NASA NGSLR Precise (~1ns) Transmit Epoch Timing to On-station Time Reference for LRO Transponder Support

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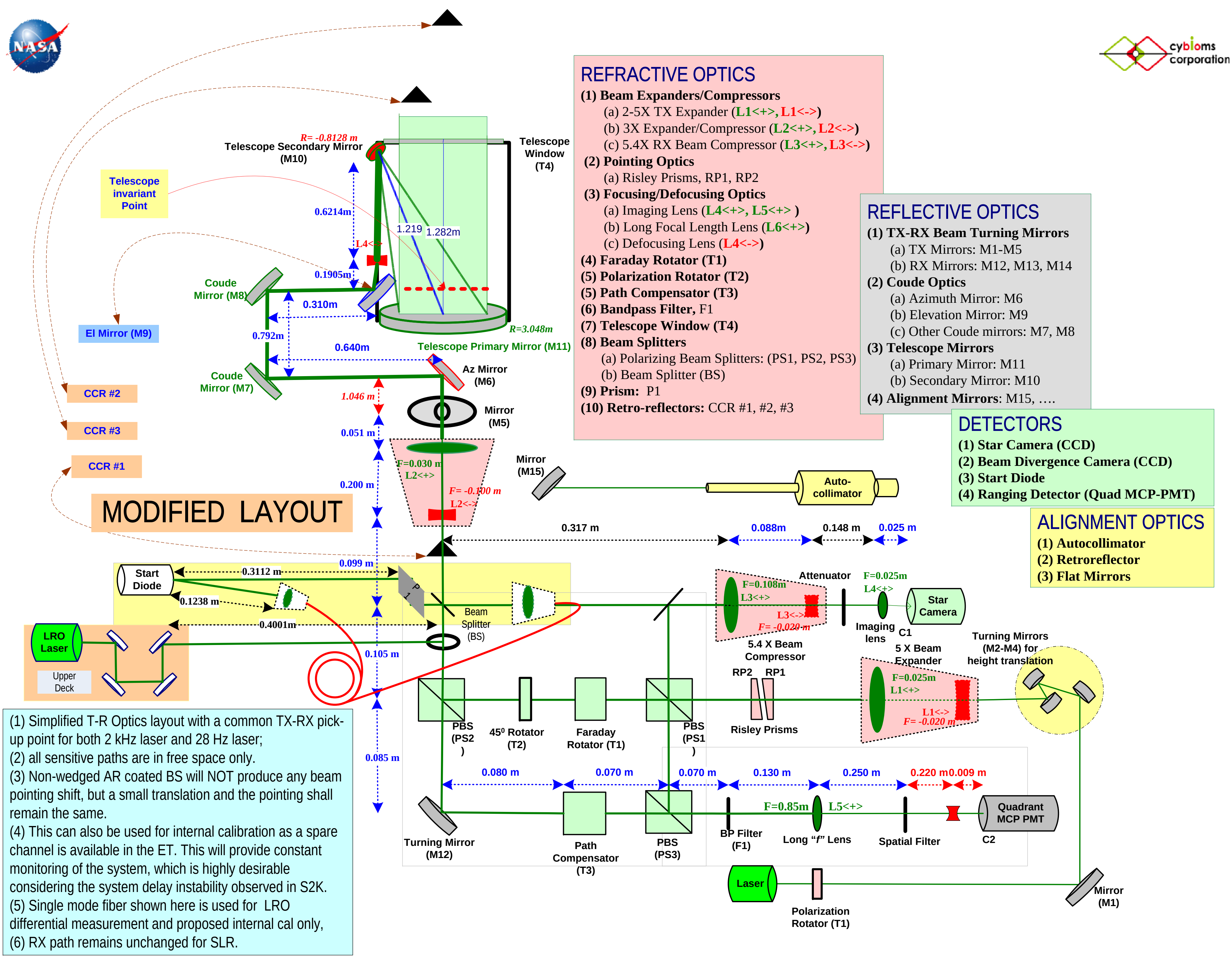
