A Wireless Power and Data Acquisition System for Large Detectors

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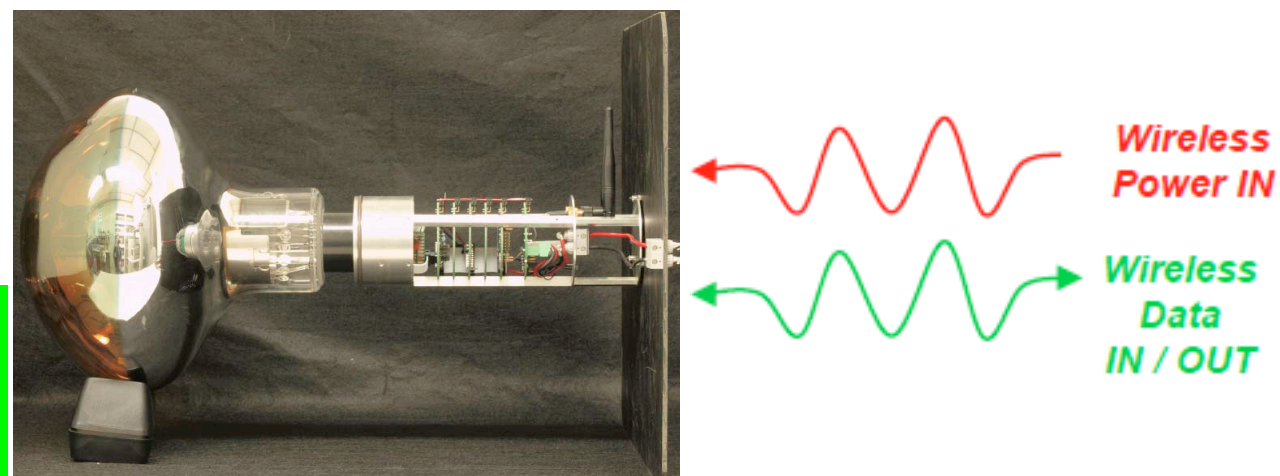
Outline

- Motivation for an all wireless DAQ
- Design considerations for wireless
  - Data
  - Power
- Description of prototype system
- Performance measurements
- Summary

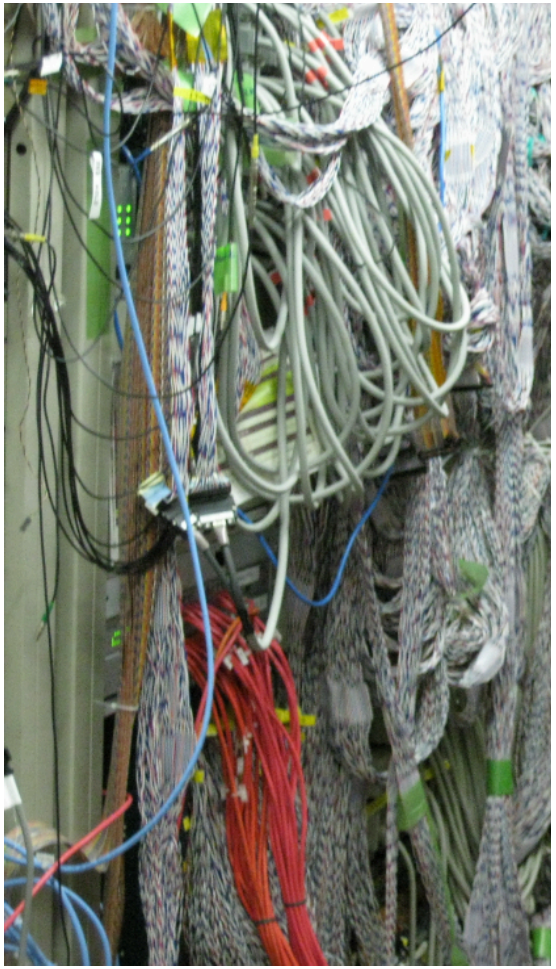
Goal of this R&D:

A feasibility study to build a stand-alone PMT base detector in free space.



Motivation for R&D

- With the detectors increasing in its size and complexity, it is complication to use traditional approach where the power and data are transferred with electrical cables.
- Cabling may represent a significant cost and complication in the experiment.
- Cabling is not practical for detectors in remote location or hostile environment.


Example cable plant

Goals:

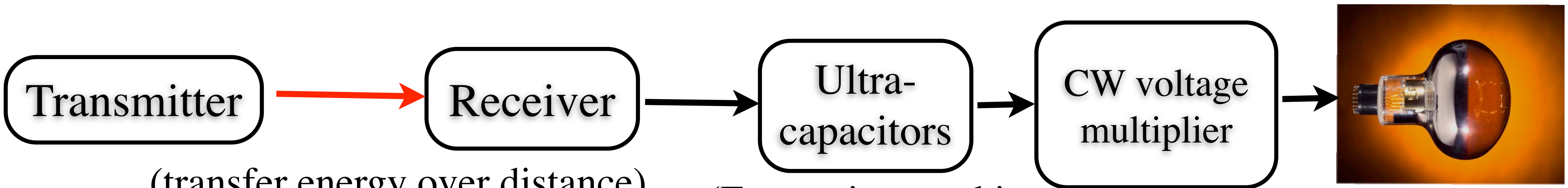
☑ wireless : communication without wires.

☑ Elimination of all cables, no physical connection to the detector.

Approach

- The project is for large detectors containing photomultiplier tubes (PMT).
- Our goal is to develop a PMT base that is powered wirelessly and transfers data wirelessly.

10'' PMT
Hamamatsu R7081



(transfer energy over distance)

(Energy is stored in a series of ultra-capacitors)

(conversion from few to ~1000 V by Cockcroft-Walton)

Two main components of this R&D project:

- ☑ Wireless Data Transfer (802.11n wireless technology)
- ☑ Wireless Power Transfer (Radio Frequency and Optical beam)

Target Specifications

Detector Assumptions	Specifications
Maximum event rate (single p.e.)	**10 kHz**
Bytes per event	6 (2 pulse height, 4 time-stamp)
Average data rate per front-end	**60 kBytes/sec**
Data/Power transmission distance	**~5 meters**
DAQ Specifications	**Target**
Total Power Consumption (10 K events/s)	**< 250 mW**
Digital	120 mW
Front-End	30 mW
HV	80 mW
Data transfer rate	**35 Mbit/s**
Bit Error rate	$<10^{-12}$
Additional Features	Self triggered for pedestals
	Data pull, Programmable HV
	Programmable Discriminators

Wireless Data Transmission

Free-space Optical or Radio Frequency (RF)?

Free-space Optical

Positive:

- Gbit/sec links readily achievable

Negative:

- Requires one RX/TX link per front-end
- **Requires line-of-sight**
- Tricky alignment

RF

Positive:

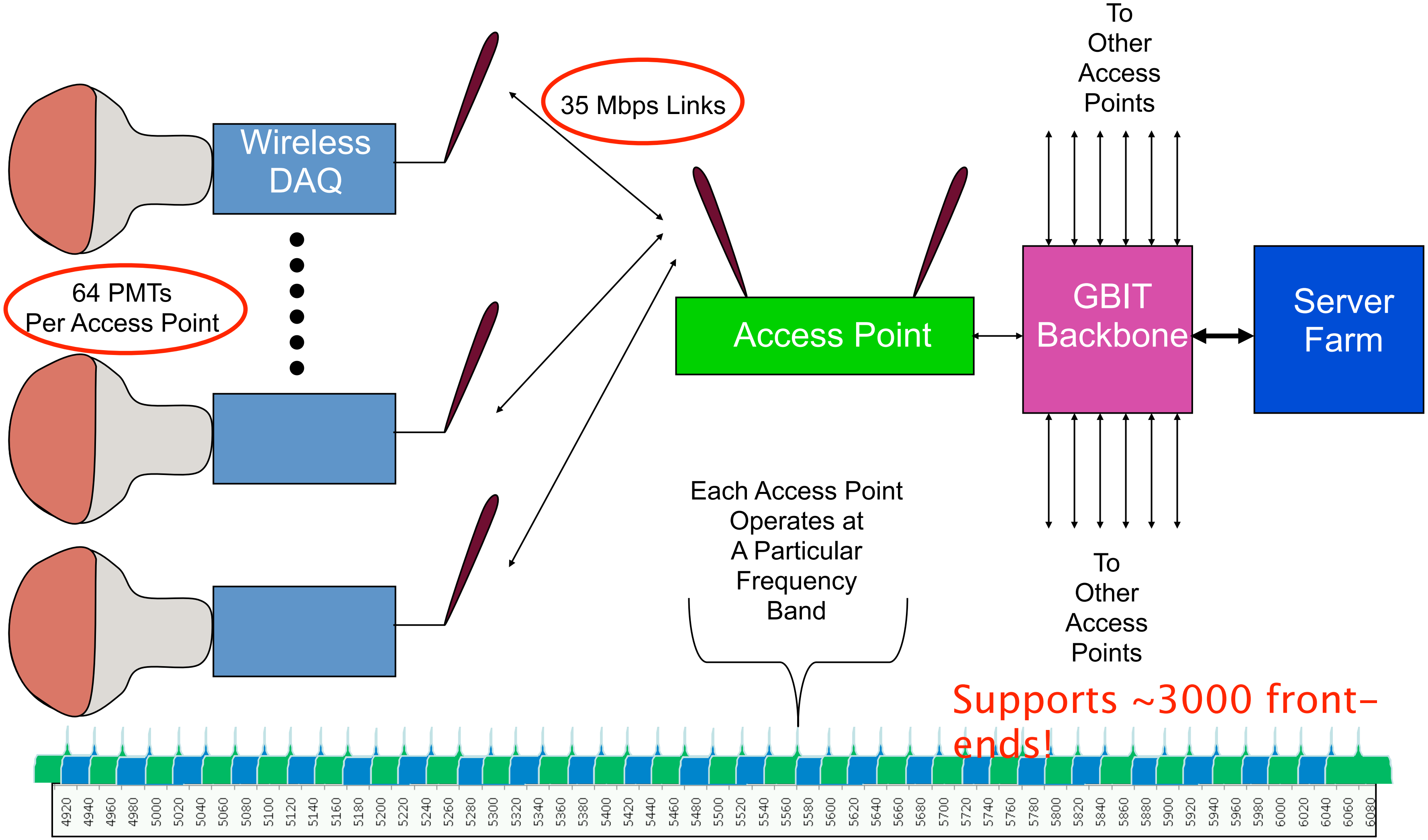
- **One receiver services many front-ends**
- **Does not requires line-of-sight**
- No alignment is necessary
- Can use commercial RX/TX

Negative:

- Fastest commercial links ~1 Gbit/sec

☑ RF data transmission is chosen for this project.

