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Low cost RoF solution development for Mobile Fronthaul networks

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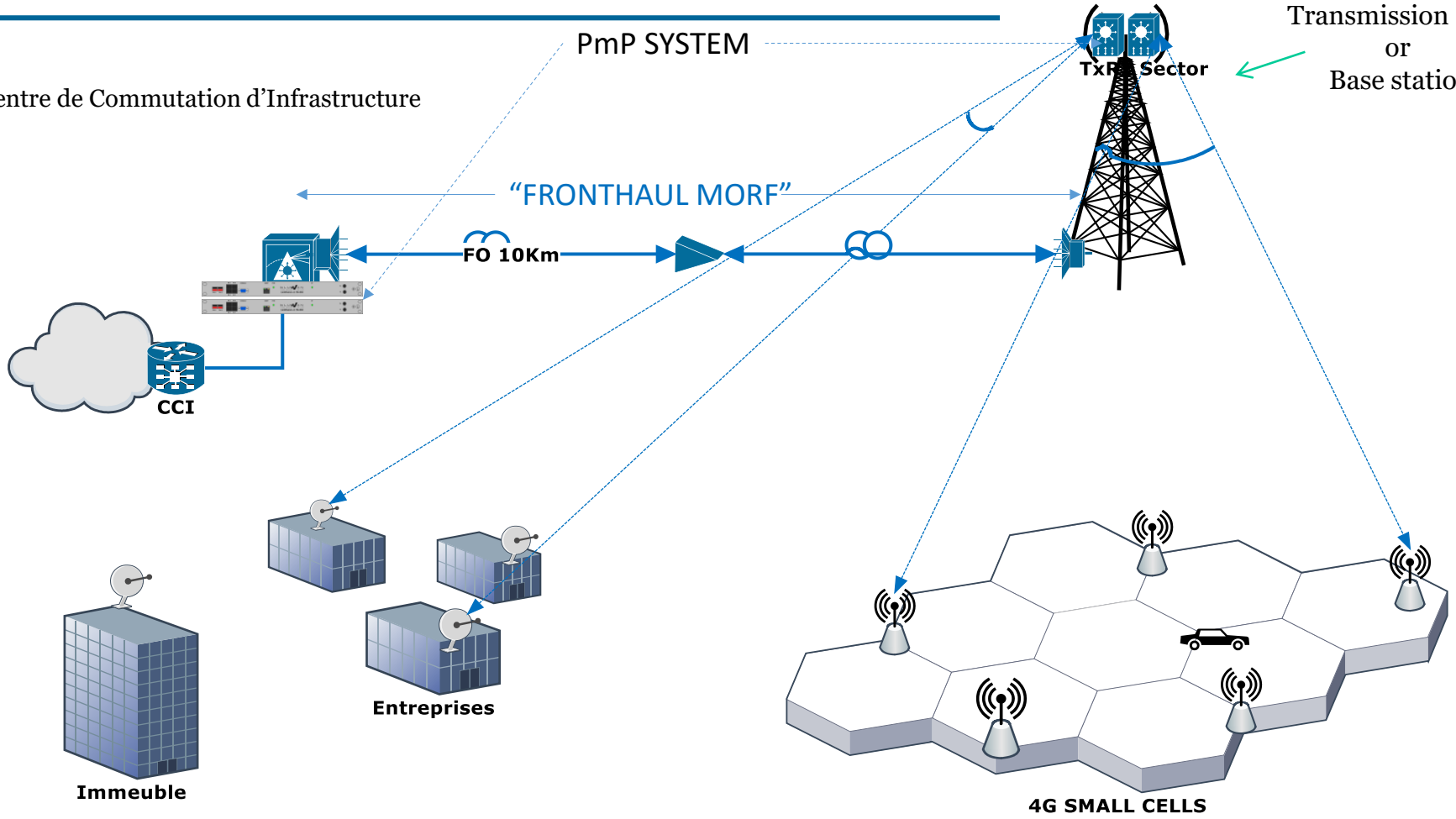
Outline

- Introduction: MORF Project, FUI, March 2015
  - Context and goals
- OM RoF simulation tool
- OM quantities
- Behavioral model implementation
- RoF link Design simulation Analysis
- OM Individual performance extraction
- Conclusions and Perspectives

