FREE SPACE OPTICAL LINK DESIGN

-Falak Shah & Kavish Shah
Guided By Prof. Dhaval Shah

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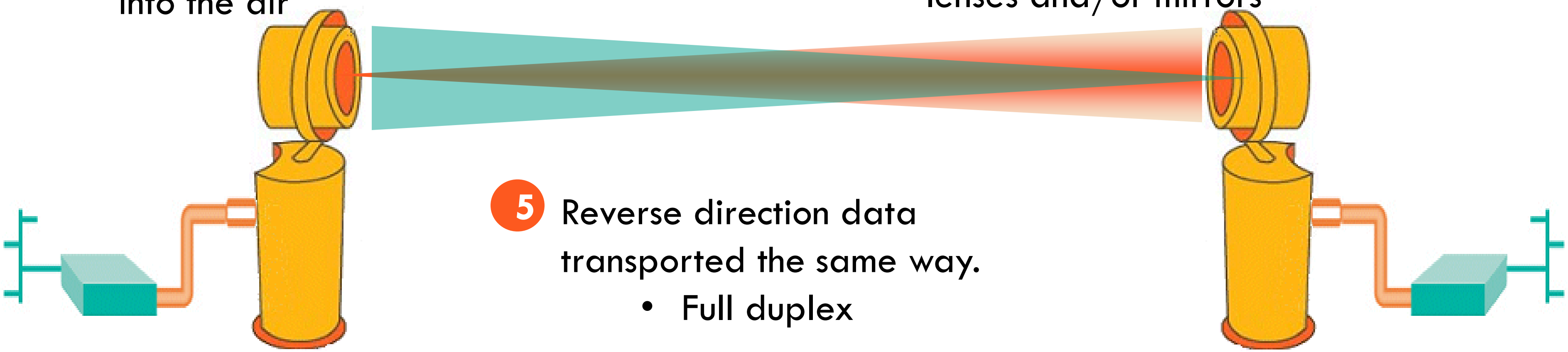
1. What is FSO ?
2. FSO v/s Fiber, RF & DSL lines
3. Advantage, Limitation, Application of FSO
4. Transmitter
5. Receiver
6. Transceiver Implementation

Block Diagram

2 Transmitter projects the carefully aimed light pulses into the air

3 A receiver at the other end of the link collects the light using lenses and/or mirrors



5 Reverse direction data transported the same way.

- Full duplex

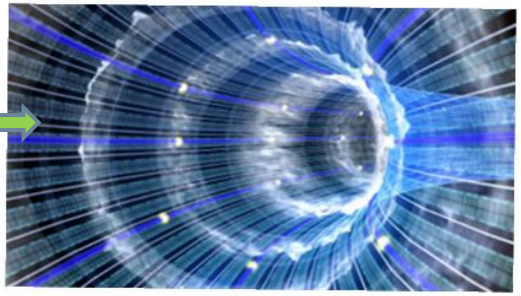
1 Network traffic converted into pulses of invisible light representing 1's and 0's

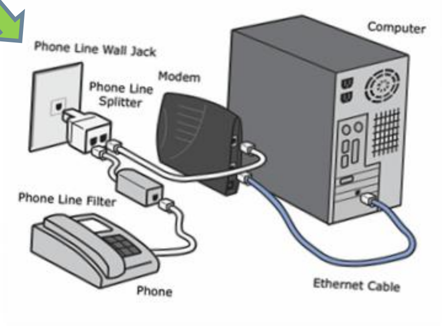
4 Received signal converted back into fiber or copper and connected to the network

Practical Setup

- Cable-free optical communication system
- LOS
- The first-ever 10-Gbit/sec FSO link was deployed for The Post Group, a Hollywood post-production company The Post Group went with the highest speed available, MRV Communications' Tele-Scope 10GE. System Support Solutions, based in the Twin Cities area of Minnesota, conducted the installation. Feb 12, 2010

High BW- Options





With Fiber – steps to install

Electronic Signage
Two variable speed limit signs installed

This special machine cut the trench for the new fiber cable directly through the existing pavement.

After it was installed on the south shoulder of US 2, the fiber optic cable was buried.

Paving over the fiber cable trench

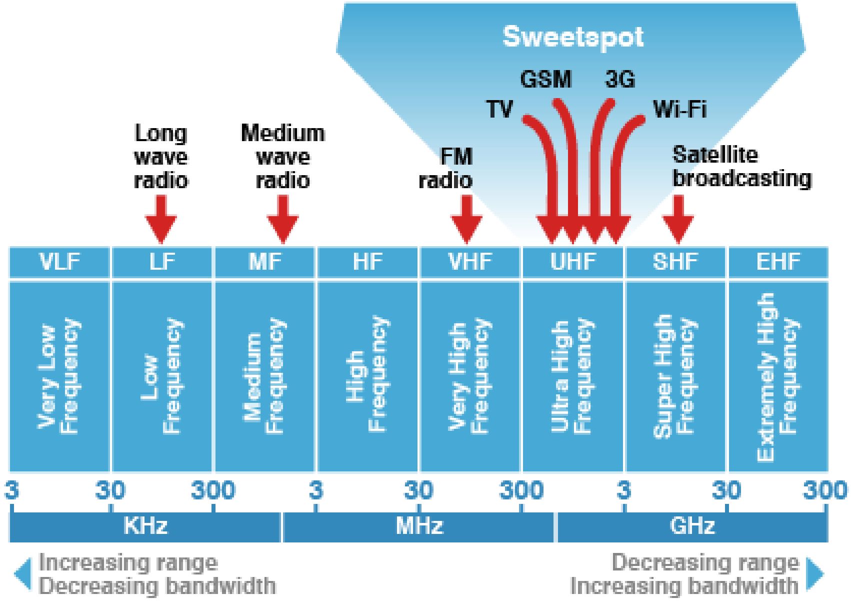
Fiber is …

But Sunk Cost as they cost US $100000-$200000/km in metropolitan areas, with 85 percent of the total figure tied to trenching and installation.[1]

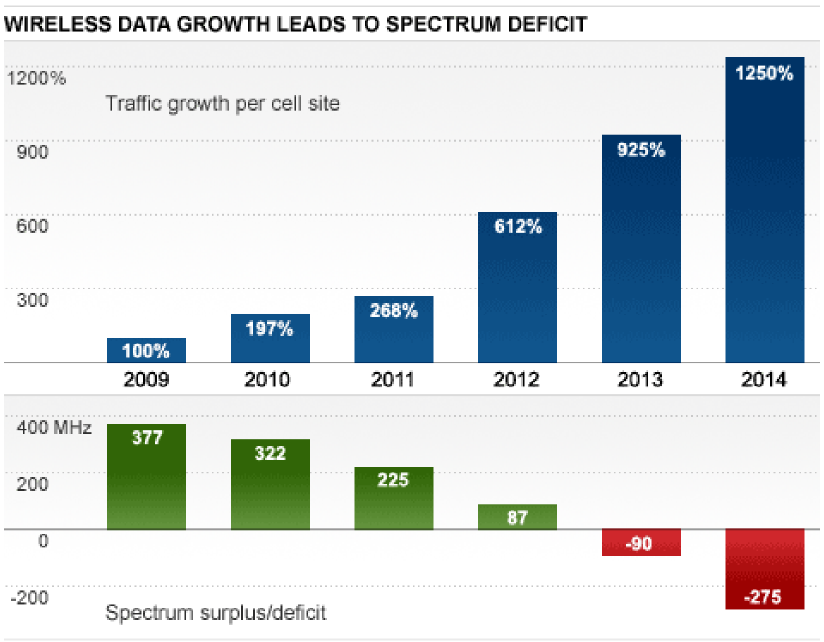
Why not RF?

Immense capital investment

To acquire RF spectrum



BW- Endangered

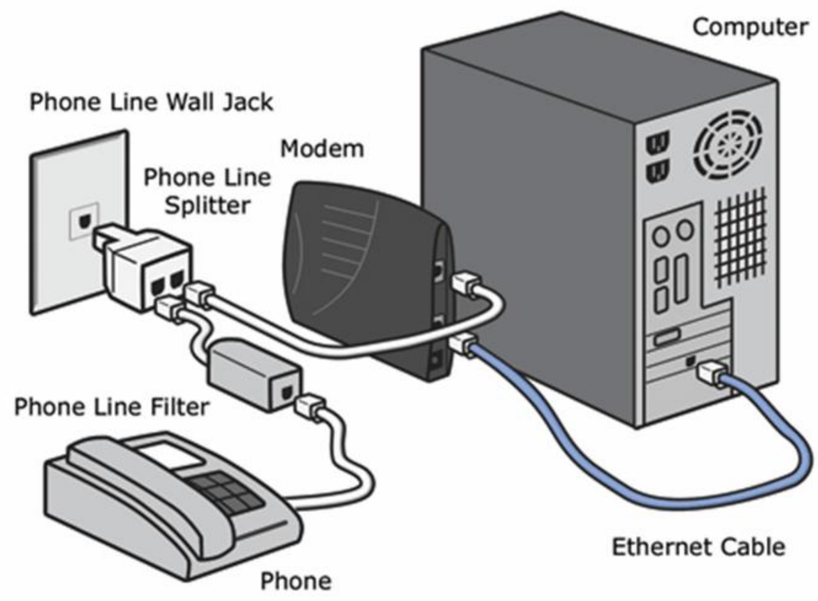


- Bandwidth is becoming an endangered species, so to speak, and carriers are running out of airwaves to cram data into.
- The **Federal Communications Commission** has said that a current wireless spectrum surplus of 225 MHz will become a deficit of 275 MHz in about 2 and a half years.

