IEEE Internet of Things

The Importance of Linearizers Onboard Satellites

(Especially at Millimeter-wave)

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The Internet of Things (IoT)
and the mmWave Frontier

RWW IEEE AESS

Outline

- Introduction – Need for Linearization at Higher Frequencies and Greater Bandwidth for Communications Satellites
- Power Amplifier Linearization
- Satellite Linearizers (Digital vs. Analog)
- What is New:

  -More Versatile and Wider Band

  -Higher Frequency (Q, V, E & W-Band)
- Conclusion

Introduction

- There is great interest in the transmission of very high data rate signals as 64 and 256 QAM/APSK particularly at Millimeter-wave (MMW) frequencies where > BW is available.
- The transmission of such signals requires a highly linear PA… $R<BW[\log_2(1+S/N)]$.
- Nav satellites need linearity for constant phase

Introduction

- Linearity usually achieved by operating PAs at a reduced output power.
- Results in Bigger & Heavier, Lower Efficiency, Hotter, and Higher-Cost PAs.
- Can make satellite communication systems impractical.
- Linearization thus of great interest.
- For satellites it is essential!

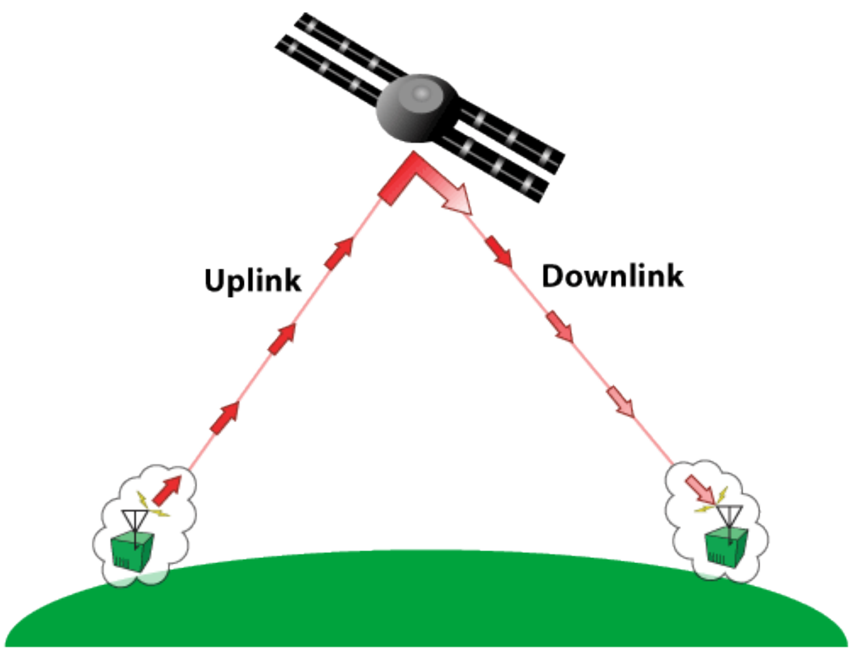
Introduction

- Linearization benefits TWTAs and SSPAs:
- Satellite SSPAs have made big gains as a result of GaN
- TWTAs still most efficient PAs.
- TWT & GaN based HPAs offer **power**, **size** and **efficiency** advantages **when linearized**.

Nano MPM

PA Linearization

Linearizers in HPA's are used for Uplinks as well as Downlinks.

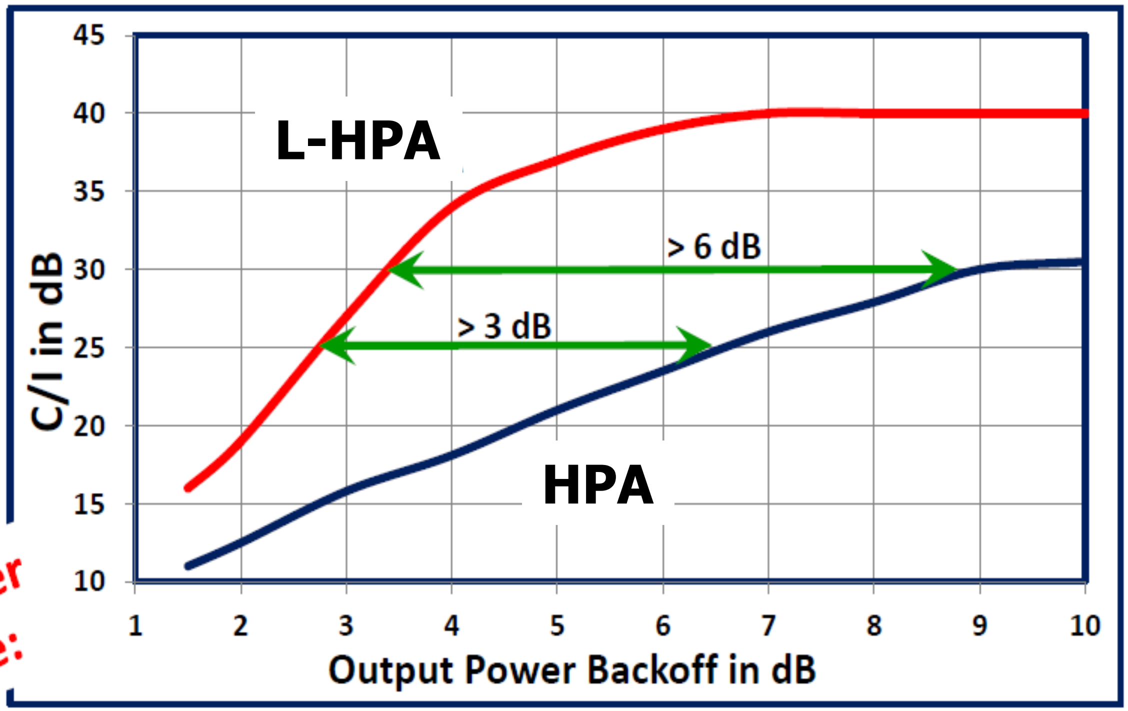


Bent Pipe

	Downlink/Uplink
C band	3.5-4.5/5-6 GHz
Ku band	10-13/14-15 GHz
Ka band:	18-21/26-31 GHz
Q band:	38-40/43-45 GHz
V band:	76/48-50 GHz
	Cross 60 GHz
W band:	91-96/81-86 GHz

PA Linearization

Today, linearization is used on virtually all satellites to improve HPA efficiency as well as in ground systems to increase linearity and **save cost**.

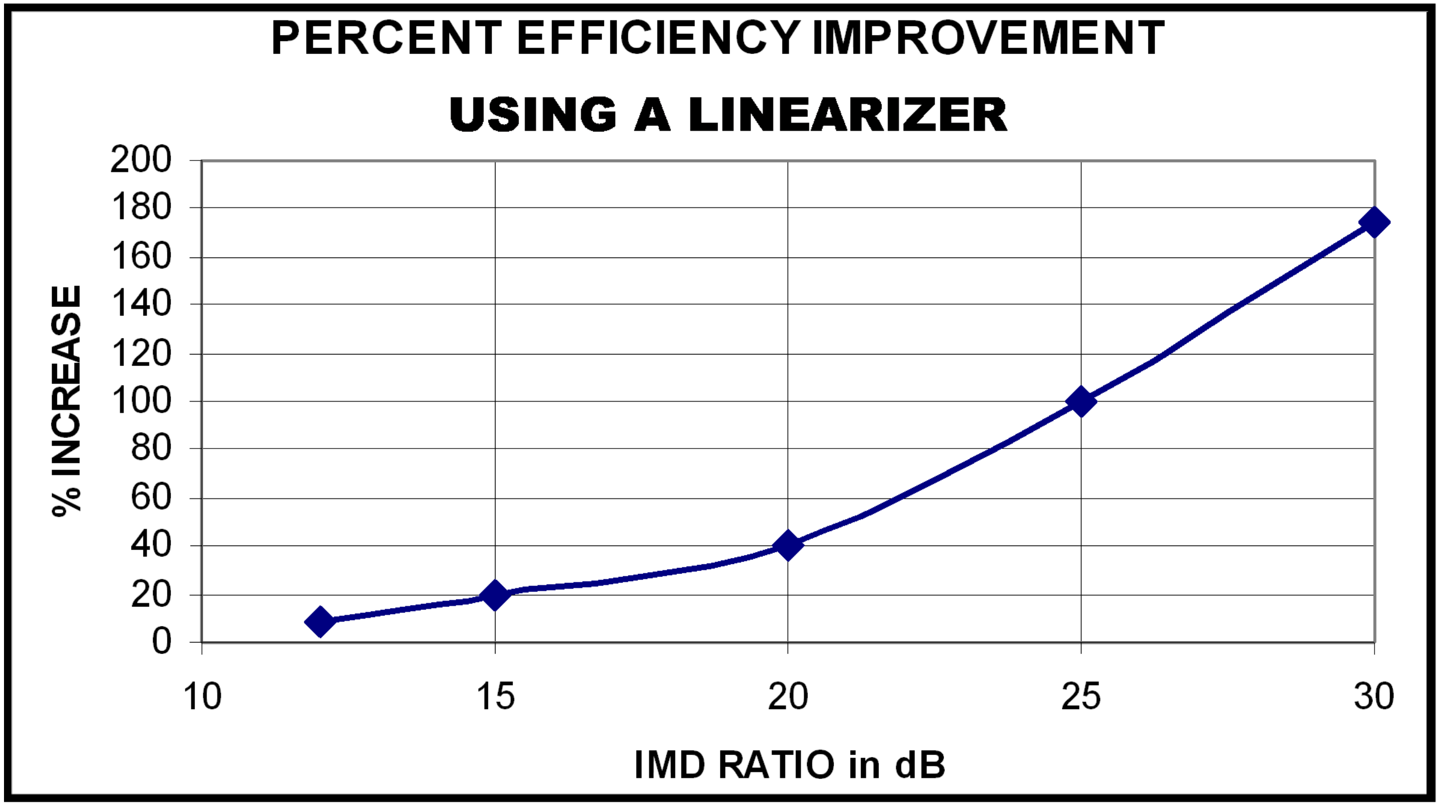


A predistorter can provide:

2X increase (3 dB) in output power for a 2-tone **C/I of 25 dB**

4X increase (6 dB) in output power for a 2-tone **C/I of 30 dB**

PA Linearization



Linearization can > **double** efficiency

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Digital vs. Analog

LINEARIZER TECHNOLOGY INC.