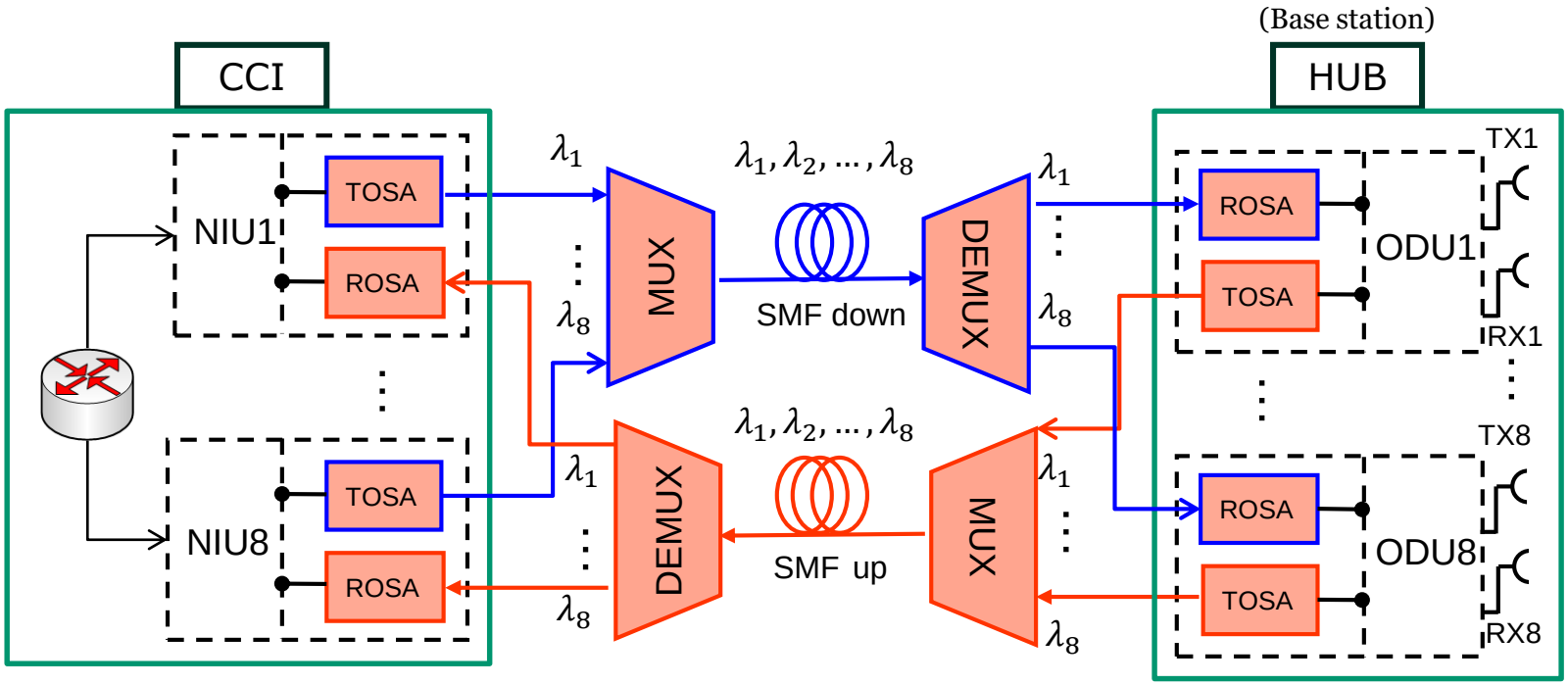
MORF – Multiplex OFDM Radio-over-Fiber



- RoF Technology over 10 to 20km
- Bidirectional optical links carrying OFDM multiplex channels
- Low cost base stations – data/signal processing centralized at the CCI
- Dark Fiber compatibility

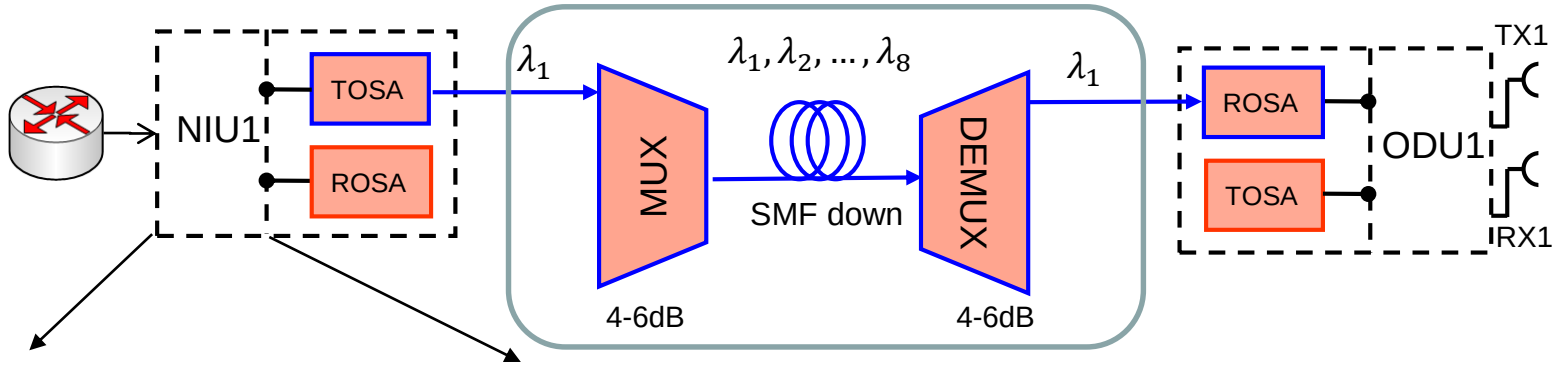
Point-to-Point Architecture

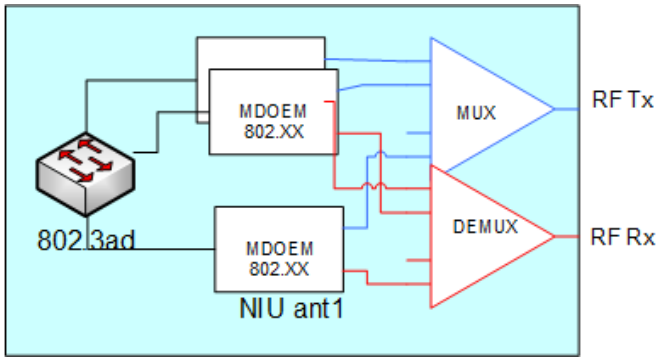
TOSA – Transmitter Optical Sub-Assembly
ROSA – Receiver Optical Sub-Assembly
WDM – Wavelength Division Multiplexing



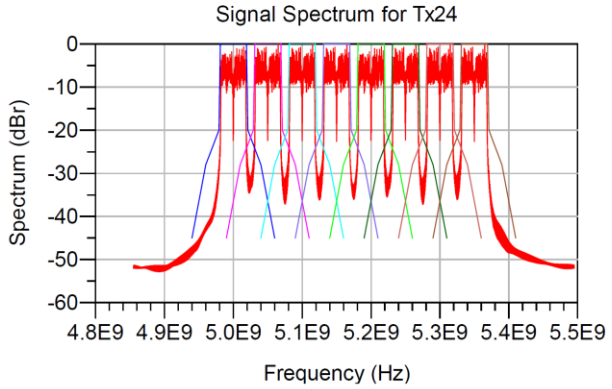
- 4 to 8 INU/ODU in order to implement 4-8 radiocells
- Integration of the TOSA and ROSA modules and the implementation of the WDM

Point-to-Point Architecture





- Modulation signals specs:
  - 5 to 10 channels of 40MHz OFDM signals Based on 802.11n/ac
  - Total of 500MHz bandwidth centered at 5-6GHz
  - ±3 dB difference between adjacent channels
  - ±6 dB over the entire 500MHz
  - 35 dB C/N



