Low Power Consumption and Low Phase Noise Broadband DC-40 GHz RFoF Links for Antenna Remoting

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2024 DUISBURG GeMiC German Microwave Conference

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Outline

- Motivation
- RF over fiber system basics
- System configurations
- Applications
- System characteristics of developed RFoF system
    - Link gain
    - Saturated output power
    - Noise modelling
    - Noise figure
    - Phase noise
    - Trace noise
- Conclusion

Motivation

- Conventional coaxial cables suffer from
  - High loss over long distance
  - Heavy and bulky
- Exploiting RF over fiber benefits from
  - Low loss operation
  - Broadband
  - Low weight
  - Small size
  - Reconfigurability
  - Immunity to EMI

Conventional Cable*

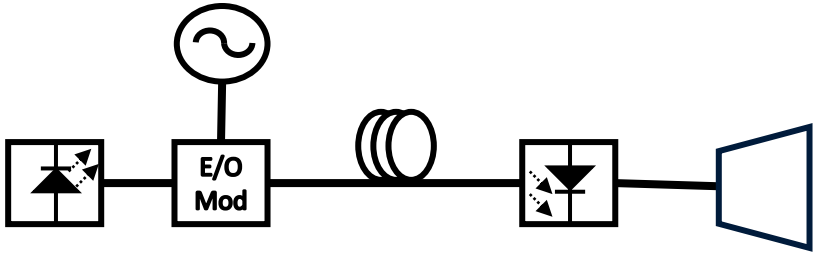
- ✓ 3.72 dB/m attenuation
- ✓ ~10 kg/100m

Optical fiber**

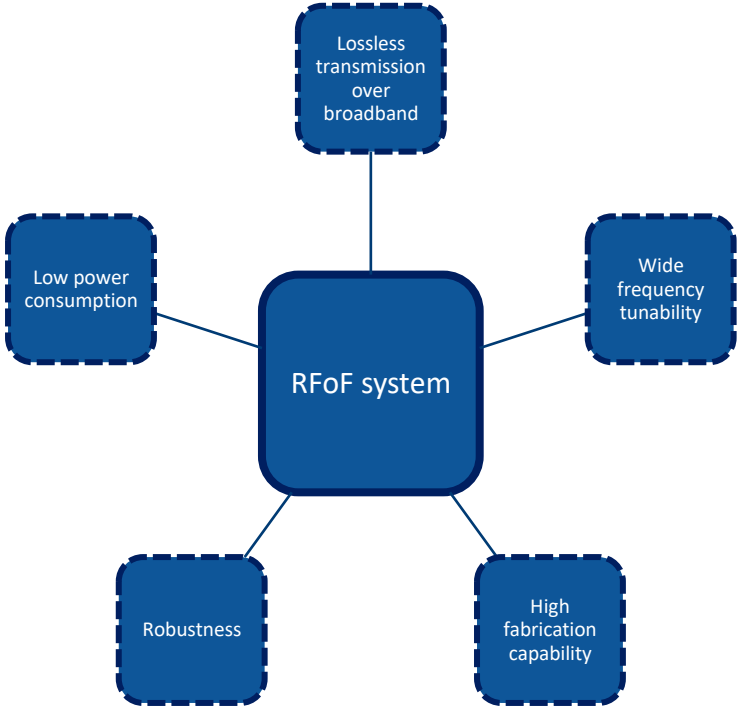
- ✓ 0.2 dB/km attenuation
- ✓ <3kg/100m

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

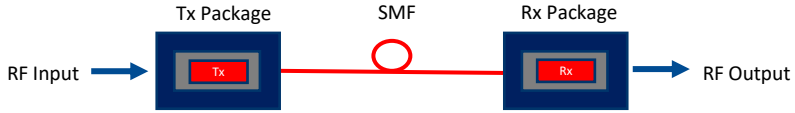
RF over Fiber System Basics



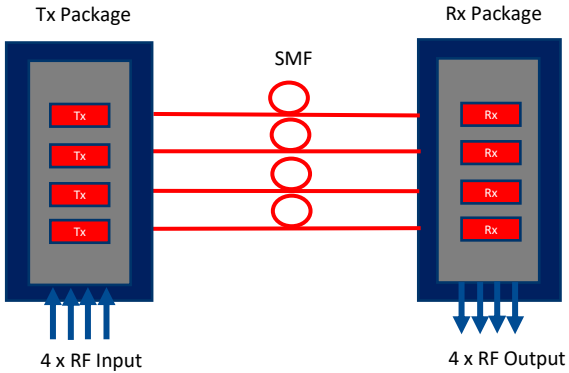
- Optical source
- Electrical source
- Electro-optic modulation
  - Direct modulation
  - External modulation
- Fiber optic
- Opto-electronic conversion



