

Wide Bandgap Semiconductor Devices & Systems for Communications in Extreme Environment

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Abstract



The feasibility of Ka-band gallium nitride (GaN) based high power amplifier (HPA) for signal amplification in extreme planetary environment is investigated and its measured performance is presented. The data includes Pout, PAE, EVM for several waveforms and data rates, output spectrum, IMD, Noise Figure, and Gain. The data indicates excellent overall performance. Potential application of this HPA includes communication systems required to operate in the extreme hot environment of Mercury and Venus, extreme cold and high radiation environment of Jupiter's icy moons, and Artemis missions that involve human/robotic exploration and long-term presence on the Moon.



Outline



- Introduction
- Gallium Nitride (GaN) for High Power Amplifiers (HPAs)—Advantages
- HPA Architecture
- Measured Performance Characteristics
  - Output Power & Power Added Efficiency (PAE) vs. Input Drive Power
  - Error Vector Magnitude (EVM) for several types of Communication Waveforms & Data Rates
  - Output Spectrum for several waveforms
  - Third-Order Intermodulation Distortion Products
  - Noise Figure and Gain
- Conclusions & Discussions

Introduction

- NASA's mission requirements and operating environments are very diverse and different for each mission
  - This is true in the case of NASA's Discovery and New Frontier class science missions for instance to Venus (high temperatures), Jupiter's Icy Moons (cryogenic temperatures and high energy radiation), and Exploration missions for example Artemis to Moon and Mars (extreme temperature variations)
- Additionally, these missions require communication systems that — are small-in-size, have low mass, consume small amount of DC power, operate with high efficiency, and can perform reliably over extended periods
- RF/microwave circuits and components based on wide bandgap (WBG) semiconductor materials are suited for operation in the above environment



Introduction (continued)



- In this paper, we focus on the performance characteristics of Ka-band MMIC high power amplifiers (HPAs) based on WBG semiconductor such as gallium nitride (GaN) for communications in extreme environments

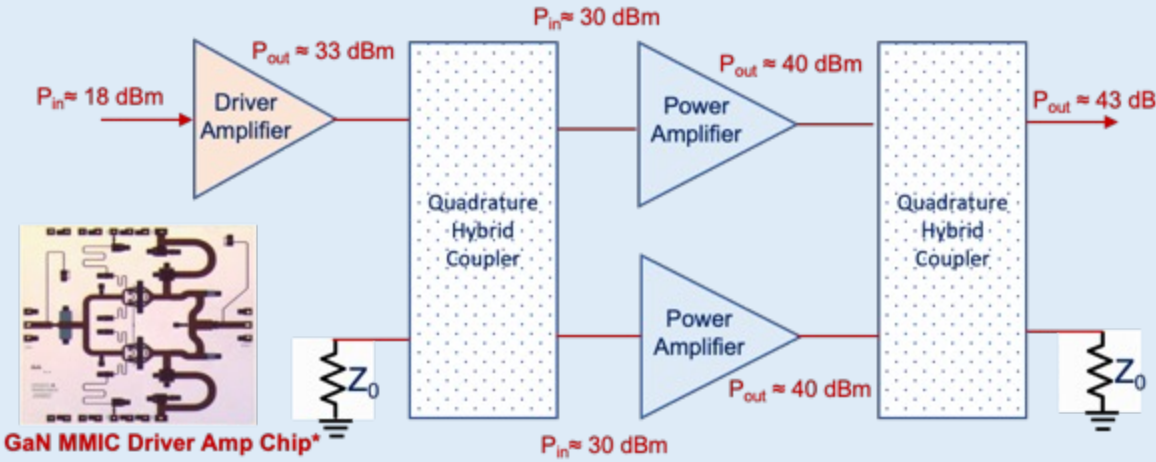


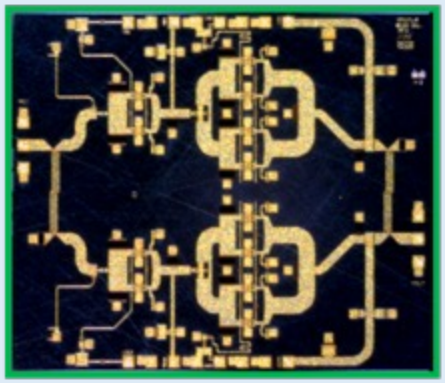
GaN for Microwave High Power Amplifiers—Advantages



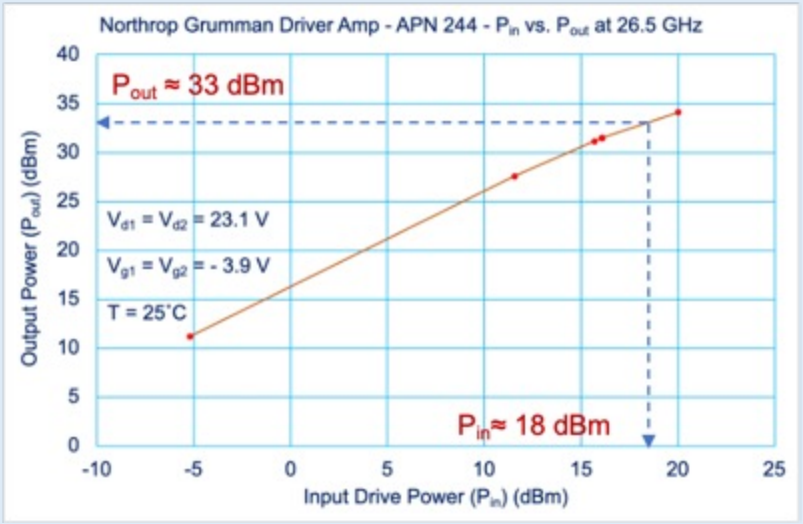
- Gallium nitride (GaN) has large bandgap, high electron saturation velocity, excellent thermal properties, and good chemical stability
- Consequently, high electron mobility transistors (HEMTs) fabricated on epitaxially grown GaN-on-SiC wafers can
  - Operate at high frequencies
  - Deliver high RF output power
  - Offer good linearity
  - Bestow high power added efficiency
  - Perform at elevated temperatures

