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# RF Over Fiber
# Design Guide Overview

Provided by

OPTICAL ZONU CORPORATION

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## Why use fiber?

Transmission of RF and Microwave Signals via waveguides or coaxial cable suffers high insertion loss and susceptibility to interference (EMI). Single Mode Fiber Optic Analog RF (aka RFoF) Transceivers provide an excellent alternative for this type of application. Fiber Optic transmission offers significant advantages for the reliable transport of RF signals in their native format over many types of optical networks and across a broad range of frequencies. For analog type signals, especially at high frequencies, in which premium performance at high Spurious Free Dynamic Range (SFDR) is desirable, there are but a few methods to achieve such a goal.

- Less signal degradation per meter
- Higher signal carrying capacity / bandwidth
- Less costly per meter
- Lighter and thinner than copper wire
- Free from electromagnetic interference (Poor weather does not affect signal)
- Lower transmitter launching power
- Flexible (used in medical and mechanical imaging systems)

## Functionality & How it Works?

The incoming RF signal is input to the Transmitter Module, which contains RF signal conditioning, provides complex impedance matching between 50 Ohm input impedance and the Laser, Laser Bias Control, APC, Monitoring and Alarm electronics. The transmitter module utilizes an Intensity Modulation scheme to convert RF to light, which is transported through an optical fiber into the Optical Receiver. The Receiver Module converts the modulated light back into an RF signal. The recovered RF signal is again complex impedance matched and amplified before it becomes available at the output of the receiver. Generally the photodiode is a high impedance current source with an impedance around 2 k-ohms, followed with several amplifiers. The broadband matching is achieved with variety of schemes that will be dictated by the overall user modulation bandwidth and Noise density and Intermodulation distortion requirements. There are many types of RFOF Direct modulation transmitters including CWDM grade, but for most part. The following two types cover majority of applications.
The two types of Links are, without any Low Noise Amplifiers (LNA) and other with LNA built-in.

- Typical RFoF Link without LNA has a Gain offering from 1dB +/- 1, but higher Gain is available based on customer overall bandwidth, NF and IIP3 requirements.

- Typical RFoF Link with LNA has a Gain offering from 20dB +/- 1, but higher Gain is available based on customer overall bandwidth, NF and IIP3 requirements.

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## RF Attenuation vs. Optical Loss

<u>1 dBo of optical loss corresponds to 2 dBe of RF loss</u>.

The photo diode generated current can be calculated from the following expression:

Ipd = rpd x Popt   Where,

Ipd  = photodiode current (A),
rpd = small signal photodiode responsitivity (A/W),
Popt = optical power detected by photodiode (W).

The output RF power can also be calculated using the photo Diode generated current

Prf = Ipd^2 x Rload Where

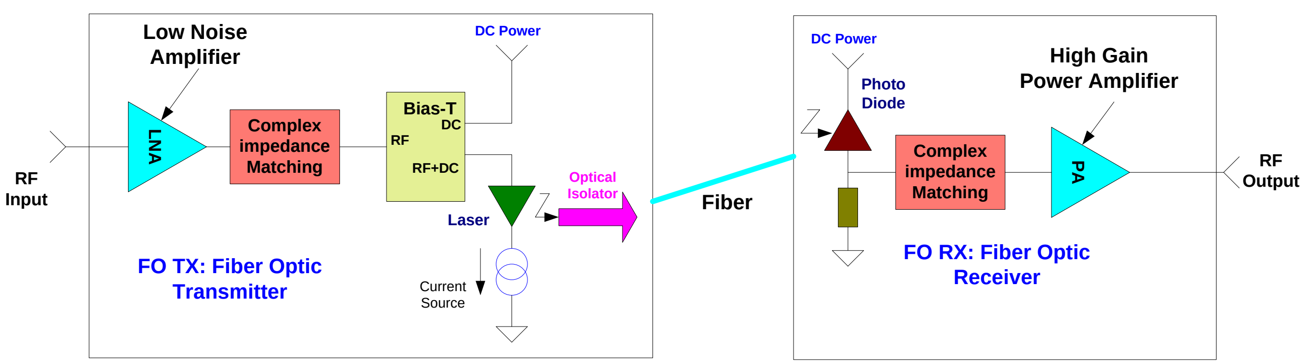
Prf = power delivered to load resistance connected to photodiode (W),
Rload = load resistance connected to photodiode (Ω).

