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# Demonstration of a Switched Wideband GaN High-Power Amplifier for Future Space Missions

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# Outline

- Introduction
- Gallium Nitride (GaN) for High Power Amplifiers — Advantages
- HPA Architecture
- Measured Performance Characteristics
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  - Error Vector Magnitude (EVM) for Various Waveforms & Data Rates
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  - Third-Order Intermodulation Distortion Products
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  - SSB Phase Noise
- Conclusions & Discussions

# Introduction

- NASA Plans to transition in a phased manner to commercial SATCOM networks
- Therefore, there is a need to evaluate commercial SATCOM capabilities
- This requires developing terminals for user spacecraft that are capable of roaming and having performance flexibility to interoperate between multiple U.S. commercial service provider networks and space networks owned by U.S. government agencies
- However, legacy systems operate over different frequency bands within the Ka-band spectrum
- Hence, there is a need to develop wideband RF/microwave components and high power amplifiers based on GaN

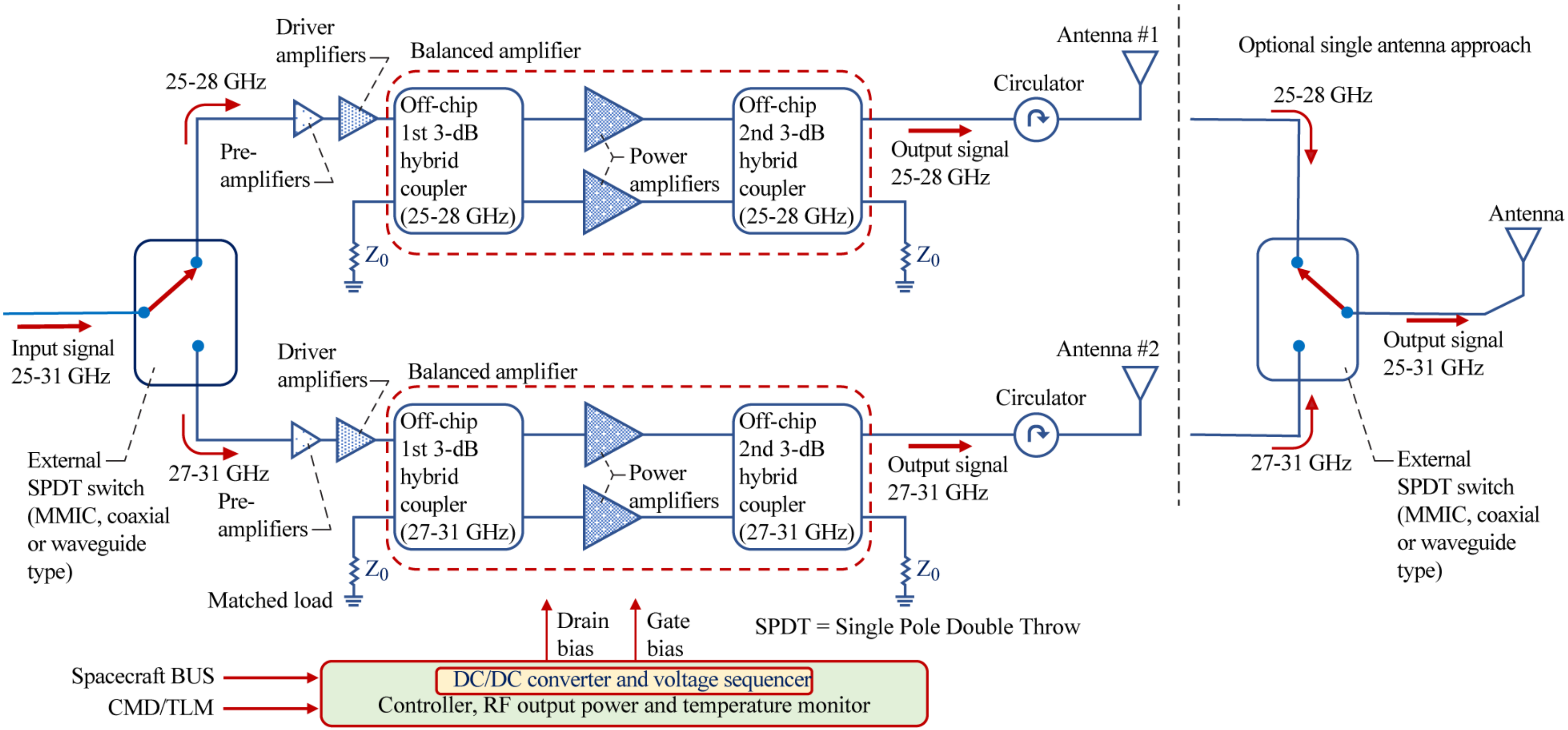
# GaN for High Power Amplifiers — Advantages

