Modulating Retro-Reflector Cubesat Payload operating at 1070nm for Asymmetric Free-space Optical Communications

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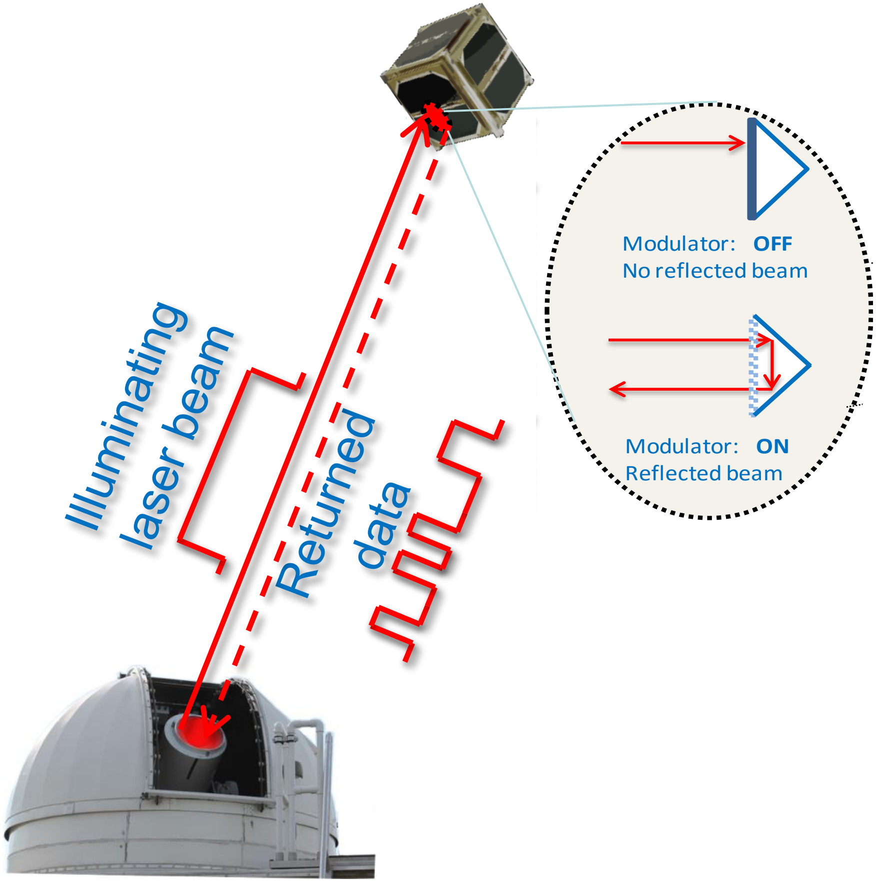

AIAA/USU 13th Annual Summer CubeSat Developers' Workshop

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Modulating Retro-Reflectors would provide high data rate optical communication without strict pointing constraints

Goal: Provide high-speed comm. to low fidelity spacecraft

Advantages to standard RF and optical communications:

High-rate communication for CubeSats and larger:

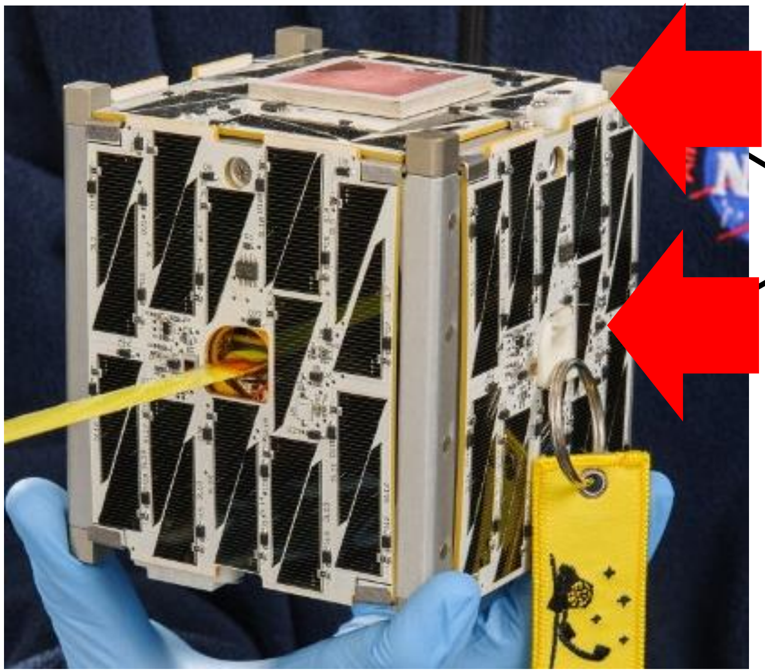
a. Low on-board power consumption
b. Coarse on-board pointing requirements (±15º)
c. Solves RF spectrum allocation issues using tight beam communications
d. Improved security due to tight beam