With some Simple substituting:

Prf = rpd^2 x Popt^2 x Rload

Thus the converted RF power is related to the square of the optical power, and due to this relationship, a 1dB loss of optical power will become a 2dB loss of RF power. To eliminate confusion between optical losses and electrical losses the unit dBo and dBe has been adopted respectively.

## Simple RF over Fiber Link Block Diagram

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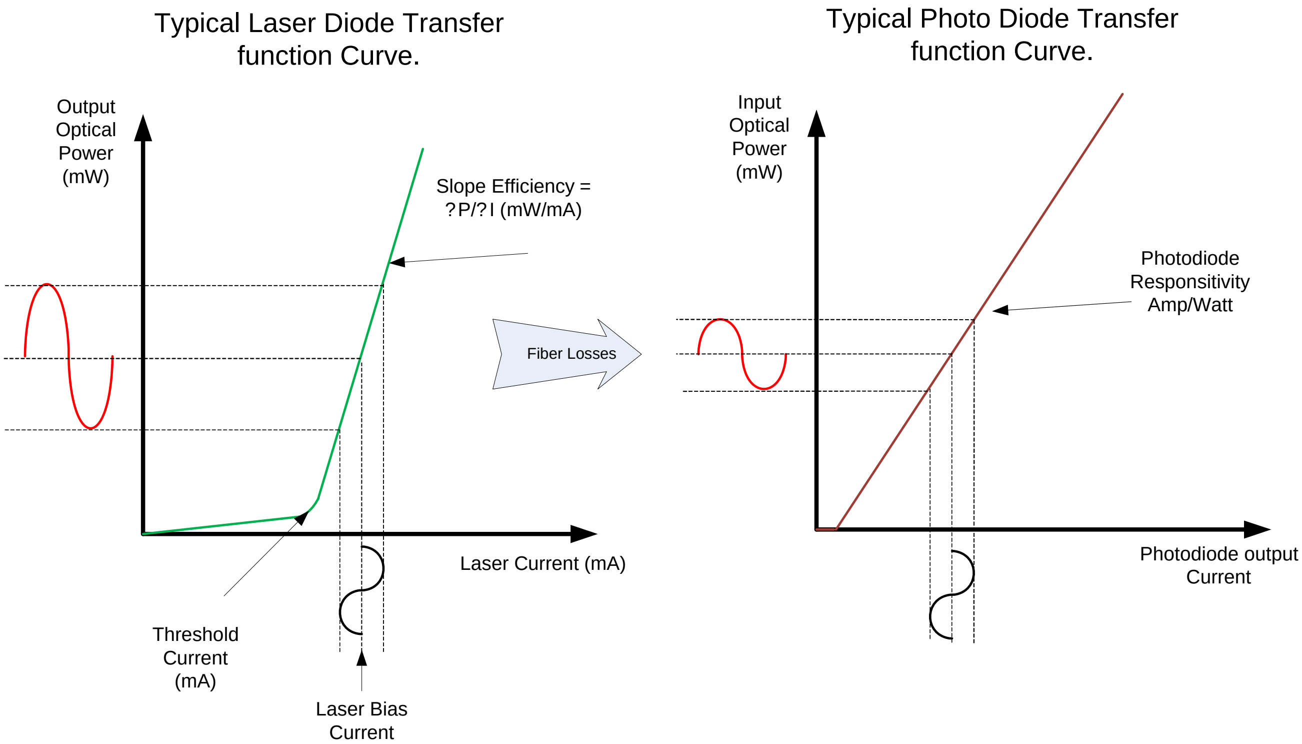
## Link Gain




