination of the results the determination of a "weighted mean value" as the most probable true measurement value is useful. The measurement values reported by each participating laboratory l on the travelling standard s may be A_{ls} . If the weighting factor is g_{ls} and the normalized weighting factor G_{ls}

$$G_{ls} = \frac{g_{ls}}{\sum\limits_{l=1}^{m} g_{ls}} \qquad (9)$$

(m is the number of participating laboratories), the weighted mean value is defined by

$$\overline{(A_s)_w} = \sum_{l=1}^{m} A_{ls} G_{ls} \qquad (10)$$

and its uncertainty range is defined by

$$\Delta(A_s)_w = \sqrt{\sum_{l=1}^{m} (\Delta A_{ls})^2 \, G_{ls}^2} \qquad (11)$$

If one laboratory measured more than once within the cycle, e.g. the pilot laboratory and the home laboratories of the transfer standards, the mean value of these results was introduced in (10) corresponding

$$A_{ls} = \frac{1}{p} \sum_{q=1}^{p} A_{qls} \qquad (12)$$

p being the number of measuring periods.

Assuming a weighting factor

$$g_{ls} = \frac{1}{d_{ls} \Delta A_{ls}} \exp \{-(d_{ls}/d_{s,min})(1 + \Delta A_{ls}/\overline{\Delta A_s})\} \qquad (13)$$

with

$$d_{ls} = \sum_{r=1}^{m} |A_{ls} - A_{rs}|$$

$d_{s,min}$ smallest value of d_{ls} for all values of l for a fixed s

$$\overline{\Delta A_s} = \frac{1}{m} \sum_{l=1}^{m} \Delta A_{ls} \qquad *)$$

The numerical values of the weighted mean values calculated in this way are given in table II.

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*) It is presumed that $\Delta A_{ls} = t_p \cdot \sigma_{ls}$ with t_p = const holds for all values l,s. (σ_{ls} is the total standard deviation and t_p corresponding to "Student's factor t" for $n \rightarrow \infty$ at the confidence level P; e.g. for P = 95 % is t_p = 2,0)

T A B L E I

MEAN VALUES OF ATTENUATION MEASURED BY EACH PARTICIPATING LABORATORY (in dB)

Transfer standard

Measuring Laboratory	PTB-2.22-481	NBS - 0.1	OMH-10-01	UK-18- S 2	PTB-2.22-311
NBS	-	0.1128	-	-	-
OMH	-	-	10.7372	-	-
RSRE	-	-	-	21.1787	-
PTB	0.01144	0.1012	10.745	21.1768	40.1310
OMH	0.01163	0.10168	10.7626	21.1722	40.1276
IENGF	0.0117	0.1018	10.751	21.217	40.080
PTB	0.01143	0.10080	10.745	21.1748	40.1287
RSRE	0.01141	0.10025	10.7557	21.1777	40.1316
NBS	0.0112	0.1112	10.739	21.159	40.110
PTB	0.01150	0.1011	10.744	21.1745	40.1286
OMH	-	-	10.7556	-	-
RSRE	-	-	-	21.1775	-

TABLE II

WEIGHTED MEAN VALUES

Transfer Standard	Weighted mean value dB
PTB-2.22-481 (0.01 dB)	0.01145 ± 0.00020
NBS-0.1 (0.1 dB)	0.10085 ± 0.00042
OMH 10-01 (10 dB)	10.7502 ± 0.0035
UK 18-S2 (20 dB)	21.1767 ± 0.0020
PTB-2.22-311 (40 dB)	40.1299 ± 0.0028

6.4 DISCUSSION OF THE RESULTS

The measurement results of all participants for the five transfer standards circulated are presented in Figs. 11 to 15. The weighted mean values and their uncertainty ranges with regard to the weighting function assumed are indicated.
The measurement diagrams are interpreted as follows

a) PTB-2.22-481 (0.01 dB):

All measurement results show good consistency with the weighted mean value and its uncertainty range. The maximum distance between two measurement values is 0.0005 dB. The measurement values of OMH, PTB and RSRE are in good agreement within ± 0.0002 dB.
A possible long-time drift of the standard's measurement value was within the uncertainty range and certainly smaller than 0.0001 dB over the whole measurement period.

b) NBS-0.1 (0.1 dB)

All measurement values - except one - are in good agreement with one another and with the weighted mean value calculated. Excluding the one measurement value outside the range of the others, the main distance between two measurement results is 0.0015 dB.
The transfer standard showed a good stability and its drift was smaller then 0.0005 dB.