- Both analog and digital predistortion linearization (PDL) are used.
- Digital (DSP) based PDL may provide higher distortion correction than analog,

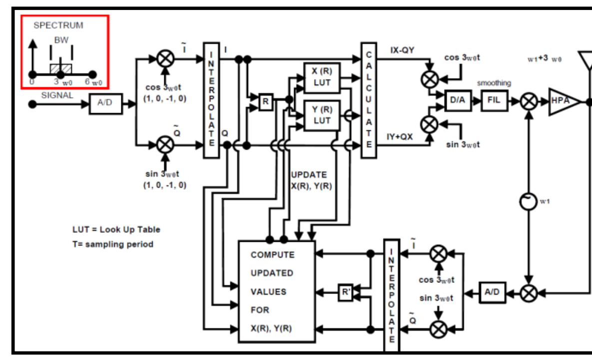
But – ONLY at OPBOs > than NEEDED by satellites

ONLY with greater complexity

All use adaptive approach.

Not easily adj. NL with freq.

– ONLY over a limited bandwidth



- Now demand for WB – often multi GHz BW

Digital vs. Analog

Decision primarily ECONOMIC $$$

- DIGITAL PDL
  - If have digital baseband signal & sufficient BW (3-7xCBW):

NO BRAINER! BUT can't easily combine multiple signals.

- ANALOG PDL – PROVEN TO 100 GHz.
  - As BW increase analog gains the advantage.

DIGITAL'S COST & POWER OVERHEAD INCREASE.

  - Need to consider both IN-BAND (EVM & BER) and OUT-OF-BAND (C/I & ACPR) distortion.

PERFORMANCE IS SIMILAR – DEPENDS ON *SPECS.*

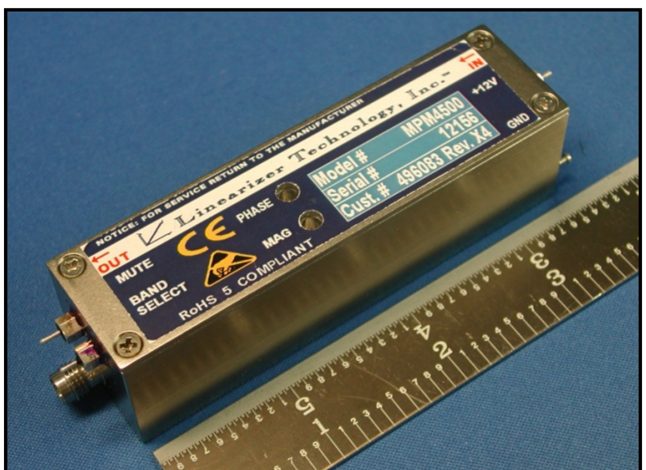
For very WB (MULTI GHz) analog is the only practical option.

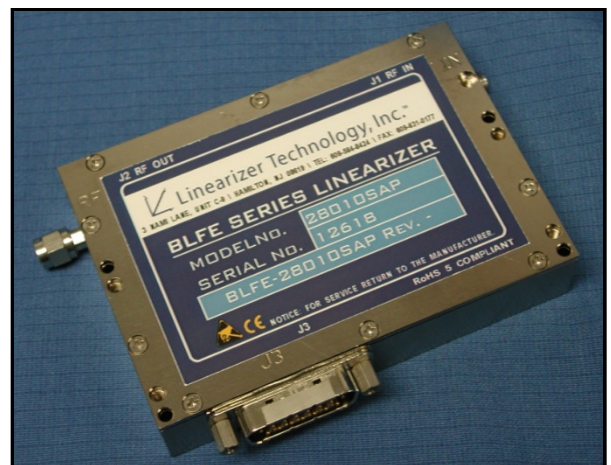
PA Linearization - Uplink

Analog PDL selected for Satcom ground sys.

- Offers multi-GHz Bandwidth > 4 GHz
- Offers Instantaneous Bandwidth
- Less Complex Circuitry

Ground System Linearizers





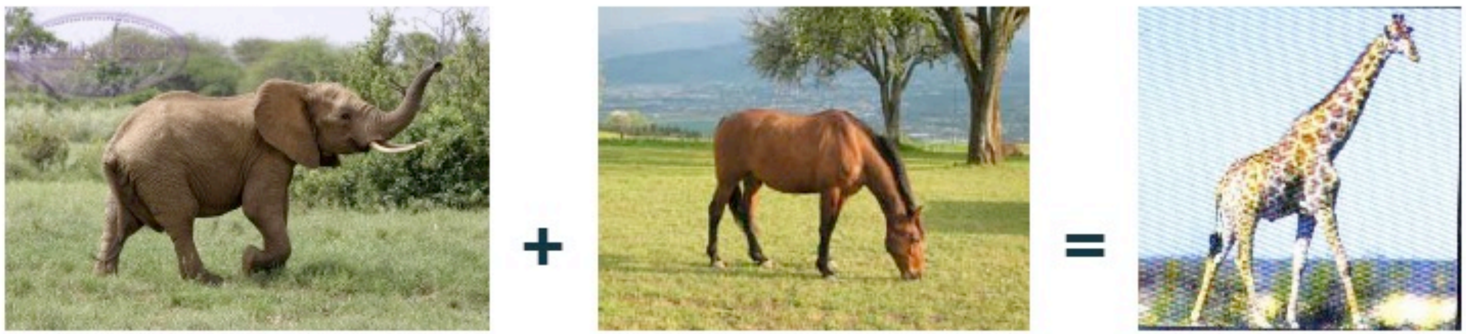
MW & MMW WB Predistortors

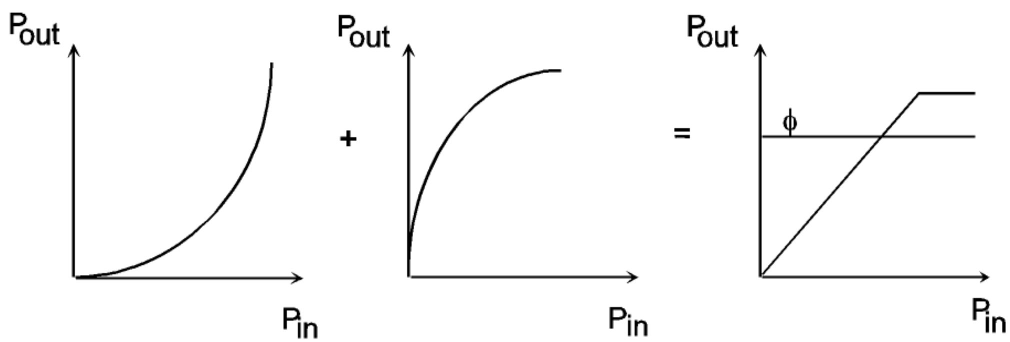
- *Challenge*: to develop Predistortors modules at needed frequencies that produce the required nonlinear characteristics over very wide bandwidths

- A PD must generate a transfer characteristic that is the complement of a PA's nonlinearity in MAGNITUDE and PHASE over the frequency band.

Predistortion linearization (PDL)

