Documentation of measuring conditions

National Metrology Centre, A*SATR, Singapore employed two setups for the measurement at different measuring ranges: 0 to ± 150 arcsec (inclusive) and ± 160 to ±1000 arcsec (inclusive). The measuring conditions of the two setups are listed in the table below.

1. For the range of 0 to ± 150 arcsec (inclusive)

    The measurement is based on comparison of the test autocollimator with a high resolution reference autocollimator (S/N: 262). The calibration set up is shown as Figure 1. During the measurement, a small angle was generated by a precision small angle generator (S/N: 137/1918 - LE6003). The small angle generated was then measured by both autocollimators. And the angle deviation of the test autocollimator was obtained by calculating the difference between the readings of the reference autocollimator and the test autocollimator.

    Due to the difficulty of setting the angle for every 0.1 arcsec, the measuring step was set to 0.5 arcsec for the range of 0 to ± 10 arcsec.
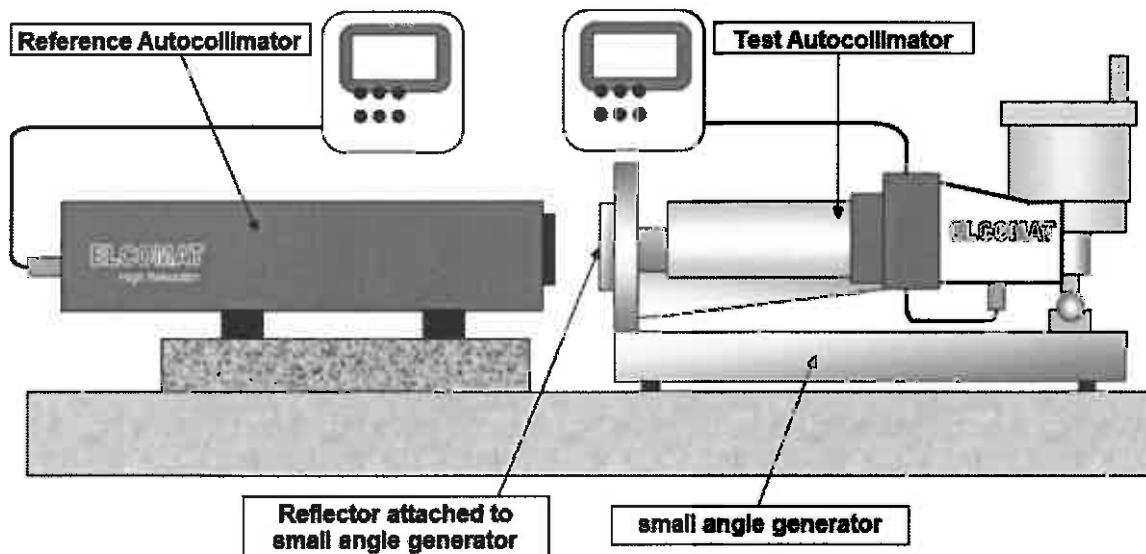

Figure 1 Autocollimator calibration setup for the range of 0 to ± 150 arcsec

2. For the range of ± 160 to ± 1000 arcsec (inclusive)

    The calibration set up is shown as Figure 2. During the measurement, a small angle was genrated by the precision small angle generator (S/N: 137/1918 - LE6003). The angle deviation of the test autocollimator was obtained by comparing the angular reading of the test autocollimator with the set angle.
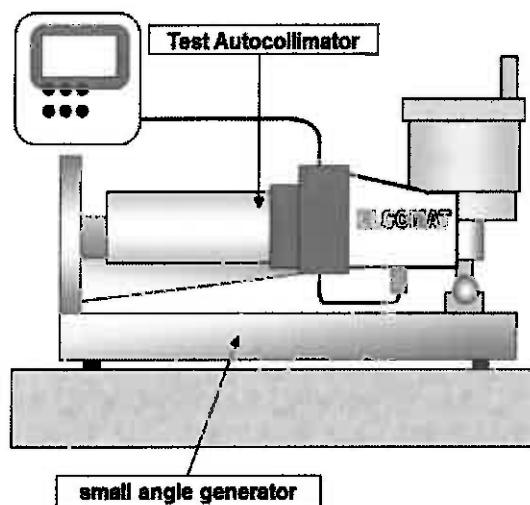
Figure 2 Autocollimator calibration setup for the range of ± 160 to ± 1000 arcsec

