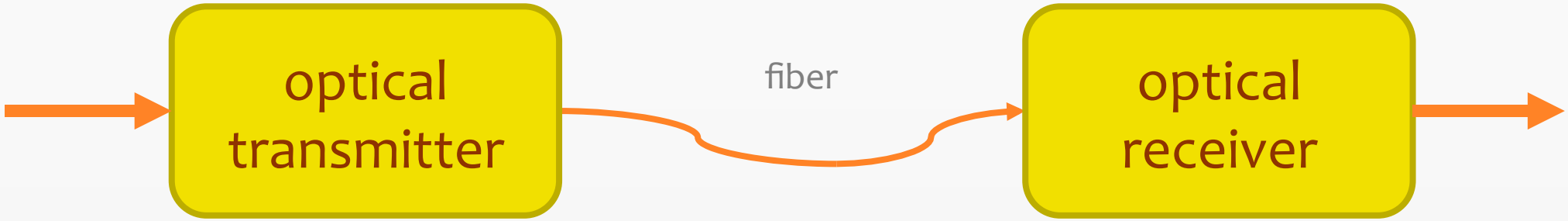
Theory and measurements of wide-band fiber-optic links

James W Lamb

Owens Valley Radio Observatory

Caltech

Components of a fiber-optic link



source
- laser diode

modulation
- direct (current)
- external (optical)

characteristics
- optical power
- wavelength
- laser noise

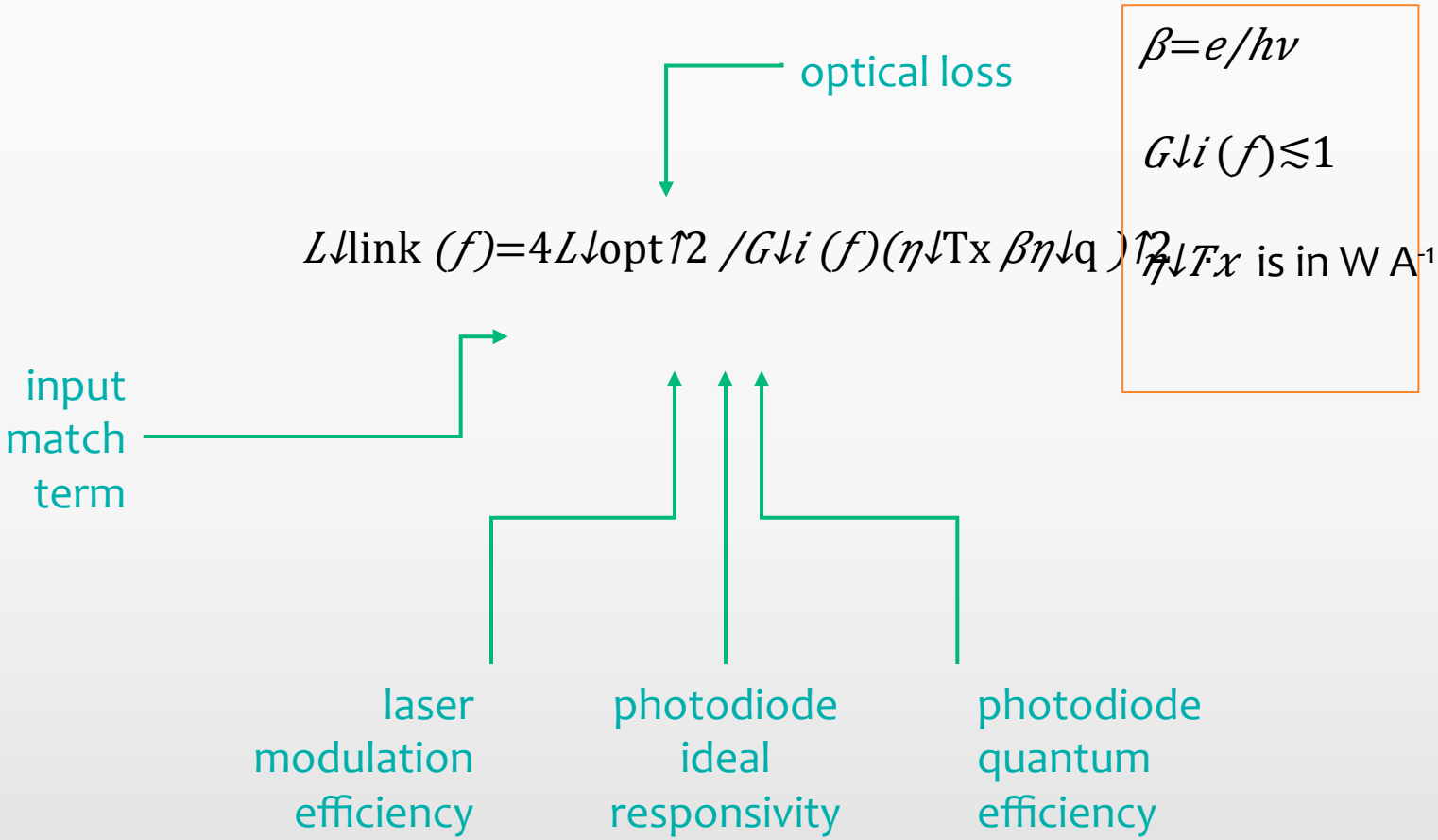
characteristics
- wavelength
- loss
- polarization

detector
- photodiode

matching
- shunt resistance

characteristics
- quantum efficiency
- wavelength
- power handling

Link loss (power ratio)

