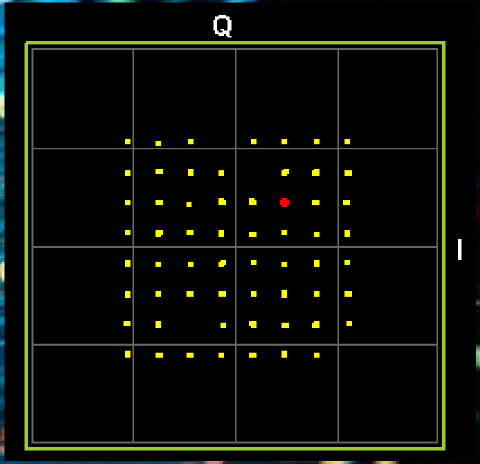
Electro-Optical Performance Requirements for Direct Transmission of 5G RF over Fiber



Presented by
APIC Corporation
5800 Uplander Way
Culver City, CA 90230
www.APICHIP.com
sales@apichip.com

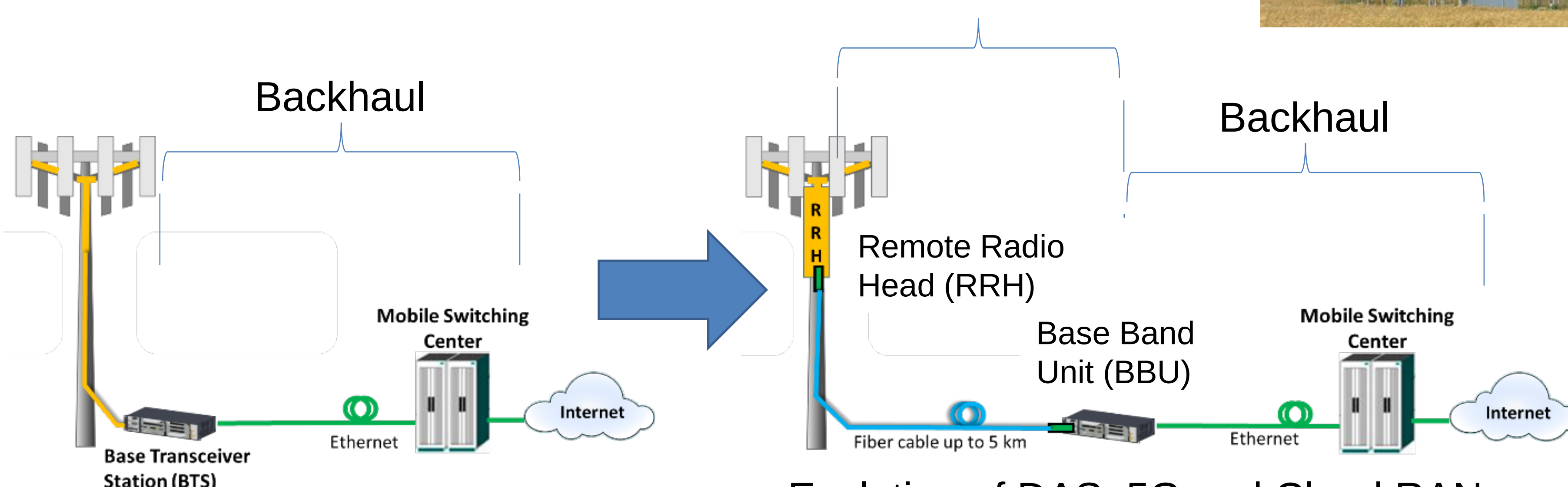
Revised 10/25/2017

Introduction

- In the last 20 years mainstream opto-electronics was driven by 2 goals:
  - Increase transmission data rate based on 2 level modulation (recently PAM4 is being considered, 4 levels)
  - Reduce cost of transmitters
- The above objectives were achieved at the expense of:
  - Optical links noise floor - Typical digital links operate at > 30dB above the electronics shot noise limit.
  - Linearity - In order to achieve lower cost modulation for two level states, linearity was not a priority, because it was compensated with limiting amplifiers.
- In contrast, wireless transmissions have taken the approach to use the spectrum as efficiently as possible and apply high order modulation, lower data rates and densely spaced carriers. This requires low noise and high linearity from the link components.
- Therefore, in order to carry wireless signals in fiber the options are:
  - High linearity, low noise optical components (APIC's solution)
  - Convert to digital using oversampling, inefficient data rate payload, added latency and back conversion to RF as implemented by CPRI
- Legacy optical components are not the optimal solution for future 5G

What is “Fronthaul?”

Fronthaul: In a classic cell tower there is a base transceiver station (BTS) adjacent to the tower. The BTS is contained in an enclosure which requires significant power for radio amplifiers and environmental conditioning. To improve network efficiency the BTS has been split between the remote radio head (RRH) at the antenna and the baseband unit (BBU) which is located further away from the antenna.
The RRH and the BBU communicate through a “fronthaul” link currently using Common Public Radio Interface (CPRI) or Open Base Station Architecture Initiative (OBSAI) standards.

