RMIT University

EEET2115 Communication Engineering 2

Assignment 1

PHOTONIC SYSTEM FROM DANDENONG TO MELBOURNE

S3827143 – Duckhyung Ryu

S3660795 - Matthew Planner

Table of Contents

Introduction

Photonic communications systems provide an alternative way to transmit data over long distances. Traditionally, wired or wireless techniques have been used to transmit data from one point to another. However, data transmission using optical fibre has provided a way to construct communication systems with high data rates and increased transmission quality. Optical fibre utilizes the electro-optical properties of light, such as internal reflection, to transmit data from one location to another. Much like other communication systems, attenuation and noise are limiting factors in data transmission via fibre. Both attenuation and noise reduce the quality of photonic communication systems over large distances and from system components. noise can arise from various components and affect the transmitted signal differently during optical communications. Optical communication systems typically consist of a Laser Diode (LD), optical fibre and a Photodetector to receive the transmitted light. The total noise of an optical communication system is composed of Shot noise, Thermal noise, Dark noise and Relative Intensity Noise (RIN), all of which originate from specific components within the system. The Dynamic Range of a communication system indicates the operational range of the signal before it becomes saturated, clipped or both. The Dynamic Range is dependent on the total noise power and 1 dB compression point output power. A communication system with a large Dynamic Range is desirable, therefore, as engineers, it is important to maximise this range. The following design proposal outlines a series of components that could be used to construct a photonic communication system according to the system requirements.

Design Proposal

Before any calculations were made with respect to specific components, the distance between Dandenong and Melbourne was obtained in order to understand the length of optical fibre needed for the photonic system. The distance between Dandenong and Melbourne was found to be 29.62 km using Line of Sight, as shown in the figure below.

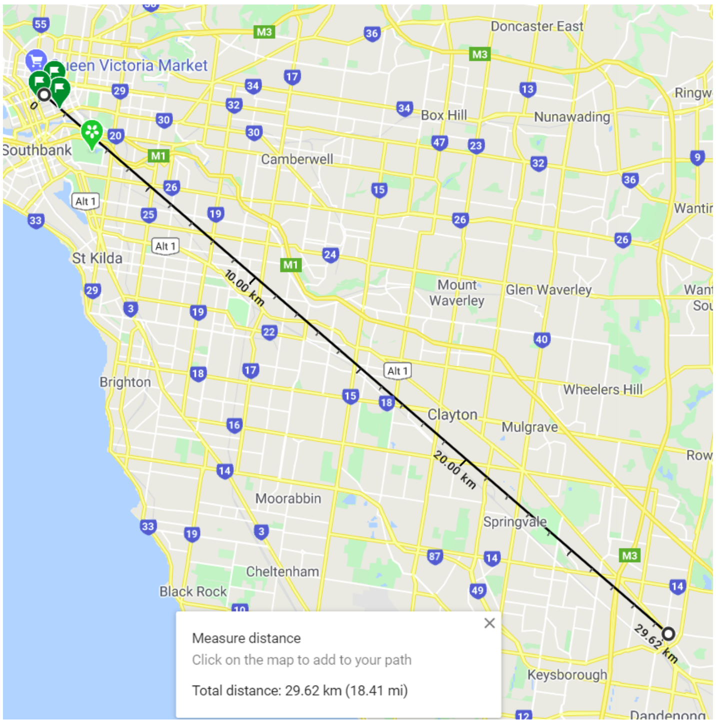

Figure 1: Illustration of the distance travelled by the photonic communication system

This length was used as the optical fibre length of the photonic communication system. Typically, photonic communication systems are constructed using a laser diode (LD), optical fibre and a photodetector (PD). However, due to the transmission distance, an RF amplifier may be needed to increase the Link Gain. The following specifications were taken into account when designing the photonic communication system from Dandenong to Melbourne:

Table 1: Photonic System requirements

Modulation Frequency	1.8	GHz
Link Gain	>1	dB
Pin1dB	>-4	dBm
Dynamic Range	>55	dB
B_N	1	MHz

During the design process, the cost of each component was not taken into consideration because a budget was not specified. The most important system requirement taken into account during the design process was the Dynamic Range, which indicates the quality of the photonic communication. The Dynamic Range outlines the operational RF powers that the photonic system can allow before reaching the 1 dB compression point. The 1 dB compression point illustrates the maximum RF signal that the system can allow before it becomes saturated and clipped, which is undesirable for data communication. The following figure outlines the proposed design of the photonic communication system, including both the components, manufacturers and function.

