Service category : Calibration of Stopwatch

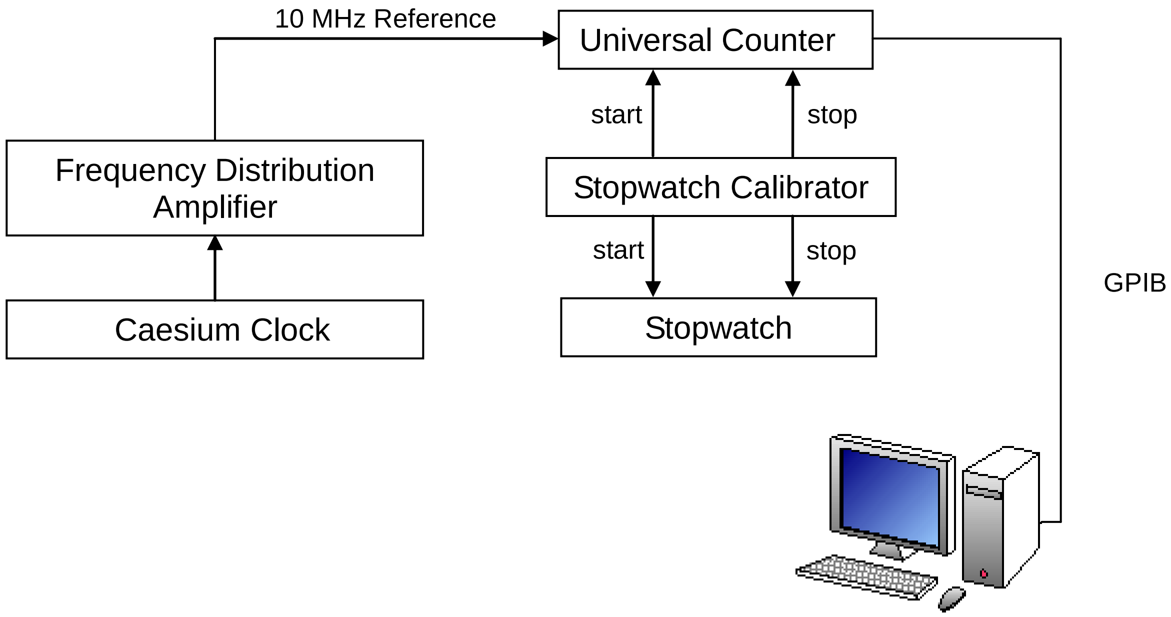
Basic information

- Quantity — Time interval
- Instrument or Artifact — Stopwatch
- Instrument Type or Method — Time interval measurement
- Measurand Level or Range — 0.01 to 100000 s
- Measurement Conditions
  - Number of measurements = 10

Instruments

- Atomic Clock (Model : Agilent 5071A)
- Frequency Distribution Amplifier (Model : HP 5087A)
- Universal Counter (Model : Agilent 53131A)
- Stopwatch Calibrator (Model : NML-SIRIM)

Measurement configuration



List of uncertainties

1. Uncertainty of Caesium Clock
2. Cable Uncertainty
3. Frequency Distribution Amplifier Uncertainty
4. Universal Counter Uncertainty
5. Stopwatch Calibrator Uncertainty
6. Display Resolution of Stopwatch

Details of Uncertainty Calculations

1) Values taken from Agilent 5071A (High Performance) specifications.

2) Referring to Appendix in Figure 3, we extrapolate using a line with slope τ^{-1} to get the uncertainty of the cable in the worst case event of ± 7°C change at 100000 s observation time.

3) From the measurement results at 100000 s observation time which are shown in Figure 5 in the Appendix.