- 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 wafer can
  - Operate at high frequencies
  - Deliver high RF output power
  - Offer good linearity
  - Enhance power added efficiency
  - Perform reliably at elevated temperatures

# Ka-band HPA Brief Set of Requirements

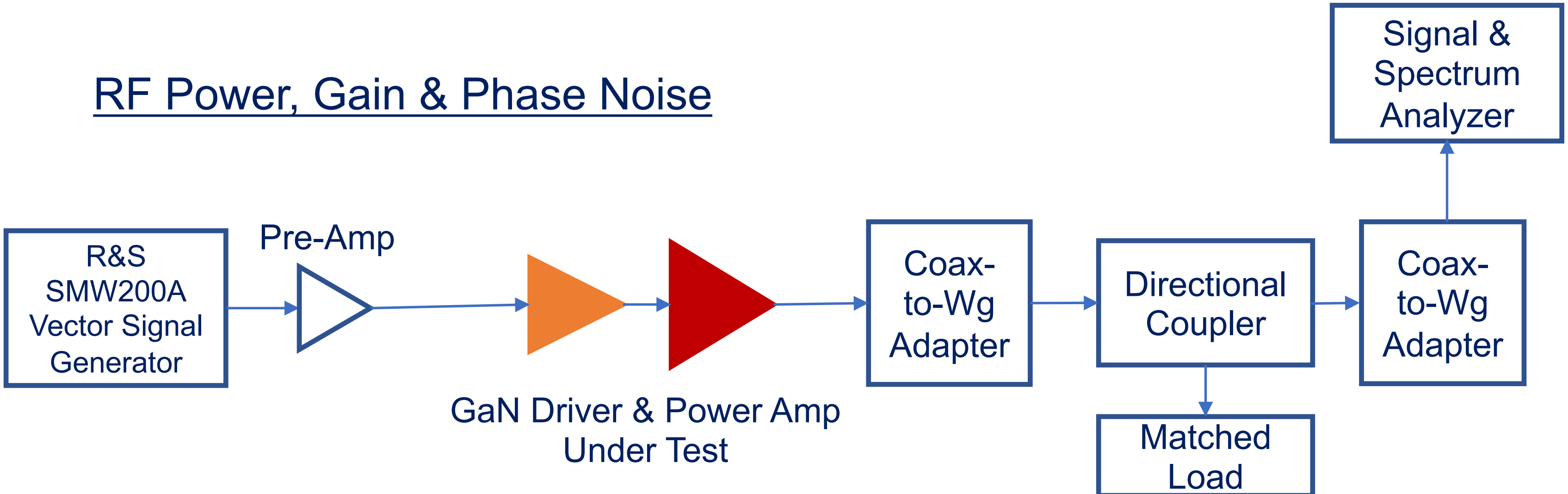
- Satured output power (Psat) (Balanced): 17-20 watts
- Operating frequency range: 25-31 GHz
- Power added efficiency (PAE): 23-25%
- Small signal Gain (driver & power amplifier): >30 dB
- Input/output return loss: < -10.0 dB