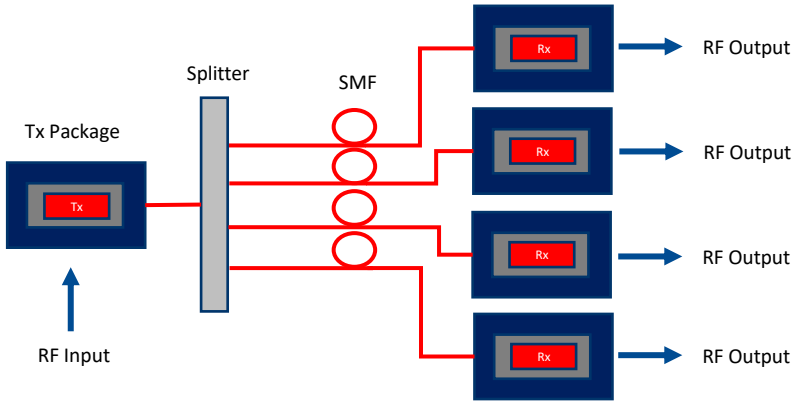
RF over Fiber System Configurations



Single channel RFoF link



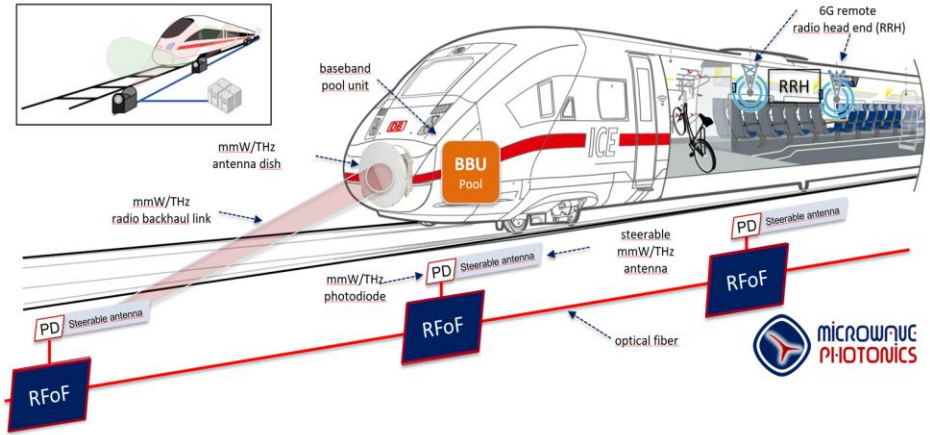
4-channel RFoF link



1x4 RFoF distribution link

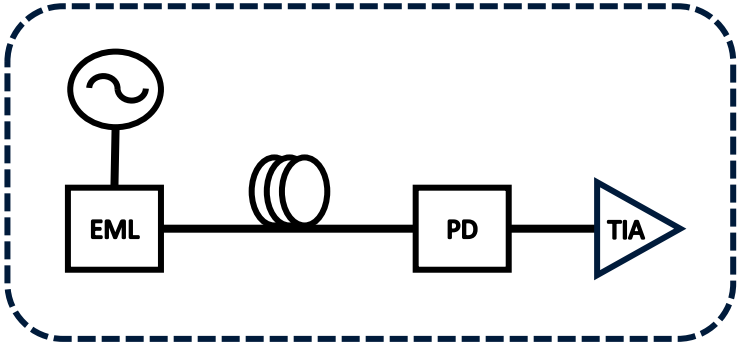
Applications

- Satellite communications
- Mobile 6G base stations
- Terrestrial fixed wireless access
- Test & measurement
- General use in antenna and LO remoting

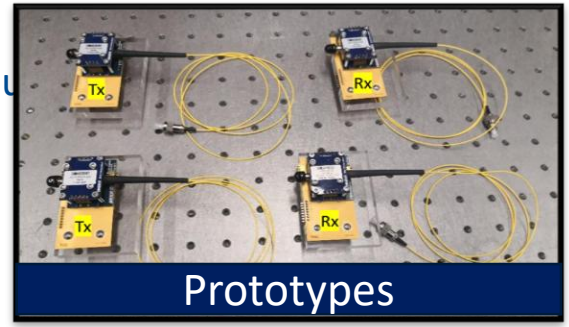


Low-Power RF over Fiber System

- Transmitter side
  - Electro-absorptive modulated laser (EML)
    - Distributed feedback (DFB) Laser
    - Electro absorption modulator (EAM)
- Receiver side
  - Photoreceiver
    - Photodiode (PD)
    - Transimpedance amplifier (TIA)

