# Final Report

Project No 828

EUROMET TF.TI-K1
Comparison of time interval (cable delay) measurement

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# 1. Introduction

At the EUROMET meeting held in Ljubljana during 3rd and 4th April 2003 the idea of a time interval comparison was discussed. As obvious solution a cable delay measurement was selected. Werner Mache (BEV) suggested to produce three cables with different length, equipped with BNC connectors and fitted in a box.

The BEV was therefore responsible for providing the travelling standard and was selected as pilot laboratory, which is responsible for coordinating the schedule, collecting and analysing the comparison data, and preparing this report.

The time delay of a pulse through the cable was measured from input to output connector for each cable**.** The reference plane of the BNC connector is defined at the outer end of the dielectric of BNC connector. The participants were free to choose their own method of measurement.

This EUROMET project had been named originally as a “EUROMET supplementary comparison TF.TI-K1” and as a “Comparison of time interval measurement”. At the end of the activity it became clear that the measurement task given to the participating laboratories had not been sufficiently well defined to justify both assignments.

The project does not immediately support the currently defined T&F Key Comparison and should thus not be considered as a Supplementary Comparison.

## 2. Participant list and time schedule

The pilot laboratory and 24 NMIs agreed to participate in this comparison. The table below lists all participating laboratories in chronologic order. The row “Time period” includes the period of the measurements and the time for transportation between the laboratories. The schedule worked well and all measurements were finished in the scheduled time frame.

| Institute | Country | Time period |
|---|---|---|
| BEV (Pilot Lab) | Austria | 31.1. – 13.2.2005 |
| PTB | Germany | 14.2. – 27.2.2005 |
| OP/SYRTE | France | 28.2. – 13.3.2005 |
| EIM | Greece | 14.3. – 27.3.2005 |
| SMD | Belgium | 28.3. – 10.4.2005 |
| SP | Sweden | 11.4. – 24.4.2005 |
| GUM | Poland | 25.4. – 8.5.2005 |
| MKEH | Hungary | 9.5. – 22.5.2005 |
| BEV | Austria | 23.5. – 5.6.2005 |
| SMU | Slovakia | 6.6. – 19.6.2005 |
| IREE/CMI | Czech Republic | 20.6. – 3.7.2005 |
| INRIM | Italy | 4.7. – 17.7.2005 |
| SIQ | Slovenia | 18.7. – 31.7.2005 |
| NPL | UK | 1.8. – 14.8.2005 |
| VMT/PFI | Lithuania | 15.8. – 28.8.2005 |
| BEV | Austria | 29.8. – 18.9.2005 |
| METAS | Switzerland | 19.9. – 9.10.2005 |
| NCM | Bulgaria | 10.10. – 30.10.2005 |
| INM | Romania | 31.10. – 20.11.2005 |
| ZMDM | Serbia and Montenegro | 21.11. – 11.12.2005 |
| UME | Turkey | 12.12.2005 – 1.1.2006 |
| INPL | Israel | 2.1. – 22.1.2006 |
| JV | Norway | 23.1. – 12.2.2006 |
| MIKES | Finland | 13.2. – 26.2.2006 |
| NMi/VSL | The Netherlands | 27.2. – 12.3.2006 |
| IPQ | Portugal | 13.3. – 26.3.2006 |
| ROA | Spain | 27.3. – 9.4.2006 |
| BEV | Austria | 10.4.. – 23.4.2006 |

Table 1: Time schedule and participating laboratories

# 3. Transfer standard and measurements of the pilot laboratory

## 3.1 Travelling cable standard

Fig. 1: Travelling cable standard

Three microwave cables, type (Quickform 141 PTFE, semi rigid), with different lengths were fitted in a box and equipped with BNC connectors (see Figure 1). The three standards were named "Cable #1 (short)" with approximately 4m, "Cable #2 (medium)" with approximately 10m, "Cable #3 (long)" with approximately 35m.

The cable was tested in respect to temperature changes (temperature chamber) and mechanical changes. We found out, that the differences of the delay measured before and after the tests (-20°C to +40°C) were far below the uncertainties of the Time Interval Counter SR620 we used (changes below 10 ps).

## 3.2 Measurement method

### 3.2.1 General

The main issue of this comparison is the measurement of the delay of pulses, so we did some observations about the influence of the pulse shape (rise time) on the results. The rise time causes a big influence on the delay value.

Large rise time: Rise time of the output pulse is almost the same than the input pulse ($\Delta t_{10\%} = \Delta t_{90\%}$).

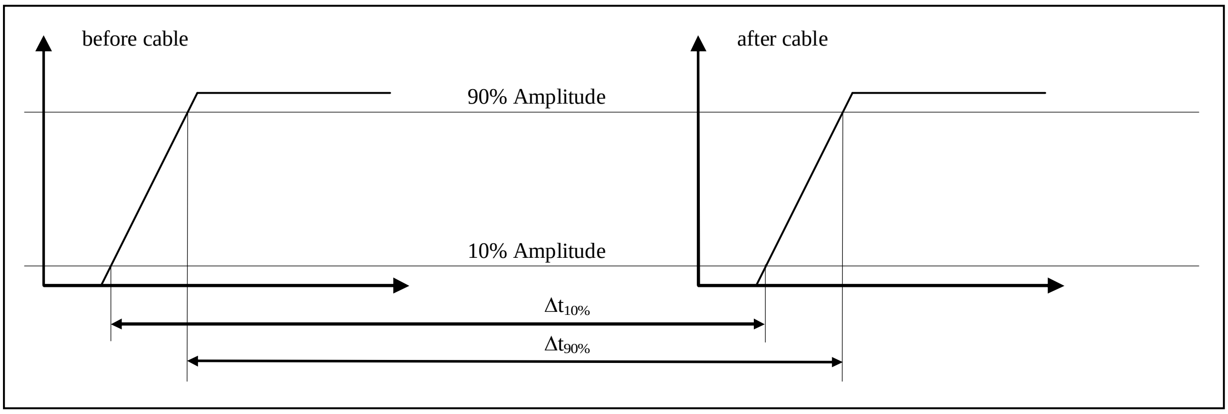


Fig. 2: Change of rise time of pulse after cable with large rise time

Small rise time: Rise time of the pulse after the cable is larger than on the input (because of the group delay of the spectrum and the higher frequencies that appear there, $\Delta t_{10\%} << \Delta t_{90\%}$).