### RFoF Total LINK GAIN

- RFoF Total Link Gain (dB) = GT
- LNA Gain (dB) = GLNA
- Optical TX RF EO efficiency (mW/mA) = αTX (*includes 50 ohms to Laser Matching losses and Laser slope efficiency*)
- Optical RX RF OE efficiency (mA/mW) = αRX (*includes matching losses of PD high impedance to 50 ohms and PD responsitivity losses*)
- Fiber cable losses (dB) = Lopt (*includes fiber losses, and coupling or splices etc…)*
- GT (dB) = GLNA (dB) + 20log(αTX . αRX ) - 2Lopt

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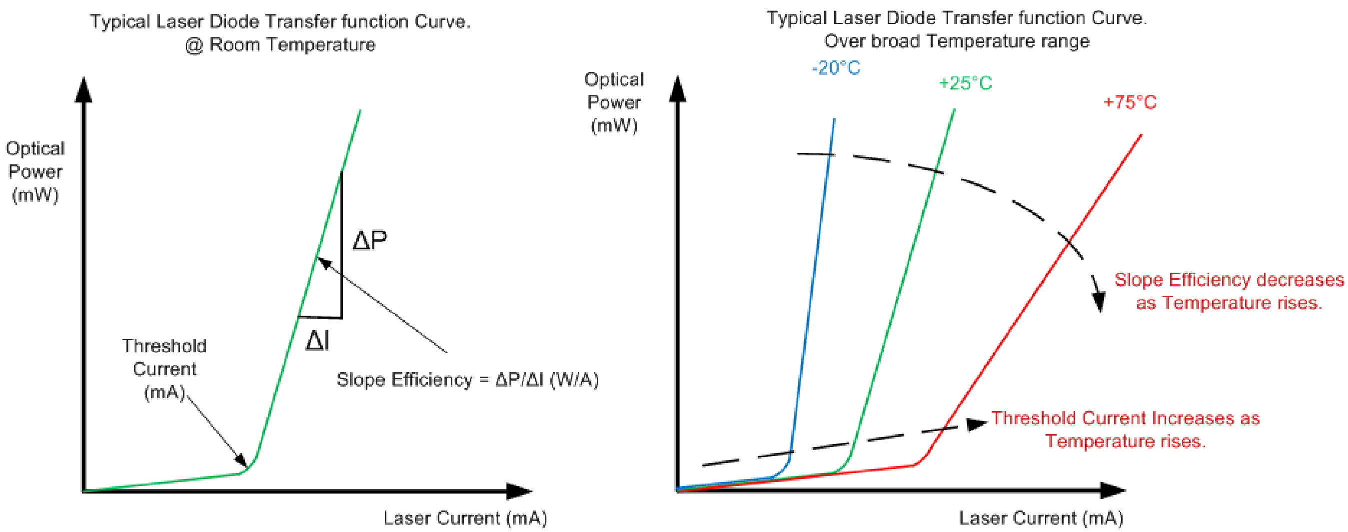
# Effects of Laser Slope Efficiency

In all Lasers the slope efficiency parameter is very temperature sensitive. As the Laser temperature changes, so does the slope efficiency of the Laser, and consequently, all of the other critical Laser parameters such as Gain, OMI, NF, IP3,etc.. The temperature characteristics of the Laser diode are such, that as the threshold current increases, the slope efficiency of the Laser device decreases, and an increasing Laser temperature results. This phenomenon makes the Laser less efficient, thus reducing the RF signal Gain and increasing the link Noise figure, as well as causing additional degradation in the Laser linearity.