# GaN MMIC Based Ka-band High-Power Amplifier Overall Architecture

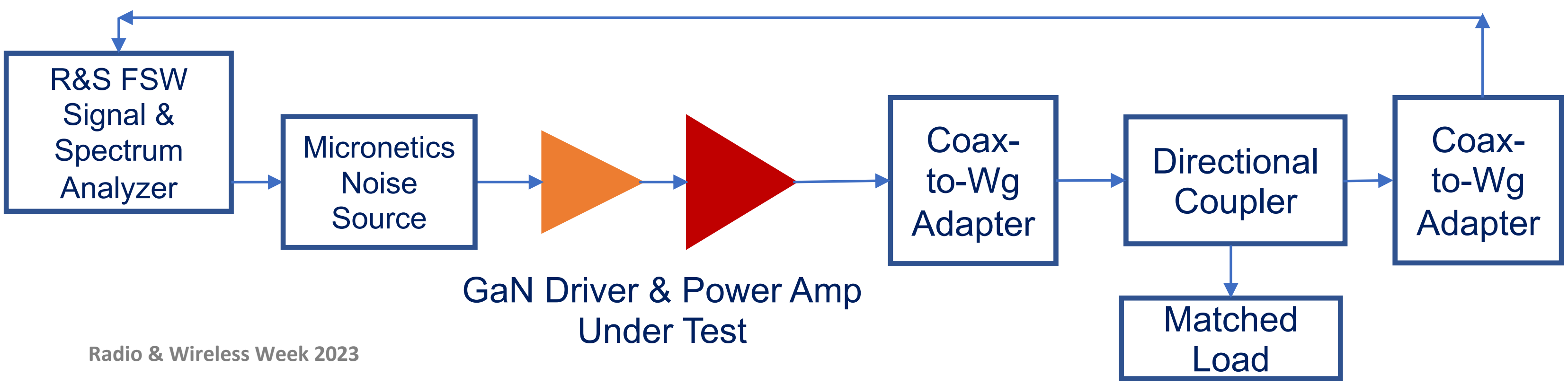


# Measurement Test Set Ups

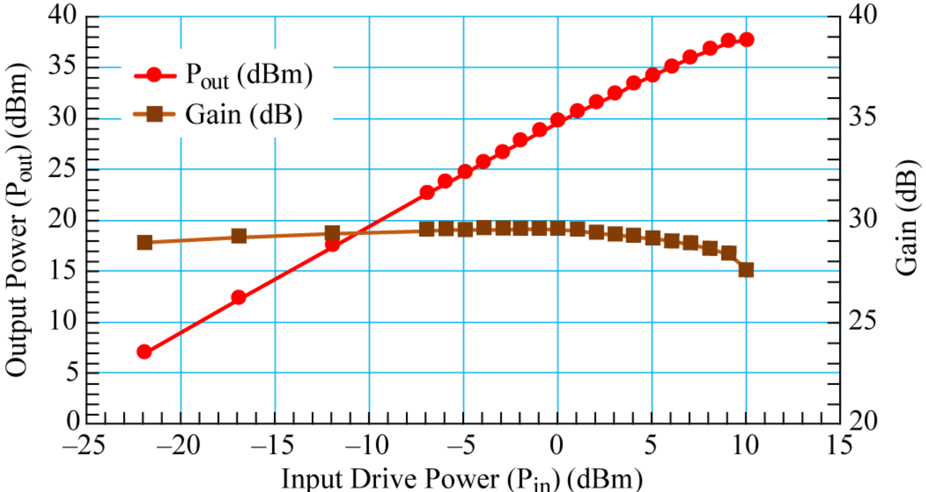
## RF Power, Gain & Phase Noise



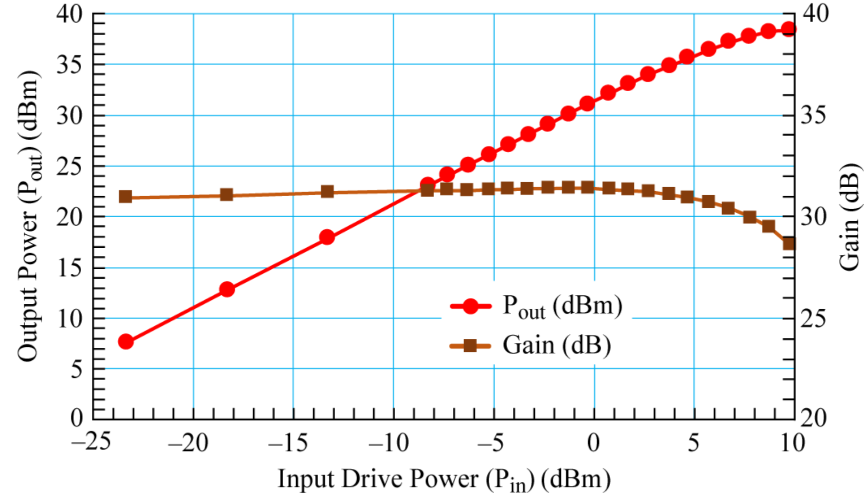