- RoF Link:
  - SMF link at 1.55µm
  - Up to 22dB optical losses (20km, connectors, mux/demux, ..)
  - Bandwidth of 6GHz
  - 37 dB C/N, 1.5% EVM
  - Asymmetric available power: Down/Up load link

OM RoF simulation tool

OM quantities

Behavioral model implementation

RoF link Design simulation Analysis

OM Individual performance extraction

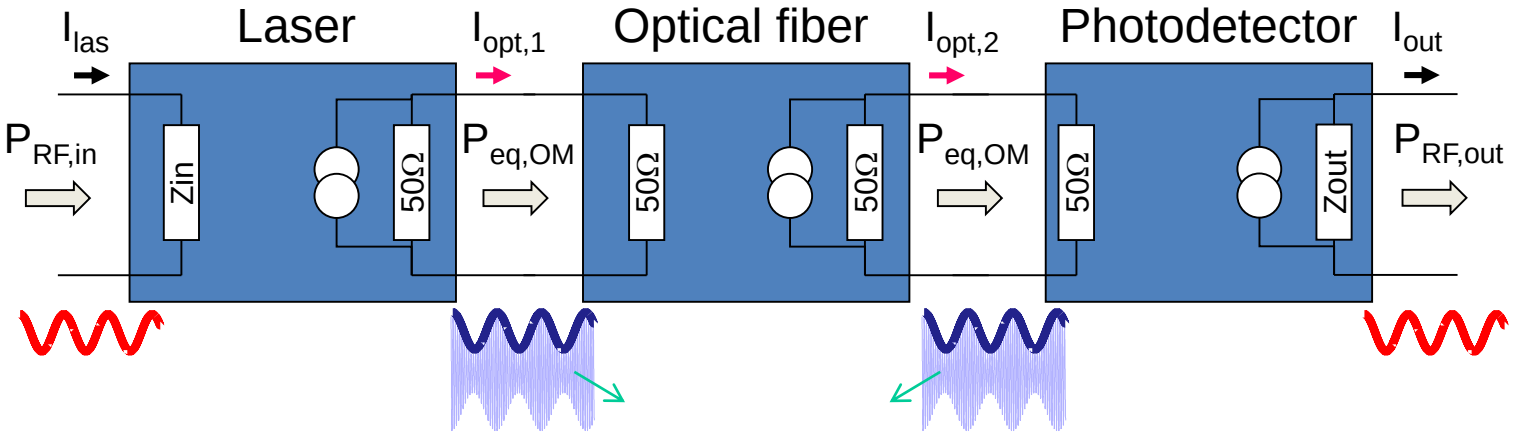
OM quantities Electronic/Photonic conversion

- Equivalent opto-microwave power

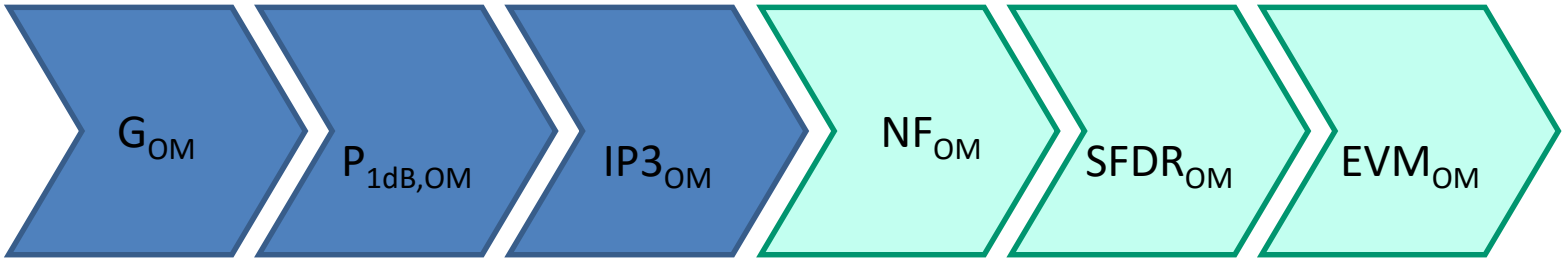
J.L. Polleux et al, "Optimization of InP/InGaAs HPT's gain : Design and Realization of an Opto-microwave Monolithic Amplifier," in IEEE Trans. MTT, vol.52, n°3, pp.871-881, March, 2004.

$$I_{opt} = {}^{1A}\!/_{W} \cdot P_{opt}$$

$$P_{eq,OM} = \frac{1}{2} \cdot R_0 \cdot I_{opt}^2 = \frac{1}{2} \cdot R_0 \cdot \left(1 {}^{A}\!/_{W} \cdot P_{opt} \right)^2$$



As probed by a 1A/W (normalized) reference photodiode loaded by 50Ohms



OM quantities

With equivalent opto-microwave power:

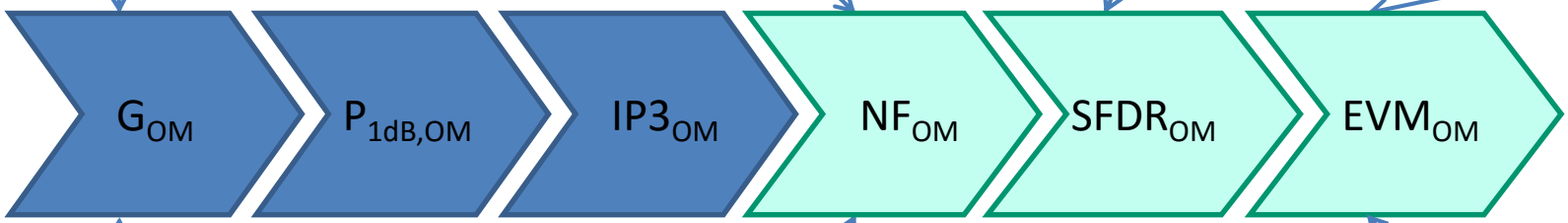
- $OIP3_{OM}$ and $OP1dB_{OM}$ for the laser & optical parts
- $IIP3_{OM}$ and $IP1dB_{OM}$ for the photodiode & optical parts
- P1dB and IP3 systems relation