One method to overcome this phenomenon, which yields high performance, is to use an integral Thermoelectric Cooler (TEC) with DFB Lasers. This technology assures a high level of Laser stability and assures excellent RF performance, A typical cooled DFB Laser has a high “slope efficiency”, which means that the Laser is highly sensitive and requires a lower modulation current in order to achieve the usual high modulation index.

## Laser Slope Efficiency over Temperature




In Case of Cooled DFB Laser Transmitter, the slope Efficiency of the laser is not changed even though the Transmitter module will be exposed to wide temperature variations of up to -40C to +85C

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## Total Link Noise Figure Analysis

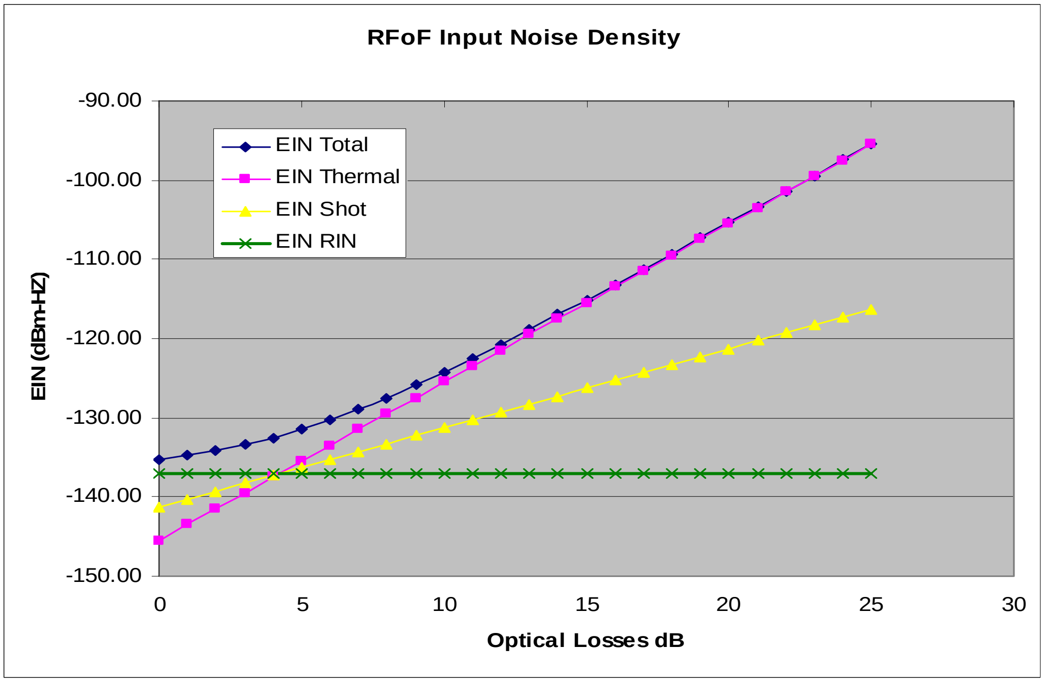
- Equivalent Link Input Noise Density (dBm-Hz), EIN is the amount of Noise at the input of the RFoF link that produces output Noise Density (EON) at the receiver end if the total link itself were Noiseless)
- Noise figure (NF) is a measure of degradation of the Signal-to-Noise Ratio (SNR), caused by components in a RF signal Chain. The noise figure is thus the ratio of actual output noise to that which would remain if the device itself did not introduce noise.

*EIN = EON - GT* Where, **GT (dB) = GLNA (dB) + 20log(αTX . αRX ) - 2Lopt**
NF = EIN+174 dBm-Hz Where, KBT is ideal device that is terminated by a passive load at temperature 290 Kelvin (T0). KB= 1.38x10^-23 J/K Boltzmann constant

The End to end link noise is due to variety of sources, such as the Laser Relative Intensity Noise (RIN), Photodiode Shot Noise and the Thermal Noise due to the receiver post amplifiers following the PD. As you can see above the optical losses due to the fiber inherent losses and any coupling losses is also degrades the Link equivalent input noise density EIN.