Relevance:

Advances in comm. without imposing additional requirements to spacecraft

→ potential for crosscutting benefits to multiple missions

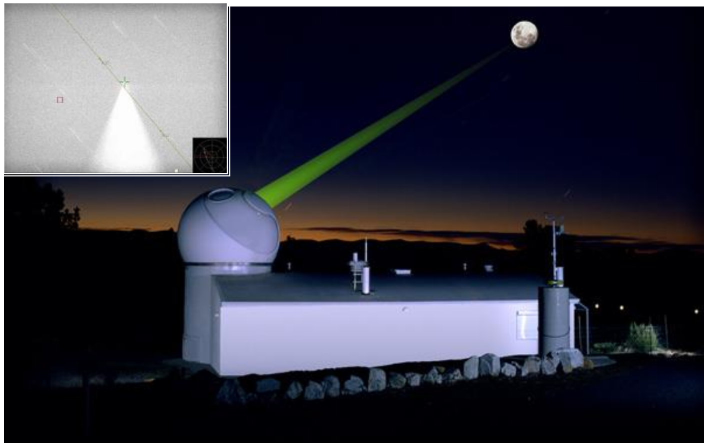
A non-modulating Retro-Reflector aboard PhoneSat 2.4 has been laser tracked by EOS Space Systems



PhoneSat 2.4

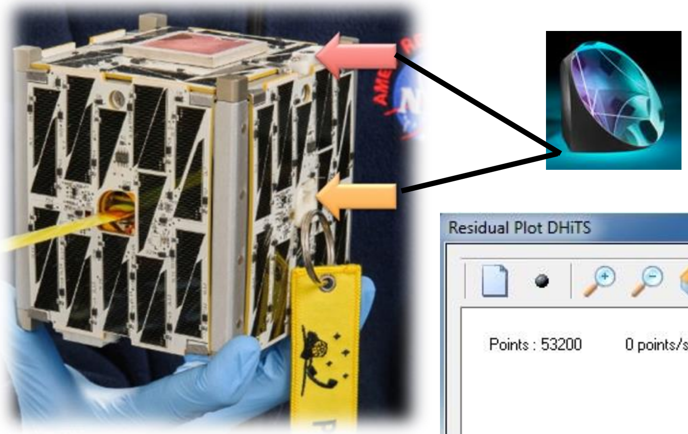
Passive Retro-Reflector
(7mm diameter)