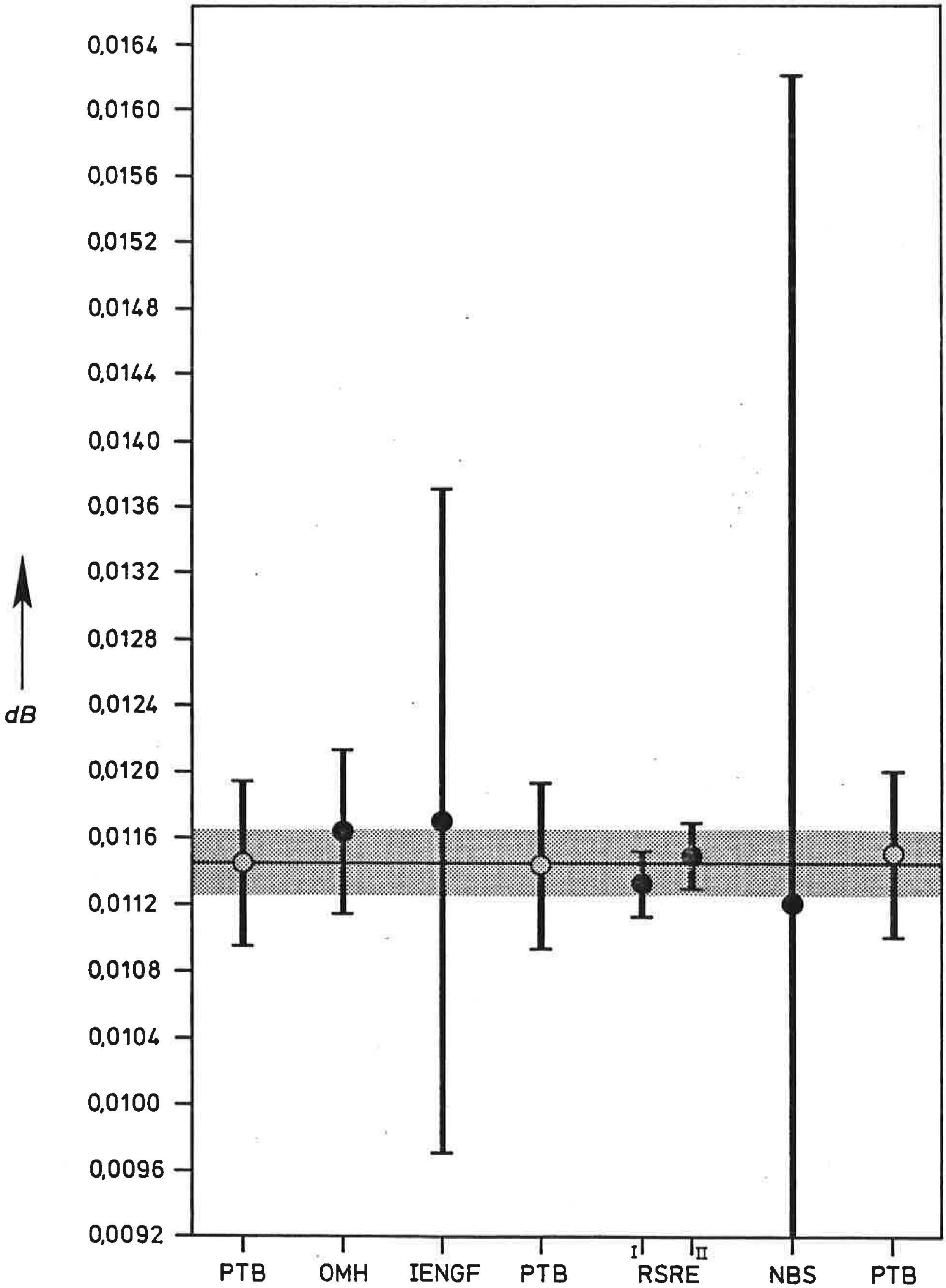

Fig. 11 Measurement results for transfer standard PTB 2.22-481 (0.01 dB)
(The weighted mean value and its uncertainty range are marked in)

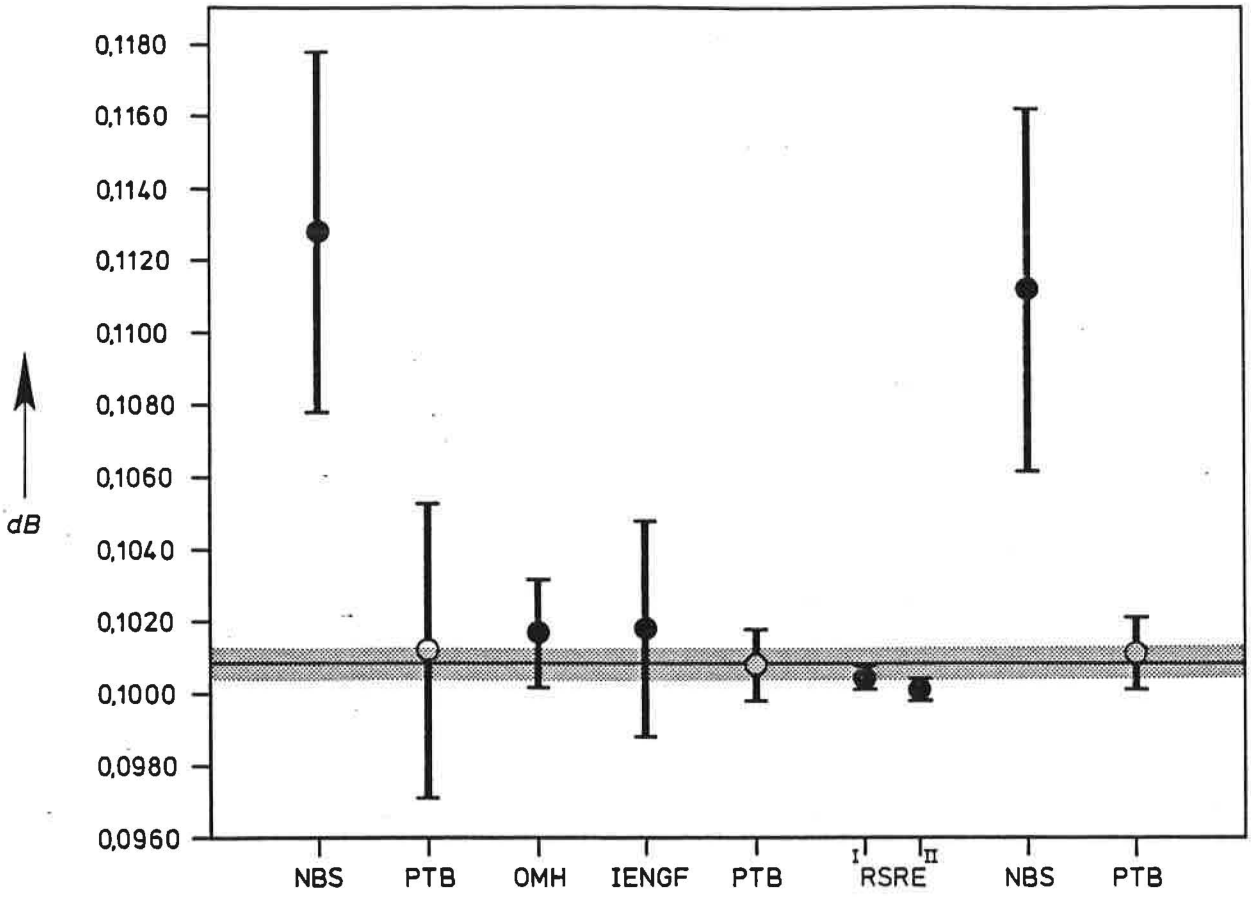

Fig. 12 Measurement results for transfer standard NBS-0.1 (0.1 dB)