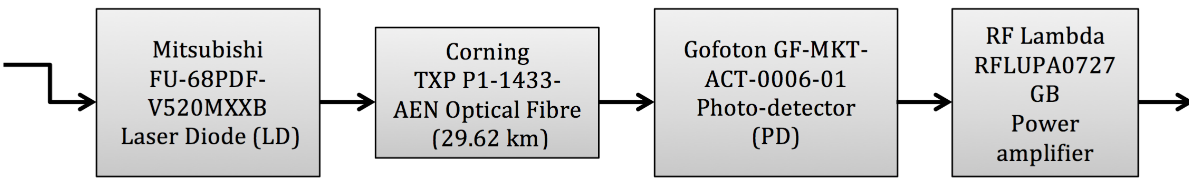

Figure 2: Proposed components to be used during photonic communication system construction

When researching for potential LD, the Mitsubishi FU-68PDF-V520MXXB LD was chosen because of its relatively large slope efficiency of 0.22 mW/mA, high optical output power 20 mW and low impedance 25 Ω (see Appendix A1 for LD specifications). Seeking a LD with a large slope efficiency is imperative to maximize the Link Gain as it is proportionally dependent on the square of the slope efficiency. In addition, this LD has a bandwidth of 2 GHz, which enables a modulation frequency of 1.8 GHz to be used during operation. The RIN value (RIN_v) for this LD is very small (-155 dB/Hz), therefore, this LD is advantageous because it will only contribute a small amount of Relative Intensity Noise (RIN) during operation.

Minimizing the optical loss during photonic communication is one of the main priorities of a communications engineer because it will maximize the signal power at the receiver. The Corning P1-1433-AEN optical fibre operates at a wavelength of 1550 nm and has an attenuation of 0.17 dB/km. Since the distance of the fibre is required to span 29.62 km from Dandenong to Melbourne, then the total optical fibre loss will be approximately 5.035 dB for this photonic system. This optical fibre is proposed because it provides the least amount of attenuation compared to other optical fibres advertised when it is operating at 1550 nm.

The GF-MKT-ACT-0006-01 photodetector manufactured by Gofoton is proposed as the system's PD because of its relatively high responsivity (0.75 A/W) and is operating with a bandwidth of 2 GHz. As mentioned previously, increasing the Link Gain of the photonic system is imperative during design. The Link Gain is also proportional to the square of the responsivity, therefore, using a PD with a high responsivity, such as the GF-MKT-ACT-0006-01 PD, will help increase the overall system quality.

The proposed design includes the RF Lambda RFLUPA0727GB power amplifier at the output of the PD to amplify the signal after photonic transmission at the receiver. Introducing this power amplifier will provide an additional 57 dB of gain to the system, thereby increasing the overall Link Gain. The RF Lambda RFLUPA0727GB power amplifier is also advantageous in this proposed system because it has a relatively large 1 dB compression point output power of 51 dBm. The 1 dB compression point output power is used to determine the Dynamic Range of the system, hence increasing this value will also increase the Dynamic Range of the system. The Dynamic Range of the system must exceed 55 dB according to the system requirements, therefore its maximization is paramount.

Conclusion

Using the design proposed above, the photonic system was simplified using a schematic, as shown below.