1.	General information on the measuring conditions	0 to ±150 arcsec (inclusive)	±160 to ±1000 arcsec (inclusive)
1.1	Mounting		
	• Horizontal orientation of the AC x-axis	-	-
	• Vertical orientation of the AC x-axis	Yes	Yes
	• Use of additional optics for beam rotation (If yes, please provide a short description)	No	No
1.2	Plane mirror		
	• Use of the plane mirror provided by the PTB	No	No
	• Use of the plane mirror owned by the NMI	Yes	Yes
	o Reflectivity (%)	96%	96%
	o Size (mm x mm)	Ø 45 mm	Ø 45 mm
	o Flatness deviation (rms or pv, if know) (nm)	0.06 µm (pv)	0.06 µm (pv)
1.3	Distance between autocollimator and reflector		
	• Distance (mm)	205	205
1.4	Temperature of the measurement room		
	• Temperature (°C)	19.8°C	19.8°C
1.5	Autocollimator settings		
1.5.1	Automated measurements		
	• Use of the RS232 interface 'text' protocol	Yes	Yes
	• Use of the RS232 interface 'compatible 'protocol	No	No
	• Use of the USB interface	No	No
1.5.2	Manual measurements		
	• Resolution setting (arcsec)	-	-
1.6	Details to the measurement procedure		

•	Static measurement	Yes	Yes
•	Dynamic measurement	No	No
•	Number of repeat measurements ($n_r =$)	5	3
•	Repeat measurements in different relative angular orientations between the autocollimator and the reference system	N.A	N.A
•	Number or repeat measurements of the autocollimator in each measuring position (n_{AC}=)	200	200
•	Number or repeat measurements of the reference in each measuring position (n_{REF}=)	200	N.A (set angle of the small angle generator)

Date   NMI   Signature

NMC/A*STAR

5/Jan/2015 .....Singapore.   .....Chen.....

1. Uncertainty budget table for the measurng range of 0 to ± 150 arcsec (inclusive)

Source of Uncertainty	Symbol x_i	Type	Uncertainty value arcsec	Probability distribution	Coverage factor	Standard uncertainty arcsec	Sensitivity coefficient c_i	$\lvert c_i \rvert * u(x_i)$ arcsec	Degrees of freedom v
Repeatability of reading	$u(Rpt)$	A	-	-	-	0.020	1	0.020	4
Resolution of UUT	$u(UUT\_Res)$	B	0.02	rectangular	$\sqrt{12}$	0.006	1	0.006	∞
UUT rdg stability	$u(UUT\_Var)$	B	0.05	normal	2	0.026	1	0.026	∞
UUT sampling points variation	$u(UUT\_Samp)$	B	0.007	rectangular	$\sqrt{12}$	0.002	1	0.002	∞
Resolution of reference autocollimator	$u(Ref\_Res)$	B	0.01	rectangular	$\sqrt{12}$	0.003	1	0.003	∞
Uncertainty of reference autocollimator	$u(Ref\_Uc)$	B	0.02	normal	2.2	0.009	1	0.009	∞
Error of reference autocollimator	$u(Ref\_Err)$	B	0.06	rectangular	$\sqrt{12}$	0.017	1	0.017	∞
Stability of reference angle	$u(Ref\_Drift)$	B	0.05	rectangular	$\sqrt{12}$	0.014	1	0.014	∞
Error caused by reflecting mirrors	$u(Ref\_Mirror)$	B	0.02	rectangular	$\sqrt{12}$	0.006	1	0.006	∞
			Combined uncertainty			0.042	arcsec		76.22
			Expanded uncertainty		2	0.084	arcsec		