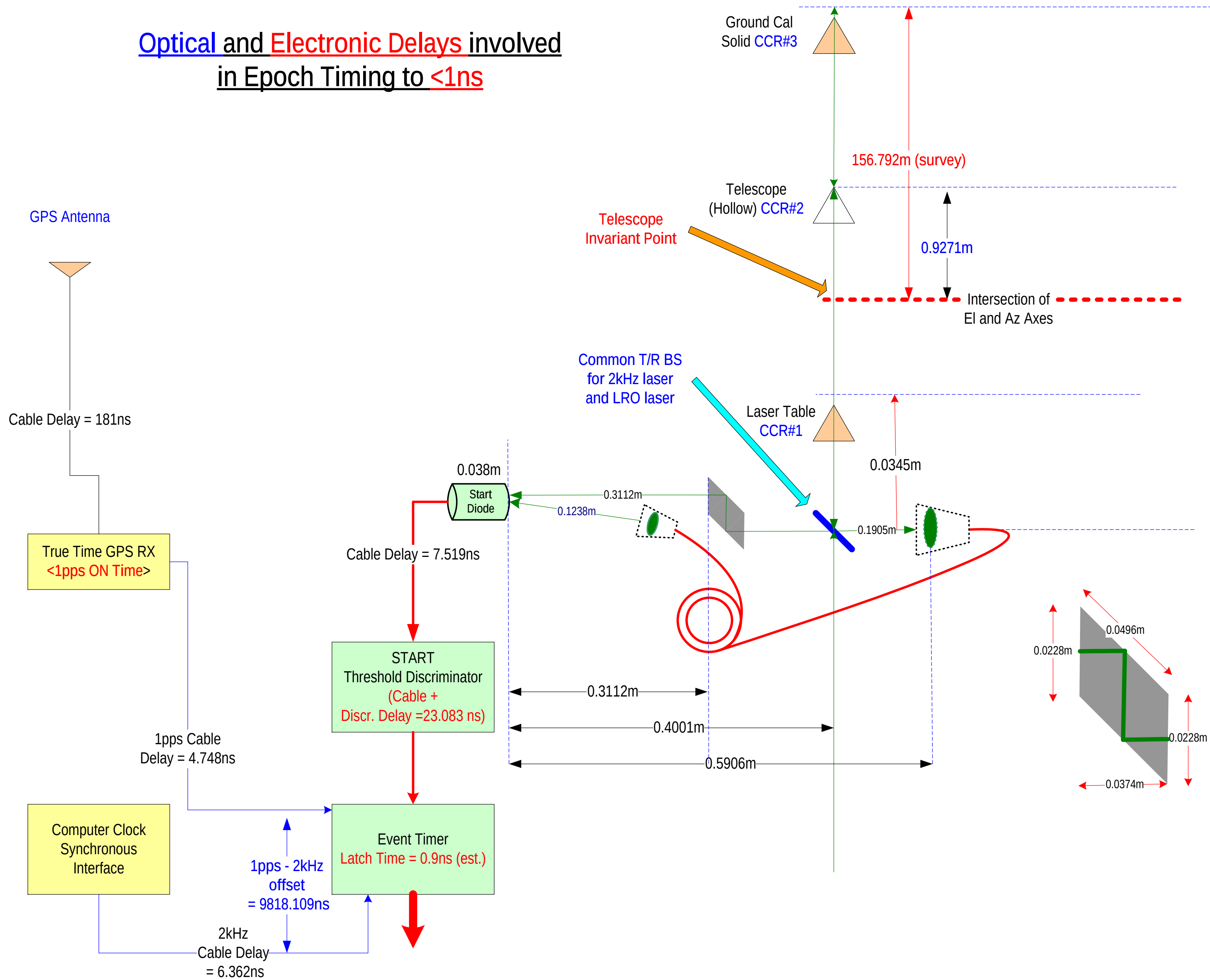
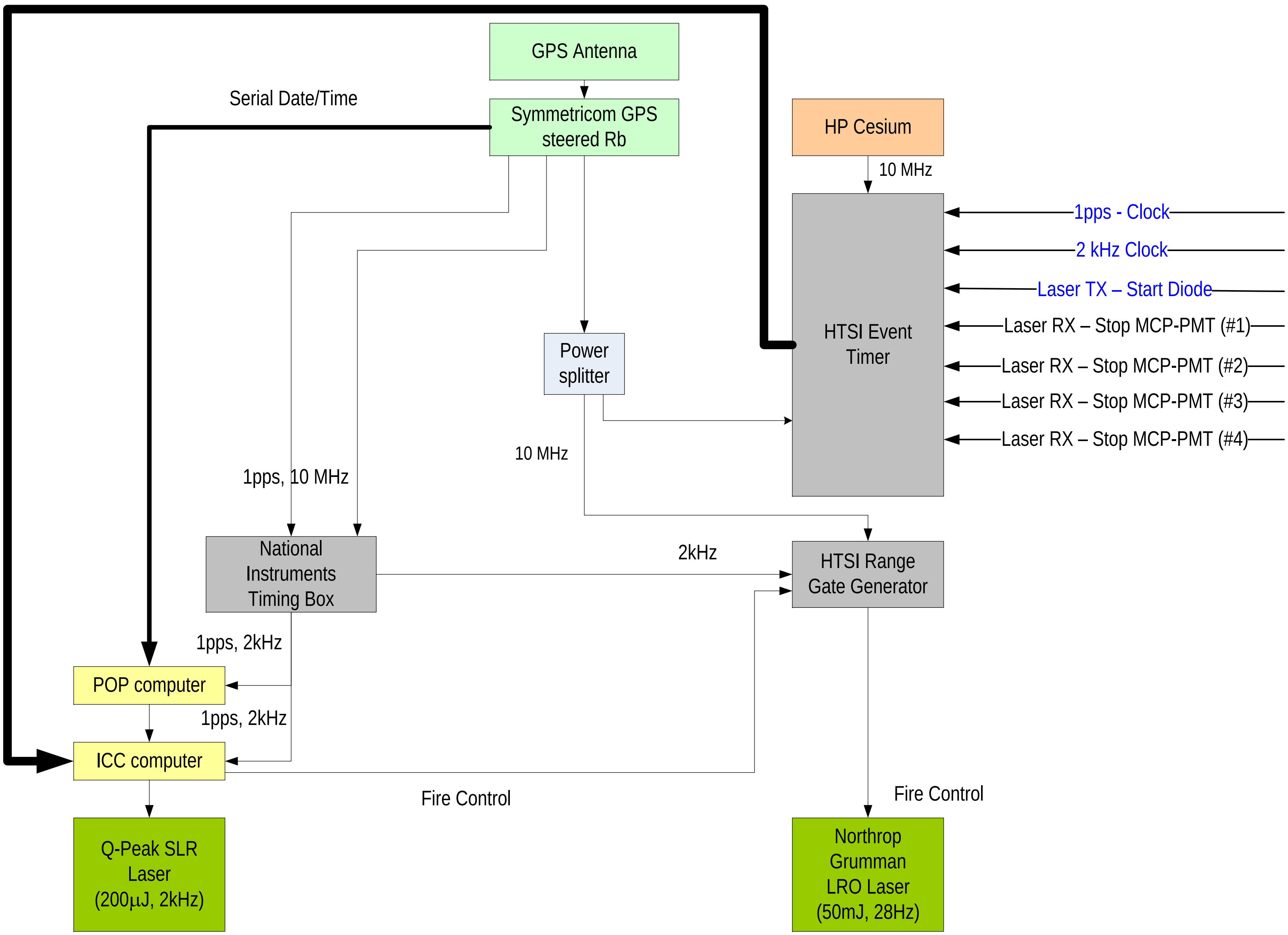