Multiple access point system



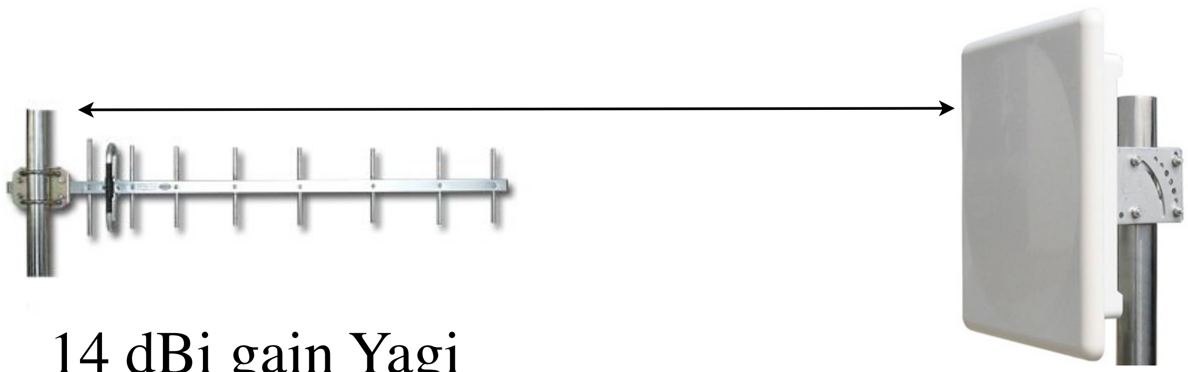
– **48 Access Points per sector x 35 Mbit/s per Access Point = 1.68 Gbit/s**

- Extrapolation to large system requires careful planning of frequency space.

Wireless Power Transmission

We tested both RF and optical power transfer methods.

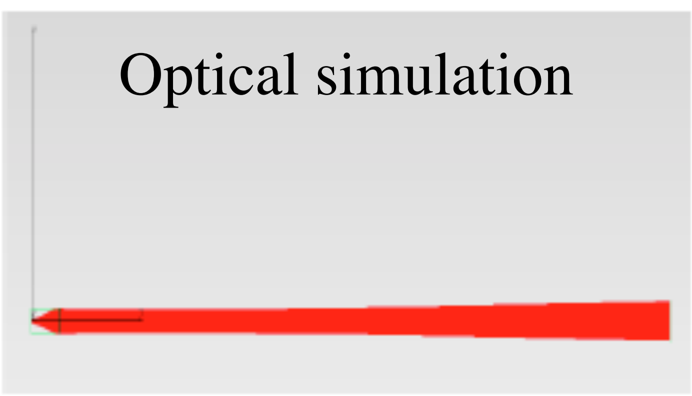
RF : using microwave antenna



14 dBi gain Yagi antenna

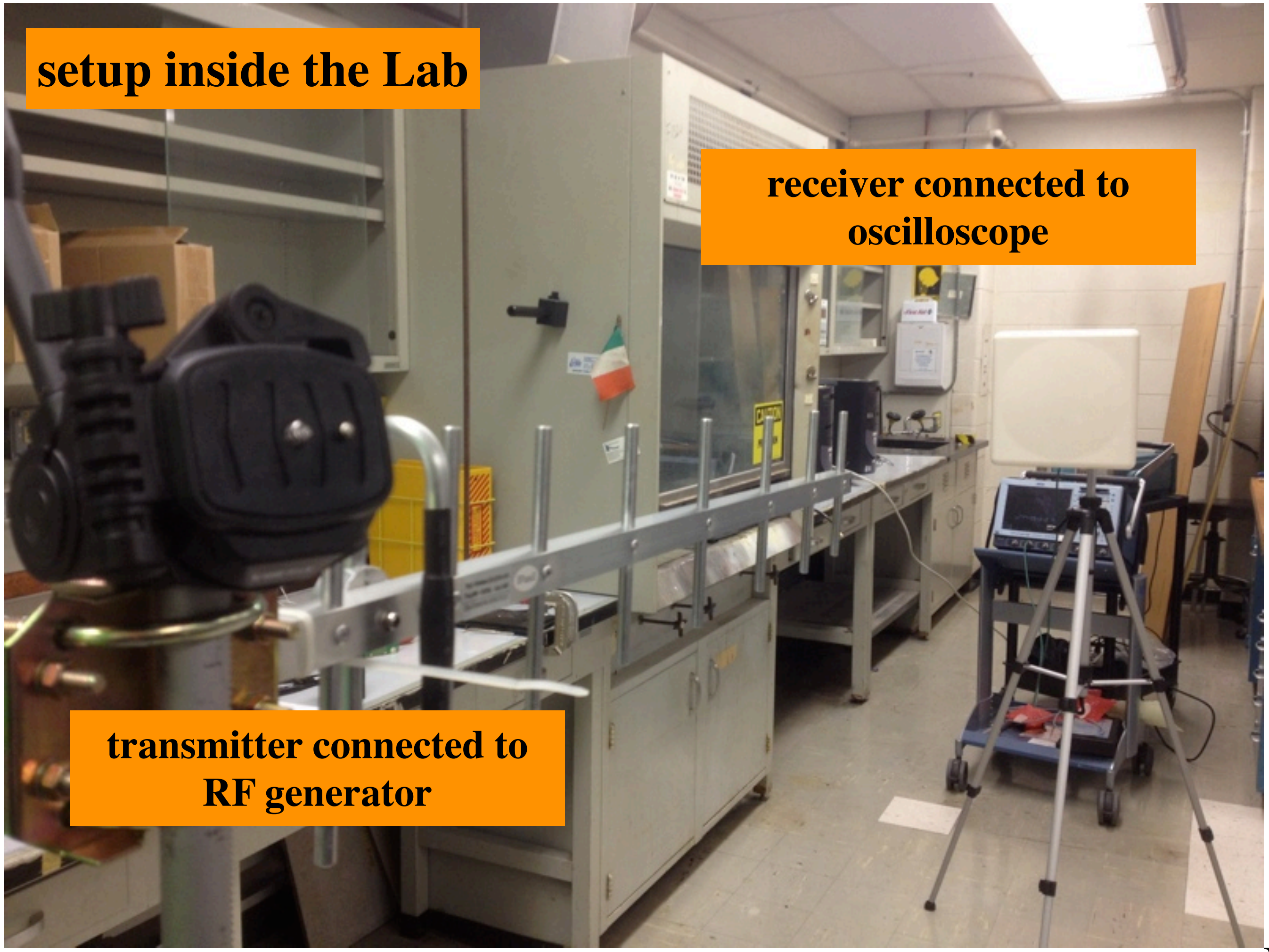
11 dBi gain patch (/flat panel) antenna

Optical : Diode with a collimator



The light from a high power LED is collimated into an 8” diameter beam and received by a photovoltaic panel.

RF Power Transmission



Power transfer using microwave antennas

Transmitter:
14 dBi gain Yagi antenna
Receiver:
11 dBi gain Patch antenna
Frequency : 915 MHz

Friis Transmission Equation:

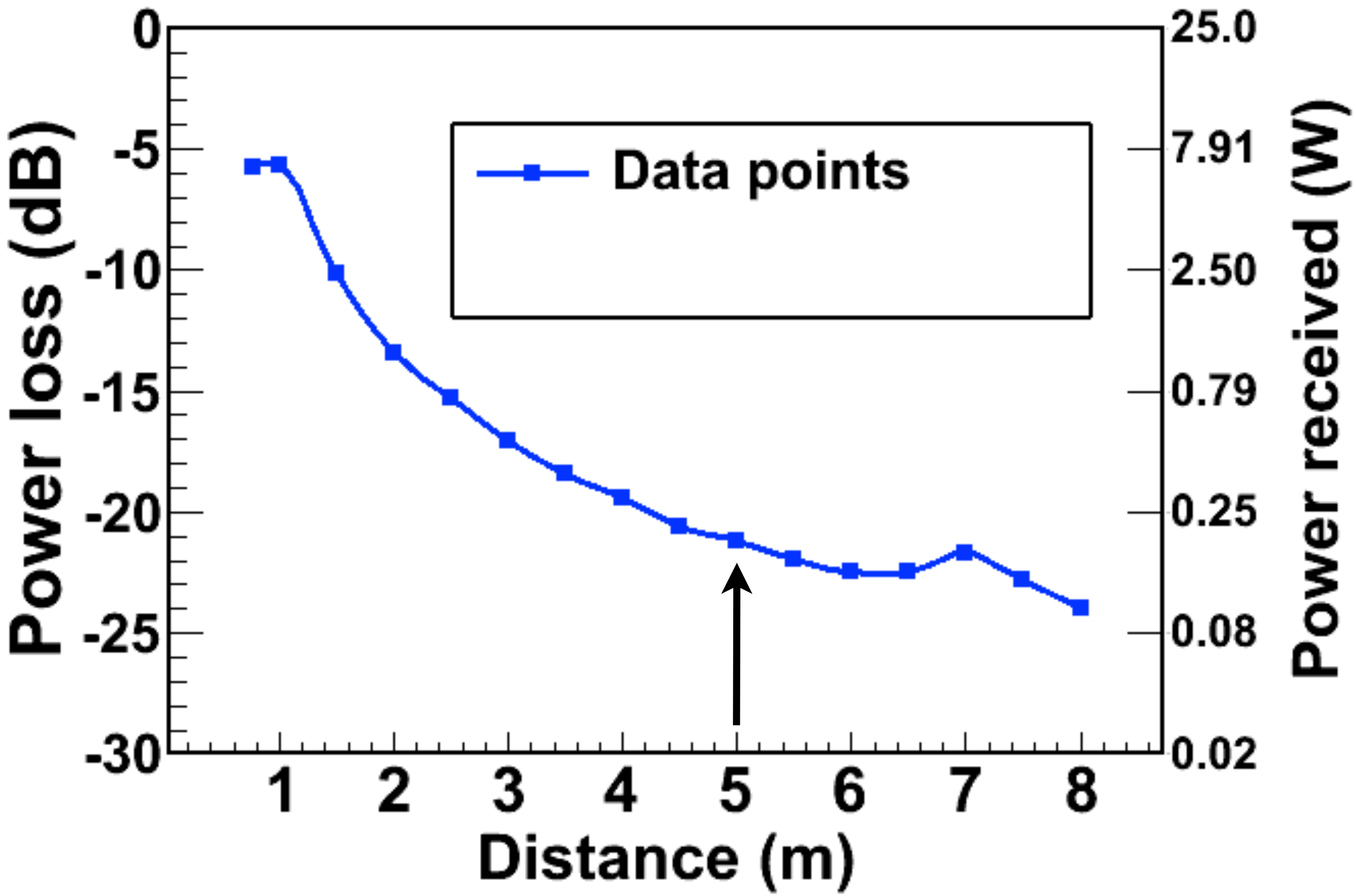
$$\boxed{\frac{P_r}{P_t} = G_t G_r \left(\frac{\lambda}{4\pi R}\right)^2}$$

power gain distance wavelength

Free space propagation under ideal conditions:

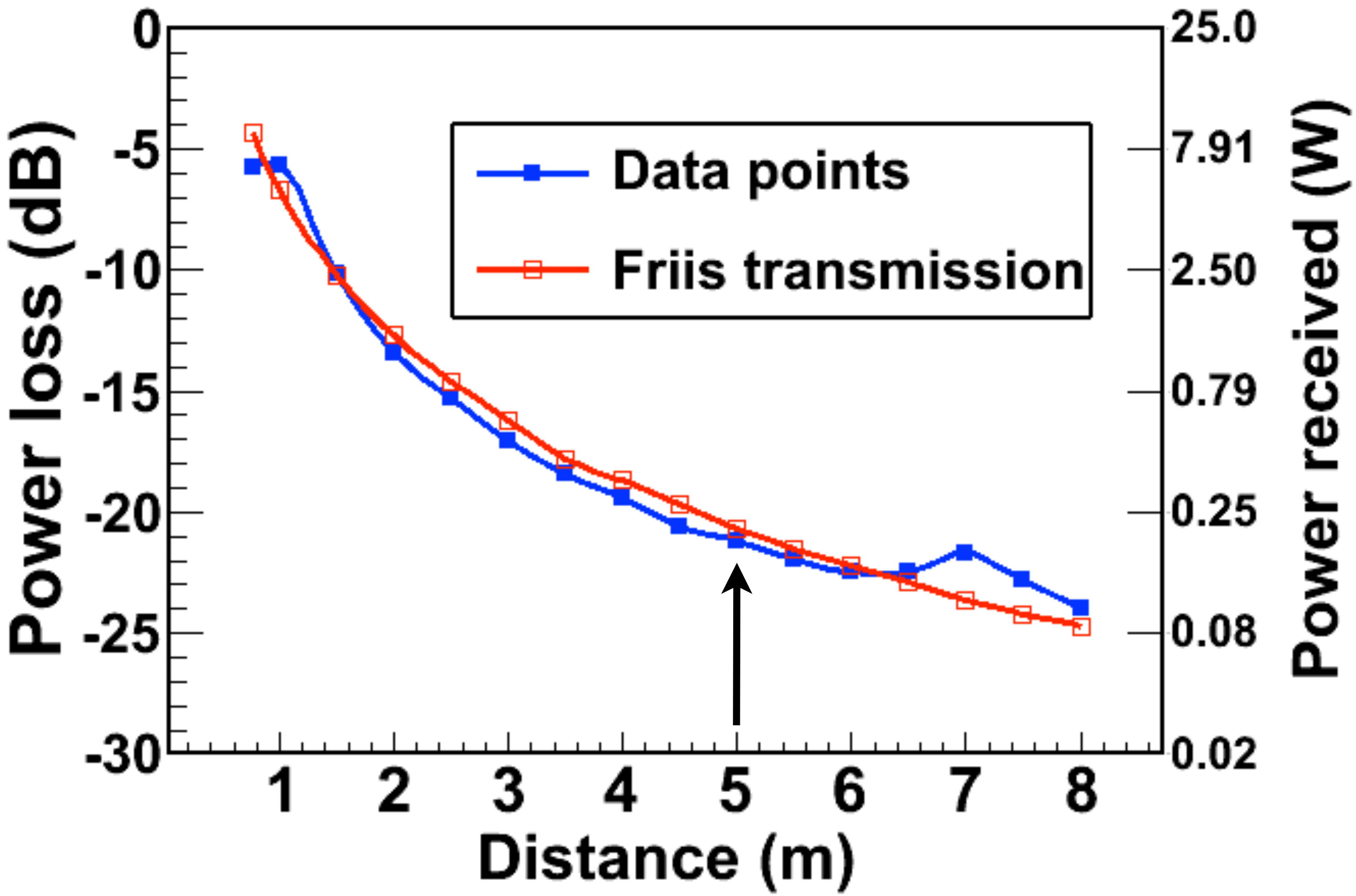
- ☑ no object present to affect propagation
- ☑ no scattering from buildings.. etc.

Power Received



20 dB power loss at a distance of five meters from the transmitter

Power Received



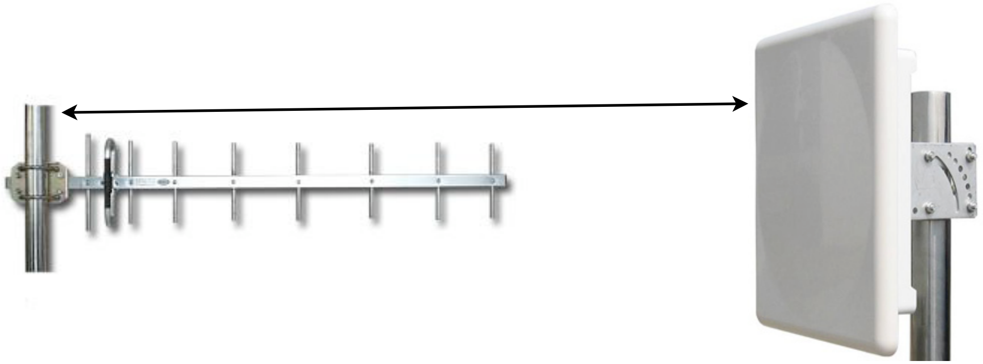
20 dB power loss at a distance of five meters from the transmitter

Pro-Cons of RF option

RF Power transmitter

Positive:

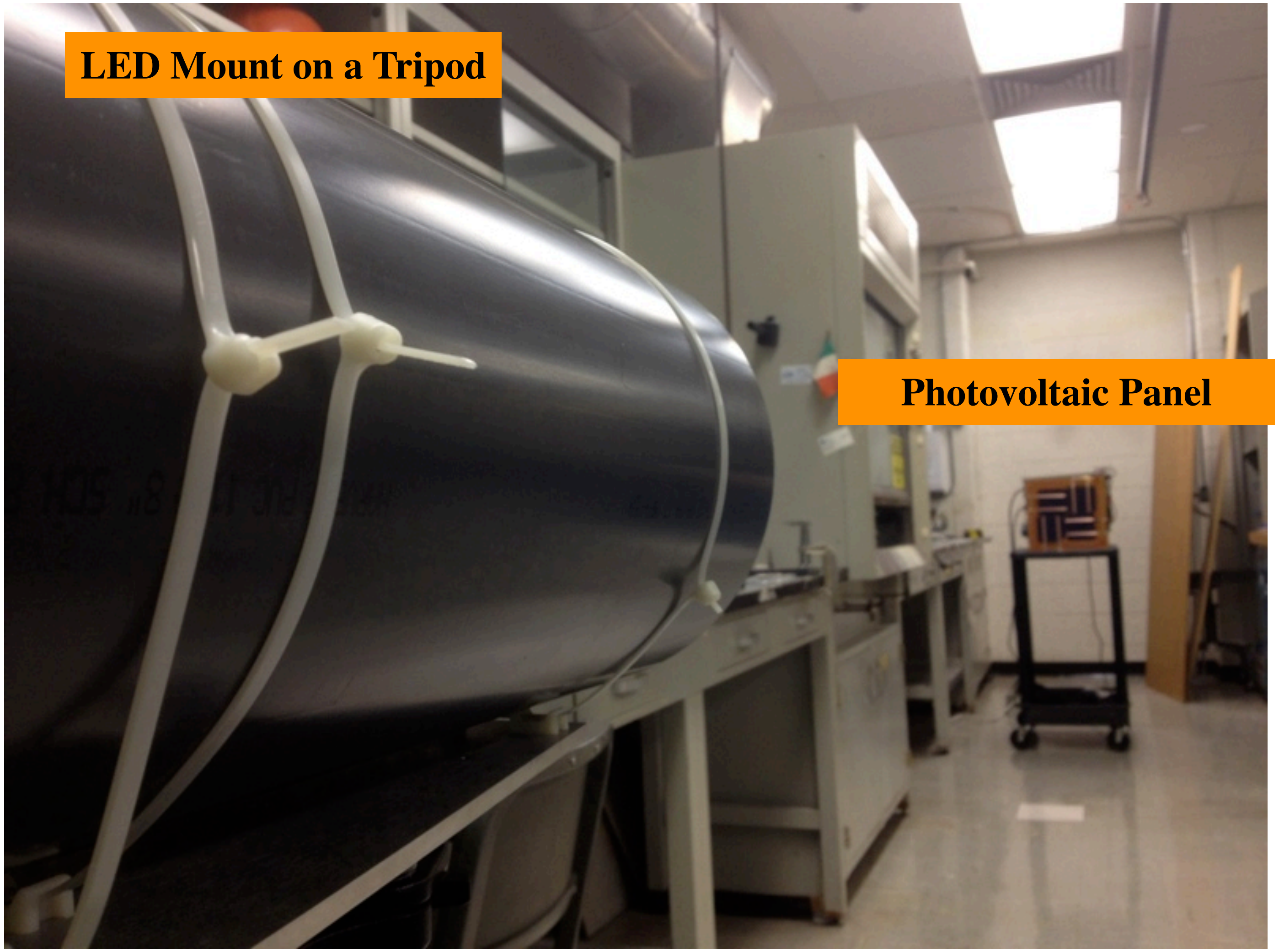
- High Power generation is possible
- Generation and conversion efficiency ~80%
- **One RF generator and transmitter antenna for multiple receivers** : simple system
- **Does not require control system, not necessarily line-of-sight** i.e. more easily implemented



Negative:

- **RF➜DC conversion is required at the receiver end**
- Long distance transmission is possible, but requires high power generation with exclusion zone requirement
- RF interference with RF data transfer.
- Geometrical inefficiencies due to wider angle emission

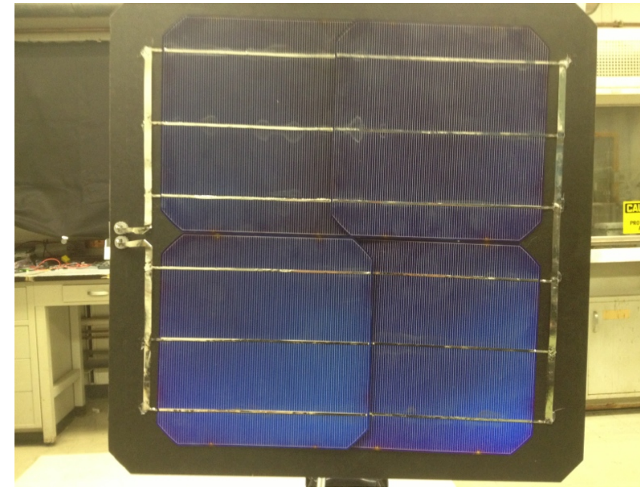
Optical Power Transmission



Power transfer using an optical source (high power LED) and receiver (PV cell)

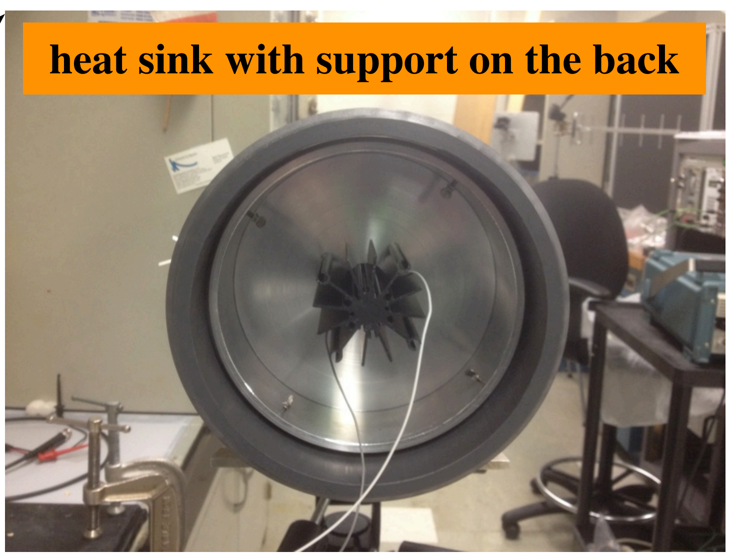
High power LED :
wavelength 940 nm (infrared)
max current : 1A
optical power : 3.5 W

Receiver : Photovoltaic Panel
each PV cell dimension (15.6×15.6 cm^2)

