Benefits of Ka-Band GaN MMIC High Power Amplifiers With Wide Bandwidth and High Spectral/Power Added Efficiencies for Cognitive Radio Platforms

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Outline

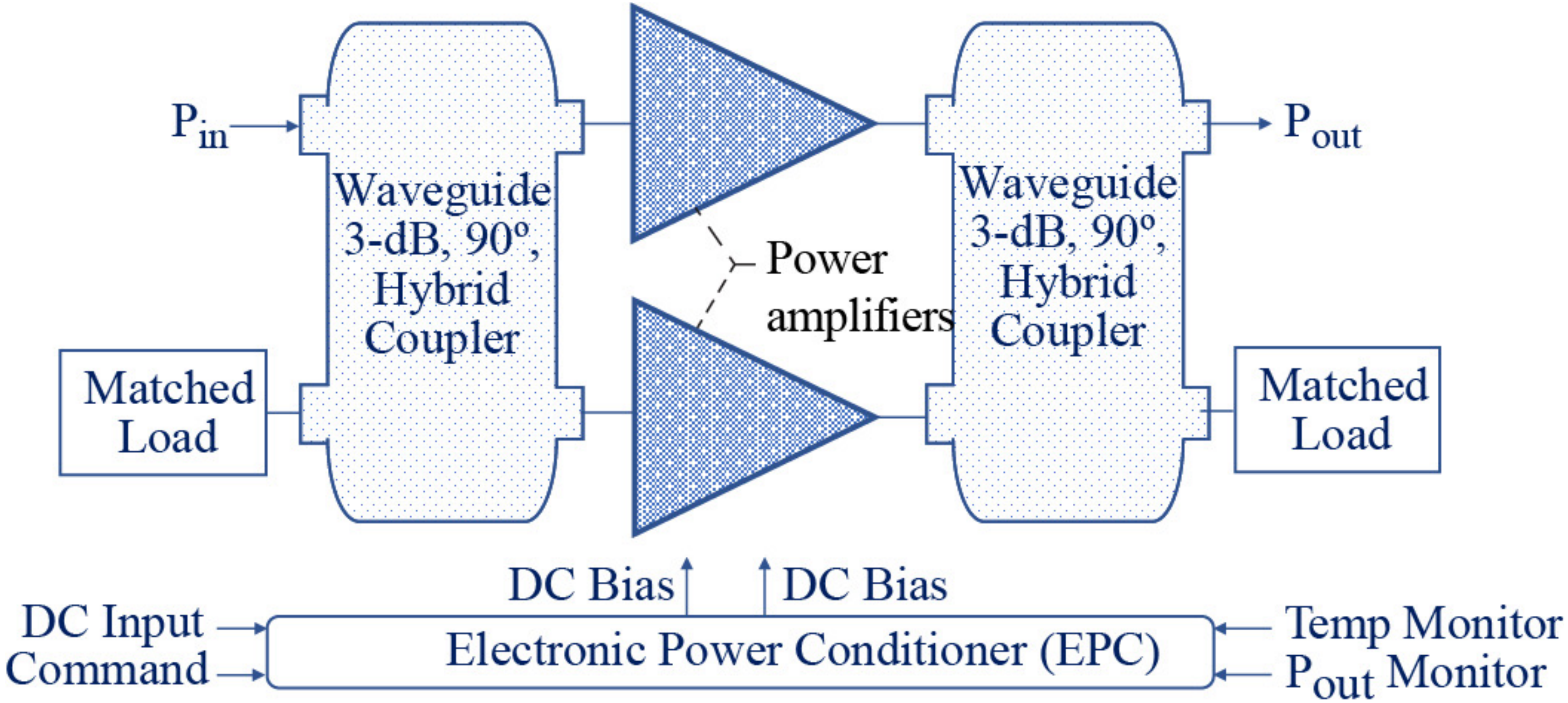
- Introduction
- High-Power Amplifier (HPA) Architecture & Specifications Relevant to Cognitive Radio Platforms
- Benefits of HPA for Cognitive Radio Platforms
- HPA Performance Validation
- HPA Potential Use Cases for Cognitive Radio Platforms
- Conclusions/Discussions