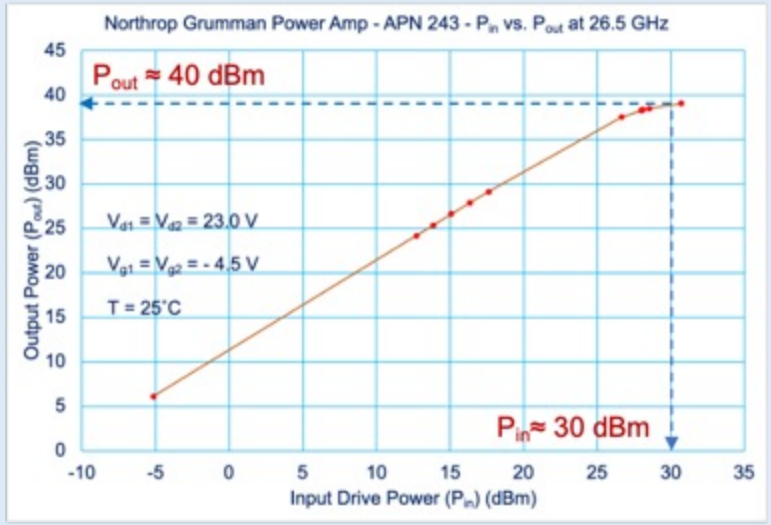
Ka-Band GaN HPA—Architecture



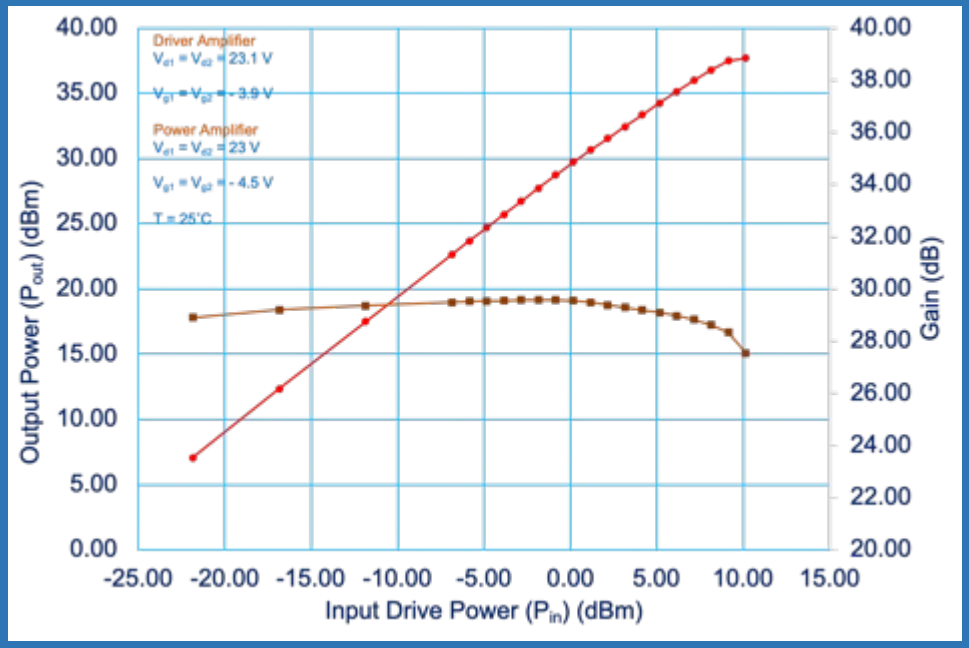


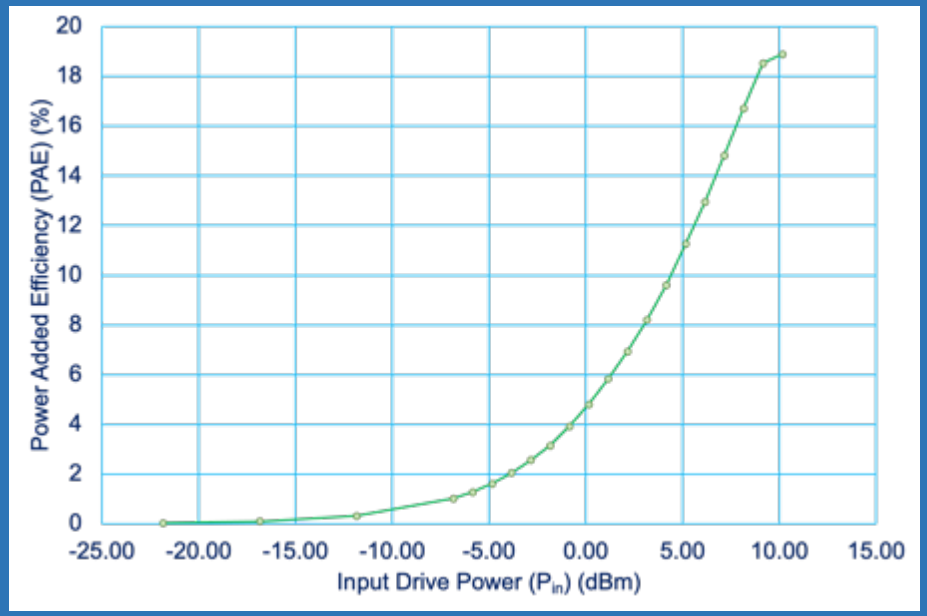
GaN MMIC Power Amp Chip*



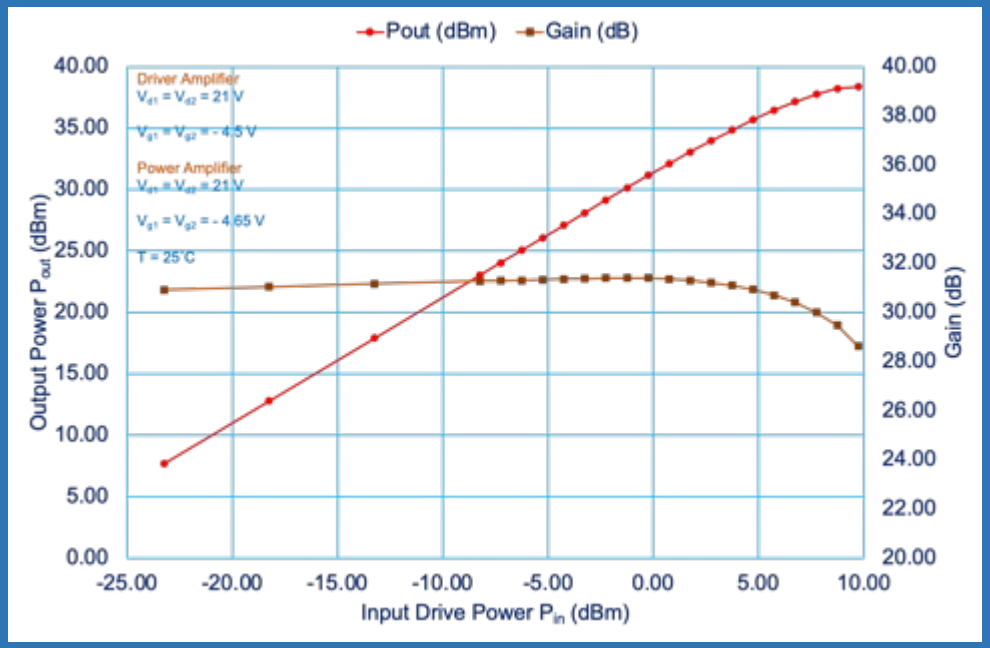


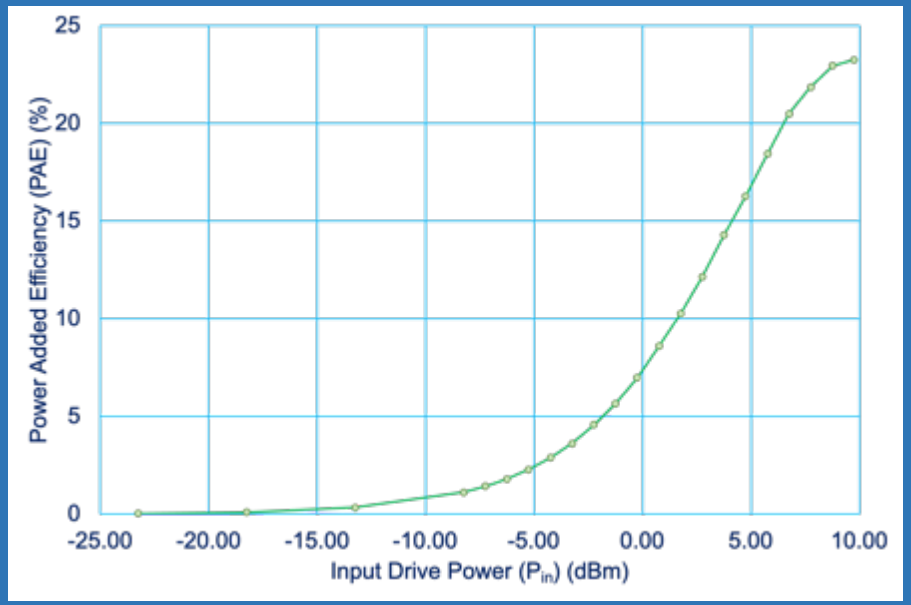
Measured Output Power (P_{out}) & Power Added Efficiency (PAE) vs. Input Drive Power (P_{in}) at 26.5 GHz