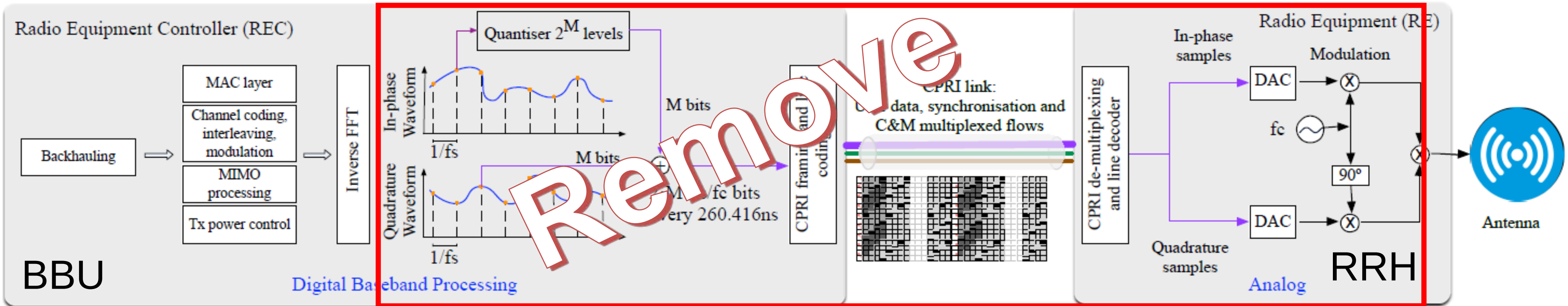


Conventional Tower

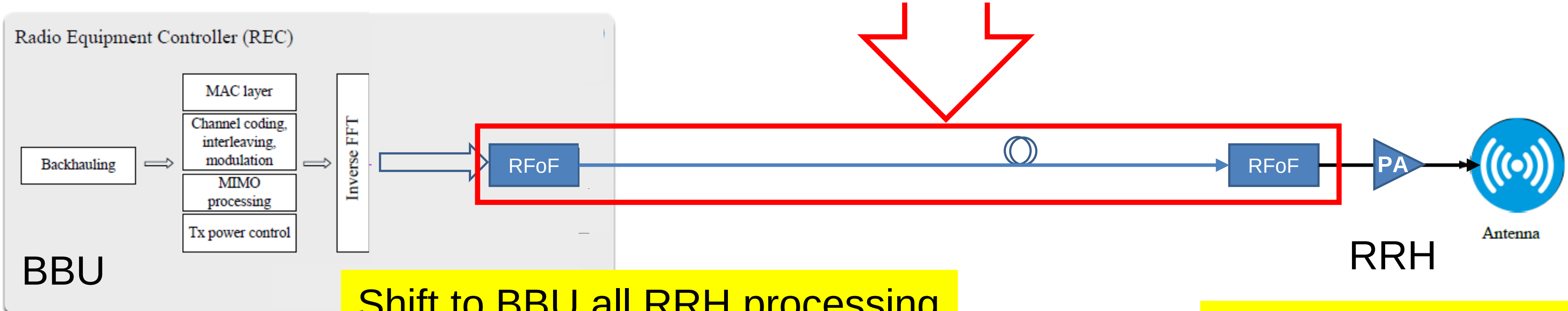
Evolution of DAS, 5G and Cloud RAN centralizes and virtualizes the BBU

Fronthaul Link with Direct Transmission of 5G RF over Fiber

Instead of digitizing the RF signal (as in CPRI or OBSAI) transport the RF signal in its native OFDM form via light through fiber – Direct Transmission of RF over Fiber (RFoF)



Proposed solution: direct transmission of high order modulated RF signals over fiber

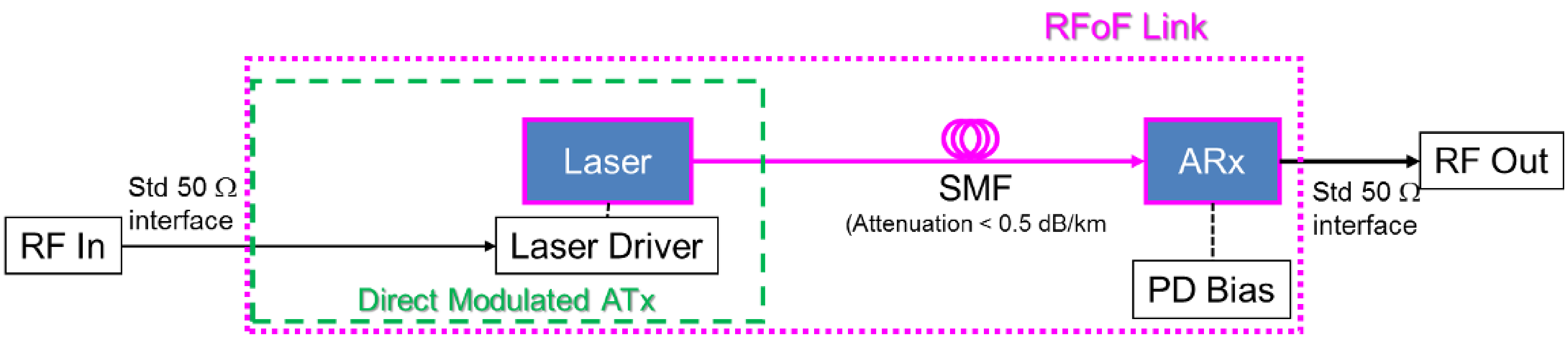


Shift to BBU all RRH processing including PA DPD – Virtualize the RRH

Leave only passives and PAs

Technical Requirements for High Fidelity RF Links

Overview:

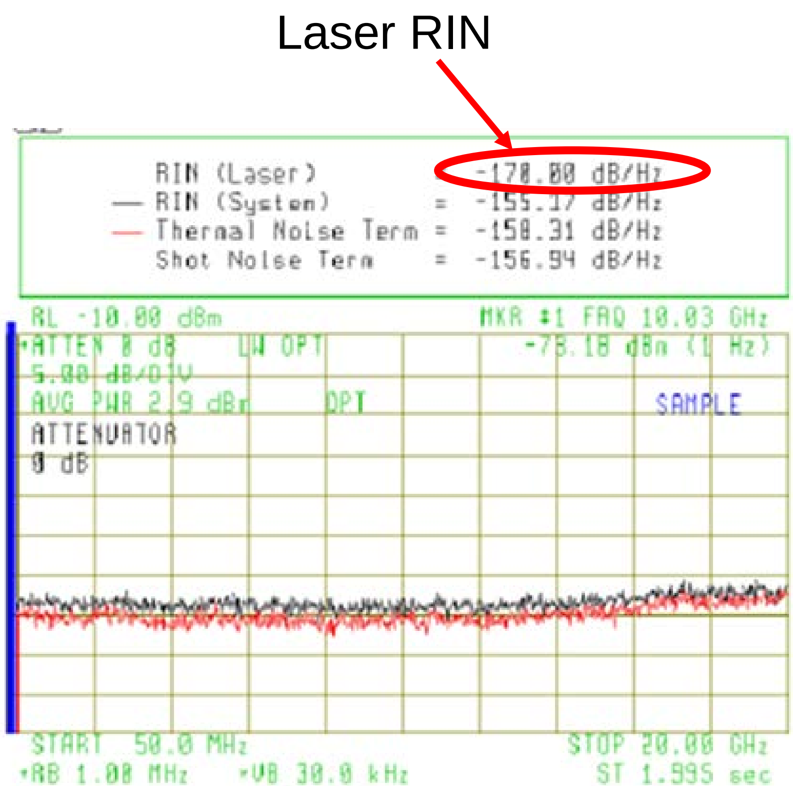


Block diagram of a directly modulated RFoF link for 50 MHz to 6 GHz RF

- Ultra low noise lasers that operate at shot noise levels, below -160 dB
- Highly linear lasers; light intensity is directly proportional to drive current
- Highly linear photo detectors; output current is directly proportional to light intensity
- Highly efficient/responsive photo detectors; above 0.9 responsivity
- Link must have a high dynamic range, above 112 dBHz$^{-2/3}$
- Link must have a high IIP3; ≥ 36 dBm
- Impedance matched devices; optical transceivers have a 50 Ω interface

Ultra Low Noise Lasers

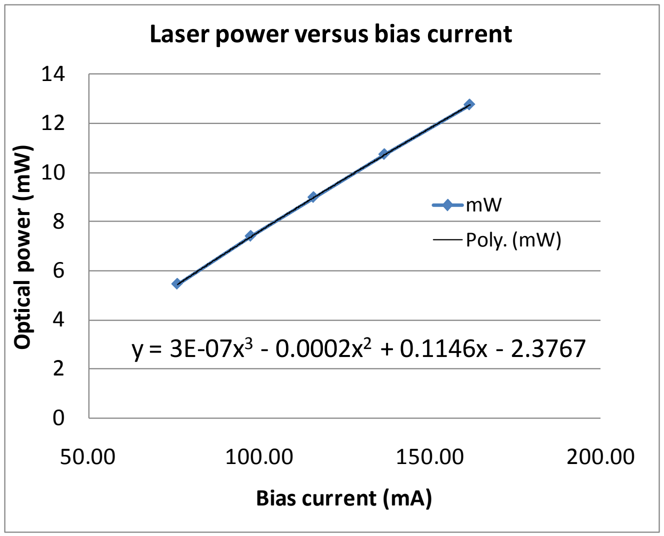
- The single greatest contributor of noise in lasers is the Relative Intensity Noise (RIN).
- Low RIN is achieved by
    - Proprietary EPI wafer design and laser structure
    - High thermal conductivity away from the laser
    - Isolation of intrinsic electronic noise
    - Elimination of back reflections into the laser
- Benefits of Ultra Low RIN:
    - Laser noise floor is at or below shot noise level – no contribution from laser noise



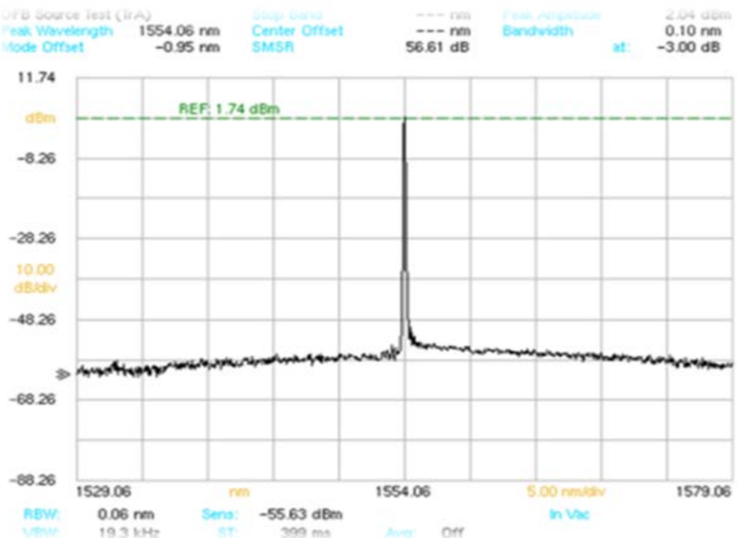
Laser RIN (noise) of -170 dB measured from 0.5 to 20 GHz

Highly Linear Lasers

- Light intensity is directly proportional to drive current over the operating range
- Side modes are suppressed by > 55 dB



