HYBRID MICROWAVE FIBER OPTIC LINKS

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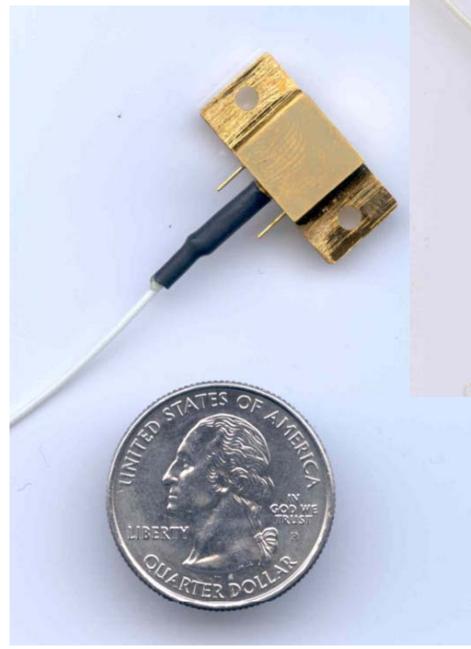
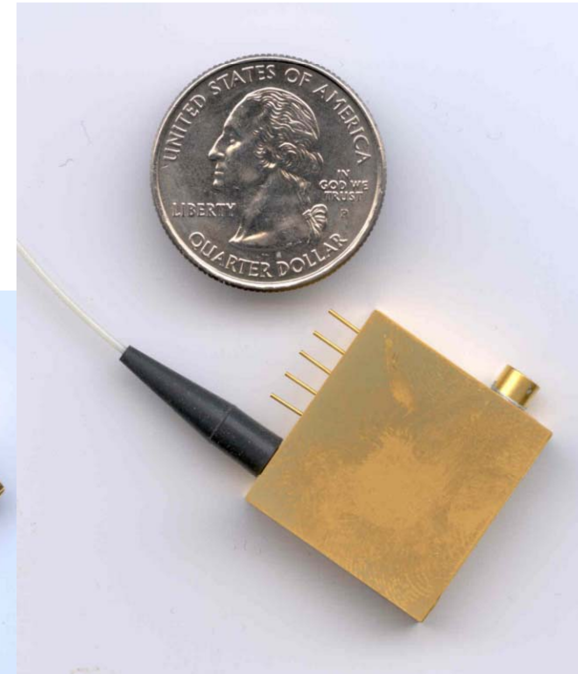




MICROWAVES ON MY MIND
ATLANTA
IMS 2008
INTERNATIONAL MICROWAVE SYMPOSIUM
June 15-20, 2008

LINEAR PHOTONICS

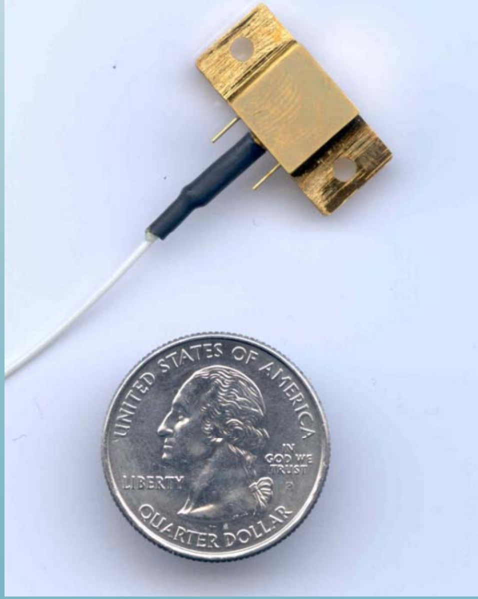
LINEAR PHOTONICS, LLC

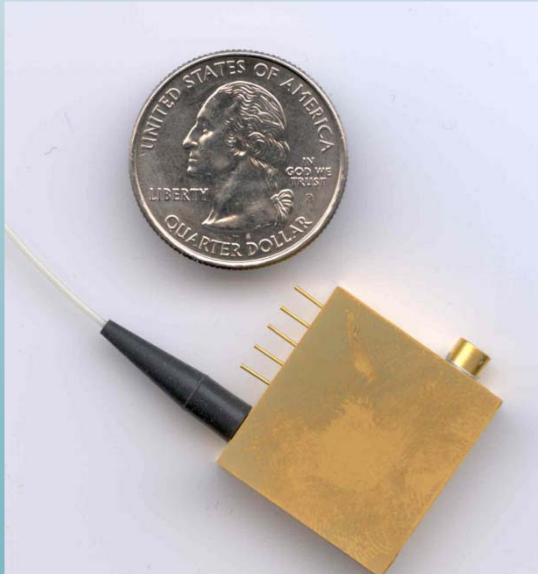
Bringing Performance to Light!