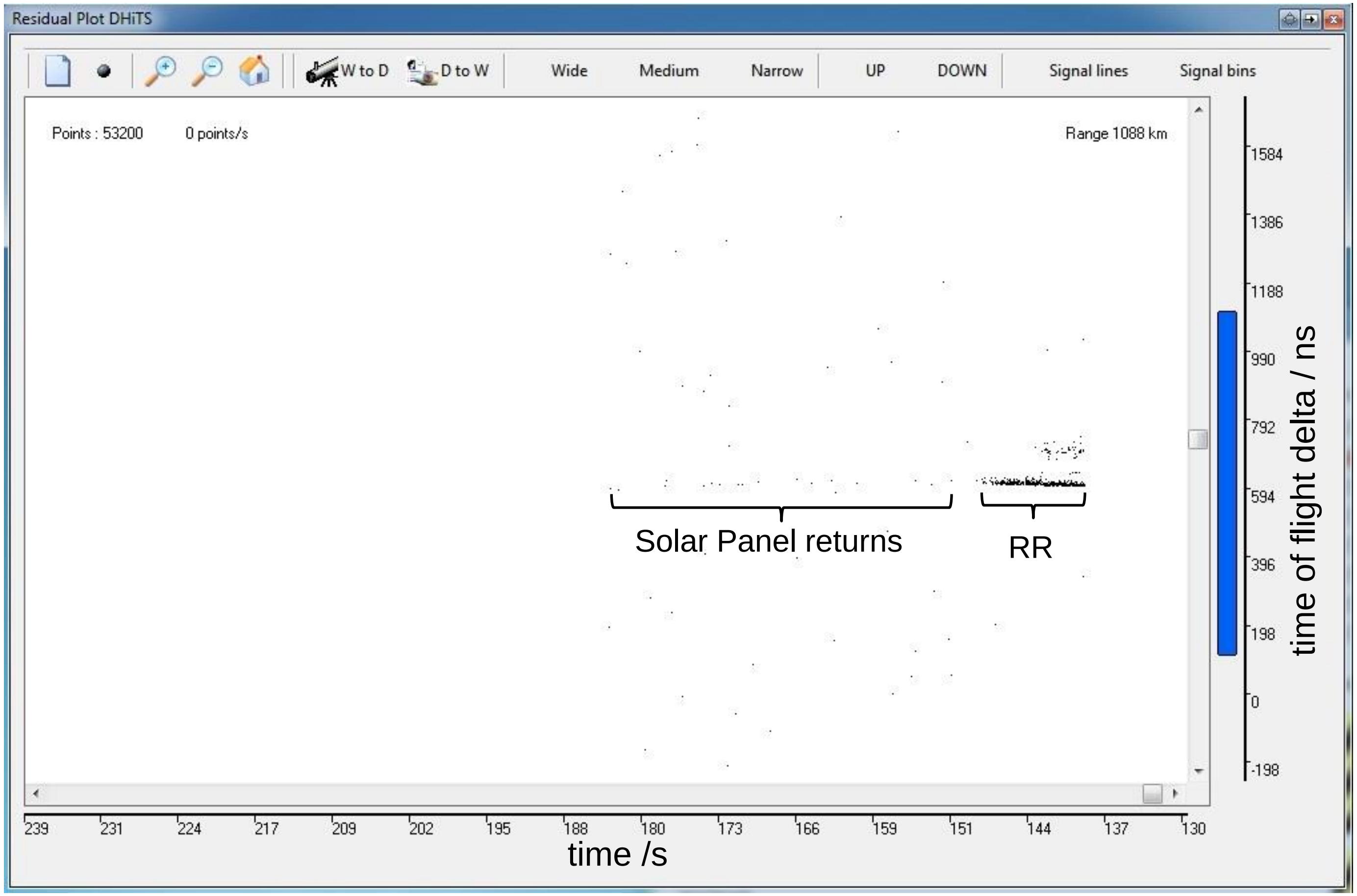
EOS Laser debris ranging station



Source: EOS Space Systems

Tracking results allow distinction between reflections from solar panels and the retro-reflector





Points : 53200

0 points/s

Range 1088 km

Source: EOS Space Systems

Link Budget for Modulating Retro-Retroreflector is challenging for ground stations

$$P_{rec} = \boxed{P_{laser}\, G_T\, L_T}\ \boxed{L_R\, T_{atm}}\ \boxed{G_{MRR}\, M}\ \boxed{L_R\, T_{atm}}\ \boxed{G_{rec}\, L_{rec}}$$

P_{rec} = received signal power
P_{las} = transmitter power laser
G_T = transmitter optical antenna gain
L_T = transmitter losses
G_{MRR} = MRR optical antenna gain
L_{MRR} = MRR optical losses
M = modulation efficiency
G_{rec} = receiver optical antenna gain
L_{rec} = receiver losses
L_R = range losses
T_{atm} = atmospheric transmission

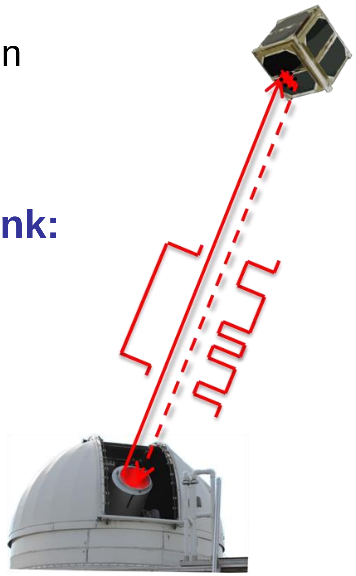
Example:

700km dist., 10kW laser, 30 μrad divergence, 1cm MRR, 1.5m receiver, 1Mbps

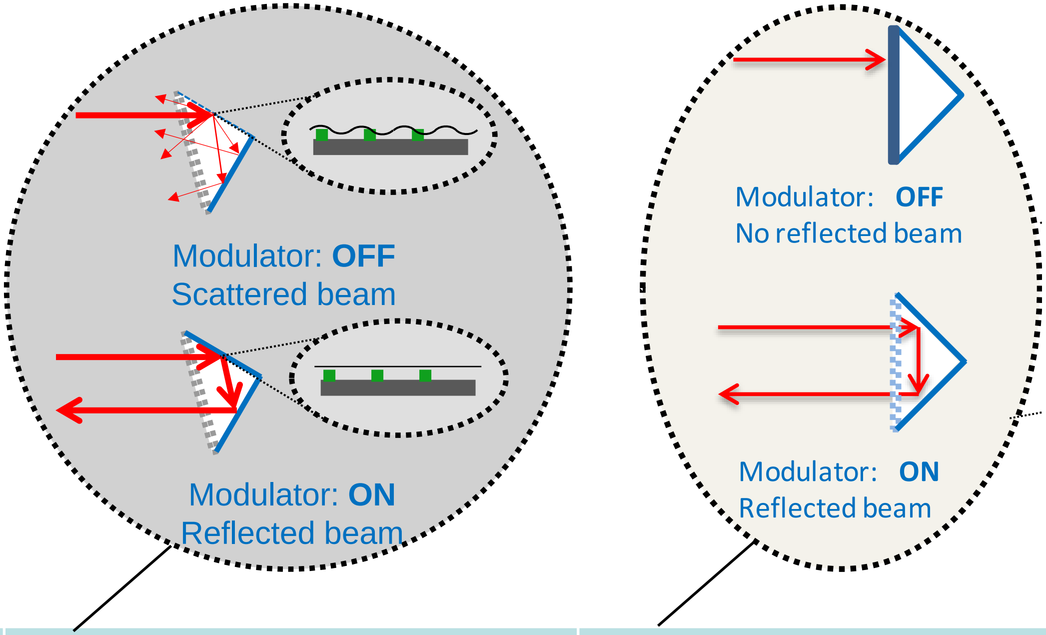
	dB	linear
Tx Power (dBm)	70.0	10000
Tx Loss (dB)	-1.0	0.8
Tx Gain (dB)	105.5	3.6E+10
Range Loss (dB)	-258.3	1.5E-26
Atmospheric transmssison (dB)	-0.5	0.9
Retro reflector gain (dB)	178.7	7.4E+17
Modulation efficiency (dB)	-7.8	0.2
Atmospheric transmssison (dB)	-0.5	0.9
Range Loss (dB)	-258.3	1.5E-26
Velocity aberration	-2.5	0.6
Receiver Loss (dB)	-3.0	5.0E-01
Receiver Gain (dB)	132.9	1.9E+13
Received Power (dBm)	-44.7	3.4E-08
Receiver Sensitivity (dBm)	-67.0	2.0E-10
Margin (dB)	22.3	169
detector quantum efficiency		0.5
photons per bit		9.1E+04

Particularities of the MRR link:

- Transit the atmosphere twice: path losses α distance^4
- MRR acts as a receiver and transmitter: G_{MRR} α Diameter^4



Currently, MEMS and Multiple-Quantum-Well implementations of MRR are available



	MEMS	**MQW**
Advantages	•Broadband •High contrast	•Speed: MHz+ •Power: 0.2W
Disadvantages	•speed ~100kHz •100V+ operating voltage	•Temperature control required

Decision to explore MQW for current effort, because of higher speed

ISDEFE prototyped a MQW device at 1064 nm in order to utilize available kW class fiber lasers