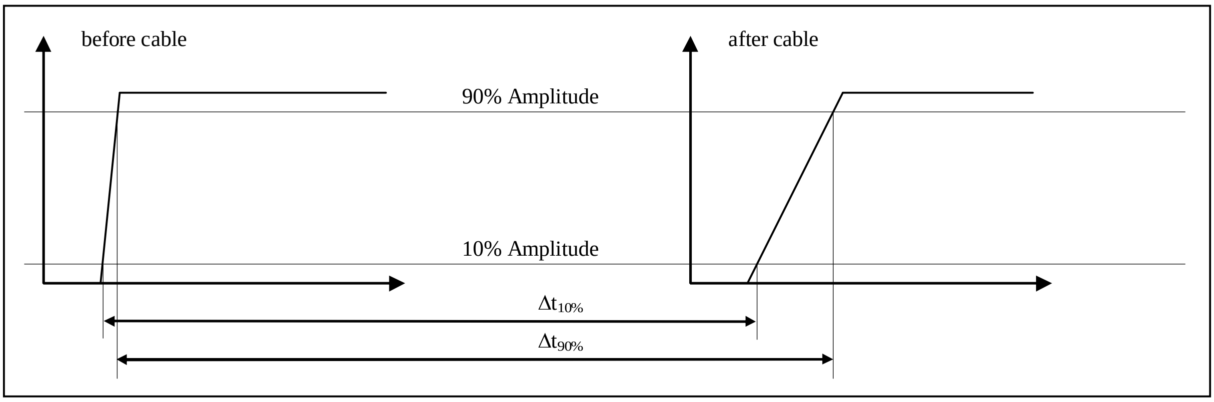


Fig. 3: Change of rise time of pulse after cable with small rise time

Our conclusion for the comparison measurements: We (time and frequency community) usually use pulses with a very small rise time, so we have to find a method where the differences of the measured delay in respect to rise time of the used pulse are very small.
The measurement differences of signals with different rise time are smaller at low trigger levels and increase with higher trigger levels. But there is some noise at the zero value of the signal, so the trigger level cannot be set extremely low.
So we decided to do the measurements with two different pulses having a different rise time at low trigger levels (10%, 20% and 33% of long term maximum level of the pulse) and include all these 6 measurements in the uncertainty budget (see Figure 4).

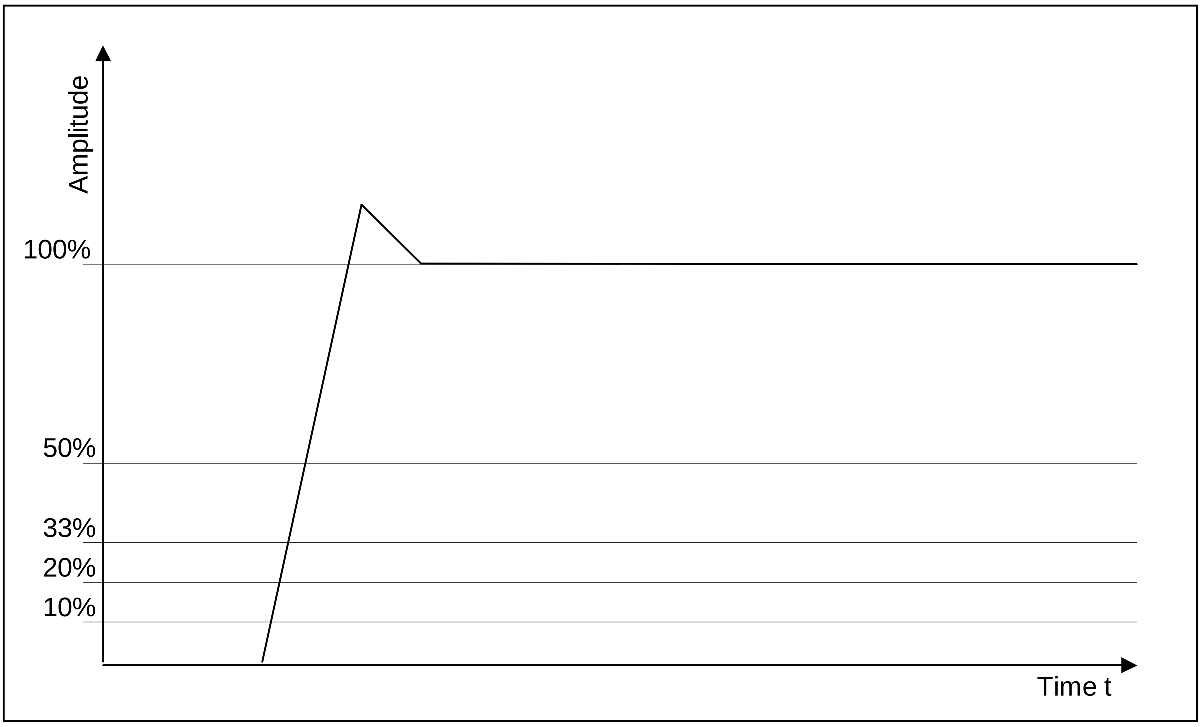


Fig. 4: Trigger levels and the typical shape of pulse after a cable

### 3.2.2 Measurement settings

To achieve the goal, to be independent to the trigger level and shape deformation - as good as possible - we used the following four settings to measure the pulse delay of the cable standards.
We did all four settings (see Figure 5 to 8) for each cable with the three trigger levels 10%, 20% and 33%.
We just did one measurement of the time difference of the two distribution amplifier outputs, because previous tests showed, that the difference change is below 10 ps rms over 2 weeks.

For example, typical measurements for the four settings are:

| Date | SN SR620 | Mode | Setting | Level A [V] | Level B [V] | Level A 10% | Level B 10% | Value [ns] | Cable delay [ns] |
|---|---|---|---|---|---|---|---|---|---|
| 30.05.2005 | 1103 | normal | 1 | 2,66 | 2,66 | 0,27 | 0,27 | 9,088 | |
| 30.05.2005 | 1103 | normal | 2 | 2,66 | 2,54 | 0,27 | 0,25 | 183,173 | 174,085 |
| | | | | | | | | | |
| 30.05.2005 | 1103 | reverse | 3 | 2,66 | 2,66 | 0,27 | 0,27 | 999999990,585 | |
| 30.05.2005 | 1103 | reverse | 4 | 2,66 | 2,54 | 0,25 | 0,27 | 999999816,503 | 174,082 |

| Level A 20% | Level B 20% | Value [ns] | Cable delay [ns] | Level A 33% | Level B 33% | Value [ns] | Cable delay [ns] |
|---|---|---|---|---|---|---|---|
| 0,53 | 0,53 | 9,141 | | 0,89 | 0,89 | 9,176 | |
| 0,53 | 0,51 | 183,353 | 174,212 | 0,89 | 0,85 | 183,618 | 174,442 |
| | | | | | | | |
| 0,53 | 0,53 | 999999990,546 | | 0,89 | 0,89 | 999999990,546 | |
| 0,51 | 0,53 | 999999816,319 | 174,227 | 0,85 | 0,89 | 999999816,099 | 174,447 |