Hybrid Photonics

- LPL has developed Hybrid Microwave Photonic Link Components
  - Directly-modulated Microwave-over-fiber extended to Ku Band
  - Very small Size and Weight
  - Lower Cost & Complexity than external modulation
  - High Dynamic Range: equivalent to external modulation

Microwave Photoreceiver

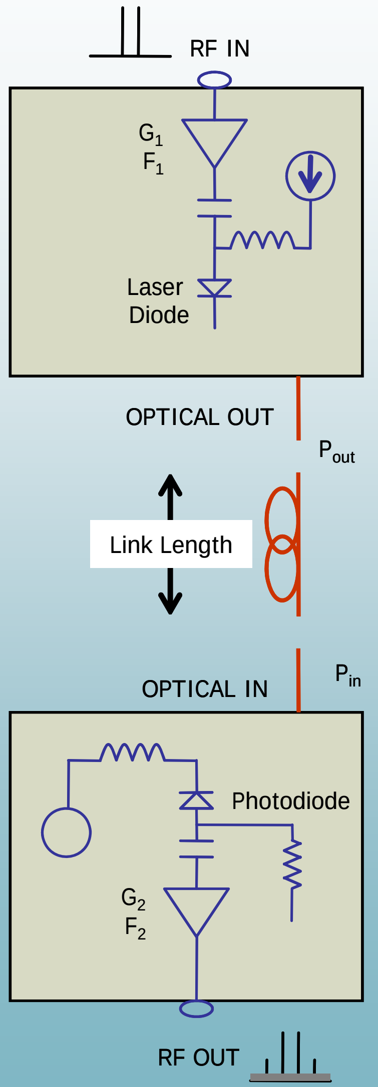




Microwave Laser Transmitter

Directly Modulated Links

- Directly-Modulated (DM) Fiber Optic Links
  - Transmitter: RF pre-amplification, biasing, and matching to low-impedance laser diode
    - Output is Intensity Modulated
    - Modulation Efficiency = ratio of peak output modulation envelope to peak microwave input current
  - Receiver: PIN photodiode, matching from high-impedance diode, RF post-amplification
    - Responsivity = ratio of generated current to incident light intensity
    - PIN diode performs direct envelope detection



Link Gain, G_L

$$G_L(dB) = G_{ref} - 2 \cdot OL$$

Link Noise Figure, F
and
Output Noise Power Density, N_{out}

$$F(dB) = N_{out}(dBm/Hz) + 174 - G_L(dB)$$

$$N_{out} = 10\log\left[10^{\frac{c_{th}}{10}} + 10^{\frac{c_{shot}-OL}{10}} + 10^{\frac{c_{rin}-2OL}{10}}\right]$$

Link Input Intercept, IIP_3

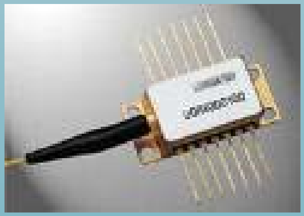
$$IIP_3(dBm) = 10\log\left[\frac{10^{\frac{OIP_{eq}+IIP_{eq}}{10}}}{10^{\frac{OIP_{eq}}{10}} + 10^{\frac{IIP_{eq}+G_L}{10}}}\right]$$

Packaged Laser Limitations

- Low Cost Commercial Laser Transmitters utilize packaged laser diodes
  - Widespread use in CATV, RF-over-Fiber
- Thermal and Frequency Limitations
  - Frequency Response Limited by package parasitics
  - Thermal Operation limited by changing gain slope

– TEC-cooled “butterfly” packages solve thermal problem
  - At expense of even lower bandwidth (more package effects)

– Uncooled “TO-Can” packages can operate to ~ 4 GHz
  - Slope change limits thermal range for stable link gain to ~ 0 to 50 C