$$SFDR_{LD,PD}^{OM}\left[dB\cdot Hz^{2/3}\right]=\frac{2}{3}\left(OIP3_{LD,PD}^{OM}-N_{LD,PD}^{OUT,NOISE}\right)$$

$$G_{OM}=\frac{Pout_{(eq,OM)}}{Pin,available_{(eq,OM)}}$$

$$F_{LD,PD}^{OM}=\frac{SNR_{in}^{OM}}{SNR_{out}^{OM}}\Bigg|_{T_o}$$

$$EVM_{LD,PD}^{OM}[linear]=\sqrt{\frac{P_{error\ vector}^{OM}}{P_{reference}^{OM}}}$$



$$N_{ref,OM}=k\cdot T\cdot B$$

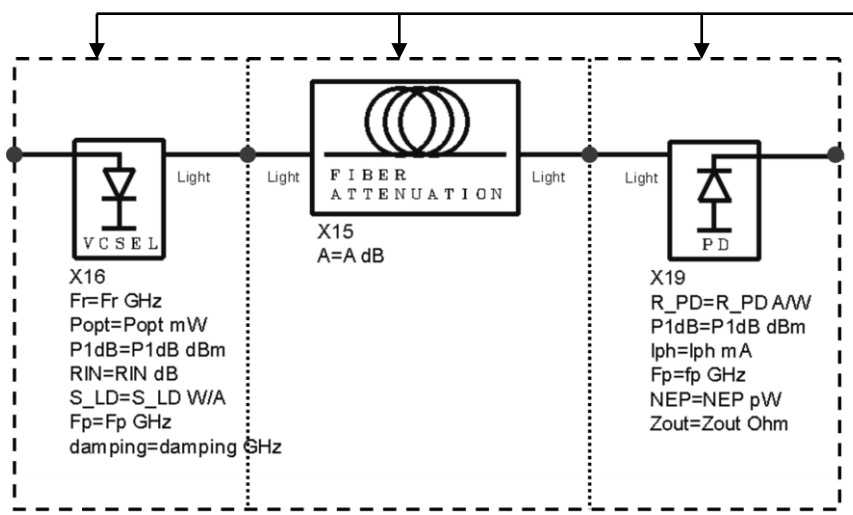
$$EVM_{LD,PD}^{OM}[dB]\approx 10\log_{10}\left[B\cdot 10^{\frac{kT+NF_{LD,PD}^{OM}-P}{10}}+10^{\frac{P-IIP3_{LD,PD}^{OM}}{5}}\right]$$

$$P_{eq,OM}=\frac{1}{2}\cdot R_0\cdot I_{opt}^2=$$

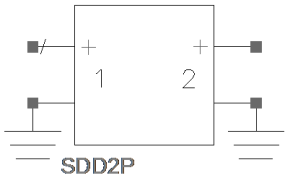
$$=\frac{1}{2}\cdot R_0\cdot\left(1\,A/W\cdot P_{opt}\right)^2$$

- Friis formula applicable
- $SFDR_{OM}$ for each individual parts
- EVM_{OM} impact
- Ready to be included into microwave CAD

OM behavior model implementation



SDD - Symbolically defined device

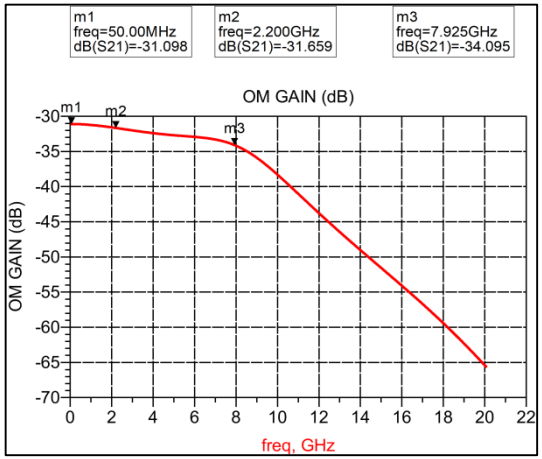


NL

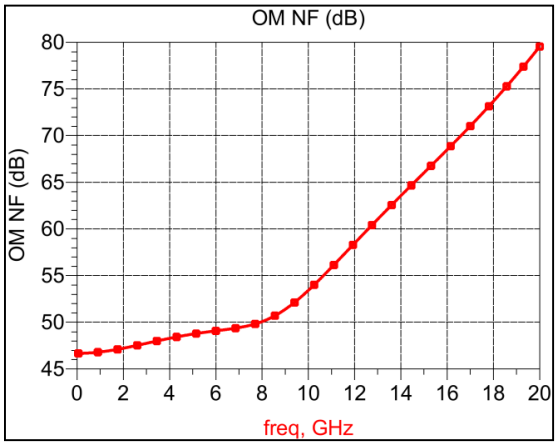
$$I_{out} = 2 \cdot I_S \cdot \tanh\left(\frac{G \cdot I_{in}}{I_S}\right) = 2 \cdot I_{opt}$$

NF

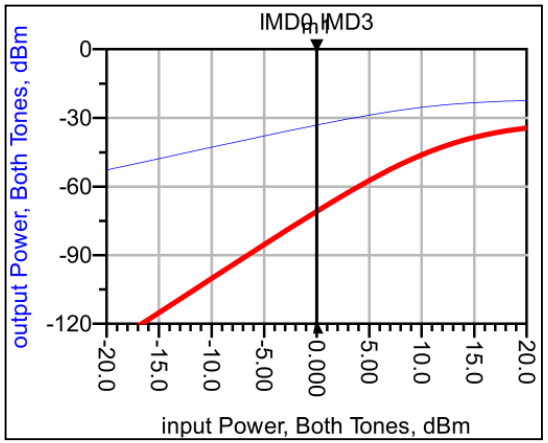
$$RIN(f) = A \cdot \frac{4\pi^2 \cdot f^2 + B}{16\pi^4\left(f_r^2 - f^2\right)^2 + 4\pi^2 \cdot \gamma^2 \cdot f^2}$$