With DSL Lines

With DSL Lines

With DSL Lines



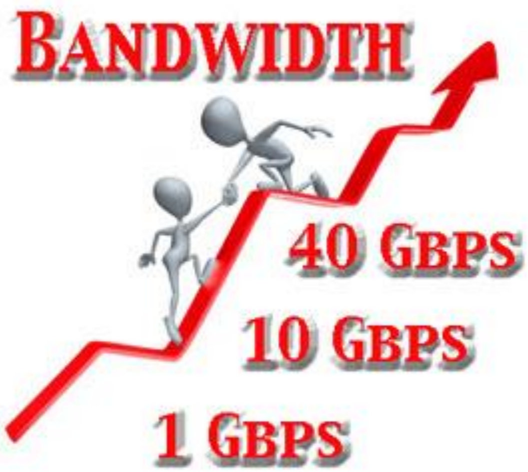
With FSO

No trenching

No licensing above 300 GHz

Advantages

Higher bandwidth



Low Cost-These free-space systems require less than a fifth the capital outlay of comparable ground-based fiber-optic technologies[2]

Faster Installation

Limitations

Atmosphere dependent

Swaying buildings

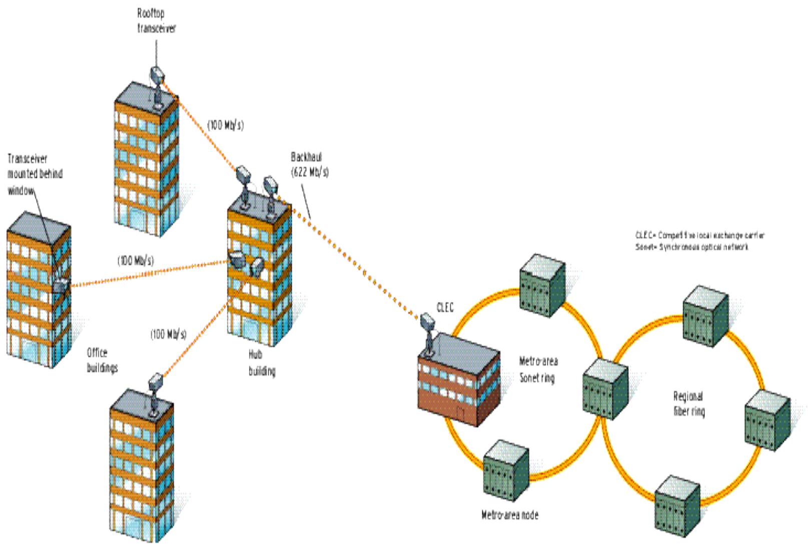
Limitations

Eye safety

Small range

Applications

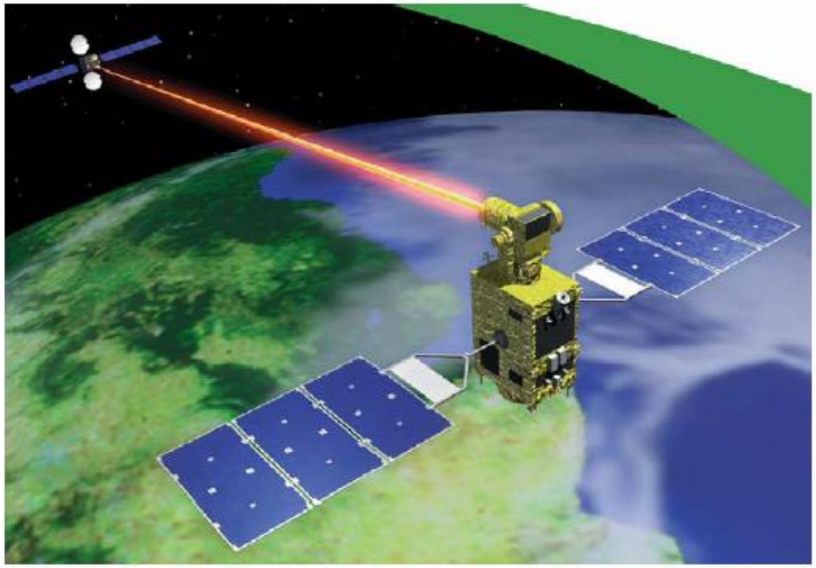
Last mile connectivity



CCTV

Applications

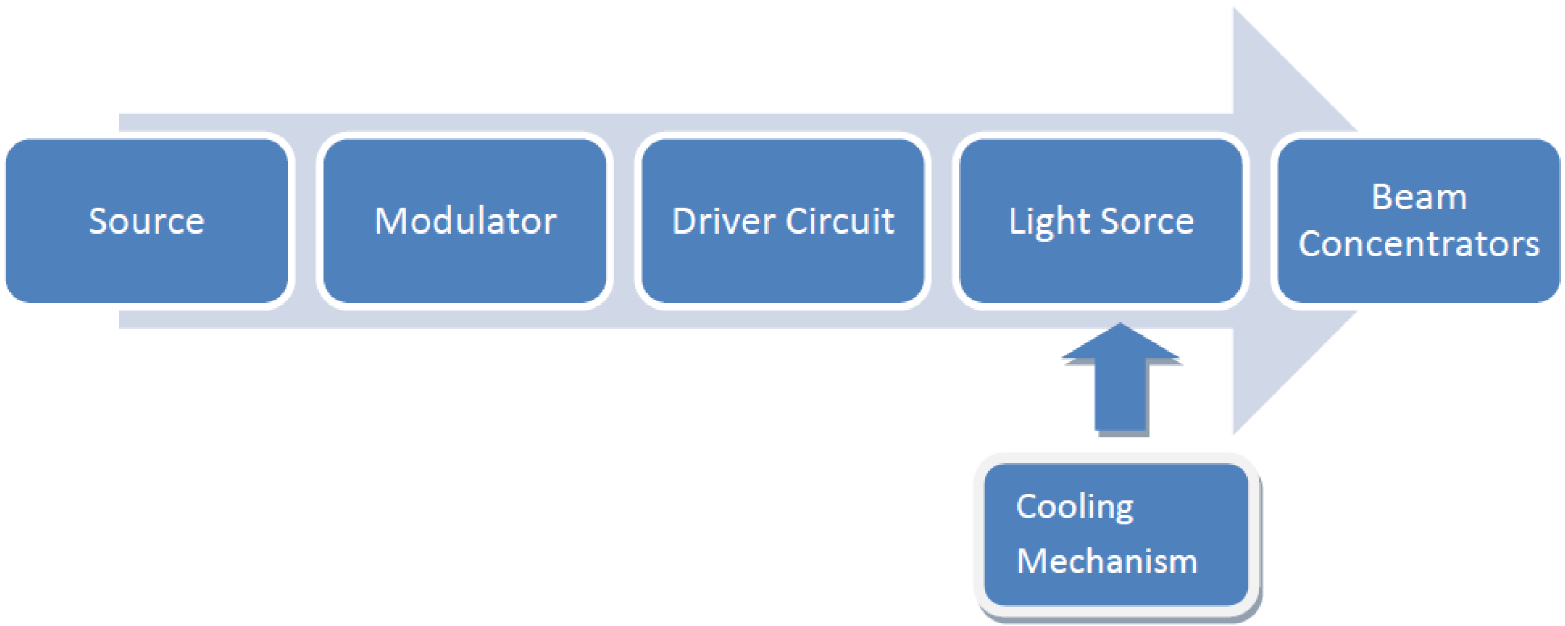
Satellite communication



Disaster recovery

TRANSMITTER

Transmitter Block Diagram



Incoming Signal

- Can be LAN signal arriving via RJ-45 cable to be entered via Ethernet kit for interfacing with transceiver.
- Can be RS232 signal to be converted to TTL or CMOS compatible using MAX232 IC.
- HyperTerminal to be used for serial communication via RS232.

Light Sources

- 42 artificial sources of light.
- 16 of them combustion based (lanterns)-too slow.
- 4 e^- simulated emission (CRT)-not directional.
- 5 incandescent light source (halogen)-too high power.
- 13 gas discharge lamps-need ballast to control light emission and are bulky.
- 3 electroluminescent sources – LEC's , LED, electroluminescent wires.
- LASERs.