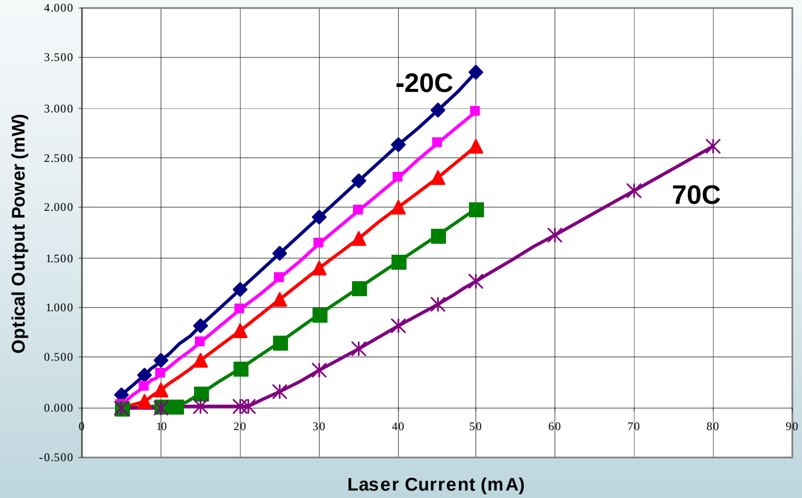


Cooled “butterfly” laser
Frequency Response < 3 GHz
High Current (TEC)
Low Reliability (TEC)

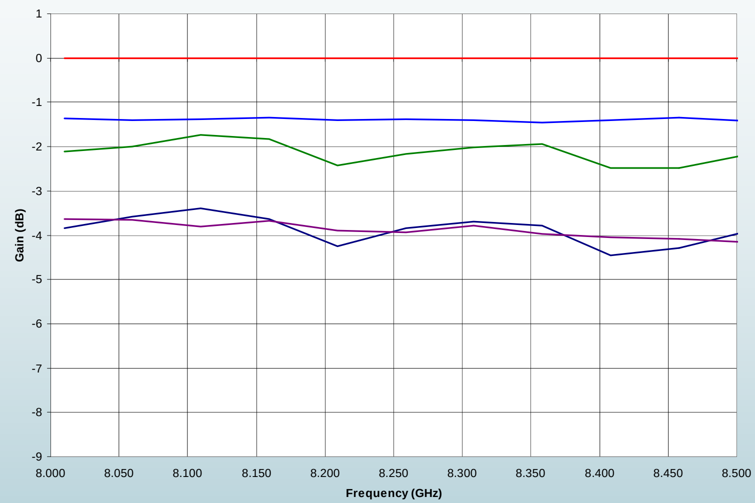
Uncooled “TO” laser
Frequency Response < 4 GHz
Limited Thermal Range

Laser Diode Thermal Operation

Laser L-I curve over Temperature



8 GHz Link Gain over Temperature



Slope efficiency and Threshold change with temperature → **Results in large variation in link gain over temperature**

- Link gain = f(Slope Efficiency) Link Gain ≠ f(Optical Power)
  - Bias adjust can maintain optical power, but not slope efficiency
  - Use of TEC maintains laser temperature
    - Requires ~ 2 W DC power
    - Not suitable for high-reliability
      - TEC MTBF may be less than Laser Diode MTBF
- Hi-Rel, Low Power solution is RF Variable Attenuation

Hybrid Laser Transmitter

OPTICAL SECTION

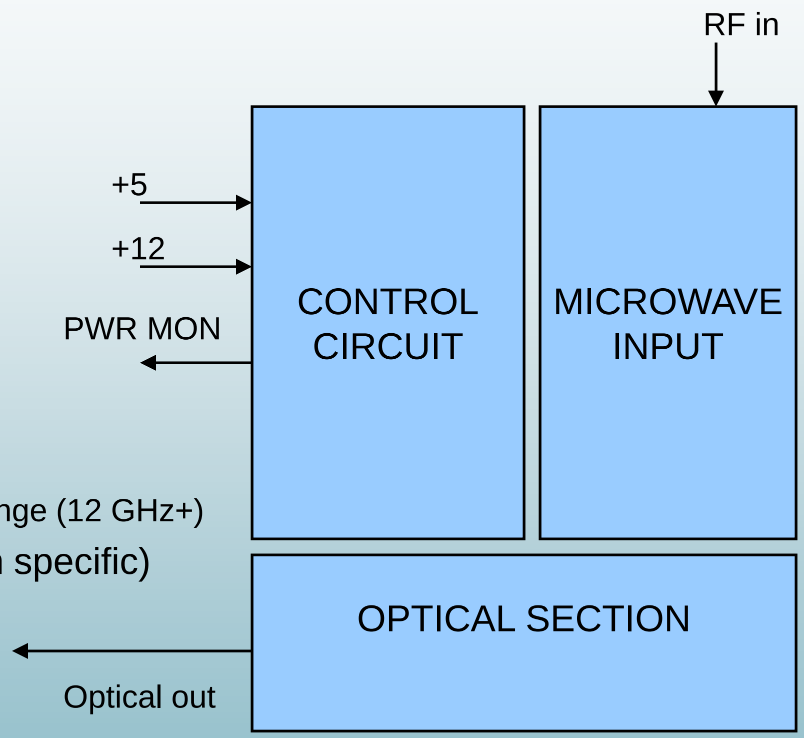
- Uncooled Laser Diode
  - High Reliability, Low Noise 1310 nm
  - Low DC Power (no TEC)
- Optical Alignment to Single Mode fiber
  - Focusing Optics and Optical Isolator

