New RGG development for bistatic LLR system based on *cRIO* controller

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II. Hardware composition
III. Timing design
IV. Software architecture
V. Prediction sync
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VII. Range compensation
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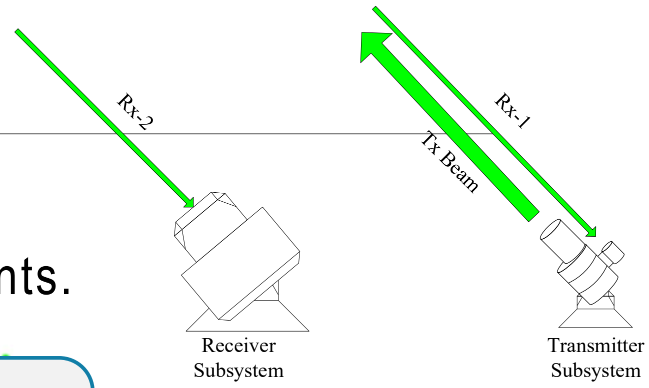
Why a New RGG (Range Gate Generator)



New LLR system is under construction (Bistatic)
Requires a customized RGG to meet the specific requirements.

Two lasers

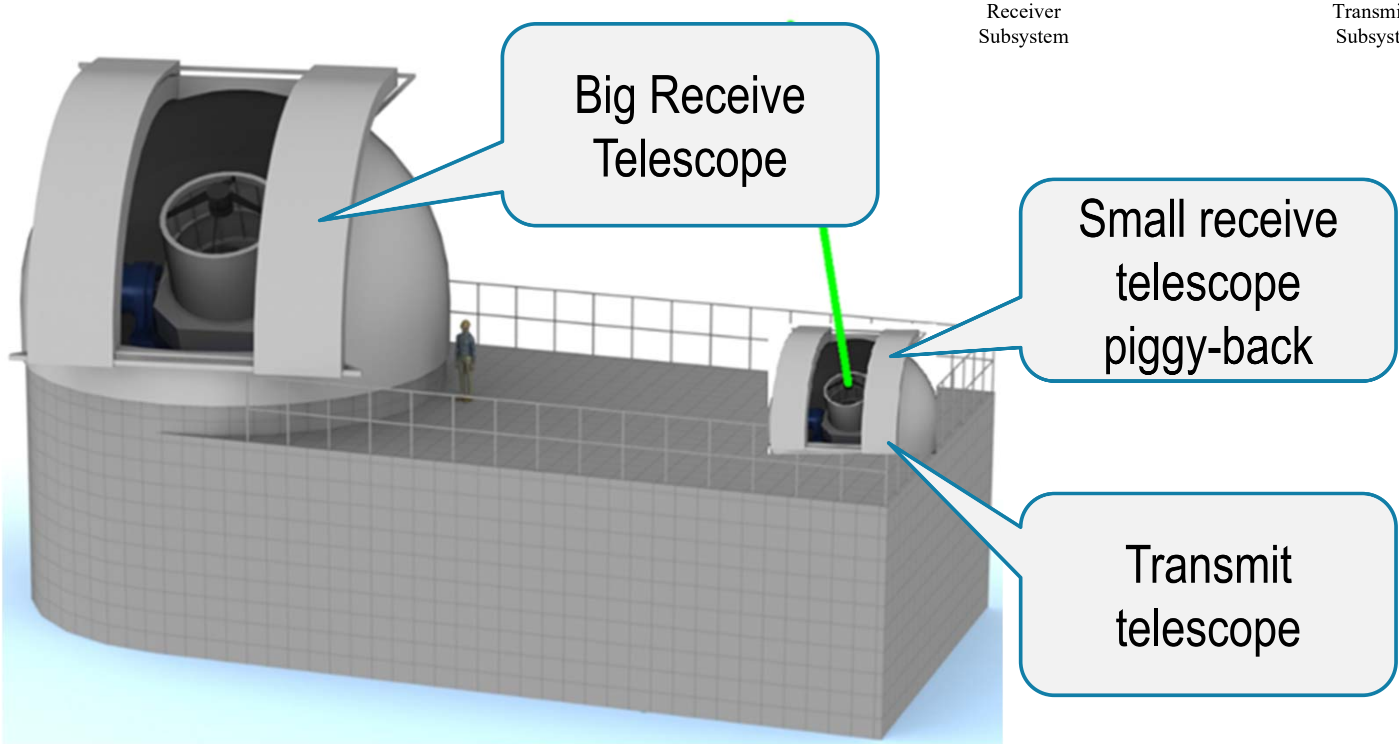
- High repetition rate (ps)
- Low repetition rate (ns)

Four Detectors

- 532nm / 1064nm

  SPADs (self-developed)

  on both sides



Considering the control complexity, I/O expansion capability, and real-time performance, et al
We choose NI Industrial cRIO controller for developing a highly integrated new RGG for LLR.