4) Calculated based on equation and value taken from Agilent 53131A specifications, as follow:

$$\textbf{Trigger Level Timing Error} = \pm\frac{15\text{mV} \pm (1\% \text{ x Start Trigger Level Setting})}{Input\ Slew\ Rate\ at\ Start\ Trigger\ Point} \pm \frac{15\text{mV} \pm (1\% \text{ x Stop Trigger Level Setting})}{Input\ Slew\ Rate\ at\ Stop\ Trigger\ Point}$$

$$= \pm\frac{15\text{mV} \pm (1\% \text{ x } 2.5\text{V})}{4\text{V}/47.68\mu s} \pm \frac{15\text{mV} \pm (1\% \text{ x } 2.5\text{V})}{4\text{V}/8.4\mu s}$$

$$= \pm 4.77\text{x}10^{-7} \pm 8.40\text{x}10^{-8}$$

$$= \pm \mathbf{5.61x10^{-7}\,s}$$

Differential Channel Error = 1.5ns

$$\textbf{RMS Resolution} = \sqrt{t_{res}^2 + \text{Start Trigger Error}^2 + \text{Stop Trigger Error}^2}$$

$$= \sqrt{(750\text{ps})^2 + (5.96\text{x}10^{-7}\text{s})^2 + (1.05\text{x}10^{-7}\text{s})^2} = \mathbf{6.05x10^{-7}\,s}$$

$$\text{Start Trigger Error} = \frac{\sqrt{E_{input}{}^2 + E_{startsignal}{}^2}}{Input\ Signal\ Slew\ Rate\ at\ Start\ Trigger\ Point}$$

$$= \frac{\sqrt{1\text{mV}^2 + 0.05\text{V}^2}}{4\text{V}/47.68\mu s} = 5.96\text{x}10^{-7}\text{s}$$

$$\text{Stop Trigger Error} = \frac{\sqrt{E_{input}{}^2 + E_{stopsignal}{}^2}}{Input\ Signal\ Slew\ Rate\ at\ Stop\ Trigger\ Point}$$

$$= \frac{\sqrt{1\text{mV}^2 + 0.05\text{V}^2}}{4\text{V}/8.4\mu s} = 1.05\text{x}10^{-7}\text{s}$$

$$t_{res} = 750\,ps$$

Note : The signal slew rate of the calibrator output pulse were measured using a digital oscilloscope.

Universal Counter Measurement Error = (Trigger Level Timing Error) + (Differential Channel Error) + 2(RMS Resolution)

$= (5.6 \times 10^{-7}) + (1.5 \times 10^{-9}) + 2(6.1 \times 10^{-7})$

$= \pm \mathbf{1.78 \times 10^{-6} s}$

5) The calibrator is an in-house developed unit, the uncertainty value of its trigger delay was determined from the measurement.

6) The uncertainty of the stopwatch's time display is obtained from the smallest resolution of displayed time (typically 0.01 seconds).

Uncertainty Budget Table

Example for stopwatch calibration (with 0.01 s resolution) at 100000 s measurement time and traceable to Malaysian National Frequency Standard (MNFS)

Uncertainty Source (i=1,…,6)	**Type**	**Value**	**Distribution Factor**	**Standard Uncertainty** $u(x_i)$	**Sensitivity Coefficient** (c_i)	$c_i u(x_i)$
1) Caesium Uncertainty	B	5×10^{-13} x 100000 s	$\frac{1}{\sqrt{3}}$	2.89×10^{-8} s	1	2.89×10^{-8} s
2) Cable Uncertainty (Worse Case : ±7 ^{0}C temperature change over 100000 s)	A	4×10^{-15} x 100000 s	1	4×10^{-10} s	1	4×10^{-10} s
3) Frequency Distribution Amplifier (± 2 ^{0}C temperature change over 100000 s)	A	4×10^{-15} x 100000 s	1	4×10^{-10} s	1	4×10^{-10} s
4) Universal Counter Uncertainty	B	1.78×10^{-6}	$\frac{1}{\sqrt{3}}$	1×10^{-6}	1	1×10^{-6} s
5) Stopwatch Calibrator Uncertainty	A	2×10^{-7} s	1	2×10^{-7} s	1	2×10^{-7} s
6) Time display resolution of Stopwatch	B	5×10^{-3} s	$\frac{1}{\sqrt{3}}$	2.89×10^{-3} s	1	2.89×10^{-3} s
Combined Uncertainty = $\sqrt{\sum_{i=1}^{6} c_i u(x_i)^2}$ = $\mathbf{2.89 \times 10^{-3}}$ **s**						
Expanded Uncertainty (k=2) = 2 x u_c = $\mathbf{5.8 \times 10^{-3}}$ **s**						