2. Uncertainty budget table for the measurng range of ± 160 to ± 1000 arcsec (inclusive)

Source of Uncertainty	Symbol x_i	Type	Uncertainty value arcsec	Probability distribution	Coverage factor	Standard uncertainty arcsec	Sensitivity coefficient c_i	$|c_i| * u(x_i)$ arcsec	Degrees of freedom v
Repeatability of reading	$u(Rpt)$	A	-	-	-	0.065	1	0.065	2
Resolution of UUT	$u(UUT\_Res)$	B	0.02	rectangular	$\sqrt{12}$	0.006	1	0.006	∞
UUT rdg stability	$u(UUT\_Var)$	B	0.07	normal	2	0.033	1	0.033	∞
UUT sampling points variation	$u(UUT\_Samp)$	B	0.007	rectangular	$\sqrt{12}$	0.002	1	0.002	∞
Resolution of small angle generator	$u(Ref\_Res)$	B	0.10	rectangular	$\sqrt{12}$	0.029	1	0.029	∞
Uncertainty of small angle generator	$u(Ref\_Uc)$	B	0.20	normal	2.65	0.075	1	0.075	∞
Error of small angle generator	$u(Ref\_Err)$	B	0.30	rectangular	$\sqrt{12}$	0.087	1	0.087	∞
Stability of reference angle	$u(Ref\_Drift)$	B	0.10	rectangular	$\sqrt{12}$	0.029	1	0.029	∞
Combined uncertainty						0.142 arcsec			45.78
Expanded uncertainty					2	0.284 arcsec			

Table 6. Information on the data rows of the ASCII file.   Unit: arcsec

Column name for file header	ACx	sdACx	ACDev	sdACDev	uACDev	k	ACy
Data value	α_{AC}	$\sigma(\alpha_{AC})$	$\delta(\alpha_{AC})$	$\sigma(\delta)$	$u(\delta)$	k	β_{AC}
Optional		X		X			X
	0.04		0.00		0.08	2	
	0.53		0.01		0.08	2	
	1.03		0.01		0.08	2	
	1.46		0.00		0.08	2	
	1.97		0.02		0.08	2	
	2.52		0.01		0.08	2	
	2.98		0.01		0.08	2	
	3.50		0.01		0.08	2	
	4.00		0.01		0.08	2	
	4.50		0.02		0.08	2	
	5.01		0.02		0.08	2	
	5.51		0.01		0.08	2	
	6.00		0.01		0.08	2	
	6.49		0.01		0.08	2	
	6.99		-0.01		0.08	2	
	7.53		0.00		0.08	2	
	7.99		0.00		0.08	2	
	8.52		0.00		0.08	2	
	9.04		0.02		0.08	2	
	9.52		0.00		0.08	2	
	10.02		0.00		0.08	2	
	20.00		-0.01		0.08	2	
	30.00		-0.03		0.08	2	
	39.97		-0.03		0.08	2	
	49.98		-0.02		0.08	2	
	59.97		-0.04		0.08	2	
	70.03		-0.02		0.08	2	
	80.01		-0.01		0.08	2	
	90.00		-0.02		0.08	2	
	100.00		-0.03		0.08	2	
	110.02		-0.03		0.08	2	
	119.99		-0.03		0.08	2	
	130.00		-0.04		0.08	2	
	140.01		-0.04		0.08	2	
	150.01		-0.05		0.08	2	
	159.97		-0.03		0.28	2	
	169.97		-0.03		0.28	2	
	179.95		-0.05		0.28	2	
	189.90		-0.10		0.28	2	
	199.90		-0.10		0.28	2	
	209.88		-0.12		0.28	2	