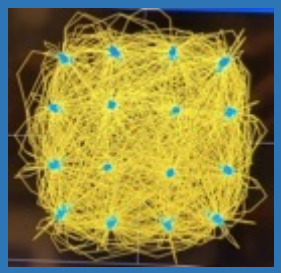
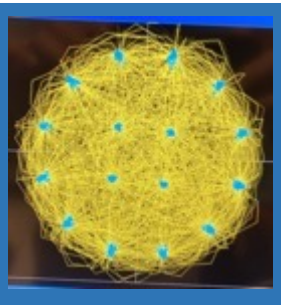
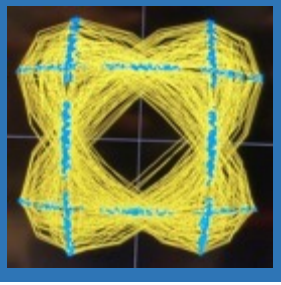
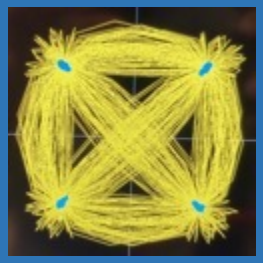
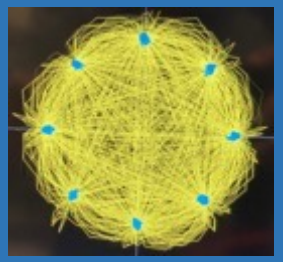


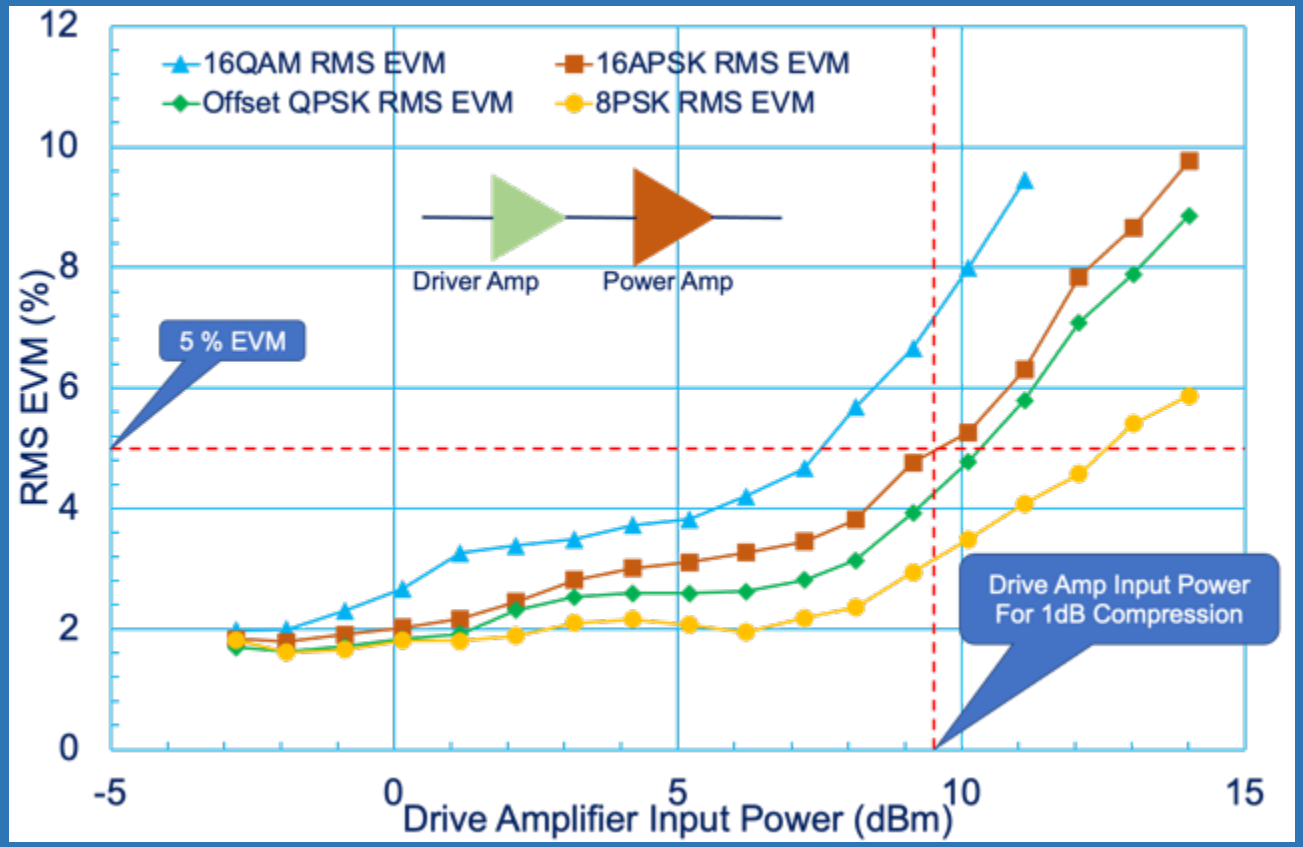
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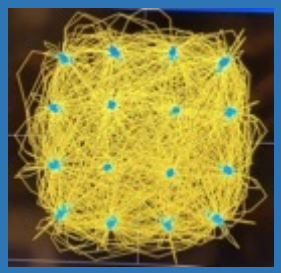
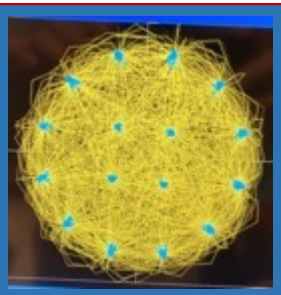
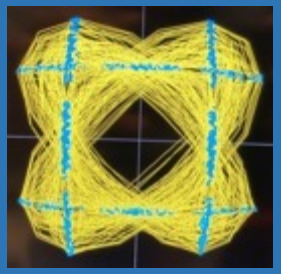
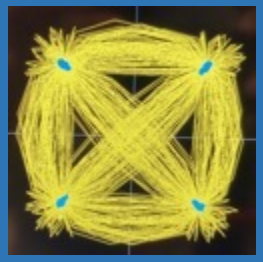
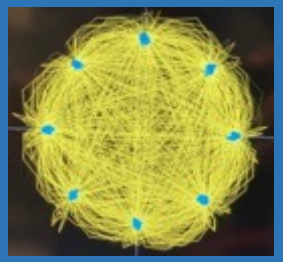


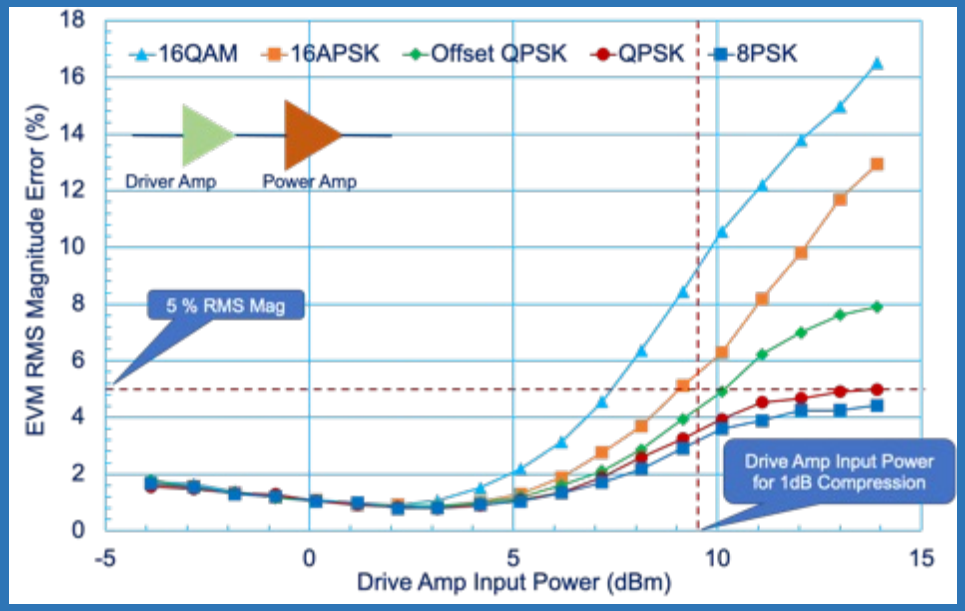
Measured EVM RMS Magnitude Error (%) Comparison — 180 Msym/s @26.5 GHz, SRRC 0.35