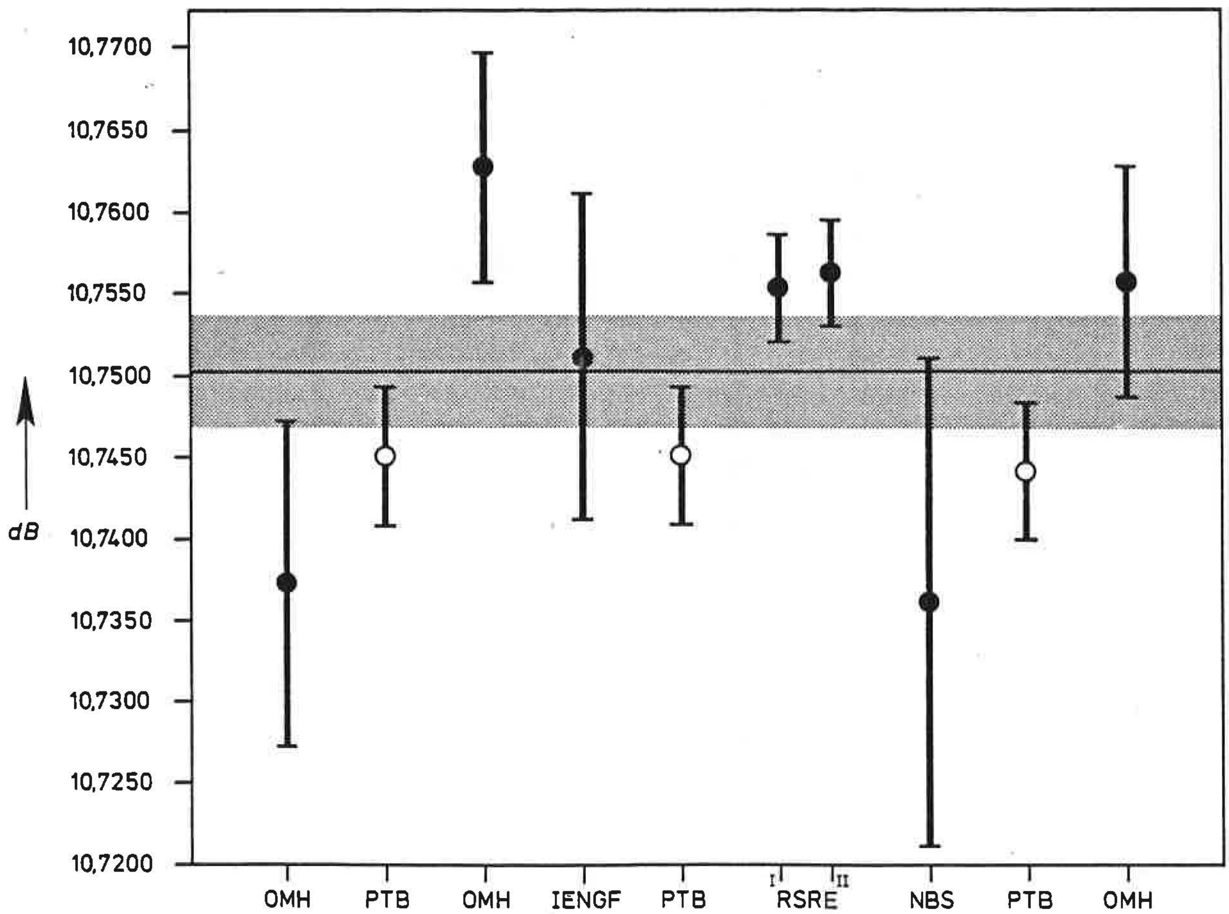

Fig. 13 Measurement results for transfer standard OMH-10-01 (10 dB)

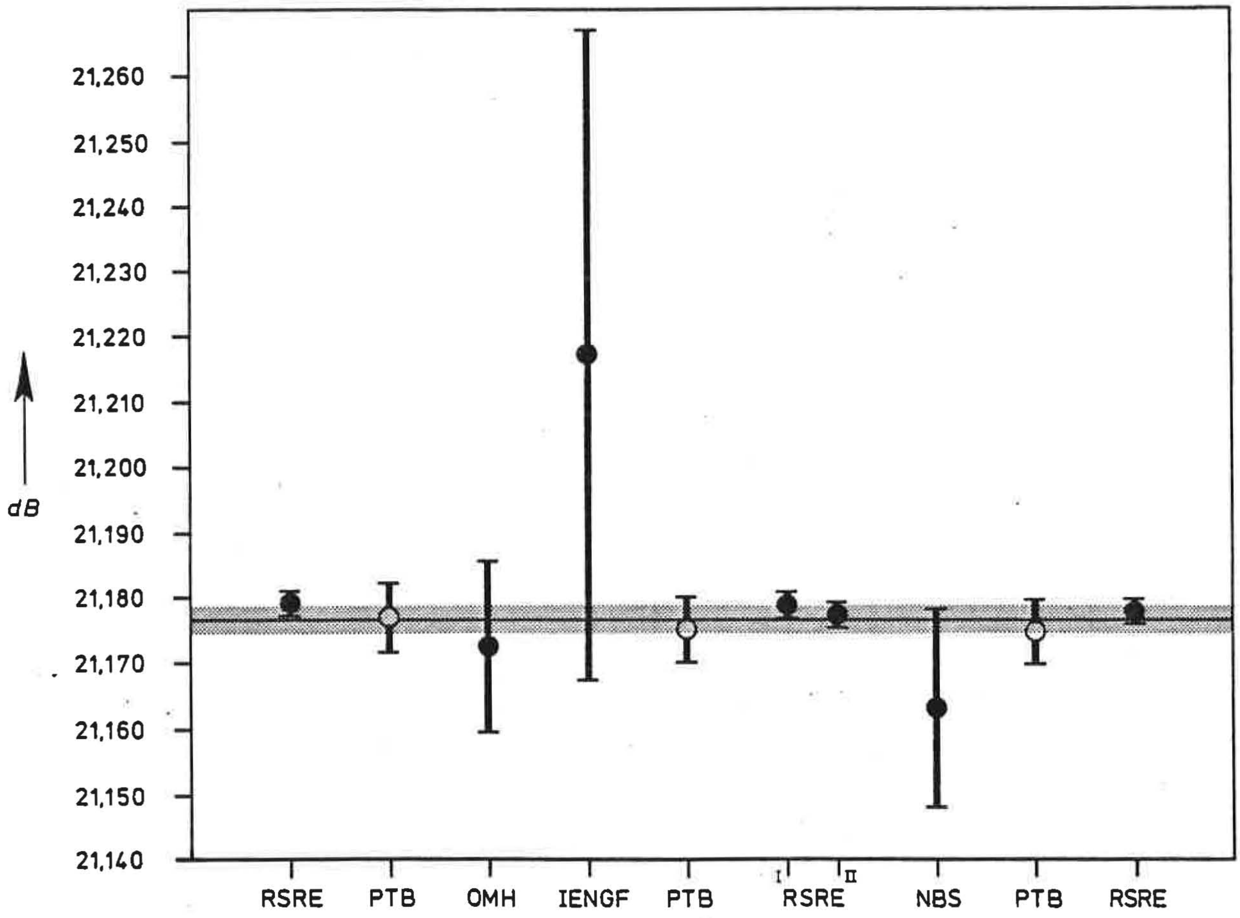

Fig. 14 Measurement results for transfer standard UK-18-S2 (20 dB)

