Session 7

System Calibration

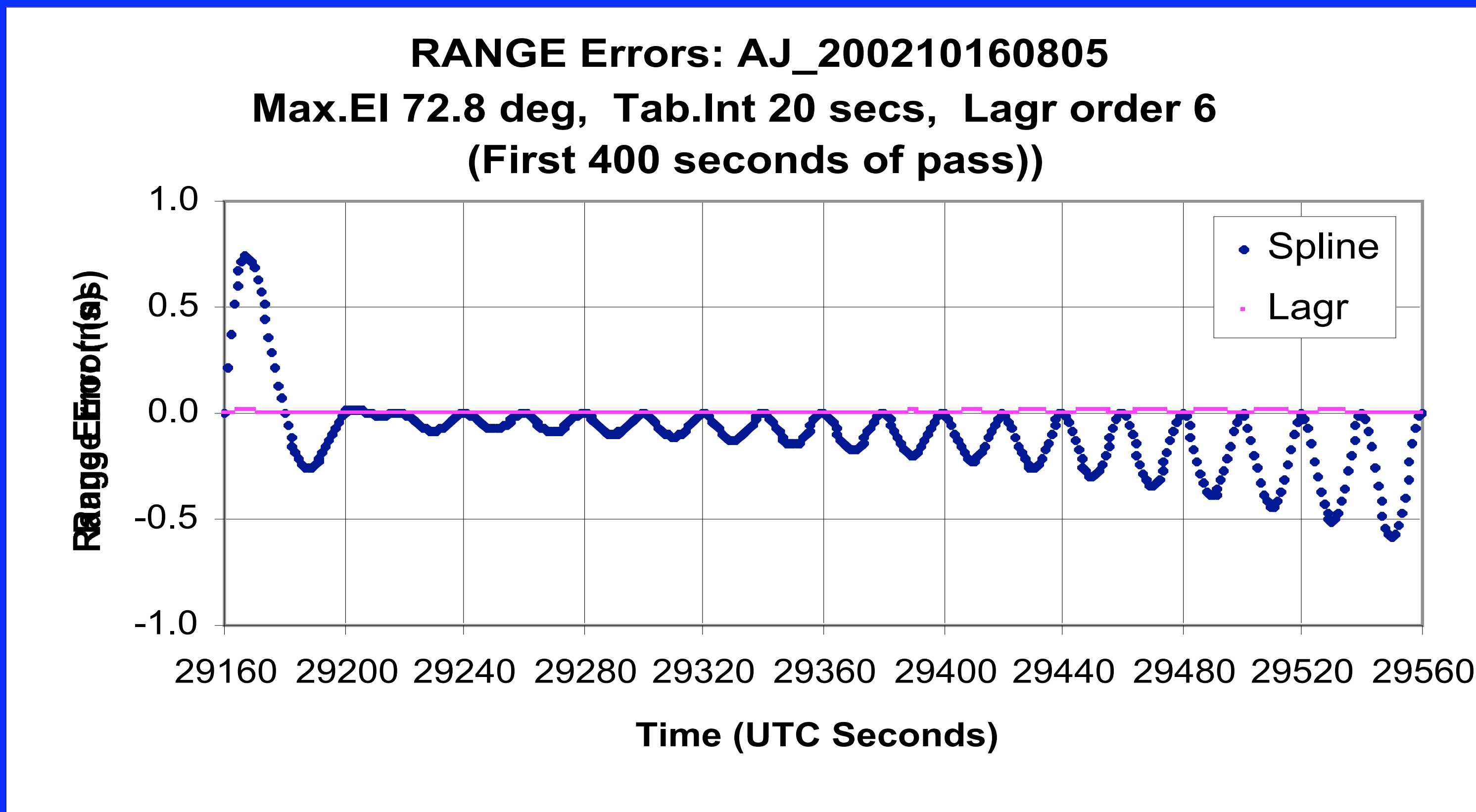
Ulrich Schreiber, Ivan Prochazka

Laser System Calibration

Ulrich Schreiber

Ivan Prochazka

Preamble



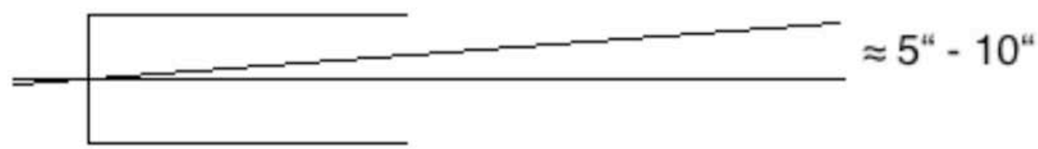
Warm regards from John Luck: The interpolation errors of the IRVs are propergating to the NP if things are not handled carefully

I. Geometrical Error Sources

Geometrical Error Sources

- Target structure (mechanical)
- Beam path through telescope (stability)

Example



Field of view is limiting the measurements to near axis ranges only

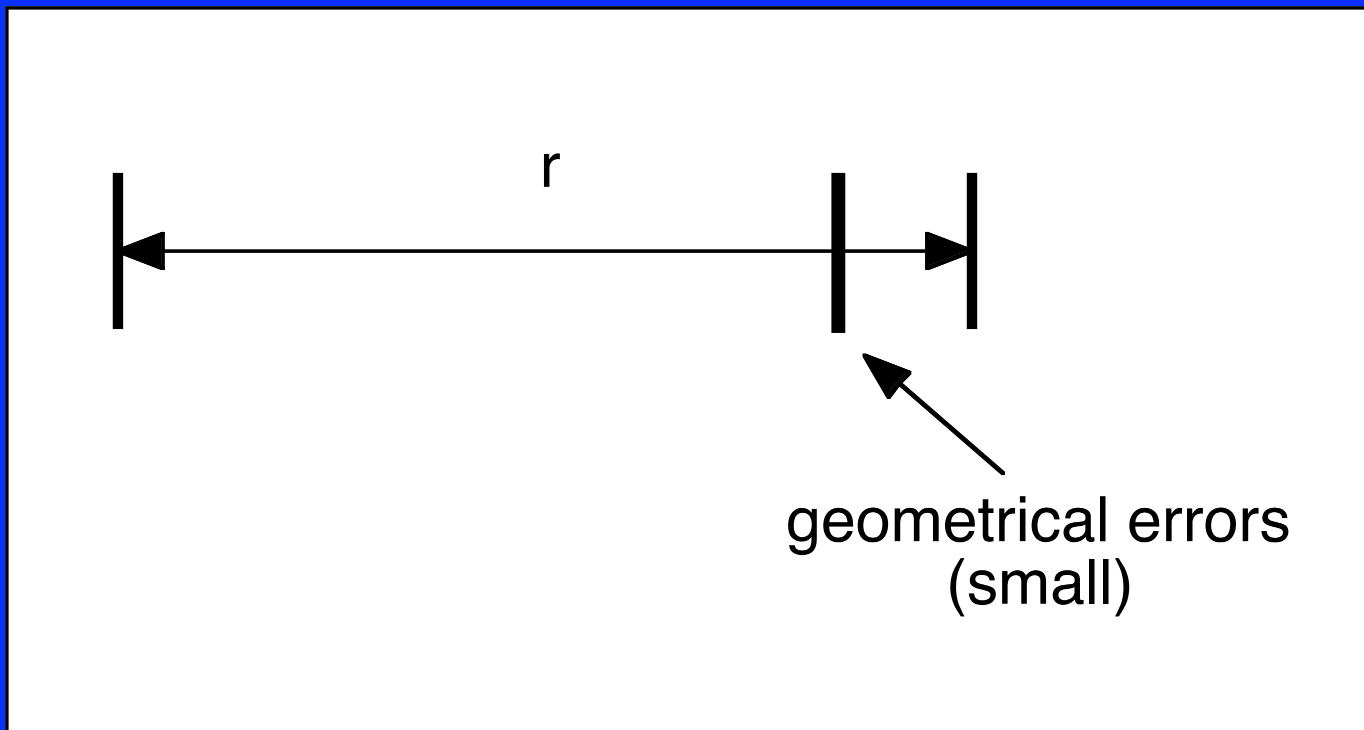
For a target 6m away from the focus it causes a sub-μm range offset