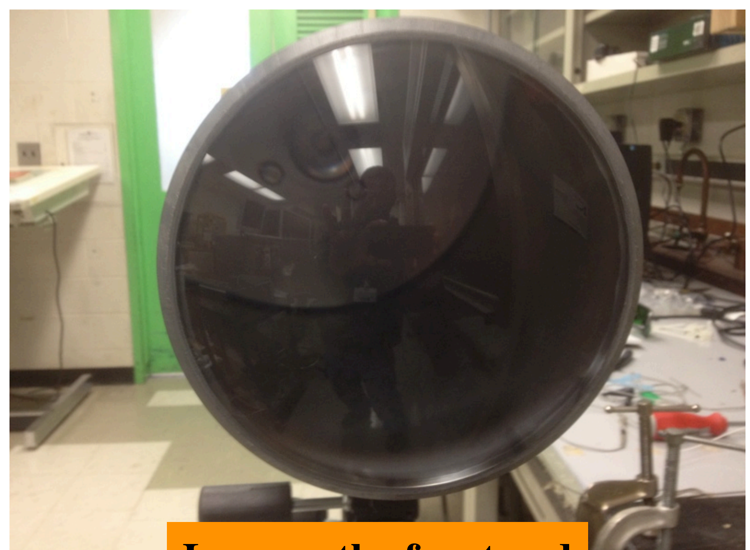


Photovoltaic (PV) panel

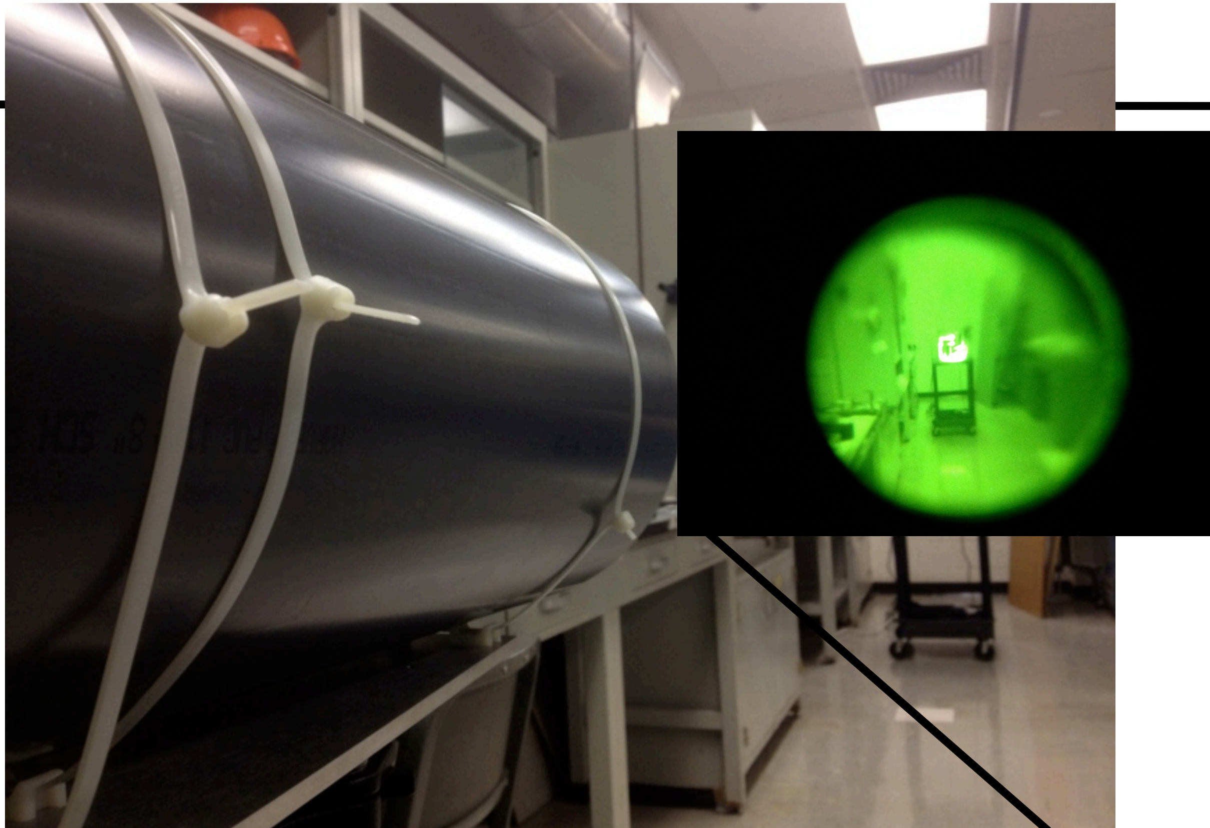
four PV cells are in series

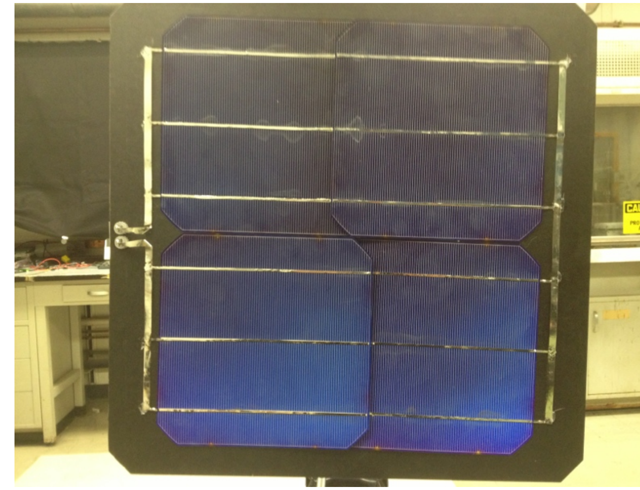


heat sink with support on the back



Lens on the front end





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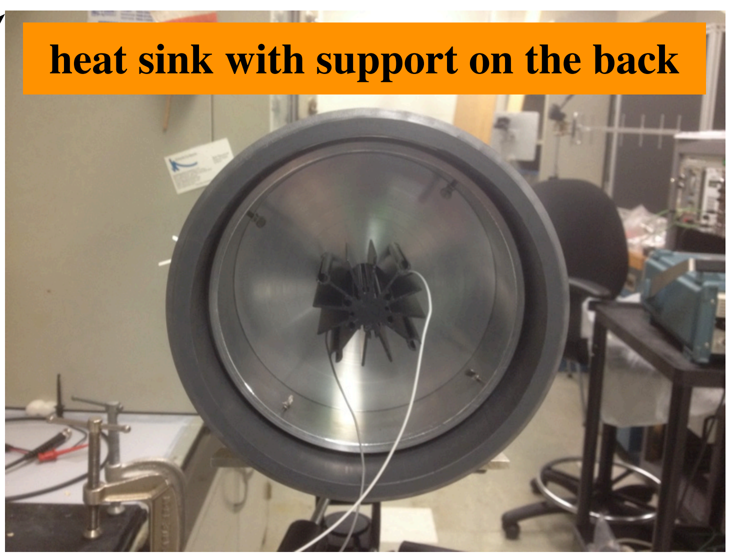
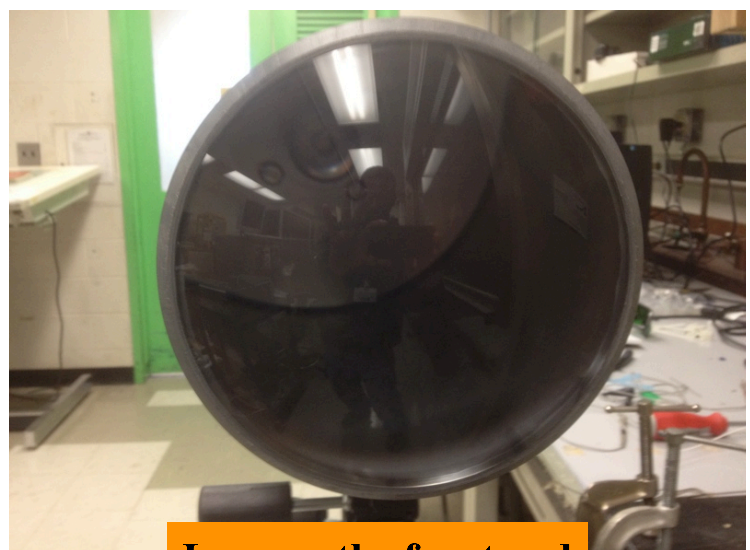


heat sink with support on the back



Lens on the front end

warning light

Laser Hazard sign

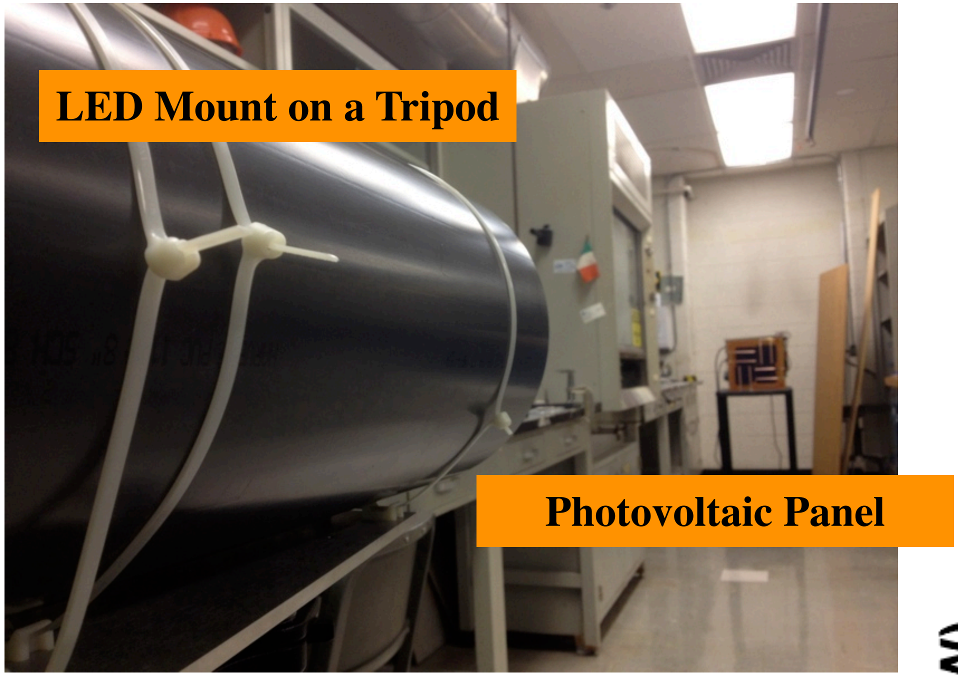
Technical Specifications

- Wavelength : 940 nm (infrared)
- Optical Power of LED : 3.5 Watt
- Peak power of the beam : 20 mW/cm^2
- Beam diameter : 8 inch
- Lens : 8 inch diameter, 400 mm focal length
- **Laser classification : Class 3B**
- Eyewear protection : O.D. 2 or greater at 940 nm

laser eyewear

ANL laser safety training and laser eye exam is required.