Hardware composition

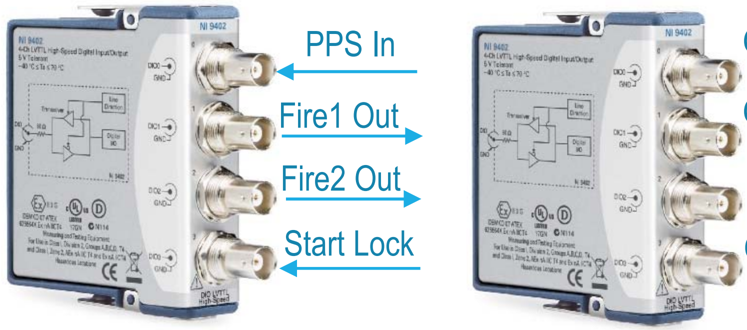
The cRIO (CompactRIO) controller consists of a real-time processor, FPGA resources, and I/O expansion modules. (choose cost-effective cRIO-9054 as the control core)

Real-time processor
(Intel Dual core, 1.33GHz, NI Linux RT)

Eth0: communication with IPC

Eth1: IEEE 1588 PTP Sync

FPGA
(Artix 7 100T)



PPS In
Fire1 Out
Fire2 Out
Start Lock

Gate1 Out
Gate2 Out
Gate3 Out
Gate4 Out

Two NI-9402 bidirectional DIO Module

- LVTTL level (Compatible with TTL input)
- I/O Propagation delay: 18ns(typical)

A highly integrated hardware solution with reliability, flexibility, easy to expand I/O features
Only focus on embedded software development, not hardware (time saving)

Hardware composition

LVTTL to TTL level converter (based on high speed MOSFET driver)

Compatible with most of fire and gate trigger level and impedance

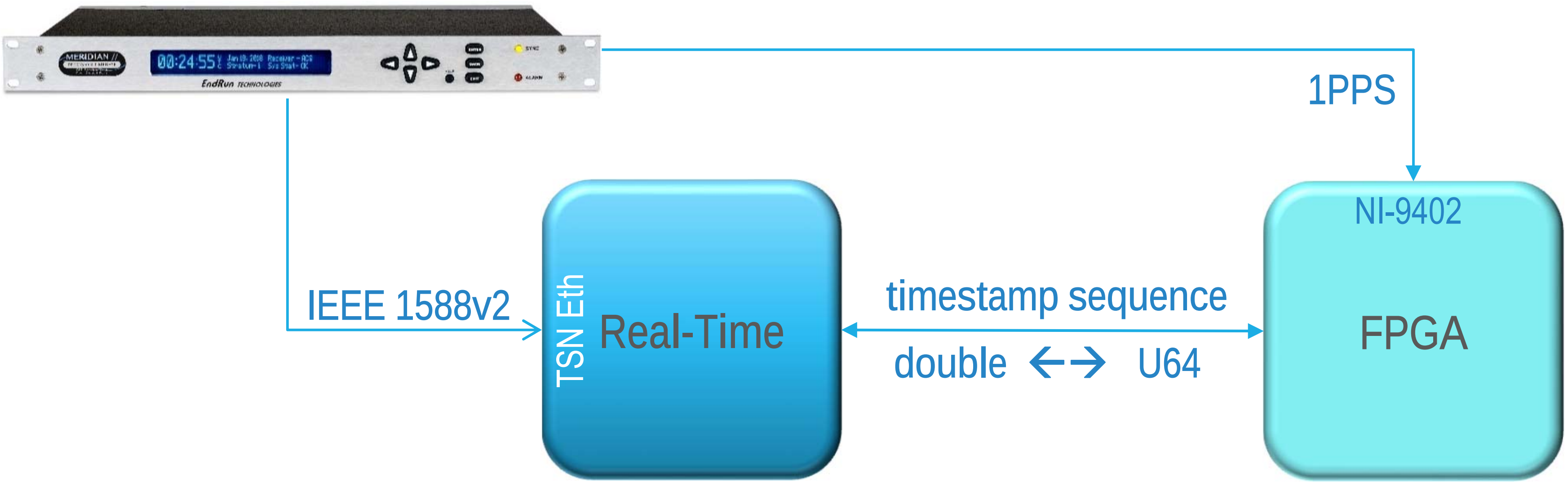
PARAMETER	DESCRIPTION	TEST CONDITIONS	MIN (Note 8)	TYP	MAX (Note 8)	UNITS
SWITCHING CHARACTERISTICS						
t_R	Driver Rise Time	Figure 2, OA, OB: CL = 100pF/1k 10% to 90%, VOH - VOL = 12V		1.2		ns
t_F	Driver Fall Time	Figure 2, OA, OB: CL = 100pF/1k 10% to 90%, VOH - VOL = 12V		1.4		ns
t_R	Driver Rise Time	Figure 2, OA, OB: CL = 1nF 10% to 90%, VOH - VOL = 12V		6.2		ns
t_F	Driver Fall Time	Figure 2, OA, OB: CL = 1nF 10% to 90%, VOH - VOL = 12V		6.9		ns
tpdR	Input to Output Propagation Delay	Figure 3, load 100pF/1k		10.9		ns
tpdF	Input to Output Propagation Delay			10.7		ns
tpdR	Input to Output Propagation Delay	Figure 3, load 330pF		12.8		ns
tpdF	Input to Output Propagation Delay			12.5		ns
tpdR	Input to Output Propagation Delay	Figure 3, load 680pF		14.5		ns
tpdF	Input to Output Propagation Delay			14.1		ns