Conclusion

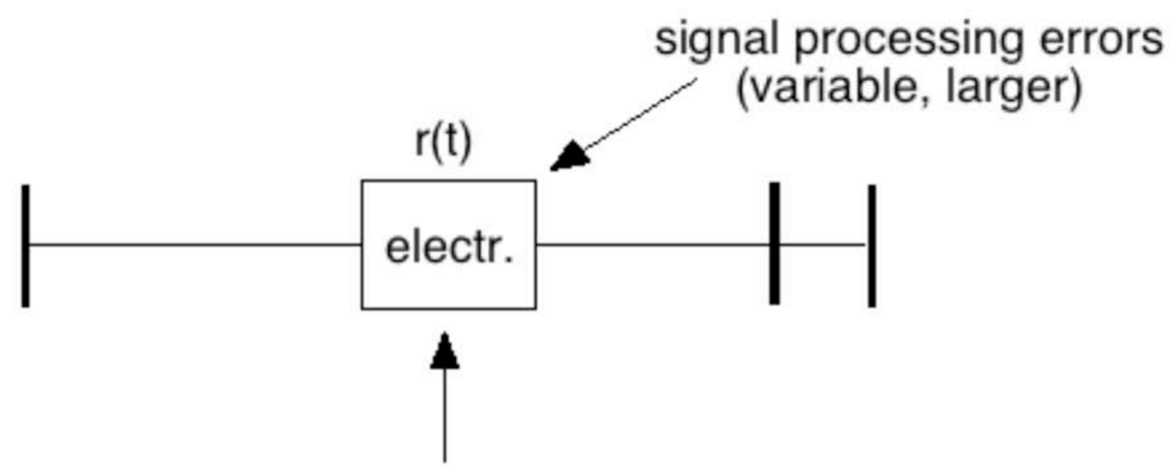
- These errors are typically small

II. Electronical Error Sources

Calibration Basics



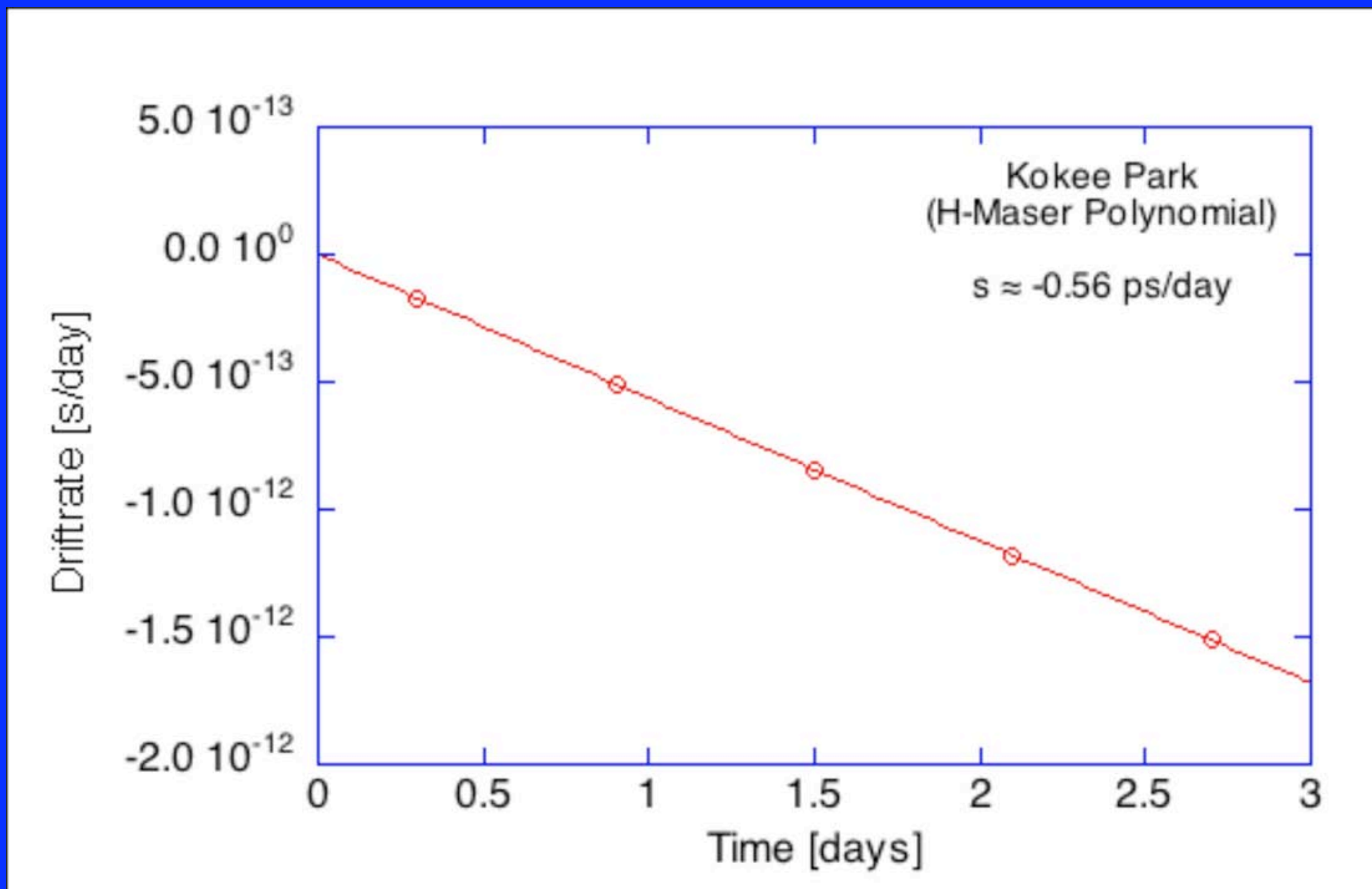
... as soon as we try to measure things they become more complicated



Discriminator Contribution to timing: ≈ 10 ns

0.1% stability **(a tall demand)** corresponds to 10 ps

H-Maser Correction in VLBI



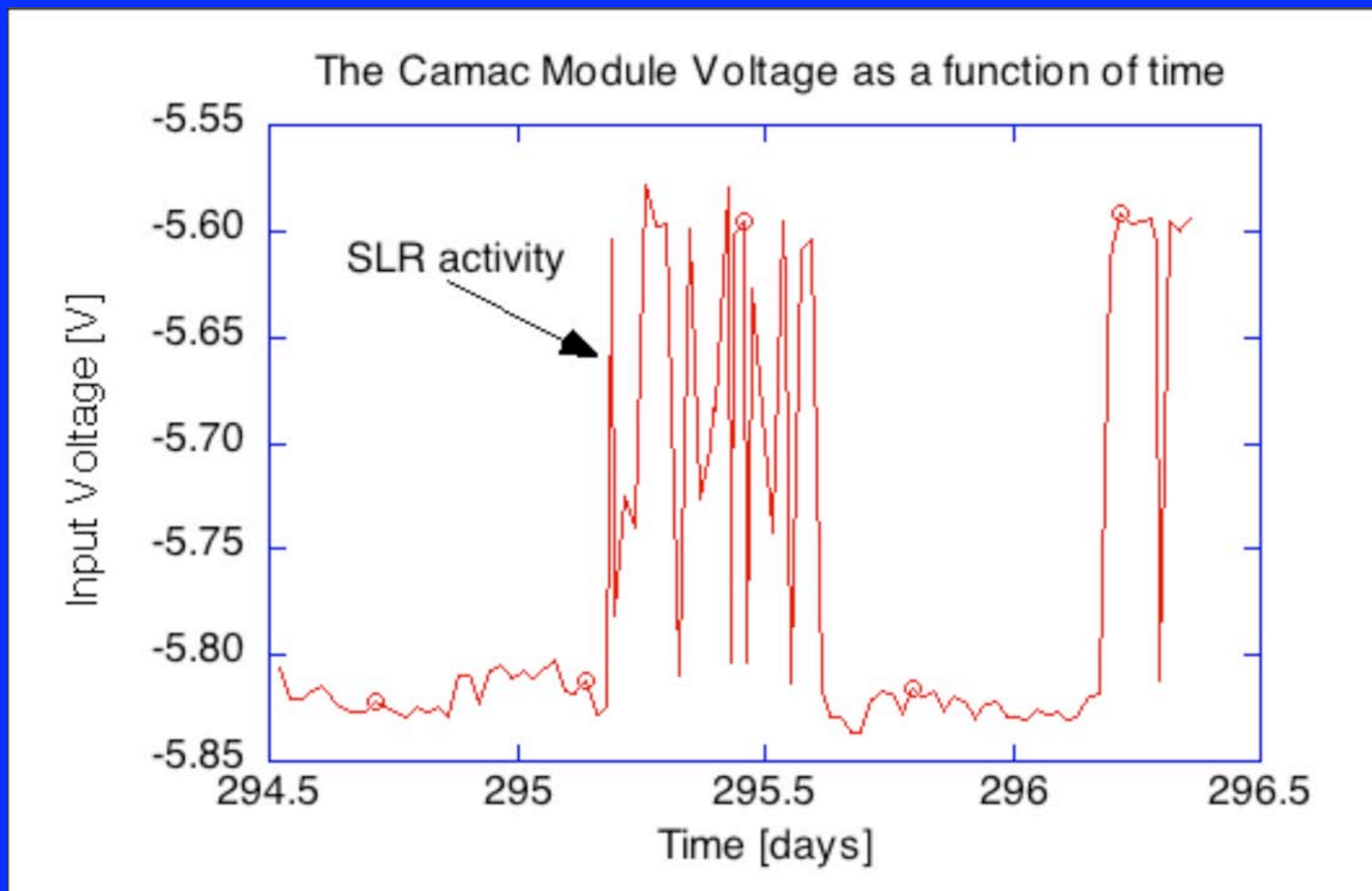
Interpretation

The intrinsic high clock accuracy is not accessible by the electronic hardware

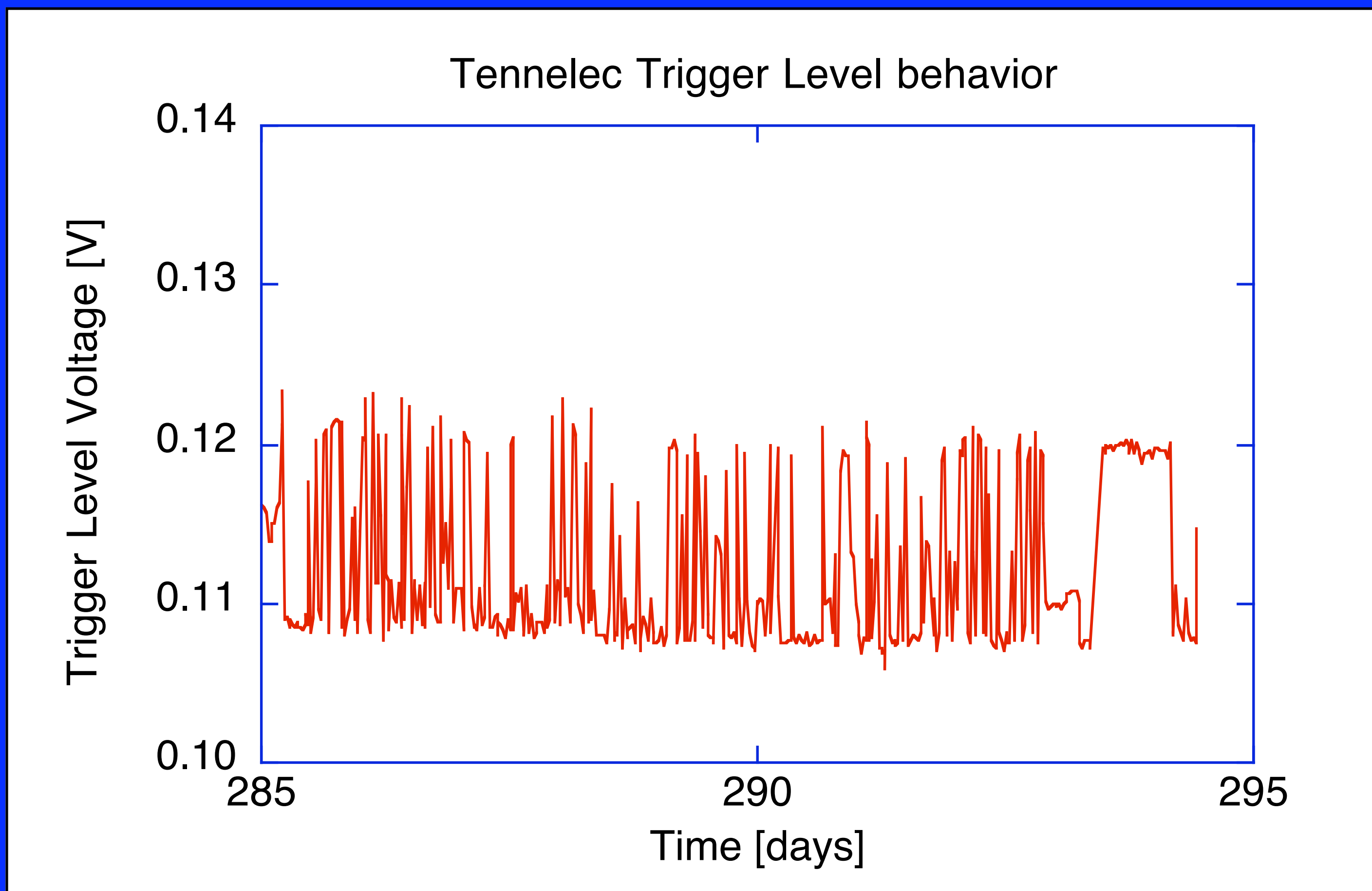
Identification of Issues

- Electronic circuits cause time varying insertion delays
- Delays show temperature dependence
- Delays show bandwidth dependence
- Delays show impedance matching issues
- Delays show signal level related issues (supply voltage stability, ground reference)