Power Received

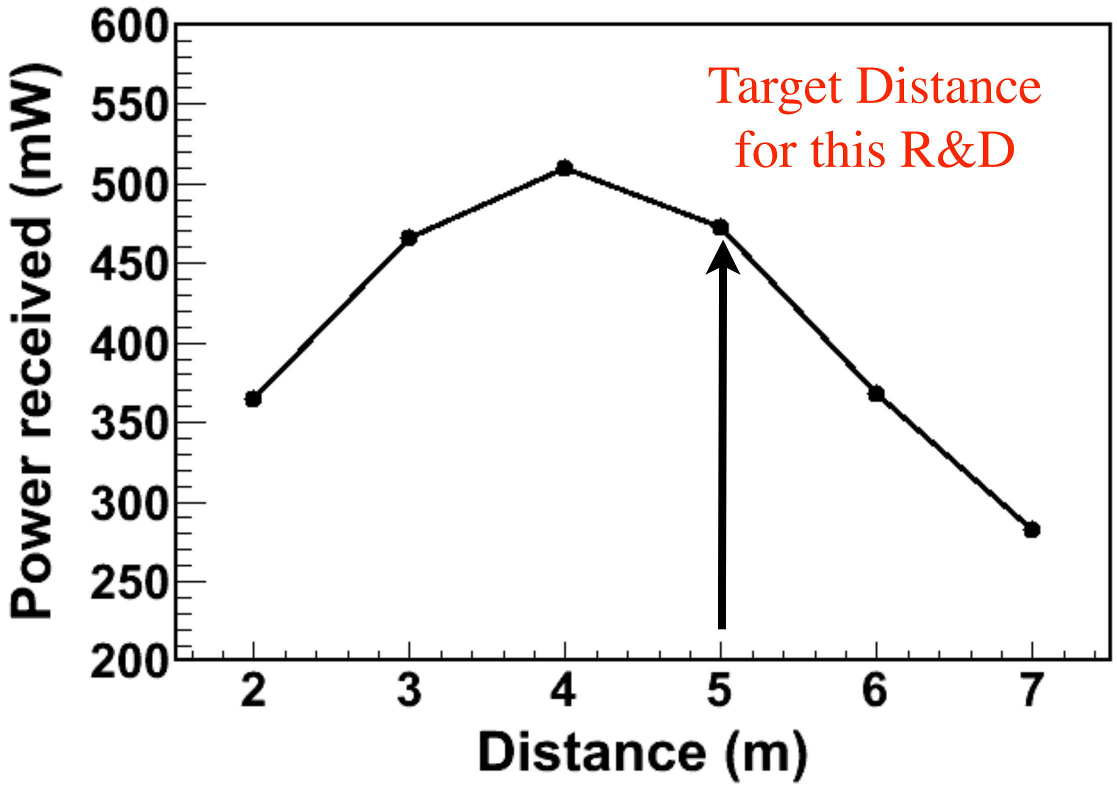


LED : infrared, 940 nm
max current : 1A
Power Transmitted : 3.5 W

Receiver : Photovoltaic Panel

"High power LED"

Nearly 470 mW of D.C. power is received at a distance of five meters from source.



Pro-Cons of Optical option

<u>Optical : Laser Diode or Diode with Collimator</u>

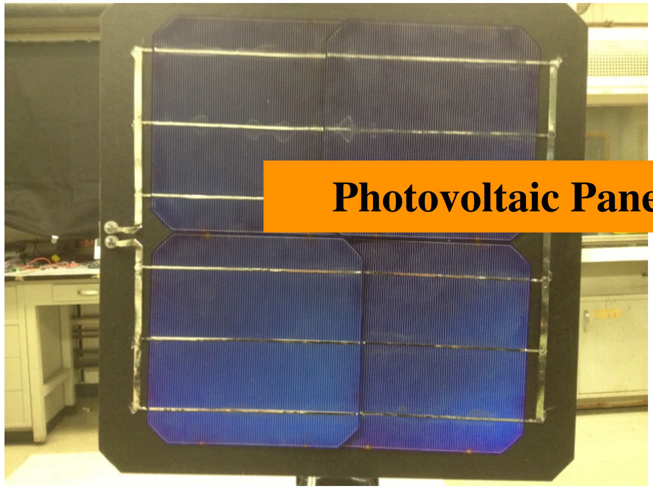
Positive:

- Straightforward technique
- Relatively inexpensive
- Class IIIb - relatively safe
- **Long distance transmission is possible with collimated beams**
- 33% generation side efficiency
- **DC power is received at the receiver end**

LED Mount on a Tripod

Negative:

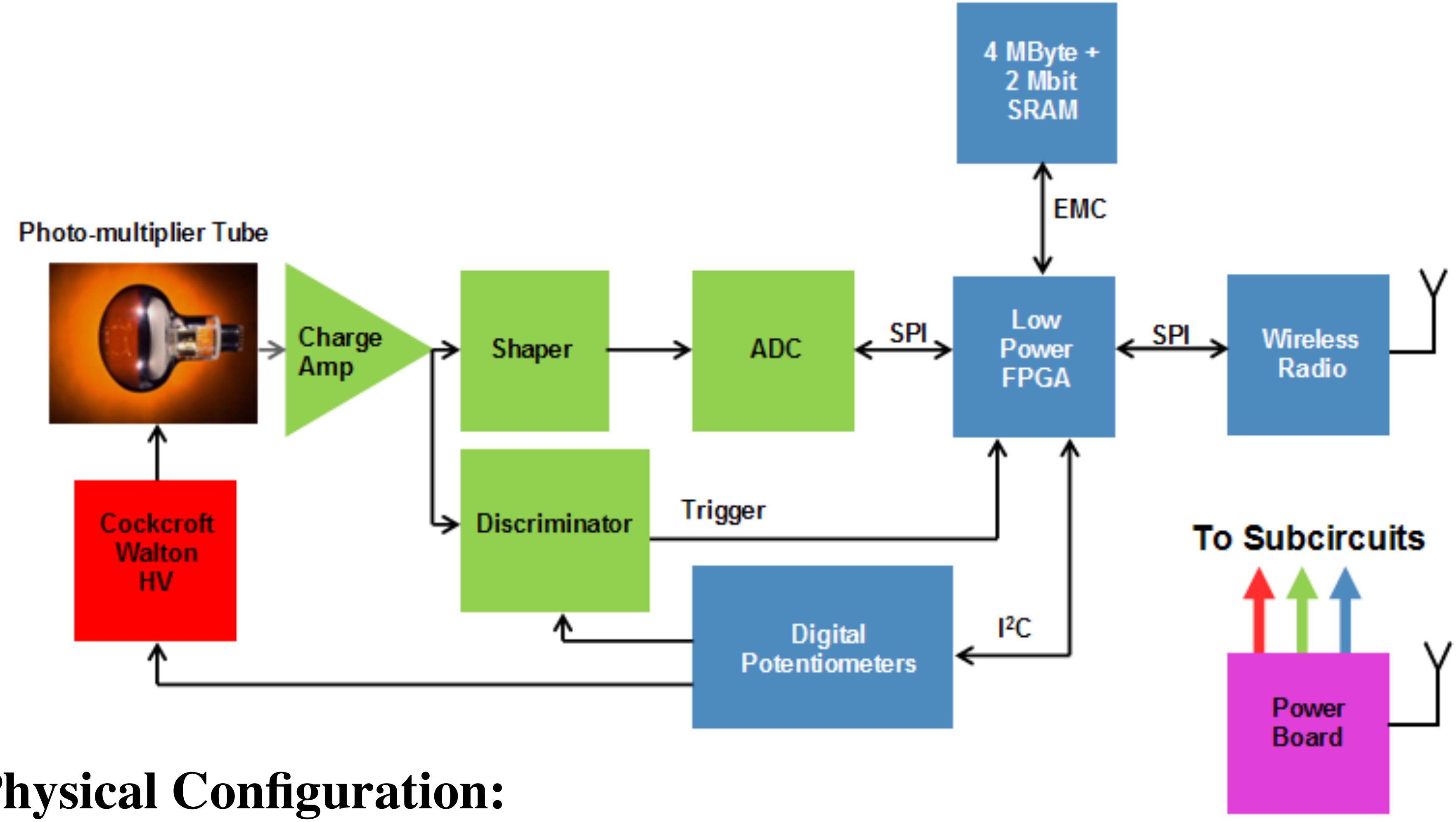
- 20% conversion efficiency at receiver
- Requires large receiver panel
- **Line-of-sight is required.**
- **One receiver to one transmitter.**



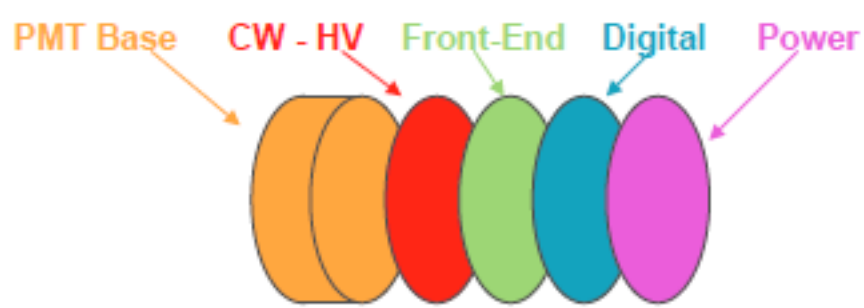
Photovoltaic Panel

☑ Optical power transmission is chosen for this project.

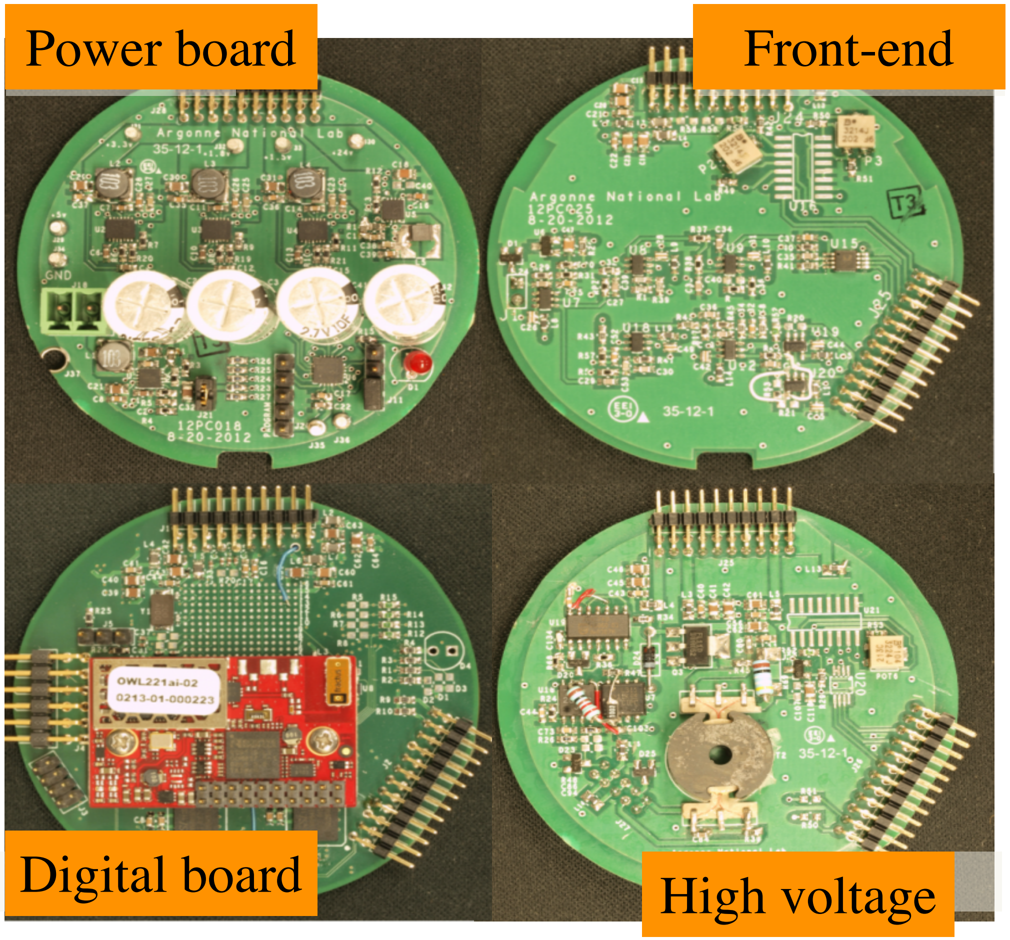
Block Diagram of Prototype



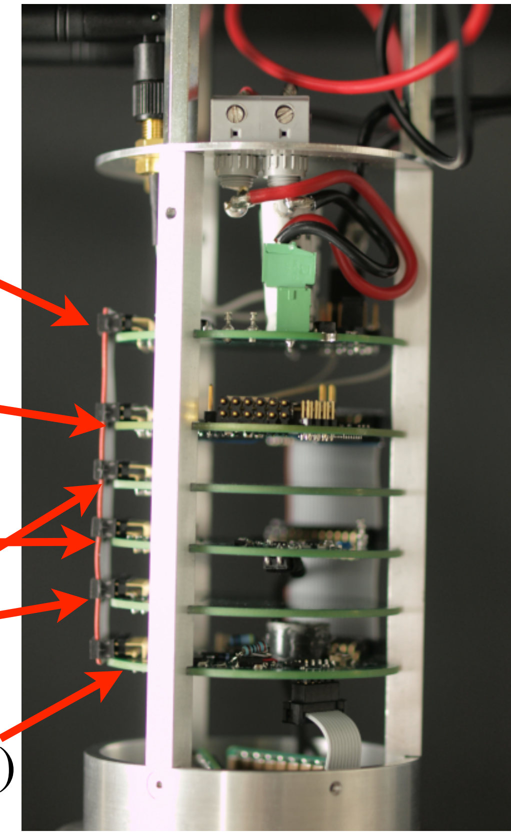
Physical Configuration:



Pictures of Individual Boards



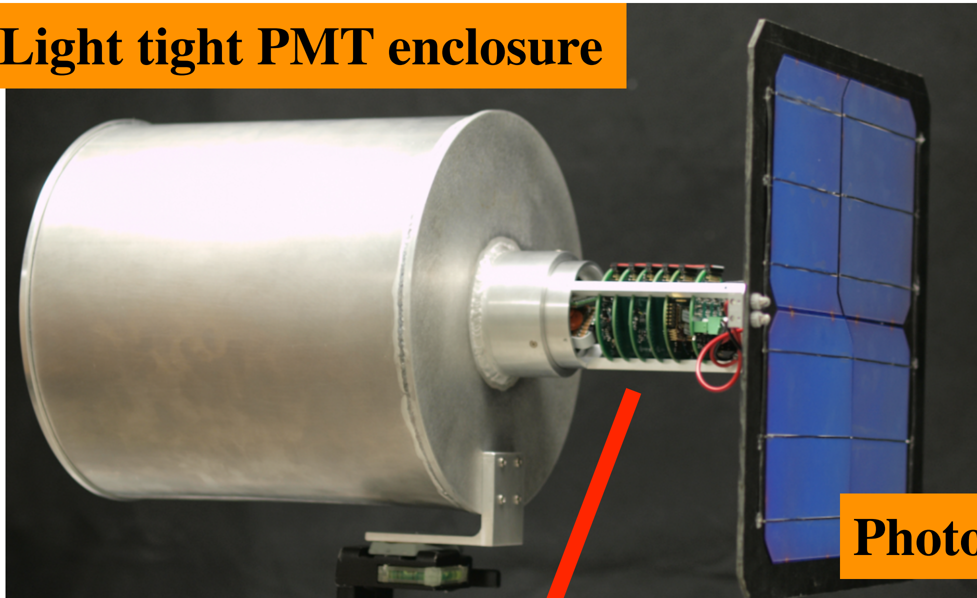
power supply
Digital
Front-end
Shield
HV (Cockroft-Walton)



assembly of the system with the PMT

Prototype Single Front-End System

Light tight PMT enclosure



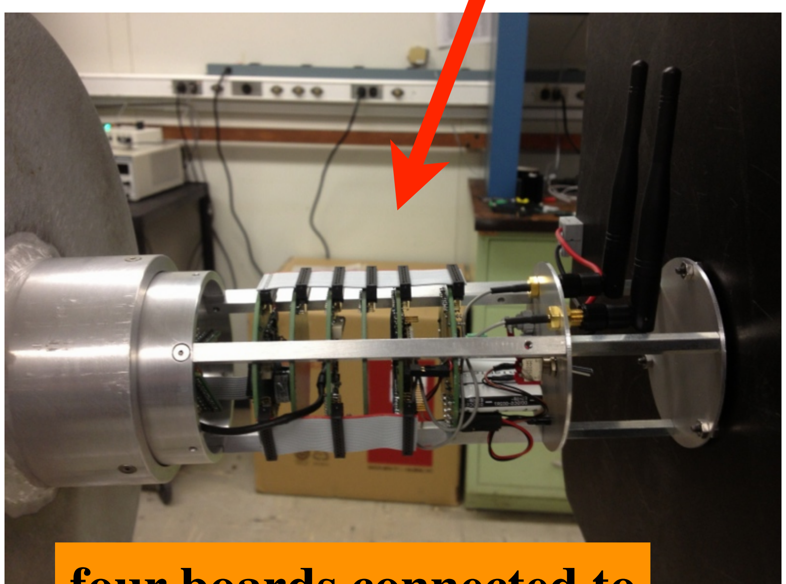
Photovoltaic panel

802.11n 5GHz

UDP Data Push

Access point

Gigabit Ethernet



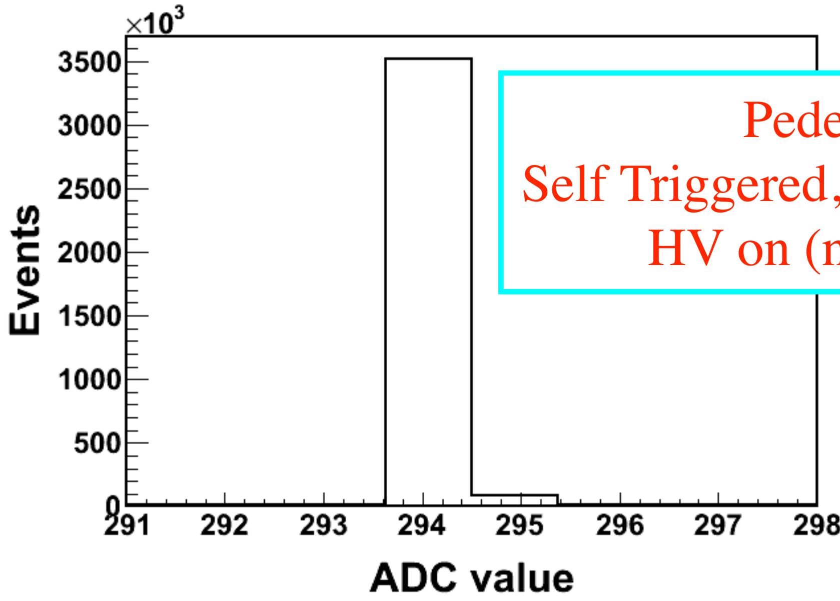
four boards connected to PMT base

The front-end transmits data once per second as a single UDP packet.

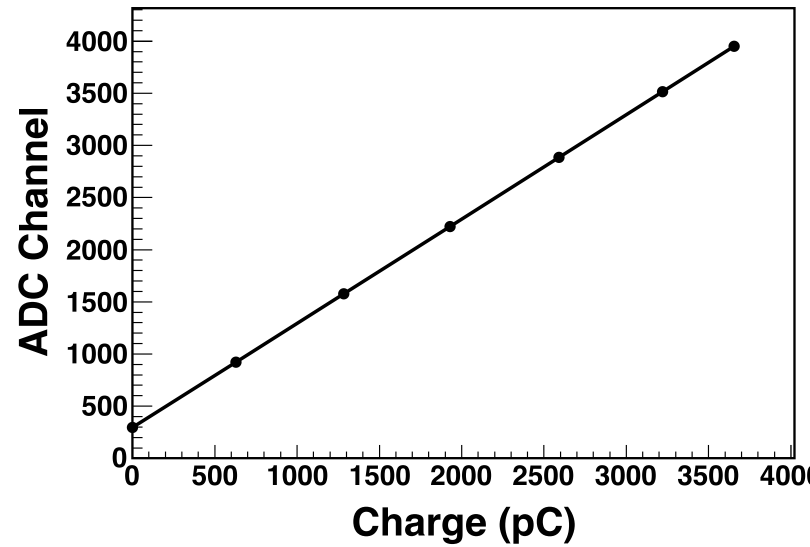
PC with Scientific Linux

System Tests (All wireless operation)

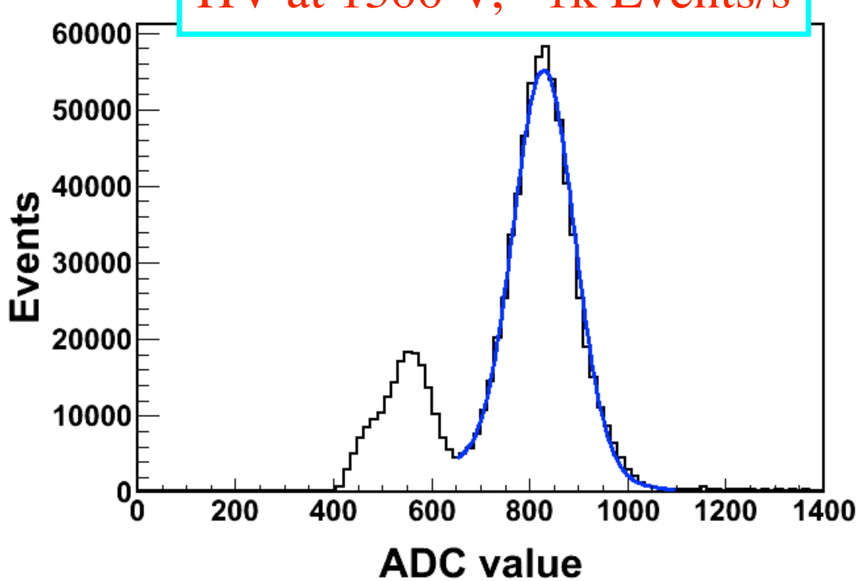
Pedestal
Self Triggered, 10 k Events/s
HV on (no PMT)



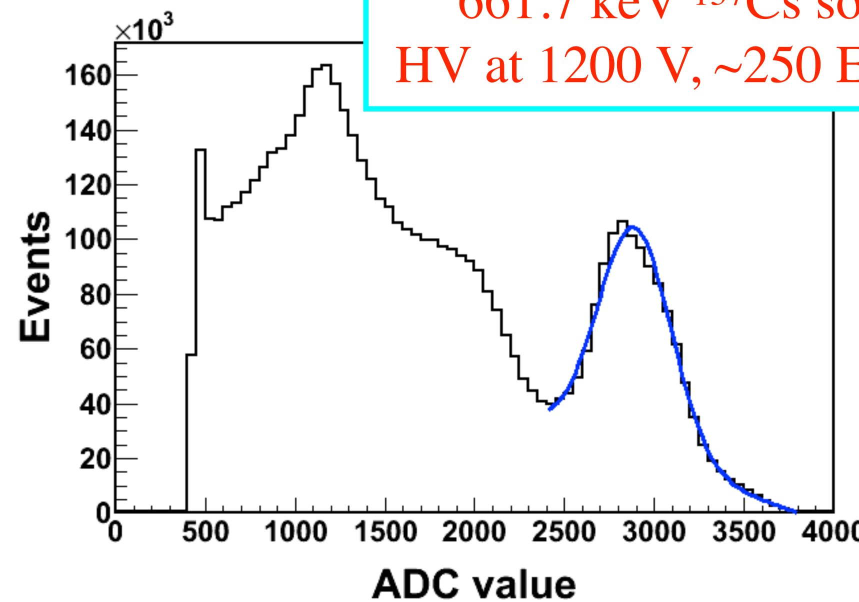
Charge Pulser Response
Self Triggered, PMT HV on