MICROWAVE INPUT SECTION

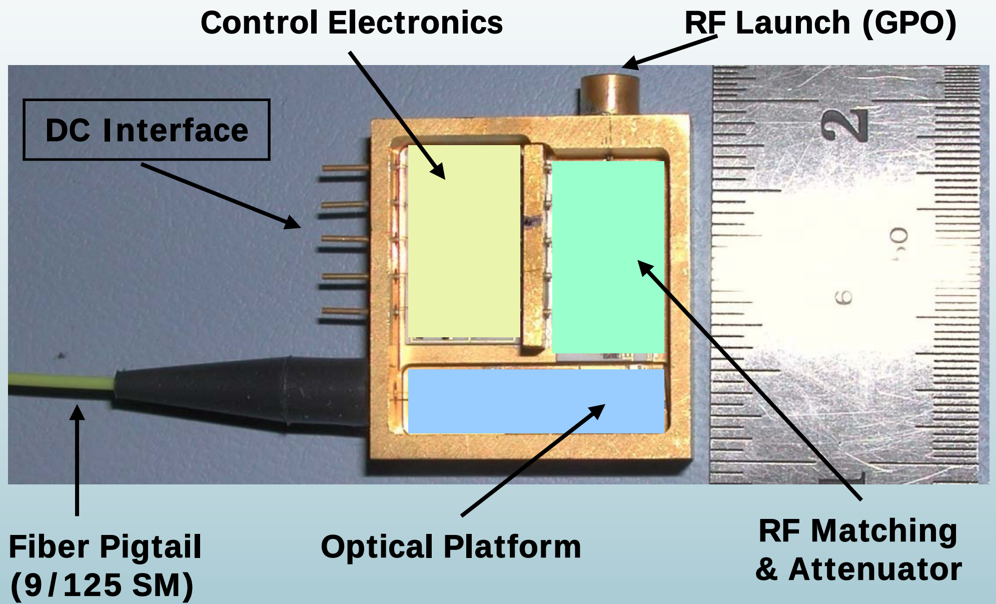
- Temperature Compensation Network
- Optimal Microwave Matching
  - Package parasitics removed
  - Operation to inherent laser diode frequency range (12 GHz+)
- Broadband or narrowband tuning (application specific)
- Provisions for Preamp / Predistortion

ANALOG CONTROL SECTION

- Analog hybrid on ceramic
  - Power supply conditioning
  - Constant Current bias loop
  - Thermal Control
  - Backfacet telemetry