Source Requirements

- Frequency response of the light source must exceed the frequency of the input signal as light is the carrier.
- The light source should launch its energy at angles that maximum portion is transmitted to receiver end.
- Faster speed of operation.
- Long lifetime.
- Frequency of operation in Terahertz range (800-1700 nm).
- Reasonably monochromatic (small spectral width).
- Temperature stability.

LED v/s LASER

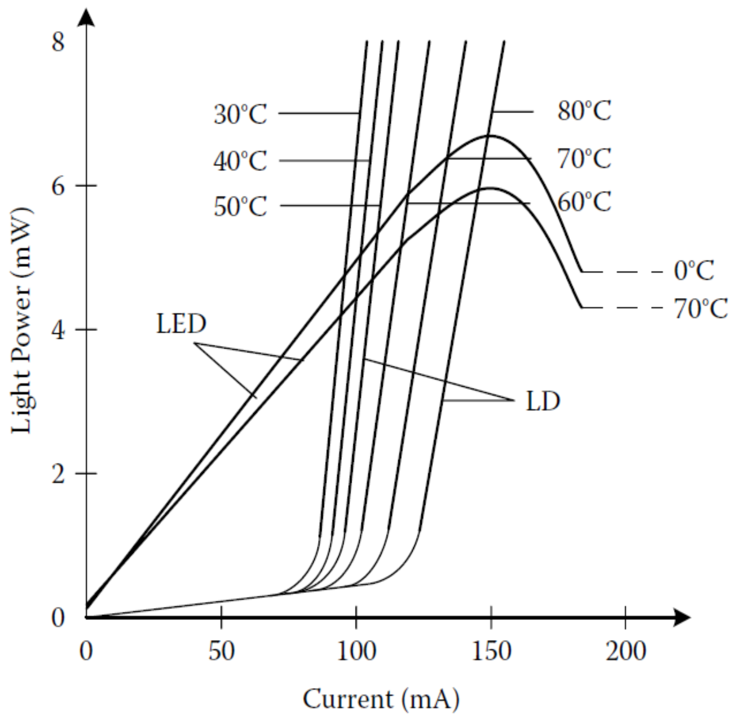
LED

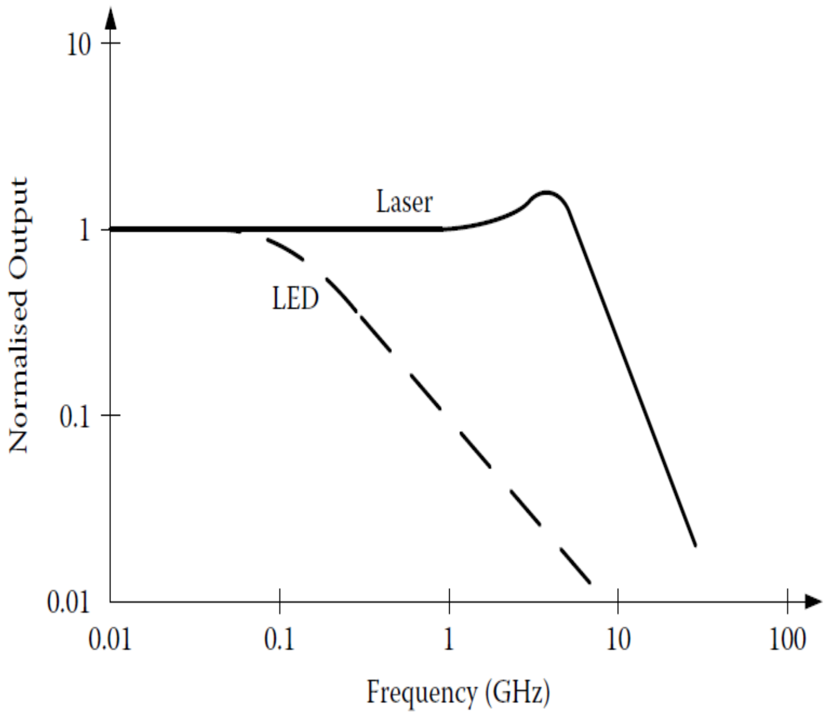
- Non-coherent.
- Few MHz.
- Eye safe.
- Preferred for indoor applications.
- Optical power output.

LASER

- Coherent Beam.
- Up to 10 GHz.
- Classes I,II,III.
- All practical outdoor FSO systems require LASER.

LED v/s LASER


Light Power (mW)
8
6
4
2
0
30°C
40°C
50°C
80°C
70°C
60°C
0°C
70°C
LED
LD
0
50
100
150
200
Current (mA)


Normalised Output
10
1
0.1
0.01
Laser
LED
0.01
0.1
1
10
100
Frequency (GHz)

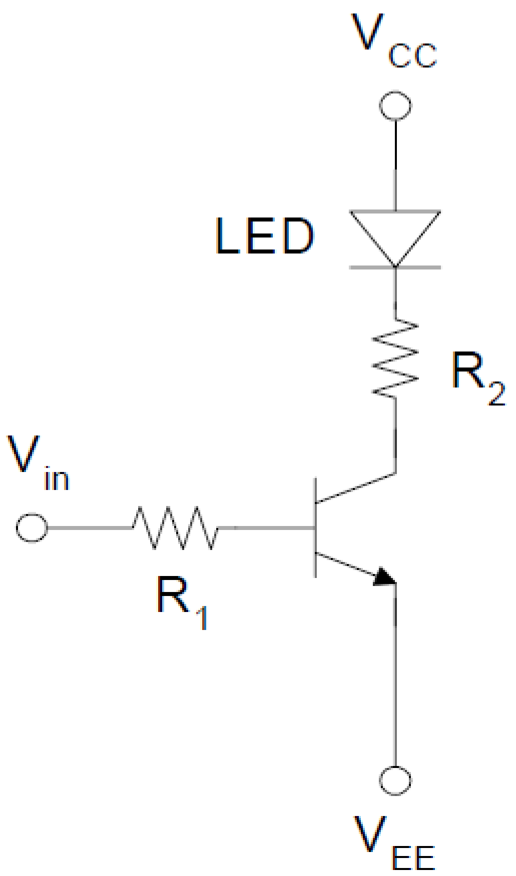
Types of LASERs

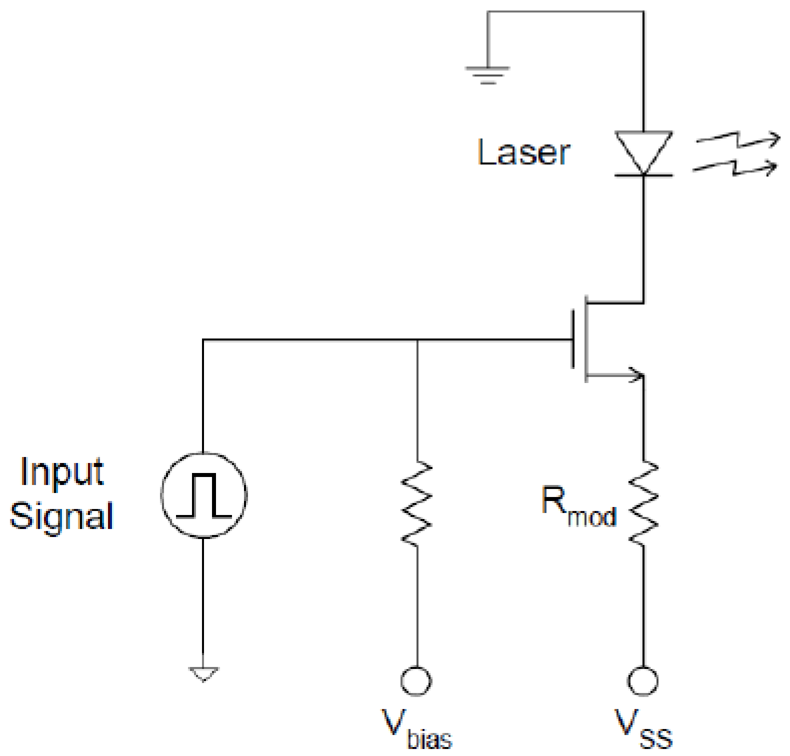
- Diode laser.
- Helium-Neon laser.
- Argon/Krypton ion laser.
- Carbon Dioxide laser.
- Helium-Cadmium (HeCd) laser.
- We use LASER diode as it is small in size, easy to handle, cost effective, electrically run and easily available as it is used in fiber optics.