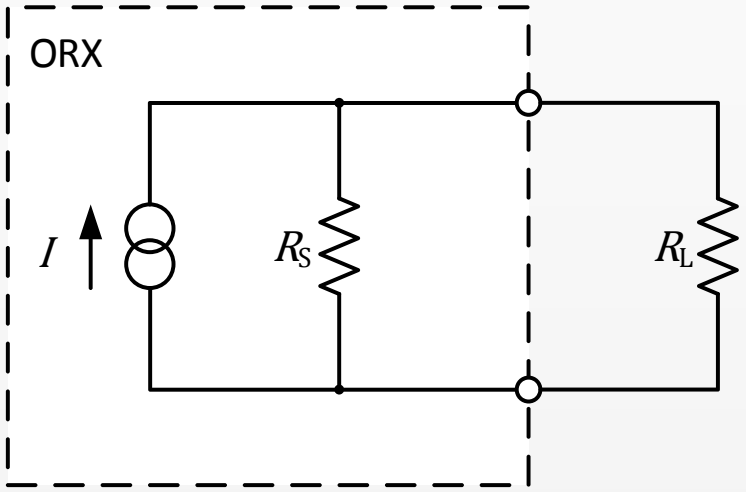


- link losses are typically 30–40 dB
- loss greater for shorter wavelength laser

Noise

- Photon noise
  - Poisson statistics
- Thermal noise
  - Johnson noise in matching resistor
- Amplifier noise
  - From low noise amplifier after link
- Laser noise
  - RIN (relative intensity noise)
  - other sources of amplitude fluctuations
  - laser technology-dependent

Optical receiver equivalent circuit



intrinsic photodiode impedance is high, so use parallel resistor to match

$$R_S \cong R_L = 50\ \Omega$$

1 photon → 1 electron
photon noise = shot noise

$$P_{phot} = \eta_q\ P_{opt}\ e^2\ R_{RF}\ /2 h\nu L_{opt}$$

output noise temperature

$$T_{out} = P_{phot}\ /k + T_{amb} + T_{amp}$$

Noise referred to link input

for just the link: $T\downarrow\text{link} = T\downarrow\text{out}\ L\downarrow\text{link}$

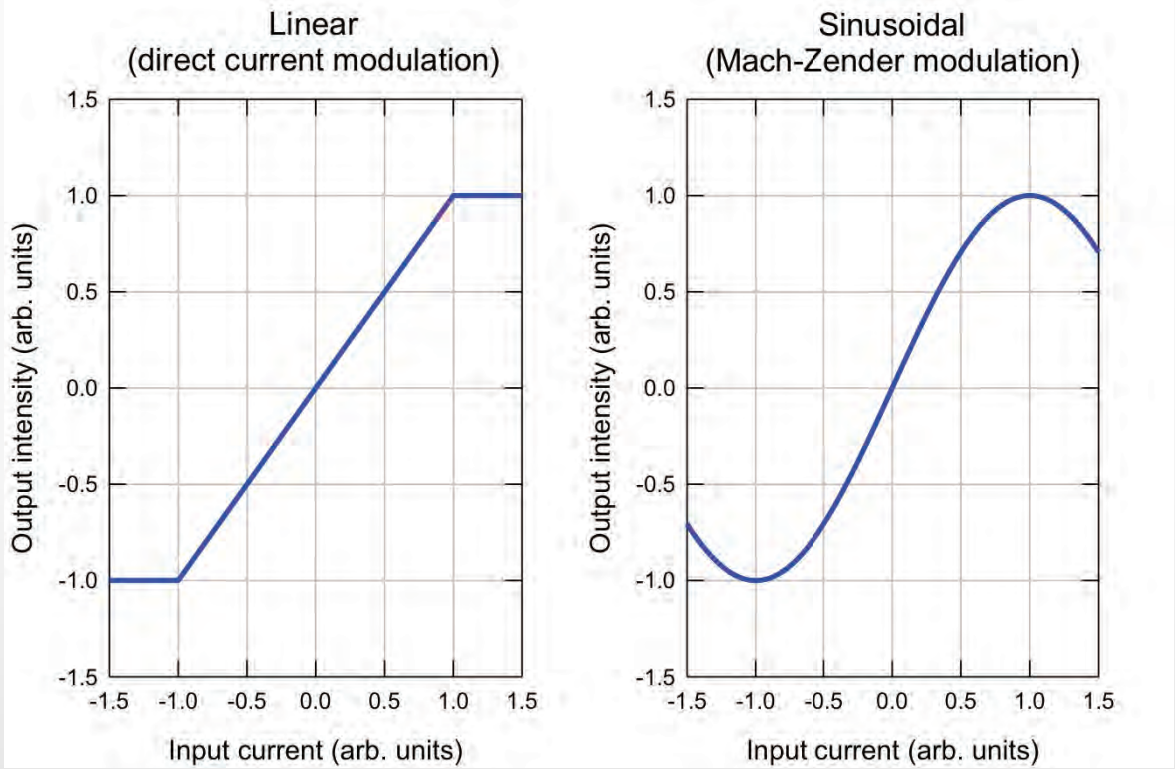
high link loss means input noise temperature is very high