Transmitter Layout



Link Performance

Typical Performance for Microwave Links

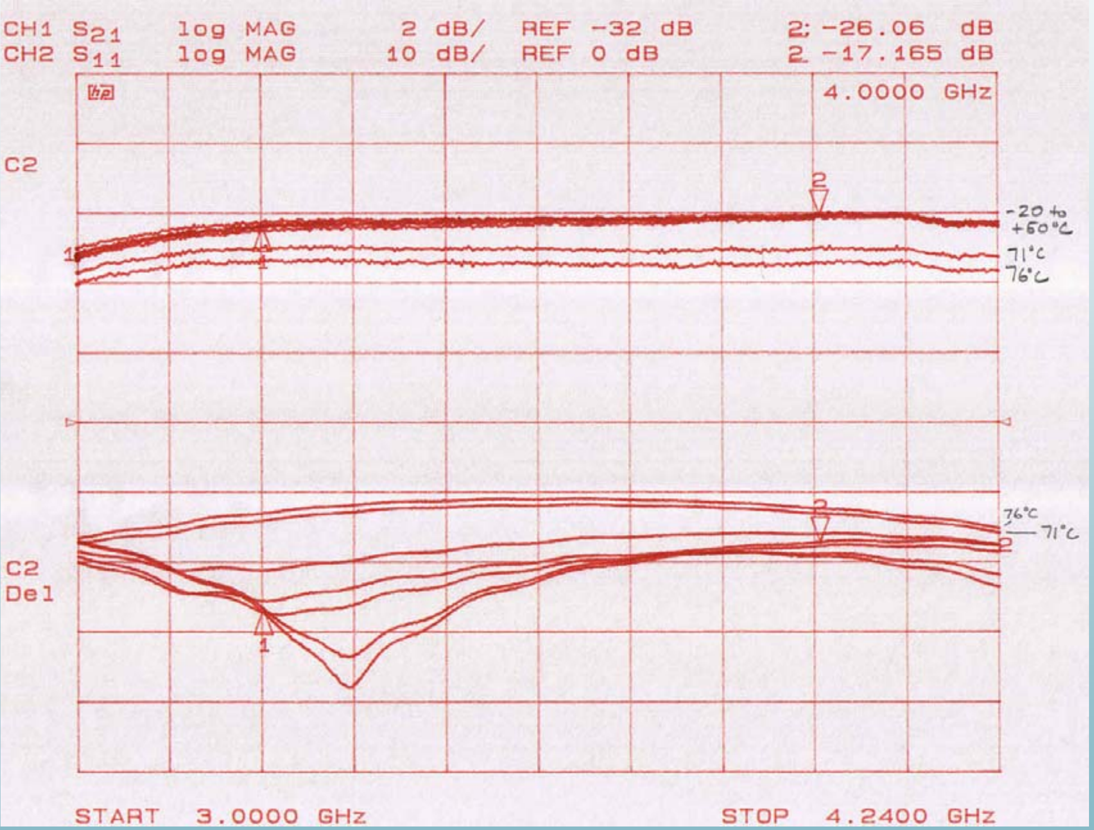
Examples: C-Band and Broadband

Links available tuned any bandwidth to 12 GHz

	C-Band	Broadband
Bandwidth	3.2 to 4.0 GHz	4 to 12 GHz
Optical Power	6 dBmo	6 dBmo
RF Link Gain	-12 dB	-15 dB
Gain Variation with Frequency	0.5 dBp-p	2 dBp-p
Gain Variation with Temperature	2 dBp-p	2dBp-p
RF Input/Output Return Loss	10 dB	10 dB
Input IP3	32 dBm	28 dBm
Noise Figure	29 dB	32 dB
SFDR	118 dB (1 Hz)	113 dB (1 Hz)
DC Power		
@ -10 C	375 mW	
@ 25 C	450 mW	
@ 70 C	600 mW	
Operational Temperature Range	-20 to +70 C	
Transmitter Weight (less pigtail)	19 grams	
Receiver Weight (less pigtail)	5 grams	

Link Performance

C-Band IF Link



Design Flexibility

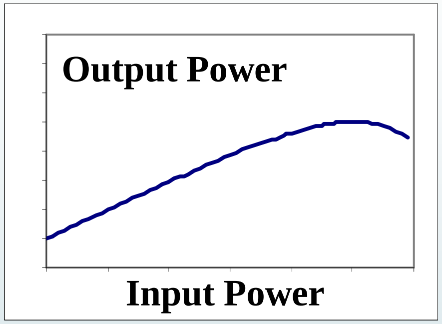
- Link optimization
  - Microwave matching design for any bandwidth requirement
  - Integrated preamplification for lower noise
    - Receive side antenna remoting
- Integrated Predistortion Linearization
  - Improves Intermodulation Distortion
- Bandwidth Extension to 20 GHz
  - Units available 4Q08

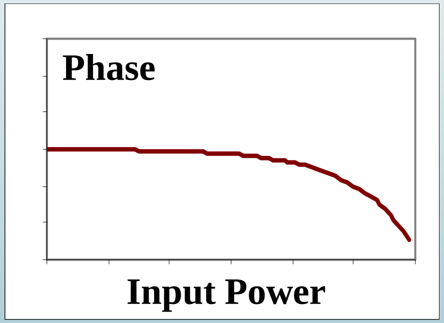
Linearity Improvement

- Linearization: Methods of improving the linearity of a nonlinear network
  - Predistortion Linearization is one technique
    - Employs a nonlinear element in the microwave signal path
    - Operates at instantaneous microwave rate
      - Not limited by delay as in feedback or feedforward approach
      - Not limited by overly complicated component-count
      - Limited primarily by microwave matching, preamplifiers, etc.
- Linearizer Technology, Inc. (Linear Photonics' sister company) has been manufacturing linearizers and linearized networks for > 15 yrs
  - Technology is readily applied to fiber optic networks

Linearizer Technology, Inc.