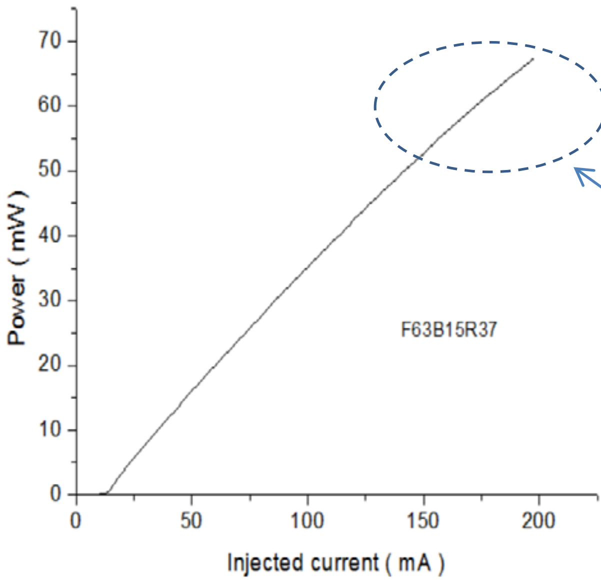
Drive Current (mA) vs. Light Output Power (mW)



Laser output vs Frequency showing no side lobes

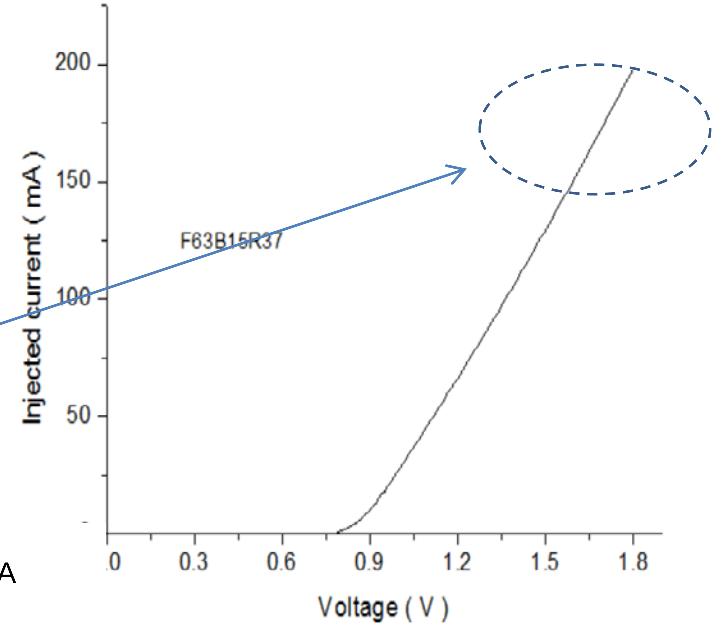
- The benefit of highly linear laser is the undistorted translation of an electrical RF signal into an optical RF signal; preserves phase, amplitude and does not create inter-modulation products.

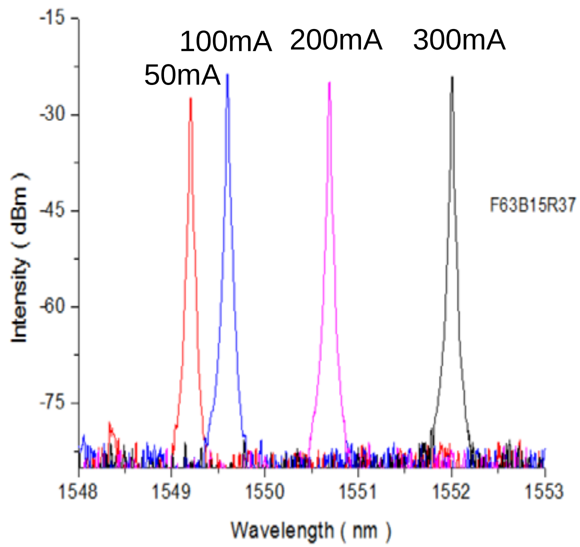
Directly Modulated Laser Gain and Linearity Tradeoffs