Frequency response

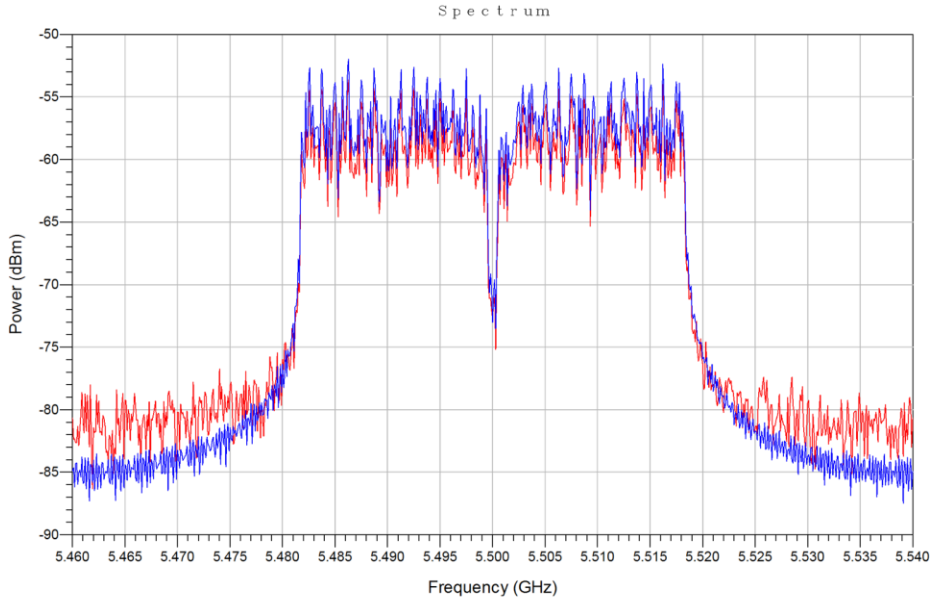


Noise Figure

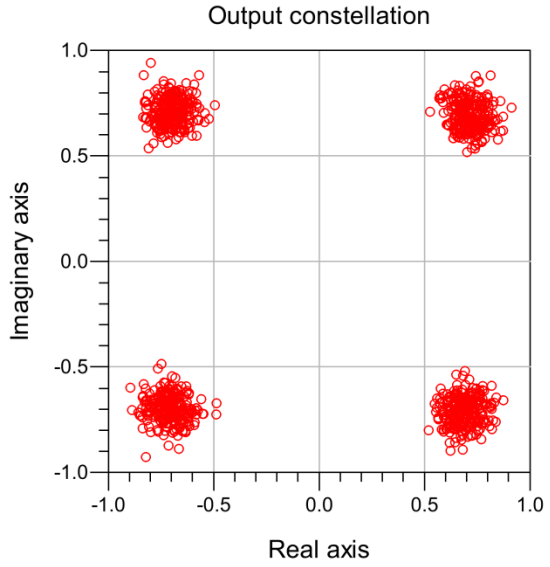


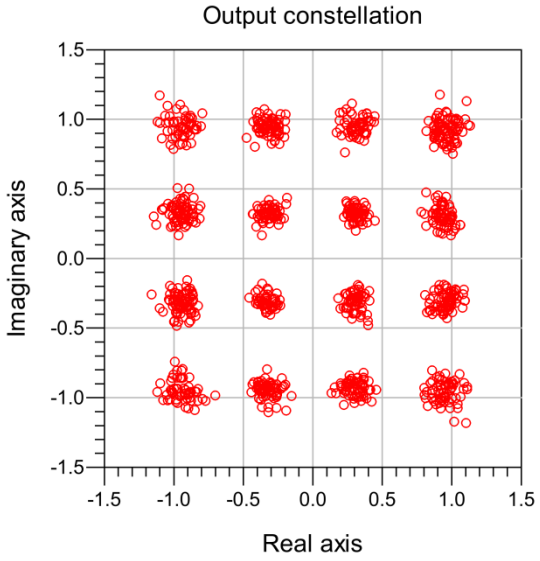
Nonlinearities

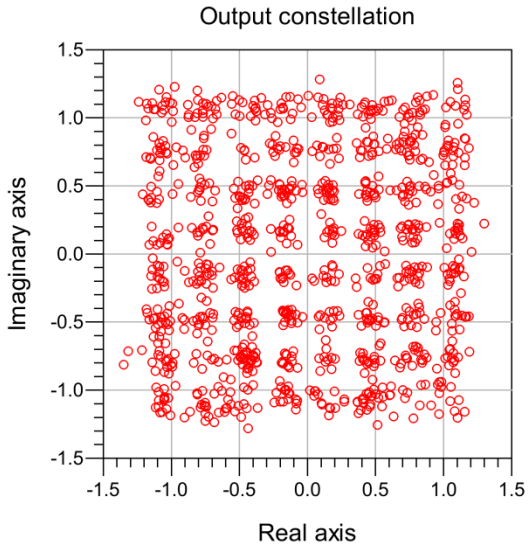
OM behavior model implementation



Signal Parameter	IEEE 802.11n OFDM PHY HT
Occupied bandwidth	33,75 MHz
Fs: OFDM Sampling rate	40 MHz
Number of subcarriers	128
FFT period (symbol duration)	3,2 µm
Subcarrier spacing	312,5kHz
GI duration	0,4µs
OFDM symbol duration	3,6 µs
Number of data subcarriers	108
Number of pilots subcarriers	6
Number of DC subcarriers	3
Modulation	QPSK 60Mbps 16-QAM 120Mbps 64-QAM 180Mbps