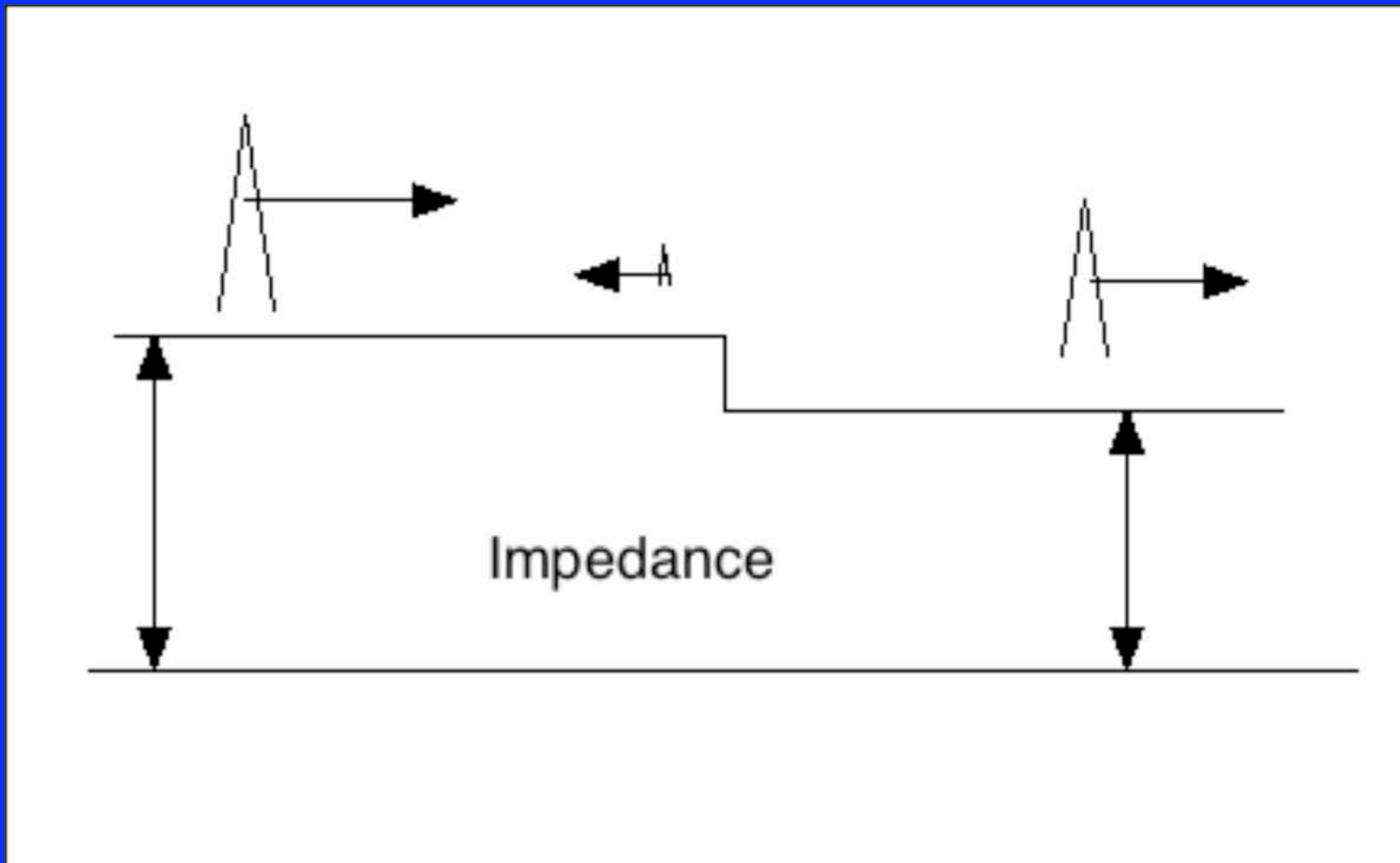
Power Level Stability



Trigger Threshold Stability



Impedance matching



III. Optical Error Sources

Optical Error Sources

- Wavefront distortions
- Higher order spatial laser modes
- Laser backreflections and saturation effects (shared aperture)

IV. Solutions

System Design Symmetry

- use the same electronic components as much as possible or at least twin chips
- carefully adjust signal levels and pulse shapes for both calibration and ranging
- avoid timewalk

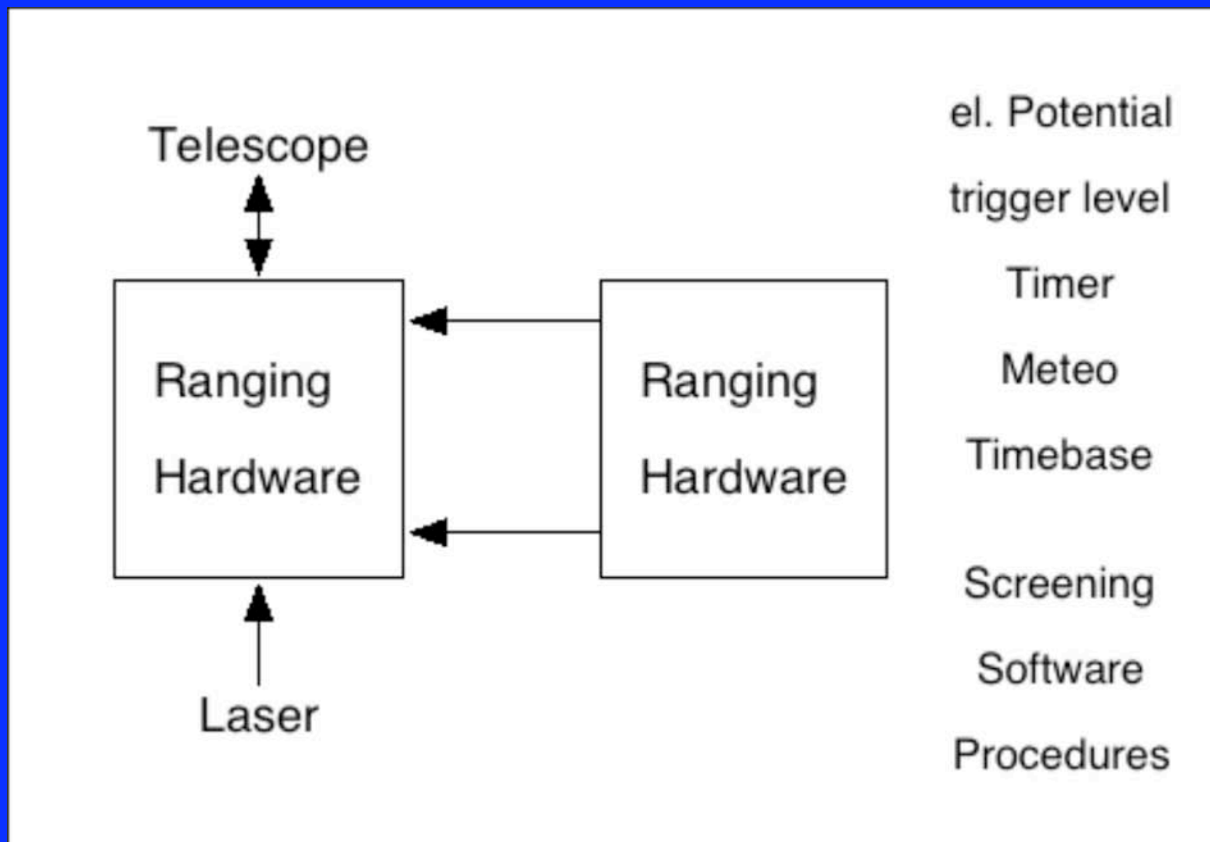
Redundancy!!!

- Co-Locations were used in the past (costly)
- Traveling barometer campaigns adjust the meteorology issues
- Several (electronic) subsystems are operated in parallel
- Counter Cluster (Graz) was the first step
- Portable Calibration Standard (flexible, cheap)

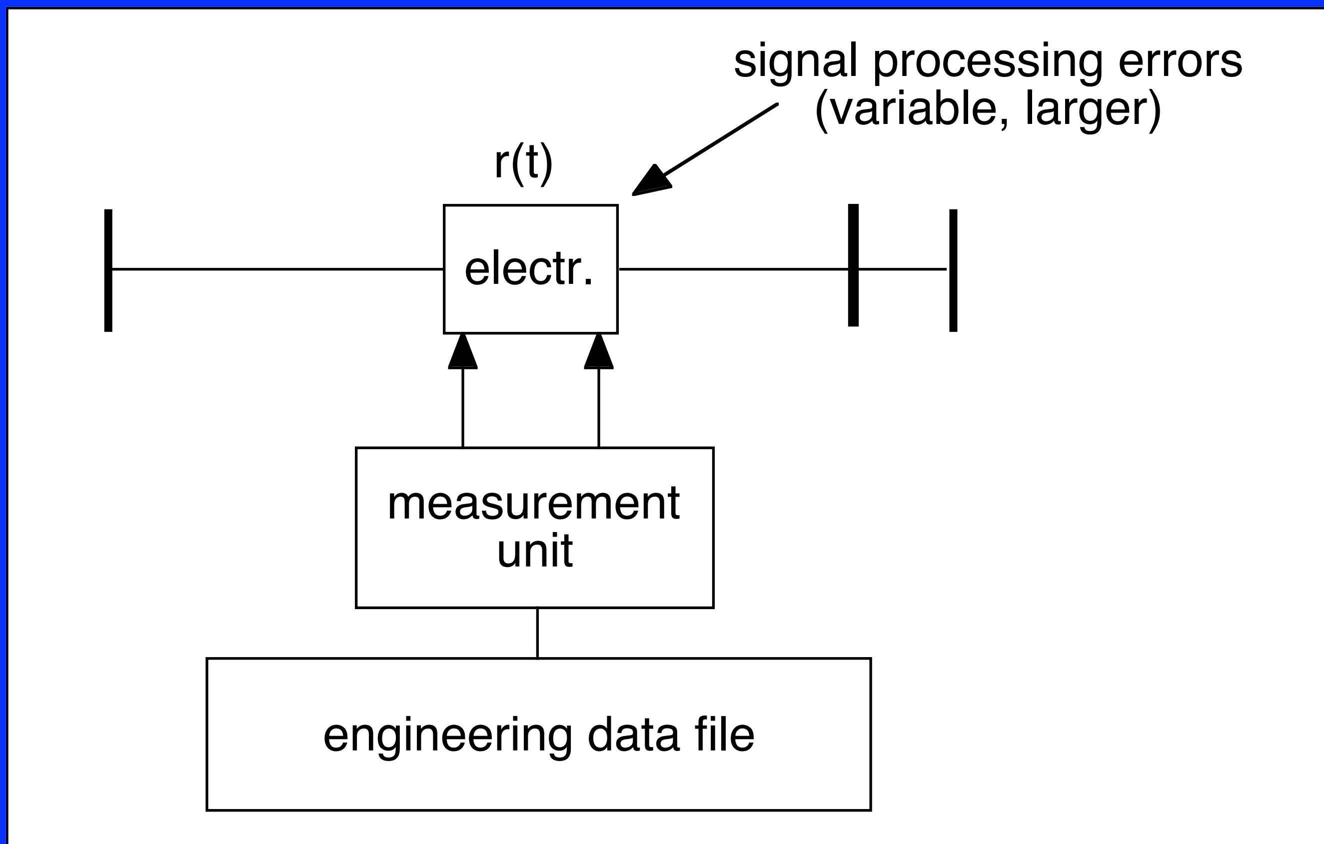
Access to a number of errors

- epoch and time interval timing
- time and frequency reference
- data aquisition, filtering and processing
- calibration scheme and ground survey
- operational procedures (habits)
- rf-interference, ground reference