Predistortion Linearization

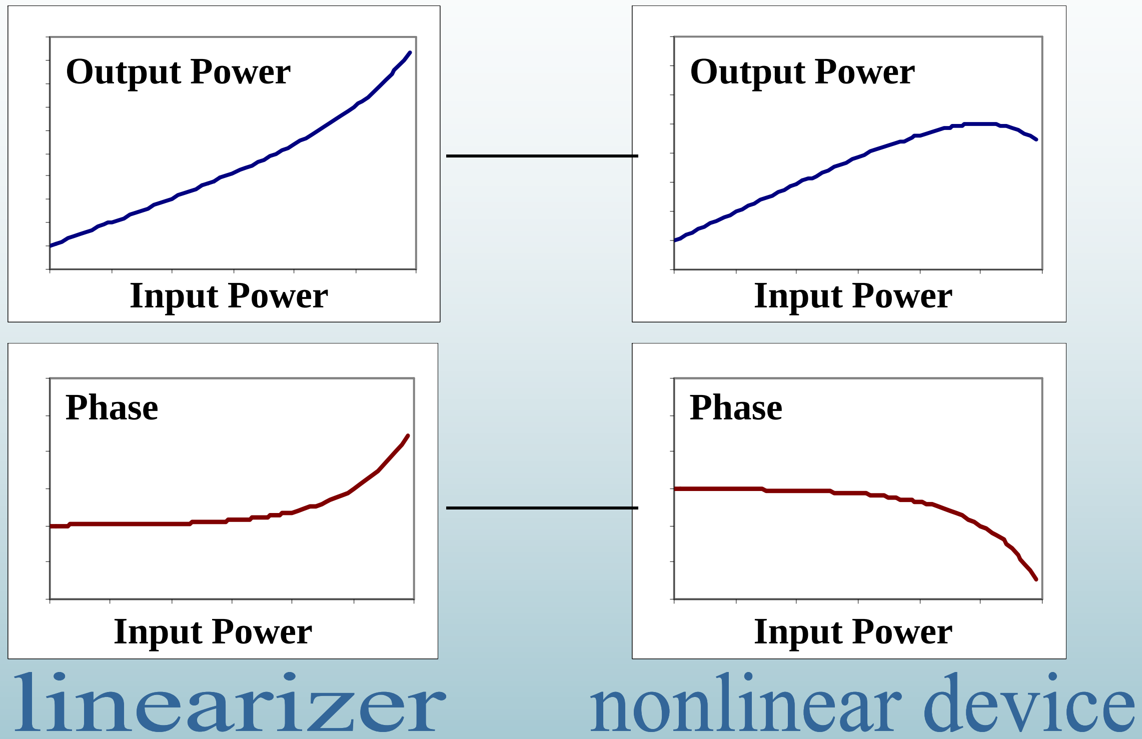




nonlinear device

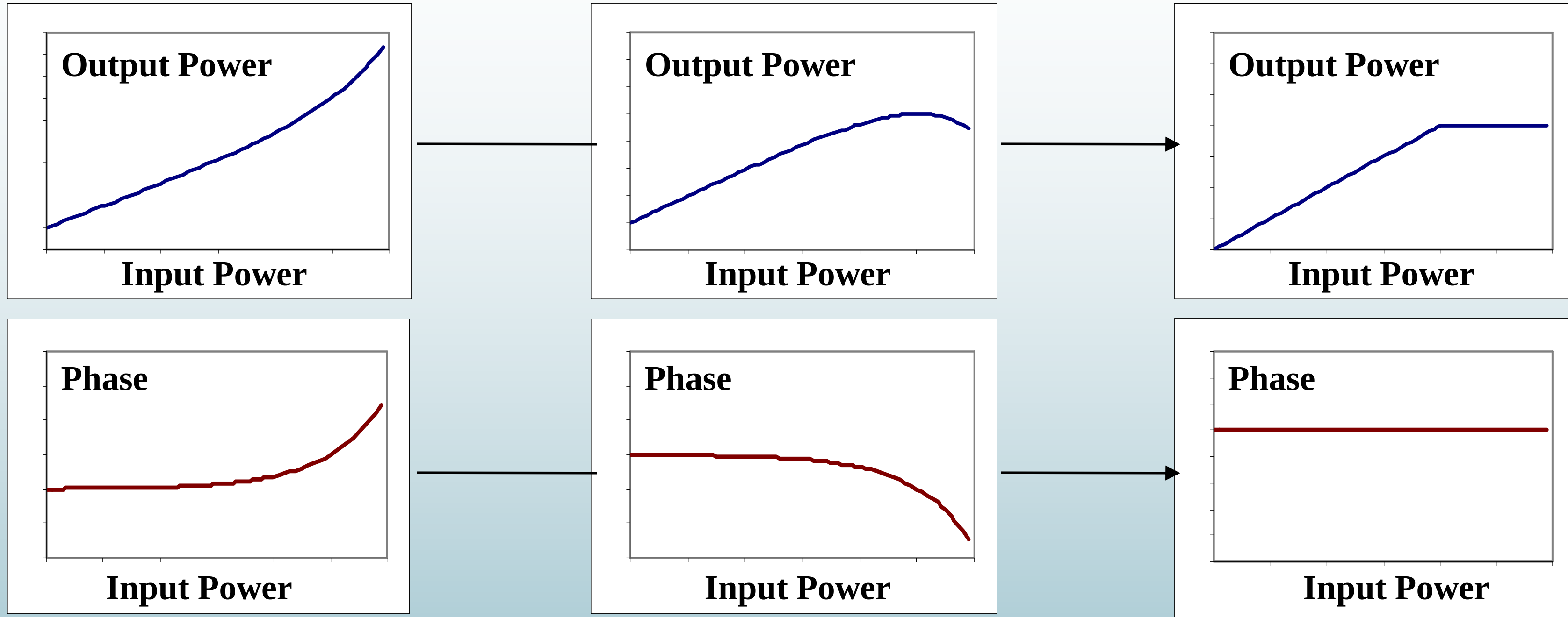
- Nonlinear Device exhibits Gain and Phase Compression

Predistortion Linearization



- Nonlinear Device exhibits Gain and Phase Compression
- Precede it with another nonlinear device that exhibits gain and phase expansion, in conjugate with the device to be linearized (the **linearizer**)