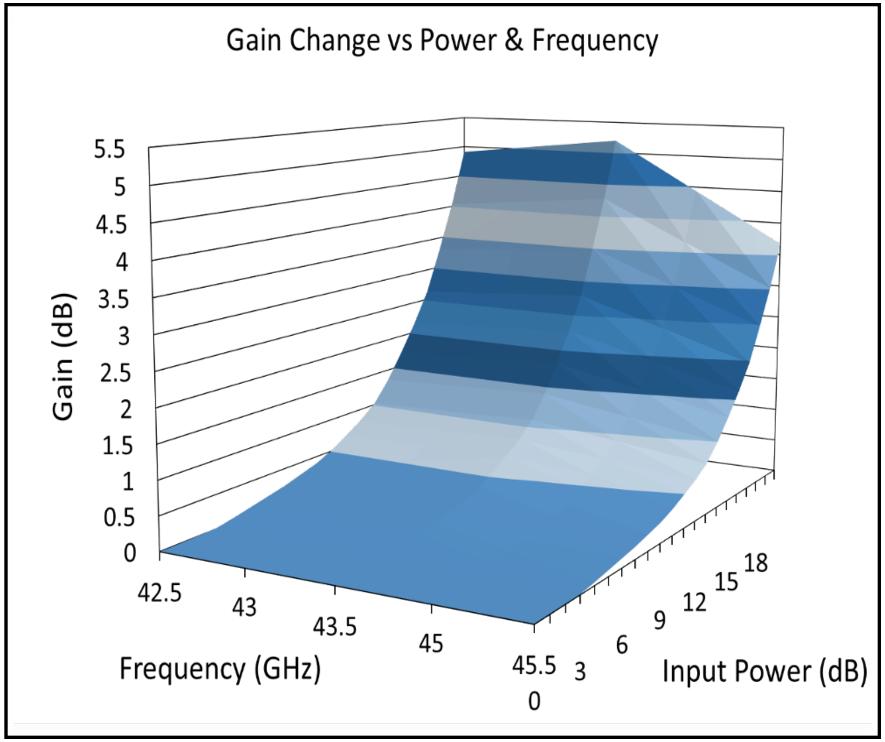
PDL is dominant form in use at MW MMW

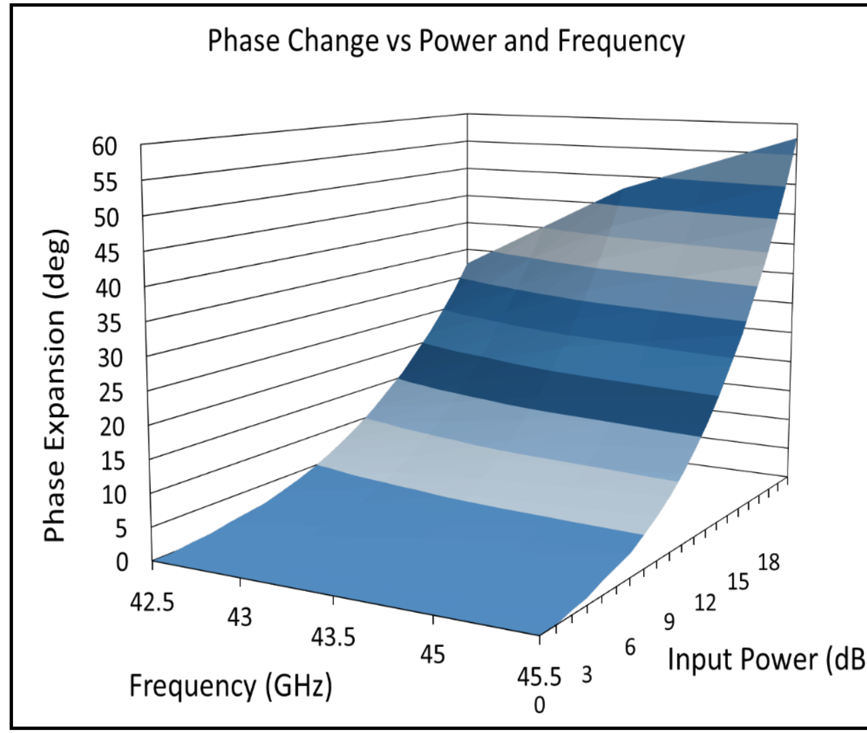




And the natural choice for linearization

MW & MMW WB Predistortors

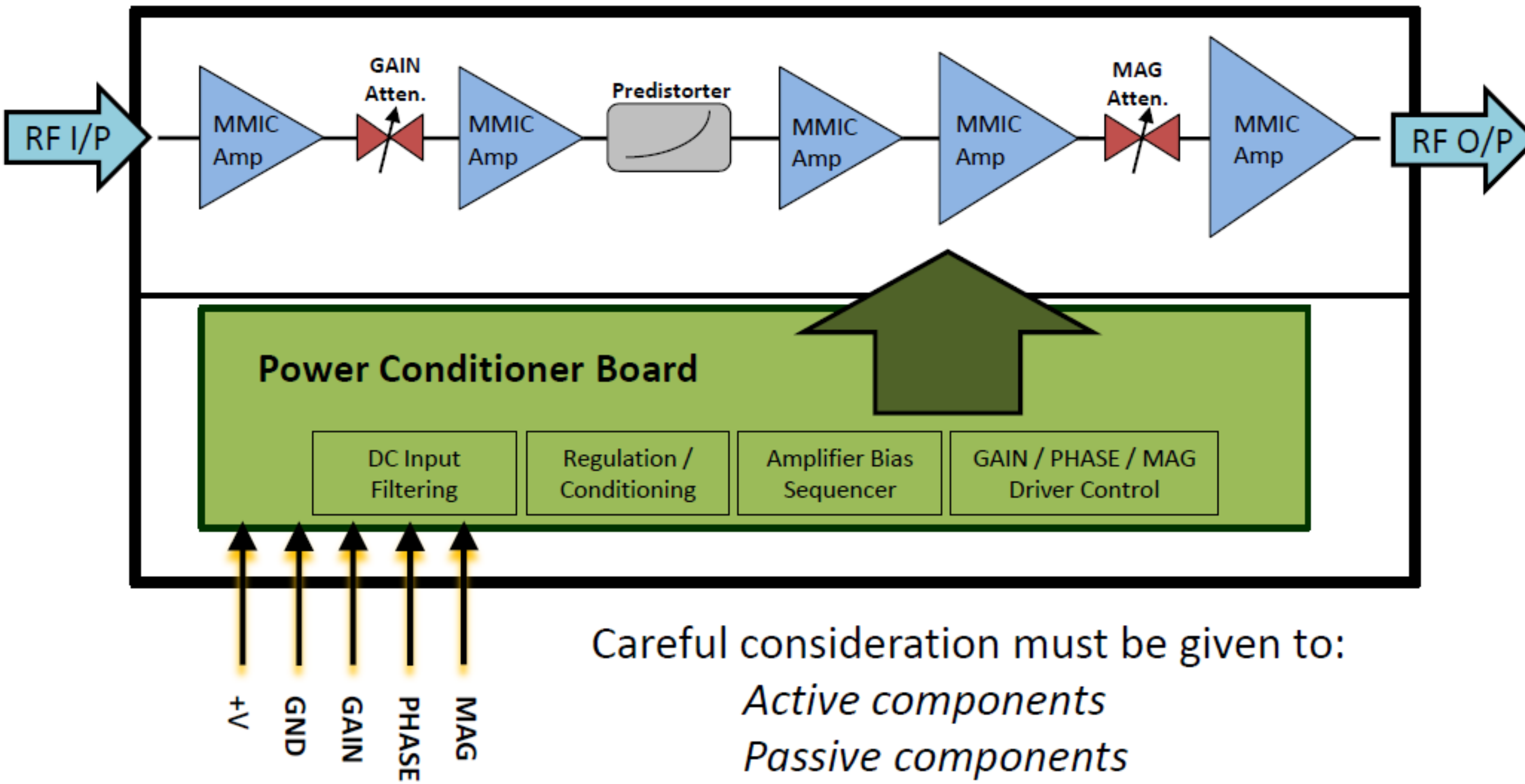




The linearizer must generate a surface for both gain and phase with frequency as the parameter

SATCOM Linearizer

Linearizers are "mini" systems providing many functions.

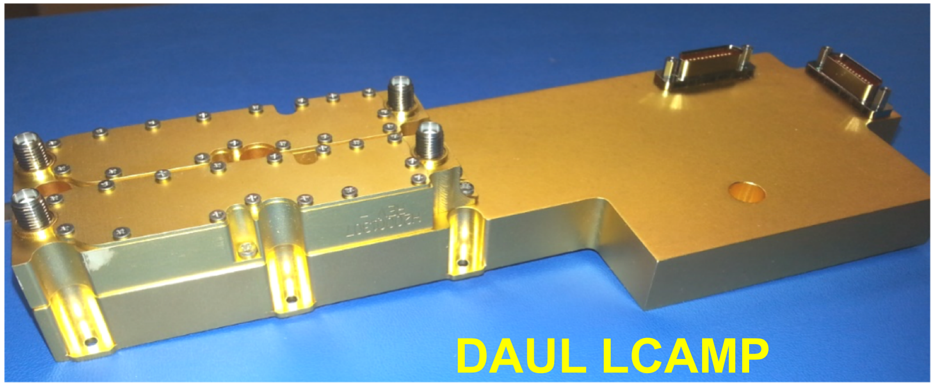


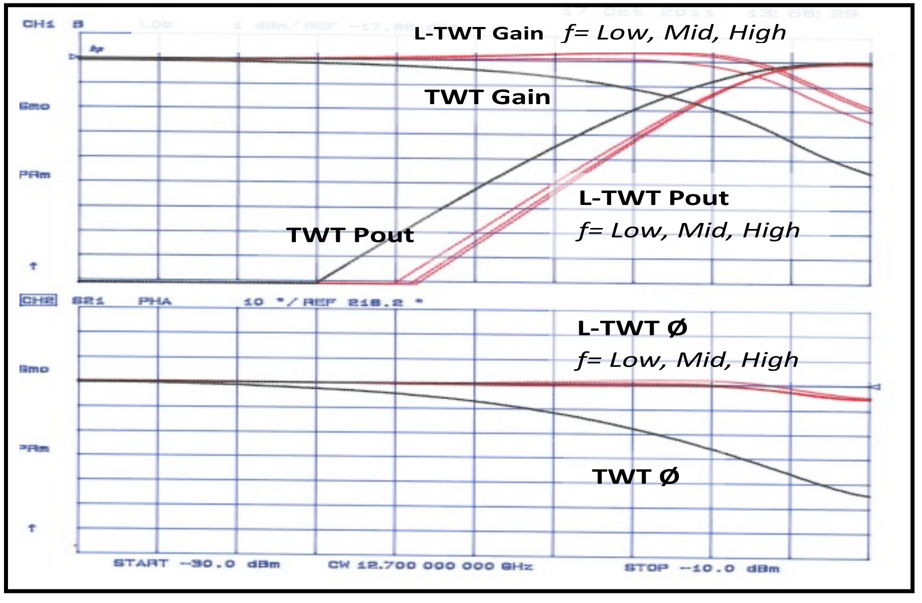
Careful consideration must be given to:

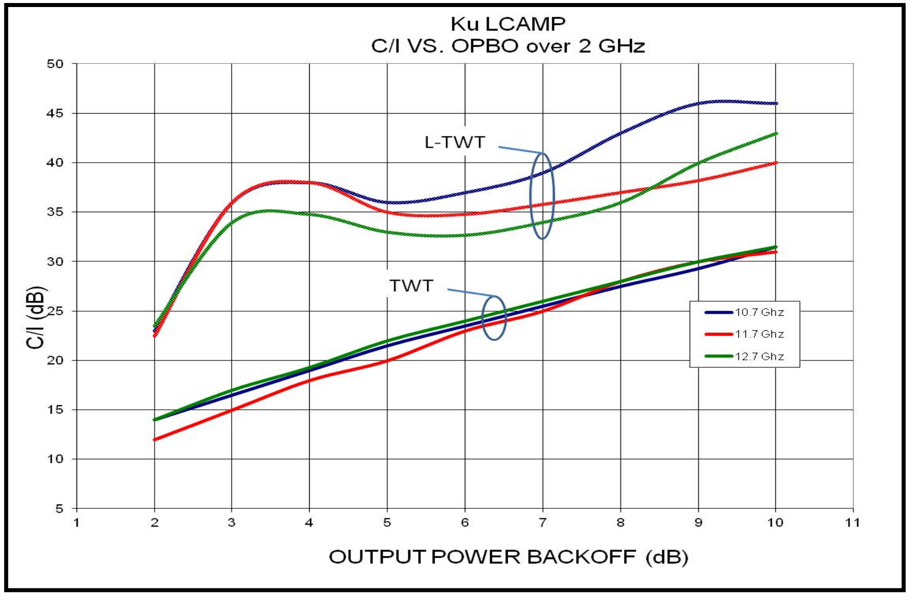
Active components
Passive components
Assembly techniques
Housing dimensions

Flexible WB LCAMP (flight)

- Ku WB 10.7 - 12.75 GHz
- Modes: FGM and ALC
- Ground Com. AM/PM adj.
- Universal Com. Board

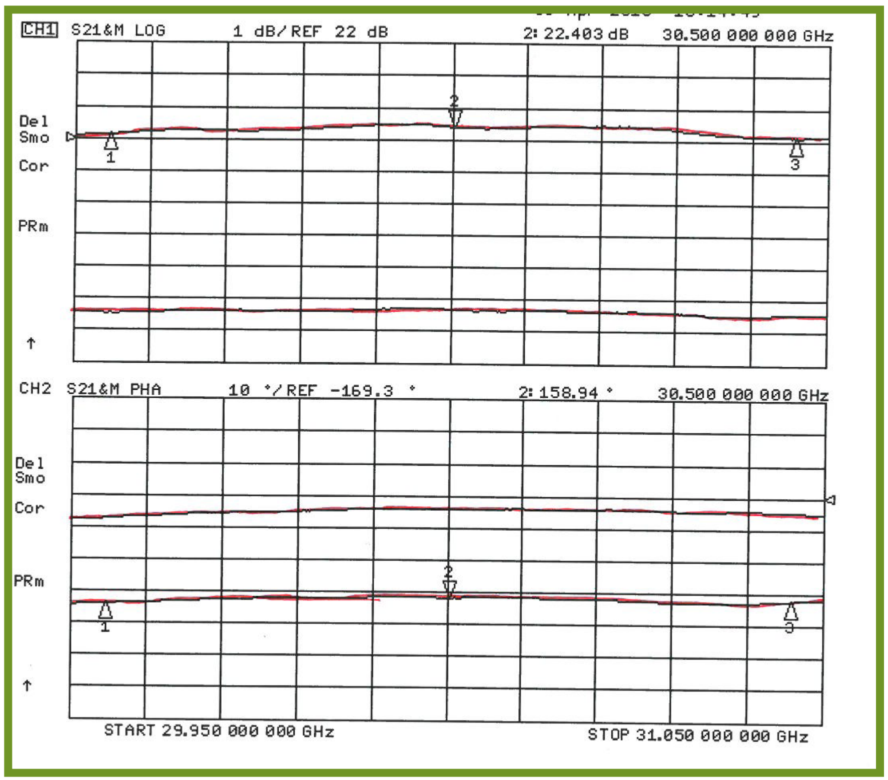


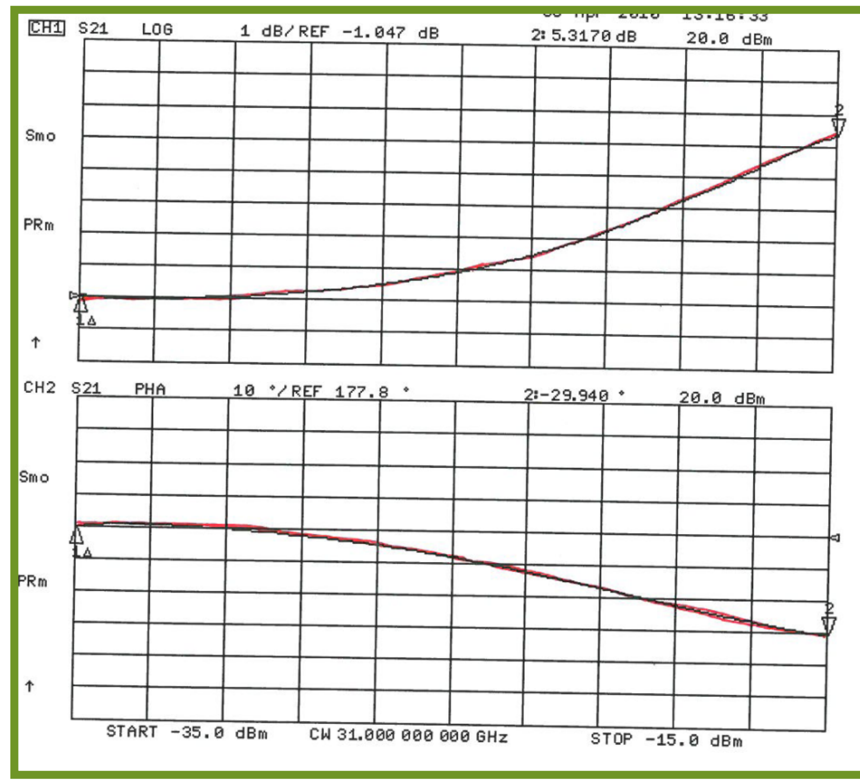




Flexible WB LCAMP (flight)