Die on submount probing

Operating range for lowest noise



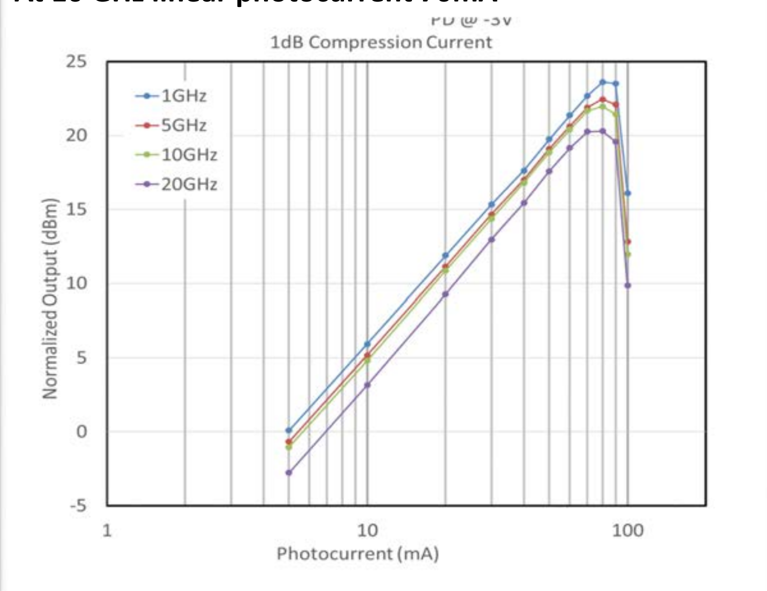


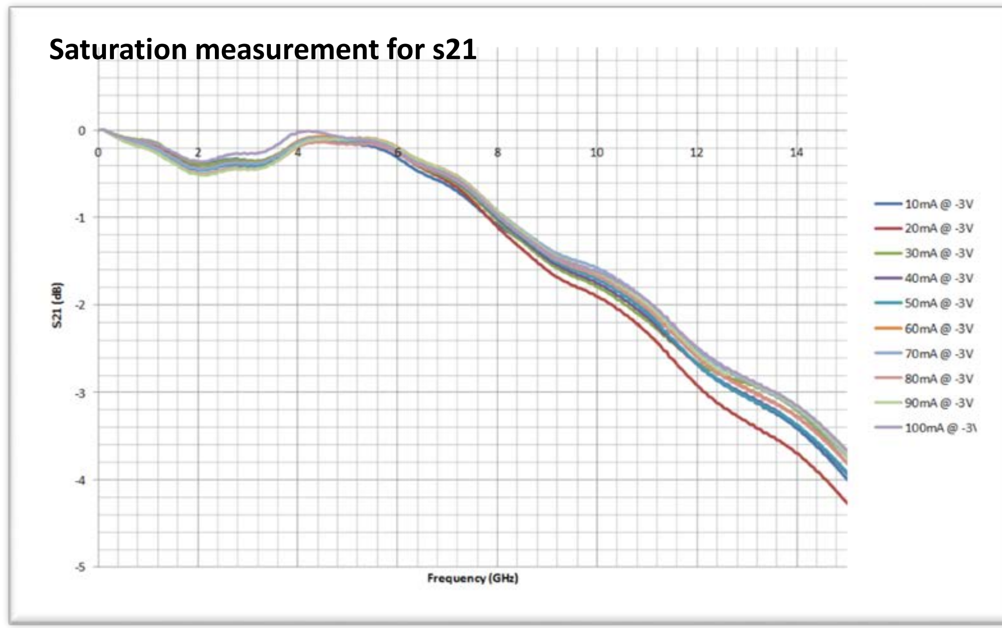
There is a tradeoff between lowest noise and optimal linearity

Highly Linear/Responsive Photodetectors

- Responsivity ≥ 0.9; nearly all light energy converted to electrical energy
- High Linearity; Output Current directly proportional to received light intensity
- The benefit of highly linear PD is the undistorted translation of an optical RF signal into an electrical RF signal; preserves phase, amplitude and minimizes the creation of harmonics or inter-modulation products.

APIC fabricated photodiode.
At 10 GHz linear photocurrent 70mA





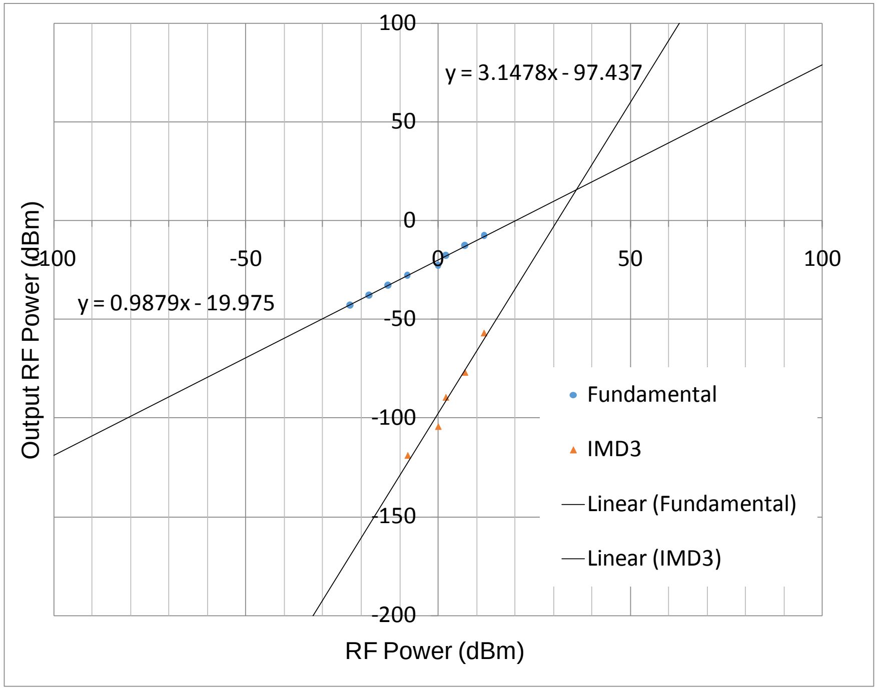
Link Linearity Requirements

- Link must have a high dynamic range, above 112 $dBHz^{-2/3}$
- Link must have a high IIP3 of 36 dBm

OFDM signals contain multiple closely separated frequency carriers. If the response of the link is nonlinear third order inter-modulation products will be generated that fall:

- Within the channel frequency band leading to direct EVM increase
- Just outside of the frequency band leading to ACLR increase and increase of EVM of the adjacent channels

Therefore, RFoF links require highest possible IIP3 point



IIP3 measurement for the RFoF link at 1 GHz. Similar results were measured at 3 GHz.