Introduction

➢ Background

- ✓ SCaN's Vision for the Future
  - NASA plans to transition in a phased manner in the next decade the Space Communications, Navigation, Timing, & Tracking Infrastructure to commercial SATCOM networks
  - Challenges – developing new radios for user spacecraft terminals capable of roaming & have performance flexibility to interoperate across multiple commercial service provider & space networks
  - On the other hand, advances in Artificial Intelligence (AI) & Machine Learning (ML) have enabled the RF/microwave community to create breakthrough capabilities in semiconductor devices, integrated circuits, & systems. Additionally, research in Artificial Neural Networks (ANNs) has demonstrated new training algorithms that enable satellite systems to learn from the environment surrounding them & adaptively allocate onboard resources to enhance performance
  - Consequently, developers of new spacecraft radios are investigating the application of AI, ML, & ANN based software training algorithms to optimize link performance in the presence of changing communications conditions
  - These cognitive radios can learn from the environment in which they are operating, then adaptively and dynamically change the operating frequency, EIRP, bandwidth, waveforms, data rates, and protocols as outlined in SCaN's vision for the future.
  - An integral part of the cognitive radio is a microwave wideband HPA that facilitates the above changes

BALANCED KA-BAND HPA DESIGN ARCHITECTURE

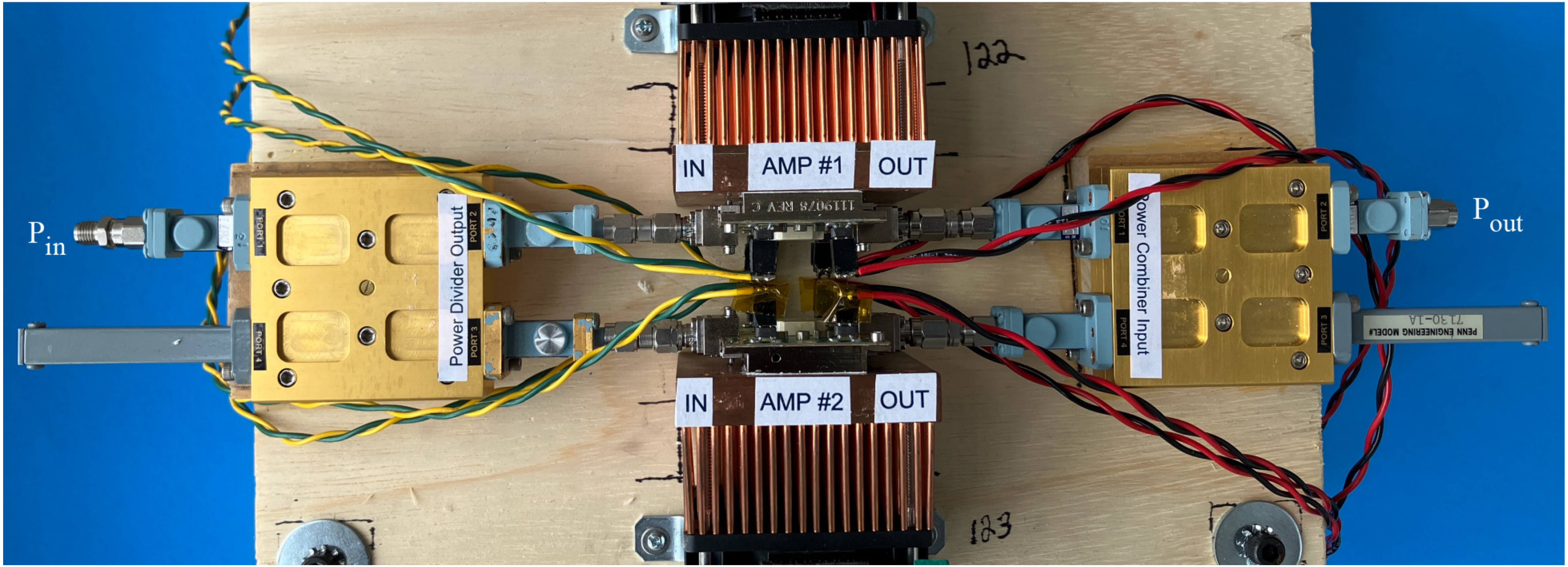


- ✓ The power amplifier (PA) is fabricated using Gallium Nitride (GaN) High Electron Mobility Transistor (HEMT) based Monolithic Microwave Integrated Circuit (MMIC)
  - GaN HEMT provides High power density – fewer chips are required to achieve a target RF output power
  - High power added efficiency (PAE)
- ✓ GaN HEMT epi-layer is epitaxially grown on a Silicon Carbide (SiC) wafer
  - SiC has excellent thermal conductivity
  - The GaN PA can operate with a higher channel temperatures than GaAs PA – improved MTBF & reliability

HPA Specifications for Cognitive Radio Platforms

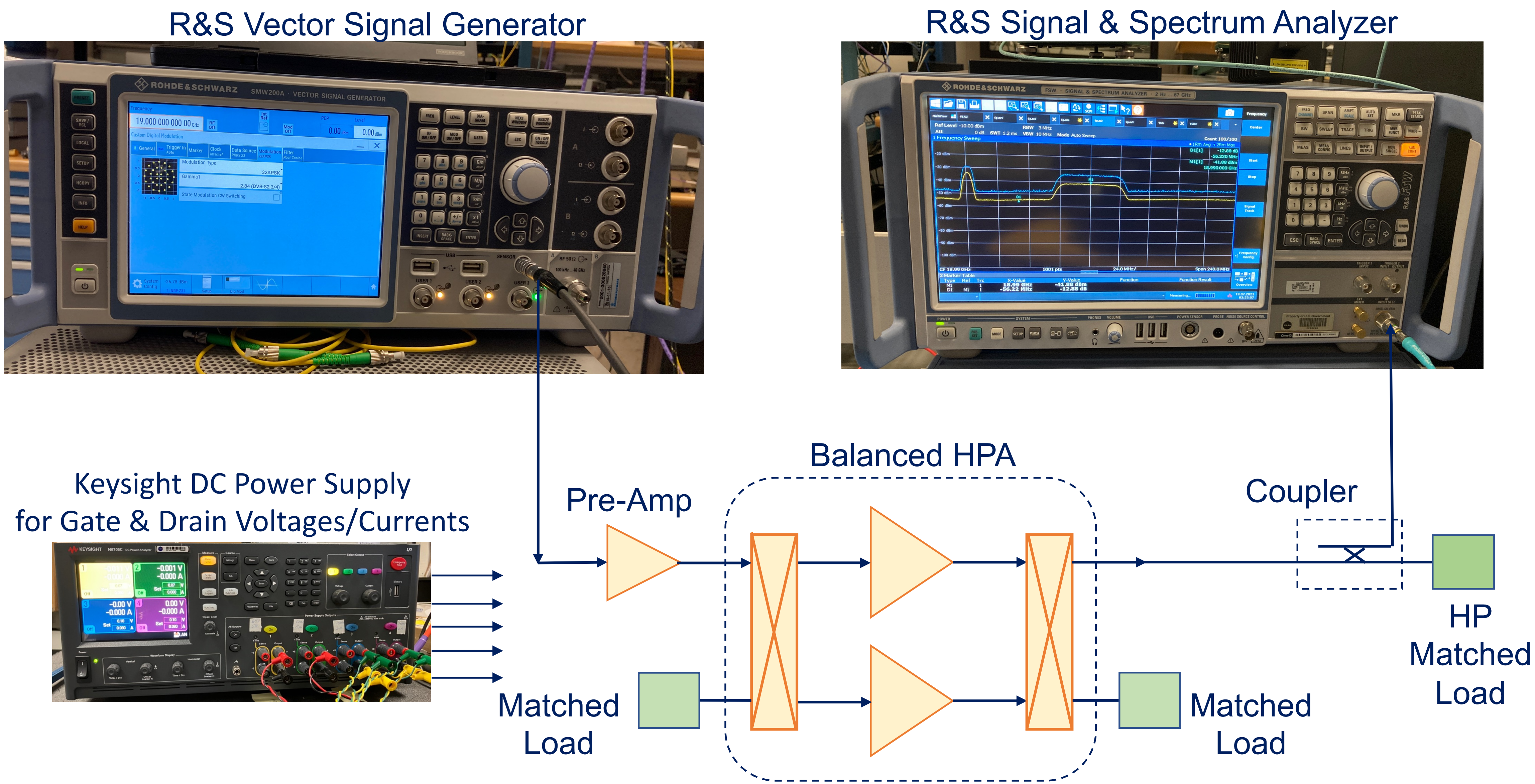
- Saturated output power (P_{sat}): 10 to 15 W (CW)
- Frequency: Ka-band
- Bandwidth: 25.25 to 31.0 GHz (extends across NASA, Commercial, & Military)
- PAE: 18 to 22 percent
- Small signal gain: 28 to 32 dB
- Input/output return loss: < –10.0 dB
- Gain flatness over full bandwidth: $\pm$ 1 dB