Predistortion Linearization

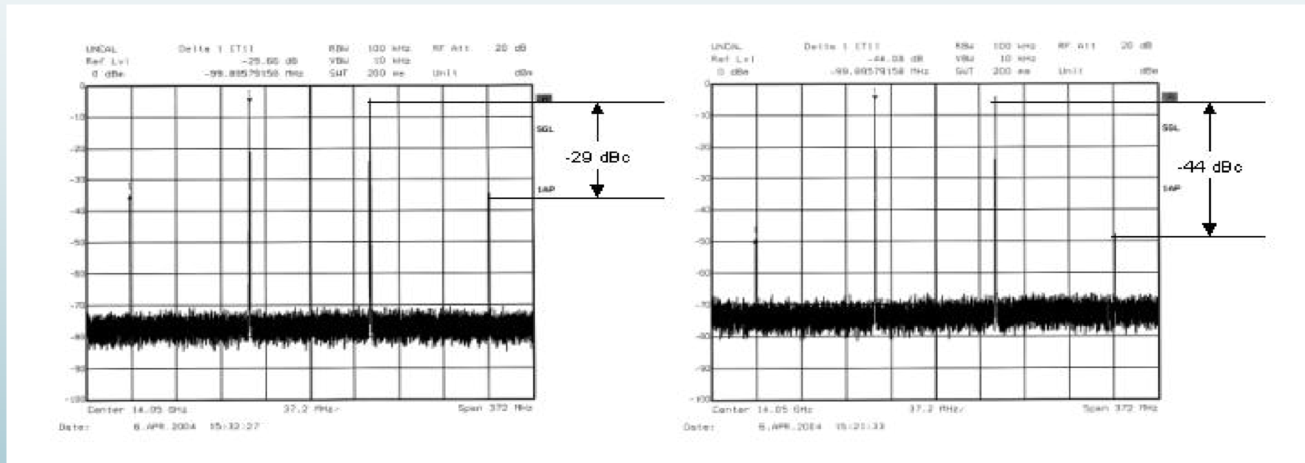


linearizer nonlinear device

- Nonlinear Device exhibits Gain and Phase Compression
- Precede it with another nonlinear device that exhibits gain and phase expansion, in conjugate with the device to be linearized (the **linearizer**)
- The desired outcome is an **ideal limiter**
  - – The linearity of an ideal limiter cannot be improved