Classes of LASERs

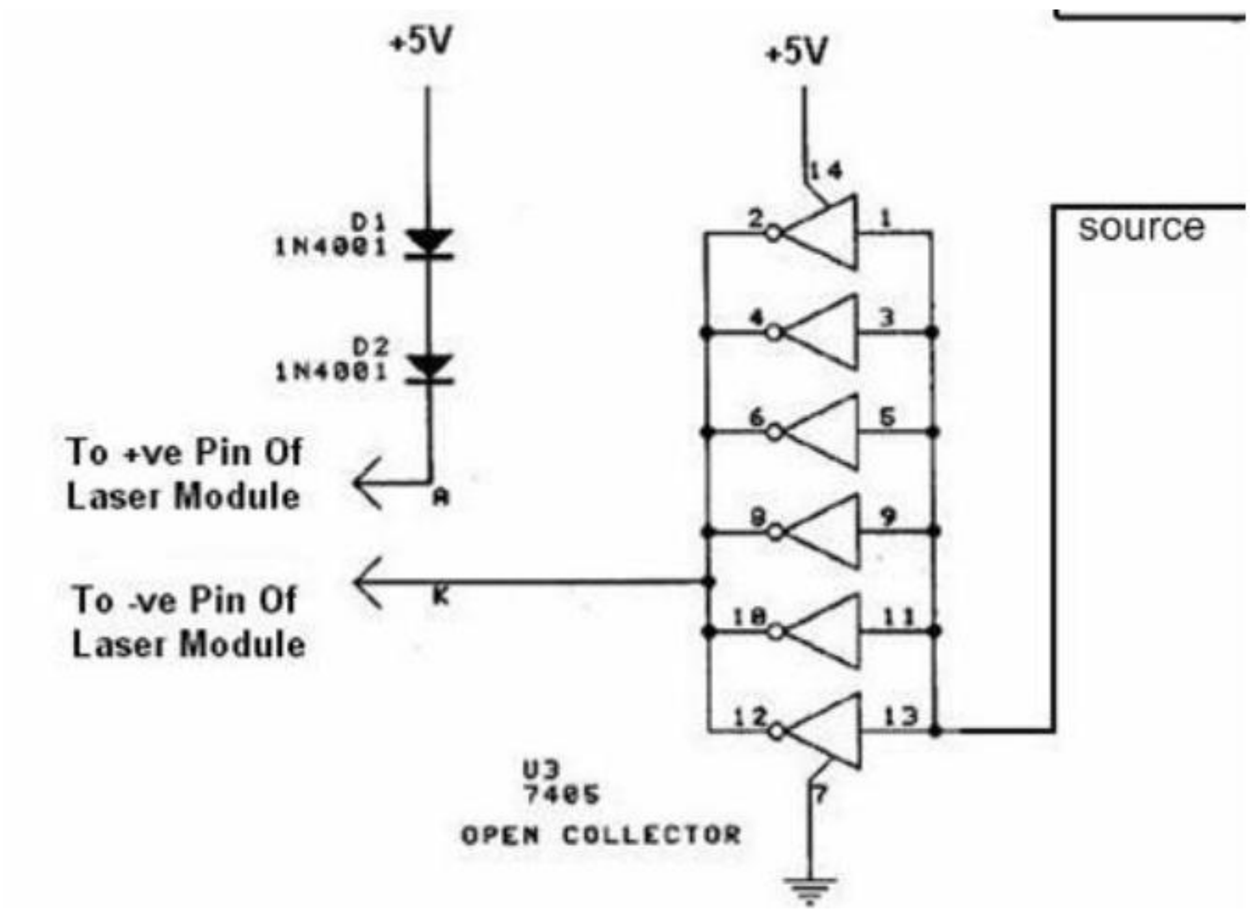
- Class 1: Inherently Safe.
- Class 2: Safe as aversion of eye prevents damage.
- Class 3: Unsafe even when reflected.
- We use red laser as near infrared (780 nm) and higher wavelength up to 1550 nm has lower attenuation.
- Class II lasers with power up to 5mW as per range requirement are used.
- When using LED, IR LED is used due to lower attenuation.

LED Driver





LASER Driver



Analog Modulation

- Electrical signal modulates carrier and modulated signal modulates light carrier.
- FM preferred over AM due to :
  1. additive noise.
  2. Frequency shift from unwanted illumination.
- PAM,PWM,PPM,PCM and then intensity modulation also possible.
- PPM highly favoured due to high power efficiency.

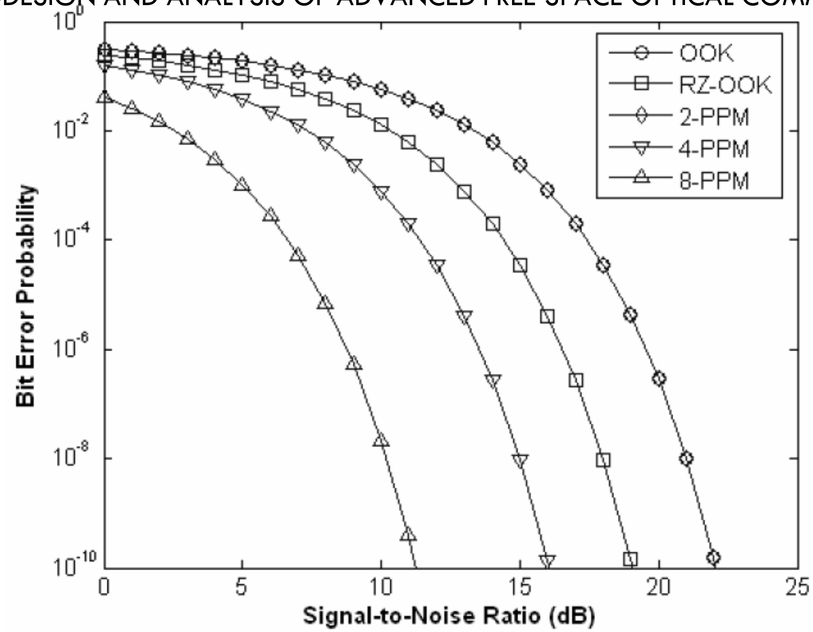
Digital Modulation Techniques

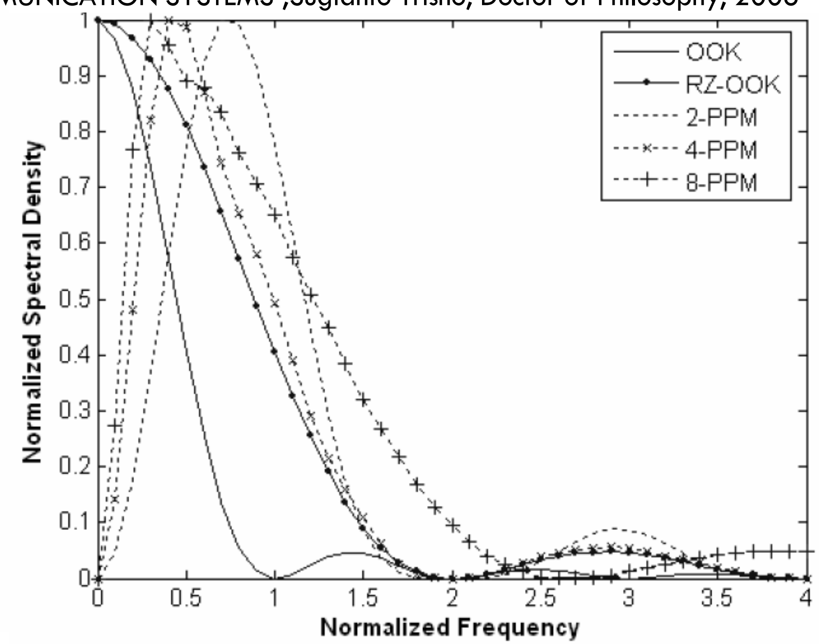
- FSK, PSK & ASK – digital signal .
- OOK.
- Variants- RZ and Manchester.
- Using Block encoding L-PPM.
- power efficiency of OOK is inferior to PPM.
- OOK encoding is more commonly used.
- Reason is efficient bandwidth usage and robustness to timing errors.