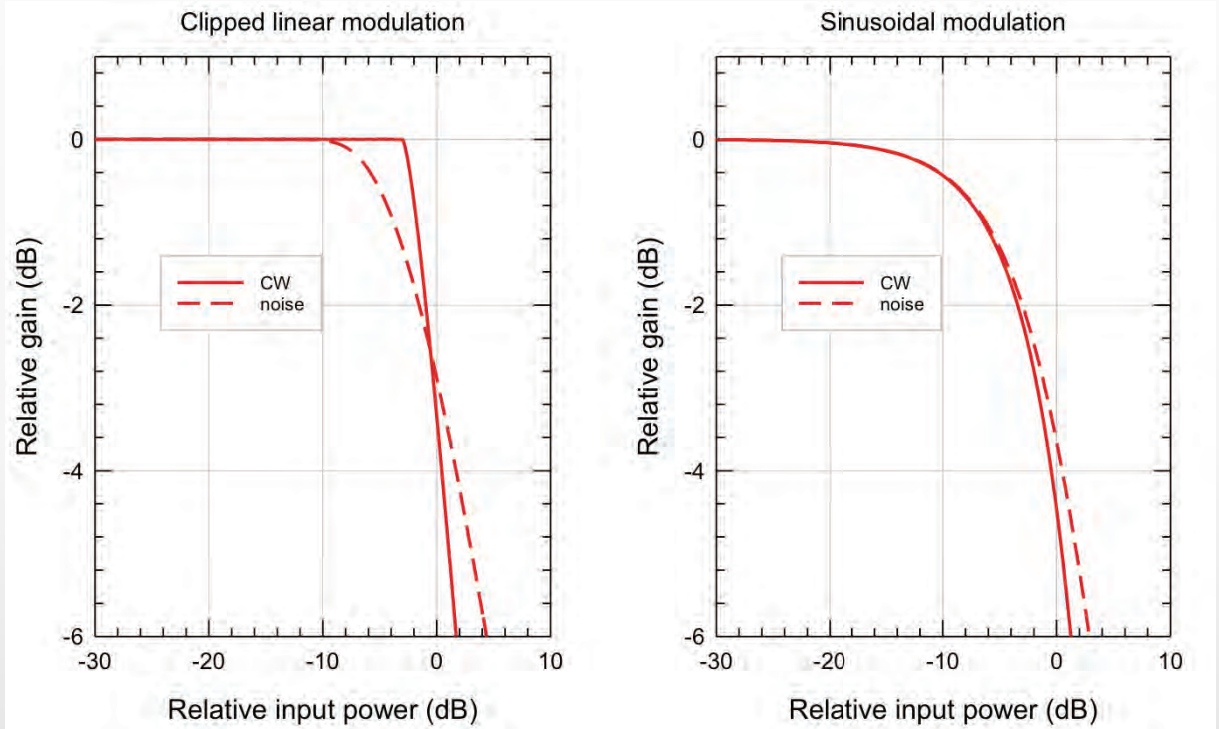
for the link including preamp: $T\downarrow\text{link} = T\downarrow\text{out}\ L\downarrow\text{link}\ /G\downarrow\text{preamp} + T\downarrow\text{preamp}$

we can make the amplifier gain large, to make $T\downarrow\text{link} \rightarrow T\downarrow\text{preamp}$

HOWEVER: we cannot increase $G\downarrow amp$ indefinitely, otherwise we will saturate the link