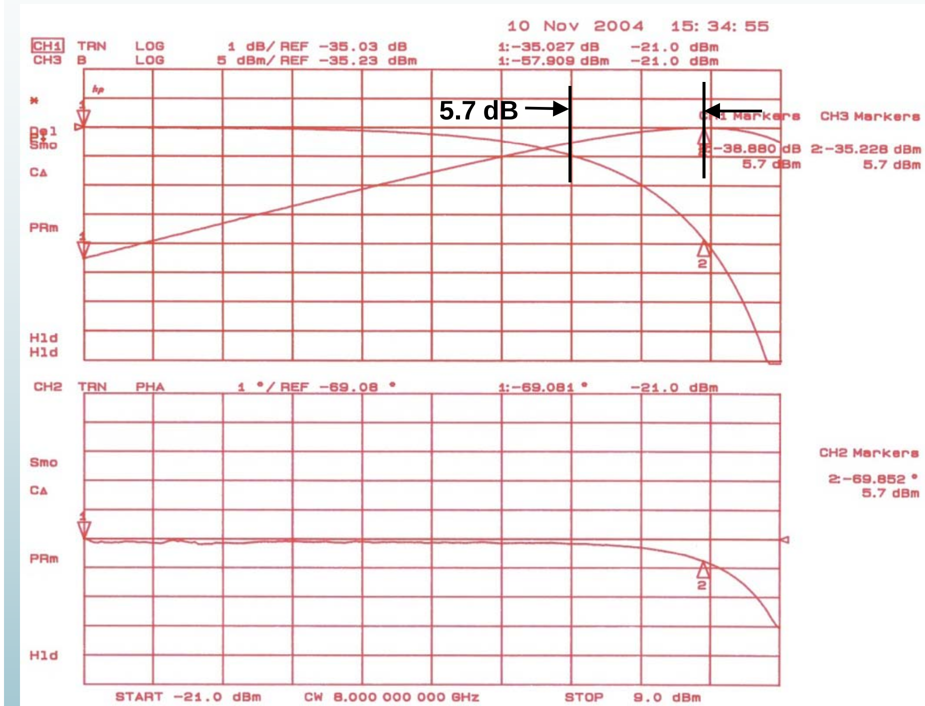
Predistortion Linearization

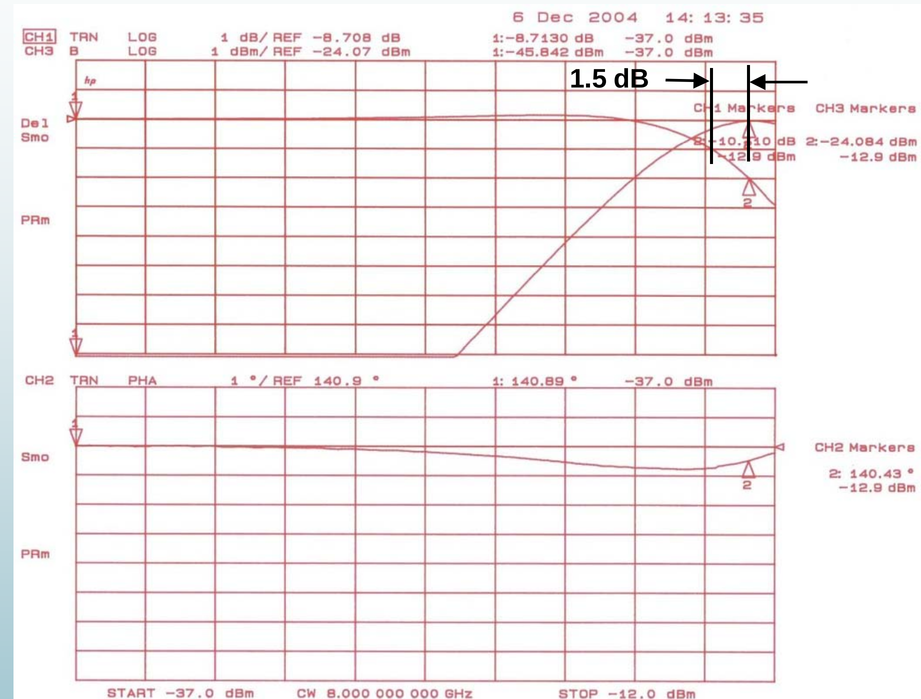
- Result is reduction in IMD:



- SFDR is impacted 1:3 (dB) with IMD

Results: Gain and Phase Transfer





<u>Non linearized @ 8 GHz</u>
P1 dB is 5.7 dB from saturation
Phase compression rapidly above sat

<u>Linearized @ 8 GHz</u>
P1 dB is 1.5 dB from saturation
Phase nonlinearity held to < 1° past sat