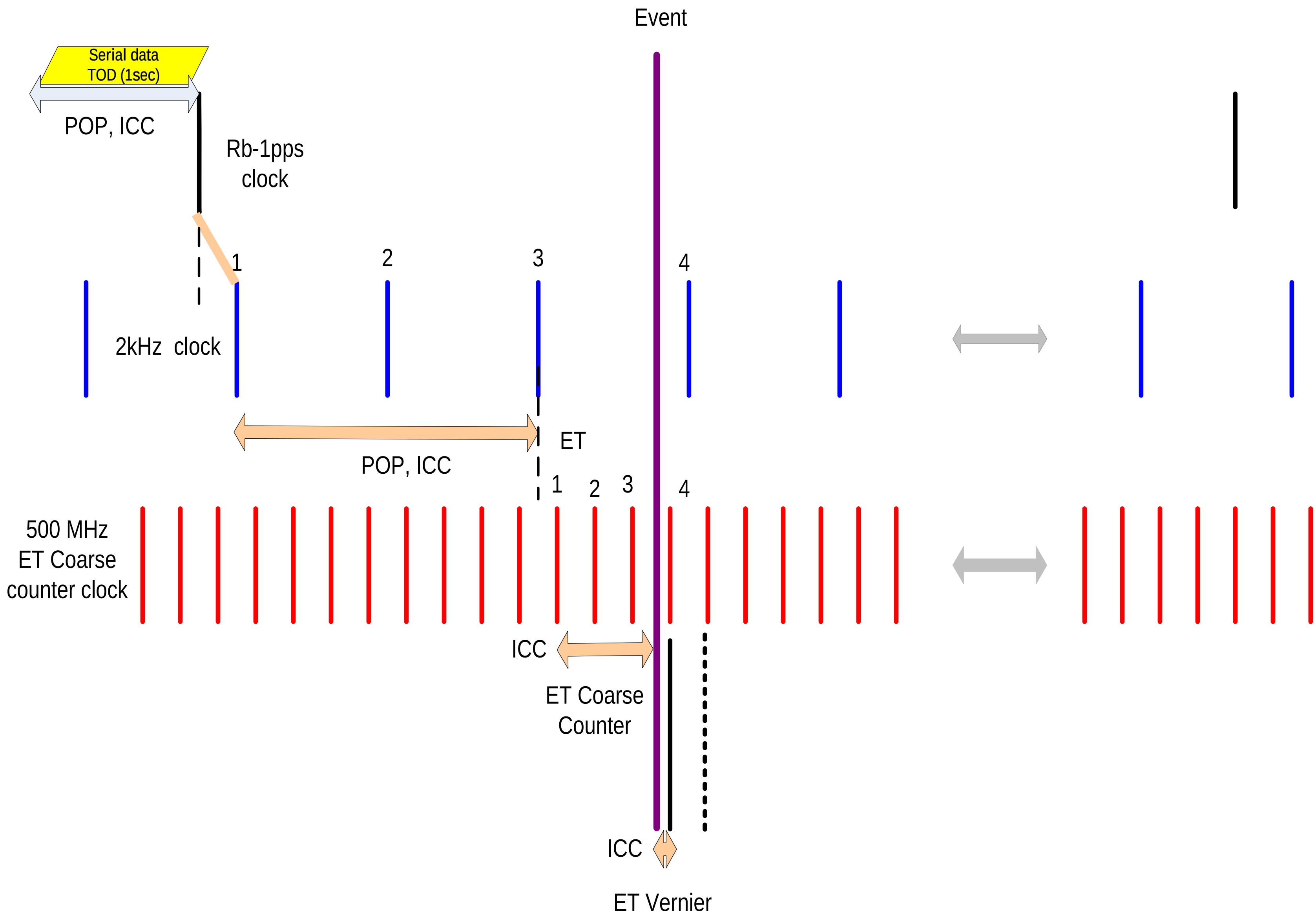
(1) Simplified T-R Optics layout with a common TX-RX pick-up point for both 2 kHz laser and 28 Hz laser;
(2) all sensitive paths are in free space only.
(3) Non-wedged AR coated BS will NOT produce any beam pointing shift, but a small translation and the pointing shall remain the same.
(4) This can also be used for internal calibration as a spare channel is available in the ET. This will provide constant monitoring of the system, which is highly desirable considering the system delay instability observed in S2K.
(5) Single mode fiber shown here is used for LRO differential measurement and proposed internal cal only,
(6) RX path remains unchanged for SLR.