Ka SSPA Linearizer Module





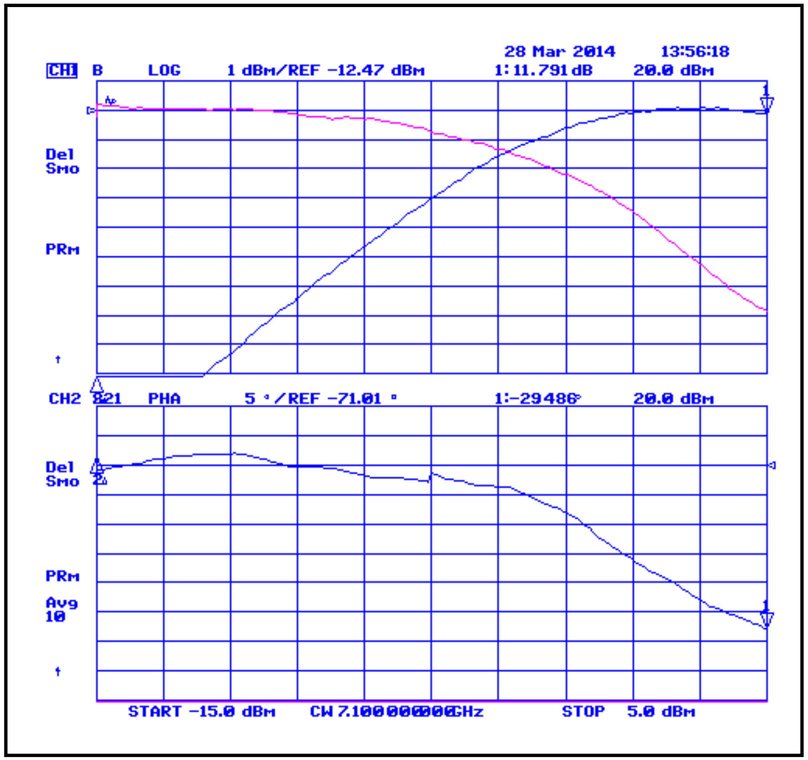
Frequency / Power vs. Gain / Phase

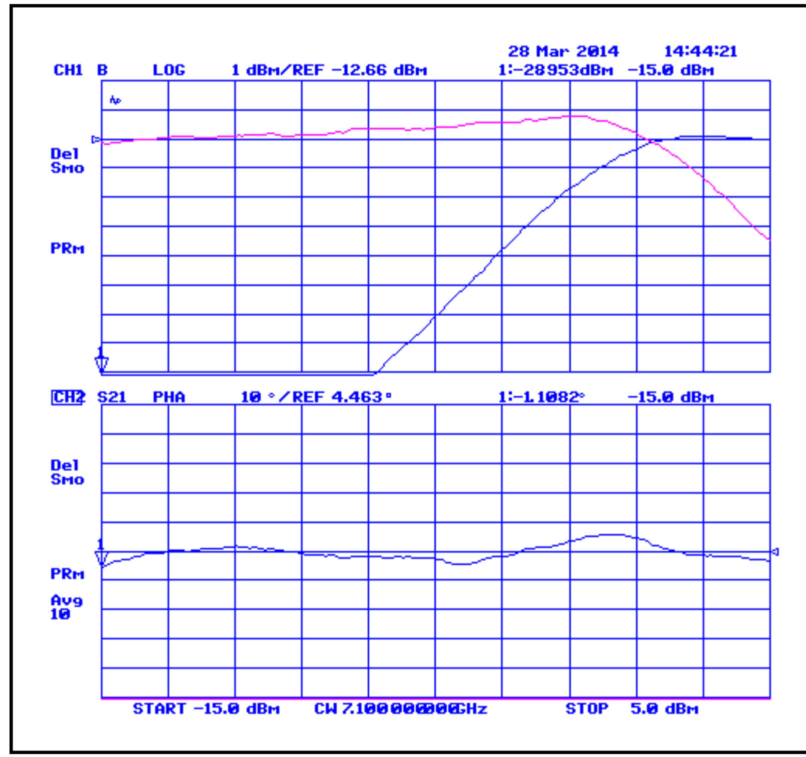
Q Band Performance with TWTA

Note: Test frequency up/down converted to Q-Band

TWTA

Linearized LTWTA

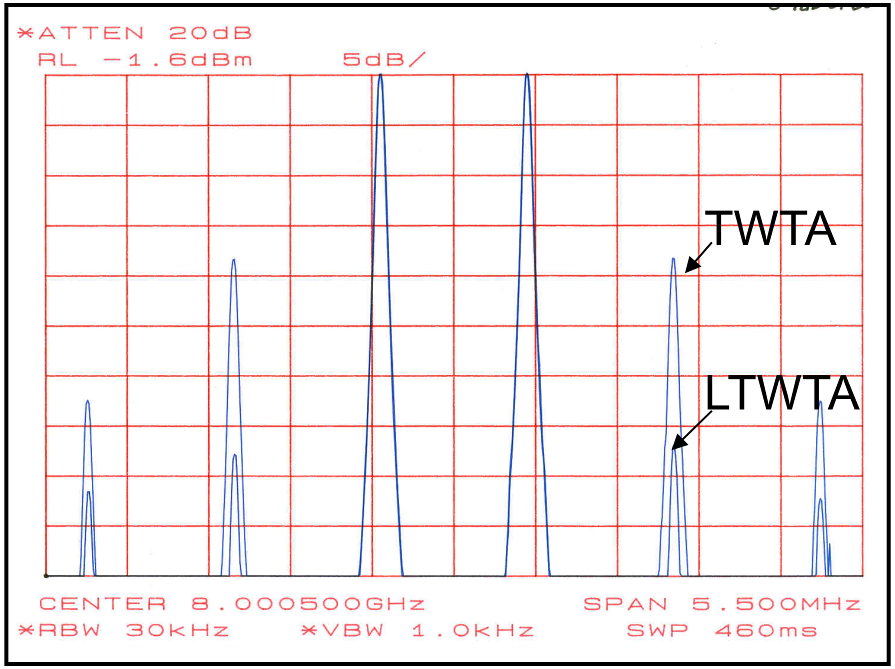


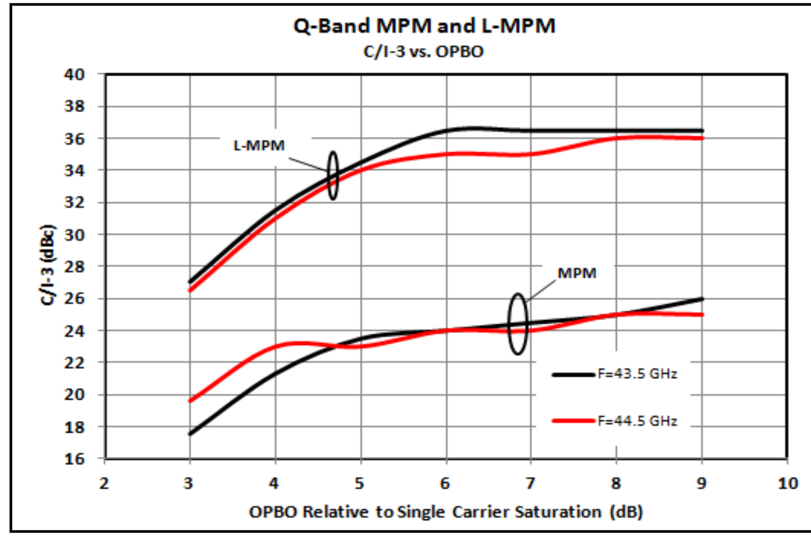


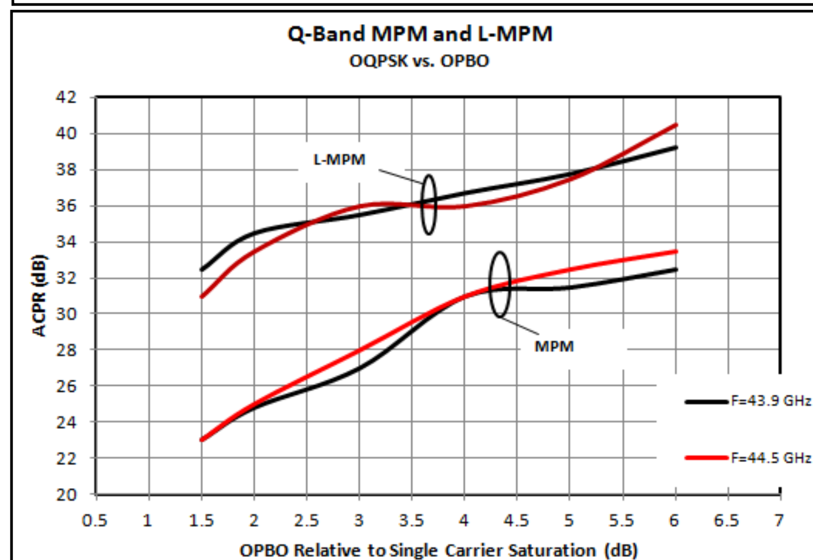
P1dB is 8dB from Sat
Δ PHASE = >25°

P1dB is at Saturation
Δ PHASE = <5°

Q Band Performance



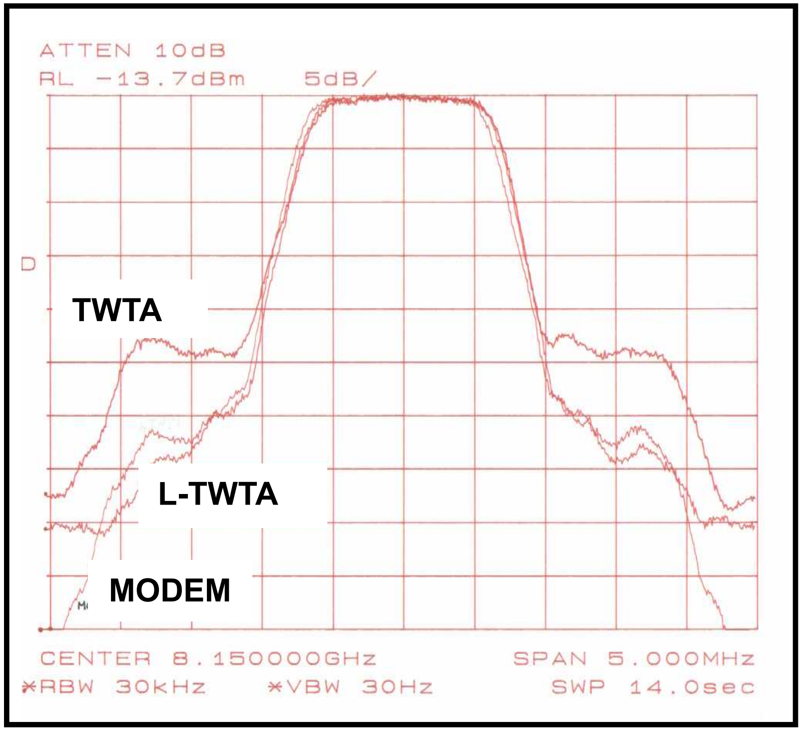




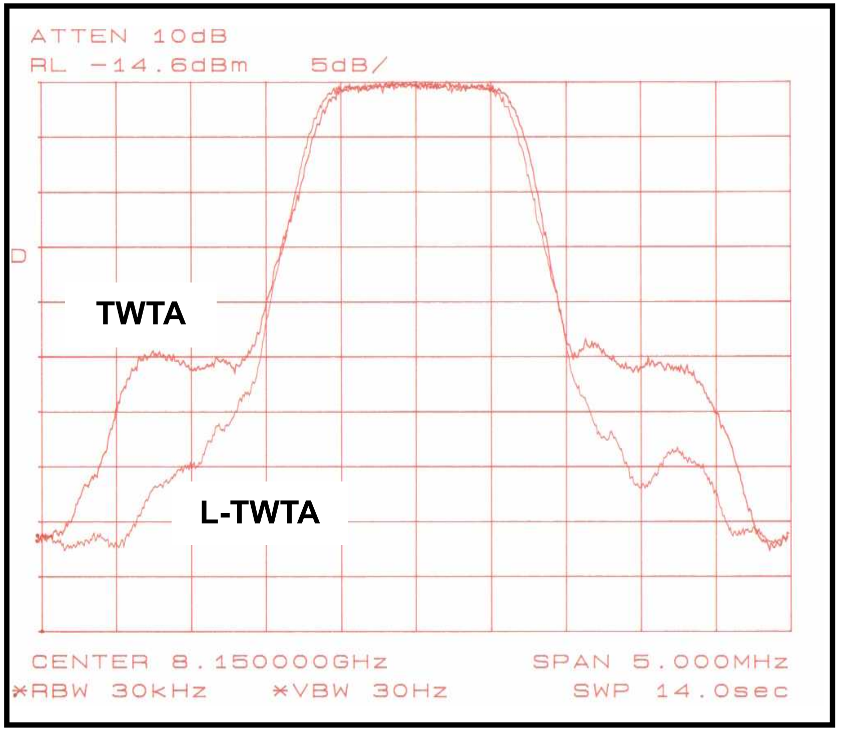
Improved Performance: C/I and OQPSK

Q Band Test Results

Spectral regrowth at 2 dB OPBO. The linearizer provides a 7 dB improvement.



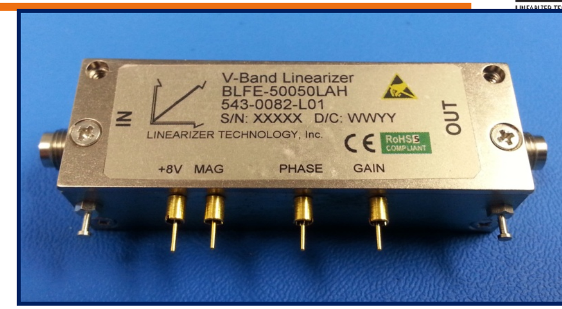
Spectral regrowth at 3 dB OPBO. The linearizer provides a 10 dB improvement.