*EIN = EIN laser RIN + EIN PD shot Noise + EIN receiver Thermal Noise (W/Hz)*

## Total Link Noise and All Its Contributors vs. Optical Loss

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# How to Reduce Noise Figure (NF)?

One what to reduce the NF of a RFoF Link (End to End) is to increase Transmitter RF to Conversion efficiency otherwise the TX Gain. Using a Low Noise amplifier Before the Laser is highly effective way achieving just that. Choosing the LNA properly is extremely important to maximize the effectiveness of such approach, and parameters such as Gain, NF and IIP3 of amplifier play a key role in all that.

The Way it works is as following:
NFTotal RFoF LINK = NFLNA + (NFRFoF Link – 1)/GainLNA
For Example:
LNA Gain 20 dB
LNA NF 3 dB
RFoF Link NF without LNA = 40 dB
NFTotal RFoF LINK = 2 + (10000-1)/100 = 102
NFTotal RFoF LINK = 10xLOG(102) = 20 dB

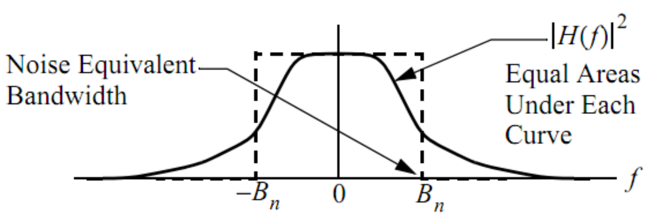
20dB improvement in NF!

* *The drawback in such approach is also reduction in Input 3rd Order Intercept Point of the total link which must be considered in overall Link system Design.*

# How to Calculate Carrier to Noise Ratio (CNR)?

Noise Equivalent Bandwidth is defined such as When white noise (flat spectrum of frequencies) is passed through a filter having a frequency response H(f), some of the noise power is rejected by the filter and some is passed through to the output. This is also known as Signal Channel Bandwidth (BW).

Thus to Calculate Carrier to Noise Ratio of a RFoF link not only one need to know the input signal level and link EIN but also the Noise Equivalent Bandwidth.




**Sinput** = RF input Signal Level dBm
**PNoise** = Total Noise at the input dBm
**PNoise** = **EIN + 10Log(BW)**

**CNR = Sinput – PNoise (dB)**

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## 3rd Order Input Intercept Point?

A Input third-order intercept point (IIP3) is a measure of nonlinearity of the RFoF link. The intercept point is a purely mathematical concept, and does not correspond to a practically occurring physical power level. In many cases, it lies beyond the damage threshold of the device. But in multichannel system knowing this parameter is critical parameter to calculate the overall Intermodulation distortion produced by the RFoF link.