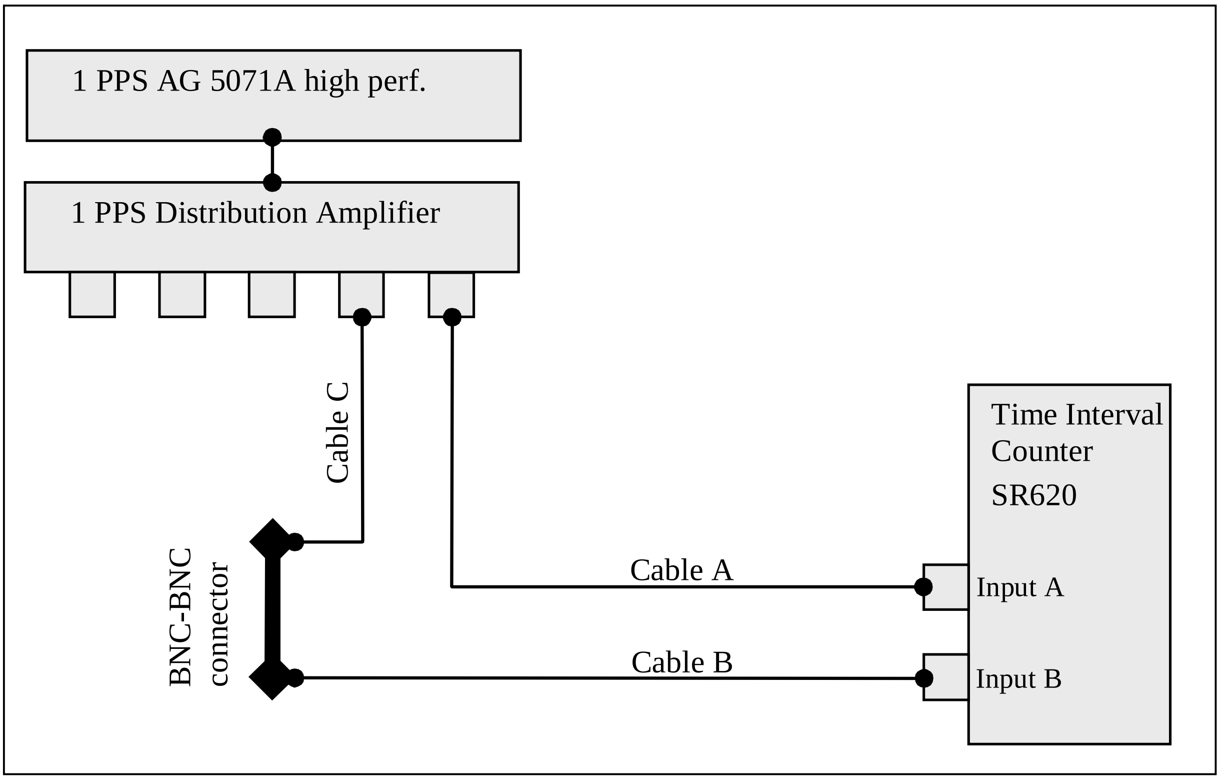


Fig. 5: Connection cables with BNC-BNC bridge, value is in ns range

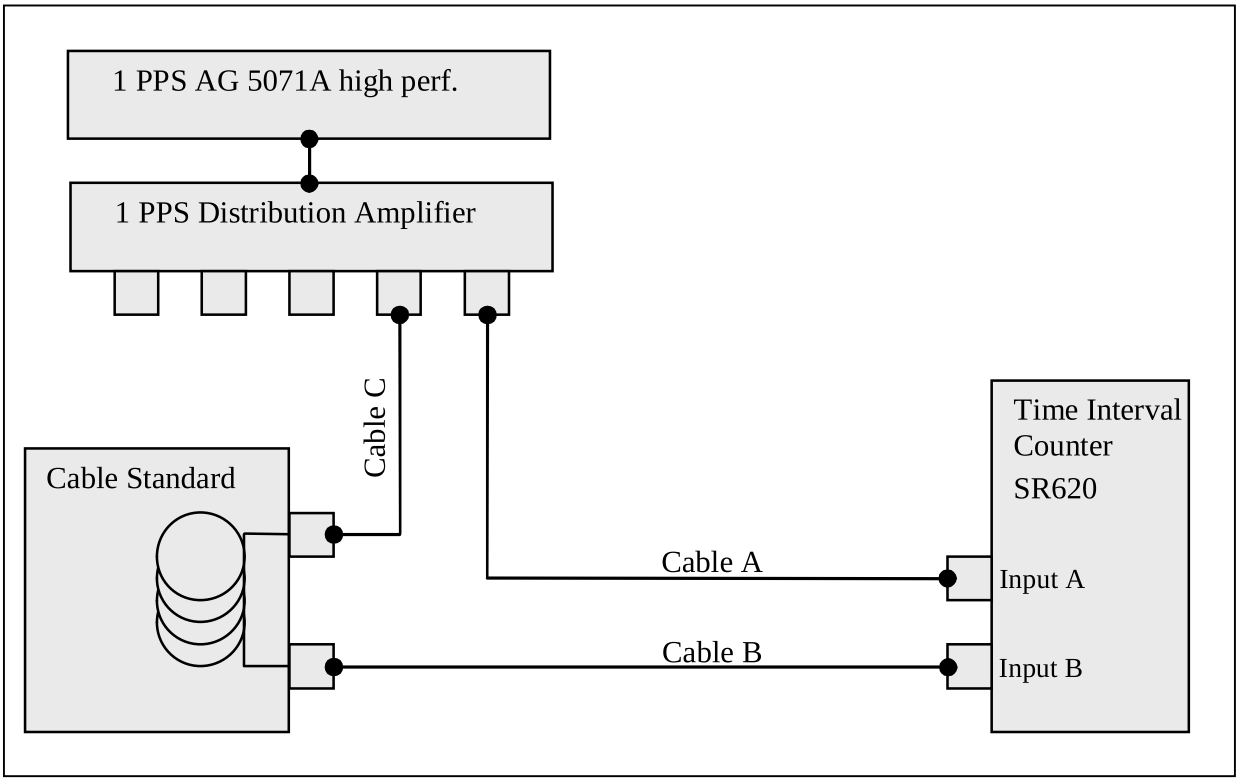


Fig. 6: Connection cables with standard, value is in ns range

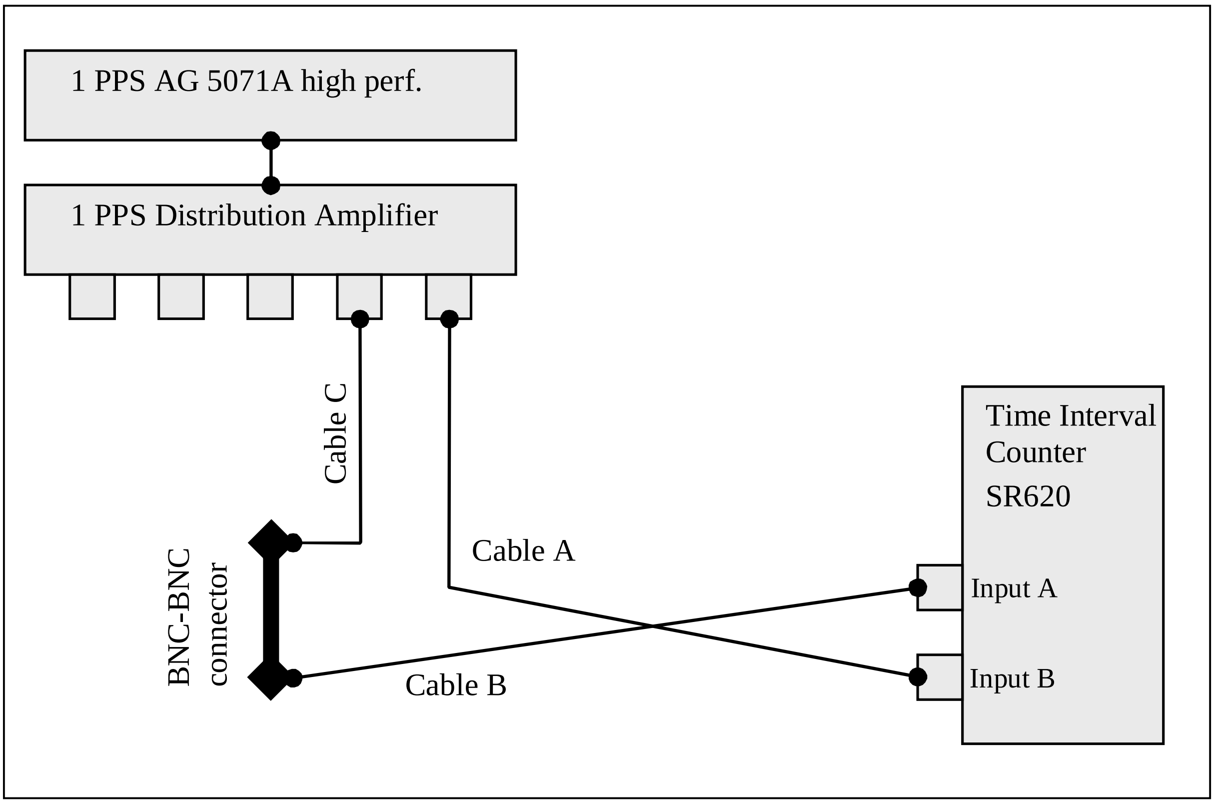


Fig. 7: Connection cables with BNC-BNC bridge, Inputs A/B changed; value is in one second range

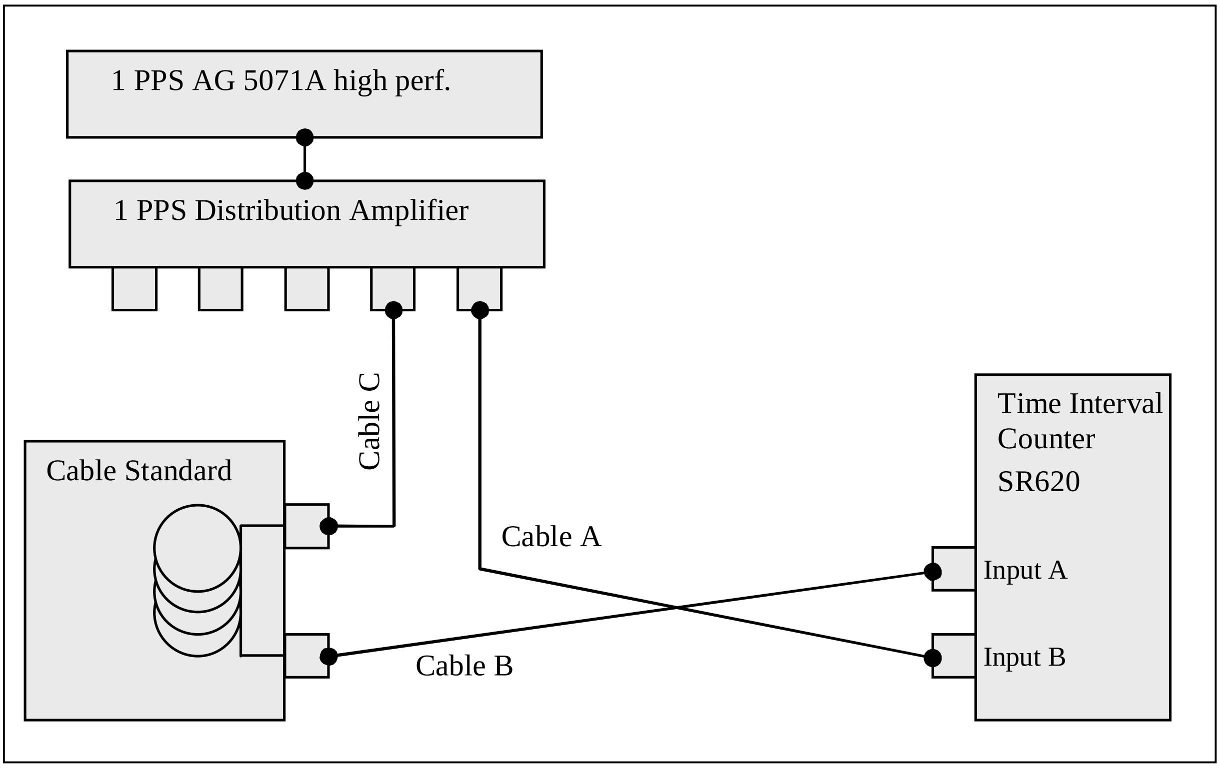


Fig. 8: Connection cables with standard, Inputs A/B changed; value is in one second range

## 3.3 Results

| | Cable #1 [ns] | u [ps] | Cable #2 [ns] | u [ps] | Cable #3 [ns] | u [ps] |
|---|---|---|---|---|---|---|
| BEV 1 | 20,323 | 46 | 48,368 | 60 | 174,358 | 157 |
| BEV 2 | 20,323 | 46 | 48,361 | 57 | 174,362 | 171 |
| BEV 3 | 20,309 | 53 | 48,348 | 63 | 174,349 | 181 |
| BEV 4 | 20,331 | 55 | 48,368 | 67 | 174,35 | 174 |
| | | | | | | |
| BEV total Mean | 20,322 | 9,1 | 48,361 | 9,4 | 174,355 | 6,3 |

Table 2: Measurement results at BEV for the three cables during the comparison period