A Proof-of-Concept Demonstration Model of the Ka-band GaN HEMT MMIC Based Balanced HPA



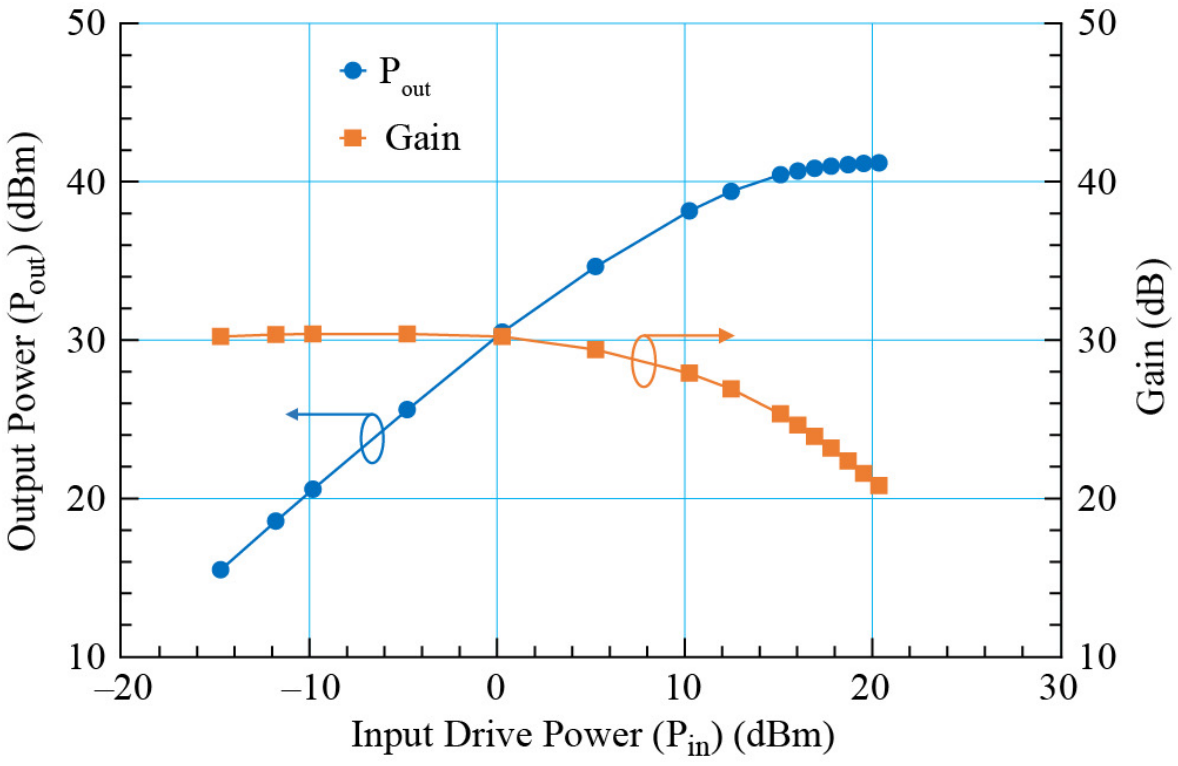
- The GaN HEMT MMICs are Qorvo TGA2595-CP and the waveguide-based (WR-28) 3-dB, 90° , hybrid couplers are manufactured by SAGE (now Eravant)
- The coupler insertion loss and isolation are on the order of 0.5 dB and 20 dB, respectively