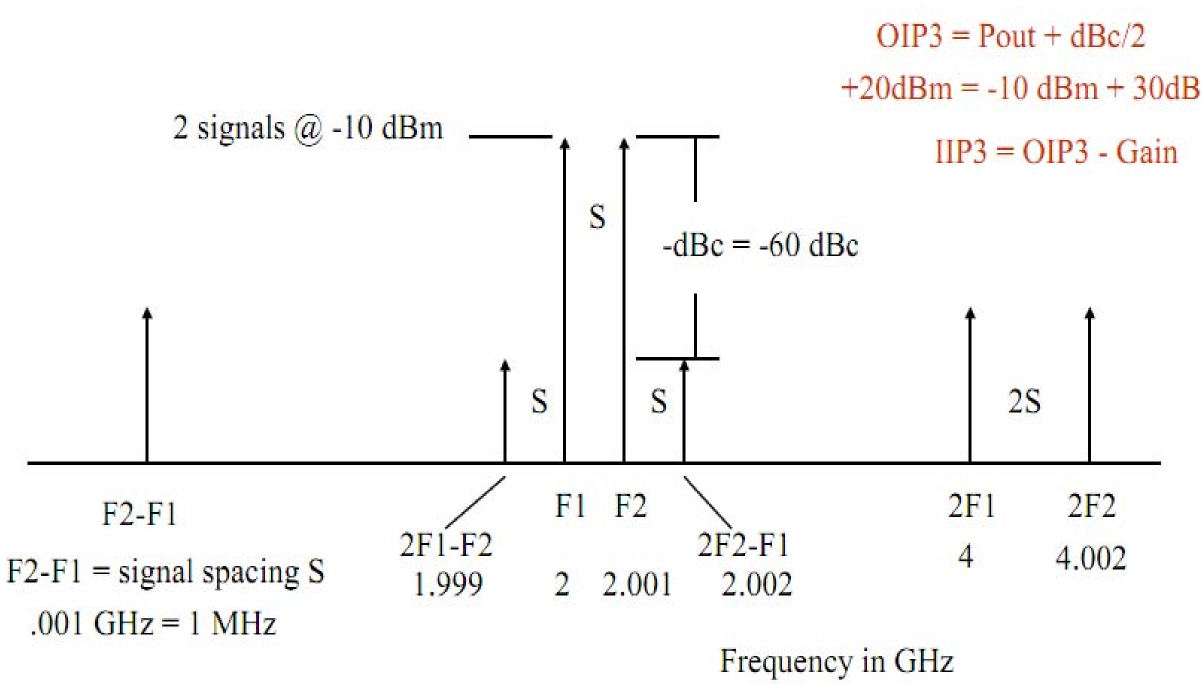
Carrier to IMD ratio = 2 x (IIP3 – Signal level) dBc, (*Intermodulation Distortion levels below Carrier*)

Another parameter is has been used to measure nonlinearity of the RFoF link is OIP3, which is the Output third-order intercept point which is measured at the output of a optical receiver.

IIP3 = OIP3 – Link Gain
OIP3 = Signal Level (dBm) + [(Signal Level (dBm) – 3rd order distortion (dBm)/2 ]

To Calculate the OIP3 of a RFoF link, is to input Two Tones into the RFoF Transmitter and measure the 3rd order distortion products as is shown below.