Impedance Matching Transceivers

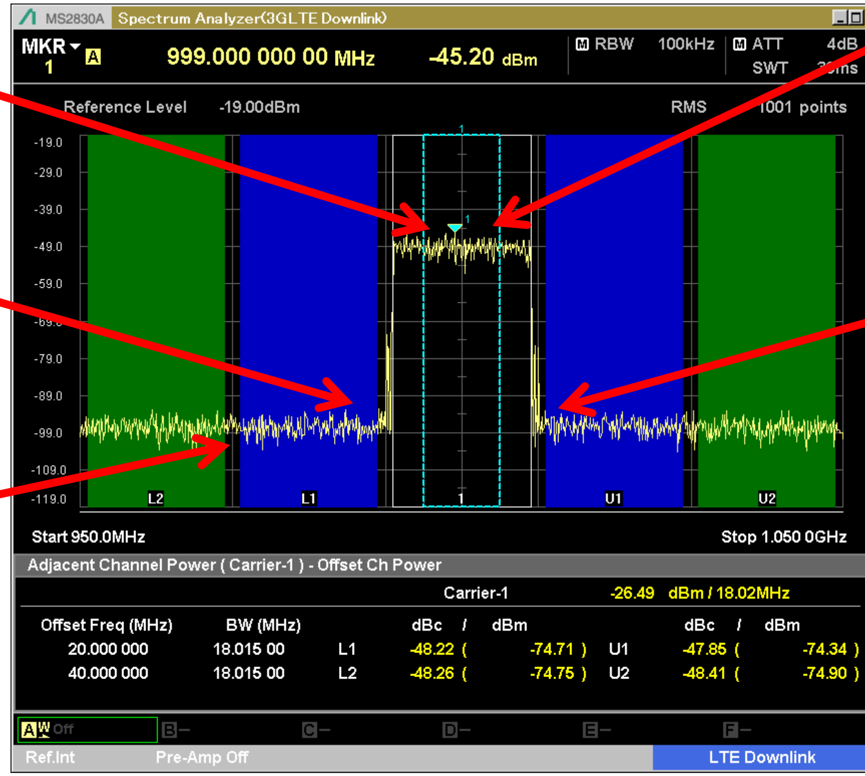
- Issue:
  - Lasers have an intrinsic impedance on the order of 4 Ω.
  - Photodiodes have output impedance > 2k Ω.
  - Standard interface for RF connectors/components is 50 Ω.
- Common and cheap solution is to add a 40-45 Ω resistor in series with the laser
  - Improves the impedance matching, but makes a high RF loss link
  - Close to 90% of the RF energy is converted to heat in the resistor
  - Added heat negatively impacts the laser performance/linearity
- APIC's uses a proprietary solution to increase the RF coupling into the laser and achieve.
  - Higher RF link gain
  - No signal distortion

Impact of Opto-Electronic Tx/Rx on High Order Modulated OFDM Signals

Transmitter gain
- Laser slope efficiency
- Packaging efficiency
- Transmission loss

Transmitter linearity
- Laser epi design
- Laser structure design
- Thermal management

Transmitter RIN*
(noise floor reduction)
- Laser epi design
- Laser structure design
- Injected current
- Packaging (feedback isolation)



Receiver gain
- Chip responsivity
- Packaging efficiency

Receiver linearity
- Type of PD design (UTC* offers much better linearity)
- Epi design

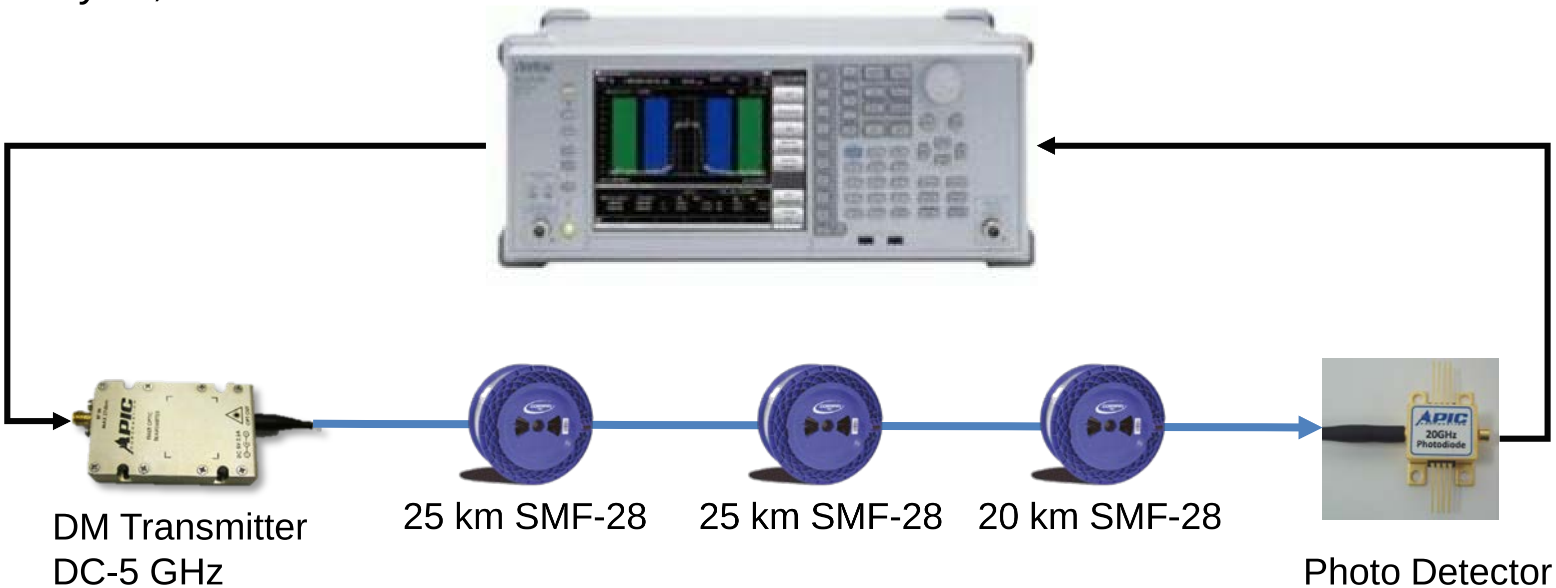
- To achieve high dynamic range of operation, gain needs to be increased and RIN minimized. This increases the range from the top and bottom ends.
- To achieve maximum ACLR, as low as possible third order inter-modulation is required. This is dominated by the transmitter nonlinearity, specified by IIP3.