219.97	-0.03	0.28	2
229.95	-0.05	0.28	2
239.92	-0.08	0.28	2
249.98	-0.02	0.28	2
259.98	-0.02	0.28	2
269.99	-0.01	0.28	2
279.96	-0.04	0.28	2
289.96	-0.04	0.28	2
299.96	-0.04	0.28	2
309.96	-0.04	0.28	2
319.94	-0.06	0.28	2
329.94	-0.06	0.28	2
339.95	-0.05	0.28	2
349.95	-0.05	0.28	2
359.96	-0.04	0.28	2
369.97	-0.03	0.28	2
379.95	-0.05	0.28	2
389.96	-0.04	0.28	2
400.02	0.02	0.28	2
409.96	-0.04	0.28	2
419.97	-0.03	0.28	2
429.96	-0.04	0.28	2
439.95	-0.05	0.28	2
449.96	-0.04	0.28	2
459.95	-0.05	0.28	2
469.95	-0.05	0.28	2
479.92	-0.08	0.28	2
489.95	-0.05	0.28	2
499.91	-0.09	0.28	2
509.97	-0.03	0.28	2
519.91	-0.09	0.28	2
529.96	-0.04	0.28	2
539.97	-0.03	0.28	2
549.99	-0.01	0.28	2
560.01	0.01	0.28	2
570.02	0.02	0.28	2
580.02	0.02	0.28	2
590.00	0.00	0.28	2
600.03	0.03	0.28	2
609.98	-0.02	0.28	2
619.96	-0.04	0.28	2
629.98	-0.02	0.28	2
639.98	-0.02	0.28	2
650.00	0.00	0.28	2
660.03	0.03	0.28	2
670.00	0.00	0.28	2
680.00	0.00	0.28	2

690.04	0.04	0.28	2
700.05	0.05	0.28	2
710.06	0.06	0.28	2
720.02	0.02	0.28	2
729.98	-0.02	0.28	2
739.98	-0.02	0.28	2
750.03	0.03	0.28	2
760.02	0.02	0.28	2
770.00	0.00	0.28	2
779.99	-0.01	0.28	2
790.03	0.03	0.28	2
799.97	-0.03	0.28	2
810.00	0.00	0.28	2
820.00	0.00	0.28	2
830.02	0.02	0.28	2
839.99	-0.01	0.28	2
850.05	0.05	0.28	2
860.05	0.05	0.28	2
870.10	0.10	0.28	2
880.08	0.08	0.28	2
890.07	0.07	0.28	2
900.10	0.10	0.28	2
910.03	0.03	0.28	2
920.02	0.02	0.28	2
930.03	0.03	0.28	2
940.00	0.00	0.28	2
950.03	0.03	0.28	2
960.02	0.02	0.28	2
970.04	0.04	0.28	2
980.05	0.05	0.28	2
990.05	0.05	0.28	2
1000.06	0.06	0.28	2
-0.03	0.00	0.08	2
-0.54	-0.01	0.08	2
-1.02	-0.01	0.08	2
-1.51	-0.01	0.08	2
-2.04	-0.02	0.08	2
-2.52	0.00	0.08	2
-2.99	-0.02	0.08	2
-3.55	-0.01	0.08	2
-3.99	0.00	0.08	2
-4.52	0.01	0.08	2
-5.00	0.00	0.08	2
-5.52	0.00	0.08	2
-6.00	0.00	0.08	2
-6.52	0.00	0.08	2

