ICTON 2025
25th Anniversary International Conference on Transparent Optical Networks

Low Power Consumption Multi-Channel RFoF System for Ka-Band Intra-Satellite Links

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Outline

- Motivation
- RF over fiber link
- 4-channel RF over fiber system
- Characterization of developed system
  - Link gain
  - Noise analysis
  - Non-linearity analysis
- Conclusion

Motivation

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- Conventional copper-based cabling suffers from
  - High loss
  - Heavy
  - Bulky
- Exploiting RF over optical fiber system benefits from
  - Low loss
  - Low weight
  - Compact
  - Immunity to EMI
  - Reconfigurability

Conventional Cable*	Optical fiber**
✓ 3.72 dB/m attenuation	✓ 0.2 dB/km attenuation
✓ ~10 kg/100m	✓ <3kg/100m

Launching cost!!!

* HUBER+SUHNER SUCOFLEX® 550S
** Corning® SMF-28® ULL Optical Fiber

Motivation

- Inherent KPIs for RF over fiber system
  - Broadband operation
  - High linearity
  - Hermetic packaging
  - Low power consumption
  - Solderless integration
  - Multi-channel operation

Conventional Cable*

- ✓ 3.72 dB/m attenuation
- ✓ ~10 kg/100m

Optical fiber**

- ✓ 0.2 dB/km attenuation
- ✓ <3kg/100m

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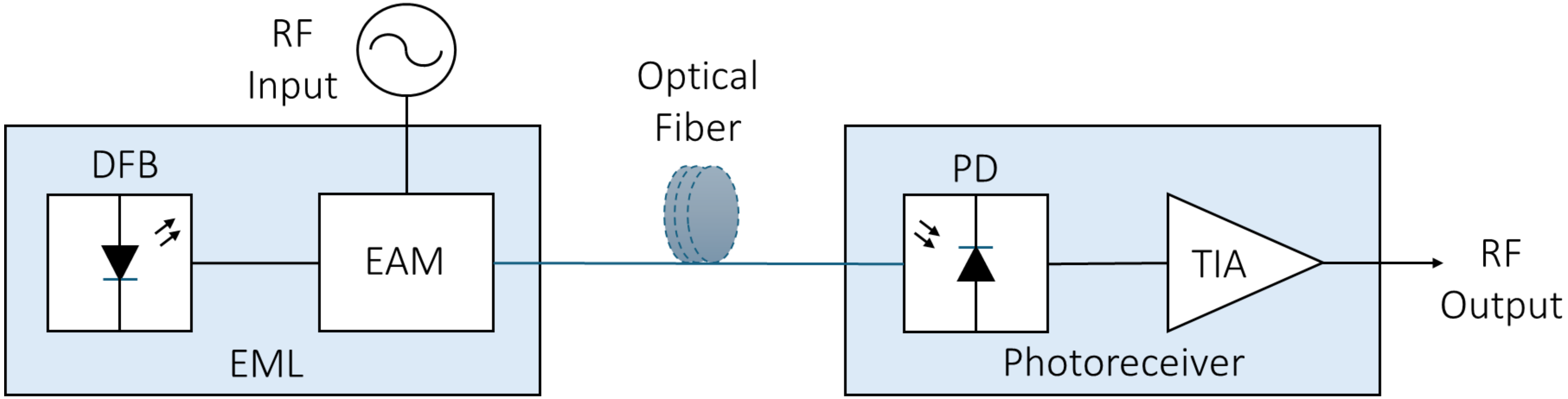
RF over Fiber Link



Transmitter side:

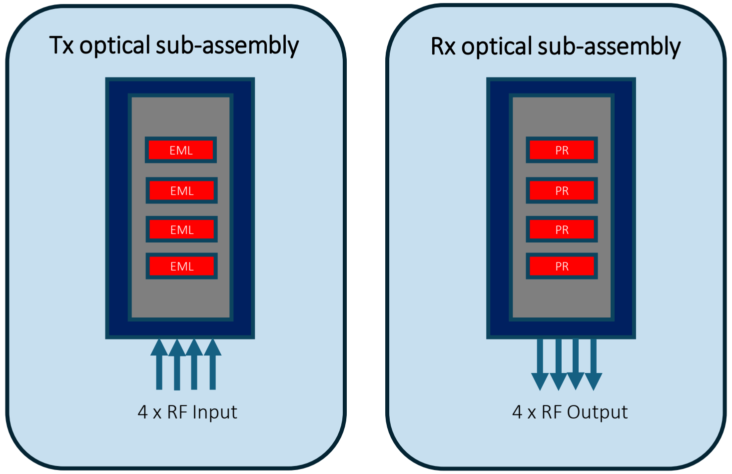
- Electro-absorptive modulated laser (EML)
  - Distributed feedback (DFB) laser
  - Electro absorption modulator (EAM)
  - Uncooled EML to eliminate TEC
  - Low power requirements due to reverse bias

Receiver side:

- Photoreceiver
  - Photodiode (PD)
  - Transimpedance amplifier (TIA)
  - TIA to compensate the loss
  - Conversion gain control of TIA

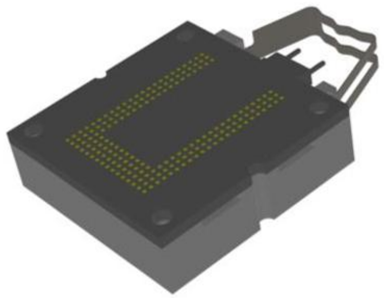
4-channel RF over Fiber System

- **Transmitter:** four 1.31 µm uncooled EML chip-on-carriers
- **Receiver:** four 1.31 µm arrayed photodiodes integrated with TIAs

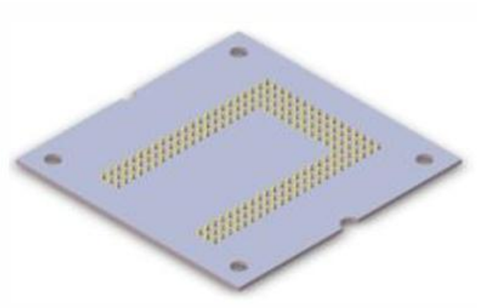


- Packaging of optical sub-assemblies features land grid arrays (LGA) to provide DC and RF connectivity