## 3rd Order Input Intercept Point Measurement

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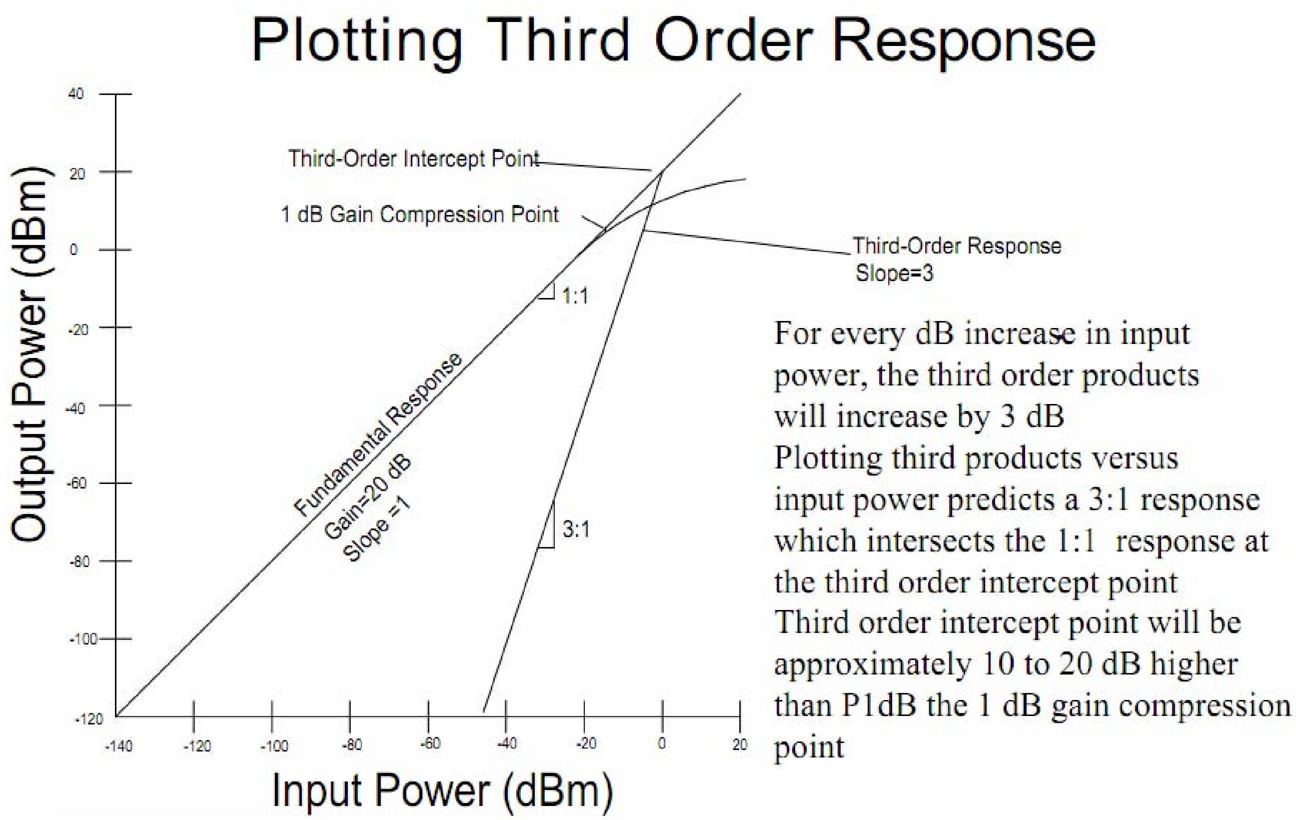
## 3rd Order Input Intercept Point Plots

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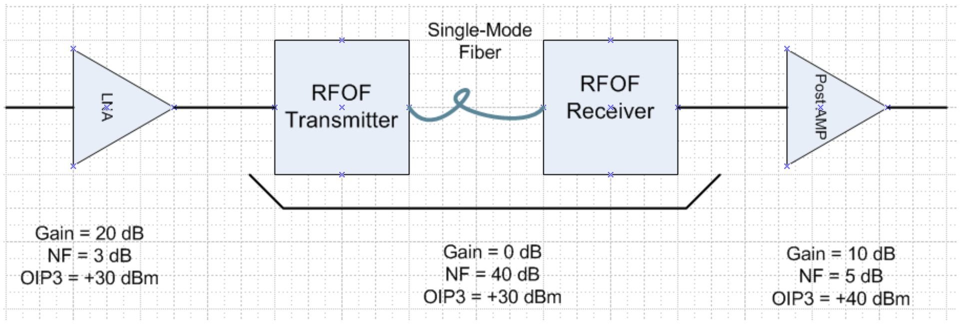
## Cascaded IIP3 Calculations

In case there are Pre-amplifiers (LNA), or other devices before and/or after RFoF link the overall Cascaded Link IP3 can be calculated as following:




1/(OIP3End-End ) = 1/(OIP3LNA*GRFoF*GPA ) + 1/(OIP3RFoF*GPA ) + 1/(OIP3PA )
1/(OIP3End-End ) = 1/(1000*1*10) + 1/(1000*10) + 1/10000 = 1E-4 + 1E-4 + 1E-4
1/(OIP3End-End ) = 3.33E3 OR +35.22 dBm

IIP3End-End = 35.22 – 30 = +5.22 dBm

## Spurious Free Dynamic Range (SFDR)

Spurious Free Dynamic Range (SFDR), is defined as the power level range of a pair of two input signals in which the two signals are above the noise floor and the 3rd order Intermodulation distortion products are below the noise floor.