APPENDIX

Cable Uncertainty

To create significant temperature changes, we used a 25 watt lighting bulb and a timer to ON and OFF the bulb. The bulb was place inside the polystyrene box with the cable under test (CUT). A thermocouple was attached to the cable's skin and the data acquisition records its temperature at 1 s interval. The measurement set-up diagram, temperature records and measurement results (Overlapping Allan deviation) are shown as in Figure 1, 2 and 3:

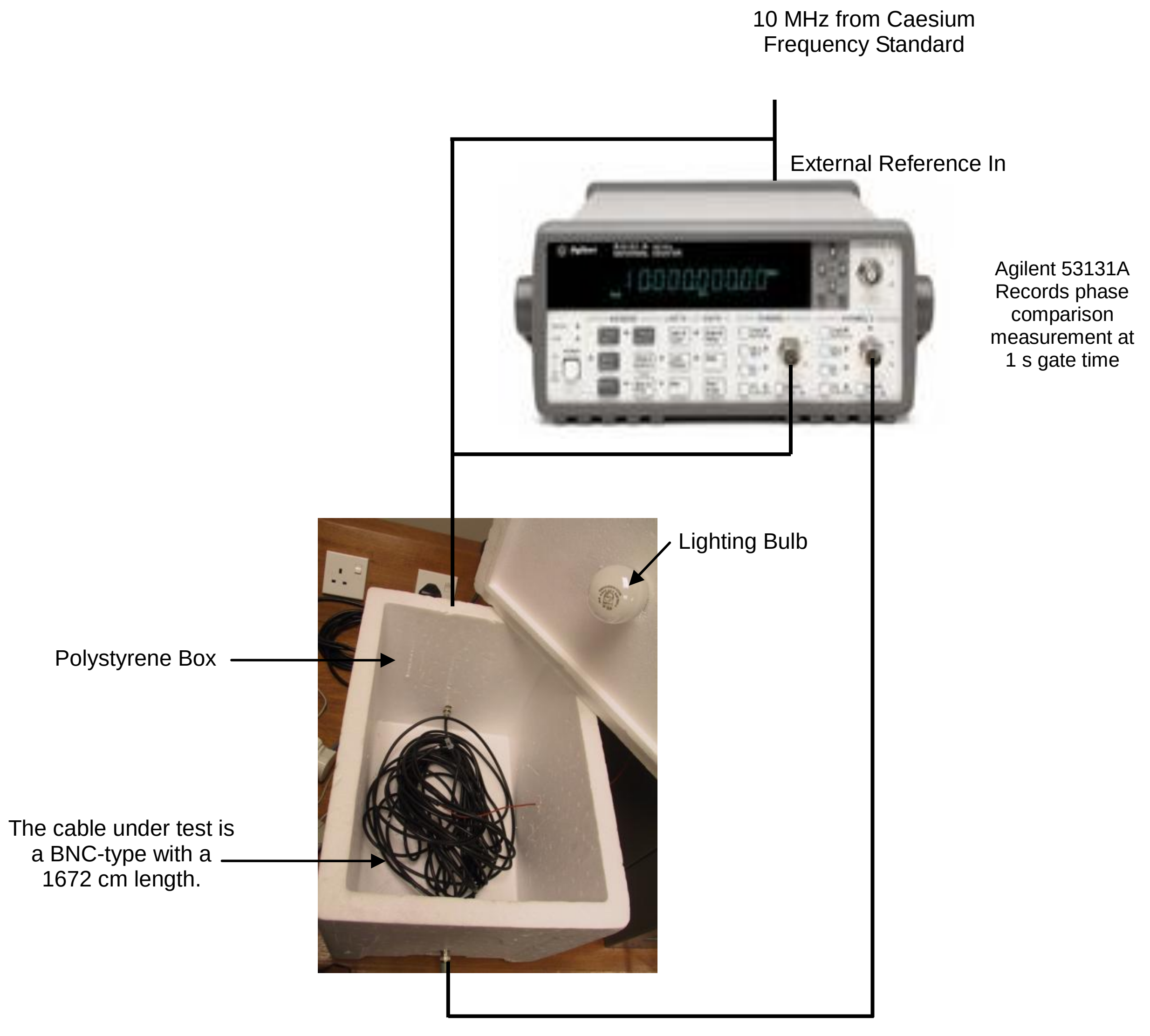


Figure 1 : Measurement set-up for estimating the uncertainty of BNC cable in phase comparison in the worst case event of ± 7°C change over 1 day.