- Innovative interposer technology:
  - Enables solderless connection
  - Multi-channel operation
  - Mixed signal operation (DC & RF)



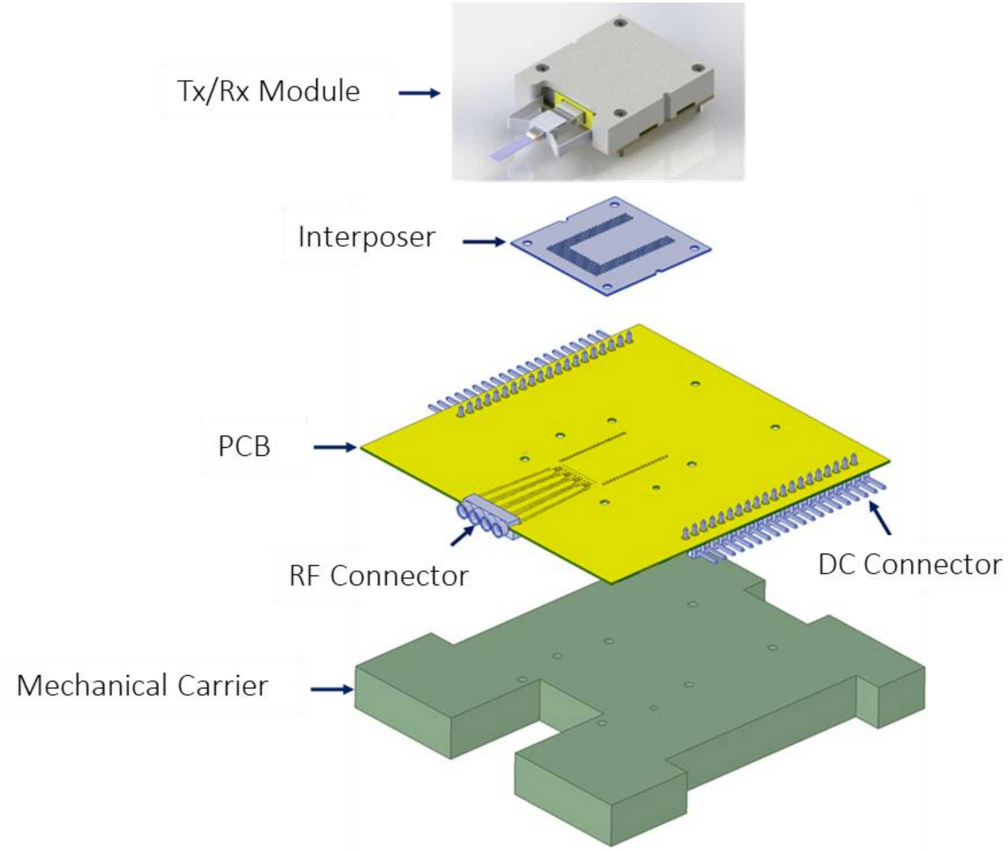
LGA

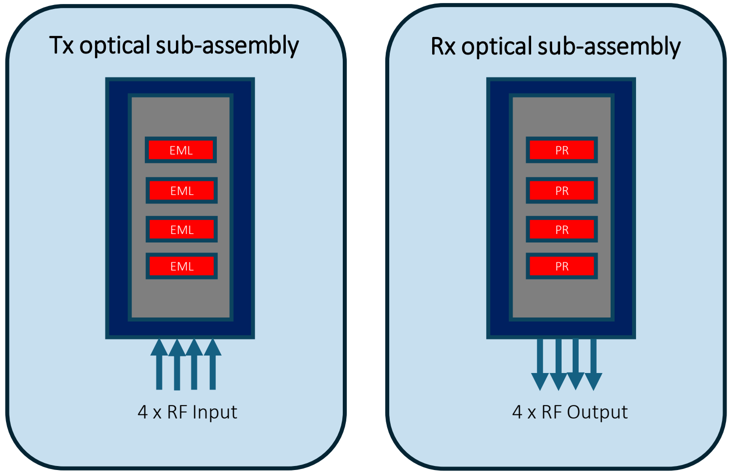


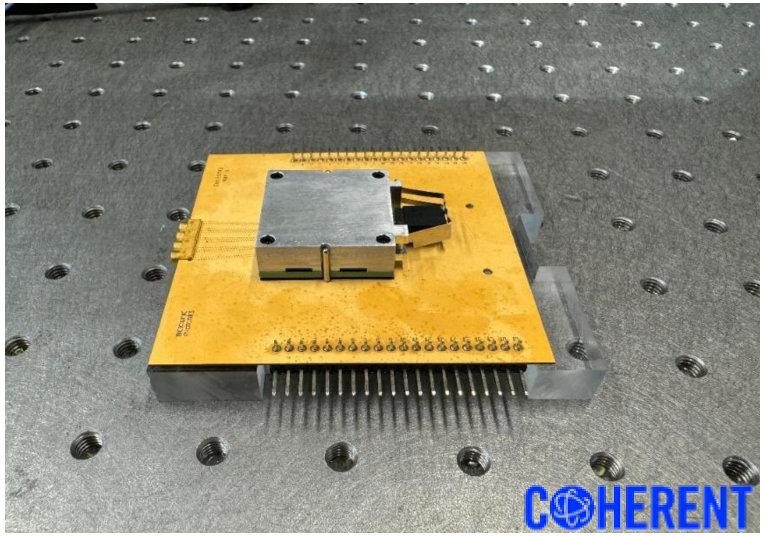
Interposer

4-channel RF over Fiber System