SFDR = 2/3 x (IIP3 – EIN – 10LOG(BW))

The larger SFDR becomes the higher dynamic range, the RFoF link posses. The SFDR can be increased several ways, among them by reducing the bandwidth or reducing the Total input Noise density or increase IIP3 of the link.

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## Conclusion

This presentation is an overview of the overall process of designing, and specifying a fiber optic system for analog RF transport - an Engineering Guide. RF over Fiber designers need to know how to factor in the key parameters of a RFoF link (such as link Gain, NF and IP3,) for their system analysis and design. Equally important are the questions you must answer prior to new development project, such as:

1. What are the system performance parameters that the application you consider requires? Those are the END to END RF performance of the link.
2. Should you use fiber optics in your communications products?
3. What are its advantages?
4. How do you specify a RFoF link to allow users to choose the proper product for their application?

We have answered all questions except item 4, so to complete this presentations we have accumulated list of questions below for the user to complete enabling them to optimize the overall link performance.

| | A | | B | C | D | E | F |
|---|---|---|---|---|---|---|---|
| 1 | Product Selection Optimization Table (click here to email) | | | | | | |
| 2 | RFoF technical Requirements Questionnaire | | | | | | |
| 3 | Parameter / Feature | | Customer Input | Request | Standard | Premium | unit |
| 4 | Signal Type, SATCOM, CATV, FM, WiMAX, Cellular etc. | | | | | | |
| 5 | Low Frequency Cutoff | | | | 20 | 0.02 | MHz |
| 6 | High Frequency Cutoff | | | | 2,700 | 3,250 | MHz |
| 7 | Minimum Input signal level | | | | -40 | -60 | dBm |
| 8 | Maximum Input signal level | | | | 10 | tbd | dBm |
| 9 | Noise Figure (NF) | without LNA | | | 40 | 35 | dB |
| 10 | | with LNA | | | 20 | 15 | dB |
| 11 | SFDR (Spurious Free Dynamic Range) | | | | 109 | 112 | dB |
| 12 | Gain | without LNA | | | 0 | 6 | dB |
| 13 | | with LNA | | | 20 | 26 | dB |
| 14 | Maximum Output signal level | | | | 0 | 17 | dBm |
| 15 | AGC (optional) dynamic range | | | | 6 | 10 | dBo |
| 16 | Manual Gain Adjust | | | ☐ Yes | 6 dBo equiv. optional | | |
| 17 | RS232, 19.2KBPS Bidirectional | | | ☐ Yes | optional | | |
| 18 | RF connector, SMA Edge Mnt or SMB Plug or SMB Jack | | | | SMA | SMB | |
| 19 | RF impedance | | | | 50 | 75 | ohm |
| 20 | Fiber Length (Link distance) | | | | 2 | >20 | Km |
| 21 | Maximum Loss Budget | | | | 6 | >10 | dBo |
| 22 | Wavelength (CWDM grade optional) | | | | 1550/1310 | CWDM | nm |
| 23 | WDM (1310/1550 nm ) | | | ☐ Yes | optional | | |
| 24 | Optical Connector of Choice, FC/APC or SC/APC | | | | SC-APC | FC-APC | |
| 25 | Rack-mount (9000)/RF Block (800/600)/Plugable (400/500) | | | | | | |
| 26 | OZ9000 Power supply, +12VDC, +5VDC, AC 110/220 | | | | AC | 12 DC | V |
| 27 | ALARMS [open collector OR dry contact (9000 only)] | | | | LOS | SD | High |
| 28 | LED indiators (OZ9000, OZ600, OZ810) | | | ☐ Yes | Optional for Oz450/510 | | |
| 29 | Rx monitor (input optical power) | | | | 100 | | V/W |
| 30 | Tx Monitor (Laser bias current) | | | | 10 | | V/A |
| 31 | Redundant Power supply in a Rack mount (OZ9000) | | | ☐ Yes | optional | | |
| 32 | Comments: | | | | | | |

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