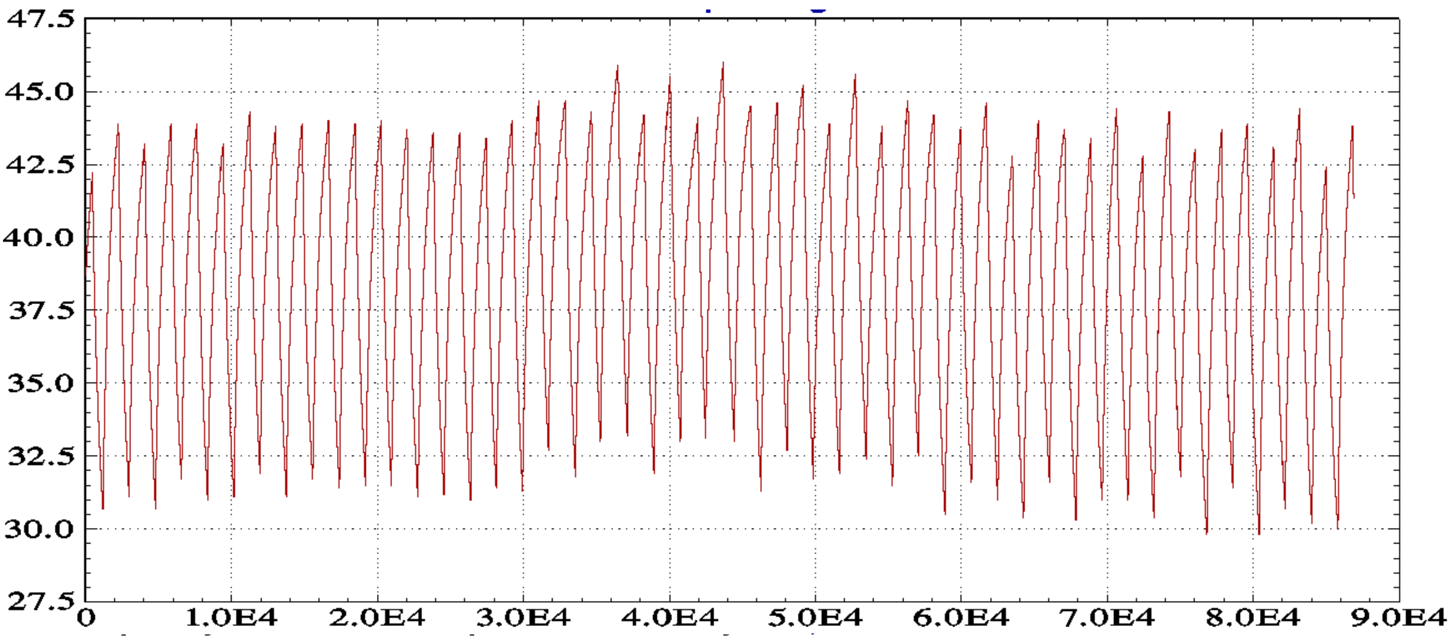


Figure 2 : Temperature measurement at 1 second interval

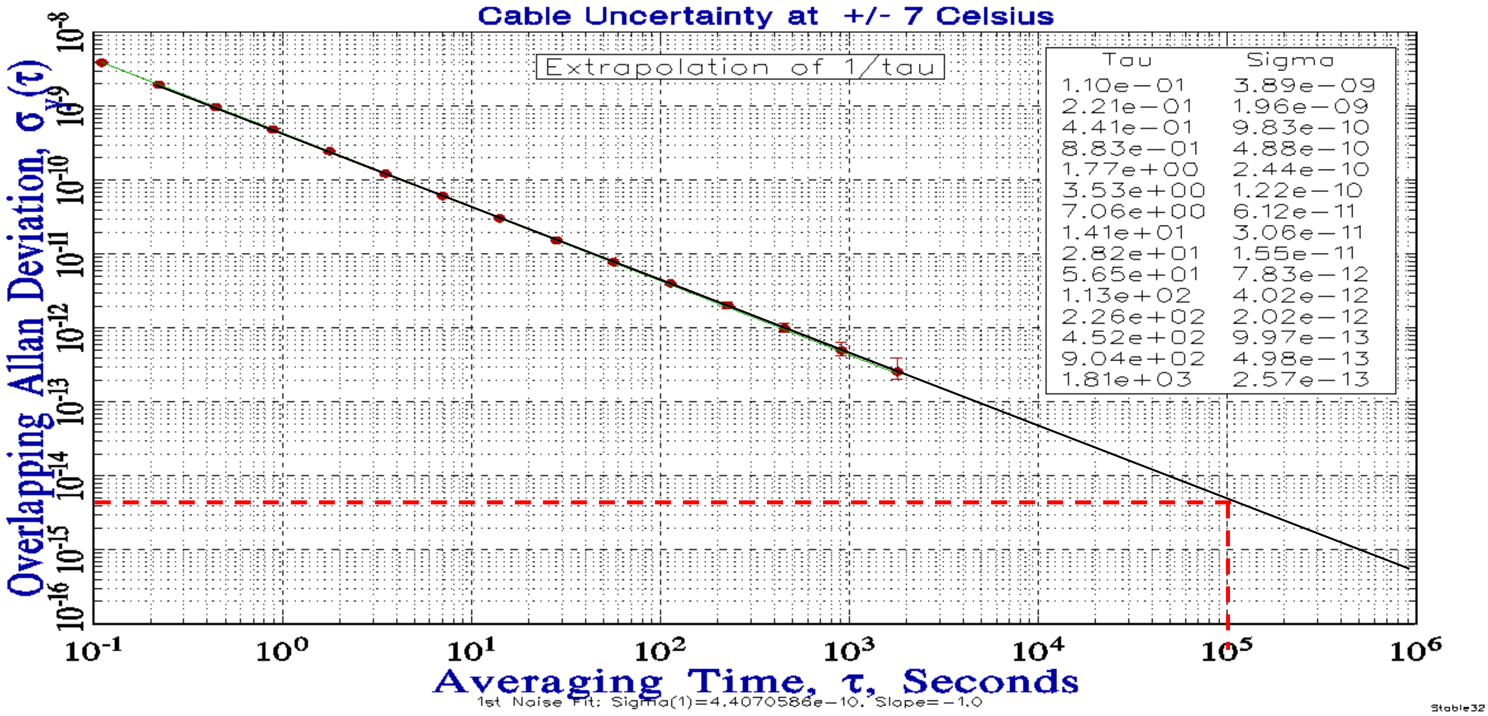


Figure 3: By using extrapolation of slope τ^{-1}, we found that the uncertainty of cable in worst case event of ± 7°C change over 100000 s is 4 x 10^{-15}.

Frequency Distribution Amplifier Uncertainty

The measurement set-up diagram and measurement results (overlapping Allan deviation) are shown as in Figure 4 and Figure 5 :