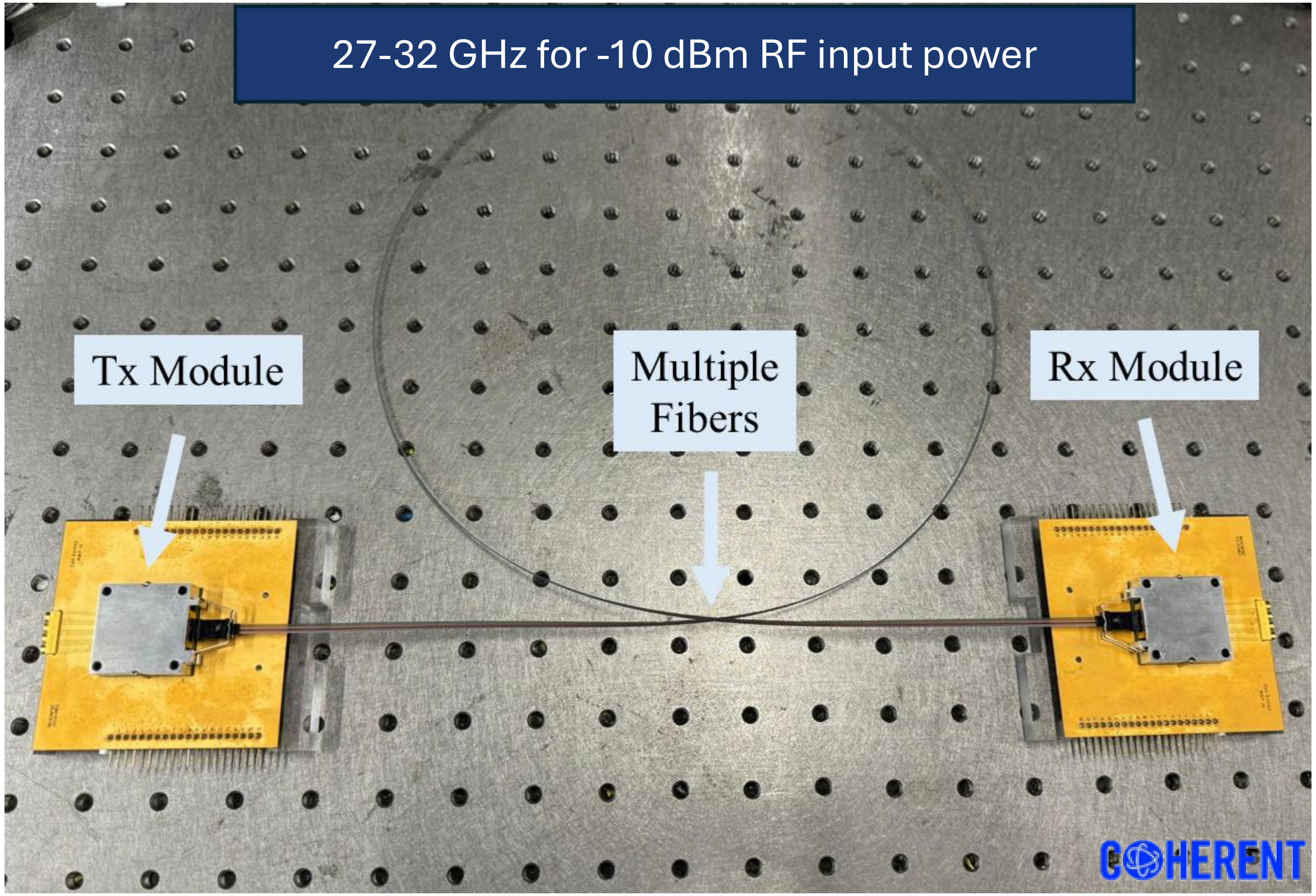
- **Transmitter:** four 1.31 µm uncooled EML chip-on-carriers
- **Receiver:** four 1.31 µm arrayed photodiodes integrated with TIAs

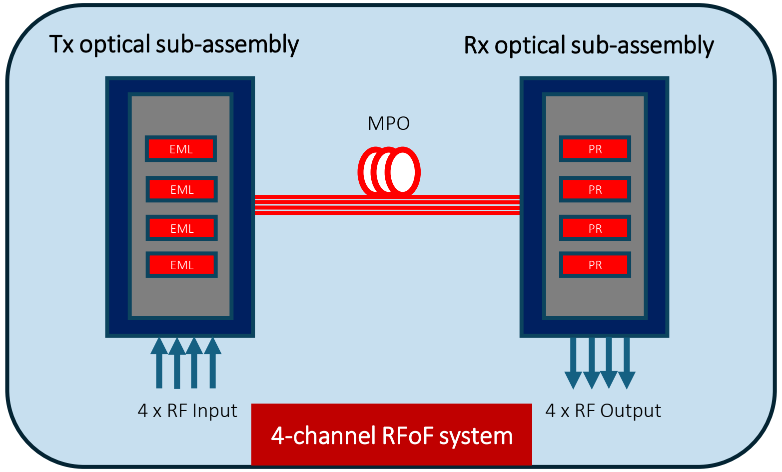






4-channel RF over Fiber System





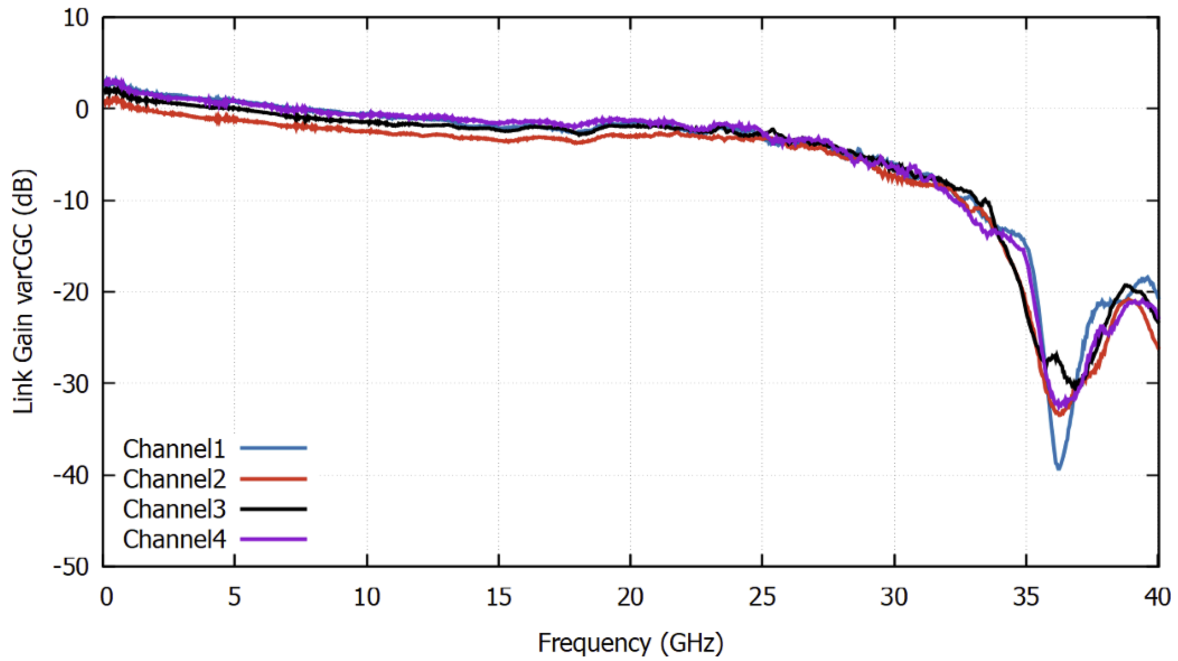
Weight: < 50 g !!!