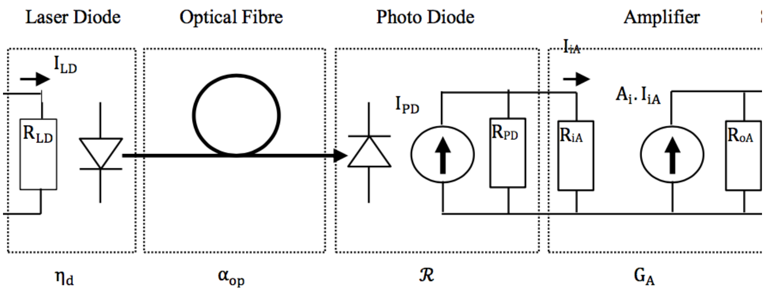

Figure 2: Design schematic of system components and associated system parameters

Each of the components within the proposed design contribute to the overall transmission quality. As shown above, the LD is used to generate the optical output power at the system input according to its slope efficiency. The LD optical output power is then attenuated over the fibre distance by the optical fibre. The optical power after attenuation is treated as the optical output power at the PD. The PD current is then calculated from its responsivity and used in subsequent noise calculations. The amplifier applies a gain to the LD to PD link.

Using the proposed components illustrated in Figure 2 and outlined in Appendix A1, the following subsequent system parameters were calculated.

Table 2: Link and Amp Gain and 1 dB compression point input power calculated using the proposed components

$G_{Link+Amp}$	355.0	W/W
	25.50	dB
P_{in1dB}	0.3422	W
	25.34	dBm

When the RF Lambda RFLUPA0727GB power amplifier was used in conjunction with the Mitsubishi FU-68PDF-V520MXXB LD, P1-1433-AEN optical fibre and GF-MKT-ACT-0006-01 PD, the overall gain of the system was calculated to be approximately 25.50 dB. This gain is much higher than the system requirement of greater than 1 dB, therefore the proposed design is performing well above initial expectation. The calculations to obtain the Link Gain is shown in Appendix C3. In addition, the specifications of the LD (shown in Appendix A1) allows a theoretical 1 dB compression point input power of 25.34 dBm. Similar to the Link Gain, this power is well above the system requirements, hence the proposed design would perform well within the requirements.

However, each component will generate noise, therefore reducing the quality of the system. The total noise is made up of four components: Thermal Noise, Relative Intensity Noise (RIN), Dark Noise and Shot Noise. The following table summarises the theoretical noise components within the system and illustrates the maximum amount total noise.

Table 3: Noise components and their associated power contributing to the total noise of the proposed system. The maximum amount of noise is displayed

Noise Component	Noise Power (W)	Noise Power (dBm)
$Thermal_{max}$	4.95E-09	-53.05
RIN	4.39E-08	-43.58
Dark	4.01E-17	-133.96
Shot	9.44E-09	-50.25
Total	5.83E-08	-42.35

If the proposed components were used to create a photonic system, theoretically, the maximum amount of noise within the system would be approximately -42.35 dBm. In conjunction with the specified 1 dB compression point output power of the RF amplifier, both the minimum and maximum Dynamic Range expected from this system was calculated (see Appendix C9 for details), as shown below.

Table 4: Maximum and minimum Dynamic Range of the proposed design

DR max (dB)	93.478
DR min (dB)	93.347

The maximum Dynamic Range was obtained using the minimum amount of noise and was found to be approximately 93.5 dB, whereas the minimum Dynamic Range was found to be approximately 93.3 dB. Therefore, when the proposed system is operating at at least optimized (highest amount of noise) it has a Dynamic Range well above the system requirement of 55 dB. As a result, it is evident that the photonic system composed of the aforementioned components will perform well above the system requirements.

As a result, the proposed design provides a photonic system that has an overall gain of 25.5 dB, 1 dB compression point input power of 25.34 dBm and a minimum Dynamic Range of 93.347 dB, all of which exceed the system requirements outlined in Table 1.