Digital Modulation schemes comparison

Modulation Scheme	Optical Power (dB)	Bandwidth Requirement
OOK	P_0	R_b
RZ-OOK	$P_0 - 3$	$2R_b$
Manchester Signaling	P_0	$2R_b$
L-PPM	$P_0 - 5\log_{10}\left[\left(L/2\right)\log_2 L\right]$	$LR_b/\log_2 L$

-DESIGN AND ANALYSIS OF ADVANCED FREE SPACE OPTICAL COMMUNICATION SYSTEMS ,Sugianto Trisno, Doctor of Philosophy, 2006





Receiver

Optical Receiver Block Diagram

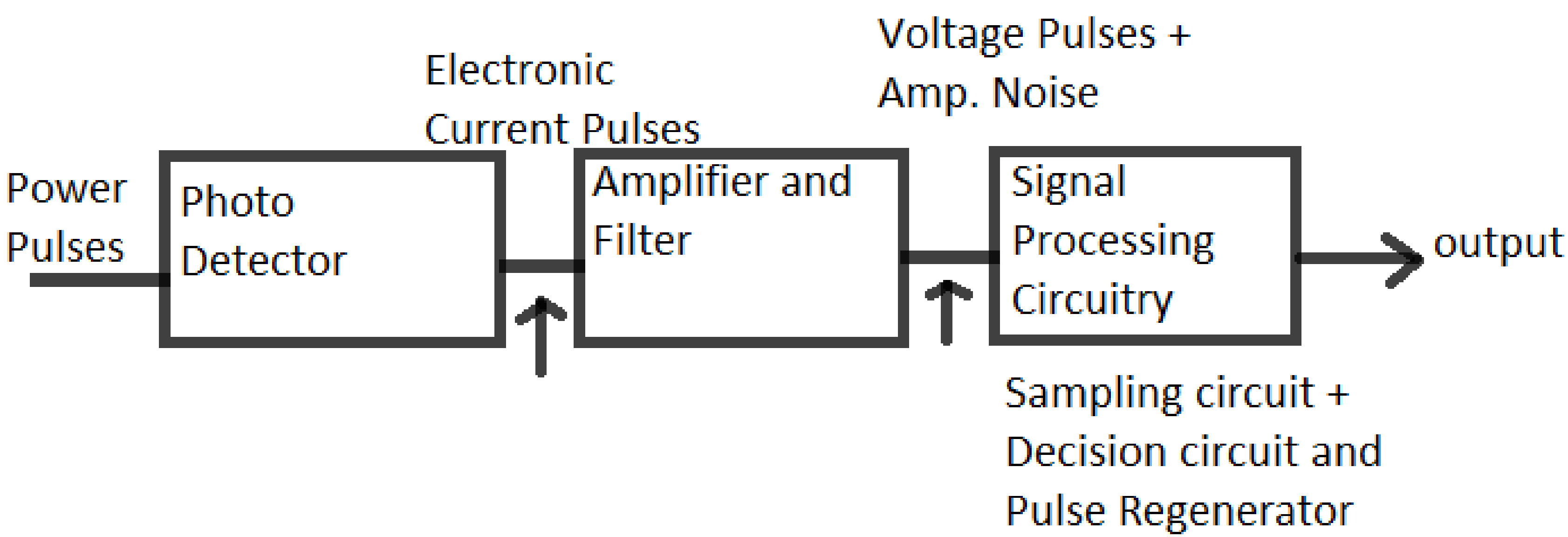
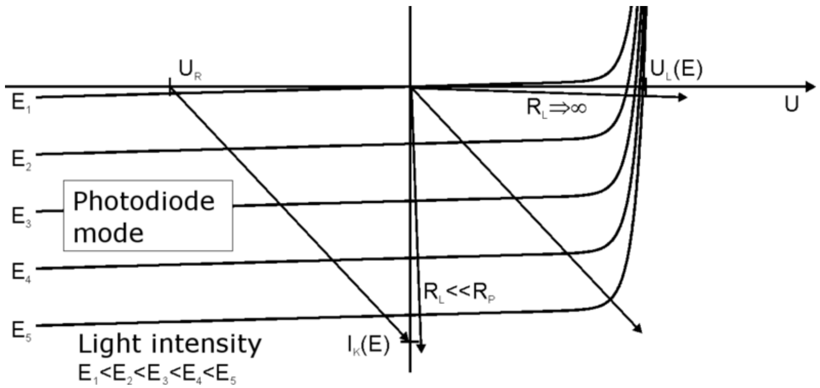


Photo detector - requirements

- High responsivity.
- Low internal noise.
- Sufficient bandwidth.
- Insensitivity to external conditions.
- Linearity.
- Cost effective, reliability, high stability, small size.

Photo diode – working principle

- Light(photons) incident on material.
- If $E_P = h * f \geq E_g$
- Then electron emission.
- Free electron – current generated.



Link Margin

- If it is desired to calculate a link margin for a link, rather than relying on the experience of the vendor or industry guidelines, this formula can be used.

$$P\,\mathrm{Re}\,ceived = PTransmitted * \frac{dr^2}{\left(dt + \left(D * R\right)\right)^2} * 10\left(a * R/10\right)$$

P = power,

dr = receiver aperture diameter in meters,

dt = transmitter aperture diameter in meters,

D = beam divergence in mrad,

R = range in kilometers,

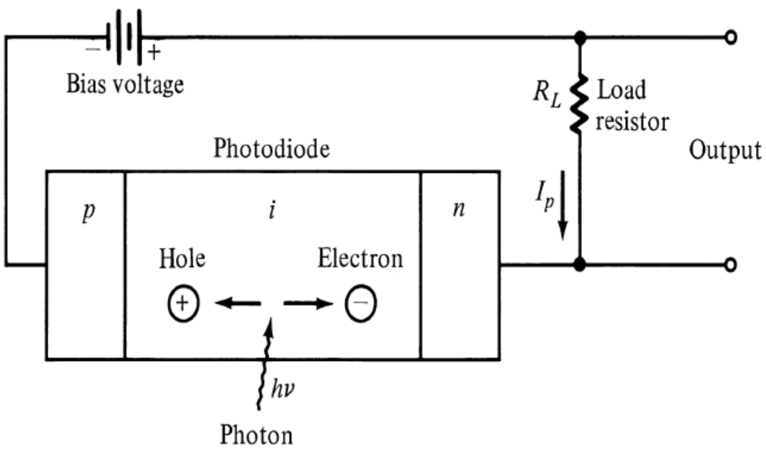
a = atmospheric attenuation factor in dB per kilometer.

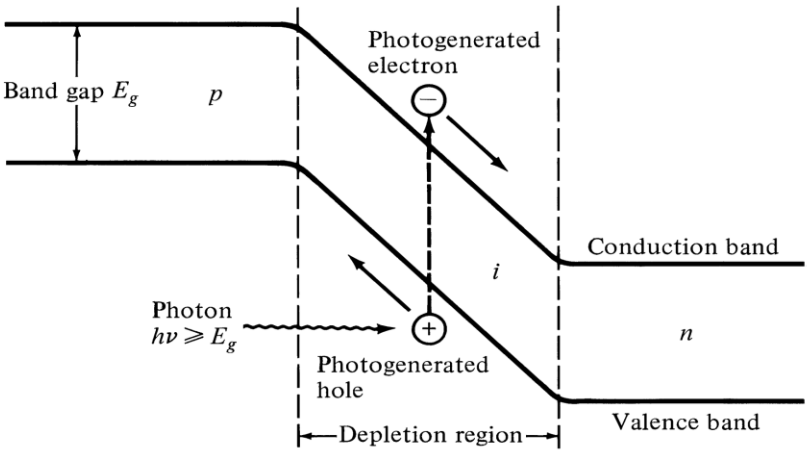
Why Photo Diode ???

- Mainly 3 types of photo detectors,

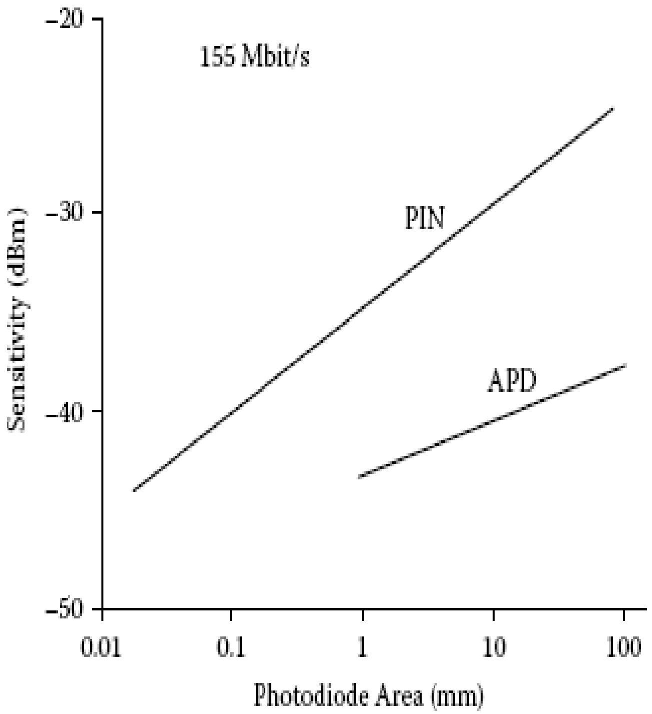
1. Photo Multiplier – Capable for low noise and high gain but, large size and high voltage requirement makes it unsuitable.
2. Pyroelectric detectors – can detect high speed laser pulse but, quite flat response over broad spectral band, less durability and less accuracy than thermopiles or photodiodes, sensitivity to vibrations and can't measure continuous light nor long pulses.
3. Semiconductor based photodiode - photo diodes are mainly used because of its small size, fast response time and high sensitivity over photo transistors.

PIN photo diode





PIN v/s APD



- APD has gain of avg. 10 dB in sensitivity than PIN photodiode.
- Responsivity,

PIN : 0.5-0.7 µA/µW.