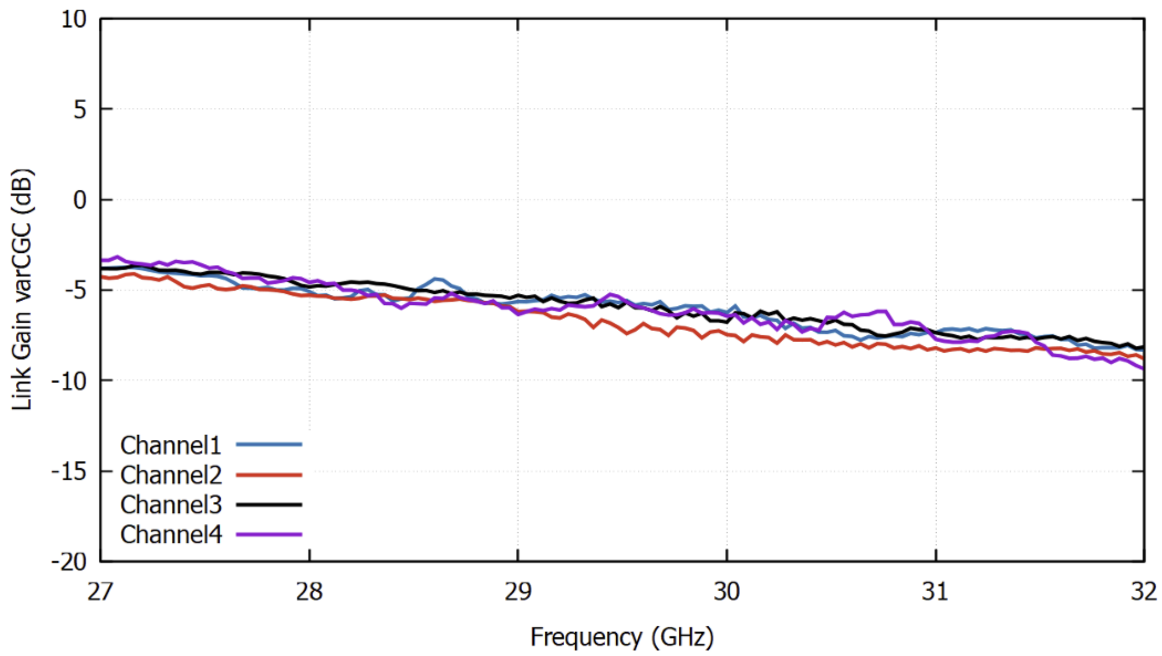
- Tx&Rx modules
- Multiple fibers

Footprint of each module: 3X3 cm^2

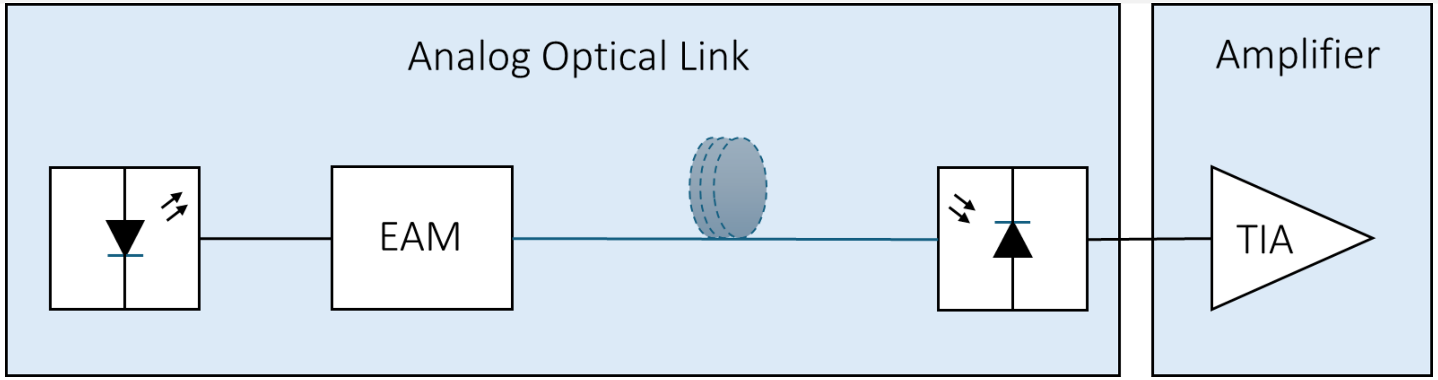
Link Gain

- Link gain measured using VNA frequency range of **DC-40 GHz** and **27-32 GHz** at **-10 dBm** RF input power
  - 4-active channel measurement
  - > -10 dB link gain
  - Harmonized link gain





Noise Modelling



Main noise contributors:

- Thermal noise equivalent current:

$$\langle i_t^2 \rangle = 4kTB/R$$

$$N_{TH,av} = kTB$$

$N_{TH,av} = -174\ \mathrm{dBm}$; k= 1.38 × 10^{-23}J/K, B=1 Hz and T= 290 K

- Shot noise equivalent current:

$$i_D(t) = \langle I_D \rangle + i_{sn}(t)$$

$$\langle i_{sn}^2 \rangle = 2q\langle I_D \rangle B$$

- RIN equivalent current:

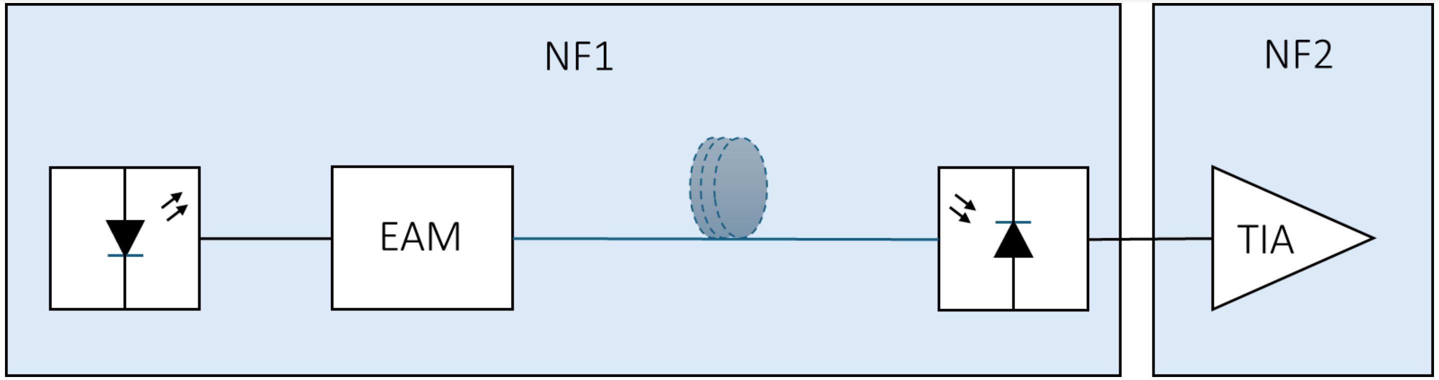
$$P_0(t) = \langle P_0 \rangle + P_{rin}(t)$$

$$rin = \frac{\langle P_{rin}^2(t) \rangle}{\langle P_0 \rangle^2} = \frac{2\langle P_{rin}^2(t) \rangle}{\langle P_0 \rangle^2 B}$$

$$RIN = 10\log\left(\frac{2\langle i_{rin}^2(t) \rangle}{\langle I_D \rangle^2 B}\right)$$

$$\langle i_{rin}^2 \rangle = \frac{\langle I_D \rangle^2}{2} 10^{\frac{RIN}{10}} B$$

Noise Modelling



- Noise Figure:

$$NF = 10\log\left(\frac{S_{in}/N_{in}}{S_{out}/N_{out}}\right)$$

$$S_{out} = g_i S_{in}$$

$$N_{out} = g_i N_{in} + N_{add}$$

$$NF = 10\log\left(1 + \frac{N_{add}}{g_i N_{in}}\right)$$

- Noise figure of a cascaded system:

$$NF_{cas} = NF_1 + \frac{NF_2 - 1}{G_1} + \frac{NF_3 - 1}{G_1 G_2} + \ldots$$

NF of analog optical link dominates!!!

Noise Modelling

- Noise Figure:

$$NF = 10\log\left(1 + \frac{N_{add}}{g_i N_{in}}\right)$$

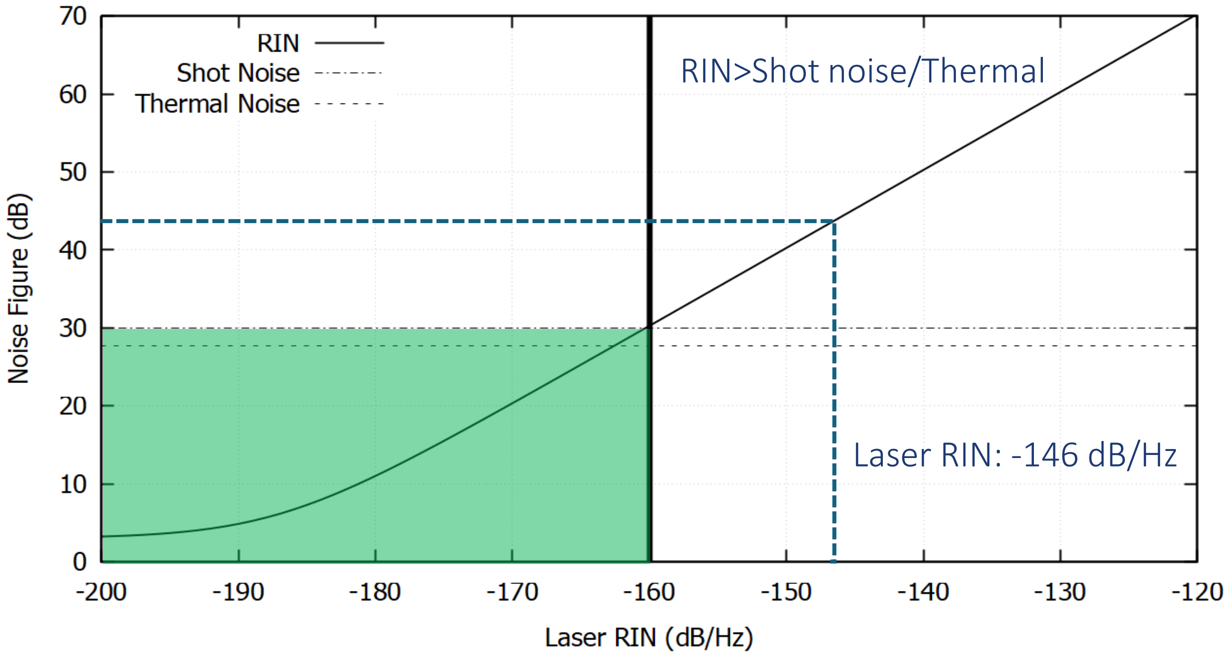
Dominant noise source

- RIN equals to shot noise:

$$RIN_{sn} = 10\log\left(\frac{2q}{\langle I_D \rangle}B\right)$$

- Noise figure of RIN-dominated RFoF link:

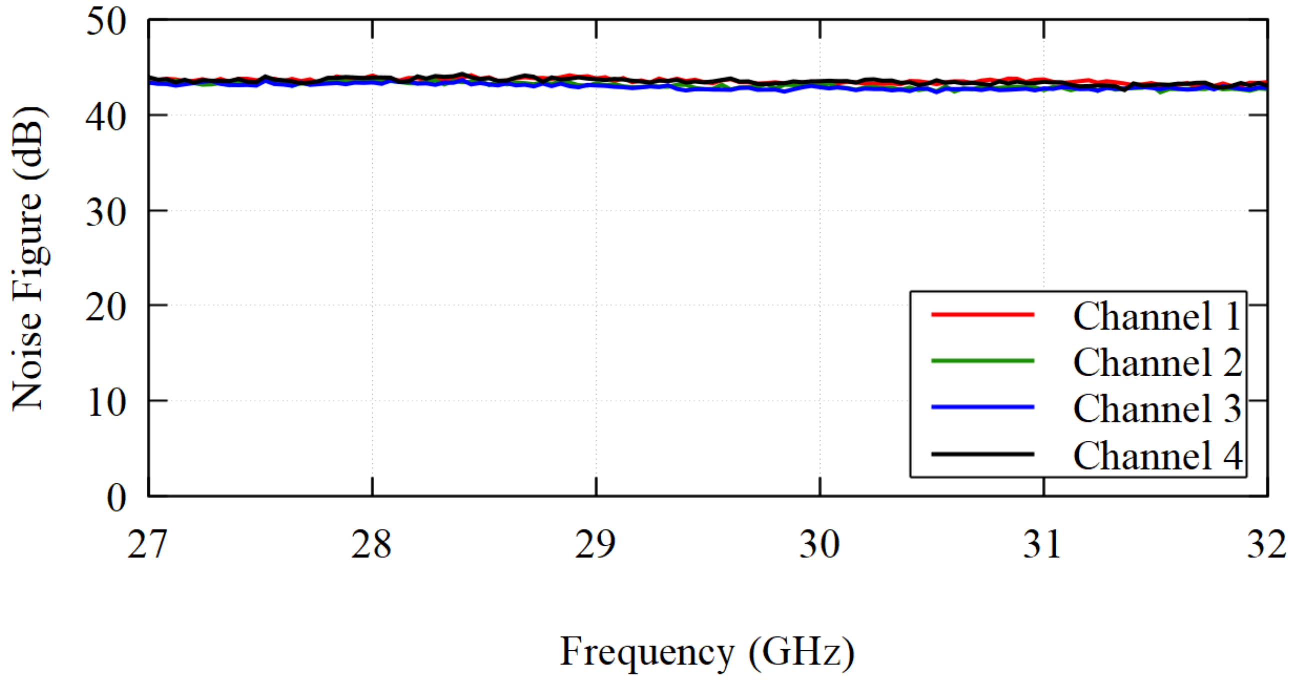
$$NF = 10\log\left(1 + \frac{g_i kTB + \langle i_{rin}^2 \rangle R_{LOAD}}{g_i kTB}\right) = 10\log\left(2 + \frac{\langle i_{rin}^2 \rangle R_{LOAD}}{s_{md}^2 r_d^2 kTB}\right)$$



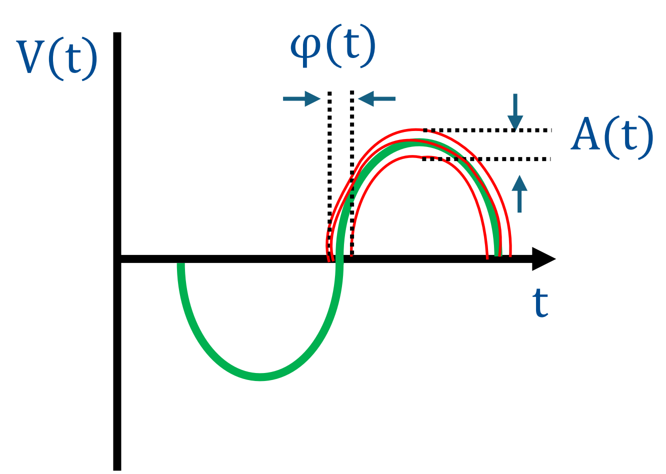
Parameter	Value
Modulator slope efficiency	0.075 W/A
Photodiode responsivity	0.55 A/W
Average photodiode current	3.4 mA
Load resistance	50 Ω

Noise Figure

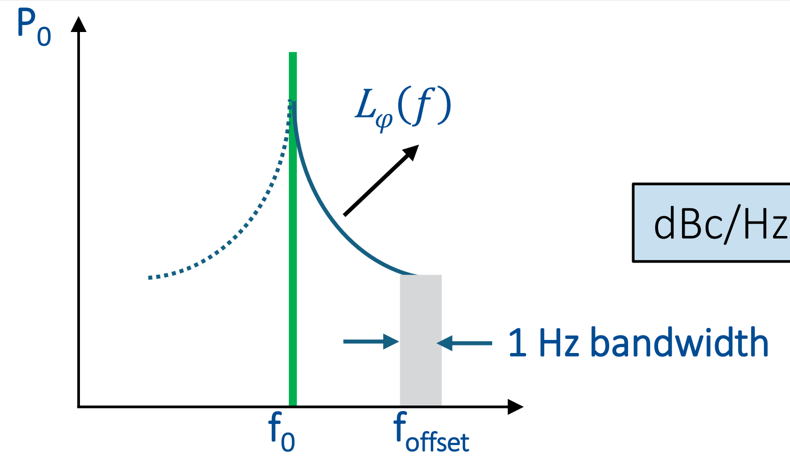
- Noise figure measured frequency range of **27-32 GHz** at **-10 dBm** RF input power
  - 4-active channel measurement
  - Around 43 dB noise figure
  - Correlated measurement results with noise modelling