Transmitter compression



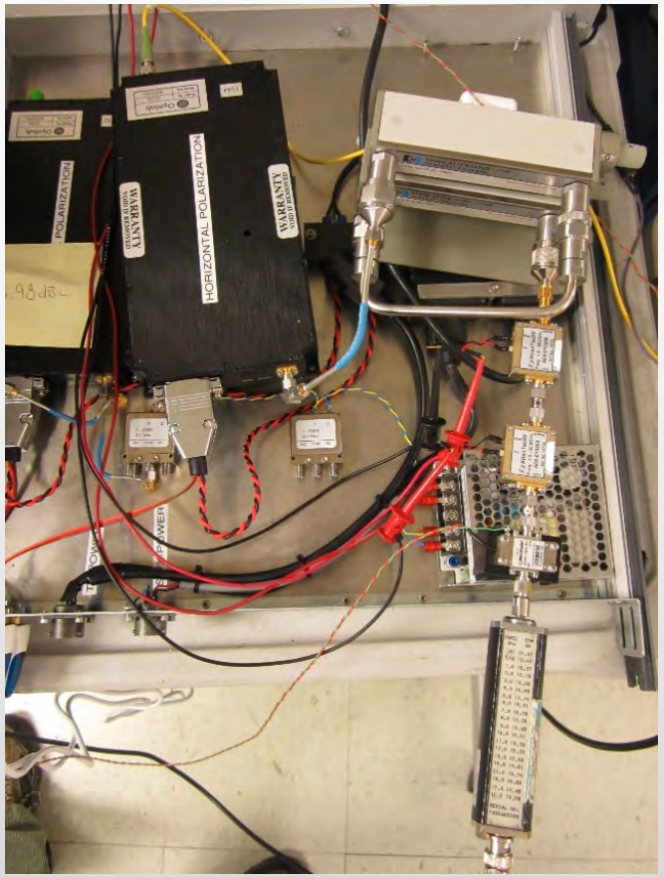


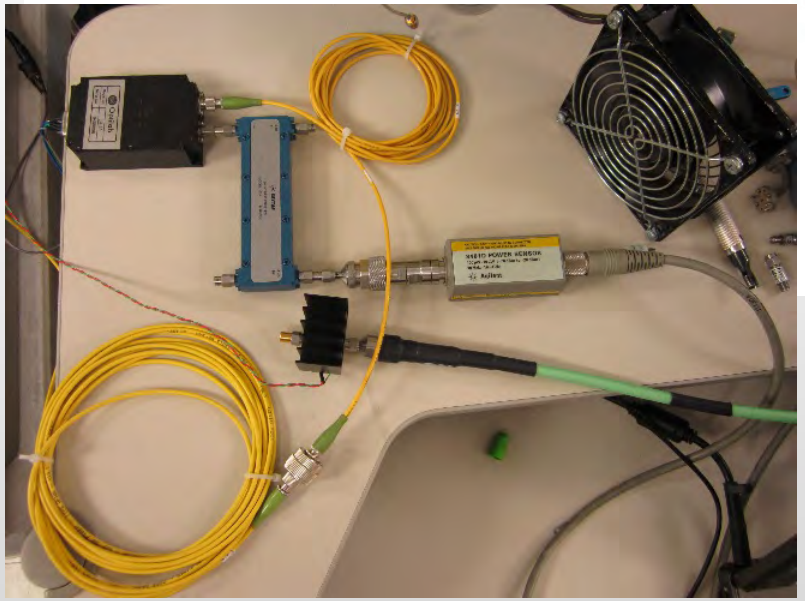
Dynamic range

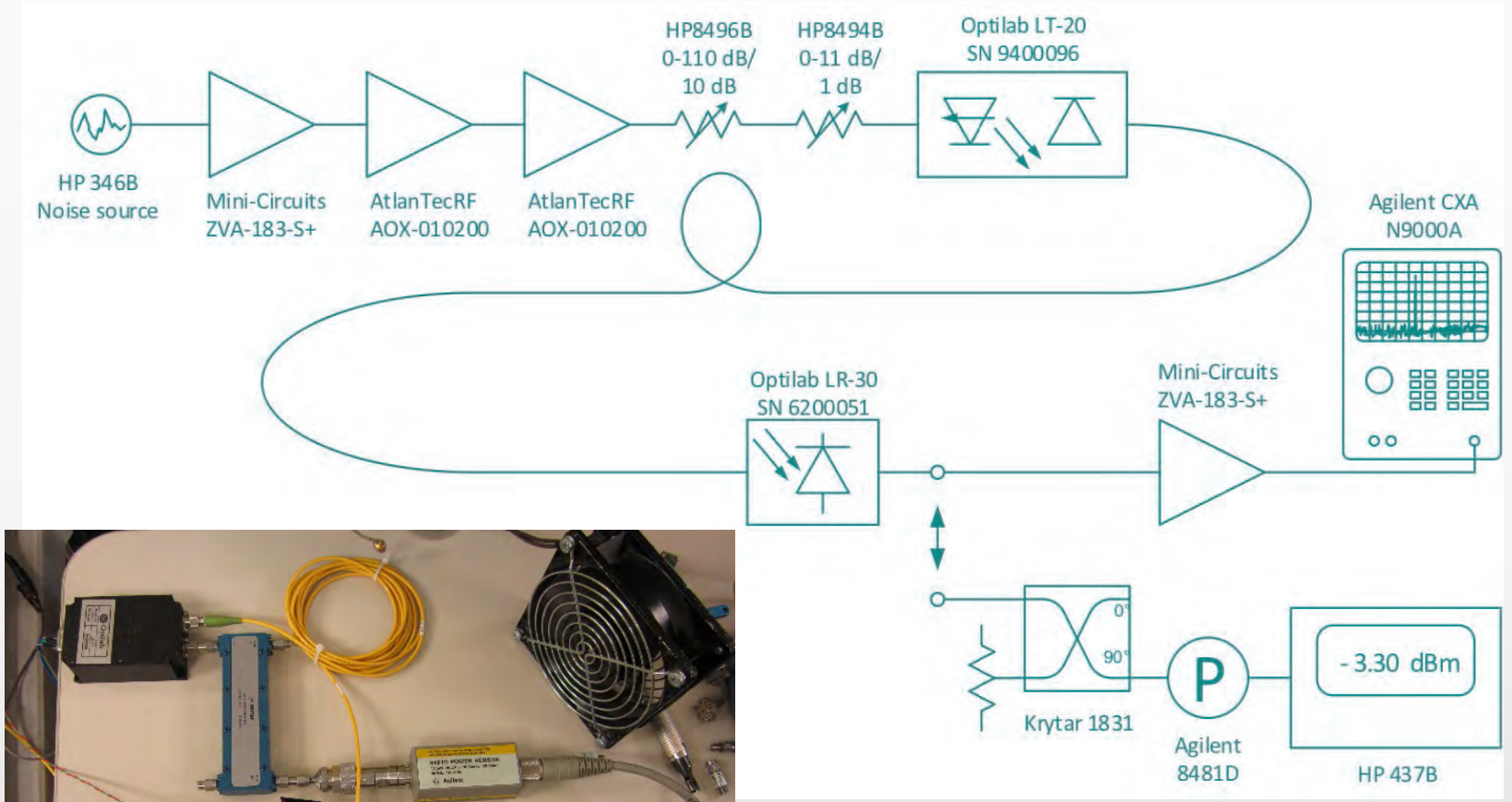
$DR = P_{sat} / P_{noise}\ |_{out}$

- P_{sat}
  - proportional to: P_{opt}^2 , L_{opt}^{-2} , ν^{-2}
- P_{noise}
  - proportional to: P_{opt} , L_{opt} , ν
- dynamic range
  - proportional to: $P_{opt} / \nu^{-3}\ L_{opt}^2$