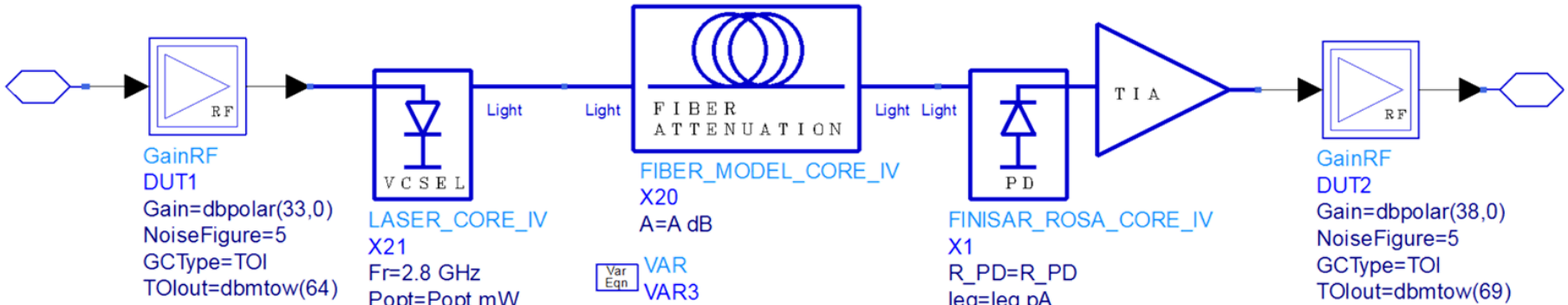




OM RoF simulation tool

- OM quantities
- Behavioral model implementation
- **RoF link Design simulation Analysis**
- OM Individual performance extraction

RoF link Design simulation Analysis: First guess



IP1dB=21dBm
Gain= 33dB
NF=5dB

IP1dB=21dBm
Gain= 38dB
NF=3dB

Laser Diode: ALM5K-6
Popt=8dBm
Sld=0,13 W/A
BW=~10GHz
RIN=-150dB/Hz
IP1dB=13dBm

Photodetector: Finisar
RPD=0,7A/W
Ieq~18pA/Hz (No TIA)
BW=~10GHz

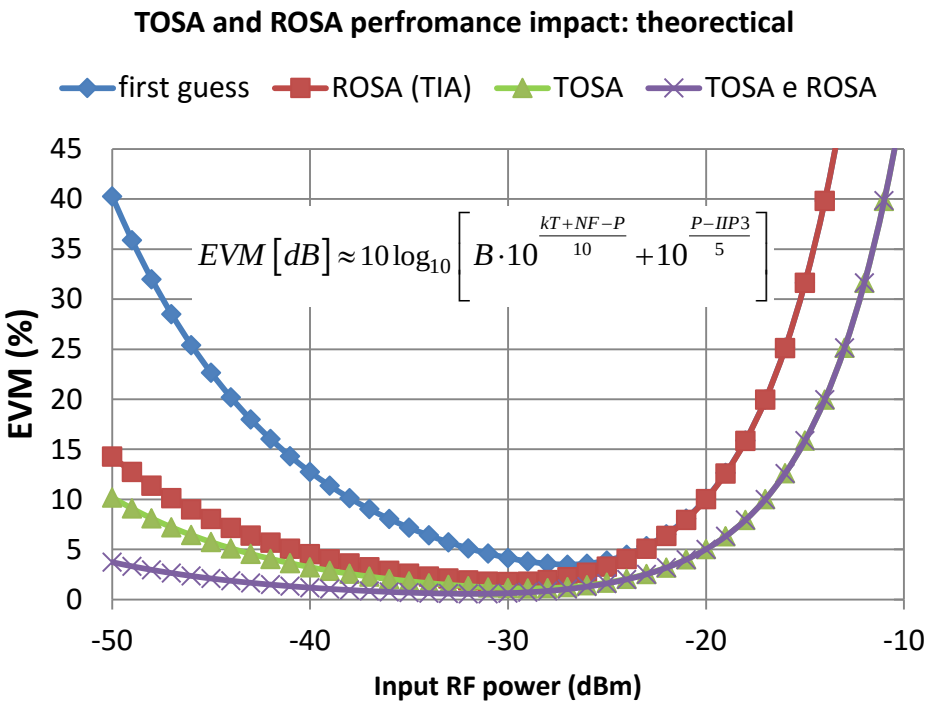
50Ω resistor

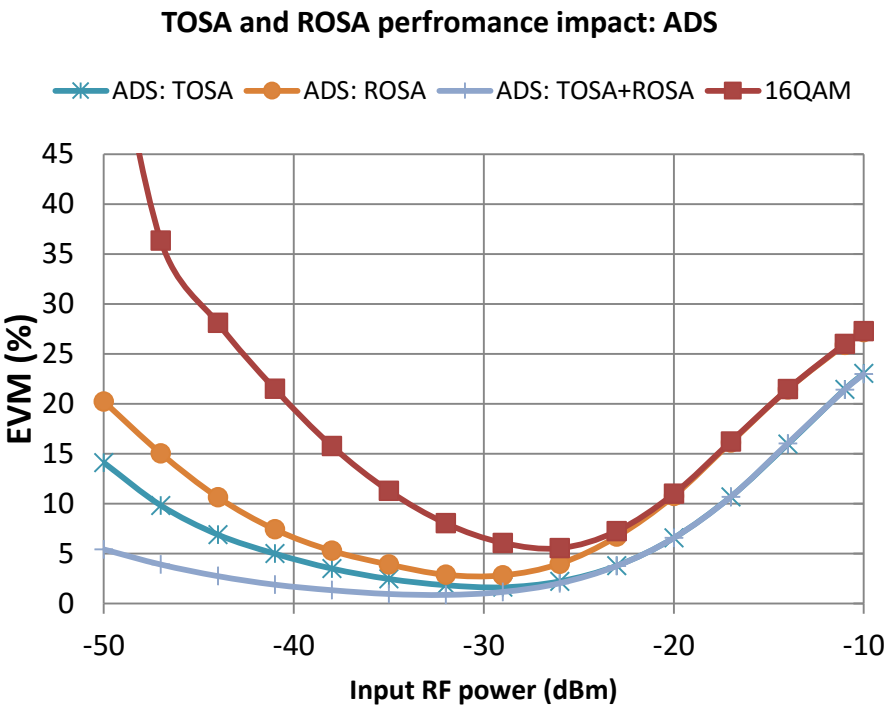
$\sqrt{4 \cdot k \cdot T / R_L}$

- Criteria:
  - 22dB optical losses (worst scenario)
  - Overall link gain of 0dB
  - Available Input power: -65 to -25 dBm