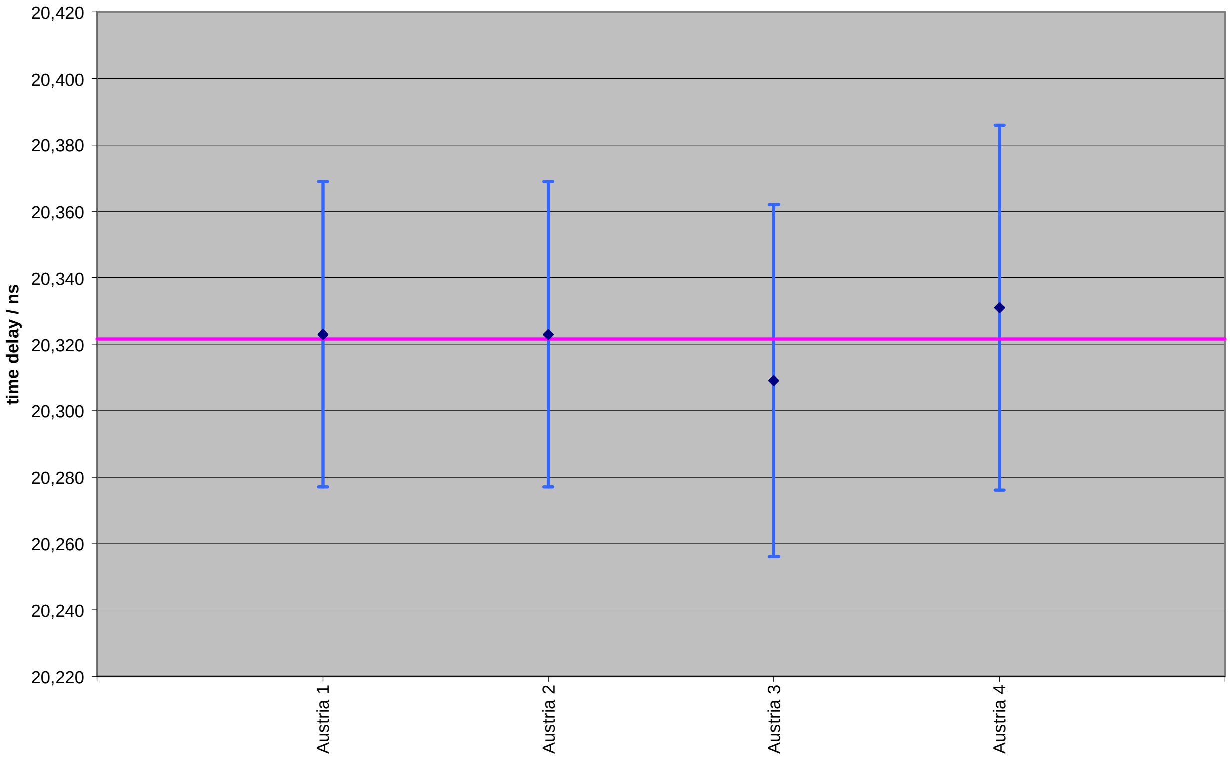


Diagram 1: Measurement results at BEV for cable #1

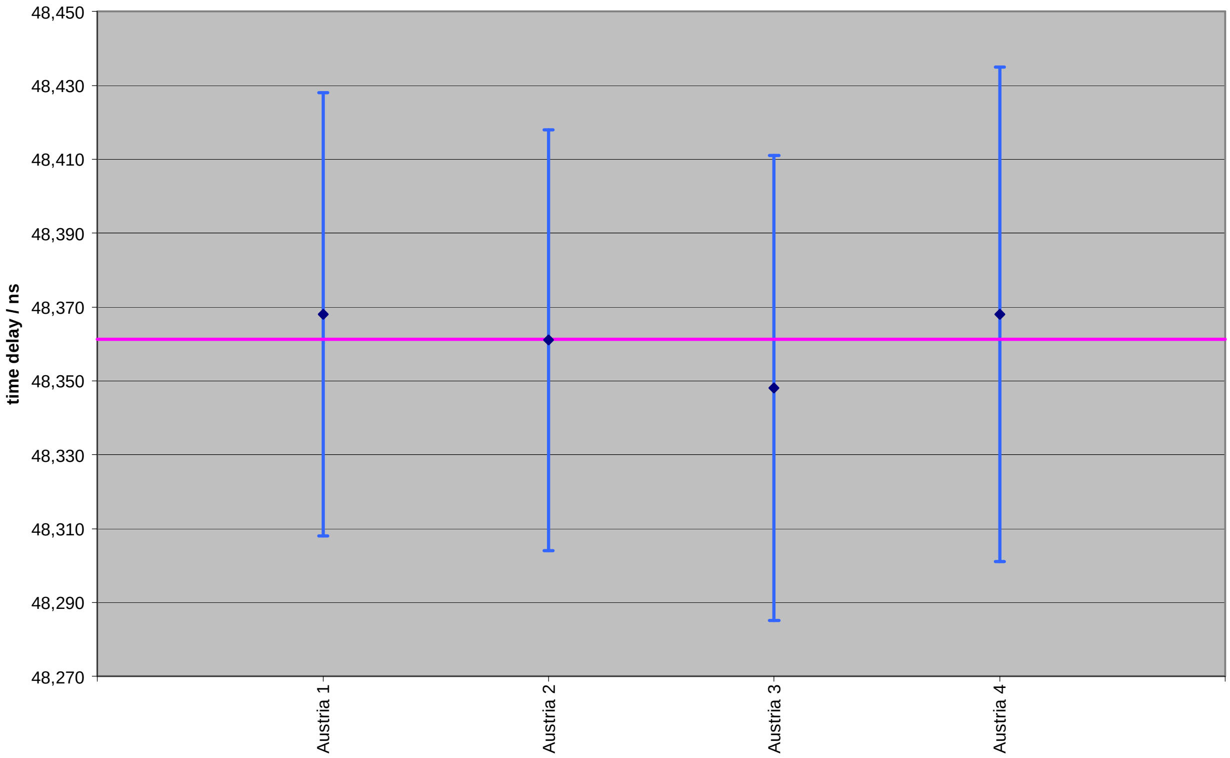


Diagram 2: Measurement results at BEV for cable #2

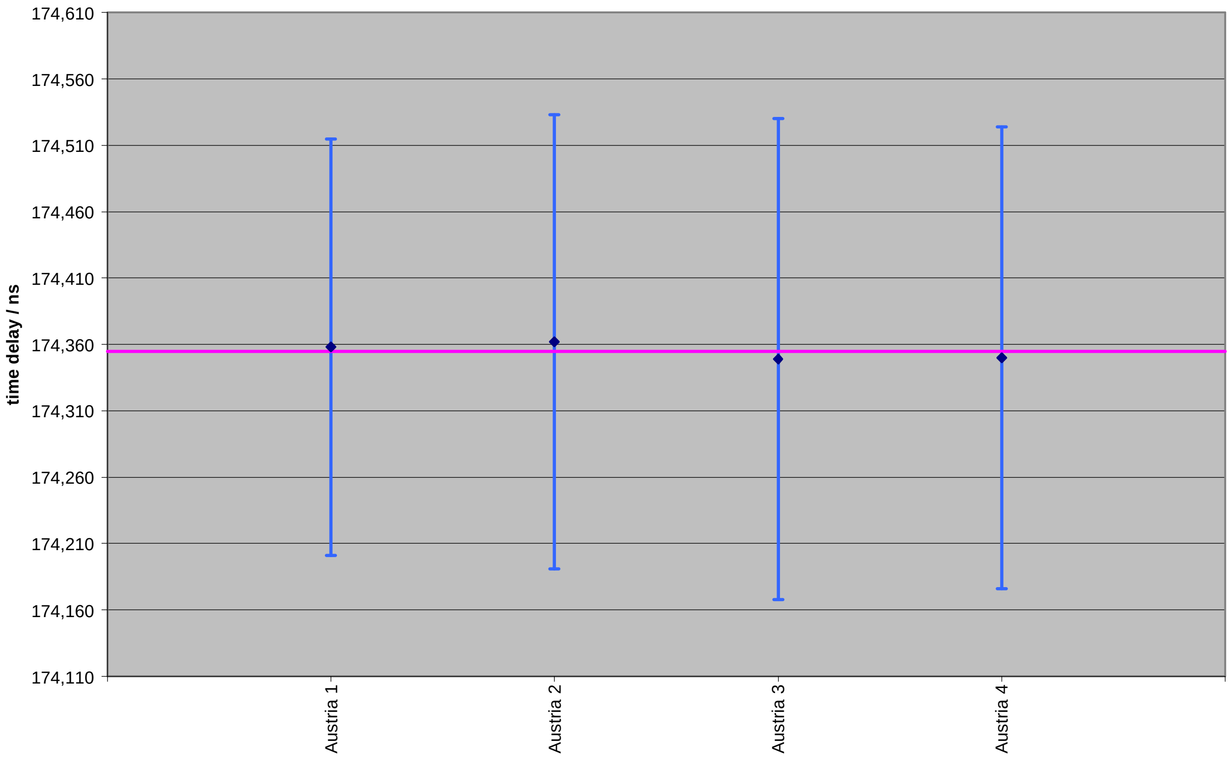


Diagram 3: Measurement results at BEV for cable #3

# 4. Measurement methods of the participants

The measurement protocols carried out by the participants are listed in Appendix A separated by A.k (k = acronym of institute).

The measurement methods differ in details generally. Most of the laboratories use counters for time interval measurements, one institute uses an oscilloscope. Different counters are used and the measurement procedures are more or less extensive. For details about the differences see Appendix A.

# 5. Measurement results

The results (time delay T[ns], measurement uncertainty u[ps] and effective degree of freedom $\nu_{eff}$) of all laboratories for the different cable lengths are listed in Table 3, 4 and 5. The institutes are listed in chronologic order.

The diagrams (Diagram 4, 5 and 6) show the measurement values with the uncertainty bars for one-sigma (yellow bars) and two-sigma (blue bars) confidence case. In the diagrams are also shown the values for the mean, the median and the weighted mean.

| Institute | Country | T [ns] | u [ps] | $n_{eff}$ |
|---|---|---|---|---|
| BEV 1 | Austria | 20,323 | 46 | 141 |
| PTB | Germany | 20,509 | 47 | 180 |
| OP/SYRTE | France | 20,473 | 51 | 278 |
| EIM | Greece | 20,200 | 100 | 10249 |
| SMD | Belgium | 20,420 | 213 | ∞ |
| SP | Sweden | 20,400 | 500 | 102 |
| GUM | Poland | 20,410 | 4 | 195 |
| MKEH | Hungary | 20,430 | 350 | 79 |
| BEV 2 | Austria | 20,323 | 46 | 140 |
| SMU | Slovakia | 20,712 | *135 | 9596 |
| IREE/CMI | Czech Republic | 20,399 | 66 | ∞ |
| INRIM | Italy | 20,450 | 60 | 100 |
| SIQ | Slovenia | 20,390 | 150 | 29295 |
| NPL | United Kingdom | 20,420 | 500 | 5 |
| VMT/PFI | Lithuania | 20,400 | 100 | 1000 |
| BEV 3 | Austria | 20,309 | 53 | 72 |
| METAS | Switzerland | 20,480 | 190 | *5 |
| NCM | Bulgaria | 20,230 | 1160 | ∞ |
| INM | Romania | 20,185 | 291 | 165431 |
| ZMDM | Serbia and Montenegro | 20,460 | 70 | 100 |
| UME | Turkey | 20,404 | 6 | 1600 |
| INPL | Israel | 20,356 | 29 | 23,1 |
| JV | Norway | 21,100 | 1400 | 60069 |
| MIKES | Finland | 20,370 | 77 | 4 |
| NMi/VSL | The Netherlands | 20,474 | 45 | - |
| IPQ | Portugal | *20,168 | 97 | 661 |
| ROA | Spain | 20,519 | 12 | 22704 |
| BEV 4 | Austria | 20,331 | 55 | 61 |

Table 3: Measurement results for cable #1 in chronologic order

* Data are changed after publishing of Draft A report