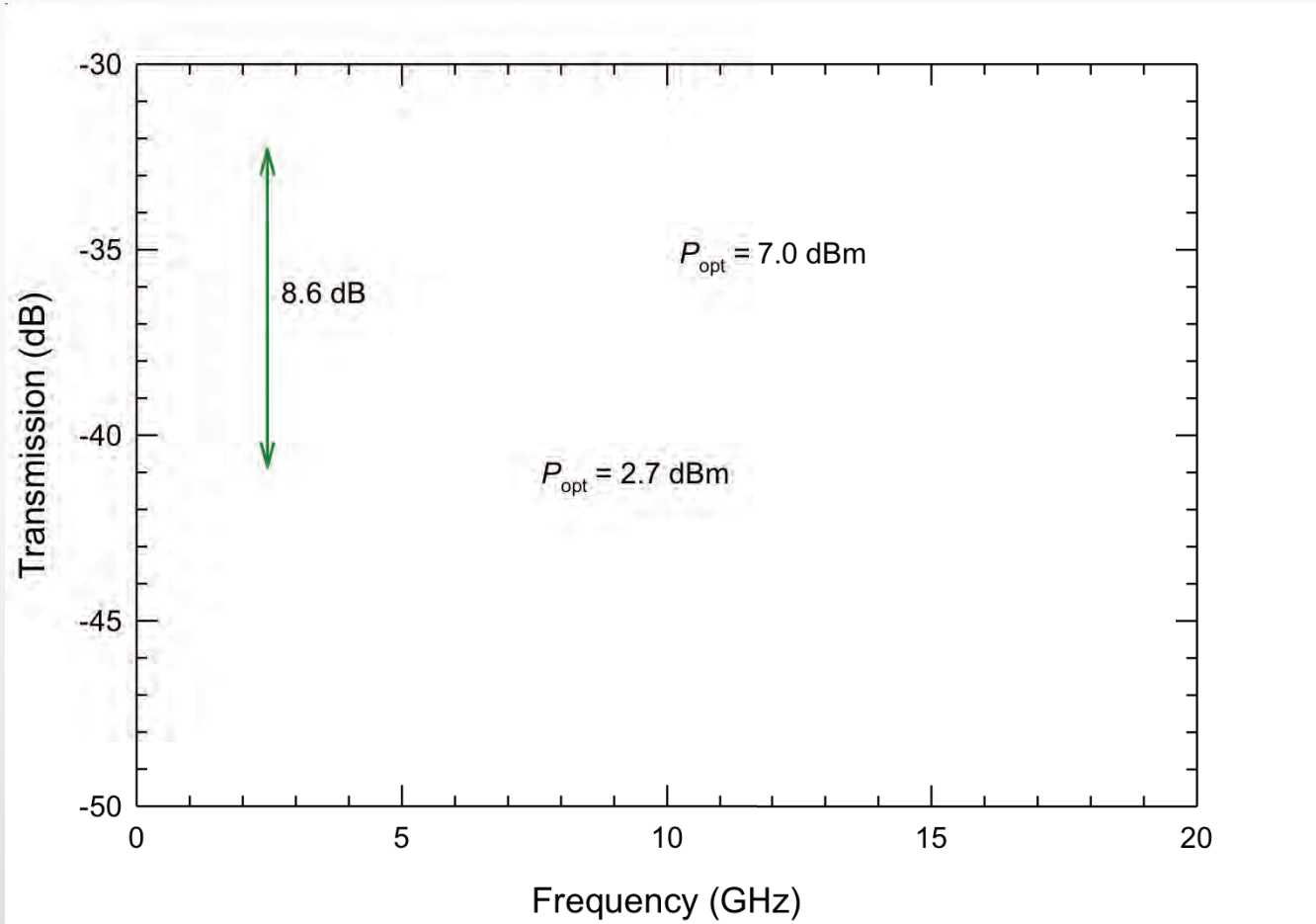
Measurement setup





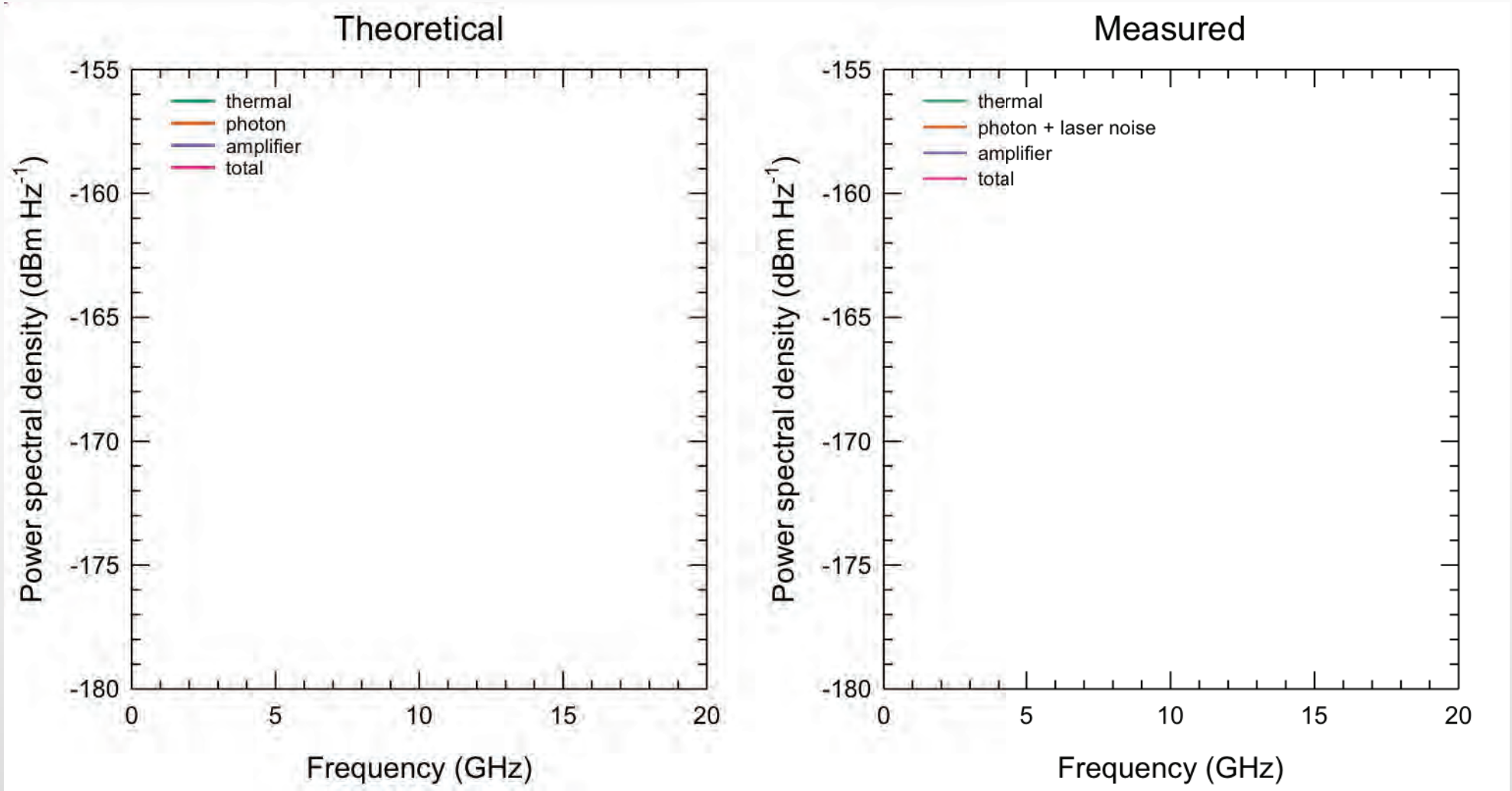


Link gain



OTX: Optilab LT-20