## Noise Figure



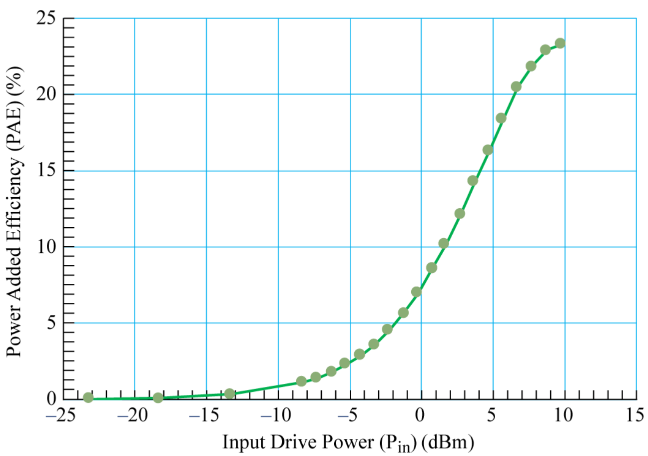
# Measured $P_{out}$, Gain, & PAE vs. $P_{in}$ at $f_0$ = 26.5 GHz & 29.5 GHz



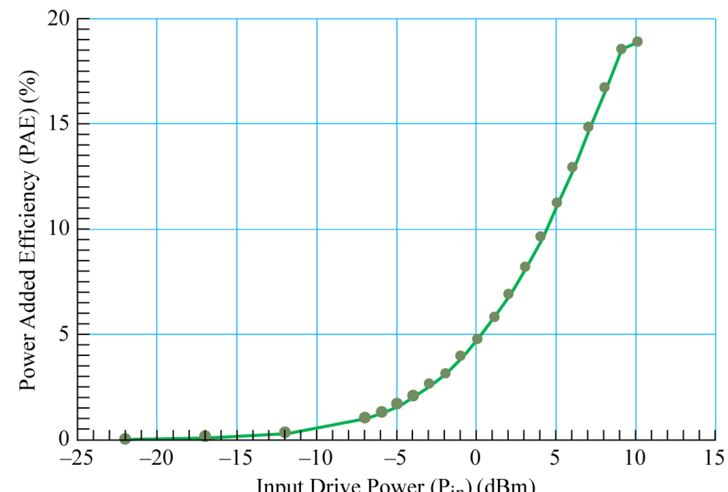

(a)




(a)