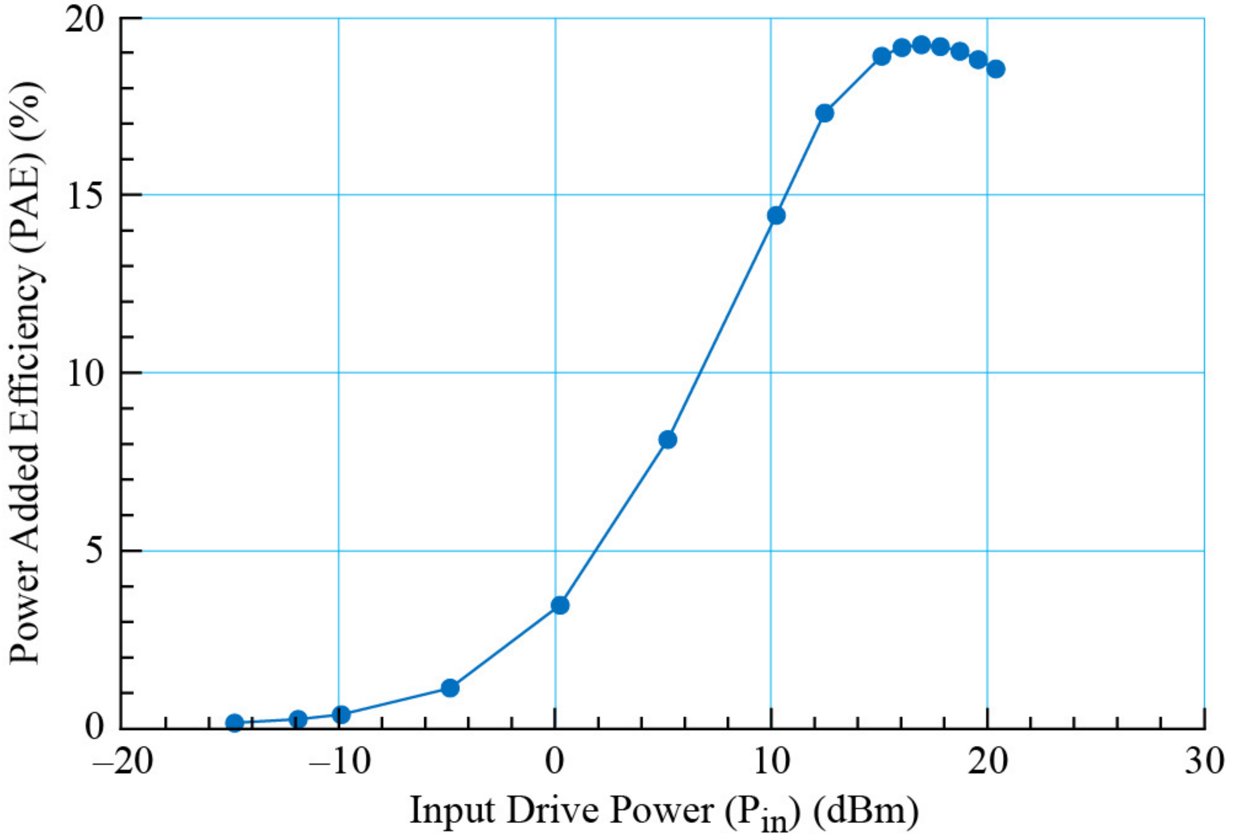
Test Setup for HPA Characterization



Measured P_{OUT}, Gain, & PAE vs. P_{IN} of the Balanced HPA

(f_0 = 27.5 GHz. $V_{d1} = V_{d2}$ = 20 V, V_{g1} = –2.2 V, V_{g2} = –2.15 V, T = 25 °C)