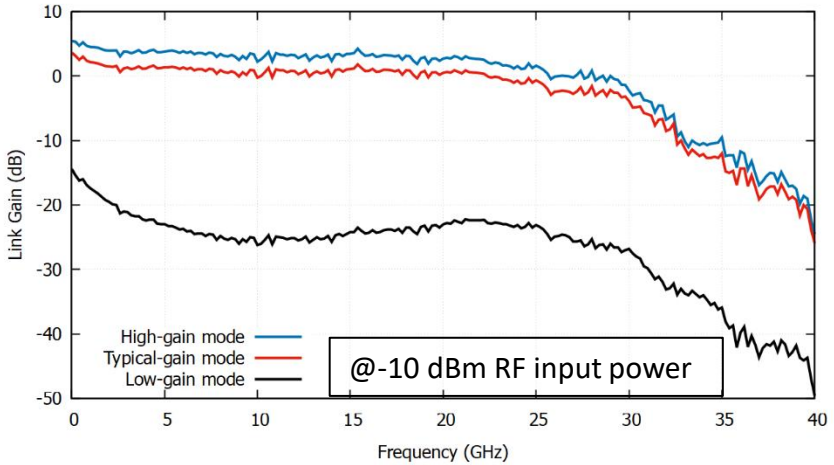


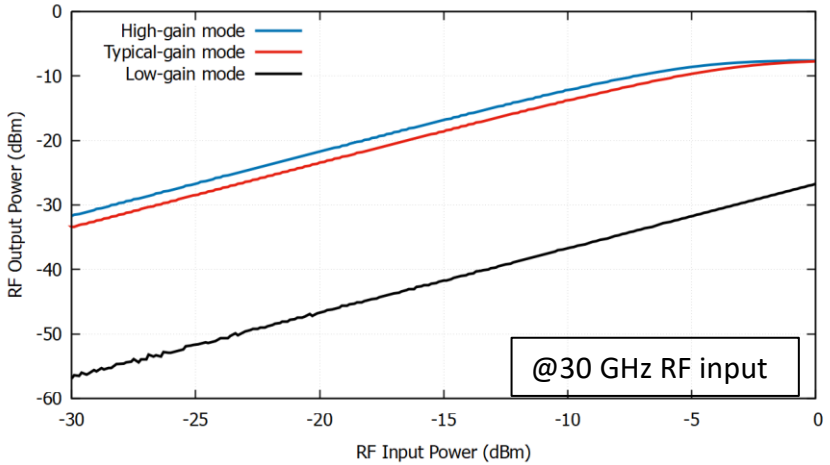
- EML is a DFB laser diode with integrated EAM
- EAM has low driving requirements compared to electro-optic modu
- Uncooled EML to eliminate thermo-electric cooler (TEC)
- TIA to ensure lossless transmission over broad bandwidth
- Conversion gain control of TIA



System Characteristics

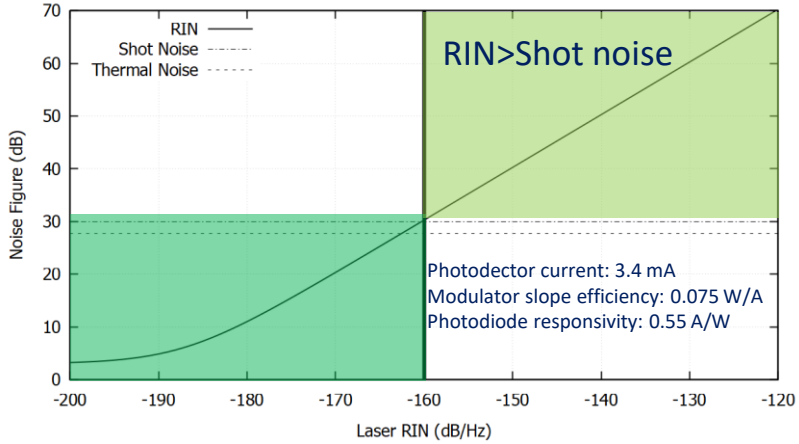
- Link gain vs. frequency for DC-40 GHz at -10 dBm RF input power
  - 3 different conversion gain modes
  - >0 dB link gain up to ~30 GHz
- Saturated output power measured between -30 dBm and 0 dBm RF input power at 30 GHz
  - 3 different conversion gain modes of TIA
  - -7.5 dBm maximum RF output power