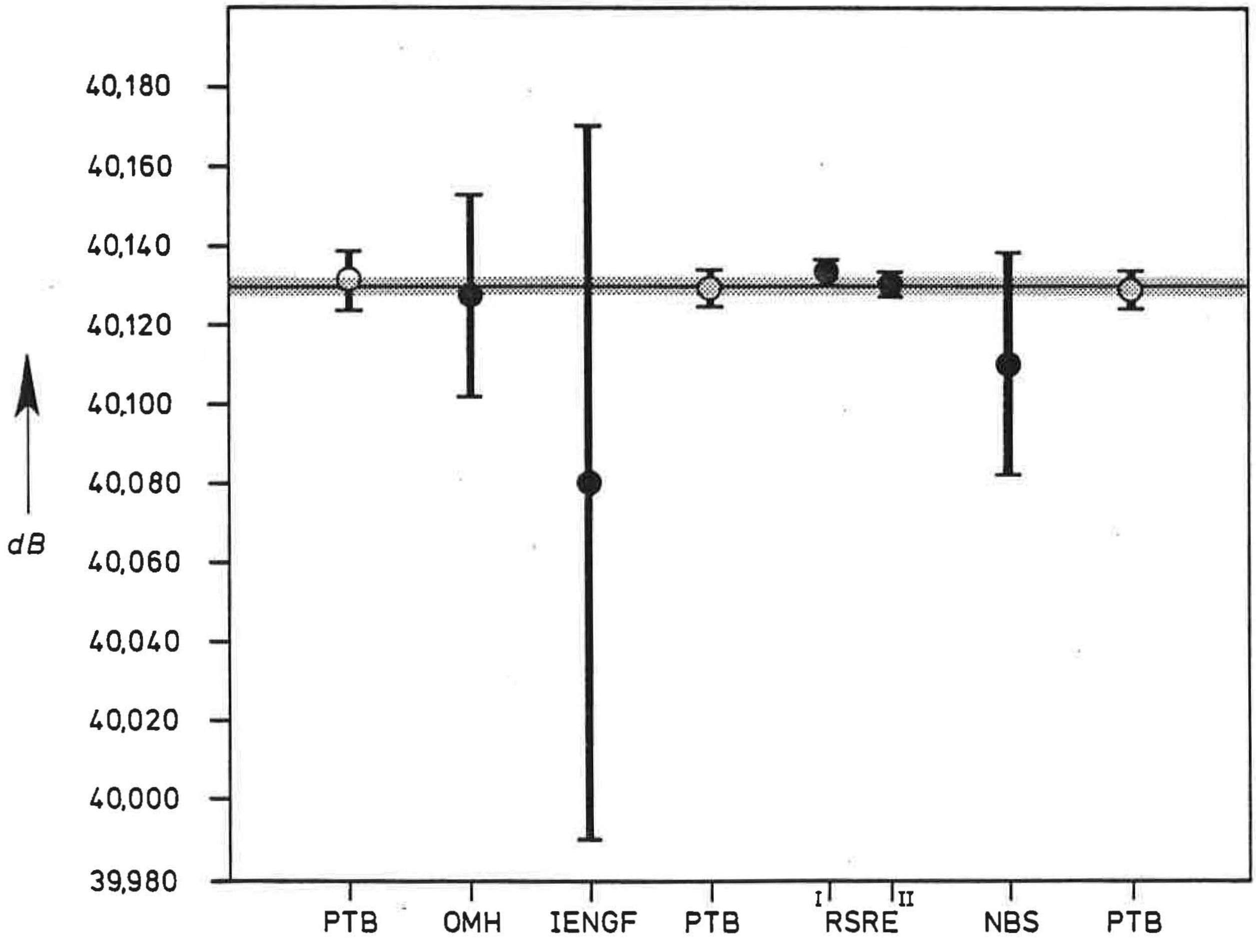

Fig. 15 Measurement results for the transfer standard PTB-2.22-311 (40 dB)

c) OMH-10-01 (10 dB)

Although most of the measured values show sufficient consistency with one another and the weighted mean value, it seems that the stablity of the transfer standard was insufficient. The standard's home laboratory - OMH - reported three measurement values with rather large differences : 10.737 dB, 10.763 dB and 10.756 dB. The corresponding attenuation differences are 0.026 dB, 0.019 dB and 0.007 dB. The first mentioned value (0.026 dB) is the largest difference between two measurement values (of all participants) on this standard. The pilot laboratory's measurement values are all about the same (≈ 10.745 dB). It is assumed that the instability which sometimes became apparent was caused by the switching mechanism and the particular way in which the switch was actuated. It was observed that a definite clicking of the switch postion was attainable only with difficulty; sometimes the positions into which the switch clicked deviated slightly from one another. The PTB was therefore extremely careful to achieve in each measurement the correct switching position into which the switch was supposed to click.

d) UK-18-S2 (20 dB)

All measurement values - except one - show good consistency with one another and with the weighted mean value. The maximum difference between two measurement results is 0.06 dB; but all other results agree within ± 0.0035 dB. The transfer standard's stability was good. A possible drift was smaller than the given uncertainty ranges and certainly within ± 0.001 dB over the whole measuring period.

e) PTB-2.22-311 (40 dB)

All measurement values and their uncertainties - again with one exception - are in good agreement with one another and with the weighted mean value. The largest difference between two measurement values is 0.05 dB; most measurements agree within ±0.002 dB. The transfer standard was of good long-term stability and its possible fluctuations are within ± 0.0012 dB.