ORX: Optilab LR-30

Link noise



-168 dBm/Hz

↓

-66 dBm
over 17 GHz

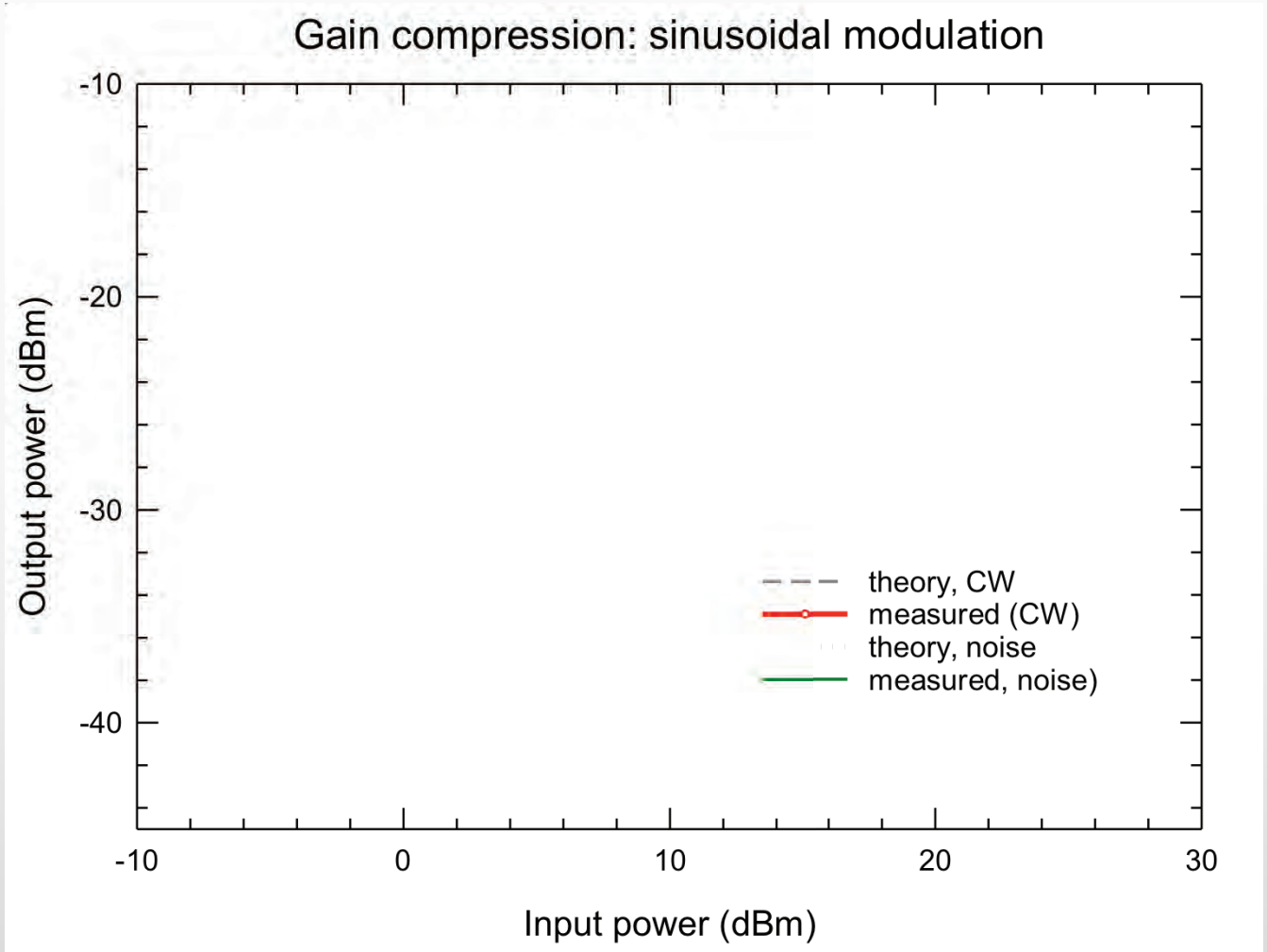
↓

-31 dBm
at link input
(35 dB loss)

