Optical Communications

System Design

Part9

Fiber Optic Communications

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Analog System Design

In a fiber system the combined component losses must be low enough to ensure that sufficient power reaches the receiver and must have sufficient bandwidth to pass the highest modulation frequencies contained in the optic signal.

System specifications:

- to design a point-to-point video system and path lengths of the order of half a kilometer.
- Signal is generated by a TV camera to intensity-modulate the light source.
- The signal bandwidth is 6 MHz.
- A signal-to-noise ratio=10^5 (50dB)
- Multimode SI fiber or multimode GRIN.
- LED with range (0.85) micrometer. Its power=1 mW, rise time=12 ns, spectral width=35nm and its emitting surface has diameter less than 50 micrometers.
- if fibers or sources do not have enough bandwidth or do not provide enough power then we must consider LDs, APDs, single mode fibers and longer wavelength (second window region)

System Design

•PIN has a capacitance of 5 pF and responsivity of 0.5 A/W at 0.85 micrometer.

•Cutoff frequency 6 MHz.

First : we find R_L

$$R_L = \frac{1}{2\pi C_d f_{3-dB}} = \frac{1}{2\pi(5\times10^{-12})(6\times10^{6})} = 5305\Omega$$

We set R_L=5100 Ω to allow some signal-bandwidth degradation. Then the bandwidth using 5100Ω is 6.24 MHz.

Power Budget

Second: we calculate the minimum power needed for PIN diode.

$$\frac{S}{N} = \frac{0.5R_L(\rho P)^2}{4kT_e\Delta f} \quad \text{......................(1)}$$

Amplifier noise figure ↑

where $T_e = FT$ → Ambient temperature K $\quad T_e = 2(300) = 600K$

Solving 1 we get

$$P = \sqrt{\frac{4(1.38\times 10^{-23})(600)(6.24\times 10^{6})(10^{5})}{0.5(0.5)^{2}(5100)}} = 5.7\,\mu m$$

For simplicity $P = 6\,\mu m$

The average current generates by PIN is $I = \rho P = 3\,\mu A > I_D(nanoamperes)$

The system is thermal-noise-limited.

To check the linearity, we find the maximum current before saturation:

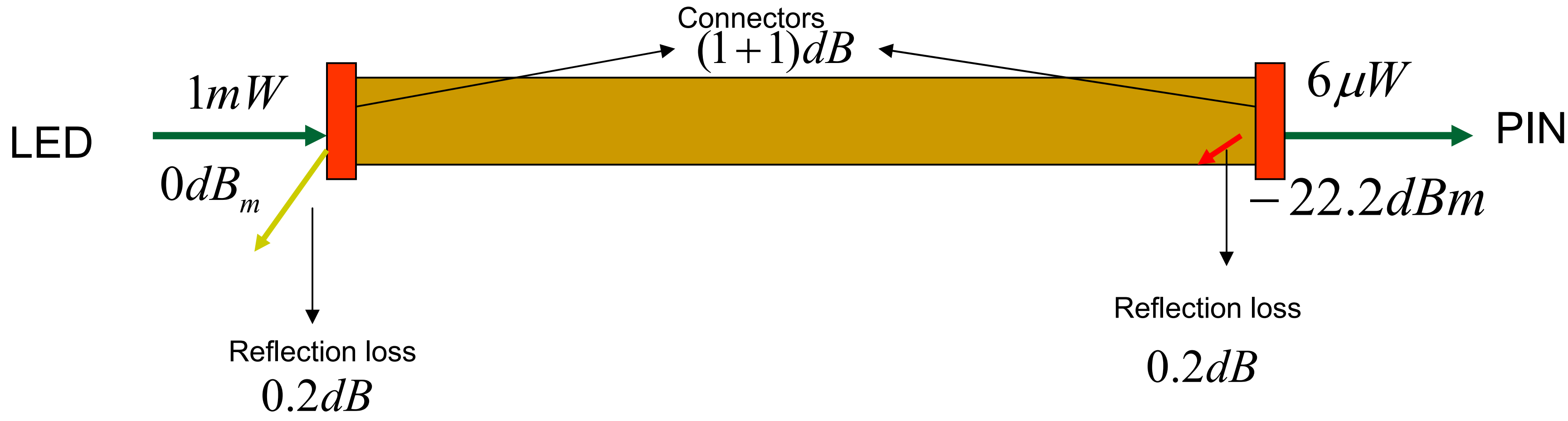
$$I_{\max} = \frac{V_{bias}}{R_L} = \frac{5}{5100} = 980\,\mu A$$

The maximum current is far greater than the average current. Saturation is no problem in this system.

System Design

Third Design:

1- using multimode SI, NA=0.24, $f_{3\text{-dB}}$XL=33MHzXkm, loss=5dBXkm and 2a=50 micrometers.



The coupling loss of SI is $\eta = NA^2 = (0.24)^2 = 0.0576(12.4dB)$

The remained power is $22.2 - 12.4 - 0.4 - 2 = 7.4dB$

Length of fiber is
$$L = \frac{7.4dB}{5dB/km} = 1.48km$$

System Design

2- using multimode GRIN, NA=0.24, $f_{3\text{-dB}}$XL=500MHzXkm (if the source is a laser diode), loss=5dBXkm and 2a=50 micrometers.

The coupling loss of SI is $\eta = \frac{NA^2}{2} = \frac{(0.24)^2}{2} = 0.0288(15.4dB)$

The remained power is $22.2 - 15.4 - 0.4 - 2 = 4.4dB$

Length of fiber is $L = \frac{4.4dB}{5dB/km} = 0.88km = 880m$

Bandwidth Budget

$$t_s^2 = t_{LS}^2 + t_F^2 + t_{PD}^2$$

System

$$t_s = \frac{0.35}{f_{3-dB}} = 58.3ns$$

Light source

$12ns$

Photo detector

$$t_{PD} = 2.19 R_L C_d = 55.8ns$$

System Design

$$t_F^2 = t_s^2 - t_{PD}^2 - t_{LS}^2 = 141$$

Thus we require that

$$t_F \leq 11.9ns$$

1- multimode SI fiber

$$f_{3-dB(electrical)} = 0.71 f_{3-dB(optic)} = 0.71(33MHz) = 23.4MHz \times km$$

The corresponding rise-time is

$$t_r = \frac{0.35}{23.4MHz} = 15ns/km$$

Length of fiber

$$L = \frac{11.9}{15} 0.793km = 793m$$

SI is bandwidth limited

System Design

2- multimode GRIN fiber (using LED)

$$f_{3-dB(electrical)} = 0.71 f_{3-dB(optic)} = 0.71(500MHz) = 355MHz \times km$$

The corresponding rise-time is

$$t_{\text{mod}} = \frac{0.35}{355MHz} = 1ns/km$$

Length of fiber

$$t_F^2 = t_{dis}^2 + t_{\text{mod}}^2$$

$$t_{dis} = M\Delta\lambda = 90(35) \approx 3.2ns/km$$

$$t_F = 3.4ns/km$$

$$L = \frac{11.9}{3.4} 4.5km$$

GRIN is power limited