RoF link Design simulation Analysis: First guess

IF 5.5GHz
QPSK
40MHz 802.11n





SLD=0.13 to 0,5 W/A
IP1dB = 13 to 16 dBm
f3dB=8GHz
RIN=-150dB/Hz

Losses = 22 dB

RPD=0,7A/W
TI= 25 to 300Ω
Ieq=18 to 10pA/Hz
f3dB=10GHz

- Min EVM <1 % with input power of -32dBm

RoF link Design simulation Analysis:

$$EVM\,[dB] \approx 10\log_{10}\left[B \cdot 10^{\frac{kT+NF-P}{10}} + 10^{\frac{P-IIP3}{5}} \right]$$

Advantage:

simple, fast, excel

Limitations

No Flexibility

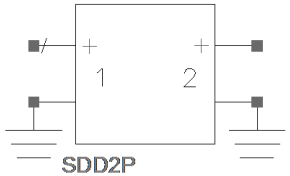
Modulation signal properties

PAPR

Schemes

…

Frequency response



SDD2P
SDDNP7
I[1,2]=_v1/50
I[2,2]= -(Vs*tanh(A*ve/Vs))/50
H[2]=1/(1+j*omega*tau)

Advantages:

Precise, flexible

Analogue properties:

Frequency response

Nonlinearities

Noise

modulation signal properties

Limitations

Nonlinear Memory-less model

(tanh, cann's,…)

OM RoF simulation tool

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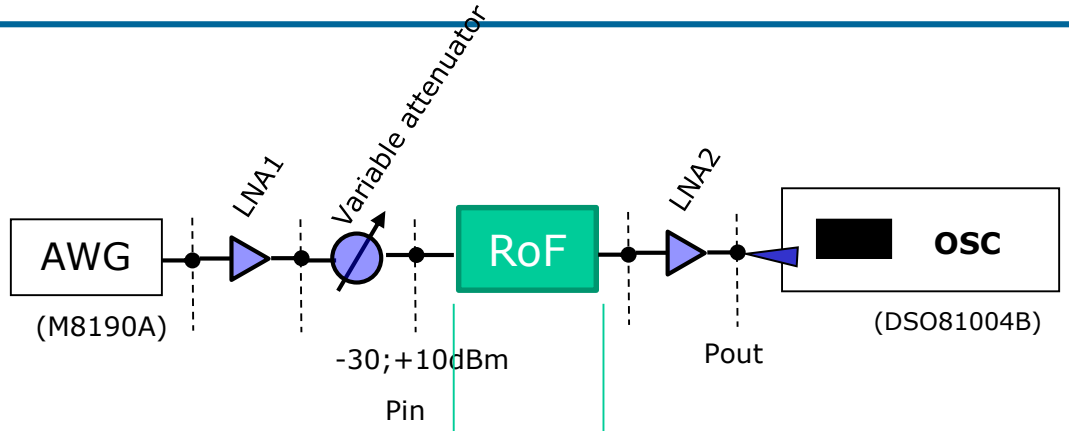
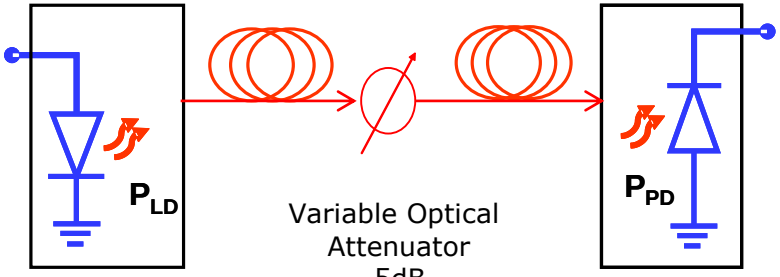
- RoF link Design simulation Analysis
- **OM Individual performance extraction**