Timing design

RGG timing design: RT system UTC sync + FPGA timebase setup

Reference Clock: Time & Frequency receiver(EndRun Meridian with PTP option)

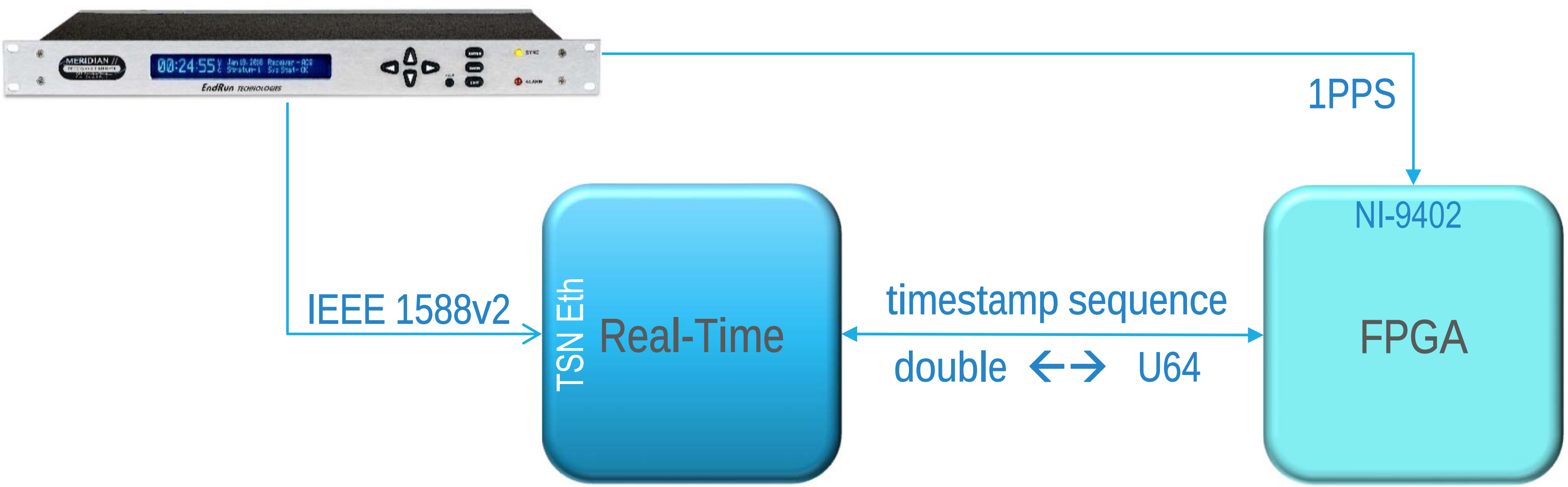
- PTP Grandmaster timestamp accuracy: 8ns
- cRIO onboard oscillator: 100MHz (automatically synchronizes to IEEE 1588)
- The RT system can automatically maintain synchronization with UTC continuously