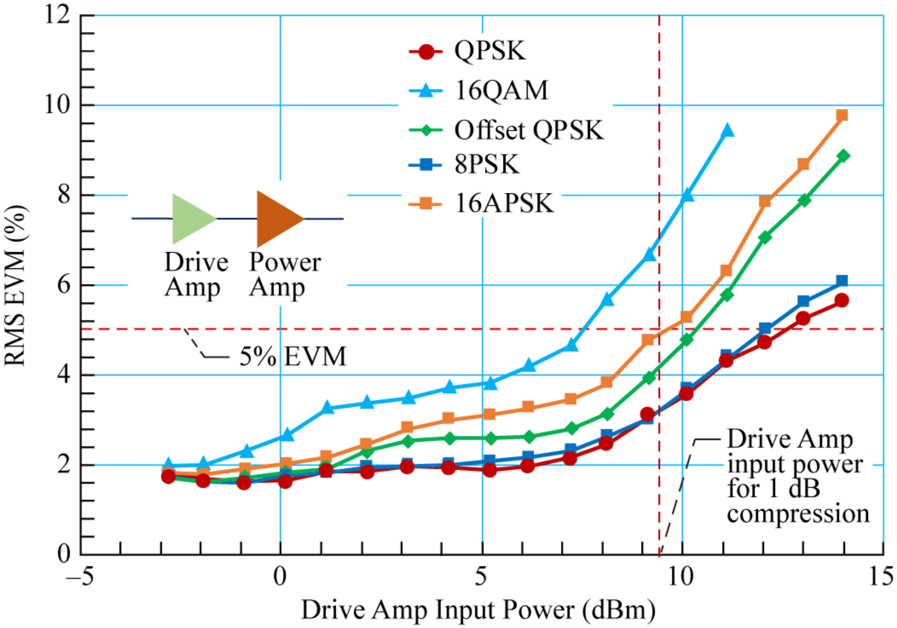


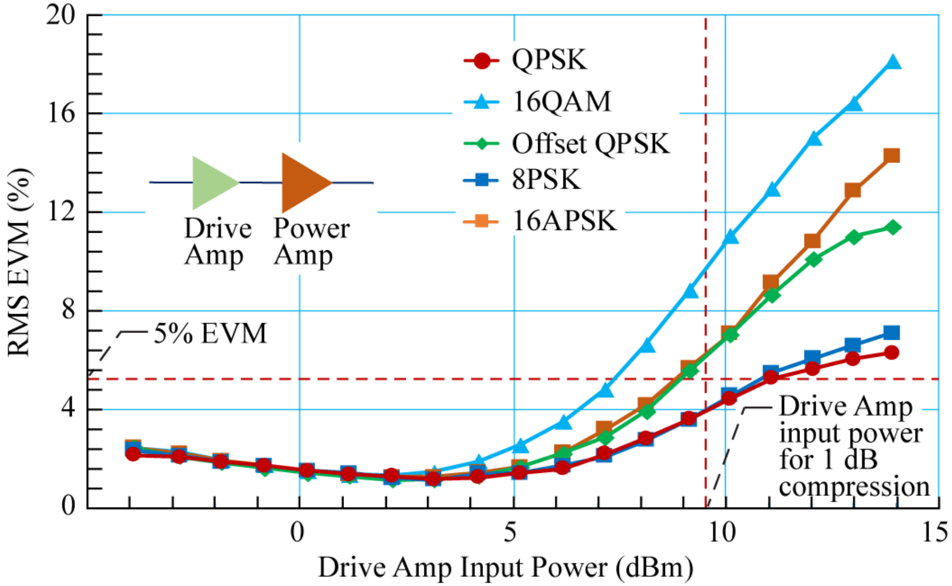

(b)