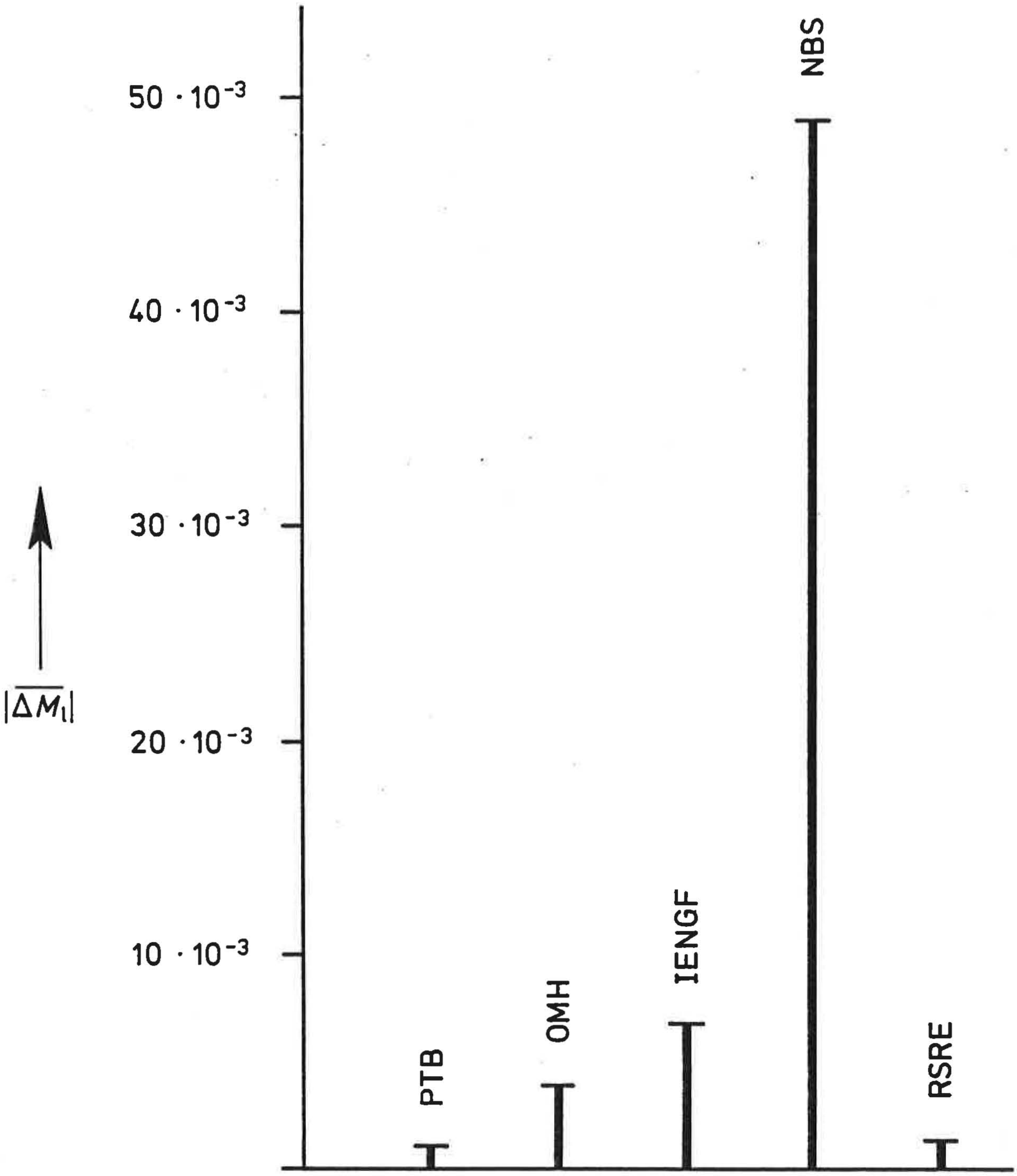

Fig. 16 Mean values averaged over the magnitudes of all relative deviations from the weighted mean values of all five transfer standards; given for each participating laboratory

To have one numerical value ,characterizing the mean deviation of each device from the weighted mean values, the magnitudes of the relative deviations from the weighted mean values are averaged over the five transfer standards for each measuring system. The expression

$$\overline{|\Delta M_1|} = \sum_{q=1}^{p} \sum_{s=1}^{5} \frac{|A_{q1s} - \overline{(A_s)}_w|}{\overline{(A_s)}_w} \tag{14}$$

is calculated and shown in Fig. 16. The tables III to VII give the differences $A_i - A_j$ of all measurement values against all the others for the five transfer standards.

DIFFERENCES $A_i - A_j$ OF THE MEASUREMENT RESULTS OF EACH PARTICIPANT AGAINST ALL THE OTHERS.

TABLE III

A = 0.01 dB

Numerical values in dB

A_i \ A_j	PTB	OMH	IENGF	PTB	RSRE	RSRE*	NBS	PTB
PTB		-0.00019	0.00027	0.00001	0.00012	-0.00005	0.00024	-0.00006
OMH	0.00019		0.00046	0.00020	0.00031	0.00014	0.00043	0.00013
IENGF	-0.00027	-0.00046		-0.00026	-0.00015	-0.00032	-0.00003	-0.00033
PTB	-0.00001	-0.00020	0.00026		0.00011	-0.00006	0.00023	-0.00007
RSRE	-0.00012	-0.00031	0.00015	-0.00011		-0.00017	0.00012	-0.00018
RSRE*	0.00005	-0.00014	0.00032	0.00006	0.00017		0.00029	-0.00001
NBS	-0.00024	-0.00043	-0.00003	-0.00023	-0.00012	-0.00029		-0.00030
PTB	0.00006	-0.00013	0.00033	0.00007	0.00018	0.00001	0.00030	

RSRE has measured with two different methods

RSRE: Modulated subcarrier system

RSRE*: Voltage ratio method

TABLE IV

A = 0.1 dB

Numerical values in dB

A_i \ A_j	NBS	PTB	OMH	IENGF	PTB	RSRE	RSRE*	NBS	PTB
NBS		0.01160	0.01112	0.01100	0.01200	0.01241	0.01269	0.00160	0.01170
PTB	-0.01160		-0.00048	-0.00060	0.00040	0.00081	0.00109	-0.01000	0.00010
OMH	-0.01112	0.00048		-0.00012	0.00088	0.00129	0.00157	-0.00952	0.00058
IENGF	-0.01100	0.00060	0.00012		0.00100	0.00141	0.00169	-0.00940	0.00070
PTB	-0.01200	-0.00040	-0.00088	-0.00100		0.00041	0.00069	-0.01040	-0.00030
RSRE	-0.01241	-0.00081	-0.00129	-0.00141	-0.00041		0.00028	-0.01081	-0.00071
RSRE*	-0.01269	-0.00109	-0.00157	-0.00169	-0.00069	-0.00028		-0.01109	-0.00099
NBS	-0.00160	0.01000	0.00952	0.00940	0.01040	0.01081	0.01109		0.01010
PTB	-0.01170	-0.00010	-0.00058	-0.00070	0.00030	0.00071	0.00099	0.01010	

TABLE V

A = 10 dB

Numerical values in dB

A_i \ A_j	OMH	PTB	OMH	IENGF	PTB	RSRE	RSRE*	NBS	PTB	OMH
OMH		-0.0078	-0.0254	-0.0138	-0.0078	-0.0180	-0.0189	-0.0018	-0.0068	-0.0184
PTB	0.0078		-0.0176	-0.0060	0.0000	-0.0102	-0.0111	0.0060	0.0010	-0.0106
OMH	0.0254	0.0176		0.0116	0.0176	0.0074	0.0065	0.0236	0.0186	0.0070
IENGF	0.0138	0.0060	-0.0116		0.0060	-0.0042	-0.0051	0.0120	0.0070	-0.0046
PTB	0.0078	0.0000	-0.0176	-0.0060		-0.0102	-0.0111	0.0060	0.0010	-0.0106
RSRE	0.0180	0.0102	-0.0074	0.0042	0.0102		-0.0009	0.0162	0.0112	-0.0004
RSRE*	0.0189	0.0111	-0.0065	0.0051	0.0111	0.0009		0.0171	0.0121	0.0005
NBS	0.0018	-0.0060	-0.0236	-0.0120	-0.0060	-0.0162	-0.0171		-0.0050	-0.0166
PTB	0.0068	-0.0010	-0.0186	-0.0070	-0.0010	-0.0112	-0.0121	0.0050		-0.0116
OMH	0.0184	0.0106	-0.0070	0.0046	0.0106	0.0004	-0.0005	0.0166	0.0116	