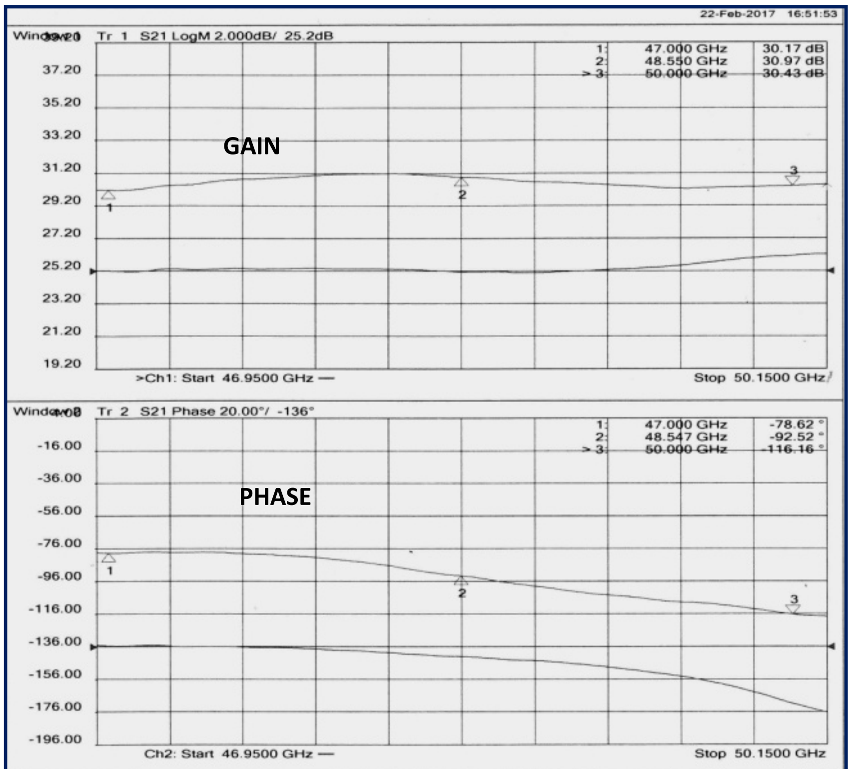


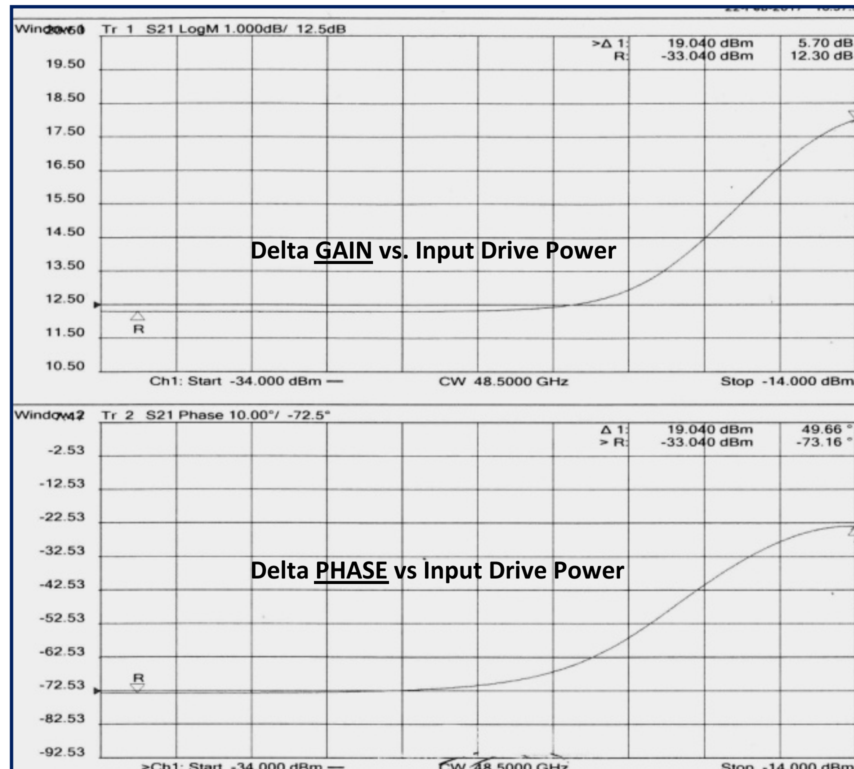
V Band SATCOM Linearizer

Integrate with HPA for LINEAR POWER

Operating Frequency 47 to 52 GHz



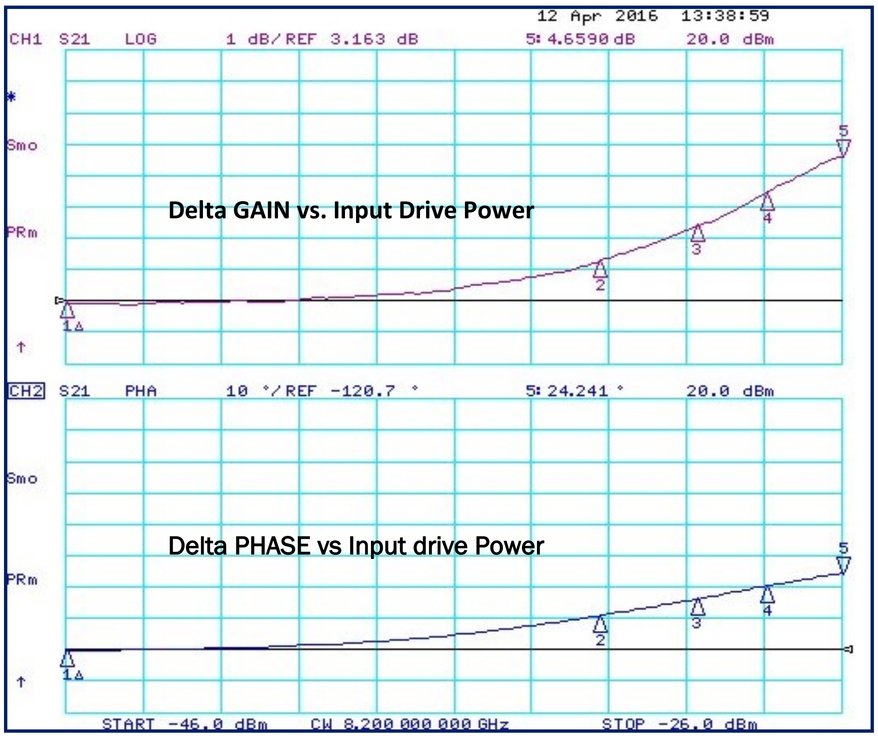


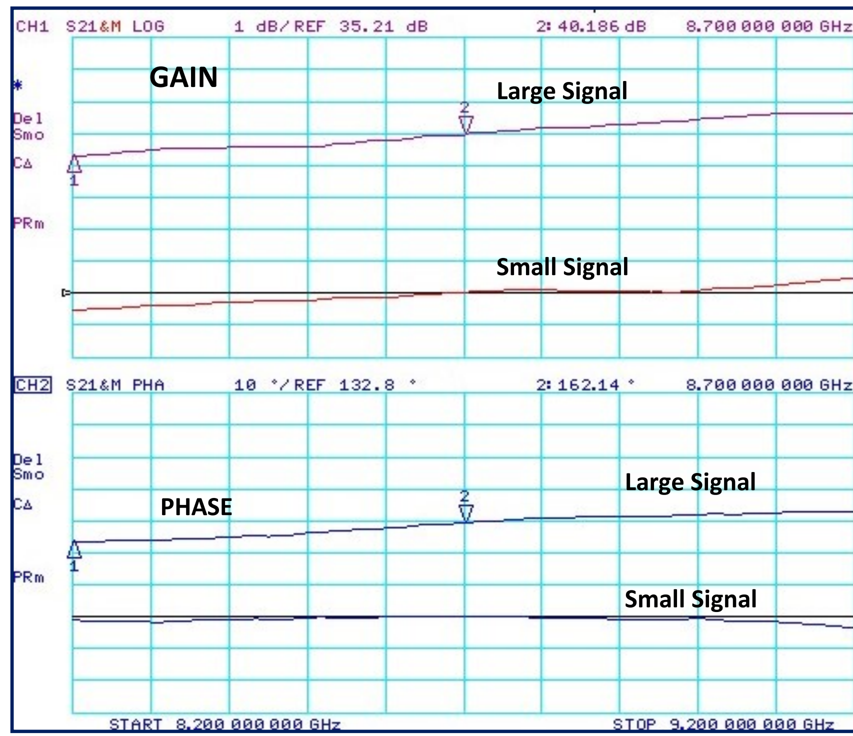


E/W Band SATCOM Linearizer

Operating Freq. 81-86 GHz
WR-10 Input and Output Connecters

Power: **+10V, 5 Watts**
Size: **2.6" x 1.6" x 1.6"**

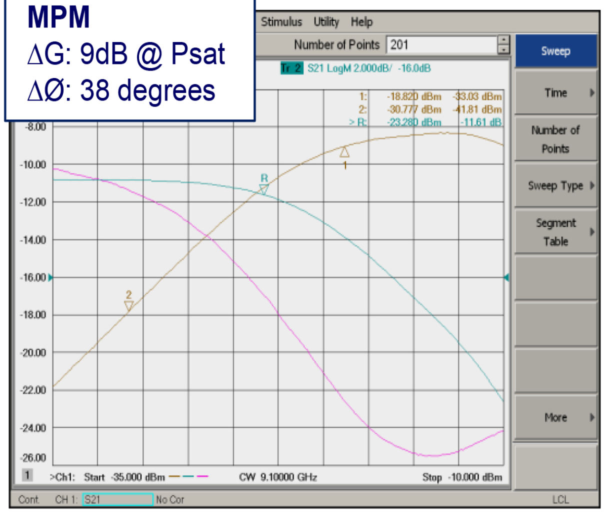




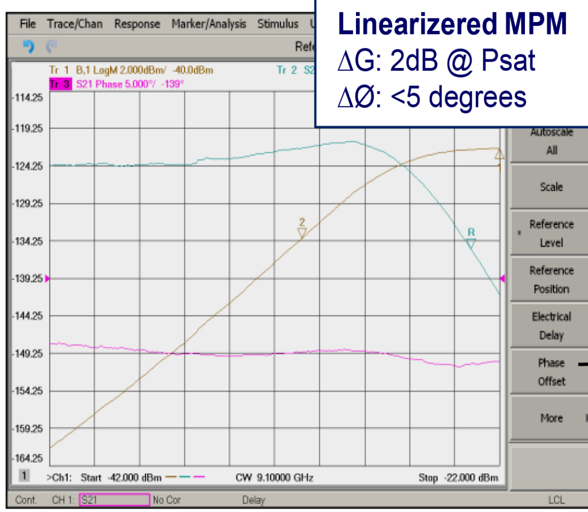