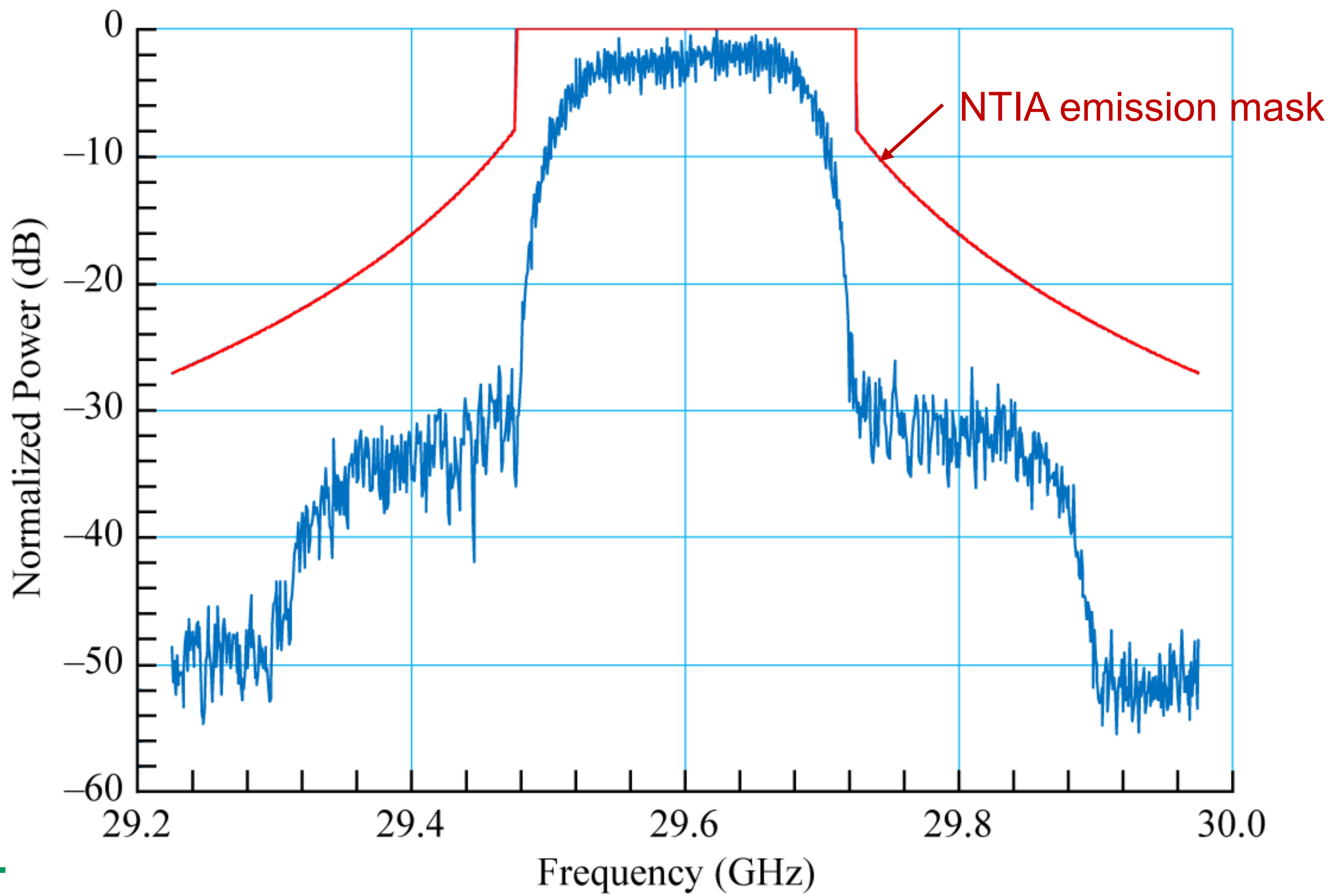

(b)