60 keV ^{241}Am source
HV at 1300 V, ~1k Events/s



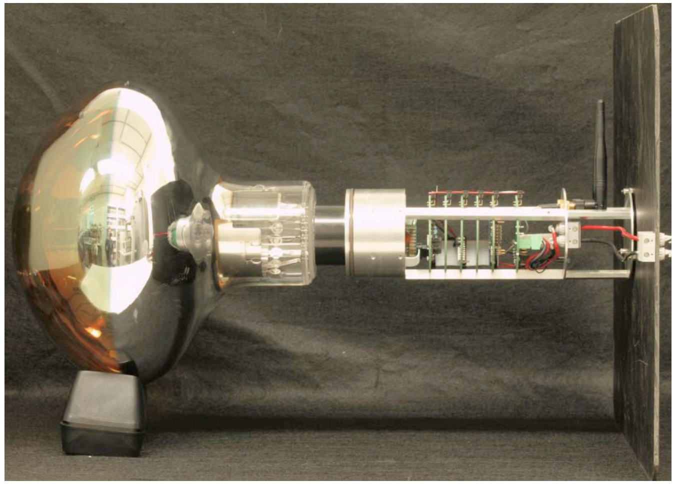
661.7 keV ^{137}Cs source
HV at 1200 V, ~250 Events/s

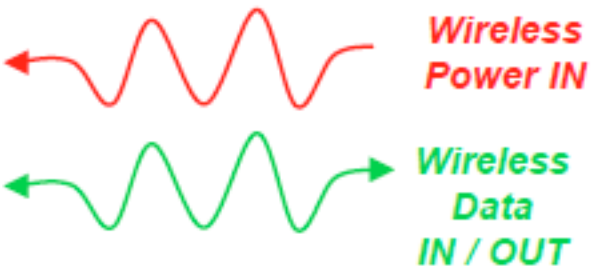


Performance Summary

Specifications	Target	Performance
Total Power Consumption (10 K events/s)	**< 250 mW**	**386 mW**
Digital	120 mW	216 mW
Front-End	30 mW	39 mW
HV	80 mW	131 mW
Maximum event rate	**10 kHz**	**80 kHz**
Average data rate per front-end	60 kBytes/s	> 60 kBytes/s
Data transfer rate	**35 Mbit/s**	**11 Mbit/s**
Bit Error rate	$<10^{-12}$	Dropped Packets

We did an excellent job in building an all in wireless DAQ implemented in a PMT base.





Summary

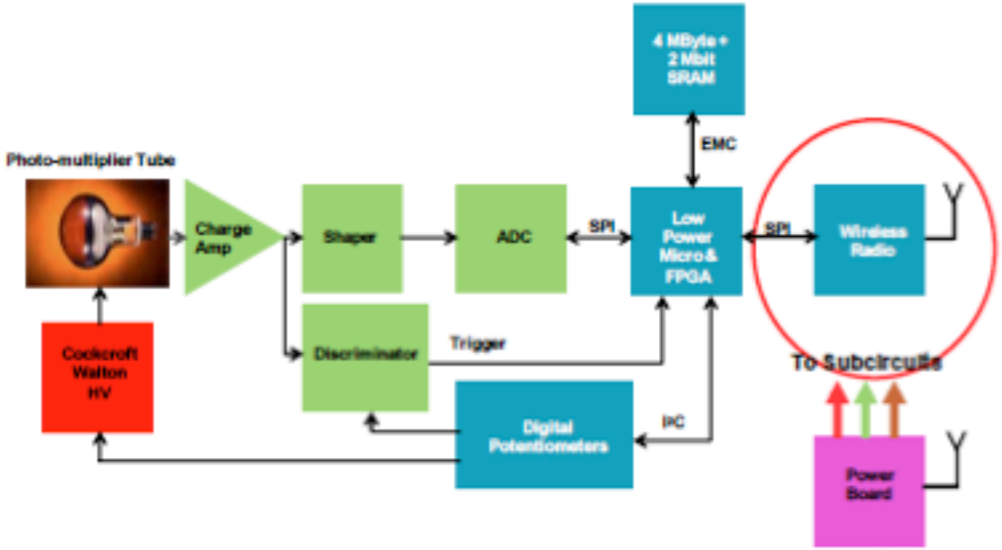
- We have designed and built a wireless DAQ implemented in PMT base:
  - Operates from wireless power
  - Sends data wirelessly
  - Maximum transfer rate of 11 Mbit/s
  - Supports up to 16 front-ends per wireless channel
- Power requirements are high to be practical for wireless power for a large system
- We have shown proof-of-principle design, but some issues yet to be worked.
- Next stage of the development focuses on:
  - Lower power operation
  - Optimized code power and transfer speed
  - Efficient RF power transfer
  - ASIC development
- We acknowledge the support from Argonne National Laboratory to carry out this project.

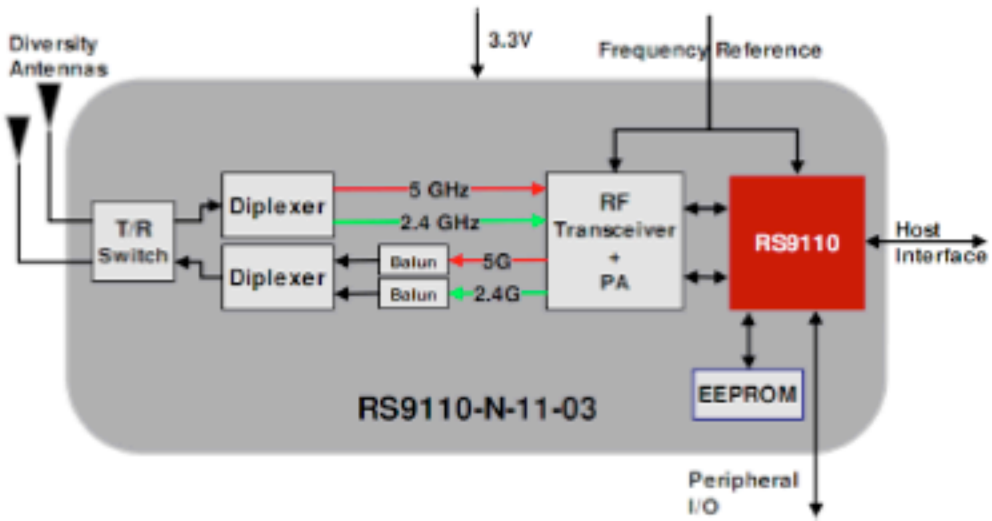
THANK YOU!

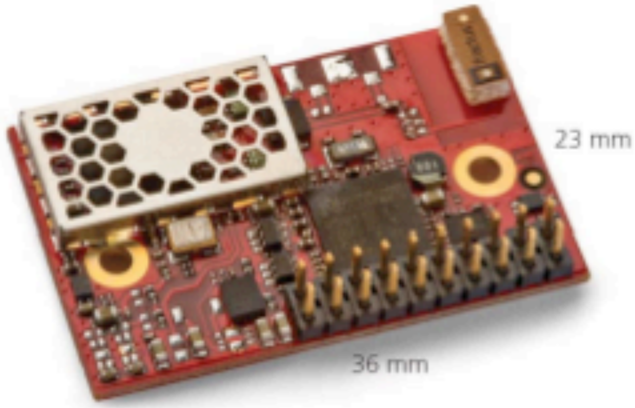
A Few Circuit Details

Wireless Radio:

– Selected commercial unit made by Connect Blue
  - Based on RedPine
  - cBOWL221a
  - SPI interface
  - 802.11n
  - Payload up to 35 Mbps

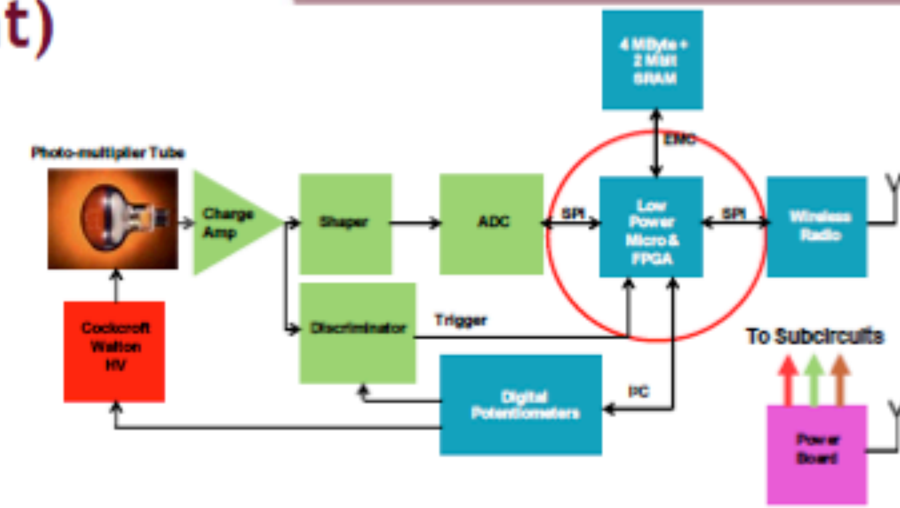






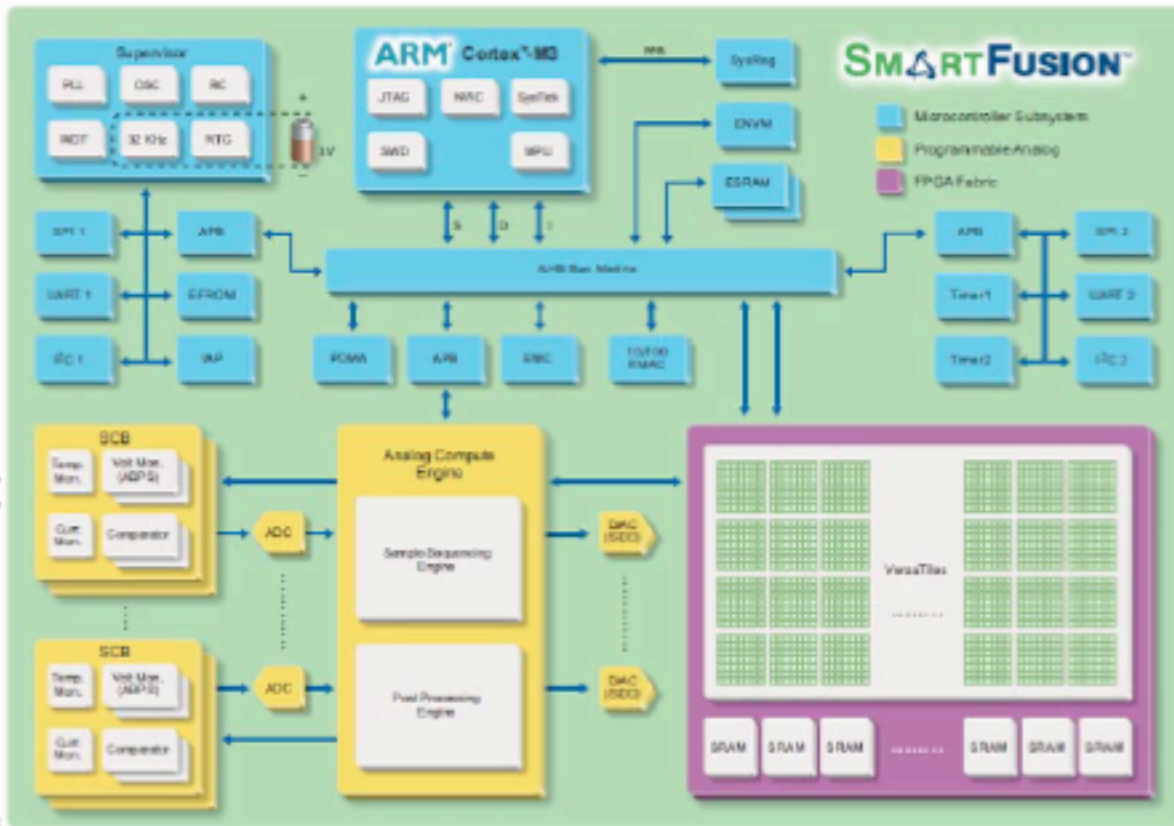
⇨ ***Need a 50 MHz SPI clock and a very low latency SPI bus!***