| Institute | Country | T [ns] | u [ps] | $n_{eff}$ |
|---|---|---|---|---|
| BEV 1 | Austria | 48,368 | 60 | 48 |
| PTB | Germany | 48,735 | 41 | 240 |
| OP/SYRTE | France | 48,666 | 52 | 289 |
| EIM | Greece | 48,407 | 100 | 10249 |
| SMD | Belgium | 48,532 | 313 | ∞ |
| SP | Sweden | 48,500 | 500 | 102 |
| GUM | Poland | 48,474 | 4 | 140 |
| MKEH | Hungary | 48,460 | 340 | 79 |
| BEV 2 | Austria | 48,361 | 57 | 57 |
| SMU | Slovakia | 48,762 | *85 | 9346 |
| IREE/CMI | Czech Republic | 48,466 | 69 | ∞ |
| INRIM | Italy | 48,430 | 60 | 100 |
| SIQ | Slovenia | 48,400 | 220 | 25470 |
| NPL | United Kingdom | 48,520 | 500 | 5 |
| VMT/PFI | Lithuania | 48,600 | 100 | 1000 |
| BEV 3 | Austria | 48,348 | 63 | 43 |
| METAS | Switzerland | 48,560 | 270 | *5 |
| NCM | Bulgaria | 48,720 | 1160 | ∞ |
| INM | Romania | 48,319 | 291 | 165480 |
| ZMDM | Serbia and Montenegro | 48,600 | 70 | 100 |
| UME | Turkey | 48,485 | 8 | 2041 |
| INPL | Israel | 48,422 | 29 | 24,8 |
| JV | Norway | 49,400 | 1400 | 38150 |
| MIKES | Finland | 48,490 | 116 | 4 |
| NMi/VSL | The Netherlands | 48,583 | 45 | - |
| IPQ | Portugal | *48,295 | 84 | 674 |
| ROA | Spain | 48,793 | 13 | 22681 |
| BEV 4 | Austria | 48,368 | 67 | 38 |

Table 4: Measurement results for cable #2 in chronologic order

* Data are changed after publishing of Draft A report

| Institute | Country | T [ns] | u [ps] | $n_{eff}$ |
|---|---|---|---|---|
| BEV 1 | Austria | 174,358 | 157 | 21 |
| PTB | Germany | 175,344 | 68 | 130 |
| OP/SYRTE | France | 175,624 | 52 | 296 |
| EIM | Greece | 174,908 | 100 | 10249 |
| SMD | Belgium | 174,913 | 482 | ∞ |
| SP | Sweden | 174,900 | 500 | 102 |
| GUM | Poland | 174,599 | 4 | 83 |
| MKEH | Hungary | 174,790 | 360 | 79 |
| BEV 2 | Austria | 174,362 | 171 | 21 |
| SMU | Slovakia | 175,271 | *106 | 9428 |
| IREE/CMI | Czech Republic | 174,519 | 82 | ∞ |
| INRIM | Italy | 174,880 | 60 | 100 |
| SIQ | Slovenia | 174,350 | 360 | 23429 |
| NPL | United Kingdom | 174,830 | 500 | 5 |
| VMT/PFI | Lithuania | 176,000 | 100 | 1000 |
| BEV 3 | Austria | 174,349 | 181 | 21 |
| METAS | Switzerland | 174,900 | 1100 | *5 |
| NCM | Bulgaria | *175,390 | 1160 | ∞ |
| INM | Romania | 174,582 | 290 | 163000 |
| ZMDM | Serbia and Montenegro | 174,900 | 70 | 100 |
| UME | Turkey | 174,766 | 10 | 2051 |
| INPL | Israel | 174,881 | 40 | 23,8 |
| JV | Norway | 176,100 | 1600 | 269748 |
| MIKES | Finland | 174,460 | 214 | 4 |
| NMi/VSL | The Netherlands | 175,298 | 45 | - |
| IPQ | Portugal | *174,682 | 85 | 685 |
| ROA | Spain | 175,965 | 13 | 23749 |
| BEV 4 | Austria | 174,350 | 174 | 21 |