↓

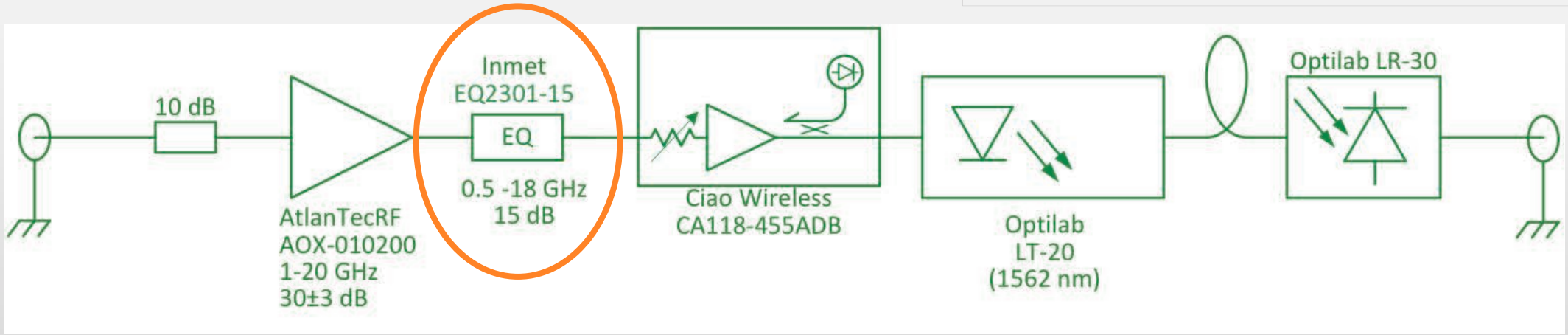
-11 dBm
min input for 1%
link noise

Compression

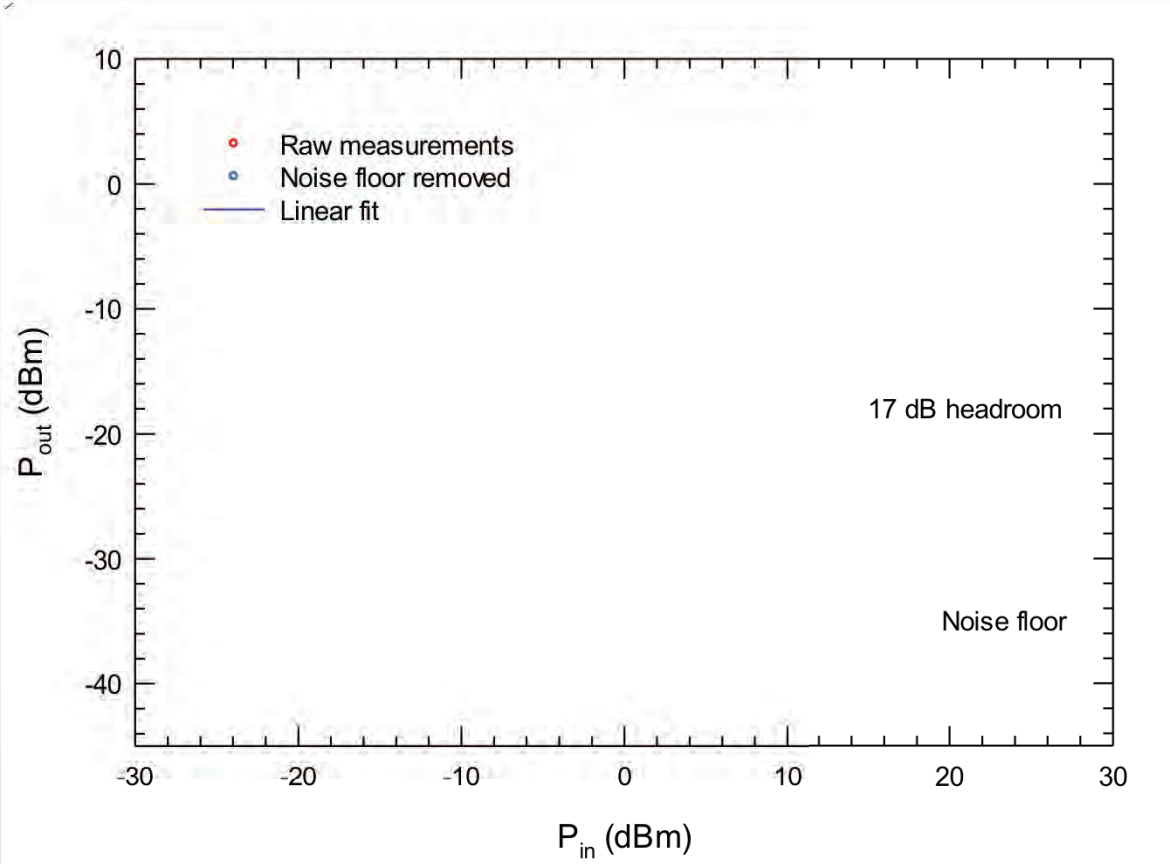


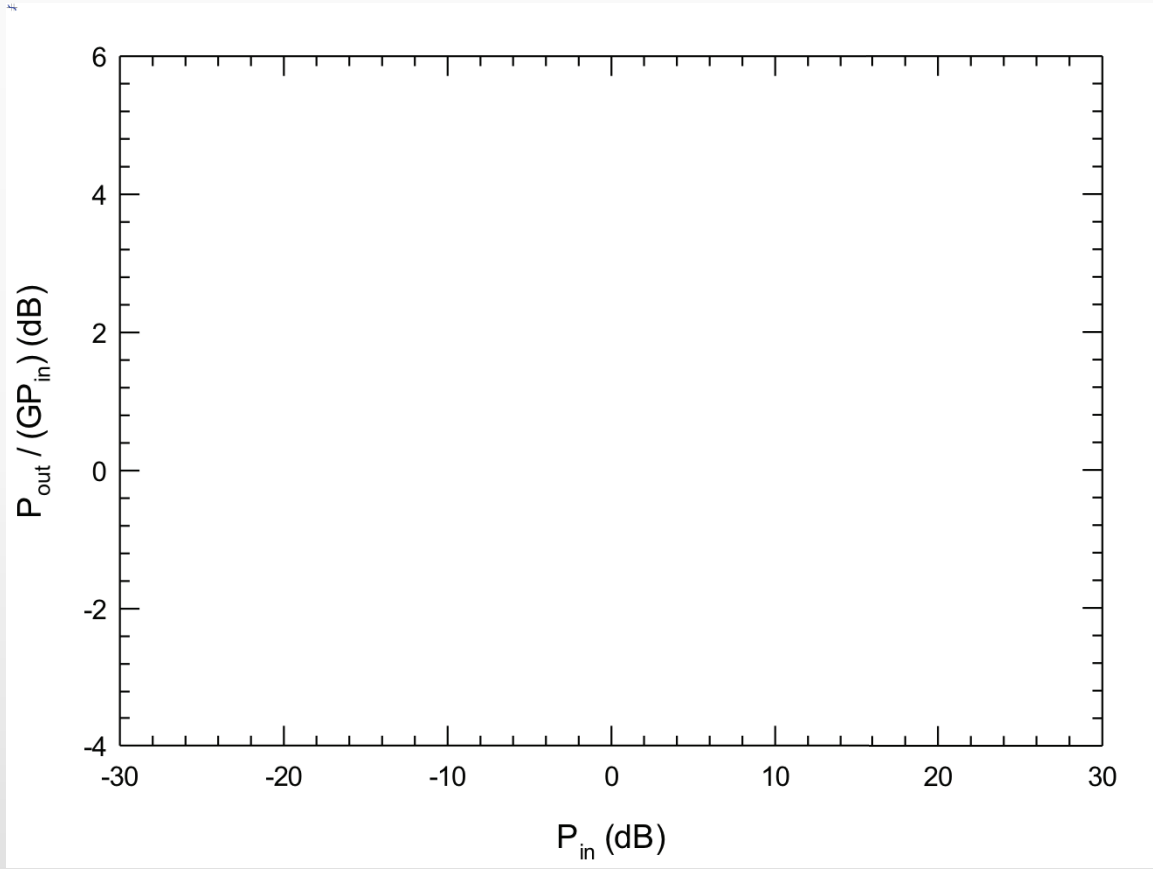
Putting it all together

- to get the best dynamic range, should have uniform SNR across band
- need to *pre-emphasize* input



Dynamic range





Bias tone