A Few Circuit Details (Cont)



FPGA: Microsemi SmartFusion Customizable System-on-Chip

- Model A2F200
- Hard 100 MHz 32-bit ARM Cortex M3 processor
  - 256 Kbyte non-volatile internal memory
  - (2) I2C peripherals
  - (2) SPI peripherals
  - (2) 32-bit timers
  - 8-channel DMA
- High-performance FPGA
  - Low-power
  - 130 nm CMOS
  - Nonvolatile config
  - 350 MHz performance
  - Embedded SRAM & FIFC



⇨ ***Ideal for this application***

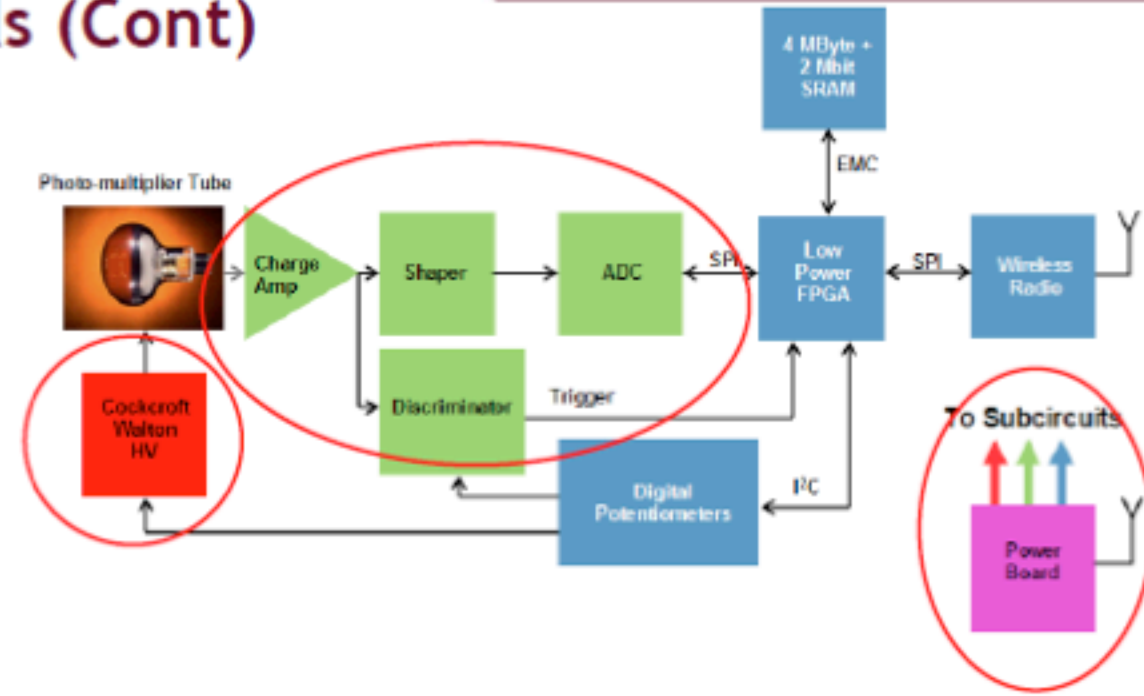
⇨ ***Programming:***

- ⇨ ***M3: C program***
- ⇨ ***FPGA: VHDL***

A Few Circuit Details (Cont)

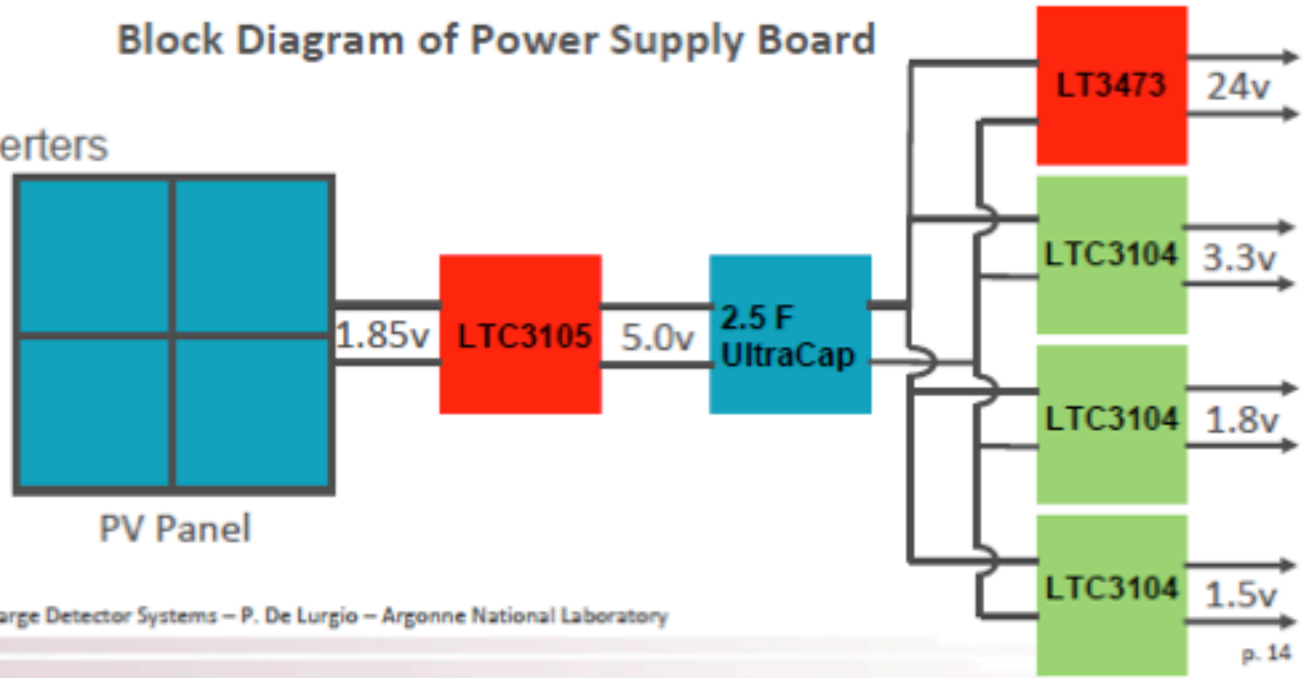
Cockroft-Walton
- 10 stage, full custom

Front-End
- Charge-sensitive amplifier
- 12-bit SPI ADC AD5074
- Programmable Lower level and zero crossing constant fraction discriminator



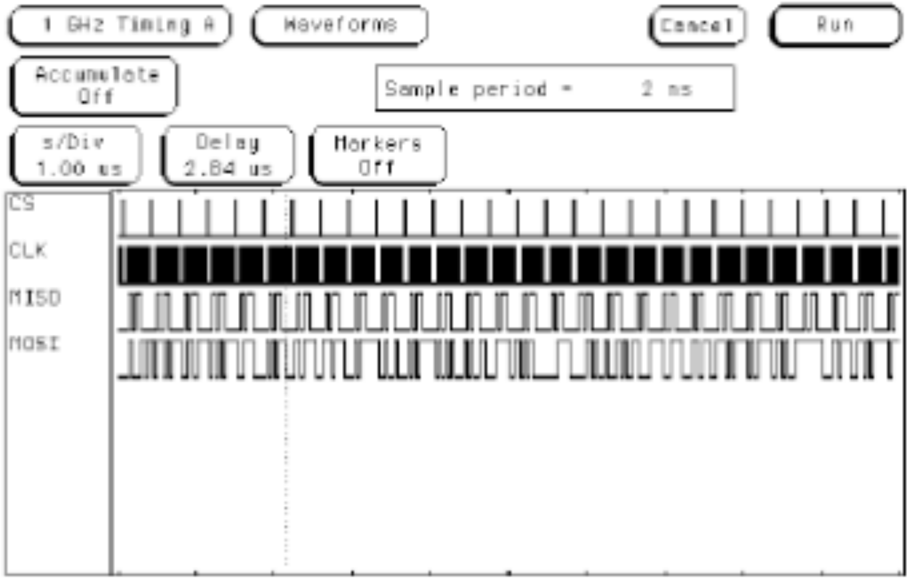
Power Board
- Uses 2.5 F super caps
- 5V Boost
- 3.3v, 1.8v, 1.5v, Buck Converters
- 24v Boost

Block Diagram of Power Supply Board



System Tests

Burst Transfer Rate

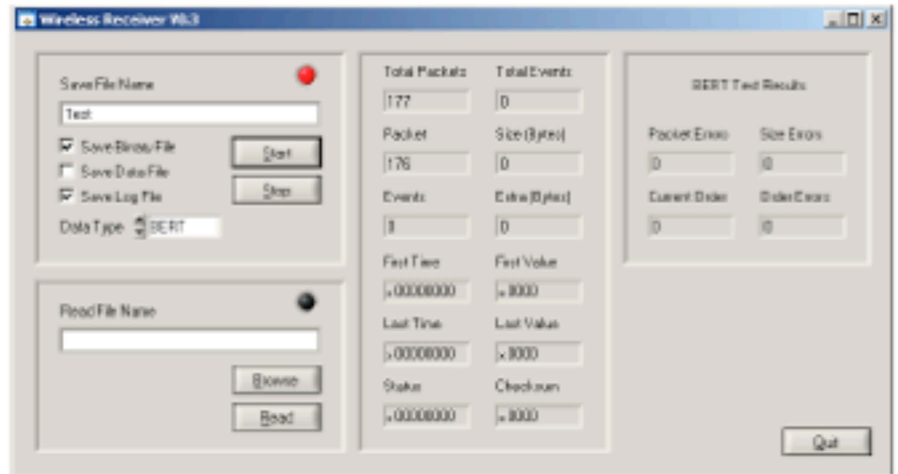


SPI Bus Activity

Target Transfer Rate: 35 Mbit/s
Maximum transfer rate achieved: 11 Mbit/s

– 25 Mbit/s SPI clock.
– SPI clock rate in processor Master Clock divided by 4.

Bit Error Rate Test



BERT Program

Target Bit Error Rate: < 10^{-12}
Bit error rate achieved: < 10^{-12}
Dropped Packet Rate: ~1/2400
Dropped packets are due to UDP transmission not being guaranteed!

Use of UDP necessitates the facility to allow re requests for data for zero data loss.