Table 5: Measurement results for cable #3 in chronologic order

* Data are changed after publishing of Draft A report

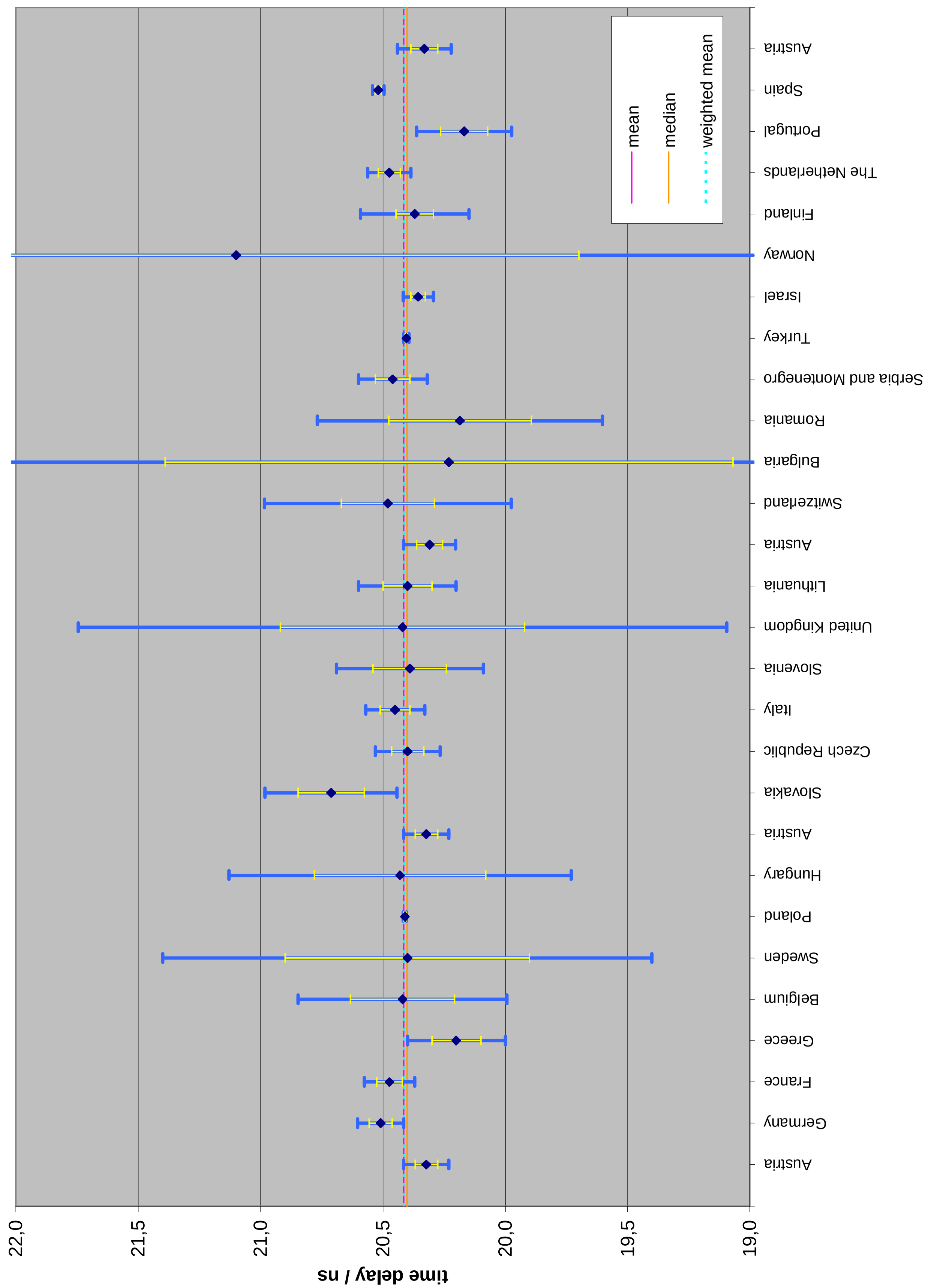


Diagram 4: Measurement results for cable #1 in chronologic order. The yellow bars are the one-sigma and the blue bars the two-sigma confidence case.