TABLE VI

A = 20 dB

Numerical values in dB

A_i \ A_j	RSRE	PTB	OMH	IENGF	PTB	RSRE	RSRE*	NBS	PTB	RSRE*
RSRE		0.0019	0.0065	-0.0383	0.0039	0.0001	0.0019	0.0197	0.0042	0.0012
PTB	-0.0019		0.0046	-0.0402	0.0020	-0.0018	0.0000	0.0178	0.0023	-0.0007
OMH	-0.0065	-0.0046		-0.0448	-0.0026	-0.0064	-0.0046	0.0132	-0.0023	-0.0053
IENGF	0.0383	0.0402	0.0448		0.0422	0.0384	0.0402	0.0580	0.0425	0.0395
PTB	-0.0039	-0.0020	0.0026	-0.0422		-0.0038	-0.0020	0.0158	0.0003	-0.0027
RSRE	-0.0001	0.0018	0.0064	-0.0384	0.0038		0.0018	0.0196	0.0041	0.0011
RSRE*	-0.0019	0.0000	0.0046	-0.0402	0.0020	-0.0018		0.0178	0.0023	-0.0007
NBS	-0.0197	-0.0178	-0.0132	-0.0530	-0.0158	-0.0196	-0.0178		-0.0155	-0.0185
PTB	-0.0042	-0.0023	0.0023	-0.0425	-0.0003	-0.0041	-0.0023	0.0155		-0.0003
RSRE*	-0.0012	0.0007	0.0053	-0.0395	0.0027	-0.0011	0.0007	0.0185	0.0030	

TABLE VII

A = 40 dB

Numerical values in dB

A_i \ A_j	PTB	OMH	IENGF	PTB	RSRE	RSRE*	NBS	PTB
PTB		0.0034	0.0510	0.0023	-0.0021	0.0010	0.0210	0.0024
OMH	-0.0034		0.0476	-0.0011	-0.0055	-0.0024	0.0176	-0.0010
IENGF	-0.0510	-0.0476		-0.0487	-0.0531	-0.0500	-0.0300	-0.0486
PTB	-0.0023	0.0011	0.0487		-0.0044	-0.0013	0.0187	0.0001
RSRE	0.0021	0.0055	0.0531	0.0044		0.0031	0.0231	0.0045
RSRE*	-0.0010	0.0024	0.0500	0.0013	-0.0031		0.0200	0.0014
NBS	-0.0210	-0.0176	0.0300	-0.0187	-0.0231	-0.0200		-0.0186
PTB	-0.0024	0.0010	0.0486	-0.0001	-0.0045	-0.0014	0.0186	

7. CONCLUSIONS

Essentially, good agreement between the measurement results of OMH, RSRE and PTB could be stated. The IENGF results are consistent with them considering the larger uncertainties reported by this institute. Only the measurement results of the NBS show some deviations which are larger than the others.

Four of the transfer standards circulated were of good long-term stability. The transfer standard OMH-10-01 showed some instabilities. It is assumed that this behaviour was caused by an inaccurate switching mechanism, resulting in some deviating measurement values.

In conclusion appreciation must be expressed to the scientists and engineers of the participating laboratories who performed the measurements and made possible this successful world-wide intercomparison by their efforts to obtain accurate and consistent measurement results: P.G.GALLIANO (IENGF), G.RIETTO (IENGF), D.H.RUSSELL (NBS), D.STUMPE (PTB), H.SZOKOL (OMH), A. TÖRÖK (OMH) and F.L.WARNER (RSRE)

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APPENDIX

COMPLETE LISTS OF THE MEASUREMENT RESULTS AND OPERATIONAL DATA REPORTED BY THE PARTICIPANTS

1. Measuring results for the transfer-standards measured in their own laboratory before having sent to the pilot laboratory

ATTENUATION IN WAVEGUIDE R 140 AT 15 GHz

GT - RF 75-A3

Pilot laboratory: PTB

Room temperature (^{0}C)		-	23 ± 0.5	20.5 ± 0.5
Room relative humidity (%)		-	≤ 50 %	40 ± 5
Measuring method		-	Dual channel audio frequ. subst., with voltage ratio transformer	Modulated sub-carrier technique
Measuring frequency (GHz)		15	15.000 ± 0.001	15.0000000 ± 0.0000002
VSWR of the measuring system		< 1.01	≤ 1.015	≤ 1.007
Designation of the standard		NBS - 0.1 dB	NOM - 10 - 01	18 S 2
RF power fed into the standard (mW)			< 0.1	0.001
VSWR of the standard	input	1.025 1.031$^+$	≤ 1.04 ≤ 1.05$^+$	1.055 1.035$^+$
($^+$switched position)	output	1.041 1.043$^+$	≤ 1.04 ≤ 1.11$^+$	1.053 1.045$^+$
Number of measurements		-	10	50
Mean value of attenuation (dB)		0.1128	10.7372	21.1787
Standard deviation (dB)			0.0034	0.0005
Standard deviation of the mean (dB)		0.0007	0.0011	0.00007
Minimum value measured (dB)		-	10.7334	21.1773
Maximum value measured (dB)		-	10.7442	21.1797
Estimated systematical uncertainty (dB)			≤ 0.01	0.002
Measuring period		September 1980	December 1979	September 1979

2. Measuring results for all transfer-standards measured in the pilot-laboratory (first measurement of the p.l.)

ATTENUATION IN WAVEGUIDE R 140 AT 15 GHz

Pilot laboratory: PTB

GT - RF 75-A3

Room temperature (^{o}C)	:	23 + 0.5
Room relative humidity (%)	:	50 ± 10
Measuring method	:	P O W E R
Measuring frequency	:	15.000 000 ± 0.000 015
VSWR of the measuring system	:	≤ 1.01

Designation of the standard		PTB 2.22-481	NBS - 0.1	NOM - 10-01	RSRE 18 S 2	PTB 2.22-311
Nominal value of attenuation (dB)		0.01	0.1	10	20	40
RF power fed into the standard (mW)		10	10	10	10	1000++
VSWR of the standard	input	< 1.01 < 1.01+	1.025 1.03+	1.025 1.015+	1.060 1.035+	1.065 1.065+
(+=switched position)	output	< 1.01 < 1.01+	1.035 1.04+	1.015 1.090+	1.055 1.045+	1.065 1.065+
Number of measurements		10	10	10	10	10
Mean value of attenuation (dB)		0.01144	0.1012	10.745	21.1768	40.1310
Standard deviation (dB)		0.00001	0.00007	0.0022	0.00020	0.0005
Standard deviation of the mean (dB)		0.000003	0.000022	0.0007	0.00006	0.00016
Minimum value measured (dB)		0.01142	0.10107	10.741	21.1760	40.1300
Maximum value measured (dB)		0.01147	0.10129	10.748	21.1776	40.1323
Estimated systematical uncertainty (dB)		± 0.0005	± 0.004	± 0.004	± 0.005	± 0.008