References:

[1] Prof. K. Ghourbani, “EEET2115 Communications Engineering 2_Lecture 11 (pdf)”, RMIT School of Engineering, Accessed May. 29, 2020 [Online], Available: <https://rmit.instructure.com/courses/64559/pages/week-11-learning-materials-slash-activities?module_item_id=2080962>

[2] Prof. K. Ghourbani, “EEET2115 Communications Engineering 2_Lecture 10 (pdf)”, RMIT School of Engineering, Accessed May. 29, 2020 [Online], Available: <https://rmit.instructure.com/courses/64559/pages/week-10-learning-materials-slash-activities?module_item_id=2080961>

Appendix:

A1: System components and their corresponding parameters used during calculations

[3] Mitsubishi, FU-68PDF-V520MxxB, Mitsubishi Optical Devices, [Online] Available: <https://www.semiee.com/file/EOL/Mitsubishi%20Electric%20-FU-68PDF-520M10B.pdf>

LD		
wavelength	1550	nm
slope efficiency	0.15	mW/mA
I_th	10	mA
I_op	130	mA
I_dark	0.1	uA
RINv	-155	dB/Hz
PoLD	20	mW
R_LD	25	Ω
Bandwidth	2	GHz

MITSUBISHI (OPTICAL DEVICES)

FU-68PDF-V520MxxB

1.55 µm DFB-LD MODULE WITH POLARIZATION MAINTAINING FIBER PIGTAIL (WAVELENGTH SELECTED, BIAS CIRCUIT INTEGRATED, DIGITAL APPLICATION)

ELECTRICAL/OPTICAL CHARACTERISTICS (Tld=Tset, Tc=25°C unless otherwise noted)

Parameter	Symbol	Test Conditions	Limits			Unit
			Min.	Typ.	Max.	
Threshold current	Ith	CW	-	10	25	mA
Operating current	Iop	CW, Pf=20mW	-	-	130	mA
Operating voltage	Vop	CW, Pf=20mW	-	-	2	V
Input impedance	Zin	Pf=20mW	-	25	-	Ω
Light-emission central wavelength	λc	CW, Pf=20mW	(Note 1)			nm
Central wavelength drift with case temp.	Δλc/ΔTc	Tc=-20~70°C	-1	-	0	pm/°C
Laser operating temperature	Tset	-	15	-	35	°C
Spectral line width	Δf	CW, Pf=20mW	-	-	20	MHz
Side mode suppression ratio	Sr	CW, Pf=20mW	33	40	-	dB
Cutoff frequency (-1.5dB optical)	fc	Pf=20mW	2	-	-	GHz
Polarization extinction ratio	Ex	CW, Pf=20mW	20	25	-	dB
Relative intensity noise	Nr	CW, Pf=20mW, 0.5~3GHz	-	-155	-145	dB/Hz
Tracking error (Note 2)	Er	Tc=-20~70°C, APC, ATC	-	-	0.5	dB
Differential efficiency	η	CW, Pf=20mW	0.15	-	-	mW/mA
Monitor current	Imon	CW, Pf=20mW, Vrd=5V	0.2	-	4	mA
Optical isolation	Iso	Tc=25°C	35	-	-	dB
		Tc=-20~70°C	23	-	-	
Dark current (PD)	Id	Vrd=5V, Tc=-20~70°C	-	-	0.1	µA
Capacitance (PD)	Ct	Vrd=5V, f=1MHz	-	-	10	pF

Note 1) See Table 1.
Note 2) Er=max|10×log(Pf / Pf@25°C)|

[4] Corning, P1-1433-AEN, 2019, [Online] Available: <https://www.corning.com/media/worldwide/coc/documents/Fiber/PI-1433-AEN.pdf>

Optical Fibre		
cable loss	0.17	dB/km
total loss (for L)	5.0354	dB
Dm	23	ps/nm.km
n_eff	1.465	

Optical Specifications

Maximum Attenuation

Wavelength (nm)	Maximum Value (dB/km)
1550	≤ 0.17
1625	≤ 0.19

Attenuation vs. Wavelength

Range (nm)	Ref. λ (nm)	Max. α Difference (dB/km)
1525 – 1575	1550	0.02
1550 – 1625	1550	0.03

The attenuation in a given wavelength range does not exceed the attenuation of the reference wavelength (λ) by more than the value α.

Macrobend Loss

Mandrel Radius (mm)	Number of Turns	Wavelength (nm)	Induced Attenuation* (dB)
30	100	1550	≤ 0.1
30	100	1625	≤ 0.1

*The induced attenuation due to fiber wrapped around a mandrel of a specified radius.