MRR design goals

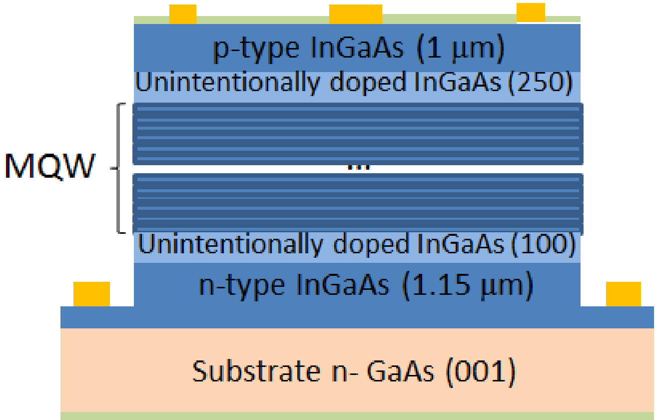
Parameter	Goal
Wavelength	1064 nm
Contrast	3:1
Modulation eff.	-7.8 dB
Data rate	5 Mbps
Driving Voltage	< 10 V
Power consumption	< 1 W

Industrial 10 kW laser

Source: IPG Photonics

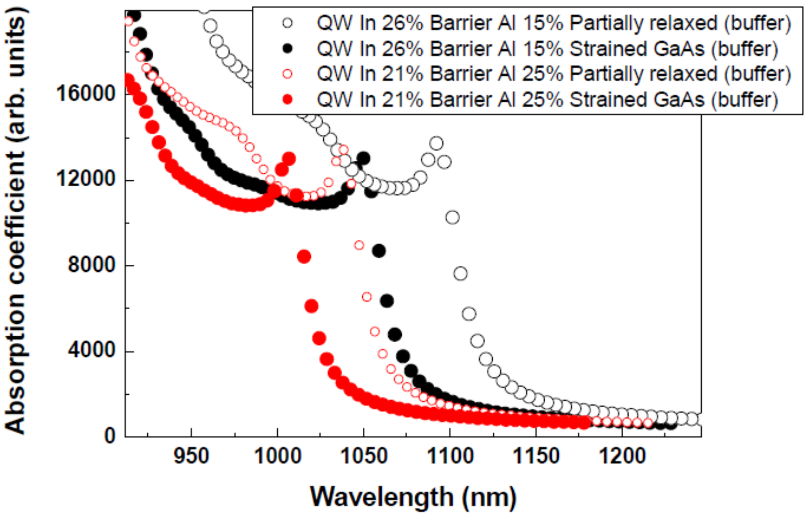
- Diffraction limited performance
- 1070nm wavelength
- YAG fiber

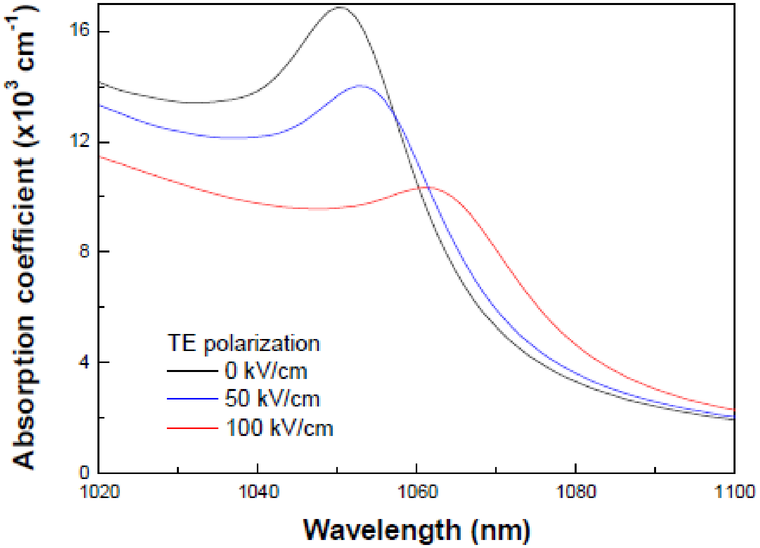
ISDEFE has a capability to simulate and optimize the optical properties of MQW