Basic Concept



Inter-System Redundancy



Satellite Laser Ranging Machine Bias Reduction Procedures

Toward Millimeter Accuracy
Vademecum

Karel Hamal, Ivan Prochazka
Czech Technical University, Prague, Czech Republic

Goals

- SLR systems bias reduction

- inter-comparison and standardization of SLR systems

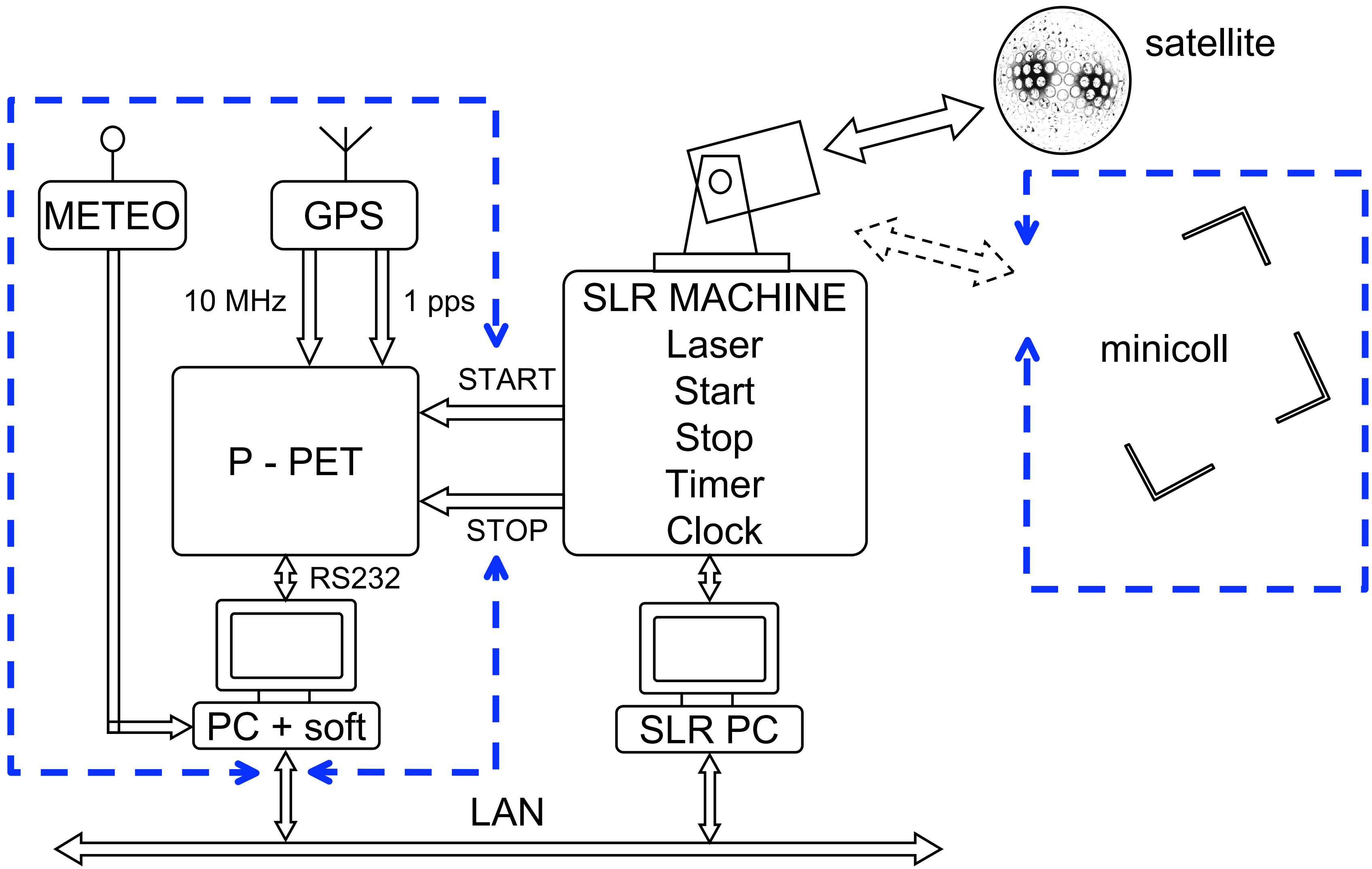
- Portable Calibration Standard for Satellite Laser Ranging machine diagnostics
  identification of error sources due to :
    - epoch and time interval timing
    - epoch and frequency reference
    - data acquisition, filtering and processing
    - calibration scheme and ground survey
    - operational procedures
    - radio frequency interference
    - other sources

Portable Calibration Standard Philosophy

- high degree of **redundancy**
- based on top **quality and certified** hardware
- **independent** on SLR under test
  - signal processing and cabling
  - grounding, power line, RF shielding
  - timing (time interval, epoch)
  - calibration targets and ground survey
  - data acquisition and data processing
  - staff
- operated **in parallel to existing SLR**
- **easy to re-locate** (personal luggage)