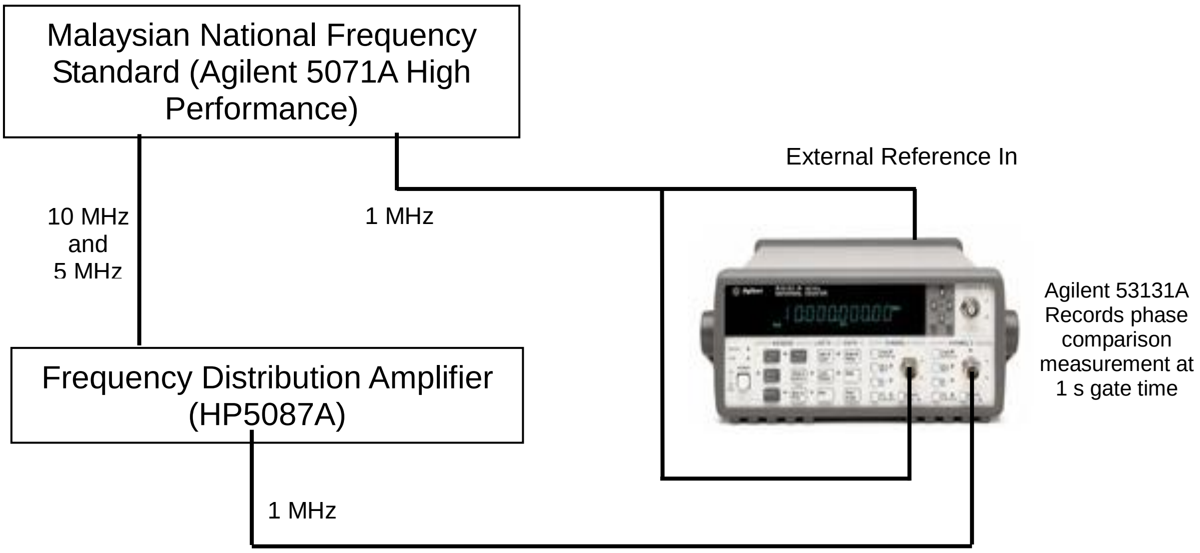


Figure 4 : Measurement set-up for estimating the uncertainty of Frequency Distribution Amplifier (HP5087A) in the event of ± 2°C change over 3 days

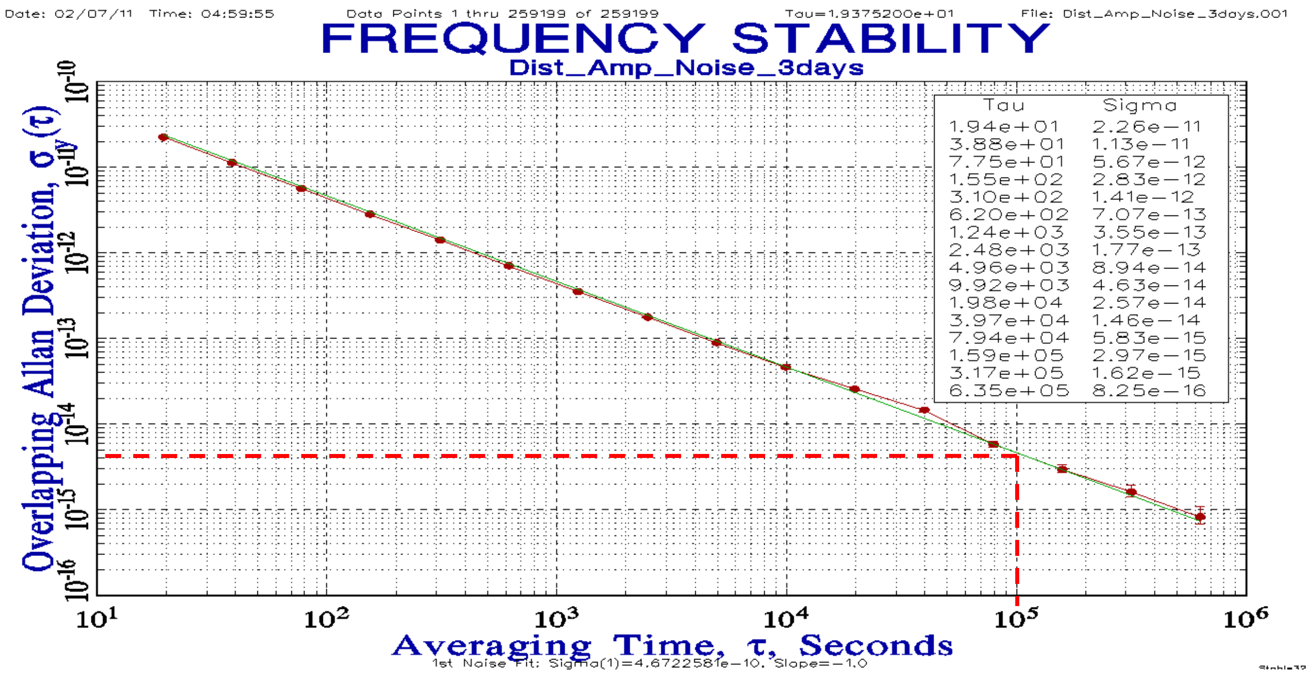


Figure 5: The uncertainty of HP5087A in the event of ± 2°C change over 3 days