Point Discontinuity

Wavelength (nm)	Point Discontinuity (dB)
1550	≤ 0.05

Cable Cutoff Wavelength (λ_{cc})

λ_{cc} ≤ 1520 nm

Mode Field Diameter

Wavelength (nm)	Mode Field Diameter (μm)
1550	12.4 ± 0.5

Dispersion

Wavelength (nm)	Dispersion Value [ps/(nm•km)]
1550	≤ 23
1625	≤ 29

Dispersion Slope at 1550 nm ≤ 0.070 ps/(nm²•km)

Polarization Mode Dispersion (PMD)

	Value (ps/√km)
PMD Link Design Value	≤ 0.04*
Maximum Individual Fiber PMD	≤ 0.1

*Complies with ITU-T G.650-2 Appendix IV, (m = 20, Q = 0.01%), August 2015.

The PMD link design value is a term used to describe the PMD of concatenated lengths of fiber. This value represents a statistical upper limit for total link PMD. Individual PMD values may change when fiber is cabled.

[5] Gofoton, 1310/1550 WDM, [Online] Available: <http://28051x1461kpkihoucwqjp12-wpengine.netdna-ssl.com/wp-content/uploads/2018/03/Integrated-1310-1550-WDM-TAP-Detector-Datasheet-1.pdf>

PD		
Responsivity	0.75	A/W
I_dark	0.02	nA
Bandwidth	2	GHz
R_PD	50	Ω
PoPD	6.27E-03	W
T_PD max	358	K
T_PD min	233	K

Unless otherwise noted, test condition is at 1550nm, 25°C, Vr:5V.

PARAMETER	SYMBOL	UNIT	SPECIFICATION			NOTES
			MIN.	TYP.	MAX.	
Input Operating Wavelength Range	λ_{R-T}	nm	1260	-	1360	-
			1480	-	1500	-
			1545	-	1565	-
Transmission Wavelength Range	λ_T	nm	1545	-	1565	Input to PD
Reflection Wavelength Range	λ_R	nm	1260	-	1360	Input to Output
			1480	-	1500	
Responsivity	Rs	A/W	0.80	-	-	-
Insertion Loss @ λ_R	IL	dB	-	-	0.2	-
Wavelength Dependent Loss @ λ_R	WDL	dB	-	-	0.3	-
Polarization Dependent Loss @ λ_R	PDL	dB	-	-	0.2	-
Isolation @ λ_T	-	dB	12	-	-	-
Isolation @ 1260~1360nm	-	dB	45	-	-	-
Isolation @ 1480~1500nm	-	dB	40	-	-	-
Return Loss	RL	dB	45	-	-	-
Optical Power Handling	P_{op}	mW	-	-	500	-
Responsivity @ λ_T, Vr:5V	Rs	A/W	0.75	-	-	
Linearity @ λ_T, Vr:5V	Lin	%	-10	-	10	
Dark Current @ 25°C	Id_{RT}	nA	-	0.02	0.10	-
Dark Current @ 85°C	Id_{HT}	nA	-	-	5	-
Capacitance	C	pF	-	-	1	1MHz, Vr:5V
Bandwidth	BW	GHz	-	2.0	-	-3dB,RL=50Ω,Vr:5V

[6] RF-Lambda, RFLUPA0727GB Wide Band Solid State Power Amplifier, 2020, [Online] Available: <https://rflambda.com/pdf/poweramplifier/RFLUPA0727GB.pdf>

RF Amplifier		
Gain	57	dB
P_out1dBcomp	51	dBm
NF	15	dB
R_iA	50	Ω
R_oA	50	Ω
Tmax_A	358	K
Tmin_A	233	K