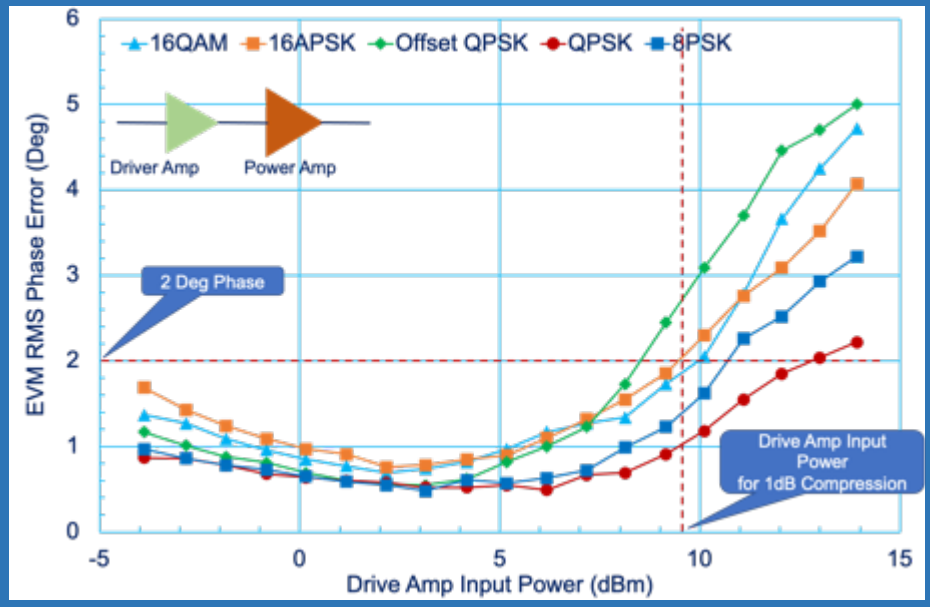








Measured EVM RMS Magnitude Error (%) Comparison — 180 Msym/s @29.6 GHz, SRRC 0.35