# Measured RMS EVM vs. $P_{in}$ at $f_0$ = 26.5 GHz & 29.5 GHz. Symbol Rate = 180 Msym/s & SRRC = 0.35

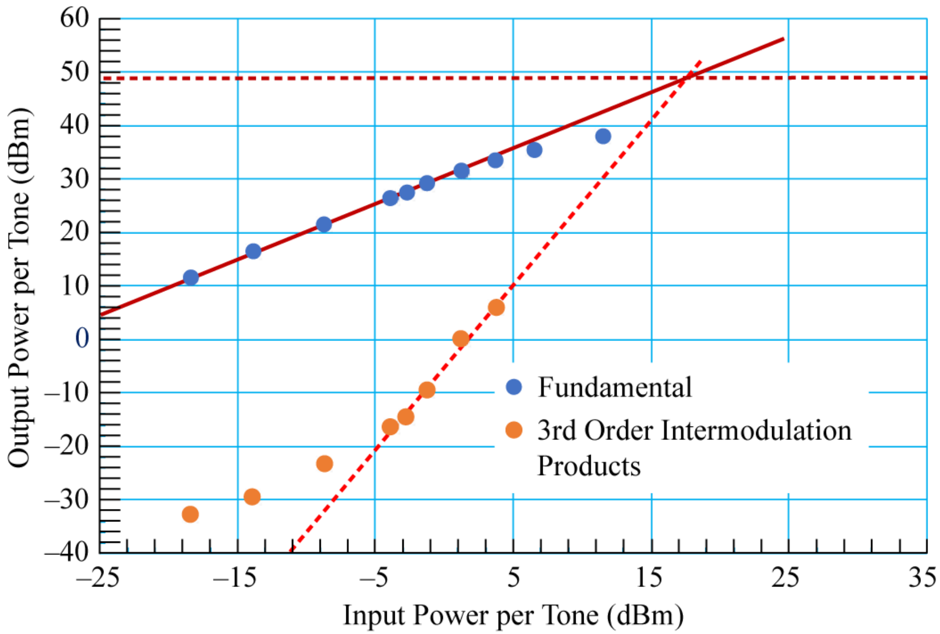


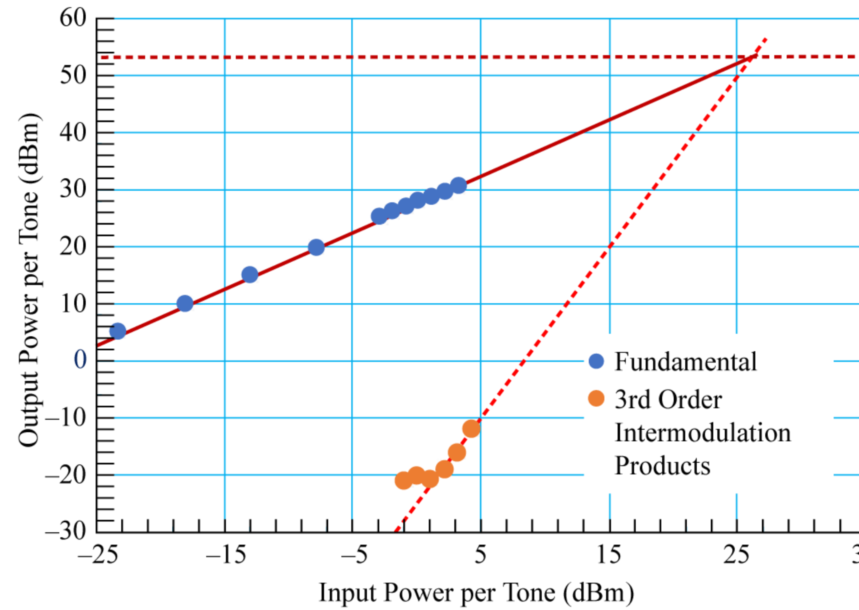



# Measured Spectrum of the 16APSK Waveform at $f_0$ = 29.5 GHz. Symbol Rate = 180 Msym/s & SRRC = 0.35

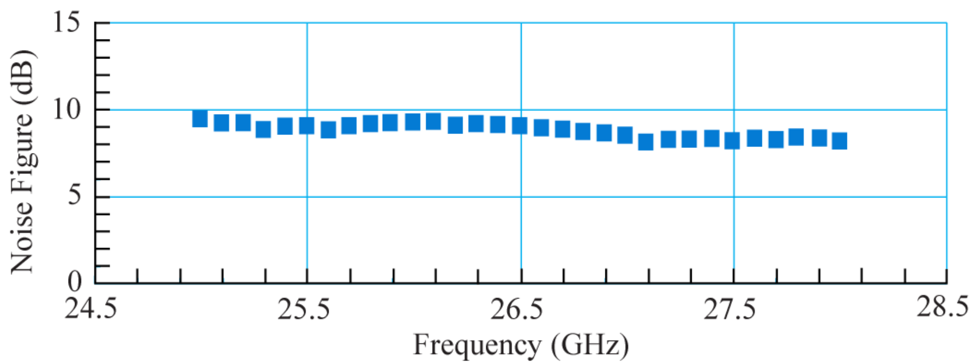


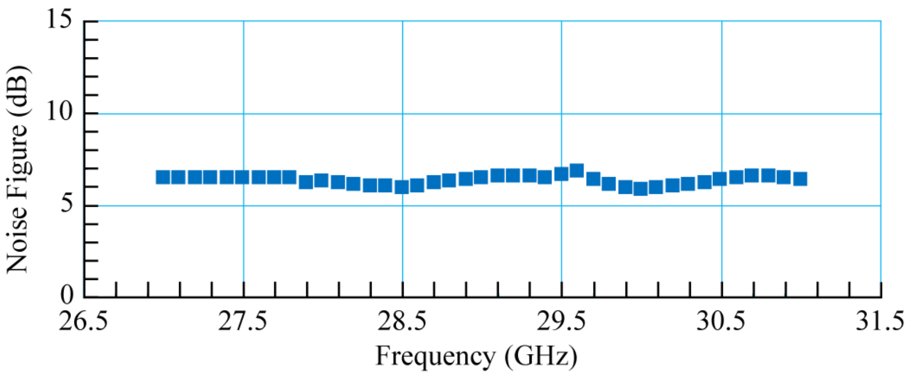
# Measured 3rd Order IMD vs. Input Power Per Tone at $f_0$ = 26.5 GHz & 29.5 GHz. Tone Spacing = 5 MHz