Timing design

32bit second of day counter	32bit decimal second counter

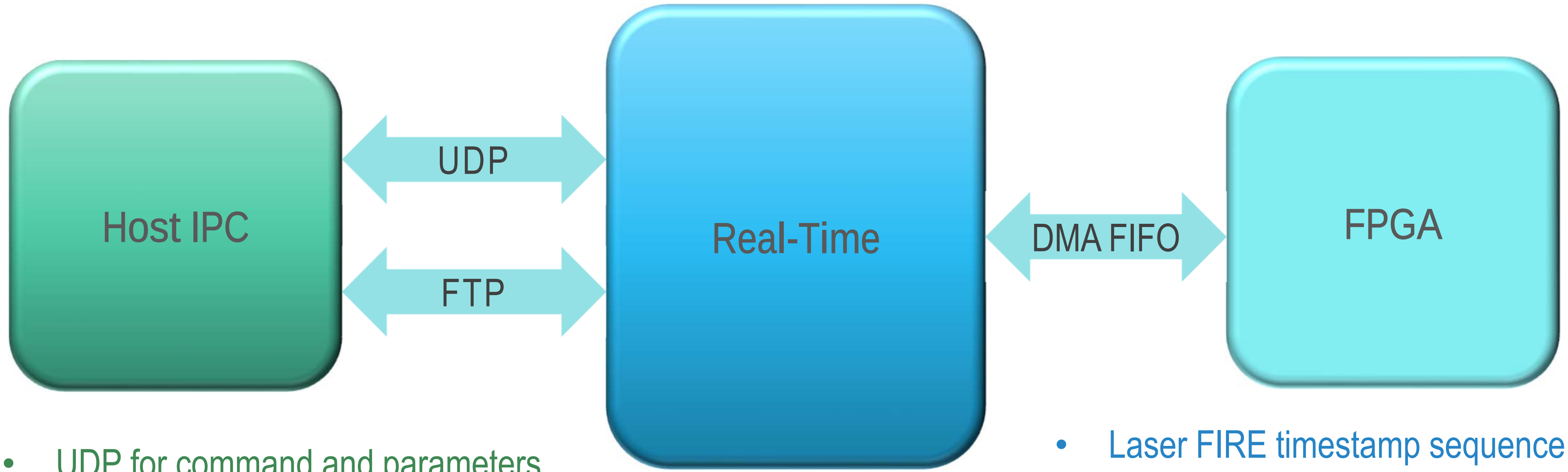
- FPGA onboard oscillator: 40MHz (derived from the onboard 100 MHz oscillator and synchronized to it)
- FPGA timebase clock: 160MHz (timing resolution: 6ns); timebase:64bit counter
- 1PPS input: decimal second counter reset every pps rising edge
- Sufficient time resolution and accuracy for fire and gate control



Software architecture

RGG embedded software development includes real-time system and FPGA parts.
LabVIEW graphical language for RT and FPGA programming. (high efficiency, good portability)

- UDP to exchange commands & data between RT and host IPC (good real-time performance)
- DMA FIFO to transfer timestamp sequence between RT and FPGA (high speed, bidirectional)



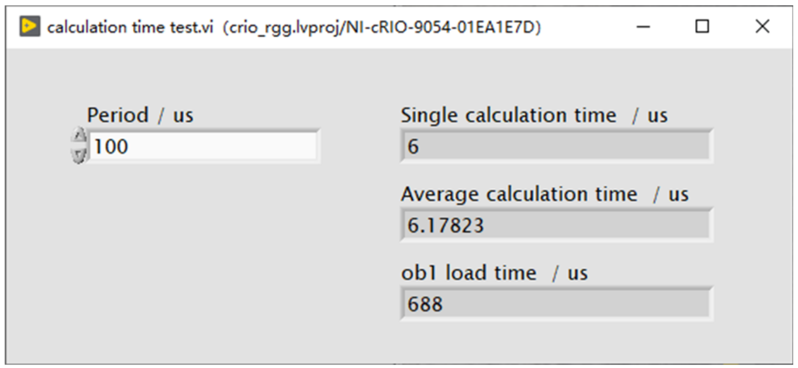
- UDP for command and parameters
  (FIRE Enable, TB, RB, system delay, et al.)
- FTP for range prediction file pre-sync