-7.00	0.00	0.08	2
-7.54	-0.01	0.08	2
-7.99	0.01	0.08	2
-8.56	-0.01	0.08	2
-9.02	0.00	0.08	2
-9.52	0.00	0.08	2
-9.99	0.01	0.08	2
-20.01	-0.02	0.08	2
-30.00	0.00	0.08	2
-40.01	-0.01	0.08	2
-50.00	-0.03	0.08	2
-59.99	-0.01	0.08	2
-69.98	-0.02	0.08	2
-80.03	-0.02	0.08	2
-90.00	0.00	0.08	2
-100.02	-0.04	0.08	2
-109.99	-0.03	0.08	2
-120.03	-0.05	0.08	2
-130.01	-0.04	0.08	2
-139.99	-0.02	0.08	2
-150.01	-0.03	0.08	2
-160.08	-0.08	0.28	2
-170.03	-0.03	0.28	2
-180.10	-0.10	0.28	2
-190.04	-0.04	0.28	2
-200.01	-0.01	0.28	2
-210.01	-0.01	0.28	2
-219.99	0.01	0.28	2
-230.03	-0.03	0.28	2
-240.05	-0.05	0.28	2
-250.03	-0.03	0.28	2
-260.08	-0.08	0.28	2
-270.05	-0.05	0.28	2
-280.08	-0.08	0.28	2
-290.05	-0.05	0.28	2
-300.01	-0.01	0.28	2
-310.00	0.00	0.28	2
-319.99	0.01	0.28	2
-329.97	0.03	0.28	2
-340.00	0.00	0.28	2
-350.03	-0.03	0.28	2
-360.04	-0.04	0.28	2
-370.07	-0.07	0.28	2
-380.08	-0.08	0.28	2
-390.09	-0.09	0.28	2
-400.11	-0.11	0.28	2
-410.06	-0.06	0.28	2

-420.06	-0.06	0.28	2
-430.04	-0.04	0.28	2
-440.01	-0.01	0.28	2
-450.07	-0.07	0.28	2
-460.08	-0.08	0.28	2
-470.03	-0.03	0.28	2
-480.02	-0.02	0.28	2
-489.99	0.01	0.28	2
-500.01	-0.01	0.28	2
-510.04	-0.04	0.28	2
-520.07	-0.07	0.28	2
-530.03	-0.03	0.28	2
-540.04	-0.04	0.28	2
-550.06	-0.06	0.28	2
-560.06	-0.06	0.28	2
-570.07	-0.07	0.28	2
-580.07	-0.07	0.28	2
-590.05	-0.05	0.28	2
-600.06	-0.06	0.28	2
-610.02	-0.02	0.28	2
-620.03	-0.03	0.28	2
-630.01	-0.01	0.28	2
-640.04	-0.04	0.28	2
-650.04	-0.04	0.28	2
-660.09	-0.09	0.28	2
-670.03	-0.03	0.28	2
-680.07	-0.07	0.28	2
-690.06	-0.06	0.28	2
-700.12	-0.12	0.28	2
-710.06	-0.06	0.28	2
-720.04	-0.04	0.28	2
-730.10	-0.10	0.28	2
-740.04	-0.04	0.28	2
-750.08	-0.08	0.28	2
-760.05	-0.05	0.28	2
-770.04	-0.04	0.28	2
-780.03	-0.03	0.28	2
-789.99	0.01	0.28	2
-800.02	-0.02	0.28	2
-810.04	-0.04	0.28	2
-820.08	-0.08	0.28	2
-830.03	-0.03	0.28	2
-840.05	-0.05	0.28	2
-850.06	-0.06	0.28	2
-860.10	-0.10	0.28	2
-870.08	-0.08	0.28	2
-880.09	-0.09	0.28	2

-890.09	-0.09	0.28	2
-900.05	-0.05	0.28	2
-910.02	-0.02	0.28	2
-920.02	-0.02	0.28	2
-930.02	-0.02	0.28	2
-940.00	0.00	0.28	2
-950.02	-0.02	0.28	2
-960.07	-0.07	0.28	2
-970.06	-0.06	0.28	2
-980.08	-0.08	0.28	2
-990.06	-0.06	0.28	2
-1000.09	-0.09	0.28	2