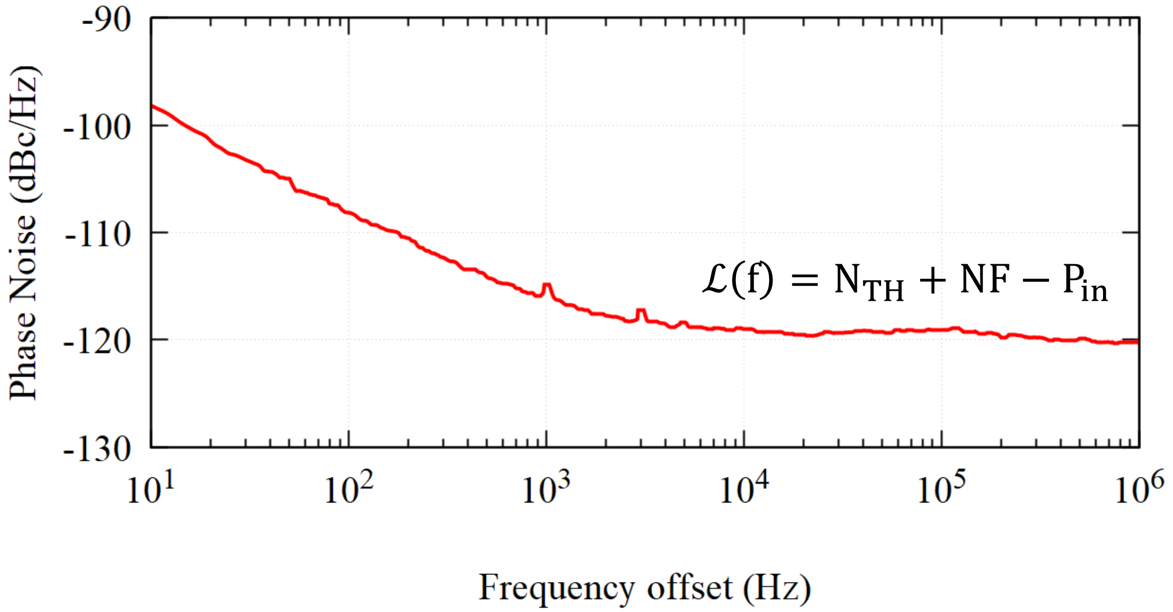
Phase Noise



$$V(t) = [V_0 + A(t)]\cos[2\pi f_0 t + \varphi(t)]$$



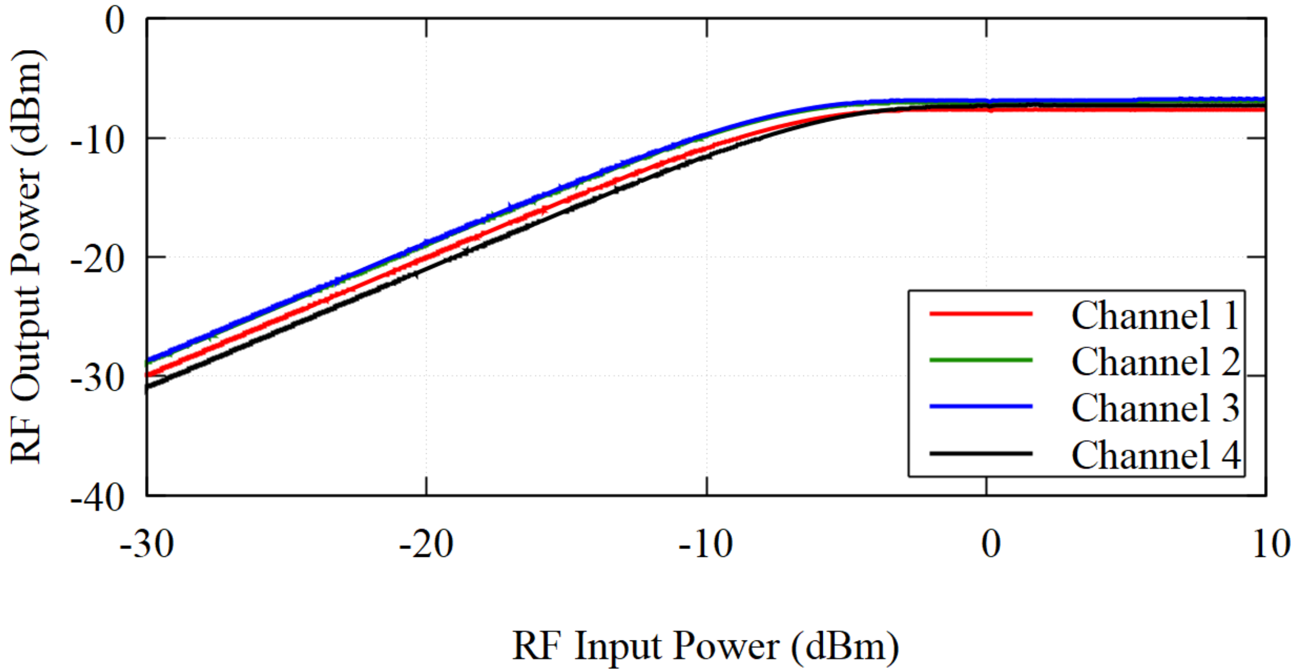
dBc/Hz @ f_{offset}

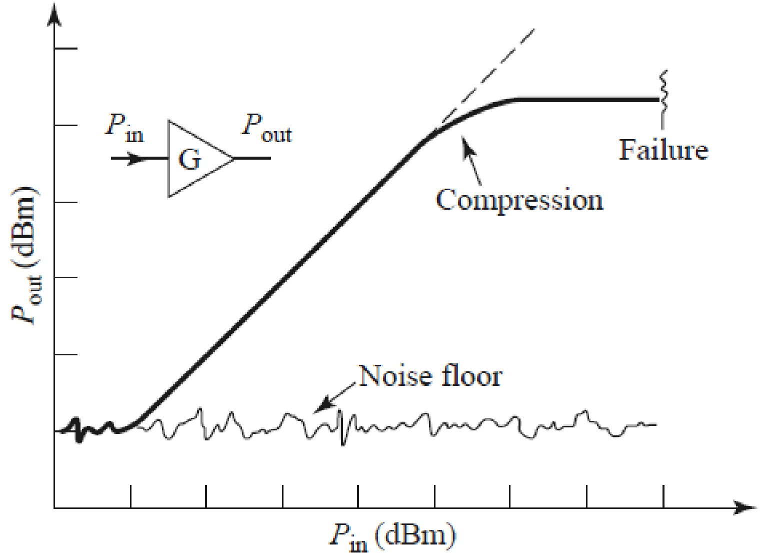


- Phase noise measured at 30 GHz for -10 dBm RF input power
  - -120 dBc/Hz @1 MHz offset frequency
  - Additive noise
  - $\mathcal{L}(f) = N_{TH} + NF - P_{in}$

Saturated Output Power

- Saturated output power measured between **-30 dBm** and **10 dBm** RF input power at **30 GHz**
  - 4-active channel measurement
  - 1 dB compression at ≈-8 dBm RF input power
  - -7 dBm maximum RF output power





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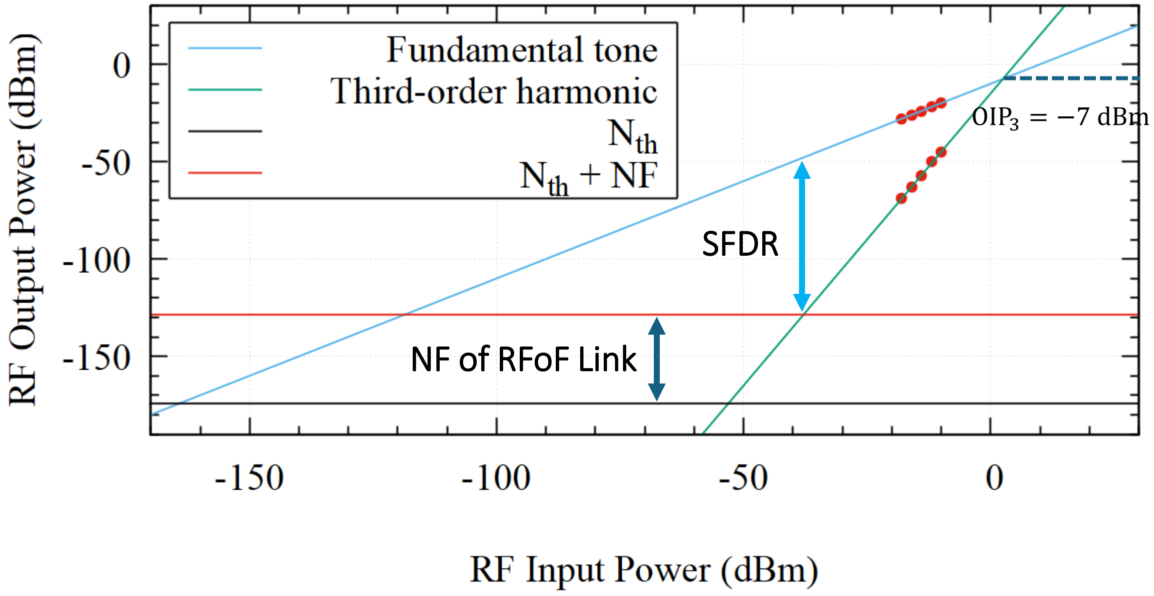
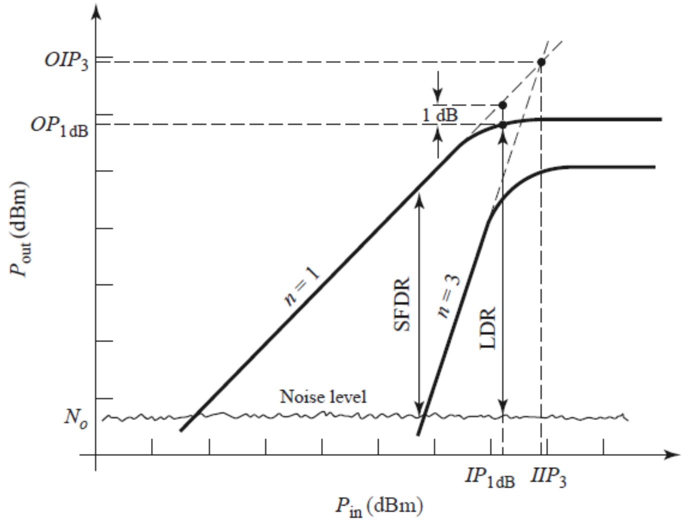
Spurious-free Dynamic Range





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- Two-tone SFDR measurement
  - f1: 30 GHz
  - f2: 30.01 GHz
  - Ideal noise floor: -174 dBm
  - Dynamic range @ -10 dBm : 30 dBc
  - SFDR: 83 dBc

$$\text{SFDR (dBc)} = \frac{2}{3}(\text{OIP}_3 - \text{NF} - \text{N}_{\text{th}})$$

Conclusion

- **Low weight, small size, low power consumption** and **multi-channel** RFoF system presented
- Developed RFoF System characterized
  - Link Gain Measurement
  - Noise analysis
    - Noise modelling
    - Noise figure measurement
    - Phase noise measurement
  - Non-linearity analysis
    - Saturated output power measurement
    - Two-tone SFDR measurement

Key Parameters	
Power consumption per channel	< 0.4 W
Weight	< 50 g
Footprint per module	3x3 cm^2

Characteristics of the link	
Link Gain (27-32 GHz)	> -10 dB
Saturated output power	-7 dBm
SFDR	83 dBc
Noise figure	43 dB
Phase noise	-120 dBc/Hz @1 MHz

Acknowledgements

The authors acknowledge financial support from the European Commission in the framework of the TERAOPTICS project (grant no. 956857) and PATTERN project (grant no. 101070506).

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Any questions/comments?