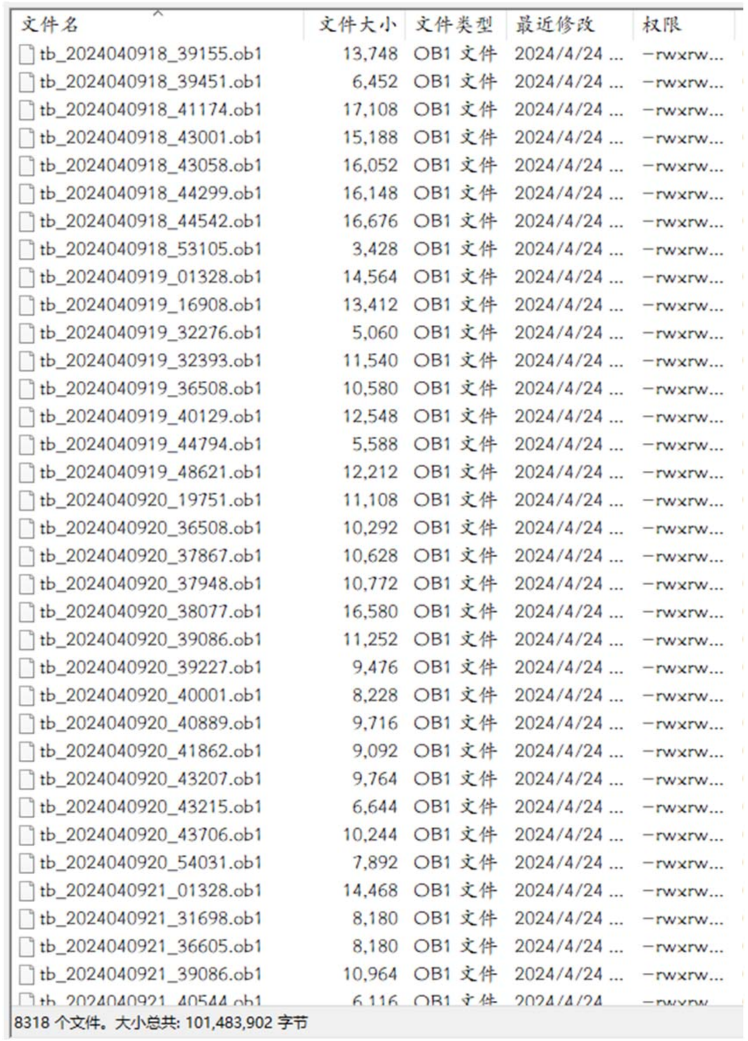
- Laser FIRE timestamp sequence
- PD START time lock sequence
- SPADs GATE timestamp sequence

Prediction Sync

When the prediction files are generated on the host IPC from CPF to OB1, it is simultaneously synchronized to cRIO by FTP or WebDAV.

- cRIO-9054 has 4GB SSD, enough for prediction storage
- When switching target, prediction is entirely loaded in RT (Low latency, Unlimited arc length, large TB)
- OB1: binary, containing third-order interpolation coefficients
- Range calculation only involves addition and multiplication, tested average range calculation time is less than 10 μs