Electrical Specifications, T_A = +25°C, Vcc = +36V

Parameter	Min.	Typ.	Max.	Units
Frequency Range	0.7		2.7	GHz
Gain	55	57		dB
Gain Flatness		±2.0	±3.0	dB
Gain Variation Over Temperature (-40°C~+85°C)		±2.5		dB
Input Return Loss		15		dB
Output 1dB Compression Point (P1dB)	49.5	51		dBm
Saturated Output Power (Psat)	51	53		dBm
3rd Order Intermodulation Product(IM3)		-35		dBc
Supply Current (Idd) (Vcc=+36V)		3.8	20	A
Efficiency at P1dB		25		%
Isolation S12		-55		dB
Input Max Power(no damage)			0	dBm
Weight		----		ounces
Impedance		50		Ohms
Input / Output Connectors	Input:SMA-Female Output:N-Female			
Finish	Nickel Plated			
Material	Aluminum			
Package Sealing	Epoxy Sealed (Standard)			
	Hermetically Sealed (Optional)			

C1 - Calculation of PD output power P_{oPD}

$$\alpha_{op} = fibre\ loss \times L = 0.17\ dB/km \times 29.62\ km$$

$$\alpha_{op} = 5.035\ dB$$

$$P_{oPD} = \frac{PoLD}{\alpha_{OP}}$$

$$P_{oPD} = \frac{20 \times 10^{-3}}{10^{(5.035/10)}} = 6.27 \times 10^{-3}\ W$$

C2 - Calculation of $P_{in1dBCP}$ through the determination of LD m_{1dB}

$$m = \frac{\sqrt{2} < I_{op} > \eta_d}{PoLD}$$

$$m = \frac{\sqrt{2} \times 130 \times 10^{-3} \times 0.15}{20 \times 10^{-3}} = 1.379$$

$$m_{1dB} = \frac{m}{\sqrt{2}} = \frac{1.379}{\sqrt{2}} = 0.975$$

$$P_{in1dBCP} = m_{1dB}{}^2 \cdot (I_{LDBias} - I_{thr})^2 \cdot R_{LD}$$

$$P_{in1dBCP} = 0.975^2 \cdot (130 \times 10^{-3} - 10 \times 10^{-3})^2 \cdot 25 = 0.342\ W$$

$$P_{in1dBCP,\ dBm} = 25.34\ dBm$$

C3 - Calculation of $G_{link+Amp}$

$$G_{link+Amp} = (\frac{\eta_d R}{\alpha_{OP}} \cdot \frac{R_{PD}}{(R_{PD} + R_{iA})})^2 \cdot \frac{R_A}{R_{LD}} \cdot G_A\ (linear)$$

$$G_{link+Amp} = (\frac{0.15 \times 0.75}{10^{(5.035/10)}} \cdot \frac{50}{(50+50)})^2 \cdot \frac{50}{25} \cdot 10^{(57/10)} = 355\ W/W$$

$$G_{link+Amp,\ dB} = 25.5\ dB$$

C4 - Calculation of Thermal noise

Both the PD and Amplifier had minimum and maximum operating temperatures, therefore, they will contribute a minimum and maximum amount of thermal noise to the system. Both min and max thermal noise power was calculated.

$$T_e = T_{PD} + T_A$$

$$T_{e_{min}} = T_{PD_{min}} + T_{A_{min}} = 233\ + 233 = 466\ K$$

Since R_{iA}=R_{PD}=R=50Ω, then we calculate the Thermal noise current by,

$$< I_{Th_{min}}{}^2 > \ = \ \frac{4k_B T_{e_{min}} B_N}{R} = \frac{4 \times 1.38 \times 10^{-23} \times 466 \times 1 \times 10^6}{50} = 5.14 \times 10^{-16}\ Amp^2$$

$$P_{Th_{min}} \ = \ < I_{Th_{min}}{}^2 > \cdot (\frac{R_{PD}}{(R_{PD} + R_{iA})})^2 \cdot G_A \cdot R_A = 5.14 \times 10^{-16} \times (\frac{50}{(50+50)})^2 \times 10^{(57/10)} \times 50 = 3.22 \times 10^{-9}\ W$$

$$T_{e_{max}} = T_{PD_{max}} + T_{A_{max}} = 358\ + 358 = 716\ K$$

$$< I_{Th_{max}}{}^2 > \; = \; \frac{4k_B T_{e_{max}} B_N}{R} = \frac{4 \times 1.38 \times 10^{-23} \times 716 \times 1 \times 10^6}{50} = 7.90 \times 10^{-16}\, Amp^2$$

$$P_{Th_{max}} \; = \; < I_{Th_{max}}{}^2 > \cdot \left(\frac{R_{PD}}{(R_{PD} + R_{iA})}\right)^2 \cdot G_A \cdot R_A = 7.90 \times 10^{-16} \times \left(\frac{50}{(50+50)}\right)^2 \times 10^{(57/10)} \times 50 = 4.95 \times 10^{-9}\, W$$