Optical and Electronic Delays involved in Epoch Timing to <1ns



LRO and SLR Timing Subsystem




Event
Serial data
TOD (1sec)
POP, ICC
Rb-1pps
clock
1
2
3
4
2kHz clock
ET
POP, ICC
1
2
3
4
500 MHz
ET Coarse
counter clock
ICC
ET Coarse
Counter
ICC
ET Vernier

Data set # (Feb 9-2009)	Measurement pair	Corresponding Equation	Mean (ns)	σ(ps)	Data Quantity
4) t1559 - 2khz & alignment cube	NEW start diode and alignment cube (CCR#1)	$\Delta T_{ET-TX1} - \Delta T_{ET-TX0}$	251.820	184	122182
5) t1646 - LRO & alignment cube	NEW start diode and alignment cube (CCR#1)	$\Delta T_{ET-TX1} - \Delta T_{ET-TX0}$	252.358	140	7070
		$\Delta T_{ET-TX1} - \Delta T_{ET-TX0}$	252.089		
8) t1734 - LRO & exit cube	NEW start diode and telescope exit cube (CCR#2)	$\Delta T_{ET-TX2} - \Delta T_{ET-TX0}$	294.588	183	8320
10)t1954 - LRO exit cube	NEW start diode and telescope exit cube (CCR#2)	$\Delta T_{ET-TX2} - \Delta T_{ET-TX0}$	295.090	88	7322
		$\Delta T_{ET-TX2} - \Delta T_{ET-TX0}$	294.839		
9) t1943 - LRO & Ground cal	NEW start diode and Ground Calibration cube (CCR#3)	$\Delta T_{ET-TX3} - \Delta T_{ET-TX0}$	1335.300	133	3855
10)t1954 - LRO &Ground cal	NEW start diode and Ground Calibration cube (CCR#3)	$\Delta T_{ET-TX3} - \Delta T_{ET-TX0}$	1335.164	126	7318
		$\Delta T_{ET-TX3} - \Delta T_{ET-TX0}$	1335.232		
		$\Delta T_{ET-TX3} - \Delta T_{ET-TX1}$	1083.143		
		$\Delta T_{ET-TX2} - \Delta T_{ET-TX1}$	42.750		

Key:

Black → Electronic delay from the start diode thrugh the Event Time = δt_{el-TX}

Blue → Optical delay from the start diode to the Beam splitter through the Prism = δt_{opt-TX}

Yellow → Optical delay from the Beam Splitter to the Start diode through the Fiber Loop

Green→ Optical delay from the Beam Splitter to the Telescope invariant Point, i.e., the reference point	19.052	ns	5.716 meters

$T_{TX-RX-C}$ = Epoch Time at the TX-RX common Point, i.e., at the beam splitter (BS)

T_{serial} = Serial data from the GPS Receiver

$T_{TX-Reference}$ = Epoch Time at the Telescope invariant point or Station reference point.

$\delta T_{(1pps-2kHz)}$ = Offset between 1pps and 2kHz

$\delta T_{(N*2kHz)}$ = Elapsed 2kHz cycles after the 1pps

ΔT_{ET-TX0} = Event time of the laser oulse wrto the START Diode

ΔT_{ET-TX1} = Event time wrto Alignment Cube (CCR#1) return

ΔT_{ET-TX2} = Event time wrto Telescope Exit Port Cube (CCR#2) return

ΔT_{ET-TX3} = Event time wrto the Ground Cal Cube (CCR#3) return

$T_{TX-RX-C} = \{T_{Serial} + \delta T_{ET(1pps-2kHz)}\} + \Delta T_{ET(2kHz-TX0)}$ – **Black** – **Blue** -- (1)

$T_{TX-RX-C} = \{T_{Serial} + \delta T_{ET(1pps-2kHz)}\} + \Delta T_{ET(2kHz-TX1)}$ – **Black** – **Yellow** – 2 (BS to **Alignment CCR#1**) ----------------(2)

$T_{TX-RX-C} = \{T_{Serial} + \delta T_{ET(1pps-2kHz)}\} + \Delta T_{ET(2kHz-TX2)}$ – **Black** – **Yellow** – **2 (Green + Telescope CCR#2)** -(3)

$T_{TX-RX-C} = \{T_{Serial} + \delta T_{ET(1pps-2kHz)}\} + \Delta T_{ET(2kHz-TX3)}$ – **Black** – **Yellow** – **2 (Green + Survey Range of CCR#3)** ----(4)

$\Delta T_{ET(2kHz-TX1)}$ – **Black** – **Yellow** – 2 (BS to **Alignment CCR#1**) = $\Delta T_{ET(2kHz-TX3)}$ – Black – Yellow – 2 (**Green** + **Survey Range of CCR#3**) ----(5)

Green = (1/2)[($\Delta T_{ET(2kHz-TX3)} - \Delta T_{ET(2kHz-TX1)}$)] + (**BS to Alignment CCR#1- Survey Range of CCR#3**) ---------------------(6)