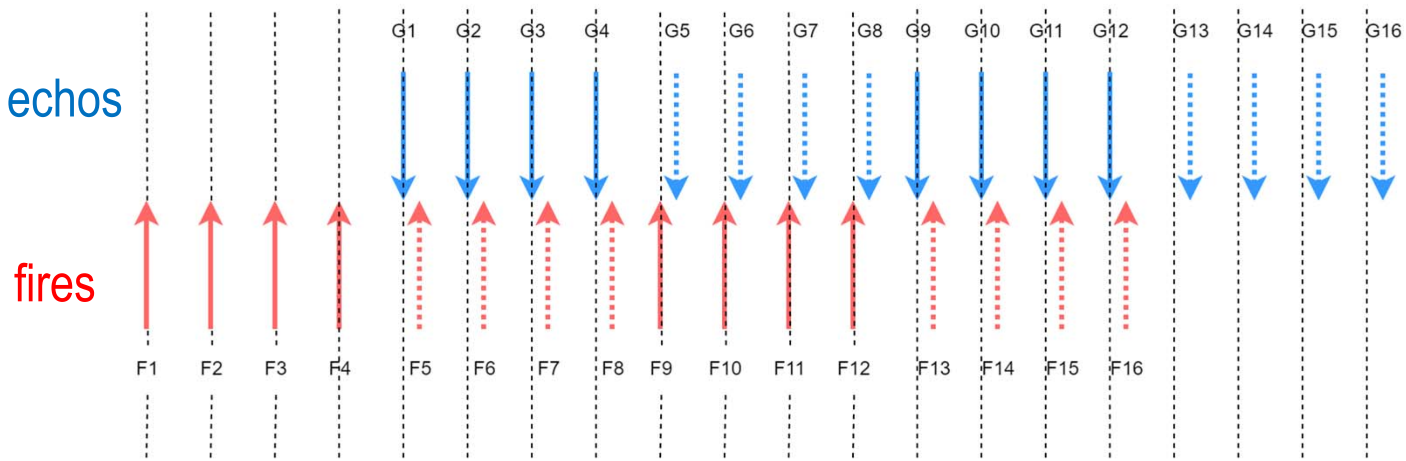


文件名	文件大小	文件类型	最近修改	权限
tb_2024040918_39155.ob1	13,748	OB1 文件	2024/4/24 ...	-rwxrw...
tb_2024040918_39451.ob1	6,452	OB1 文件	2024/4/24 ...	-rwxrw...
tb_2024040918_41174.ob1	17,108	OB1 文件	2024/4/24 ...	-rwxrw...
tb_2024040918_43001.ob1	15,188	OB1 文件	2024/4/24 ...	-rwxrw...
tb_2024040918_43058.ob1	16,052	OB1 文件	2024/4/24 ...	-rwxrw...
tb_2024040918_44299.ob1	16,148	OB1 文件	2024/4/24 ...	-rwxrw...
tb_2024040918_44542.ob1	16,676	OB1 文件	2024/4/24 ...	-rwxrw...
tb_2024040918_53105.ob1	3,428	OB1 文件	2024/4/24 ...	-rwxrw...
tb_2024040919_01328.ob1	14,564	OB1 文件	2024/4/24 ...	-rwxrw...
tb_2024040919_16908.ob1	13,412	OB1 文件	2024/4/24 ...	-rwxrw...
tb_2024040919_32276.ob1	5,060	OB1 文件	2024/4/24 ...	-rwxrw...
tb_2024040919_32393.ob1	11,540	OB1 文件	2024/4/24 ...	-rwxrw...
tb_2024040919_36508.ob1	10,580	OB1 文件	2024/4/24 ...	-rwxrw...
tb_2024040919_40129.ob1	12,548	OB1 文件	2024/4/24 ...	-rwxrw...
tb_2024040919_44794.ob1	5,588	OB1 文件	2024/4/24 ...	-rwxrw...
tb_2024040919_48621.ob1	12,212	OB1 文件	2024/4/24 ...	-rwxrw...
tb_2024040920_19751.ob1	11,108	OB1 文件	2024/4/24 ...	-rwxrw...
tb_2024040920_36508.ob1	10,292	OB1 文件	2024/4/24 ...	-rwxrw...
tb_2024040920_37867.ob1	10,628	OB1 文件	2024/4/24 ...	-rwxrw...
tb_2024040920_37948.ob1	10,772	OB1 文件	2024/4/24 ...	-rwxrw...
tb_2024040920_38077.ob1	16,580	OB1 文件	2024/4/24 ...	-rwxrw...
tb_2024040920_39086.ob1	11,252	OB1 文件	2024/4/24 ...	-rwxrw...
tb_2024040920_39227.ob1	9,476	OB1 文件	2024/4/24 ...	-rwxrw...
tb_2024040920_40001.ob1	8,228	OB1 文件	2024/4/24 ...	-rwxrw...
tb_2024040920_40889.ob1	9,716	OB1 文件	2024/4/24 ...	-rwxrw...
tb_2024040920_41862.ob1	9,092	OB1 文件	2024/4/24 ...	-rwxrw...
tb_2024040920_43207.ob1	9,764	OB1 文件	2024/4/24 ...	-rwxrw...
tb_2024040920_43215.ob1	6,644	OB1 文件	2024/4/24 ...	-rwxrw...
tb_2024040920_43706.ob1	10,244	OB1 文件	2024/4/24 ...	-rwxrw...
tb_2024040920_54031.ob1	7,892	OB1 文件	2024/4/24 ...	-rwxrw...
tb_2024040921_01328.ob1	14,468	OB1 文件	2024/4/24 ...	-rwxrw...
tb_2024040921_31698.ob1	8,180	OB1 文件	2024/4/24 ...	-rwxrw...
tb_2024040921_36605.ob1	8,180	OB1 文件	2024/4/24 ...	-rwxrw...
tb_2024040921_39086.ob1	10,964	OB1 文件	2024/4/24 ...	-rwxrw...
tb_2024040921_40544.ob1	6,116	OB1 文件	2024/4/24	-rwxrw