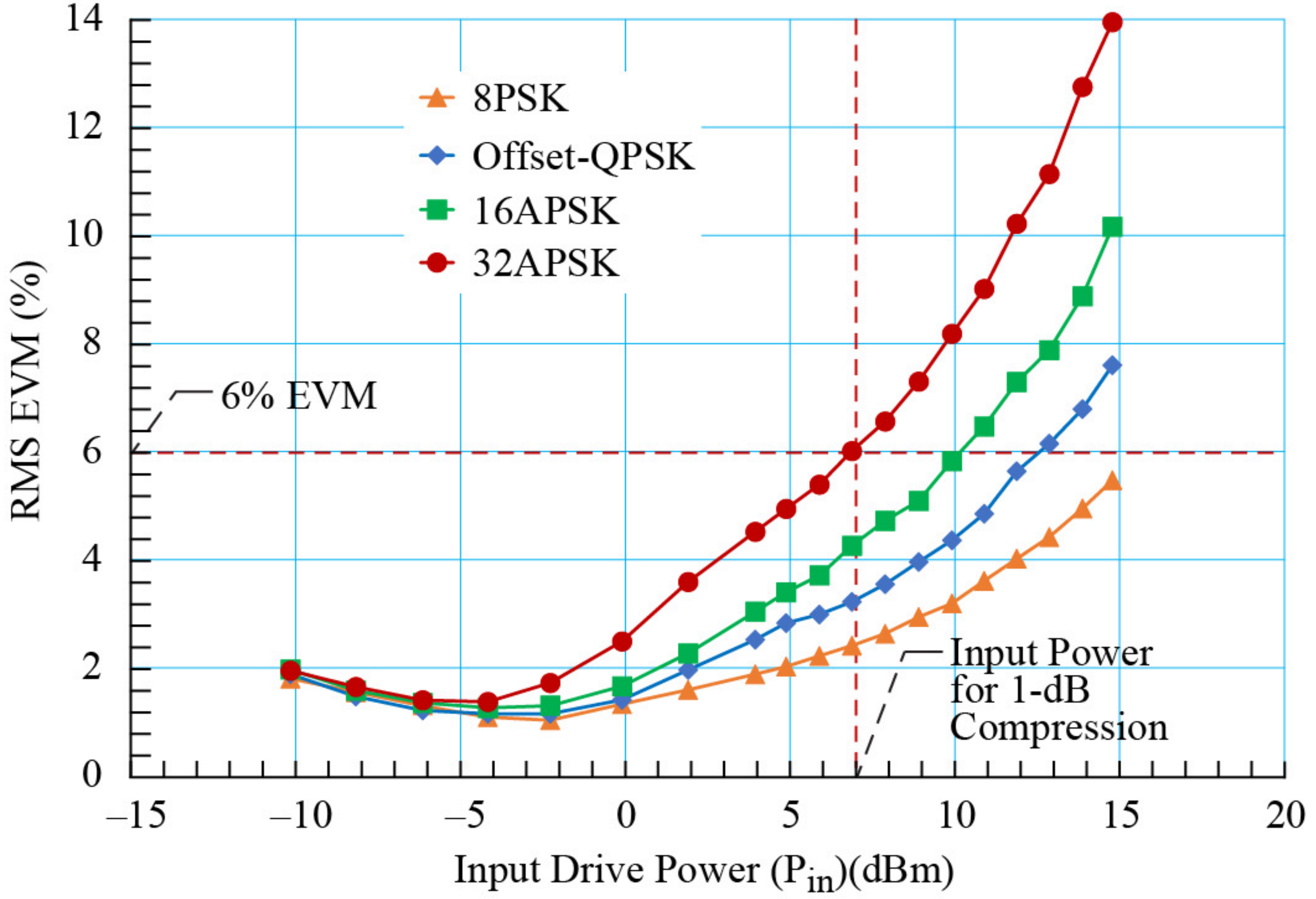


✓ The high P_{out} (13.2 watts), Gain (> 30 dB), & wide bandwidth of the HPA can be exploited by cognitive radios to enable tunability & seamless interoperability across legacy space networks that operate over different frequency bands within the Ka-band spectrum

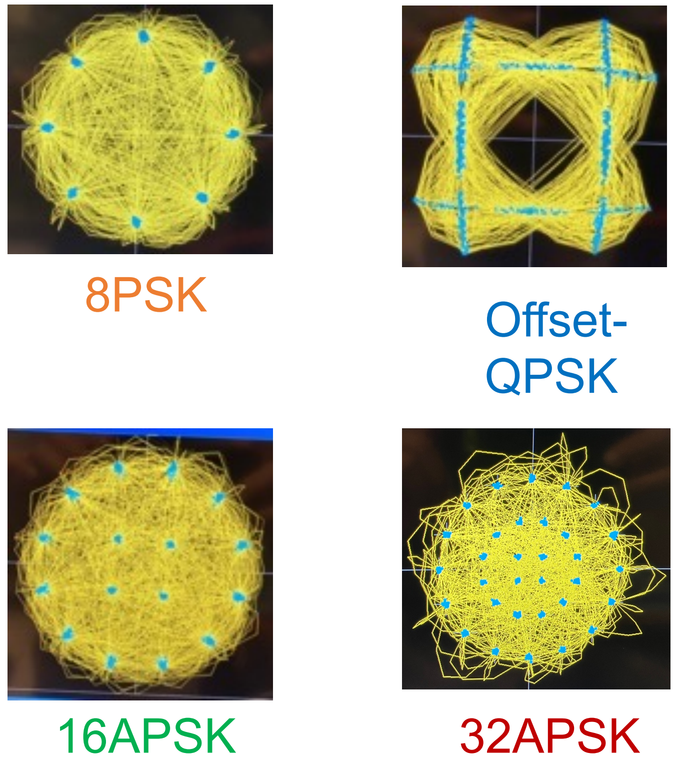
✓ High PAE of the HPA reduces power dissipation & improves thermal reliability, thereby enabling smaller size, weight, & power (SWaP) cognitive radio platforms

MEASURED RMS EVM VS. P_{IN} AT F_0 = 27.5 GHZ

(Symbol rate is 100 Msymbols per second & Square root raised cosine (SRRC) filter is set to 0.35)