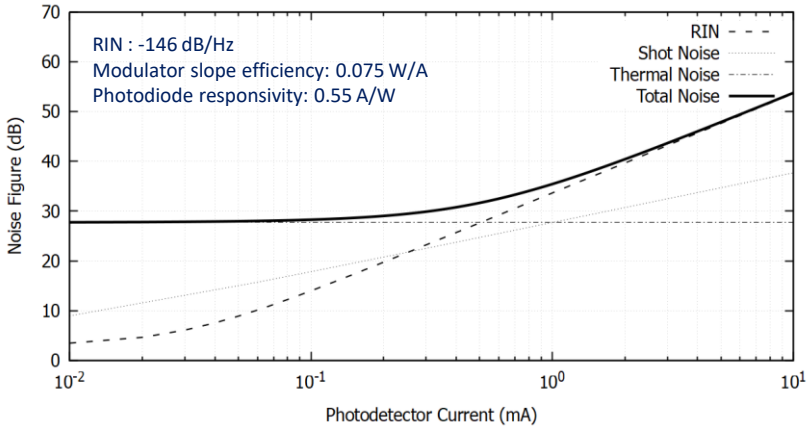




Noise Modelling

- Thermal noise equivalent current:
  - $\langle i_t^2 \rangle = 4kTB/R$
  - $N_{TH,av} = -174$ dBm; k= 1.38 X 10^{-23}J/K, B=1 Hz and T= 290 K.
- Shot noise equivalent current:
  - $\langle i_{sn}^2 \rangle = 2q\langle I_D \rangle B$
- RIN equivalent current:
  - $\langle i_{rin}^2 \rangle = \frac{\langle I_D \rangle^2}{2} 10^{\frac{RIN}{10}} B$
- RIN equals to shot noise:
  - $RIN_{sn} = 10 \log\left(\frac{2q}{\langle I_D \rangle} B\right)$
- Noise figure formula:
  - $NF = 10 \log\left(1 + \frac{N_{add}}{g_i N_{in}}\right)$
- Noise figure of RIN-dominated RFoF link:
  - $NF = 10 \log\left(1 + \frac{g_i kTB + \langle i_{rin}^2 \rangle R_{LOAD}}{g_i kTB}\right) = 10 \log\left(2 + \frac{\langle i_{rin}^2 \rangle R_{LOAD}}{s_{md}^2 r_d^2 kTB}\right)$

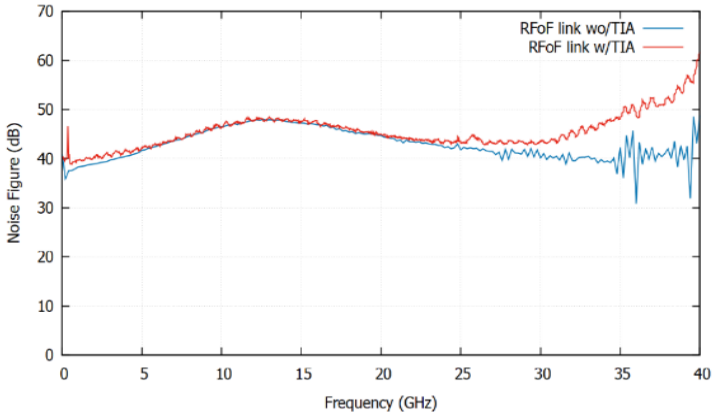


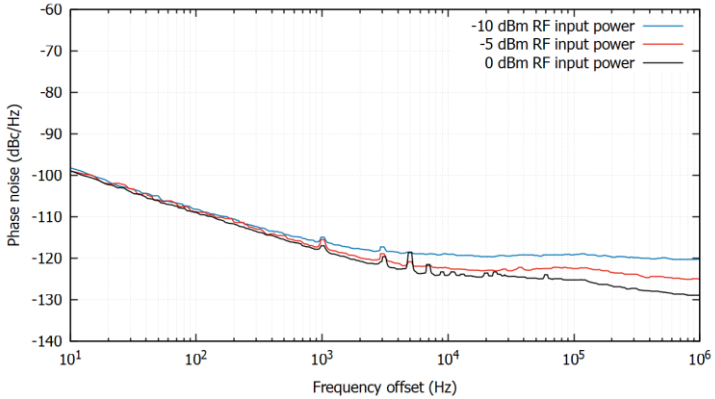


System Characteristics

- Noise figure measured frequency range of DC-40 GHz
  - RFoF link w/wo TIA
  - Around 45 dB NF up to 30 GHz
- Noise figure of a cascaded system:
  - $\mathrm{NF_{cas}} = \mathrm{NF_1} + \frac{\mathrm{NF_2}-1}{\mathrm{G_1}} + \frac{\mathrm{NF_3}-1}{\mathrm{G_1 G_2}} + \ldots$
- Attenuation of cable is NF at room temperature