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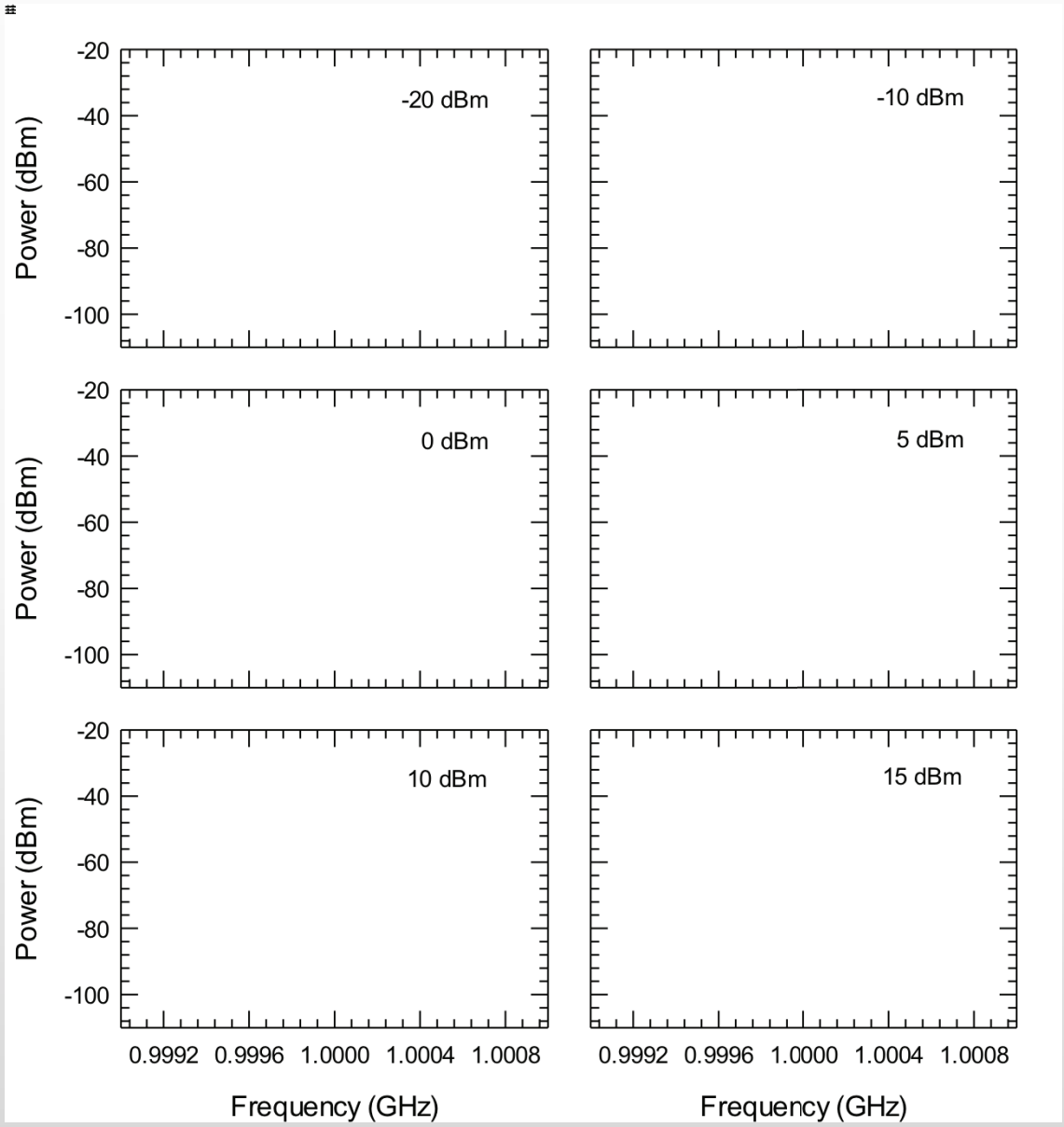

Conclusions

- fiber optical links capable of wide-bandwidth transmission
- performance close to theoretical from fundamental physics
- for best performance
  - keep optical losses low
  - use highest optical power (NB: safety issues)
  - pre-emphasize signal to give uniform SNR

Thank you!