E-Band Linearizer & MPM/TWTA

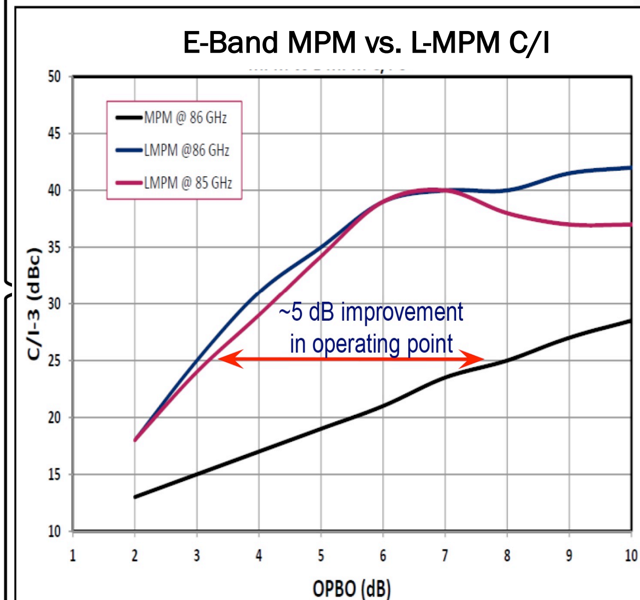
Linearized MPM - 100 Watts Linear

MPM
ΔG: 9dB @ Psat
ΔØ: 38 degrees



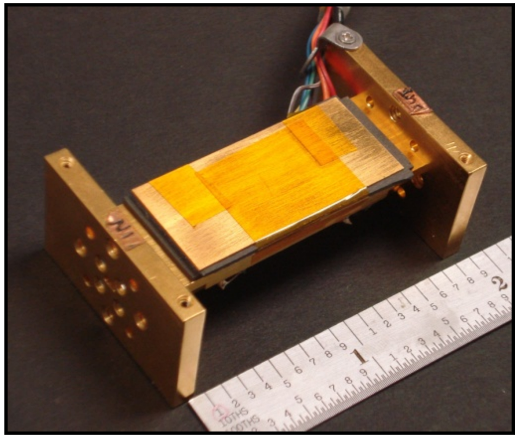
Linearized MPM
ΔG: 2dB @ Psat
ΔØ: <5 degrees





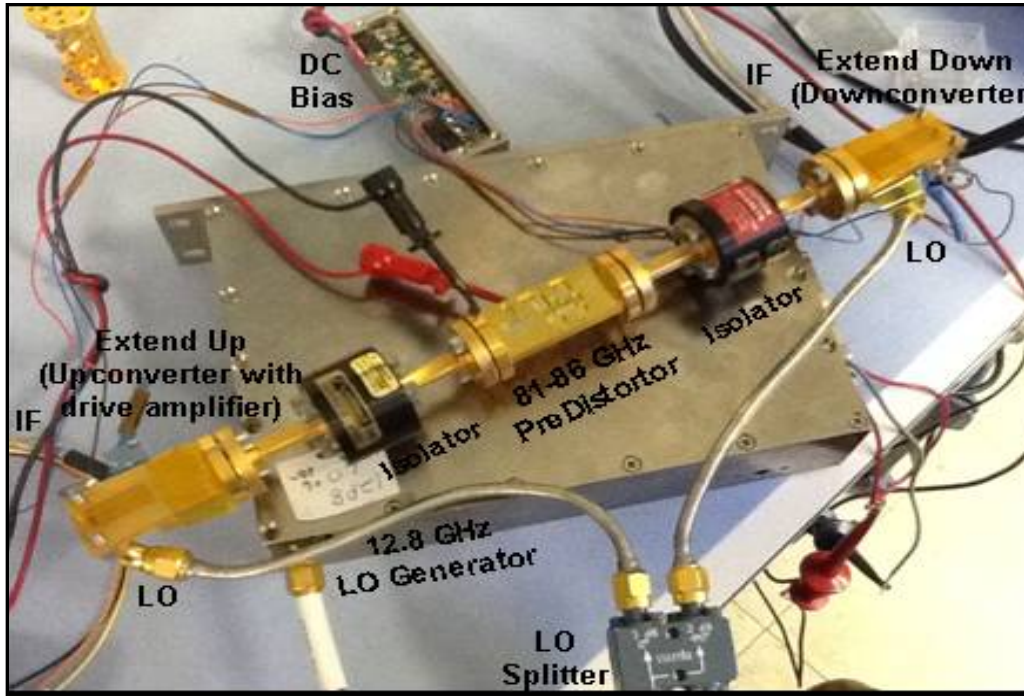
Power: **+10V, 5 Watts**
Size: **2.6” x 1.6” x 1.6”**

W Band Development/Test Results



W-Band Linearizer

- 91-96 GHz
- 40 dB Gain
- O/P Attenuator
- WR-10 Interface



Test set requires up/down conversion to E and W band.