SLR Machine Bias Reduction Procedure

PORTABLE CALIBRATION STANDARD

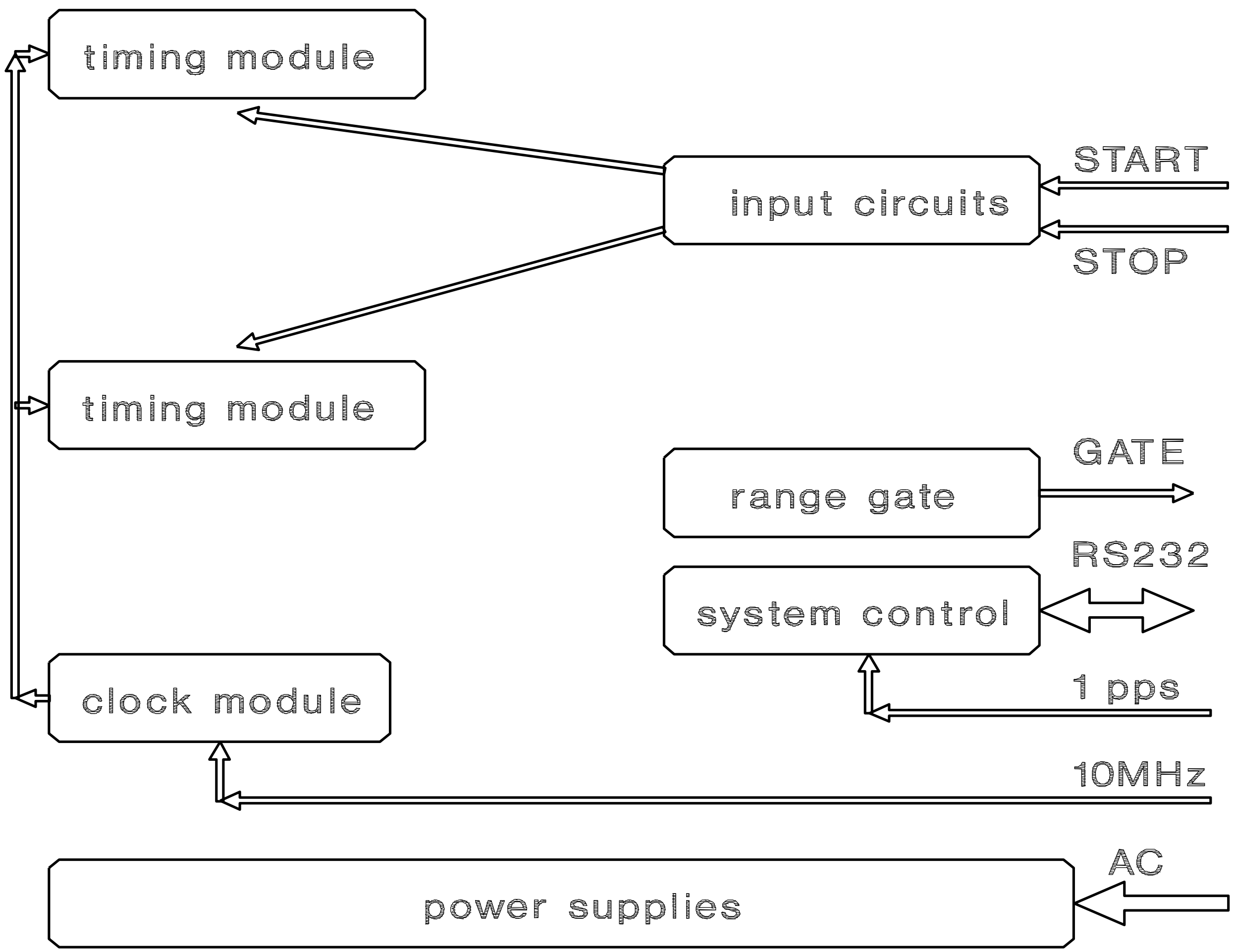


K. Hamal, I.Prochazka, Prague, May 2003

SLR Machine Bias Reduction Procedure

Portable - Picosecond Event Timer P-PET

BLOCK SCHEME



K.Hamal,I.Prochazka, EurOpto, London 1997

K. Hamal, I.Prochazka, Prague, May 2003

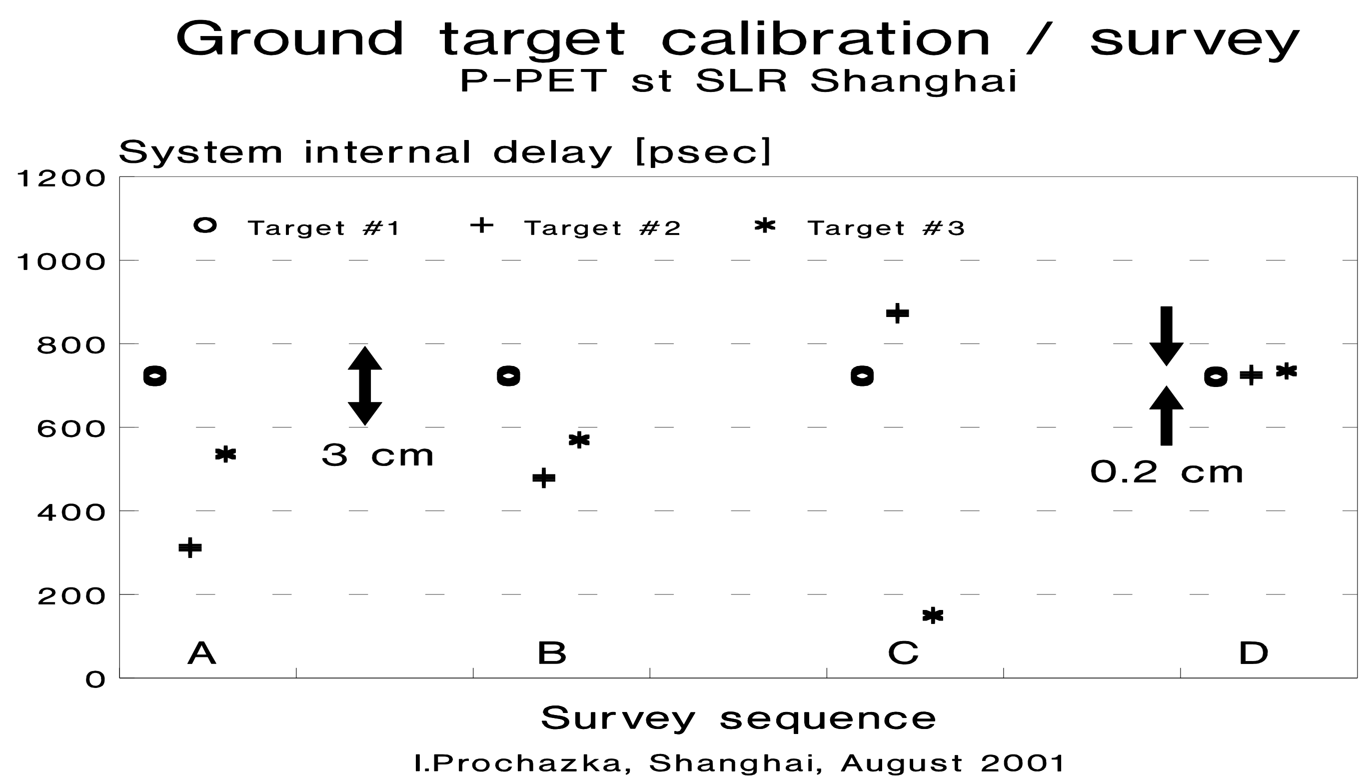
SLR Machine Bias Reduction Procedure

Pico Event Timer
Portable Calibration Standard

K. Hamal, I.Prochazka, Prague, May 2003

Ground Target Calibration

- “mini-coll” concept,
- use minimum 3 ground targets,
- distances < 100 meters,
  (difficulties to model horizontal atm. correction > 100m)
- different azimuths,
- “zero paralax” hollow retro reflectors (2D)
- targets reference points surveyed down to 1 mm accuracy 3 D
- the system internal delays evaluated by calibration ranging to different targets indicate the calibration accuracy and the calibration value confidence.
- the survey and calibration procedure has to be tuned until the internal delay consistency is on a mm level



The 3 cal. targets /hollow 2D retros/ have been re-surveyed and the calibration procedure tuned until the the system internal delay value consistency of 2 mm has been achieved.

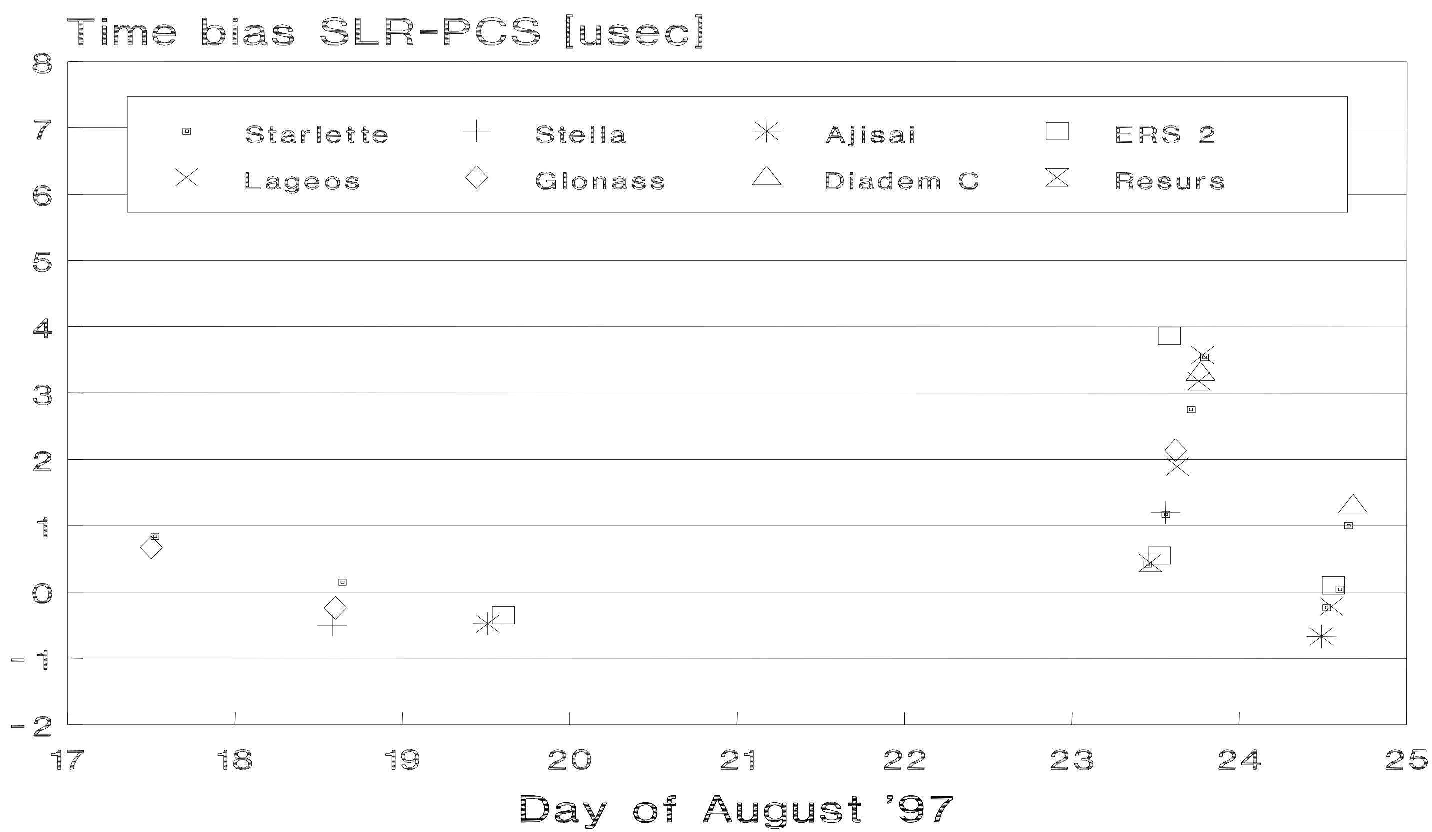
The 2mm level was a limit for the system at that time.

SLR Time Bias identification

- The PCS is operated in parallel to the SLR system under test,
- the corresponding pairs of SLR results are identified,
- the time bias is evaluated as a difference of corresponding epochs on a shot by shot basis,
- the time bias per pass is evaluated as a an arithmetic average,

SLR Machine Bias Reduction Procedure

Time Bias , PCS in Changchun



The SLR used a wrong frequency source (the slope),
the SLR time base has been synchronized only once per day
the time bias is target independent

K. Hamal, I.Prochazka, Prague, May 2003

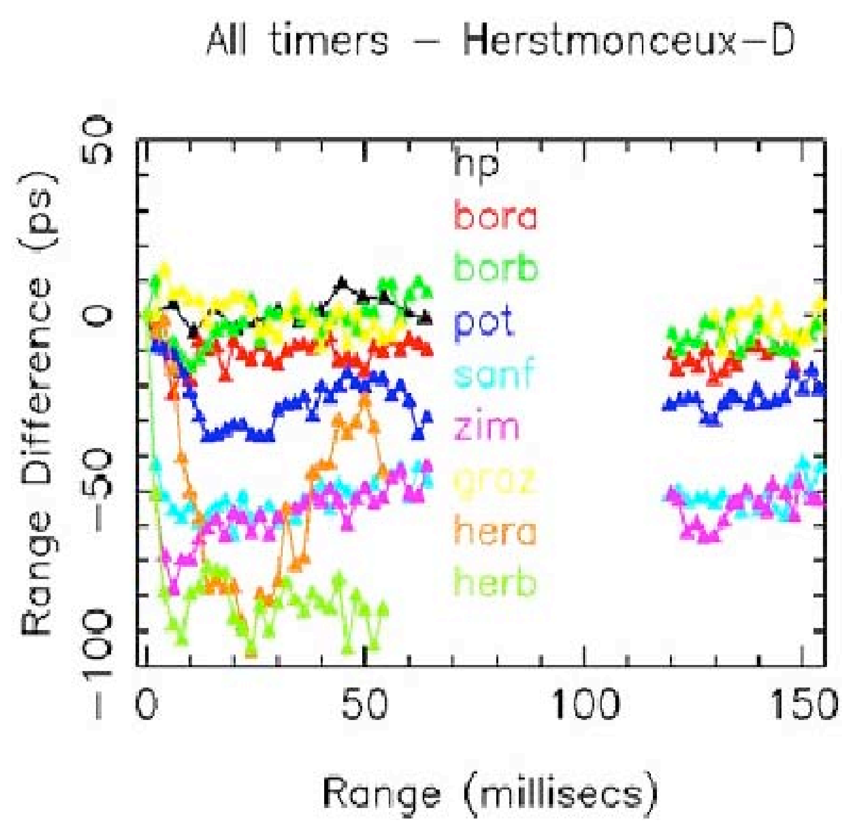
SLR Range Bias Identification

- The PCS is operated in parallel to the SLR system under test,
- the corresponding pairs of SLR results are identified,
- the range bias is evaluated as a difference of corresponding range readings on a shot by shot basis,
- on a shot by shot basis, the range bias versus range identifies the time of flight linearity
- the range bias per pass is evaluated as a an arithmetic average, it characterizes the range bias of the SLR system vers. PCS

RANGING COUNTERS COMPARISON TO P-PET

P. Gibs, Herstmonceux, 2002

- Shown here is a summary plot of all the devices.