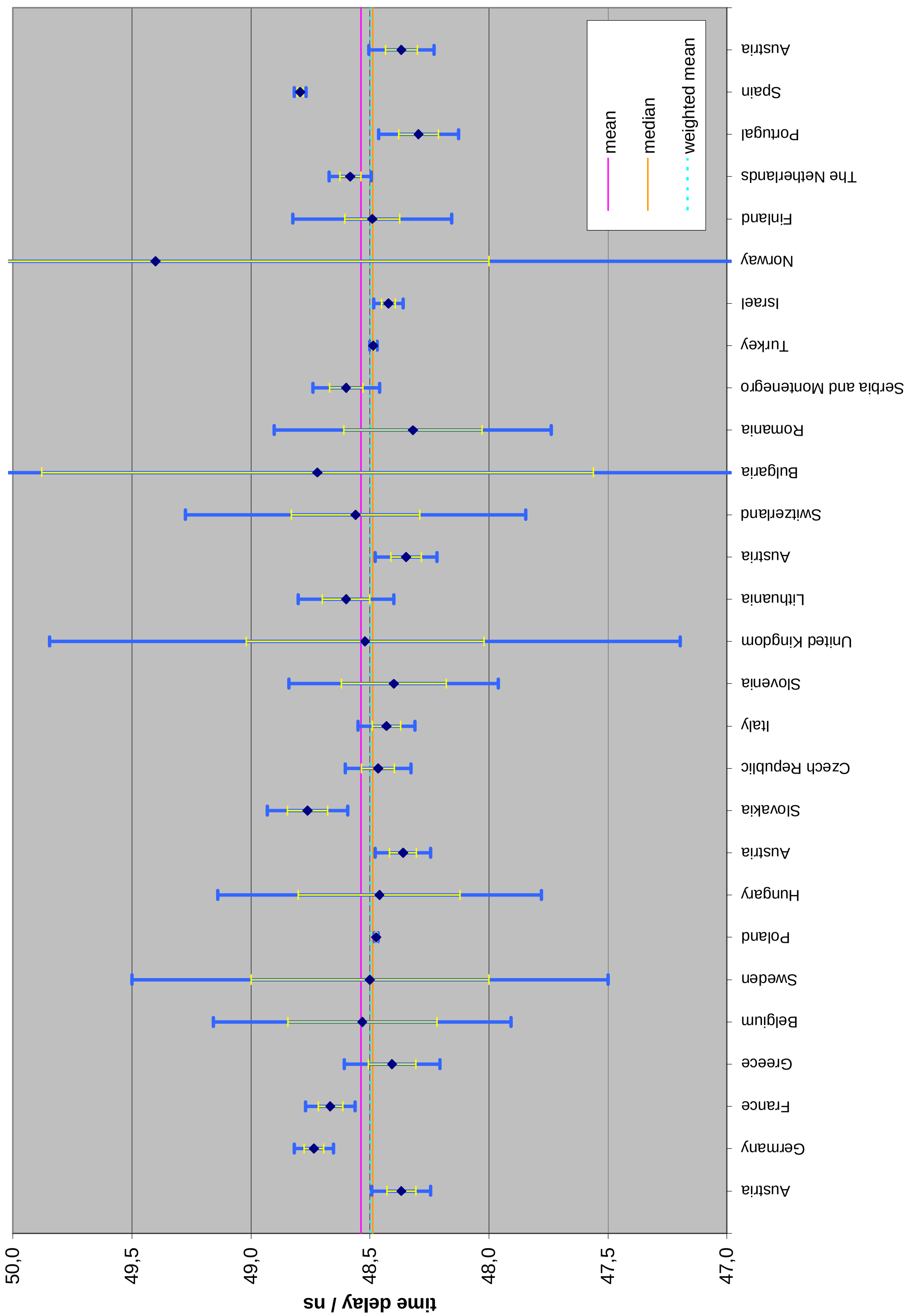


Diagram 5: Measurement results for cable #2 in chronologic order. The yellow bars are the one-sigma and the blue bars the two-sigma confidence case.

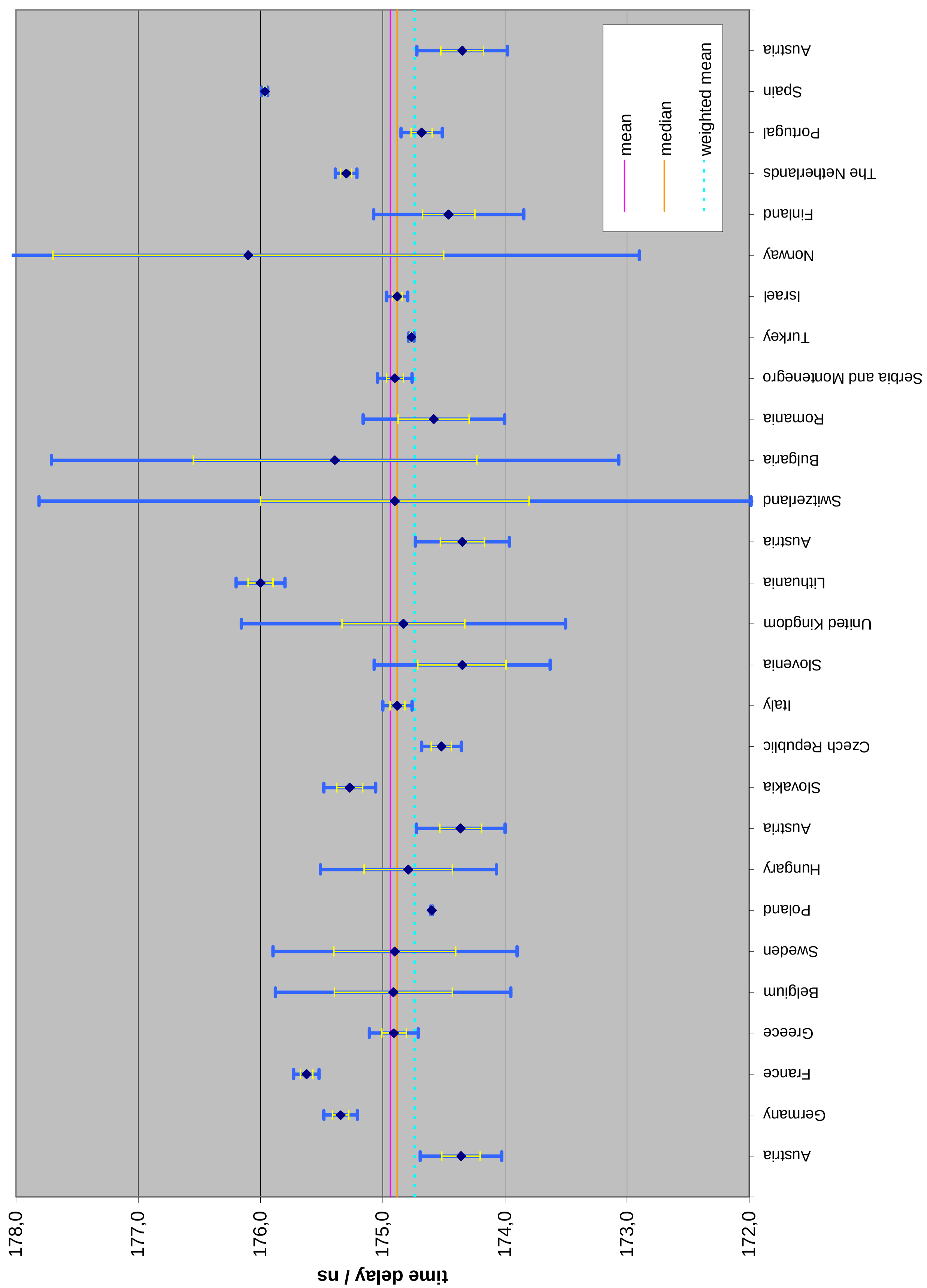


Diagram 6: Measurement results for cable #3 in chronologic order. The yellow bars are the one-sigma and the blue bars the two-sigma confidence case

# 6. Conclusions

Due to the agreement that the laboratories have chosen their own measurement method and have used their own equipment the results differ and can not immediately be compared. This freedom was in the end reflected in a dispersion of the measurement results larger than supported by the attributed measurement uncertainty in some cases. The dispersion at the cable, the use of different measurement pulses from different amplifiers and the measurement at different trigger levels cause the span of measurement values.

As been shown in previous chapter the measurements for all cables did not change significantly during the comparison period at BEV. So the artefact proved perfectly suitable for the purpose of the measurement task in the sense that

- it provided reproducible and stable measurement results at each visited site,
- and it apparently did not suffer in any way during the transportation.

There were also remarkable variations in the estimates of the measurement uncertainties and the number of degrees of freedom. It is not understandable how the stated measurement uncertainty values can vary by as much as almost two orders of magnitude although similar measurement equipments and measurement methods were used.

A detailed analysis of the statistical distribution of the measurement results – as provided by Jean-Yves Richard of LNE-SYRTE – should not be considered as meaningful, even if the statistical tools were chosen perfectly well.

This project showed that the transmission delay of any signal through a cable depends on several parameters and does not well define a measurement quantity “time interval” and we should be more aware of the fact that the value of a “cable delay”, even for the same cable, is not a fundamental constant.