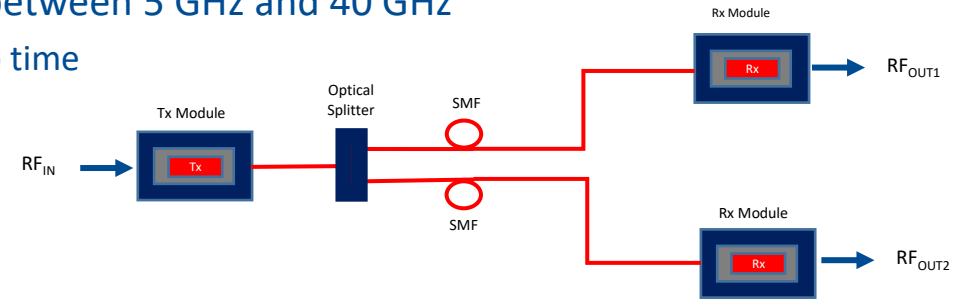
- Phase noise measured at 18 GHz
  - -120 dBc/Hz @10 MHz offset frequency
  - Additive noise
    - $\mathcal{L}(\mathrm{f}) = \mathrm{N_{TH}} + \mathrm{NF} - \mathrm{P_{in}}$
- Good agreement between noise modelling and measurement results

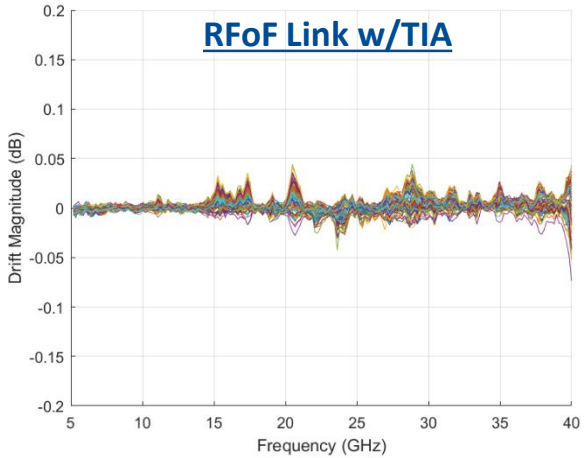


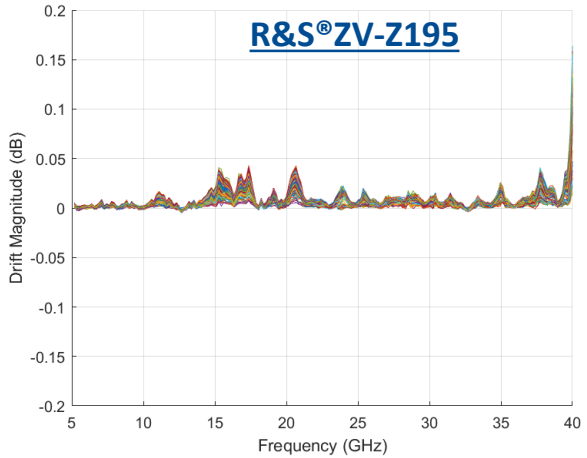


Trace Noise Measurements

- Trace noise measured 1x2 RFoF distribution link between 5 GHz and 40 GHz
  - Long term measurements >1h with 20s sweep time
  - Less than 0.05 dB drift in magnitude
- Repeated the measurement with RF cables
- Comparable results obtained







Conclusion

- Low power consumption RFoF system presented
  - <1W for entire system
  - Positive link gain up to 30 GHz
  - -7.5 dBm maximum RF output power
- Successfully demonstrated noise modelling of RFoF system
- Noise characteristics of RFoF system demonstrated
  - Around 45 dB NF up to 30 GHz
  - -120 dBc/Hz @10 MHz offset frequency
- Long term trace noise measurements of 1x2 RFoF distribution presented
  - Less than 0.05 dB drift in magnitude

Acknowledgements

The TERAOPTICS project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 956857. TERAOPTICS qualifies 15 experts (early-stage researchers) for the future THz photonics industry and academia.

Thank you for your attention!