APD : 30-80 µA/µW.

- PIN is used widely in indoor application, because of the cost factor only.

Noise in receiver

- Mainly 3 types of noise.

1. Dark current noise, $i_d^2 = 2qI_dB$
2. Quantum noise, $i_q^2 = 2qI_pB$
3. Thermal noise, $e_T^2 = 4kTB$

- Narrow band pass filters used to reduce the noise.

Pre - amplifier

- 3 types of pre-amplifiers,

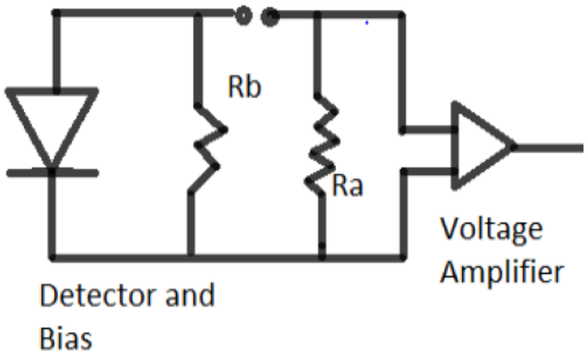
1. Low-impedance amplifier.
2. High- impedance amplifier.
3. Trans- impedance amplifier.

- 3 parameters to choose particular amplifier – noise, bandwidth and sensitivity.
- Load resistance play an important role.

Pre - amplifier

1. Low impedance pre-amplifier,

- High bandwidth is hindered by high noise and low sensitivity.



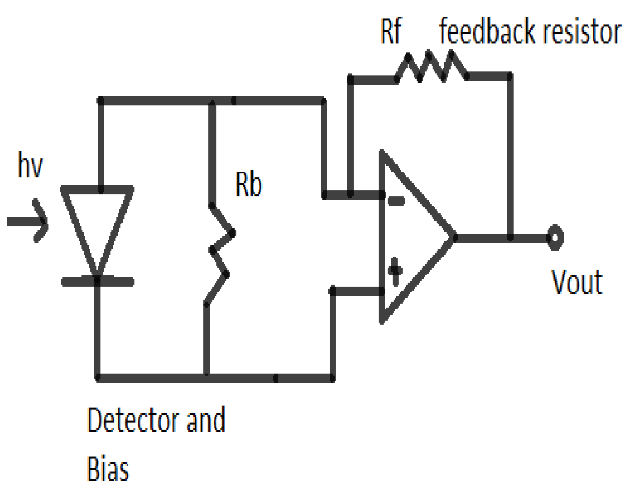
2. High impedance pre-amplifier,

- Has same figure as low impedance amplifier.
- Can be used at narrow band application, but not at wide band application – due to low bandwidth.

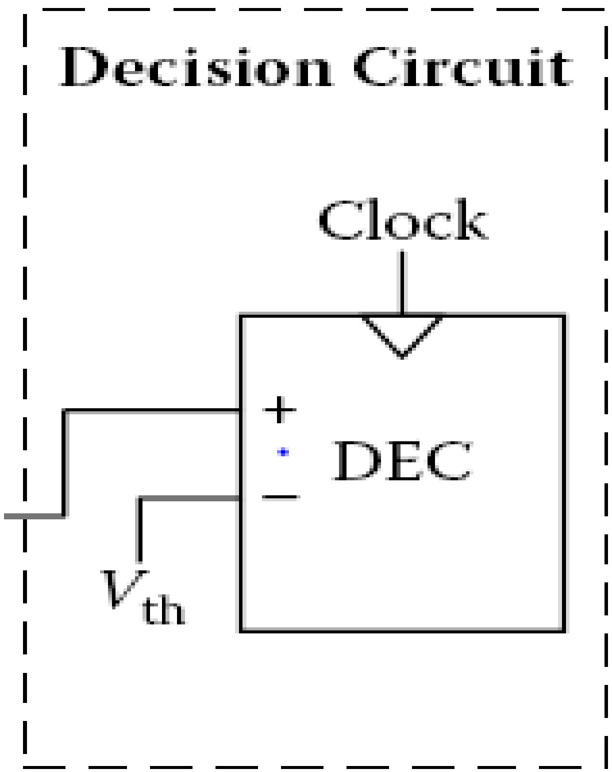
Pre - amplifier

3. Trans impedance pre-amplifier,

- Uses feedback resistance.
- More bandwidth as well as more sensitivity.
- Most preferred.