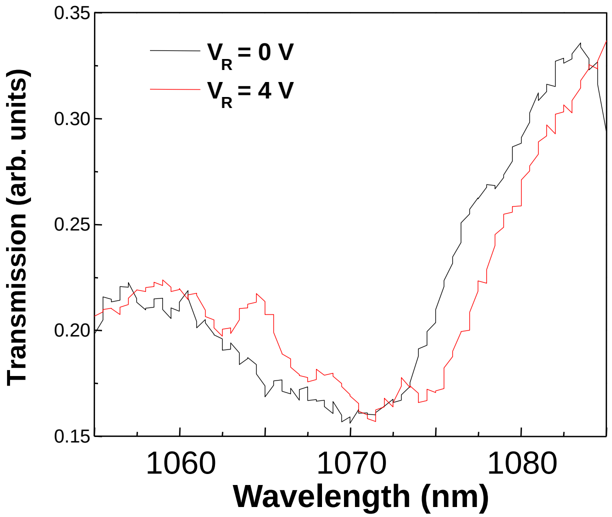
- Number of Quantum Wells: typically >50
- Active region (QWs):
  - Engineered accounting for quantum and excitonic effects
  - (In,Ga)As/(Al,Ga)As structure
  - Wells: High InAs mole fraction (>21%)
  - Barriers: designed to improve confinement (Al >10%)
- Added Anti-Reflex Coating and contacting

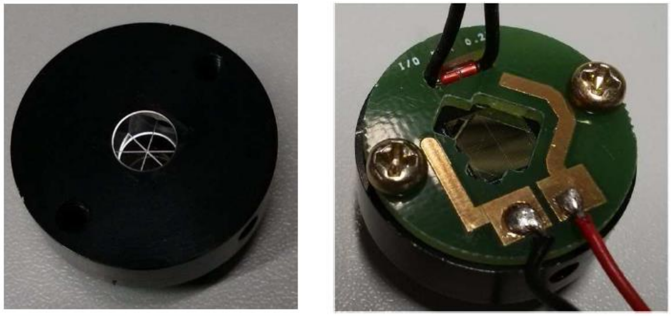
Simulation results:

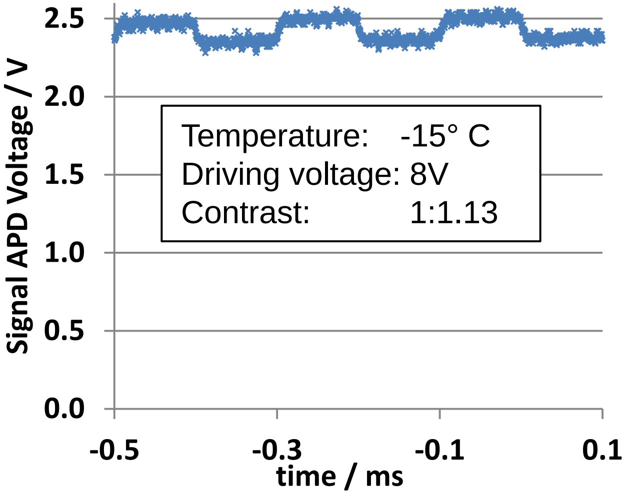




ISDEFE's MQW MRR prototype modulates at 1064 nm, but material needs further optimization


Measured Transmission


Assembled MRR

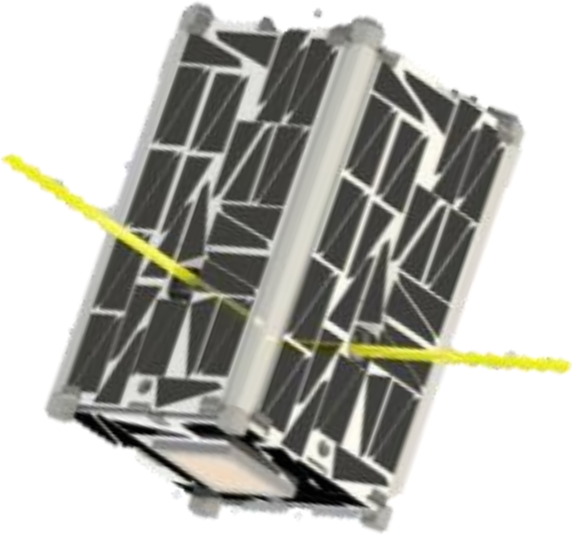

Modulated Signal

Tests at various temperatures:
→Proof-of-concept that MQW at 1064 nm and 1070 nm is possible.