OM Individual performance extraction

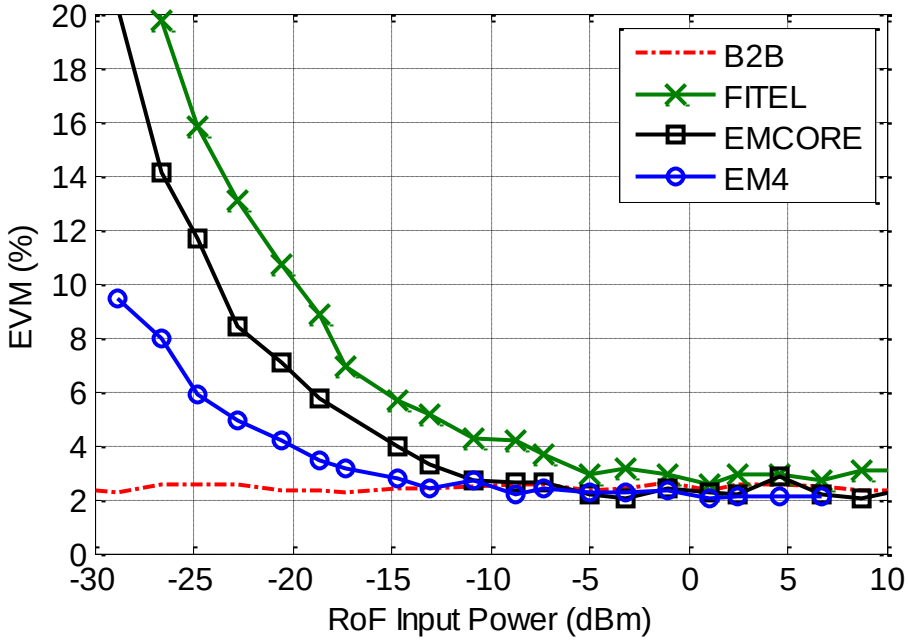
802.11n, 40MHz, QPSK
IF 4,7GHz





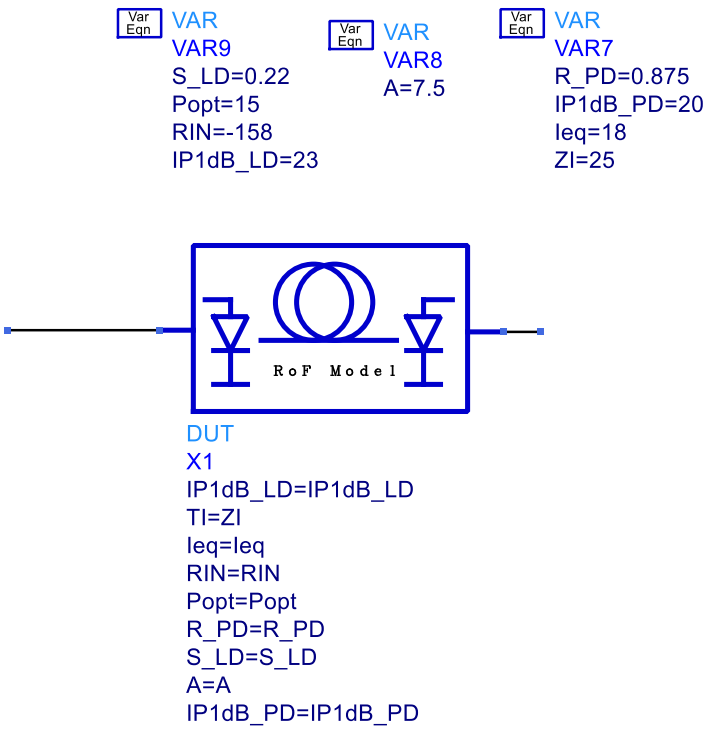
LD1 FITEL
LD2 EMCORE
LD3 EM4
@80mA

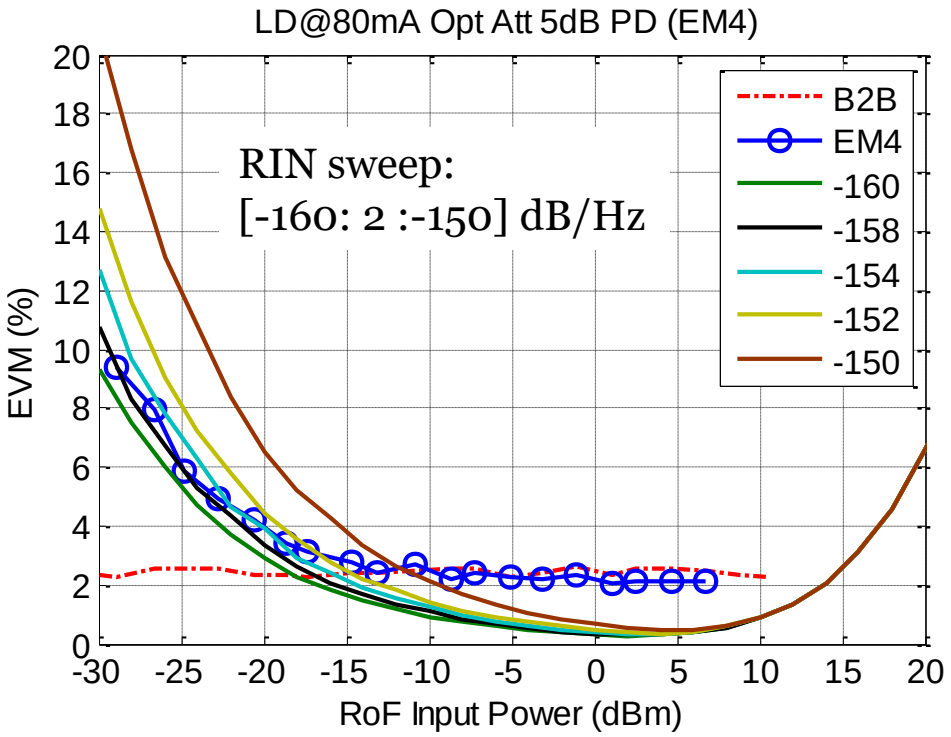
PD1 PiN EM4
@5V

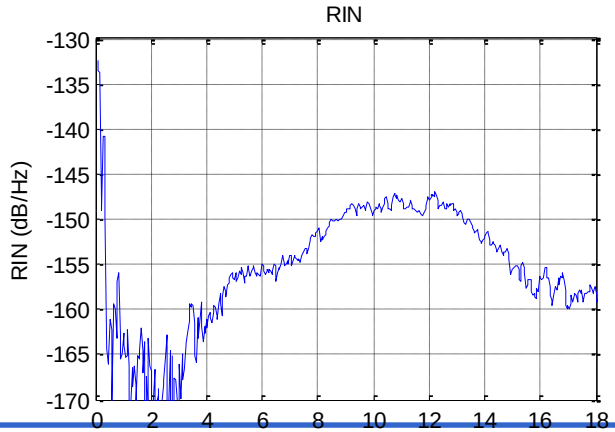


Low cost lasers:
4GHz bandwidth

OM Individual performance extraction







-Back-to-back EVM avoided: min EVM=0.32% @ +3dBm
-RIN extracted to -158dB/Hz
-NL simulation

Conclusions and Perspectives

- **Conclusions:**
  - Low cost RoF solution development for Mobile Fronthaul networks
    - MORF project: IF-RoF, WDM
  - OM RoF simulation tool
    - Opto-microwave quantities defined: from GOM to EVMOM
      - Enable further optimization of devices individually
    - Optoelectronic behavioral model
      - Precise parameter extraction from EVM measurements
      - All microwave CAD tools enabled for optoelectronic devices and circuits

- **Perspectives and Extensions:**
  - Extending the application to more than one channel
  - Widening the implementation by extending to more than one sector.
  - Extended approach to implement on 802.11.ac (80 MHz per channel)
  - Nonlinear Memory-less mode development
  - Phase noise implementation

Merci !

Author thank all contributors from MORF project:

S. Todkar[1], J.L. Polleux[1], D. Lebrouster[2], E. Lediraison[2], C.Algani[3], S.Faci[3], A.L.Billabert[3], F.Magne[4]

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