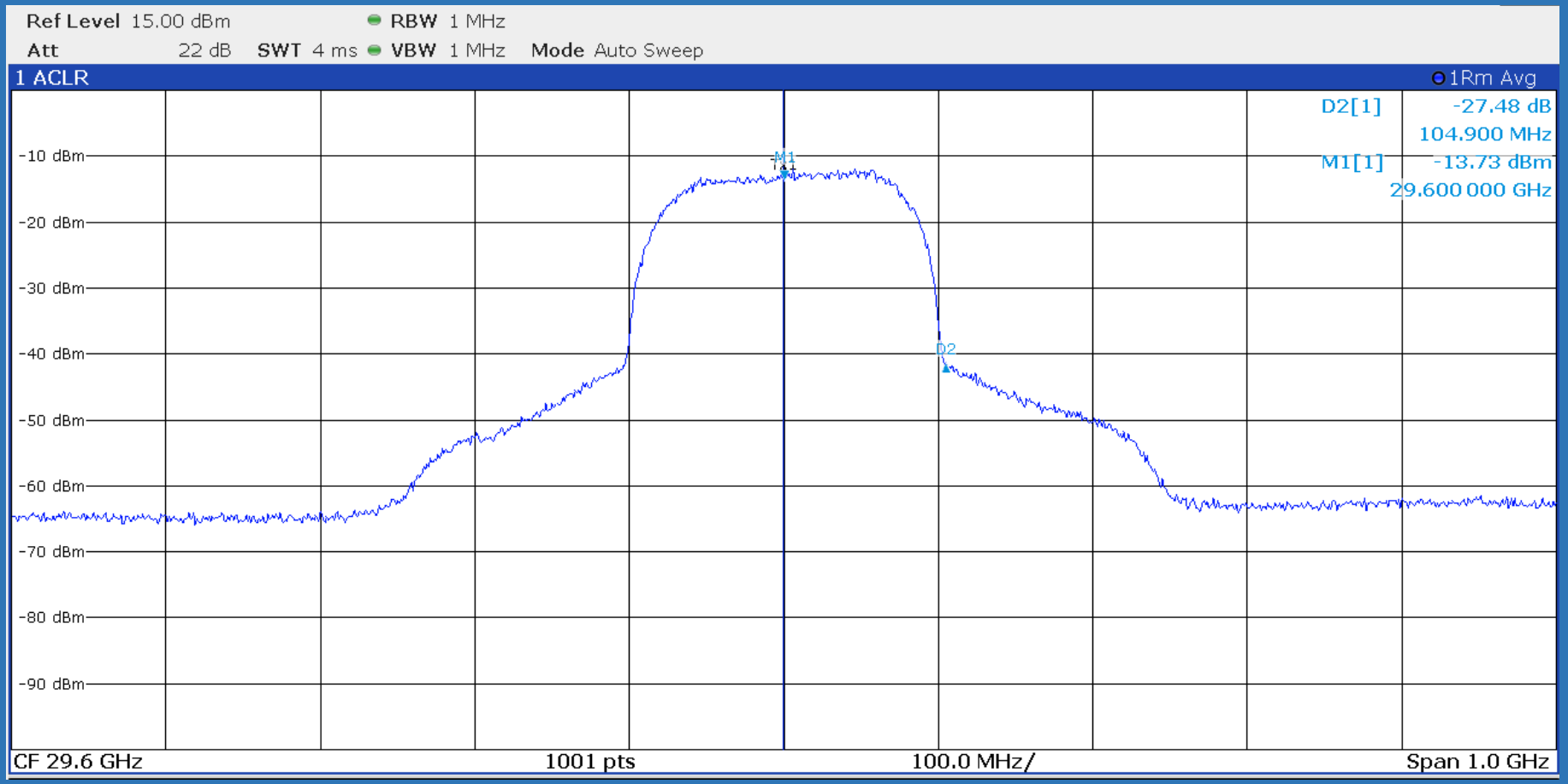










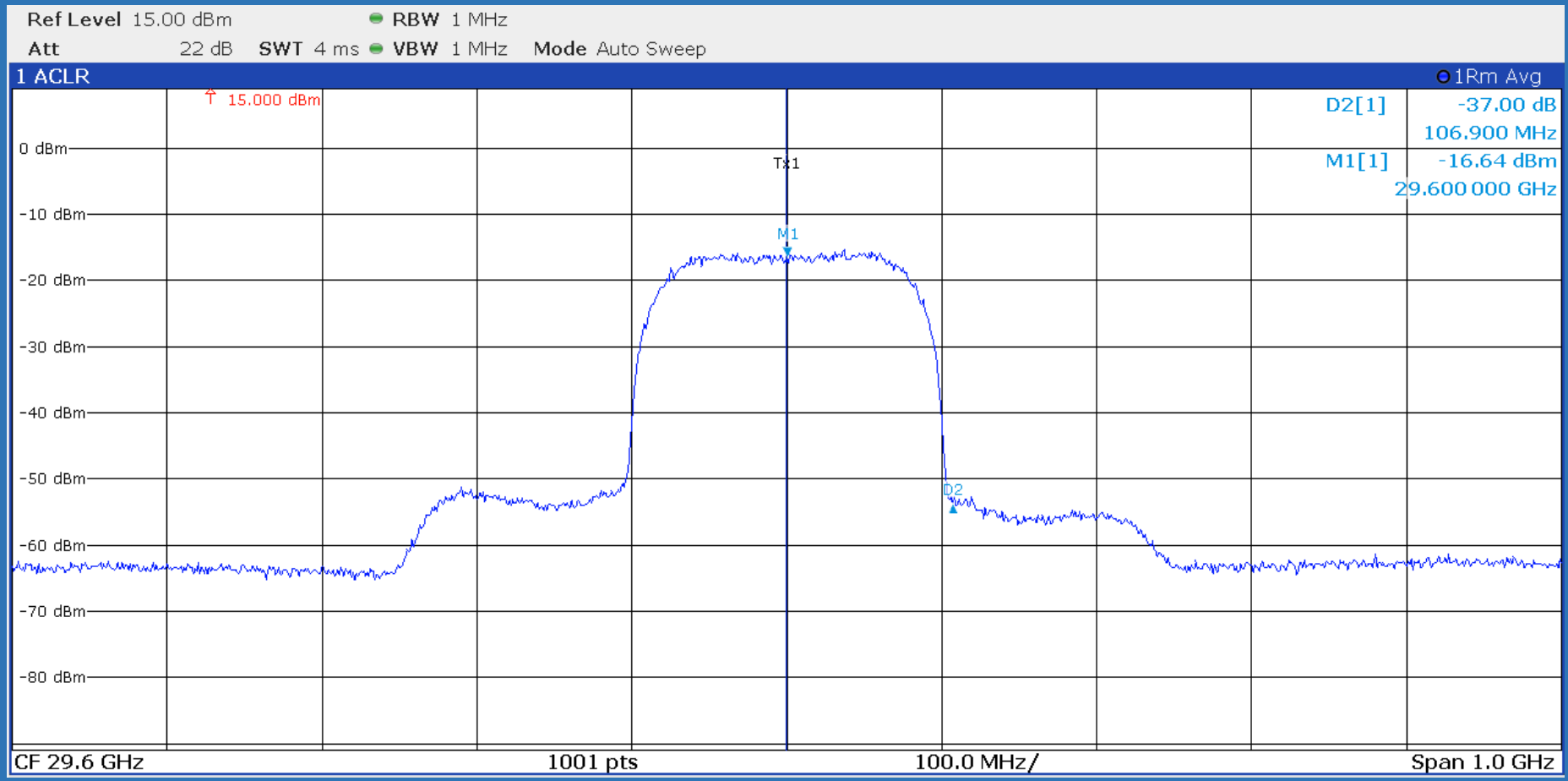
Measured OQPSK Spectrum @ 29.6 GHz —150 MSym/s—SRRC 0.35

Frequency 29.6 GHz
VSG RF Level -19.5 dBm (Corresponding to 1-dB Compression Point)
PEP -15.81 dBm, PAPR 3.69, RBW 1 MHz