*RIN = Relative Intensity Noise

*UTC = Uni-travelling Carrier

Initial Testing Validates Directly Transmitted RF over Fiber Technology

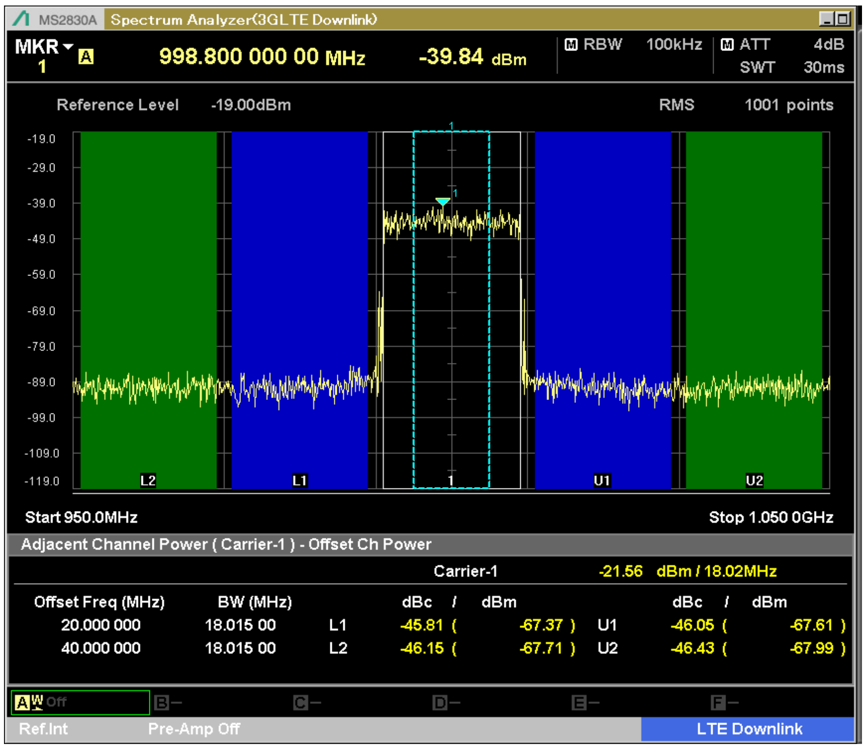
Anritsu MS2830A 6GHz Signal analyzer with: 6GHz Vector Signal Generator; bandwidth extension to 125MHz; software modules for LTE-Advanced IQ Producer; Vector Modulation Analysis; and LTE-Advanced FDD Downlink Measurement.



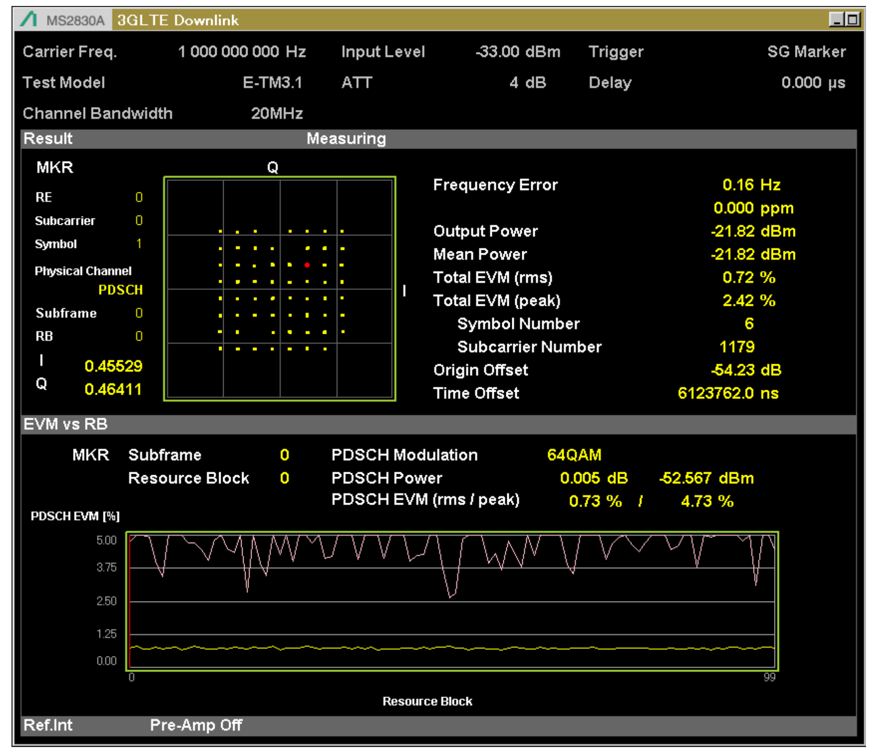
- For all testing we use E-UTRA Downlink Test Model 3.1 (E-TM3.1) with 64QAM modulation, initially with a single 20 MHz carrier and then with 5 aggregated 20MHz carriers for 100MHz transmission bandwidth.
- Performance metrics:
  - Total EVM (rms) ≦ 8%
  - ACP (ACLR) ≦ -44.2 dBm.