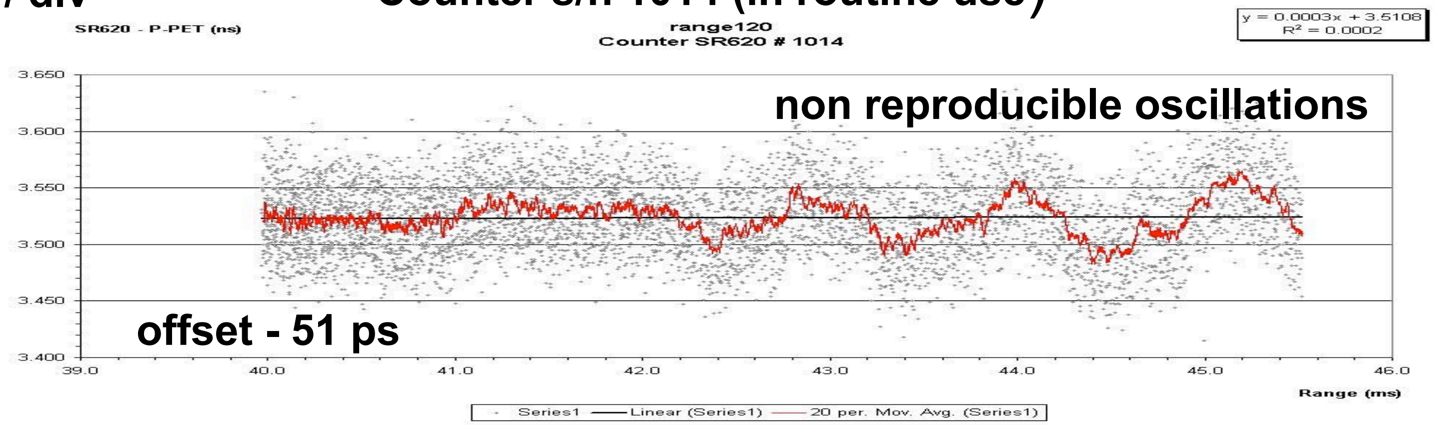


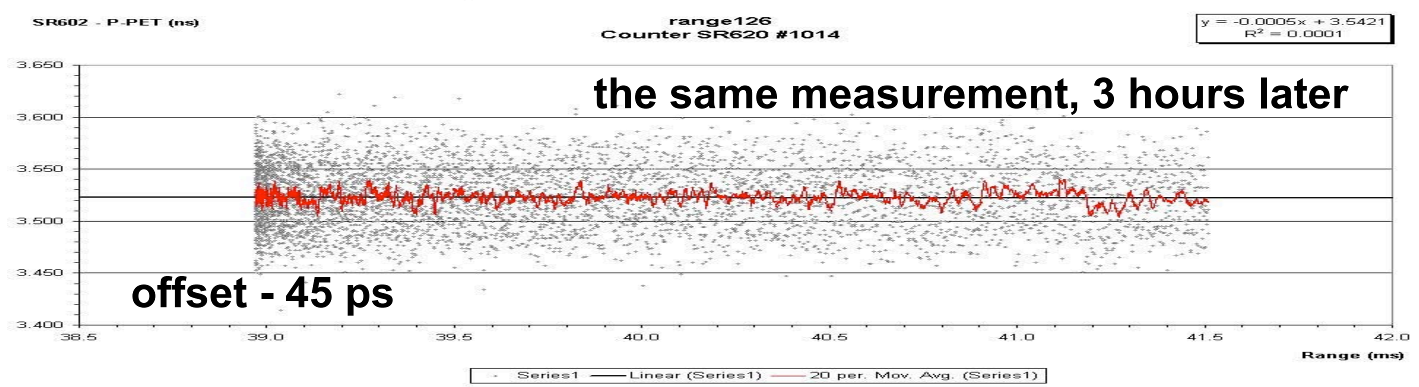
SLR Machine Bias Reduction Procedure

SR620 / P-PET Counter Linearity

Potsdam, 2001, LAGEOS pass

50 ps / div **Counter s/n 1014 (in routine use)**





L. Grunwald, R.Neubert, H.Fischer, H.Pino, Potsdam, 2001

K. Hamal, I.Prochazka, Prague, May 2003

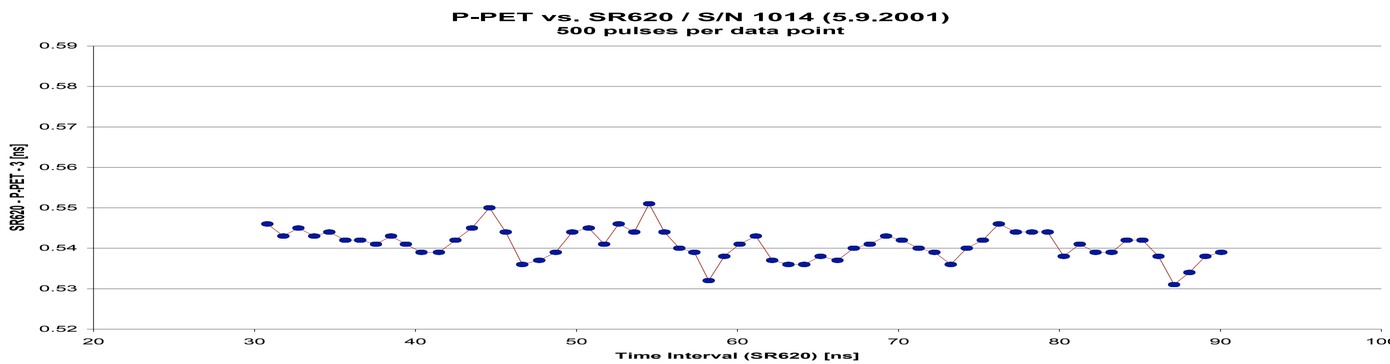
SLR Machine Bias Reduction Procedure

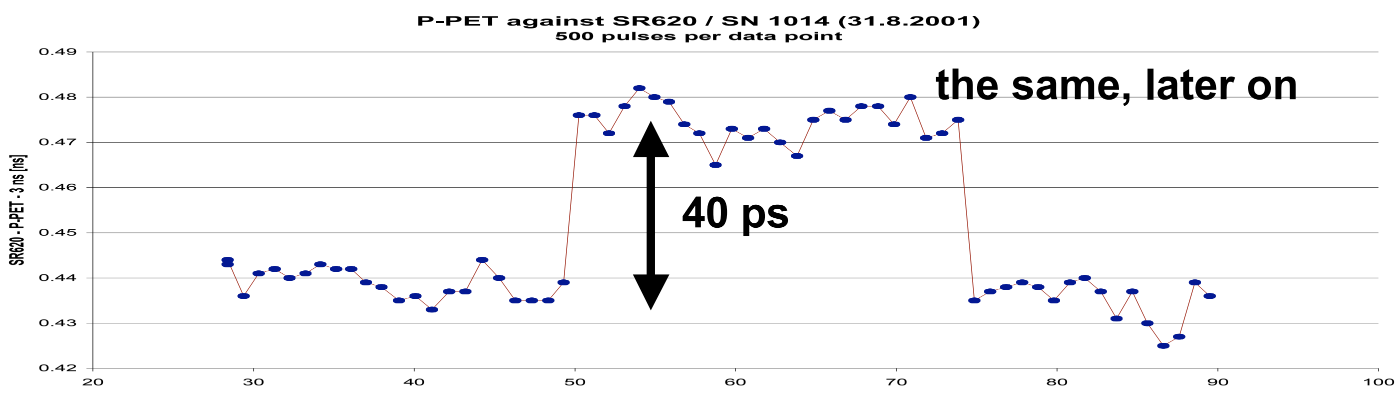
SR620 / P-PET Counter Linearity

Potsdam, 2001, Short times

Counter s/n 1014 (in routine use)

10 ps / div





0 - 100 nsec

L. Grunwald, R.Neubert, H.Fischer, H.Pino, Potsdam, 2001

K. Hamal, I.Prochazka, Prague, May 2003

SLR Machine Bias Reduction Procedure

Range and Time Biases,Shanghai 2001

Satellite	T rms(mm)	SLR rms(mm)	Time bias(us)	Rng. bias(ns)Sta

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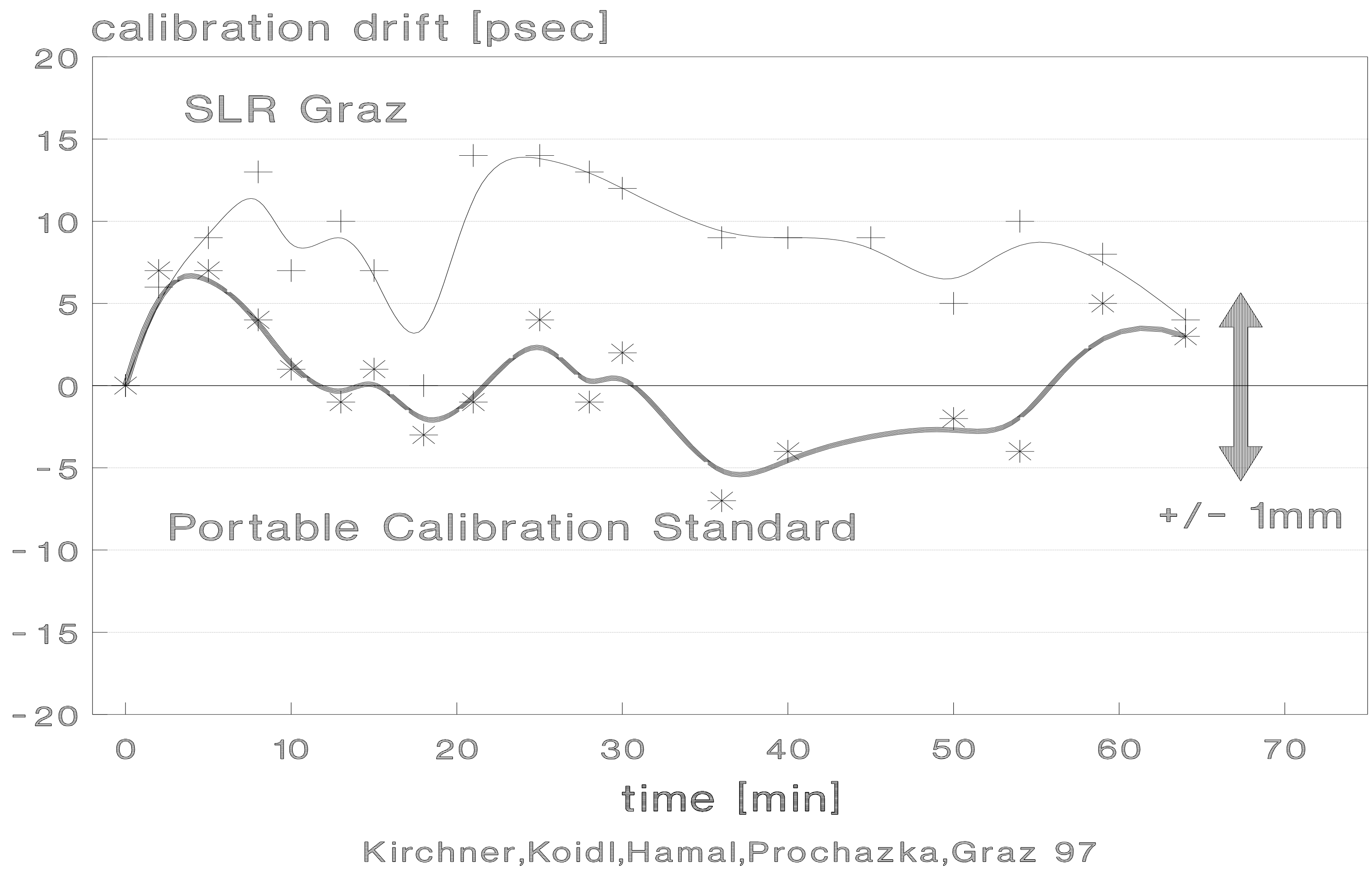
Time and Temperature Stability, SLR Graz