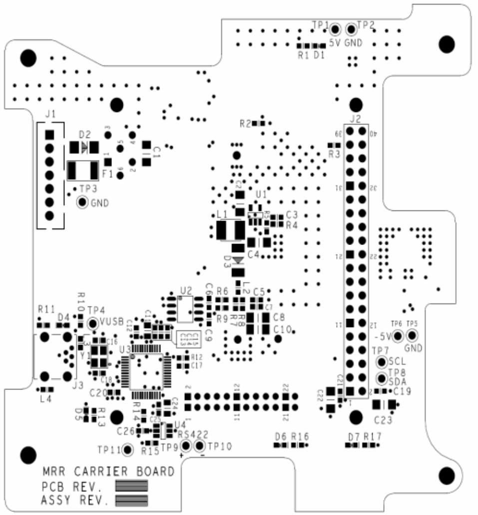
MRR driver electronics were developed at NASA Ames in parallel to the ISDEFE MQW prototyping effort

MRR driver design goals

Parameter	Design Goal
Data rate	20 MHz
Min/max voltage	Variable, 0…12 V
Form factor	1U compatible
Power consumption	< 1 W
Capabilities	1. Comm. interface 2. Independent payload

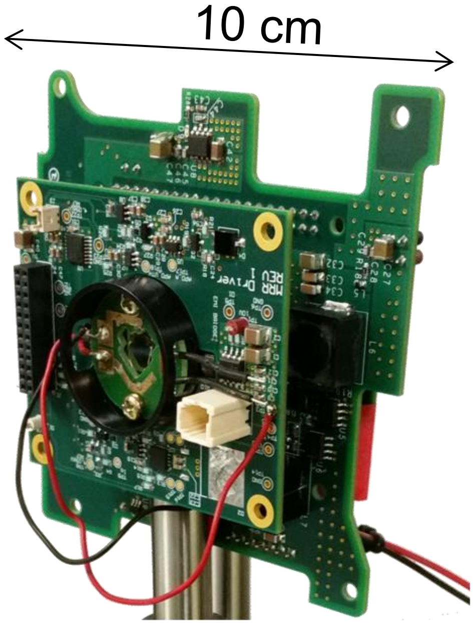


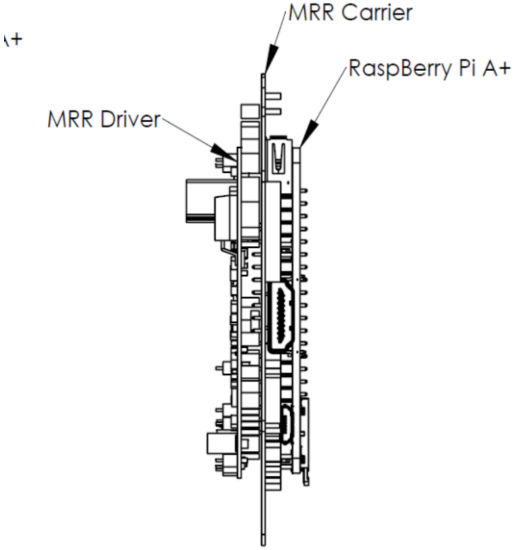
Driver electronics were developed to act both as an independent payload, or as a communication system

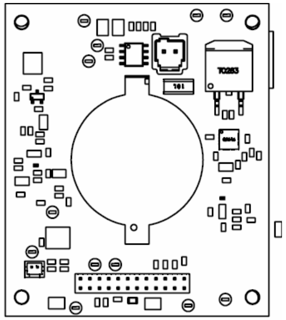


Carrier board:

- Hosts RaspBerry PI (main processor)
- Data connection to S/C (USB & UART)
- s/c power conversion (5..14V input)







Driver board:

- High speed current driver
- Sensor readout
- Hosts optional photodiodes
- Can be placed elsewhere

Summary

Summary

1) **Multiple Quantum Well modulation at 1064nm is possible with (In,Ga)As/(Al,Ga)As structures.**
2) **High performance operation of MRR will require further material optimization.**
3) **Versatile driver electronics can be fitted into cubesat form-factor.**

QUESTIONS ?

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