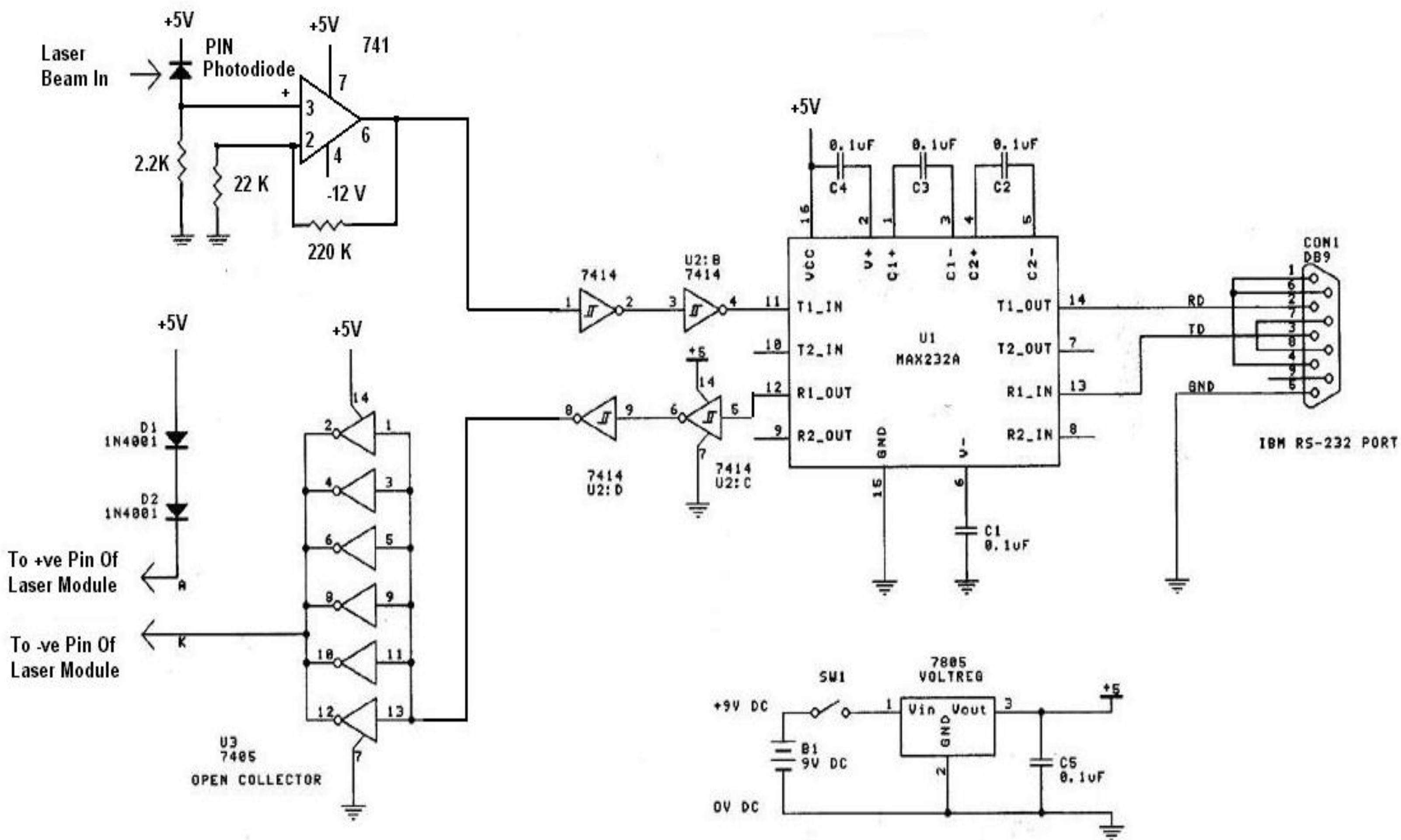
Decision circuitry



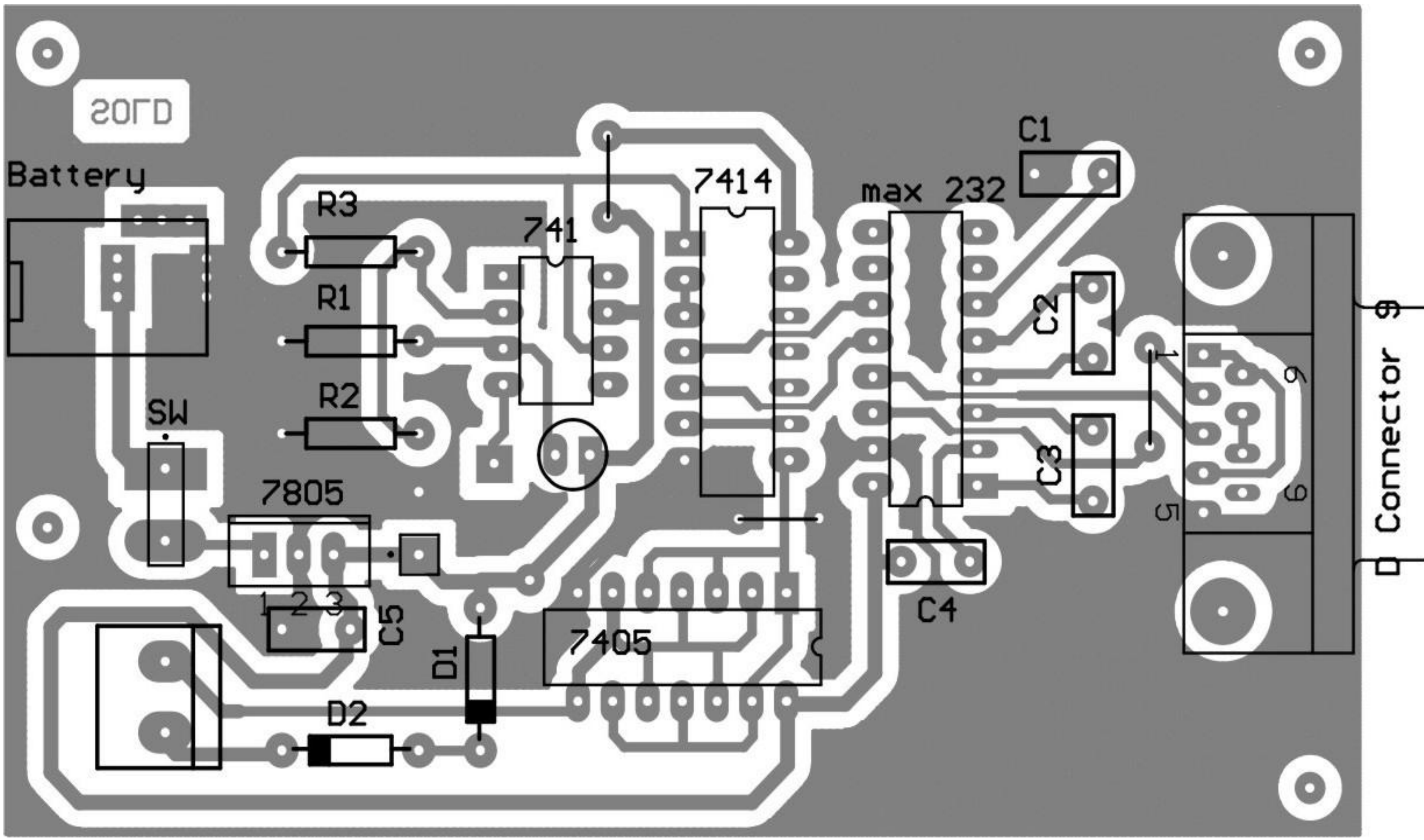
- Binary digital circuit.
- Compared a threshold value with a sample value to take decision.
- Triggered using a clock to synchronize.
- Forward error correction and adaptive equalizer in order to improve performance.

Transceiver Design

Transceiver Circuit Implemented



Layout of Transceiver Circuit



Transceiver Design Specifications

- IC used –
  - max232 – Driver of RS232(serial port).
    - Uses dual charge pump voltage converter.
  - 7405 – For laser diode driver(35 mA @ 3V).
  - 7414 – Hex inverter with Schmitt trigger.
    - Sharper Response.
  - 741 – OPAMP, with gain 10 for received signal.

Transceiver Design Specifications

- Components Used –
  - PIN Photo Diode – BPW – 34

    - 600 nm to 1050 nm
  - 1N4007 – gives 3.4 V to laser diode
  - 7805 – constant 5 V to whole circuit
  - Laser diode – red laser, 670 nm, Class II, on-off keying modulation
  - RS232 port – serial port for communication

Working Process

- Transmitter part:

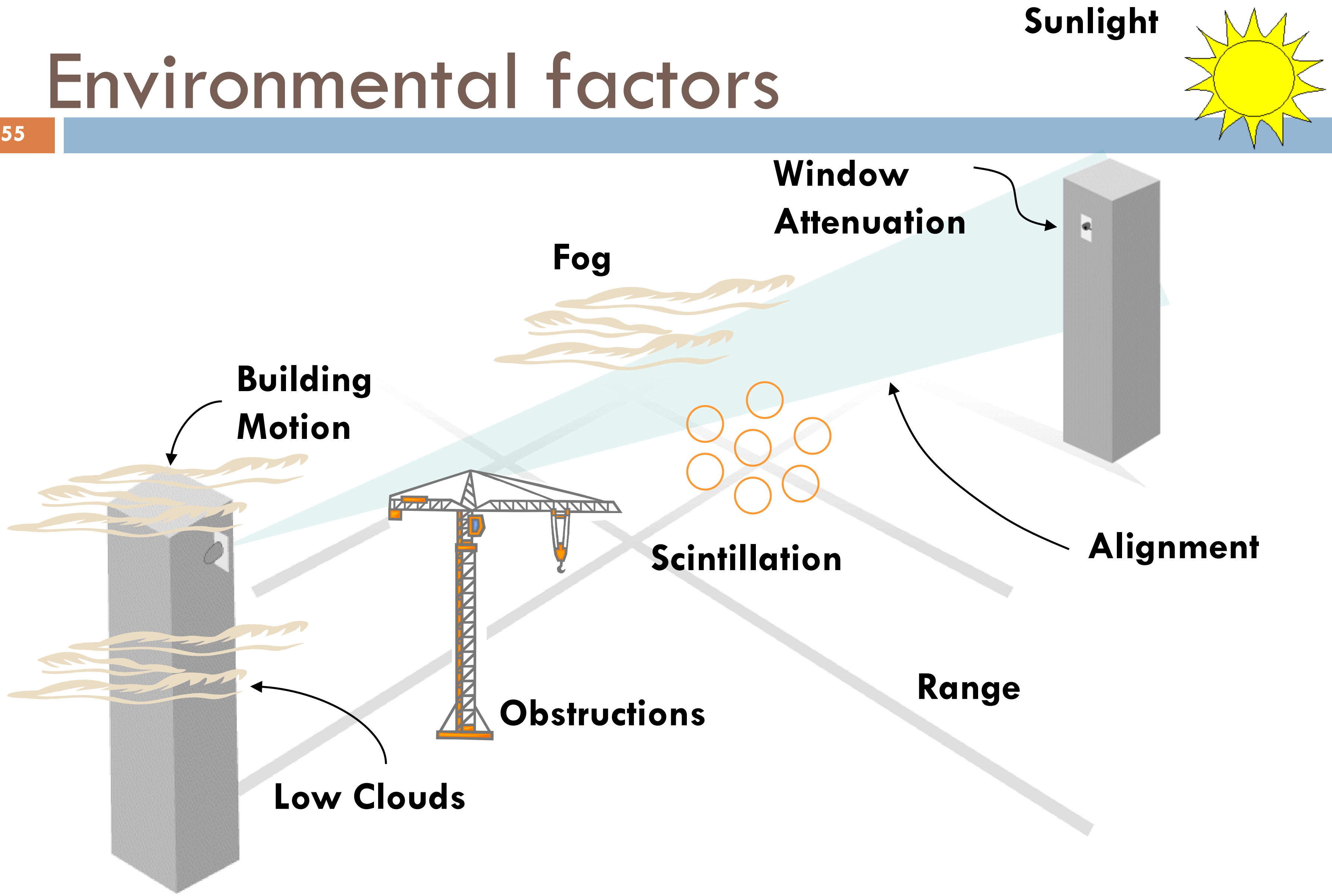
1. Digital devices - CMOS/TTL logic based, device is connected to a RS232 port and its voltage levels are converted to 0 & 5 V using max232.
2. Passed through 7414 for Schmitt triggering.
3. LASER driven through 7405 for current requirement.