TWTA Linearization at 92 GHz

TWTA

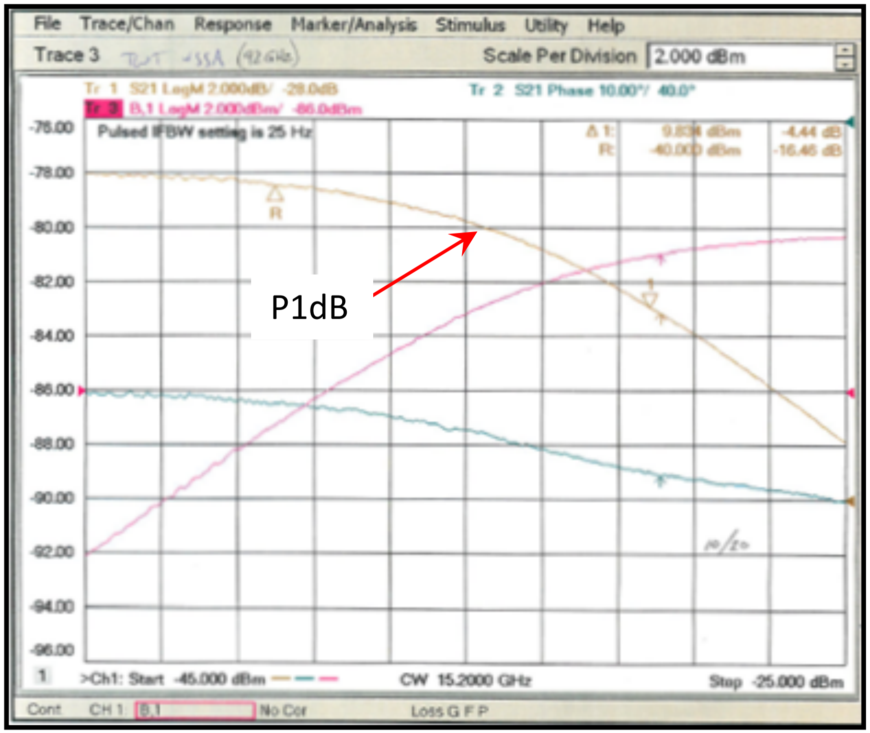
P1dB is >8 dB from Saturation

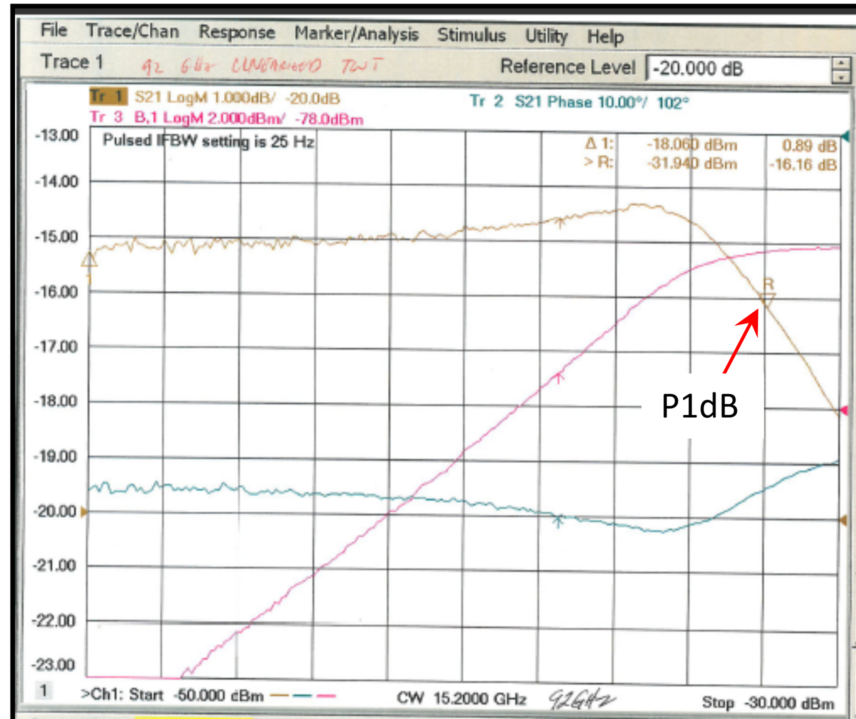
Δ PHASE = >20°

Linearized TWTA

P1dB is at Saturation

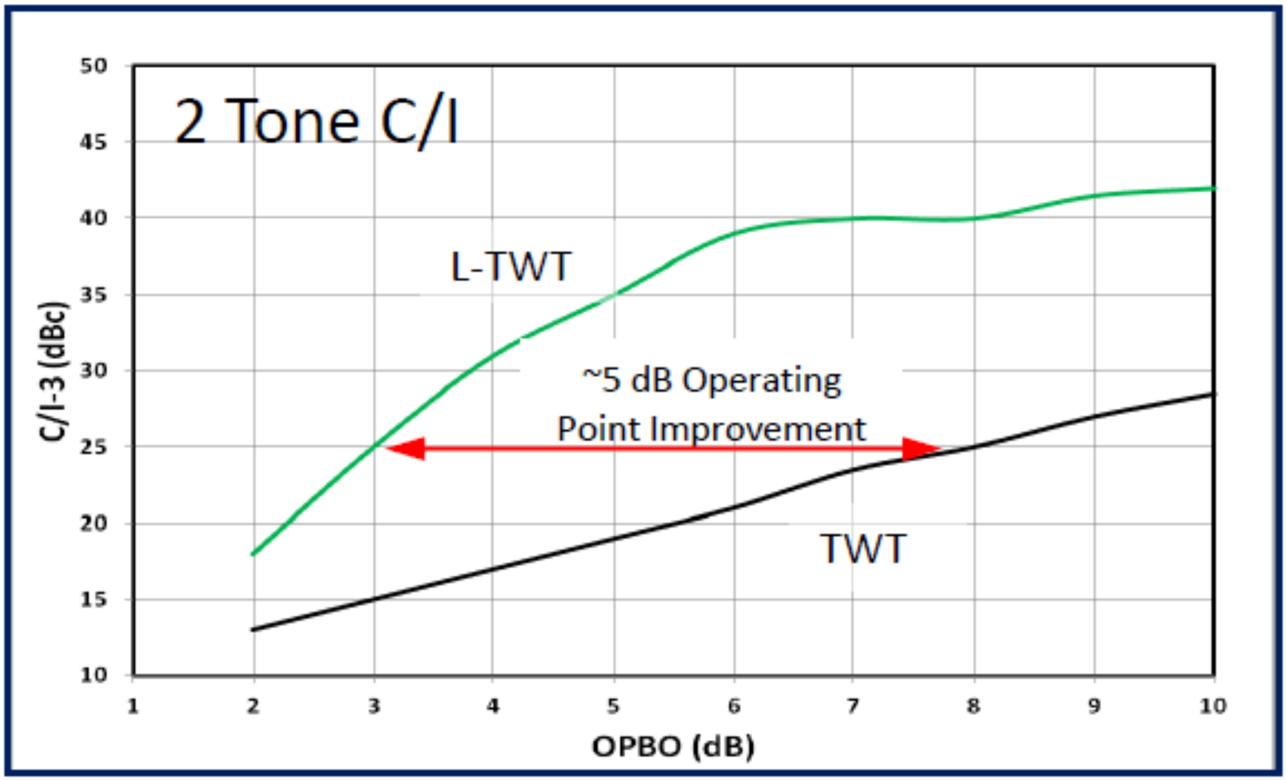
Δ PHASE = ~5°





TWTA Linearization at 92 GHz

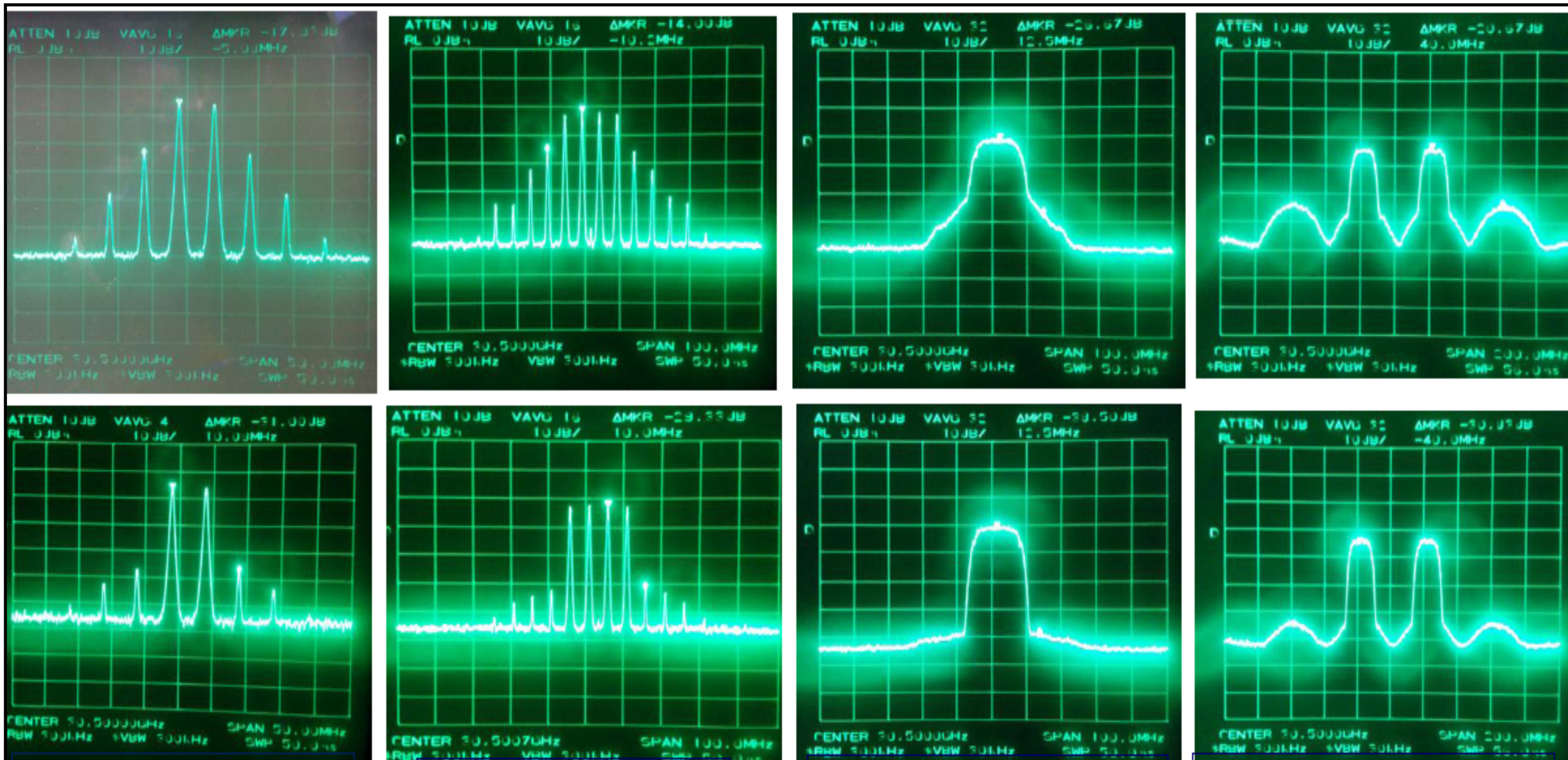
For a C/I of 25 dB, linearization provides about a 5 dB increase in power.



In development

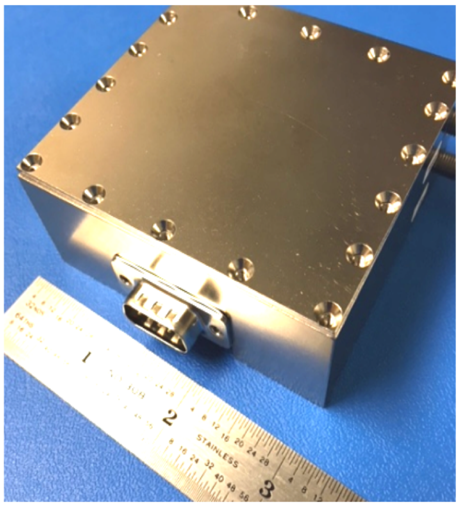
Adaptive Analog Predistortion Linearization (AAPDL)

Ka-band AAPDL: Improved WB Performance



13.2 dB improvement | 15 dB improvement | 11.8 dB improvement | 10.1 dB improvement

AAPDL Advantages



Ka-band AAPDL

- Real-time optimization for best linearity over entire operating band (Multi GHz).
- Improved WB performance – can compensate for ripple.
- Optimizes regardless of signal type/traffic (CW, QPSK, APSK, multi-carrier, or signal combination).
- The AAPDL provides constant signal gain at all levels & temperatures; even corrects for aging.

Conclusion

- Linearization provides great value for high data rate data transmission requiring WB:

  > 2.5 to 6 dB of additional linear power

  > 2 X more efficiency

- Analog PDL has been demonstrated to 100 GHz.
  (Believed to be the highest frequency reported to date).

- Fully functional MMW linearizers (Q, V, E/W) are ready for space qualification with SSPAs and TWTAs/MPMs.

- AAPDL in development for both ground and flight applications.

- PDL is prime for use in ground & flight SATCOM systems at E/W-band, where bandwidth efficiency and power consumption are of critical concern.