8318 个文件。大小总共: 101,483,902 字节

Backscatter avoidance

We use fire shifting method to avoid backscattering.

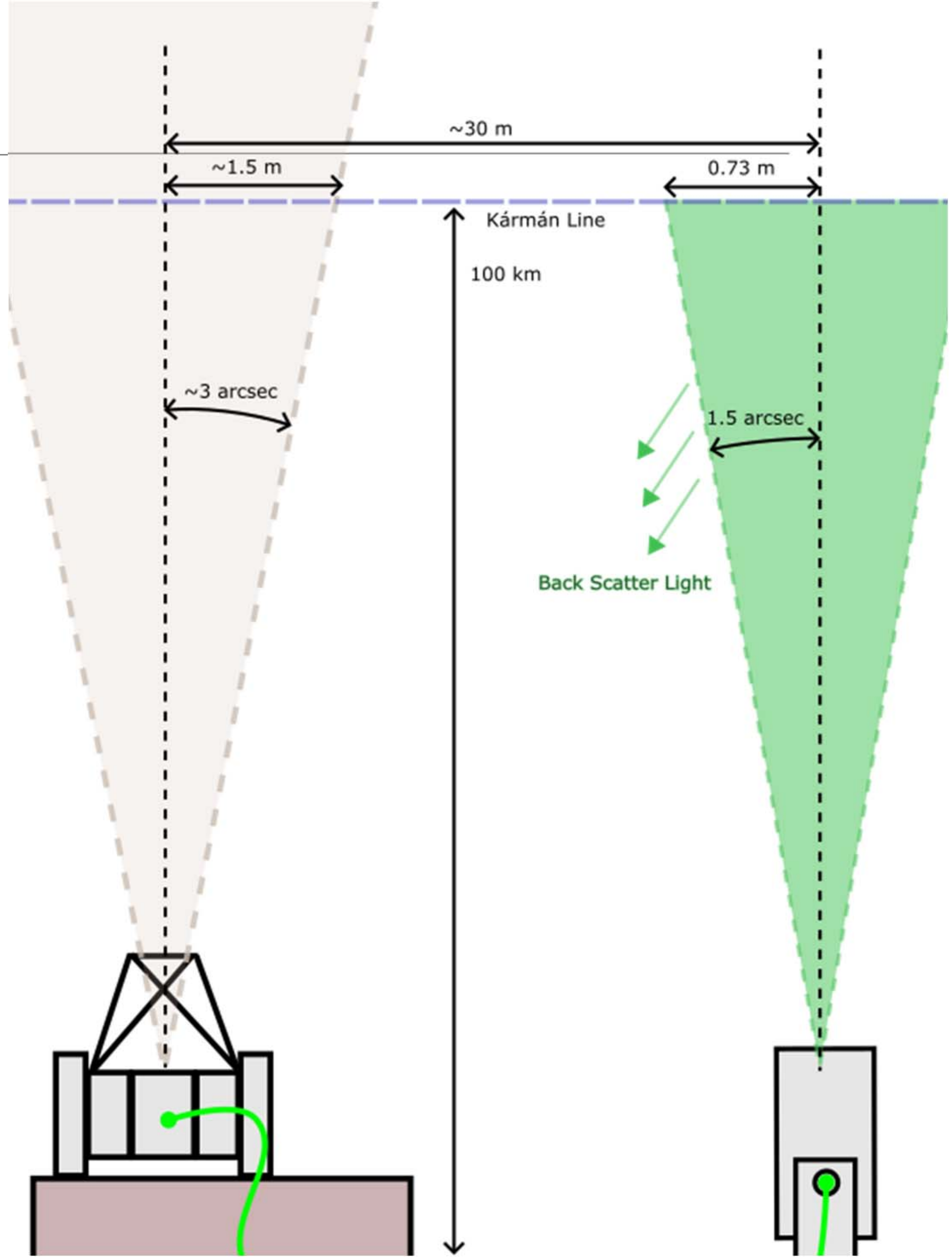


SLR system backscatter avoidance parameter: 150μs (empirical)