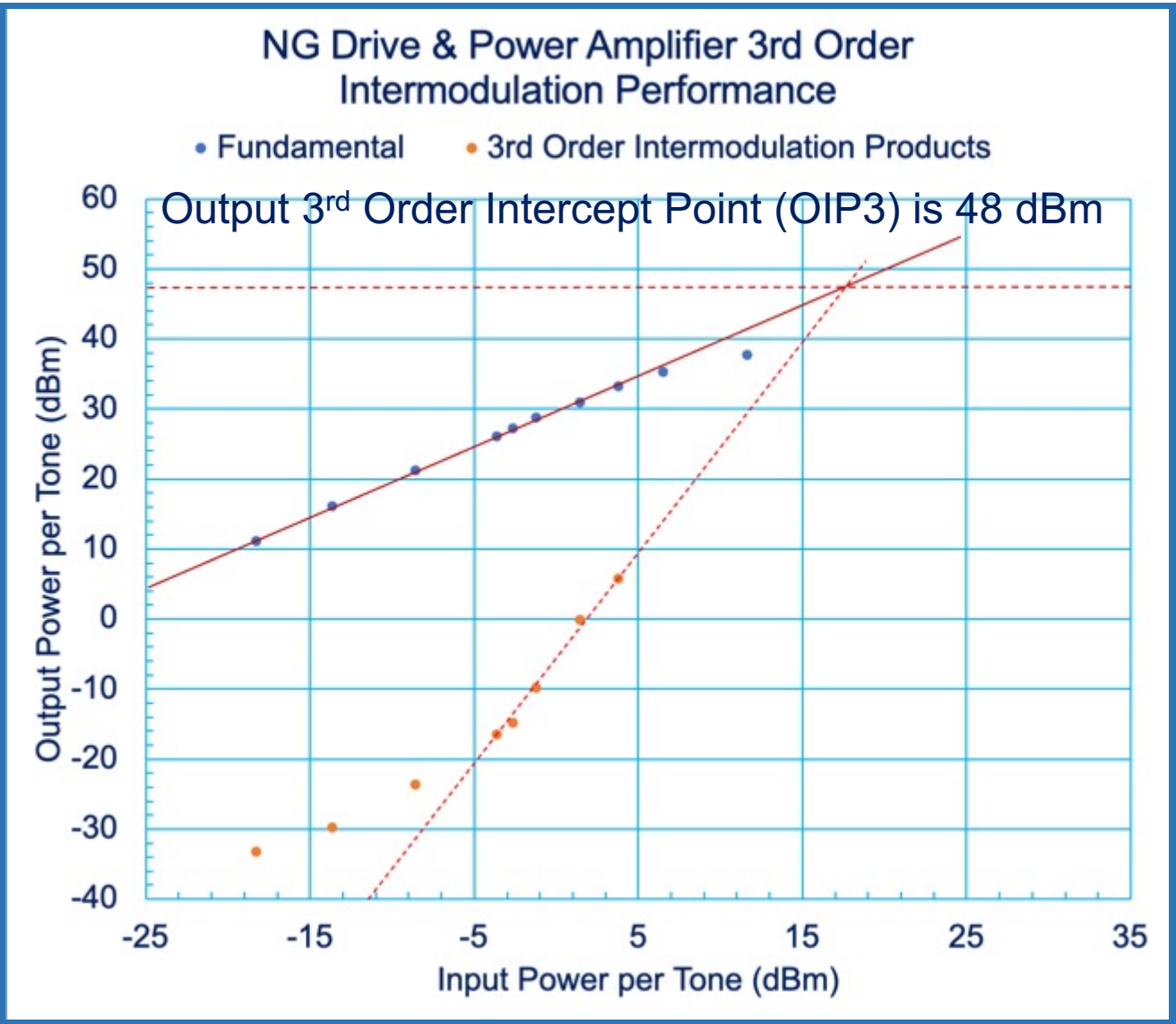


Measured 8PSK Spectrum @ 29.6 GHz —150 MSym/s—SRRC 0.35

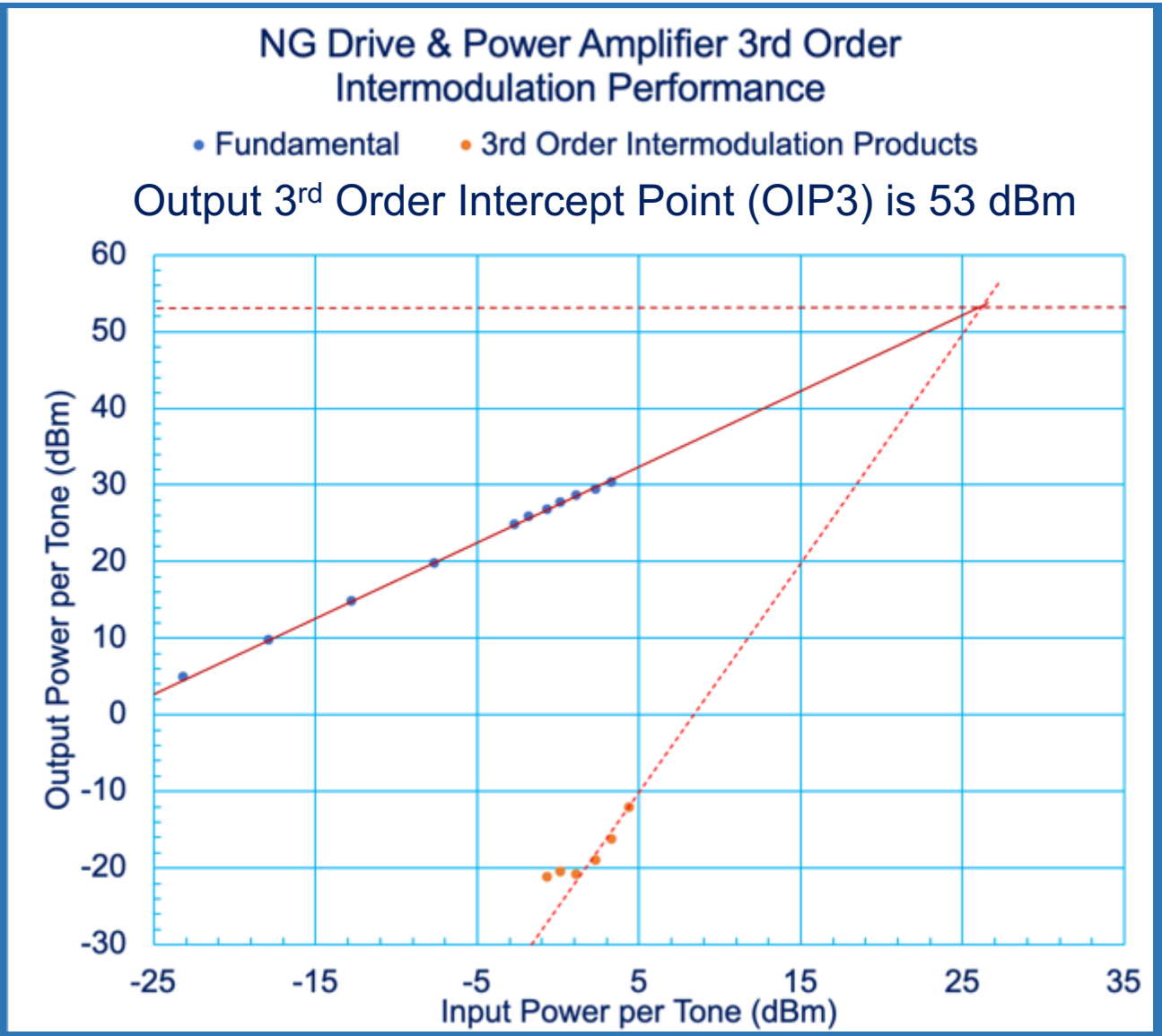
Frequency 29.6 GHz
VSG RF Level -19.5 dBm (Corresponding to 1-dB Compression Point)
PEP -15.51 dBm, PAPR 3.99, RBW 1 MHz



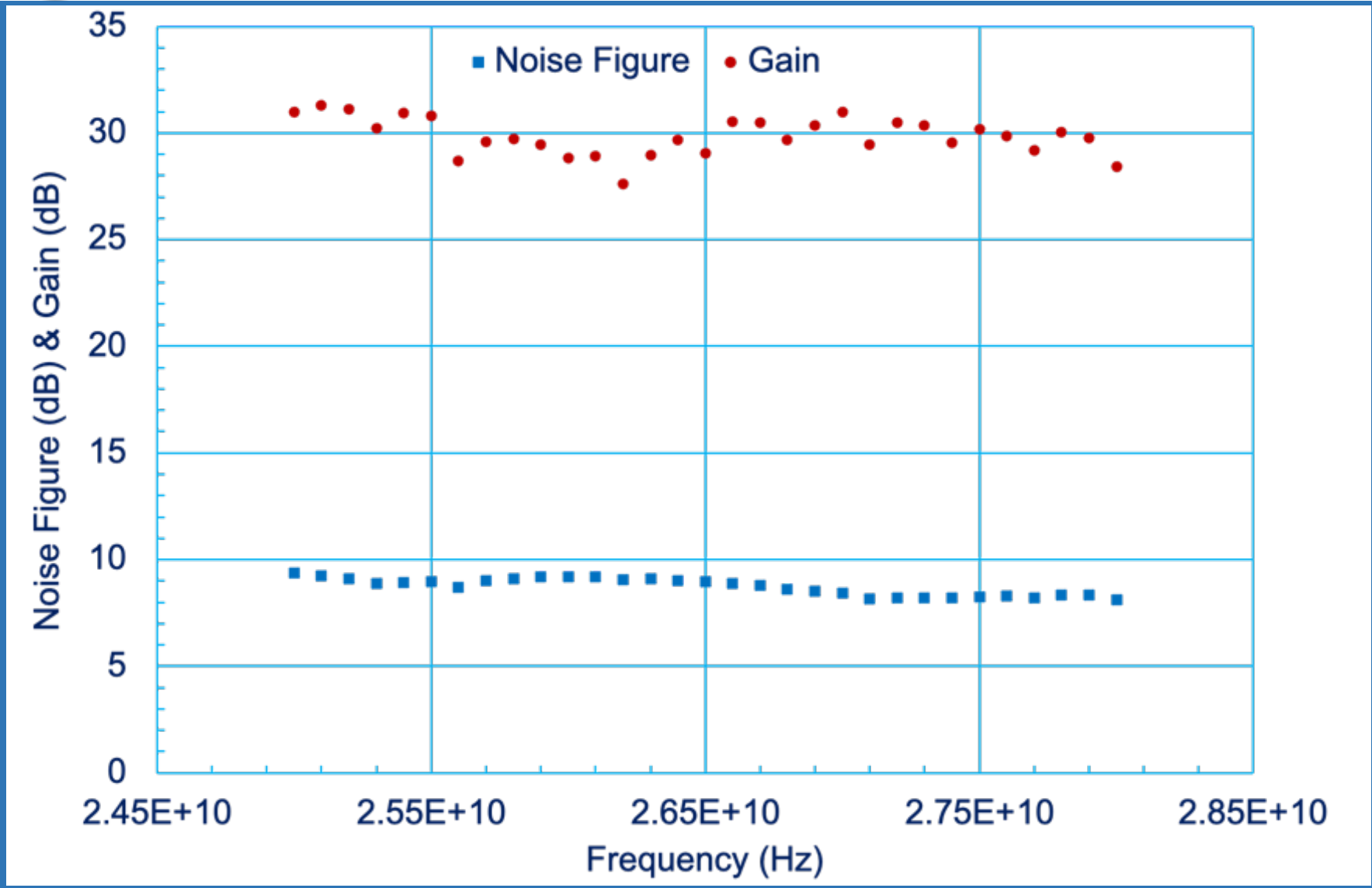
Measured 3rd Order Intermodulation Distortion (IMD) @ 26.5 GHz