- The PCS was operated in parallel to the SLR system under test,
- the temporal and temperature drifts of the PCS are below 1 ps,
- the ground target calibration was repeatedly completed within one hour,
- the thick curve corresponds to the stability (+/- 1mm) of the SLR ranging chain excluding the time of flight instrument (counter cluster),
- the thin curve corresponds to the entire SLR system temporal stability (+/- 2 mm at that configuration)

P-PET in Graz, Calibration Stability



SLR Precision Increase

- operated **in parallel to existing SLR**
- high degree of **redundancy**
- **independent** on SLR under test
  - signal processing and cabling
  - grounding, power line, RF shielding
  - timing (time interval, epoch)
  - calibration targets and ground survey
  - data acquisition and data processing
  - operators and habits
- high quality instruments (P-PET, Meteo, Epoch & Freq.)
  - => high precision SLR data acquired on the PCS
  - => identification of “problem areas” and improvement os SLR

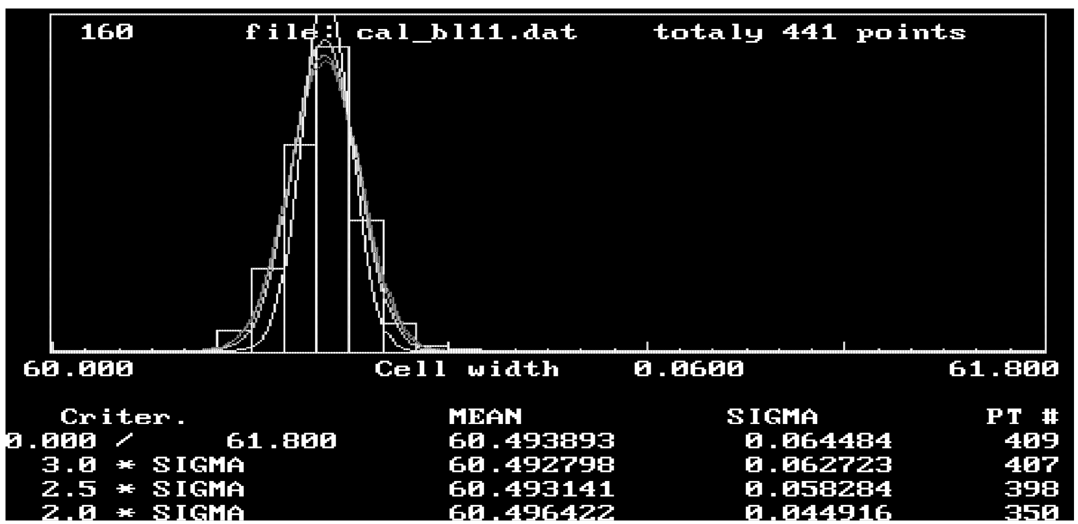
SLR Machine Bias Reduction Procedure

Zimmerwald, 24hour Mission,May 27-28,1998
Two wavelength ranging

Original station setup 150 psec

After system re-cabling and detectors tuning

SLR system	120 psec
P-PET timing	76 psec @ red
	58 psec @ blue



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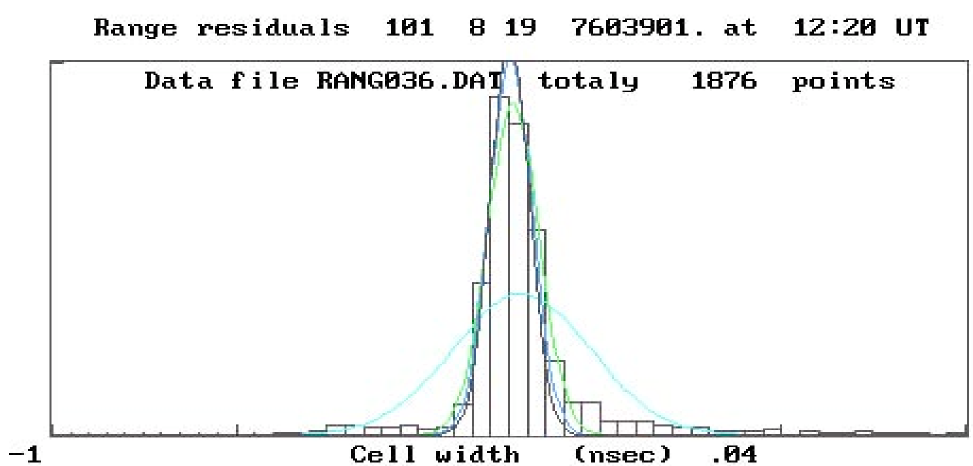
Shanghai SLR, Lageos, Aug. 19,2001

SLR timing 13.5 mm RMS
PCS-PET timing 7.0 mm RMS



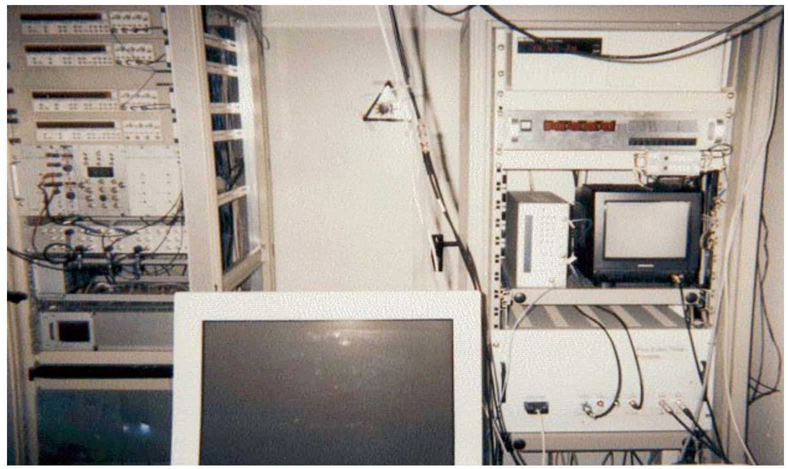
	Criter.		MEAN	SIGMA	PT #
Limits	-1.000 /	1.000	0.027430	0.151741	1315
	3 * SIGMA		0.007832	0.056696	1153
	2.5*SIGMA		0.002507	0.047051	1093
	2.2*SIGMA		0.000586	0.042044	1041

SLR Machine Bias Reduction Procedure

PCS-PET Mission, TIGO, 1998

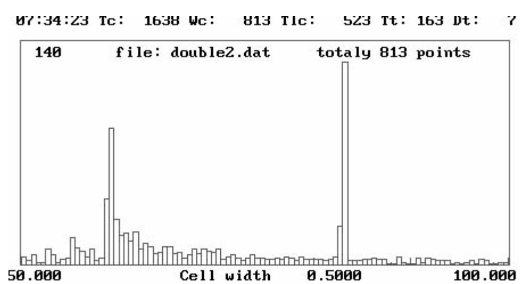
Two wavelength ranging

4 x SR620



P-PET

SR620 timing	infrared	120 psec
	blue	95 psec
P-PET timing	infrared	75 psec
	blue	45 psec



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PCS Capabilities - Comparison

atic error sourcecollocationPortable Calibration Standardfrequency and epochyesyesmount e

Conclusion

- Portable Calibration Standard based on a Pico Event Timer is a powerful tool to identify systematic error sources in the SLR "ranging machine" on the mm scale

- the entire system is compact, easy to transport fast to install and user friendly to operate,
  the calibration mission can be accomplished within one week time slot,

- P-PET mission to SLR sites did trigger several projects
  - WLRS (1998), TIGO(1999), Graz (2000) timing systems upgrade
  - European millimeter SLR joint activity (2002),
  - Herstmonceux Workshop (2002)

NASA SLR System Calibration Techniques

External Calibrations to Established, Stable and Formally Surveyed Ground Targets

- 90 minute maximum cycle time per tracking scenario – *(Offsetting potential diurnal effect and systematic drifts)*
- Calibration Target Ranges < 300M
- Calibration Pier design – concrete and metal reinforced for long term stability
- Optically calibrated corner cubes – optical transit path measured & accounted for in calibration range
- Pre & Post Calibrations to operational ground target ~ 1000 Shots
- Receive amplitudes maintained within dynamic range of the Constant Fraction Discriminator for Pre and Post Calibration AND operational satellite tracking
- Ground Test Calibrations to multiple targets also used as diagnostic tool

International Laser Ranging Service

NASA SLR System Calibration

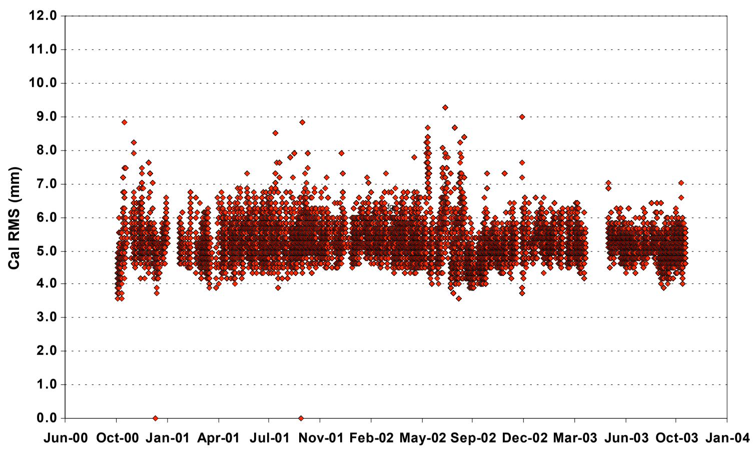
Station	Target	Azimuth	Elevation Deg.	Range m
Monument Peak USA	**A**	**103.504**	**4.093**	**187.003**
	B	177.427	-1.089	1955.268
	C	198.854	-0.433	107.371
Yarragadee Australia	A	16.856	0.176	3116.742
	B	**14.778**	**-1.154**	**150.425**
	C	12.336	-1.376	100.419
Hartebeesthoek South Africa	A	3.76	0.467	150.246
	B	48.457	2.218	96.882
	C	126.752	1.86	100.642
	D	229.49	-0.86	131.15
	E	**278.626**	**-2.344**	**198.664**
	I	104.547	3.048	141.055
Greenbelt USA	A	65.189	-3.141	106.673
	B	95.515	-1.737	174.833
	C	**105.165**	**-1.671**	**170.526**

Station	Target	Azimuth	Elevation Deg.	Range m
Tahiti French Polynesia	A	42.845	6.55	171.262
	B	**138.854**	**4.424**	**263.234**
	C	332.272	-1.526	122.695
Arequipa Peru	A	10.23	-1.81	105.949
	B	**48.167**	**-1.265**	**105.978**
	C	132.063	0.818	423.29
	D	205.412	-3.029	51.438
	E	46.928	5.073	870
Mt. Haleakala Hawaii	**A**	**116.718**	**-8.732**	**39.129**
	B	114.999	-8.709	1109.635
	C	85.511	-1.316	602.099
	D	116.718	-8.732	39.129