5618.584000	0.000000
5618.585000	0.000000
5618.586000	0.000000
5618.587000	0.000000
5618.588152	0.000152
5618.589152	0.000152
5618.590152	0.000152
5618.591152	0.000152
5618.592152	0.000152
5618.593152	0.000152
5618.594152	0.000152
5618.595152	0.000152
5618.596152	0.000152
5618.597152	0.000152
5618.598152	0.000152
5618.599000	0.000000
5618.600000	0.000000
5618.601000	0.000000
5618.602000	0.000000
5618.603000	0.000000
5618.604000	0.000000
5618.605000	0.000000
5618.606000	0.000000
5618.607000	0.000000
5618.608000	0.000000
5618.609000	0.000000
5618.610152	0.000152
5618.611152	0.000152
5618.612152	0.000152
5618.613152	0.000152
5618.614152	0.000152
5618.615152	0.000152
5618.616152	0.000152
5618.617152	0.000152
5618.618152	0.000152
5618.619152	0.000152
5618.620152	0.000152
5618.621000	0.000000
5618.622000	0.000000
5618.623000	0.000000
5618.624000	0.000000

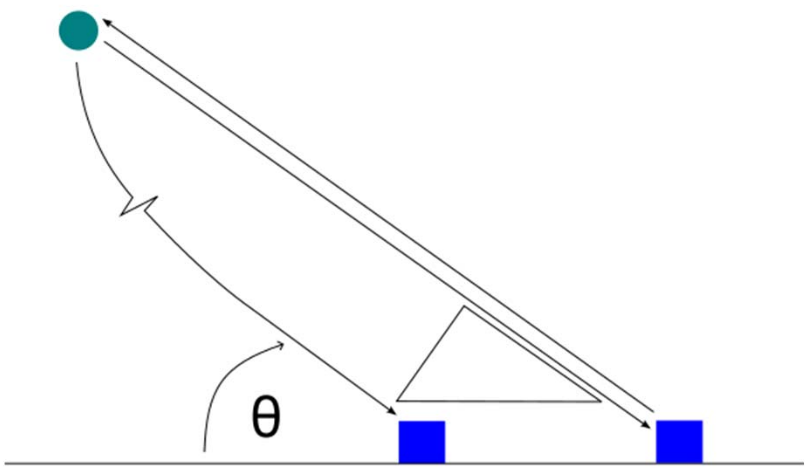
Backscatter avoidance

- For the bistatic LLR system, backscatter avoidance parameter will be greatly reduced, appropriate backscatter avoidance parameter needs further calculating and testing.
  - FOV of T/R
  - Atmosphere
  - Laser pulse energy
  - Pointing angle
- The bistatic system also suitable for ultra high repetition rate ranging (100kHz or above)



Range compensation

- T prediction for both T / R range gate calculation, range gate for R need compensation
- System delay for T / R independently
- Range difference changes with AZ / EL
- Range compensation model: vector operation
- When tracking the target, the range compensation value is calculated and send to RT in real-time
- Max range gate compensation value: 30m



$$\rho_1 - \rho_2 = l \cos\theta$$

$$\rho_2 = \rho_1 - \vec{r}_u \cdot \vec{r}_d = \rho_1 - \left(d_{\mathrm{E}} \sin A \cos E + d_{\mathrm{N}} \cos A \cos E + d_{\mathrm{U}} \sin E\right)$$

Summary

- A new and alternate RGG solution using highly integrated cRIO controller
- Reliable, scalable, easy to maintain, applicable to other cRIO model
- Ready for 100kHz and above ultra high repetition rate ranging
  (<10μs range gate calculation time)
- Suitable for multi/array detector ranging system (up to 32 I/O channel)
- Suitable for highly automated ranging system (UTC sync by PTP)


Thanks for your attention