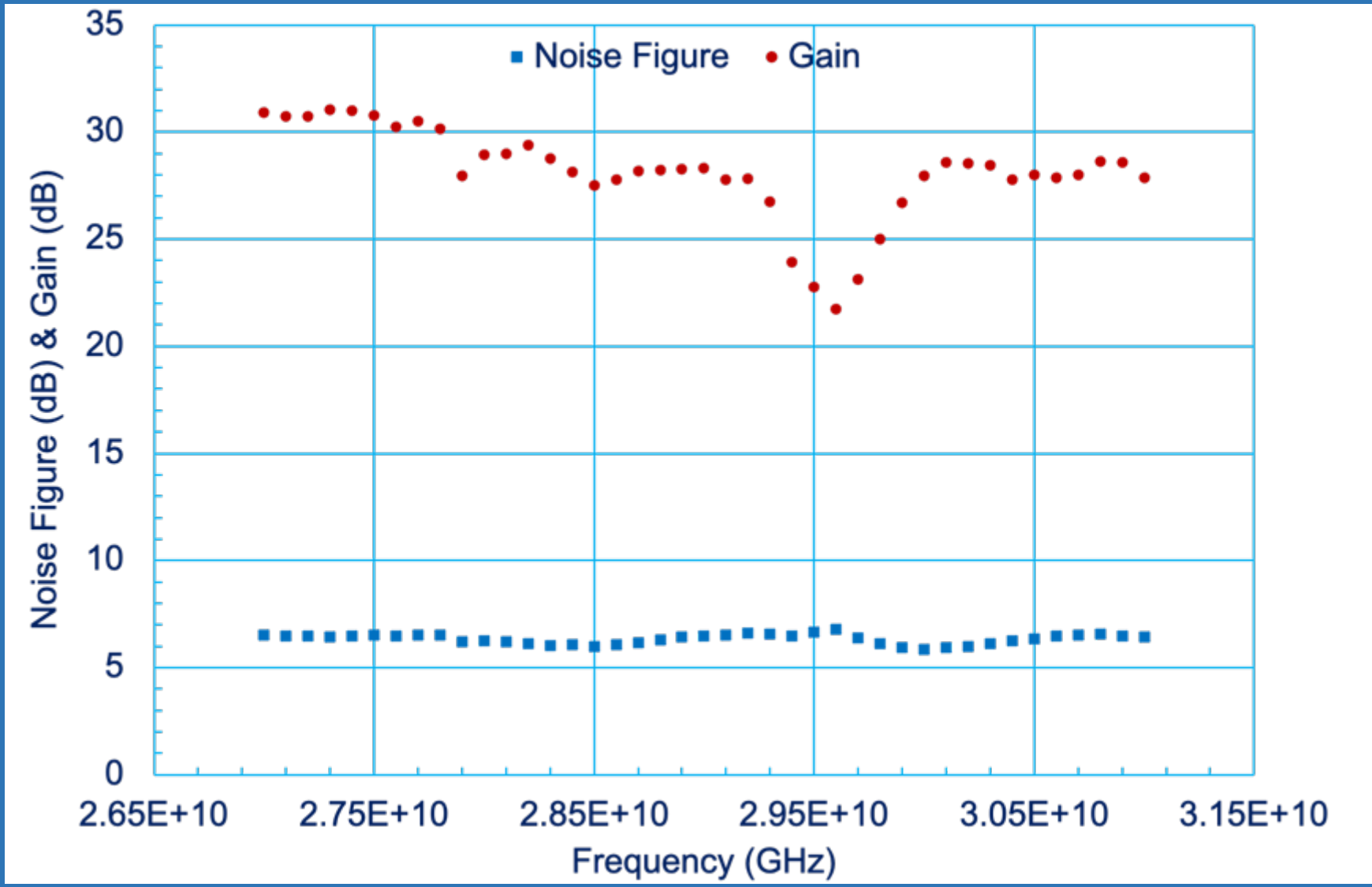
Measured 3rd Order Intermodulation Distortion (IMD) @ 29.5 GHz



Measured Noise Figure — 25 to 28 GHz



Measured Noise Figure — 27 to 31 GHz





Conclusions & Discussions



- Advantages of WBG semiconductors such as GaN for space applications is highlighted
- The architecture and design of a Ka-band GaN HEMT based MMIC HPA is discussed
- The measured data on the HPA performance is presented that includes P_{out}, PAE, RMS EVM for QPSK, OQPSK, 8PSK, 16 APSK, and 16 QAM waveforms, Output Spectrum, Noise Figure, and Gain
- GaN HEMTS enable higher power density, higher efficiency amplifiers resulting in lighter, smaller, and more efficient RF/microwave systems in contrast with Si, SiGe, and GaAs based devices



Acknowledgements

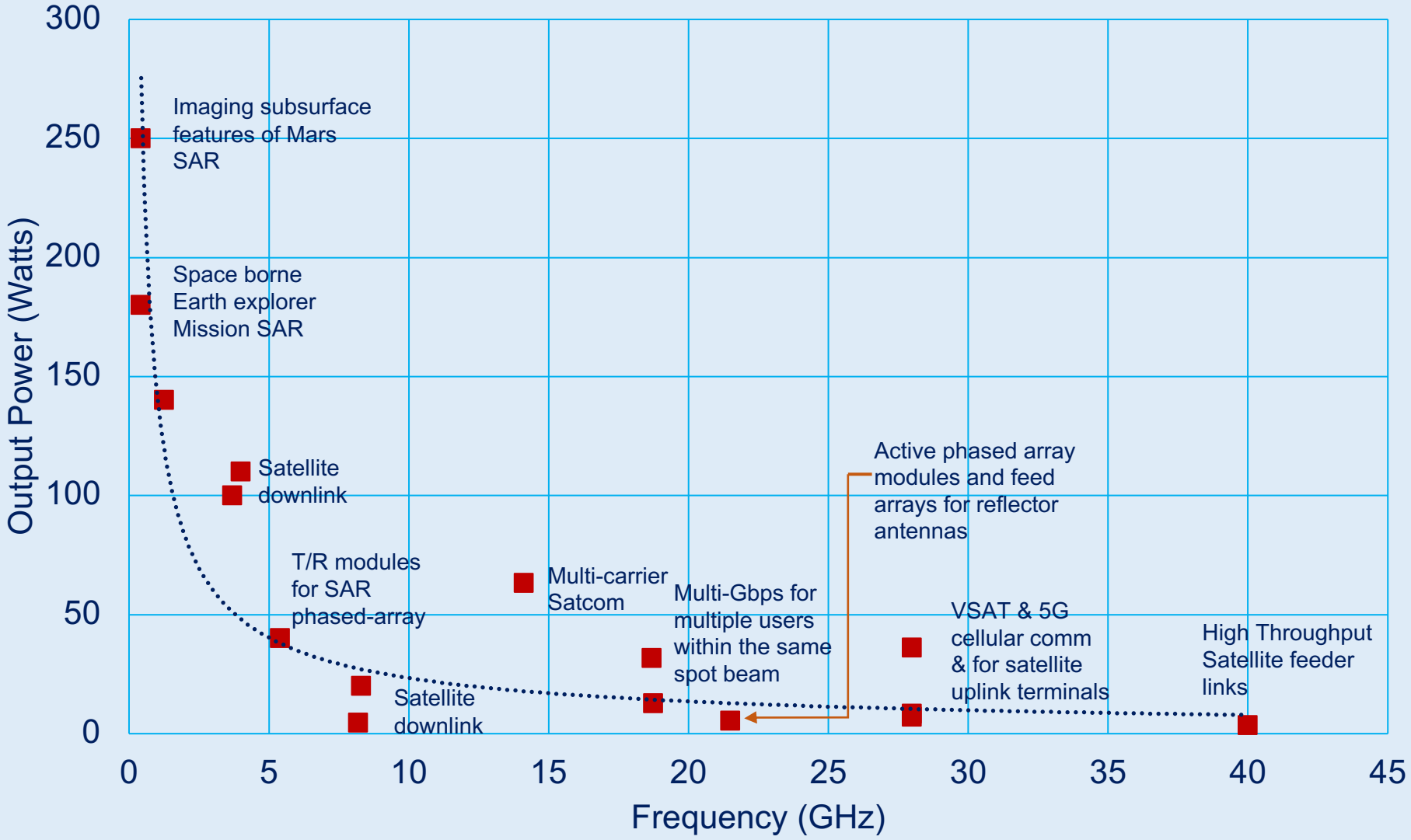


- The author would like to extend his appreciation to Joseph Downey, Marie Piasecki, Bryan Schoenholz, Nang Pham for their enthusiasm and support in carrying out the HPA measurements. The author would also like to thank Nicholas Varaljay for installing the DC bias harness on the HPAs.