$T_{TX-Reference} = T_{TX-RX-C}$ + **Green** ---(7)

$T_{TX-Reference} = \{T_{Serial} + \delta T_{ET(1pps-2kHz)}\} + \Delta T_{ET(2kHz-TX0)} + \{- \delta t_{el-TX} - \delta t_{opt-TX} + (1/2)[(\Delta T_{ET(2kHz-TX2)} - \Delta T_{ET(2kHz-TX1)}] + (\delta T_{BS\ to\ CCR\#1} - \delta T_{range\ of\ CCR\#2})\}$----(8)

$T_{TX-Reference} = \{T_{Serial} + \delta T_{ET(1pps-2kHz)}\} + \Delta T_{ET(2kHz-TX0)} + \{- \delta t_{el-TX} - \delta t_{opt-TX} + (1/2)[(\Delta T_{ET(2kHz-TX3)} - \Delta T_{ET(2kHz-TX1)}] + (\delta T_{BS\ to\ CCR\#1} - \delta T_{range\ of\ CCR\#3})\}$ ----(9)

			meter	ns
δt_{opt-TX} = Optical delay from the START Diode to the Beam Splitter = 0.4001+ ((37.4*1.5-1.0)+ (22.8*1.5))/1000		δt_{opt-TX}	0.489	1.631
δt_{el-TX} = electronic delay from the START Diode to the Event Timer =				
	propagation delay from the sensor to the cable		*0.038*	*0.193*
	(+ Cable delay to the Discriminator)		*1.486*	*7.519*
		(summed)	1.524	7.711
	(+ Intrinsic delay through the Discriminator + Cable delay to the ET)			23.083
	(+ length of the inline pulse inverter)		0.0445	0.225
	(+ Best Latch time of the Flip-Flop used in the Event Timer is ~0.8ns)			0.800
	and considering the propagation time from the input to the Flip-Flop			0.100
δt_{el-TX} =		δt_{el-TX}		31.919
$\delta T_{ET(1pps-2kHz)}$ = Timing offset measured by ET		$\delta T_{ET(1pps-2kHz)}$		9818.109
$\delta T_{BS\ to\ CCR\#1}$ =		$\delta T_{BS\ to\ CCR\#1}$ =	0.035	0.115
$\delta T_{Range\ of\ CCR\#2}$ = estimated		$\delta T_{Range\ of\ CCR\#2}$	0.927	3.090
$\delta T_{Range\ of\ CCR\#3}$ = surveyed to 1 mm		$\delta T_{Range\ of\ CCR\#3}$	156.792	522.635
$\Delta T_{ET-TX3} - \Delta T_{ET-TX1}$		$(\Delta T_{ET-TX3} - \Delta T_{ET-TX1})$		1083.143
$\Delta T_{ET-TX2} - \Delta T_{ET-TX1}$		$(\Delta T_{ET-TX2} - \Delta T_{ET-TX1})$		42.750

(1) Correction to ET Data <*wrto Telescope cube (CCR#2) (Range from external direct measurement)*>	-15.151	ns	$\delta T_{(ET-Epoch)\ correction}$
(2) Correction to ET Data <*wrto Ground Cal cube (CCR#3); (Range from Survey)* >	-14.499	ns	$\delta T_{(ET-Epoch)\ correction}$

Note:

(1) The above correction factor does not include the event offset wrto the 1pps clock as it is already embedded in the algorithm of the timing software

(2) CCR#3 range was not corrected for refraction and is considered nominal over the 156 meter range

(3) Significant mode beating was occurring in the LRO laser; LRO laser produces a 8ns multimode laser output

$T_{TX-Reference} = \{T_{Serial} + \delta T_{ET(1pps-2kHz)}\} + \Delta T_{ET(2kHz-TX0)\ New\ diode} + \delta T_{(ET-Epoch)\ correction\ (New\ Diode)}$

$T_{TX-Reference} = \{T_{Serial} + \delta T_{ET(1pps-2kHz)}\} + \Delta T_{ET(2kHz-TX0)\ Old\ diode} + \delta T_{(ET-Epoch)\ correction\ (New\ Diode)} + \Delta t_{(old\ -\ new)}$

$\Delta t_{(old\ -\ new)}$	
3.393	ns