- Receiver part:

1. Light detected using BPW34, then amplified using 741.
2. Sent to RS232 via max232 for voltage converter.

Channel Model

Environmental factors



Frequency and magnitude of causes

Type	Cause(s)	Magnitude	Frequency
Tip/tilt	Thermal expansion	High	Once per day
Sway	Wind	Medium	Once every several seconds
Vibration	Equipment (e.g., HVAC), door slamming, etc.	Low	Many times per second

Four different Channel Models

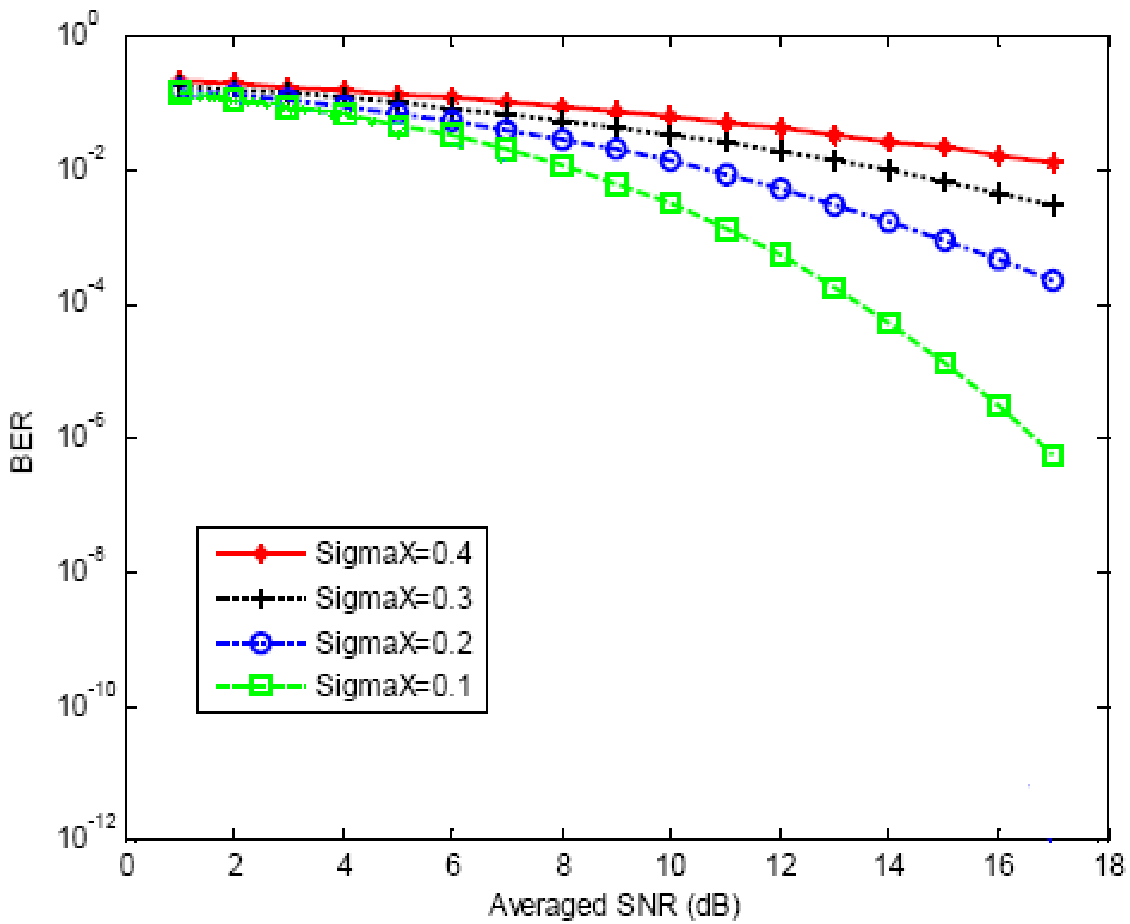
- Lognormal
- Gamma-gamma
- *K*
- *I-K*

Channel Model	Turbulence scenario	Limitation
Lognormal	Weak	High turbulence
Gamma-gamma	Weak to strong	Computation Complexity
K	strong	Low turbulence
I-K	Weak to strong	-

Lognormal channel model

- Weak turbulence scenario (S.I<0.75)
- For distances less than 100 m
- 2 methods:Gauss–Hermite quadrature approximation and based on power series for BER calculation.
- Gauss–Hermite is an approximation
- Power series:- Perfect

Numerical Solution



Where SigmaX= fading intensity

Imperfect CSI

- Don’t have channel knowledge
- Don’t know the value of η
- Can’t predict transmitted symbol from received symbol
- Can’t use conventional channel models

Gauss-Markov model

- Carl Friedrich Gauss and Andrey Markov
- Gives best estimation of the channel
- Result based on previous bits received and ML theorem

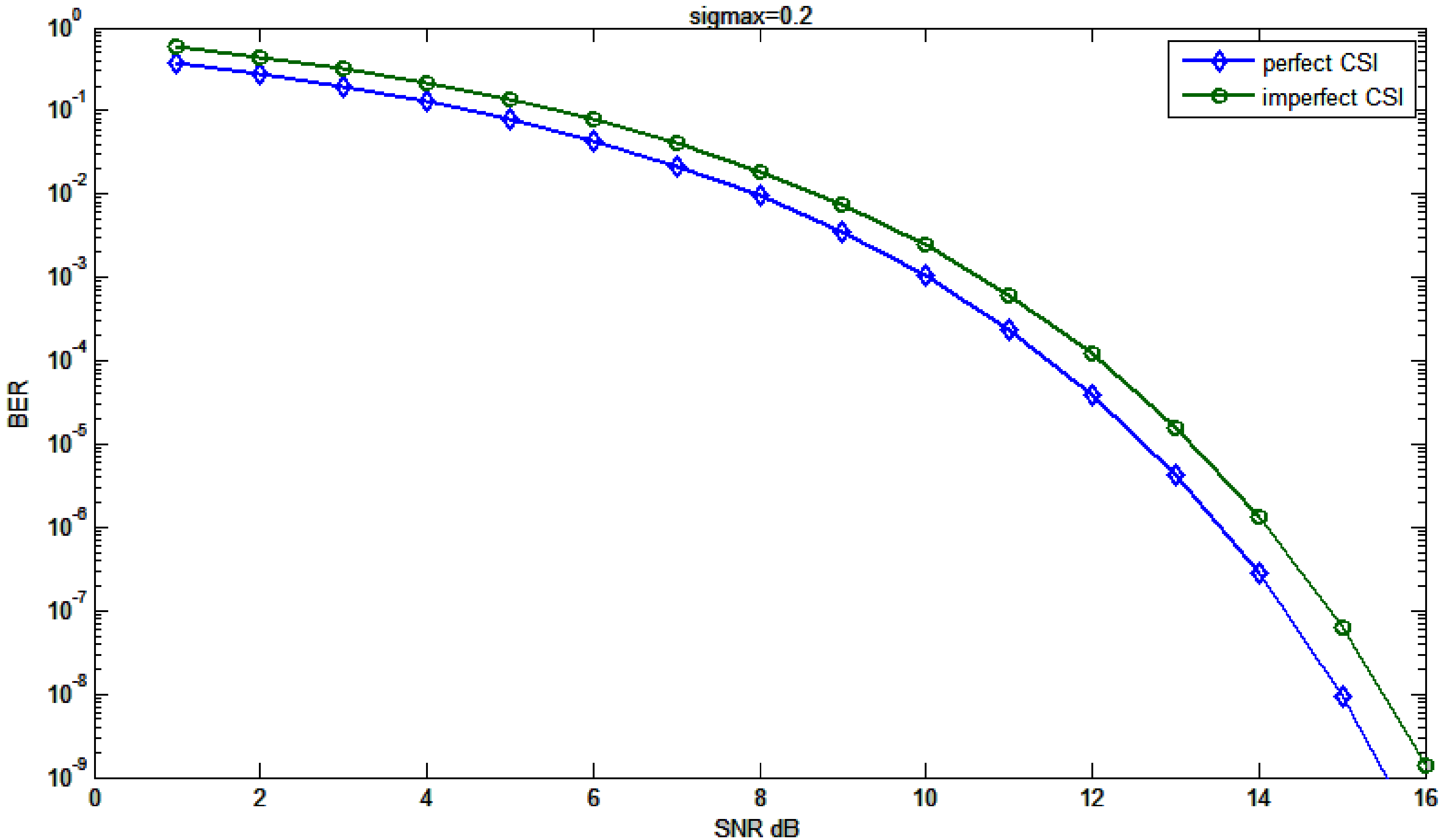
$$\mathrm{h1} = \delta h + \sqrt{1-\delta^2}\,w$$

δ is the correlation factor which varies between 0 to 1. 0 means totally uncorrelated while 1 means purely related to actual value

h is fading co-efficient

w is white Gaussian noise of channel.

BER analysis for Lognormal : Perfect Vs imperfect



Gamma-Gamma channel model

- Covers all regimes from weak to strong turbulence
- Pdf can be directly related to atmospheric condition
- Lognormal channel model is only applicable to weak turbulence conditions
- As the strength of turbulence increases, multiple scattering effects must be taken into account , lognormal statistics exhibit large deviations compared to experimental data.
- Lognormal pdf underestimates the behavior in the tails as compared with measurement results.
- Since detection and fade probabilities are primarily based on the tails of the pdf, underestimating this region significantly affects the accuracy of performance analysis.

Future Work

- Test the hardware for datarate and functioning in different environmental conditions.
- Place a proposal for FSO link between blocks of the institute.
- Study IEEE papers and present paper based on channel performance or modulation technique.

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Thank You