++ The power dependence of the standard between 10 mW and 1000 mW power input is < 0.001 dB

Measuring period: 2.6. - 4.7.1980
10.11.1980 (NBS-0.1)

3. Measurement-results of the OMH (Hungary)

ATTENUATION IN WAVEGUIDE R 140 AT 15 GHz

GT - RF 75-A3

Pilot laboratory: PTB

ROOM TEMPERATURE (^{o}C)	:	+ 23 ± 0.5
ROOM RELATIVE HUMIDITY (%)	:	50 ± 5
MEASURING METHOD	:	Audio frequency substitution and power method
MEASURING FREQUENCY (MHz)	:	15 000 ± 0.1
VSWR OF THE MEASURING SYSTEM	:	≤ 1.01

Designation of the standard	PTB-2.22-481	NBS-0.1	NOM 10-01	RSRE 18-S2	PTB 2.22-311
Nominal value of attenuation (dB)	0.01	0.1	10	20	40
RF power fed into the standard (mW)	0.01	0.01	0.01	0.01	0.01
VSWR of the standard	-	-	-	-	-
Number of measurements	10	11	12	10	10
Mean value of attenuation (dB)	0.01163	0.10168	10.7626	21.1722	40.1276
Standard deviation (dB)	0.00031	0.00023	0.0016	0.0010	0.0063
Standard deviation of the mean (dB)	0.00010	0.00007	0.0005	0.0003	0.0020
Minimum measured value (dB)	-	-	-	-	-
Maximum measured value (dB)	-	-	-	-	-
Estimated systematical uncertainty (dB)	0.0005	0.0015	0.007	0.013	0.025

Measuring period: March - April 1981

4. Measurement results in the IEN (Italy)

ATTENUATION IN WAVEGUIDE R 140
AT 15 GHz
GT-RF 75-A3

Pilot laboratory: PTB

ROOM TEMPERATURE (^{o}C)	: 23 ± 1
ROOM RELATIVE HUMIDITY (%)	: 70 ± 5
MEASURING METHOD	: a) Power ratio (A ≤ 10 dB) b) Parallel IF substitution (A = 20 dB, 40 dB)
MEASURING FREQUENCY (GHz)	: 15.0000 ± 0.0005
VSWR OF THE MEASURING SYSTEM	: 1.01

Designation of the transfer standard	PTB 2.22 - 481	NBS - 0.1	NOM 10 - 01	RSRE 18-S 2	PTB 2.22 - 311
Nominal value of the attenuation (dB)	0.01	0.1	10	20	40
RF power fed into the standard (mW)	≦ 3 mW	≦ 3 mW	≦ 3 mW	≦ 10 µW	≦ 10 µW
Number of measurements	10	10	10	10	10
Mean value of attenuation (dB)	0.0117	0.1018	10.751	21.217	40.080
Standard deviation (dB)	0.001	0.0008	0.004	0.002	0.006
Standard deviation of the mean (dB)	0.0003	0.0002	0.001	0.0007	0.002
Minimum measured value (dB)	0.0095	0.1004	10.742	21.212	40.071
Maximum measured value (dB)	0.0141	0.1025	10.757	21.218	40.087
Estimated systematic uncertainty (dB)	± 0.002	± 0.003	± 0.01	± 0.05	± 0.09

Measuring period: March, April 1982

ROOM TEMPERATURE (^{o}C)	:	23,0 ± 0,5
ROOM RELATIVE HUMIDITY (%)	:	50 ± 10
MEASURING METHOD	:	POWER
MEASURING FREQUENCY (GHz)	:	15,000 000 ± 0.000 015
VSWR OF THE MEASURING SYSTEM	:	≤ 1.01

Designation of the transfer standard		PTB - 2,22 - 481	NBS-0.1	NOM 10-01	RSRE 18-S-2	PTB - 2,22 - 311
Nominal value of attenuation (dB)		0,01	0.1	10	20	40
RF power fed into the standard (mW)		10	10	10	10	1000$^{++)}$
VSWR of the transfer standard	input	< 1.01 < 1.01$^{+)}$	1.025 1.03$^{+)}$	1.025 1.015$^{+)}$	1.06 1.035$^{+)}$	1.06 1.06$^{+)}$
	output	1.01 1.01$^{+)}$	1.03 1.035$^{+)}$	1.011 1.09$^{+)}$	1.065 1.055$^{+)}$	1.06 1.06$^{+)}$
Number of measurements		10	10	10	10	10
Mean value of attenuation (dB)		0.01143	0.10080	10.745	21.1748	40.1287
Standard deviation (dB)		0.00001	0.00010	0.0022	0.0003	0.0005
Standard deviation of the mean (dB)		0.000003	0.00003	0.0007	0.00009	0.00016
Minimum measured value (dB)		0.01141	0.10062	10.742	21.1742	40.1279
Maximum measured value (dB)		0.01146	0.10091	10.749	21.1751	40.1299
Estimated systematic uncertainty (dB)		± 0.0005	± 0.001	± 0.004	± 0.005	± 0.005

+) switched position

++) the power dependence of the attenuation value of the transfer standard is smaller than 0.001 dB/W

Measuring period: 21.5.82 - 8.6.82

5. Measurement in the RSRE

ATTENUATION IN WAVEGUIDE R 140 at 15 GHz

Pilot laboratory : PTB

GT-RF 75-A3

ROOM TEMPERATURE (^{o}C)	:	21.0 ± 0.5
ROOM RELATIVE HUMIDITY (%)	:	40 ± 5
MEASURING METHODS	:	a) Modulated subcarrier method (SC) b) Voltage ratio method (VR)
MEASURING FREQUENCY (GHz)	:	15.000 000 00 ± 0.000 000 15
REFLECTION COEFFICIENT OF THE MEASURING SYSTEM	:	< 0.0035