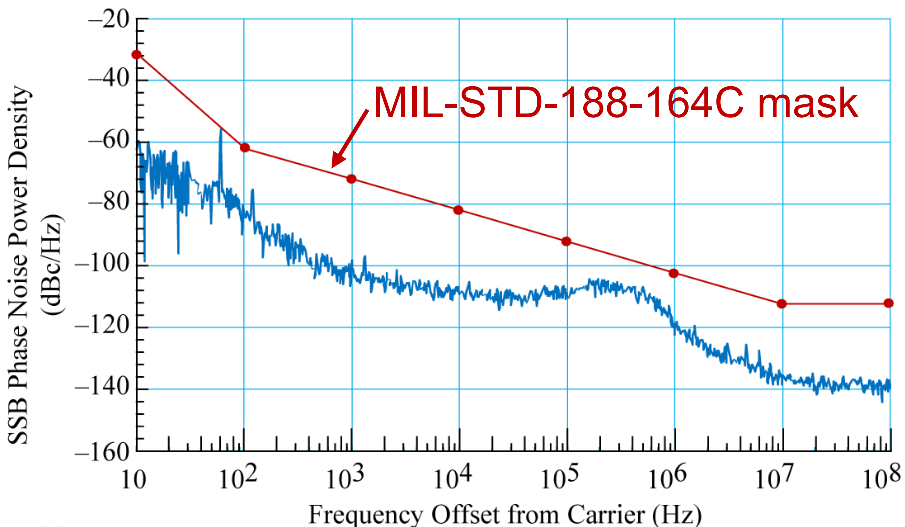



# Measured Noise Figure

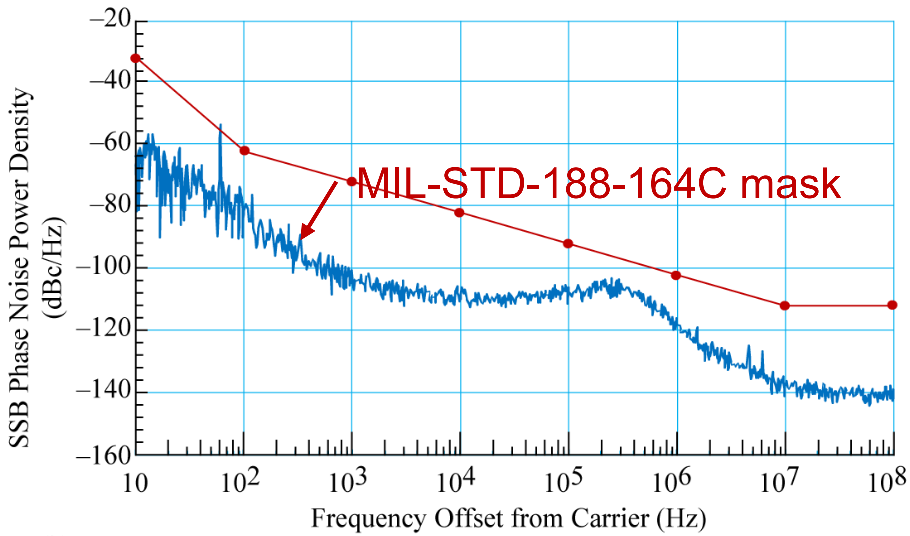


# Measured SSB Added Phase Noise vs. Frequency Offset from Carrier at $f_0$ = 26.5 GHz & 29.5 GHz




(a)




(b)

# Test Results Summary

| Parameter | Measured Value (25–28 GHz Driver & Power Amp) | | | Measured Value (28–31 GHz Driver & Power Amp) | | |
|---|---|---|---|---|---|---|
| Frequency ($f_0$ and $f_0 \pm 1.5$ GHz) | 25.0 | 26.5 | 28.0 | 28.0 | 29.5 | 31.0 |
| Output Power (dBm) ($P_{sat}$) | 39.1 | 37.7 | 37.9 | 37.5 | 38.4 | 37.0 |
| Small Signal Gain (dB) | 30.9 | 29.6 | 30.4 | 30.5 | 31.4 | 29.7 |
| PAE (%) | 22.8 | 18.9 | 19.0 | 21.5 | 23.3 | 20.6 |
| Return Loss (dB) | < –10.0 | | | < –10.0 | | |
| RMS EVM (%) (drive at 1-dB compression point) (QPSK, Offset-QPSK, 8PSK, 16APSK, & 16QAM) | 5 (All but 16QAM)<br><br>7 (16QAM) | | | 5 (QPSK & 8PSK)<br><br>6 (Offset-QPSK & 16APSK)<br><br>10 (16QAM) | | |
| Out-of-Band Spectral Regrowth (dBc) | < –30 | | | < –30 | | |
| OIP3 (dBm) | 48 | | | 53 | | |
| Noise Figure (dB) | 9 (Higher NF due to stabilizing gate resistor) | | | 7 | | |
| SSB Phase Noise Power Density (dBc/Hz) (drive at 1-dB compression point) | Compliant with MIL-STD Mask<br><br>Added Phase Noise is insignificant | | | Compliant with MIL-STD Mask<br><br>Added Phase Noise is insignificant | | |

# Conclusions & Discussions

- Advantages of GaN for NASA's space applications is highlighted
- Architecture and design of a Ka-band GaN HEMT based MMIC HPA is discussed
- The architecture is validated by characterizing interconnected driver and power amplifier modules
- The measured Pout, Gain, PAE, RMS EVM for QPSK, Offset QPSK, 8PSK, 16APSK, and 16QAM constellations, 3rd order IMD products, noise figure, and added phase noise are presented
- Gan HEMTS enables higher power density, higher PAE, resulting in lighter, smaller, and more efficient RF/microwave systems in contrast with Si, SiGe, and GaAs based systems

Thank you & Glad to Answer any Questions?