** McDonald, USA – Performs internal Calibrations*

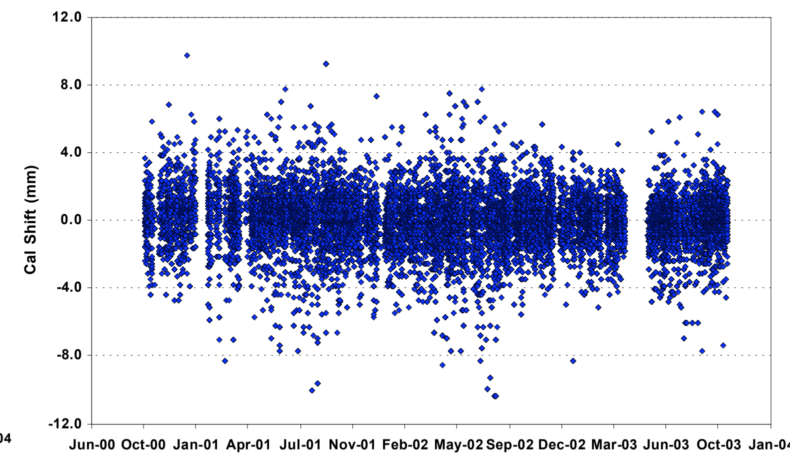
= Operational Target

Monument Peak Calibration RMS



Nominal Combined Cal. RMS 4.0mm – 6.0mm

Monument Peak Calibration Shifts



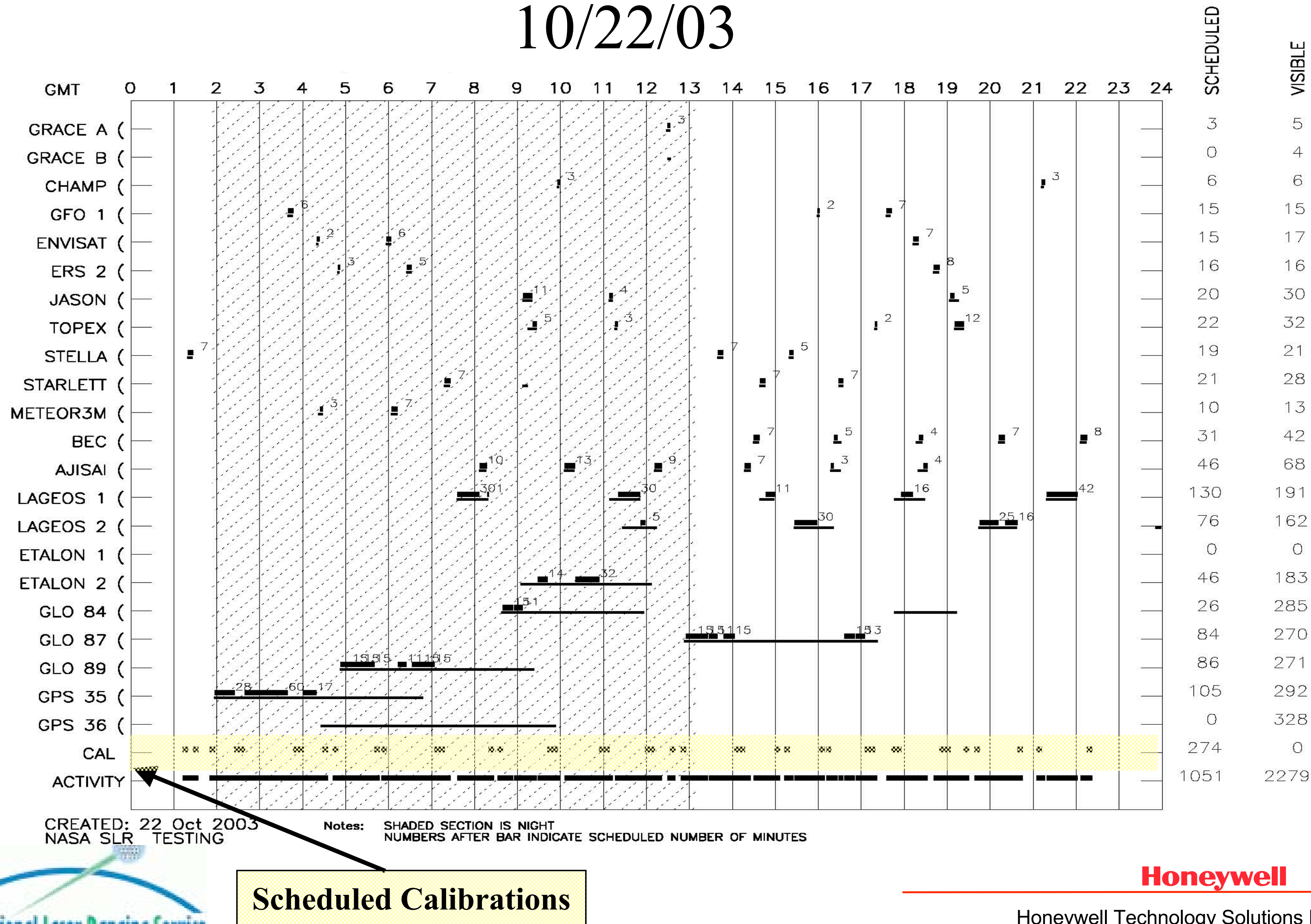
Nominal Pre to Post Calibration Shift <4.0mm

International Laser Ranging Service

Honeywell

Honeywell Technology Solutions Inc

Monument Peak (Moblas-4) Schedule for 10/22/03



International Laser Ranging Service

Honeywell

Honeywell Technology Solutions Inc

NASA SLR Meteorological Measurement Sensor (MET3) Calibration Technique

Pressure, Temperature, and Humidity Measurement

- Two Year Calibration Cycle:
  - ✓Station's unit replaced with a manufacturer calibrated sensor package
  - ✓Pre/Post installation calibration reports examined for anomalies
  - ✓Calibration reports will be maintained in a database
  - ✓NIST trace-ability maintained (Pressure Sensor)
- One Year Preventive Maintenance Cycle

Pressure – Accuracy: ± 0.08 mBar, Stability: < 0.1 mBar per year

Temperature – Accuracy: □ 0.5 Degree C, Stability: Better than 0.1 Degree C

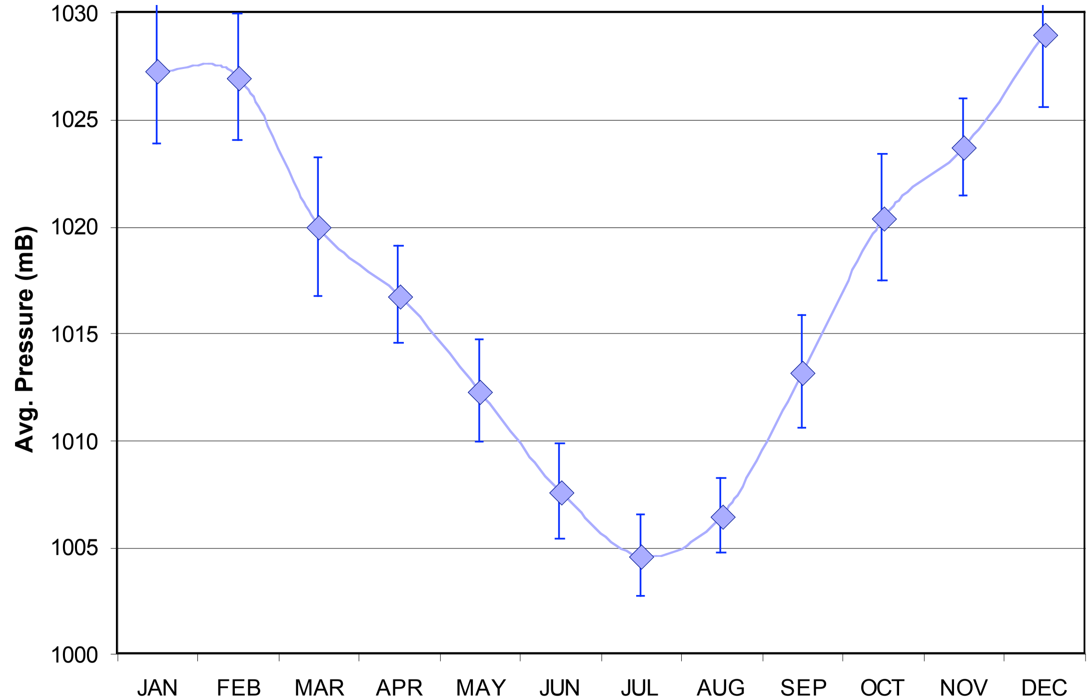
Relative Humidity – Accuracy: ± 2% RH (@ 25 Degree C), Stability: Better than 1% per year

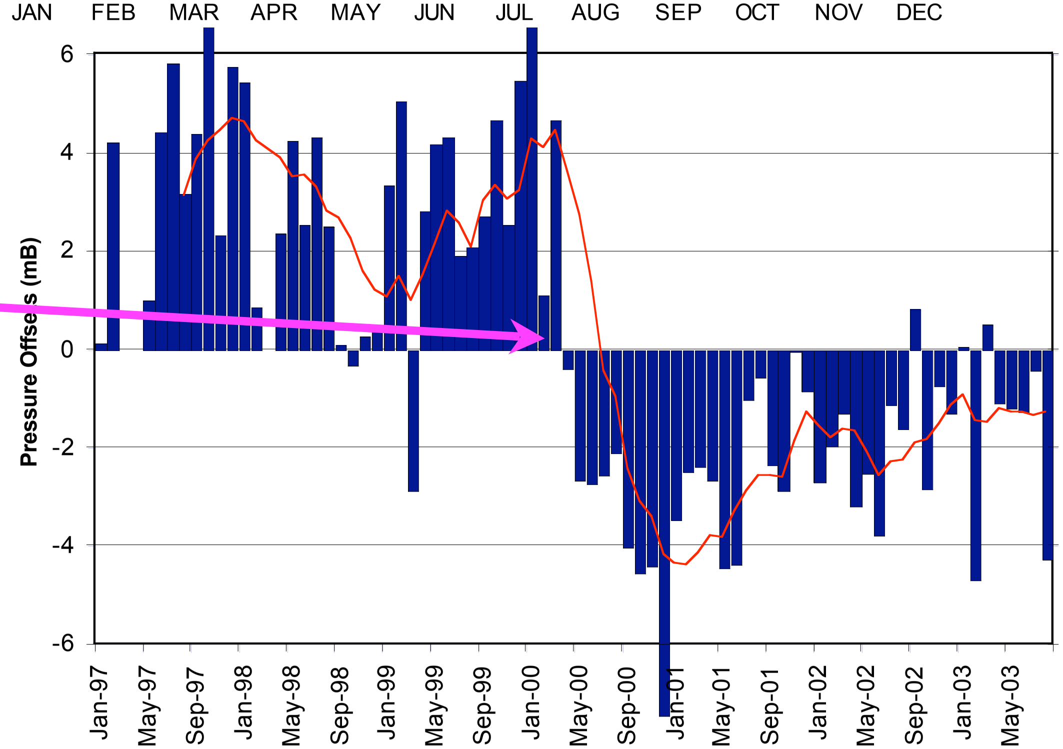
Future Improvements – MET3A, better performing pressure transducer, higher accuracy temperature readings, faster humidity saturation recovery time

International Laser Ranging Service

Honeywell

Honeywell Technology Solutions Inc





The effect of a barometer change or re-calibration