Designation of the transfer standard	I. PTB - 2.22 - 481		NBS - 0,1		NOM-10 - 01		RSRE 18-S-2		PTB - 2.22 - 311	
Nominal value of attenuation (dB)	0.01		0.1		10		20		40	
RF power fed into the standard (mW)	0.0001		0.0001		0.0001		0.0001		0.0001	
Reflection coefficient of the transfer standard input output	$0.006\,e^{-1.71j}$ $0.004\,e^{-0.976j}$	+) $0.005\,e^{-1.5j}$ +) $0.004\,e^{-0.396j}$	$0.014\,e^{-2.08j}$ $0.020\,e^{2.84j}$	+) $0.014\,e^{-2.17j}$ +) $0.022\,e^{2.86j}$	$0.011\,e^{2.26j}$ $0.014\,e^{2.90j}$	+) $0.010\,e^{0.759j}$ +) $0.042\,e^{1.14j}$	$0.025\,e^{0.412j}$ $0.023\,e^{0.079j}$	+) $0.020\,e^{-1.06j}$ +) $0.022\,e^{0.040j}$	$0.029\,e^{-2.80j}$ $0.031\,e^{-2.36j}$	+) $0.030\,e^{-2.75j}$ +) $0.032\,e^{-2.37j}$
Measuring method	SC	VR	SC	VR	SC	VR	SC	VR	SC	VR
Number of measurements	20	40	10	40	20	44	10	20	10	30
Mean value of attenuation (dB)	0.01132	0.01149	0.10039	0.10011	10.7552	10.7561	21.1786	21.1768	40.1331	40.1300
Standard deviation (dB)	0.00018	0.00014	0.00008	0.00022	0.0028	0.0040	0.00016	0.00017	0.00079	0.00047
Standard deviation of the mean (dB)	0.00004	0.00002	0.00002	0.00003	0.0006	0.0006	0.00005	0.00004	0.00025	0.00009
Minimum measured value (dB)	0.01104	0.01102	0.10029	0.09959	10.7505	10.7483	21.1782	21.1765	40.1317	40.1292
Maximum measured value (dB)	0.01156	0.01184	0.10047	0.10060	10.7598	10.7636	21.1787	21.1771	40.1343	40.1307
Estimated systm. uncertainty (95% confidence level) dB	± 0.0002	± 0.0002	± 0.0003	± 0.0003	± 0.003	± 0.003	± 0.002	± 0.002	± 0.003	± 0.003

+) switched position

Measuring period: September, October 1982

7. Measurement in the NBS (U.S.A.)

ATTENUATION IN WAVEGUIDE R 140

AT 15 GHz

GT-RF 75-A3

Pilot laboratory: PTB

ROOM TEMPERATURE ($^{\circ}$C)	: ≃ 23
ROOM RELATIVE HUMIDITY(%)	: ≃ 40
MEASURING METHODS	: RF AND IF-SUBSTITUTION
MEASURING FREQUENCY (GHz)	: 15.0000 ± 0.0015
VSWR OF THE MEASURING SYSTEM	: ≤ 1.02

Designation of the standard	PTB-2.22-481	NBS-0.1	NOM-10-0.1	RSRE-18-S2	PTB-2.22-311
Nominal value of attenuation (dB)	0.01	0.1	10	20	40
RF power fed into the standard (mW)	≤ 0.0002	≤ 0.0002	≤ 0.0002	≤ 0.0002	≤ 0.0002
Number of measurements	10	10	10	20	25
Mean value of attenuation (dB)	0.0112	0.1112	10.739	21.159	40.110
Standard deviation (dB)	0.0004	0.0007	0.0024	0.0024	0.0049
Standard deviation of the mean (dB)	0.0001	0.0002	0.0008	0.0008	0.0010
Minimum measured value (dB)	0.0108	0.1104	10.736	21.156	40.102
Maximum measured value (dB)	0.0116	0.1121	10.743	21.163	40.117
Estimated systematic uncertainty (dB)	± 0.005	± 0.005	± 0.015	± 0.015	± 0.028

Measuring period: 9.2.83 - 7.3.83

8. Last re-measurement in the pilot laboratory

ATTENUATION ON WAVEGUIDE R 140

at 15 GHz

GT-RF 75-A3

Pilot laboratory: PTB

ROOM TEMPERATURE	: 23 ± 0.5
ROOM RELATIVE HUMIDITY	: 50 ± 20 (controlling system defect)
MEASURING METHOD	: POWER RATIO
MEASURING FREQUENCY (GHz)	: 15.000 000 ± 0.000 015
VSWR OF THE MEASURING SYSTEM	: ≤ 1.01

Designation of the standard	PTB-2.22-481		NBS - 0.1		NOM-10-0.1		RSRE-18-S2		PTB-2.22-311	
Nominal value of attenuation (dB)	0.01		0.1		10		20		40	
RF power fed into the standard (mW)	10		10		10		10		40	
VSWR of the transfer standard — input (0 dB, A dB)	<1.01	<1.01	1.02	1.025	1.02	1.03	1.06	1.04	1.06	1.06
VSWR of the transfer standard — output (0 dB, A dB)	1.02	1.02	1.045	1.05	1.01	1.09	1.06	1.055	1.06	1.06
Number of measurements	10		10		10		10		10	
Mean value of attenuation (dB)	0.01150		0.1011		10.744		21.1745		40.1286	
Standard deviation (dB)	0.00011		0.00016		0.002		0.00014		0.00025	
Standard deviation of the mean (dB)	0.00003		0.00005		0.0007		0.00004		0.00008	
Minimum measured value (dB)	0.01127		0.10080		10.740		21.1742		40.1283	
Maximum measured value (dB)	0.01165		0.10131		10.747		21.1747		40.1291	
Estimated systematic uncertainty (dB), 95%	±0.0005		±0.001		±0.004		±0.005		± 0.005	

Measuring period: 28.04.83 - 11.05.83

9. Last re-measurent of the owen transfer-standards at OMH and RSRE

Pilot laboratory: PTB

ATTENUATION IN WAVEGUIDE R 140 AT 15 GHz

GT-RF 75-A 3

Designation of the standard (home laboratory)	OMH 10 - 01 (OMH)	UK 18-S-2 (RSRE)	NBS - 0.1
Room temperature (^{o}C)	23.0 ± 0.5	21.0 ± 0.5	23.0
Room relative humidity (%)	50 ± 10	40 ± 5	40
Measuring method	AUDIO FREQUENCY SUBSTITUTION	VOLTAGE RATIO	RF SERIES SUBSTITUTION
Measuring frequency (GHz)	15.0000 ± 0.0001	15.000 000 000±0.000 000 150	15.0000±0.0015
VSWR of measuring system	1.01	≦ 1.007	1.02
RF power fed into the standard (mW)	0.01	0.0001	≦ 0.2
Number of measurements	10	20	not given
MEAN VALUE OF ATTENUATION (dB)	10.7556	21.1775	0.1024
Standard deviation (dB)	0.0020	0.00020	not given
Standard deviation of the mean (dB)	0.0006	0.00005	0.0005
Minimum measured value (dB)	17.7538	21.1771	-----
Maximum measured value (dB)	17.7592	21.1779	-----
Estimated systematic uncertainty (dB), 95%	± 0.007	± 0.002	± 0.005
Measuring period	January 1984	Aug.-Sept. 1983	June 19, 1984