- Extra Material

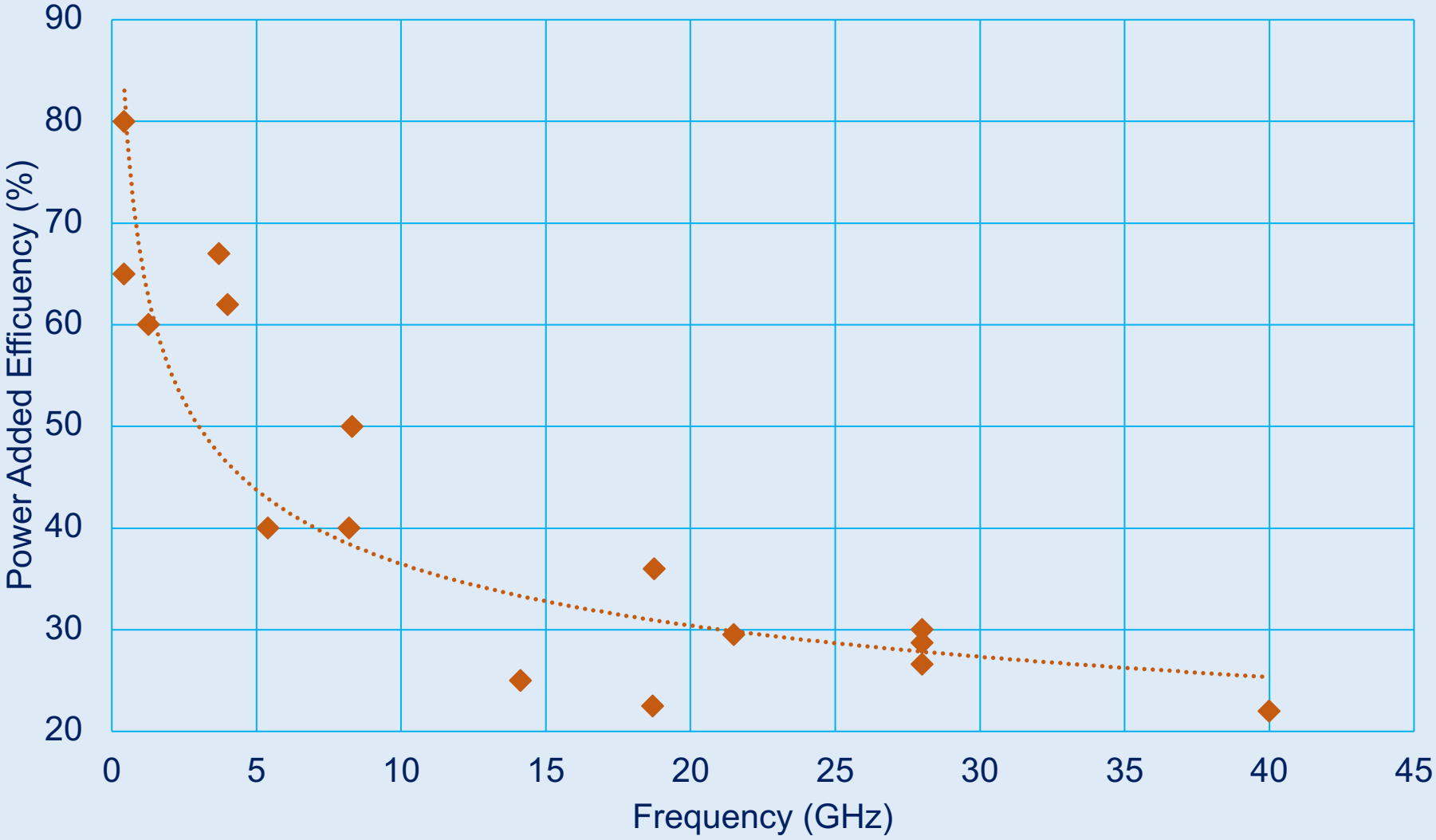
GaN High Power Amplifier Performance

(Output Power vs. Frequency)

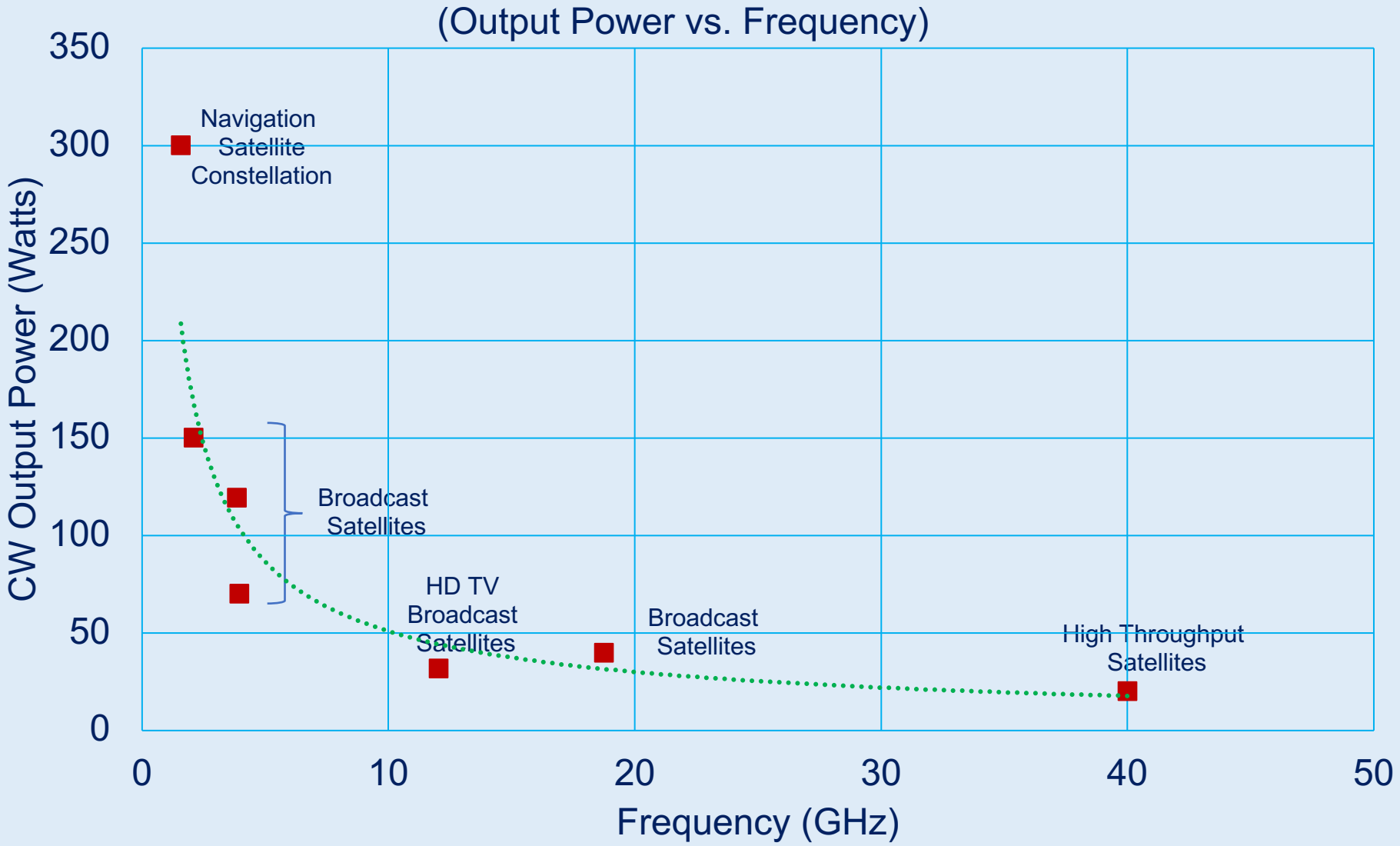


GaN High Power Amplifier Performance

(Power Added Efficiency vs. Frequency)



GaN Solid State Power Amplifier Performance



Relevant Material Properties — Wide Bandgap Semiconductors

- Literature search indicates that wide bandgap semiconductors such as SiC and GaN have unique material properties which enable them to operate in harsh environments

Material	Mobility, μ_n, $cm^2/V.s$	Bandgap, E_g, eV	Relative Dielectric Constant, ε_r	Breakdown Voltage, E_b, 10^6 V/cm	Saturation Drift Velocity, V_{sat}, 10^6 cm/s	Thermal Conductivity, K, W/cm K
Si	1350	1.1	11.8	0.3	10	1.5
GaAs	8500	1.42	13.1	0.4	10	0.43
4H-SiC	700	3.26	10	3.0	20	3.3 – 4.5
GaN	1200 (Bulk) 2000 (2DEG)	3.39	9.0	3.3	25	1.3