Test Summary: Single 20 MHz Channel

- One 20 MHz, 64QAM OFDM signal transmitted over 25 km of fiber
- 3GPP LTE ACLR Spec: ≤ -44.2 dBm • 3GPP LTE EVM Spec: ≤ 8%



Measured ACLR is -45.81 dBc

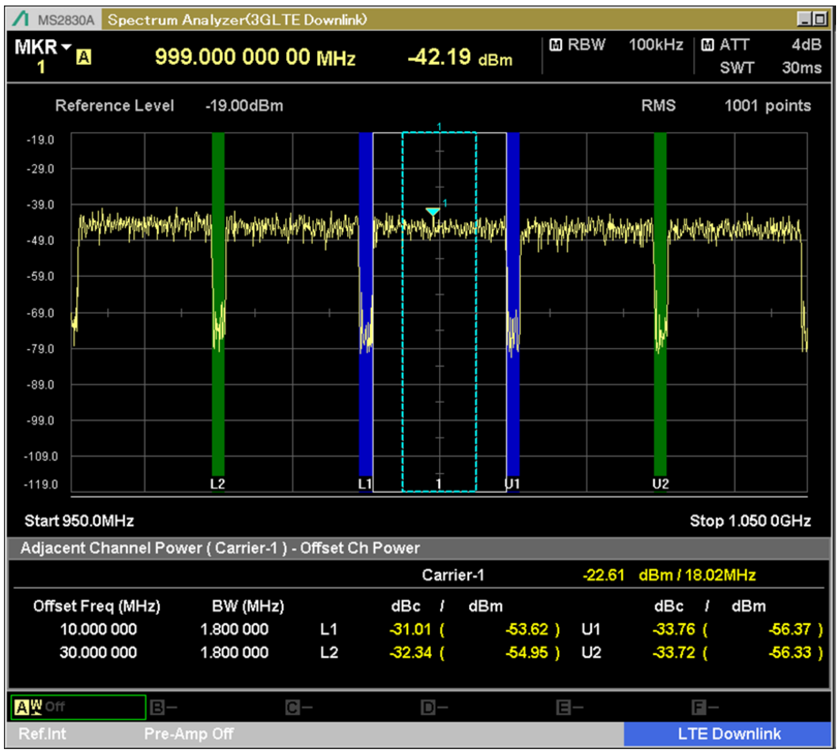


Measured EVM is 0.72%

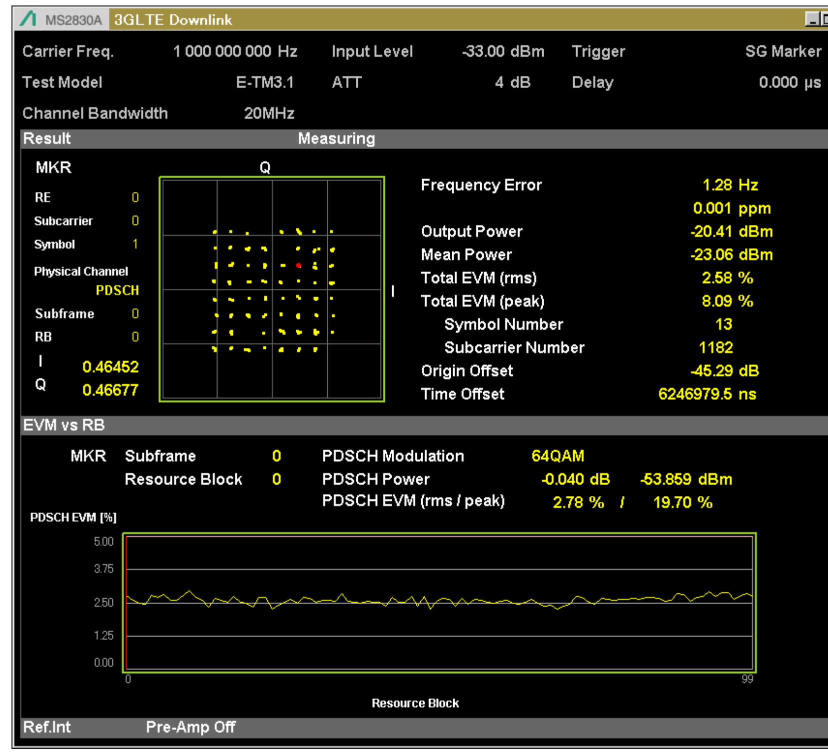
Full report is available at http://www.apichip.com/rfof-5-lte-advanced-carriers-70km/

Test Summary:
Five aggregated 20 MHz Channels

- 5 x 20 MHz, 64QAM OFDM signals transmitted over 50 km of fiber
- 3GPP LTE ACLR Spec: ≤ -44.2 dBm
- 3GPP LTE EVM Spec: ≤ 8%



5 Adjacent 20 MHz Channels



Measured EVM is 2.58%

Full report is available at http://www.apichip.com/rfof-5-lte-advanced-carriers-70km/

For More Information

- Refer to the APIC website: www.apichip.com
- Additional information on the direct transport of 4&5G Radio signals over fiber:
  http://www.apichip.com/5g-c-ran-fronthaul/
- Follow APIC on LinkedIn:
- For Business and sales contact Bob Walter directly at: walter@apichip.com
- For technical questions contact Anguel Nikolov at: Nikolov@apichip.com