C5 - Calculation of RIN

$$< I_{RIN}{}^2 > \; = \; (R \cdot P_{oPD})^2 \cdot RIN_v \cdot B_N$$

$$< I_{RIN}{}^2 > \; = \; (0.75 \times 6.27 \times 10^{-3})^2 \times 10^{(-155/10)} \times 1 \times 10^6 = 7.00 \times 10^{-15}\, Amp^2$$

$$P_{RIN} = \; < I_{RINv}{}^2 > \cdot \left(\frac{R_{PD}}{(R_{PD} + R_{iA})}\right)^2 \cdot G_A \cdot R_A$$

$$P_{RIN} = \; 7.00 \times 10^{-15} \times \left(\frac{50}{(50+50)}\right)^2 \times 10^{(57/10)} \times 50 = 4.39 \times 10^{-8}\, W$$

C6 - Calculation of Shot noise

$$< I_{PDSh}{}^2 > \; = (R \cdot P_{oPD}) \cdot 2 \cdot q \cdot B_N$$

$$< I_{PDSh}{}^2 > \; = (0.75 \times 6.27 \times 10^{-3}) \times 2 \times 1.602 \times 10^{-19} \times 1 \times 10^6 = 1.51 \times 10^{-15}\, Amp^2$$

$$P_{PDSh} = \; < I_{PDSh}{}^2 > \cdot \left(\frac{R_{PD}}{(R_{PD} + R_{iA})}\right)^2 \cdot G_A \cdot R_A$$

$$P_{PDSh} = \; 1.51 \times 10^{-15} \times \left(\frac{50}{(50+50)}\right)^2 \times 10^{(57/10)} \times 50 = 9.44 \times 10^{-9}\, W$$

C7 - Calculation of Dark noise

$$< I_{Dark}{}^2 > \; = \; 2 \cdot q \cdot I_{PDdark} \cdot B_N$$

$$< I_{Dark}{}^2 > \; = \; 2 \times 1.602 \times 10^{-19} \times 0.02 \times 10^{-9} \times 1 \times 10^6 = 6.41 \times 10^{-24}\, Amp^2$$

$$P_{Dark} = \; < I_{Dark}{}^2 > \cdot \left(\frac{R_{PD}}{(R_{PD} + R_{iA})}\right)^2 \cdot G_A \cdot R_A$$

$$P_{Dark} = \; 6.41 \times 10^{-24} \times \left(\frac{50}{(50+50)}\right)^2 \times 10^{(57/10)} \times 50 = 4.01 \times 10^{-17}\, W$$

C8 - Calculation of Total noise

$$P_{Nouttotal_{min}} = \; P_{Th_{min}} + P_{RIN} + P_{Sh} + P_{Dark} \;\; (linear)$$

$$P_{Nouttotal_{min}} = 5.65 \times 10^{-8}\, W = -42.48\, dBm$$

$$P_{Nouttotal_{max}} = \; P_{Th_{max}} + P_{RIN} + P_{Sh} + P_{Dark} \;\; (linear)$$

$$P_{Nouttotal_{max}} = 5.83 \times 10^{-8}\, W = -42.35\, dBm$$

C9 - Dynamic Range Calculation

$$DR_{max,\, dB} = P_{out1dBCP,\, dB} - P_{Nouttotal_{min},\, dB} = 51\; dBm \; - -42.48\; dBm = 93.478\; dB$$

$$DR_{min,\, dB} = P_{out1dBCP,\, dB} - P_{Nouttotal_{max},\, dB} = 51\; dBm \; - -42.35\; dBm = 93.347\; dB$$