Waveforms & Constellations

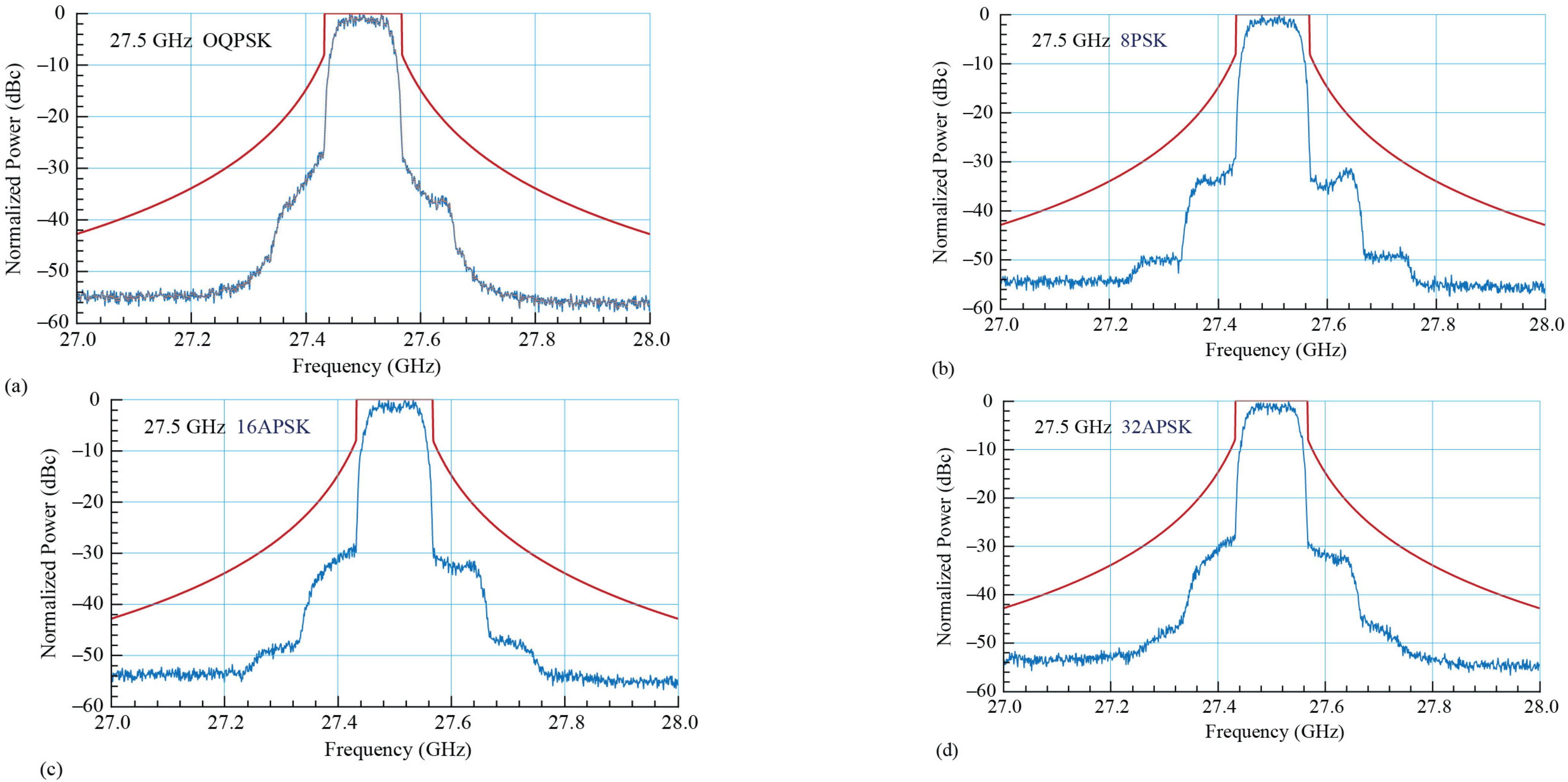


- ✓ The low RMS EVM (≤ 6%) up to the 1-dB compression point demonstrates high linearity of the HPA, which enables amplifying higher-order modulation waveforms, such as 8PSK, 16APSK, & 32APSK. This feature enables cognitive radios to support CCSDS compliant waveforms used in many NASA missions, as well as DVB-S2 waveforms typically used by commercial service providers

Measured Spectrum at F_0 = 27.5 GHz

(Symbol rate is 100 Msymbols per second, Square root raised cosine (SRRC) filter is set to 0.35, & Bandwidth is 135 MHz)

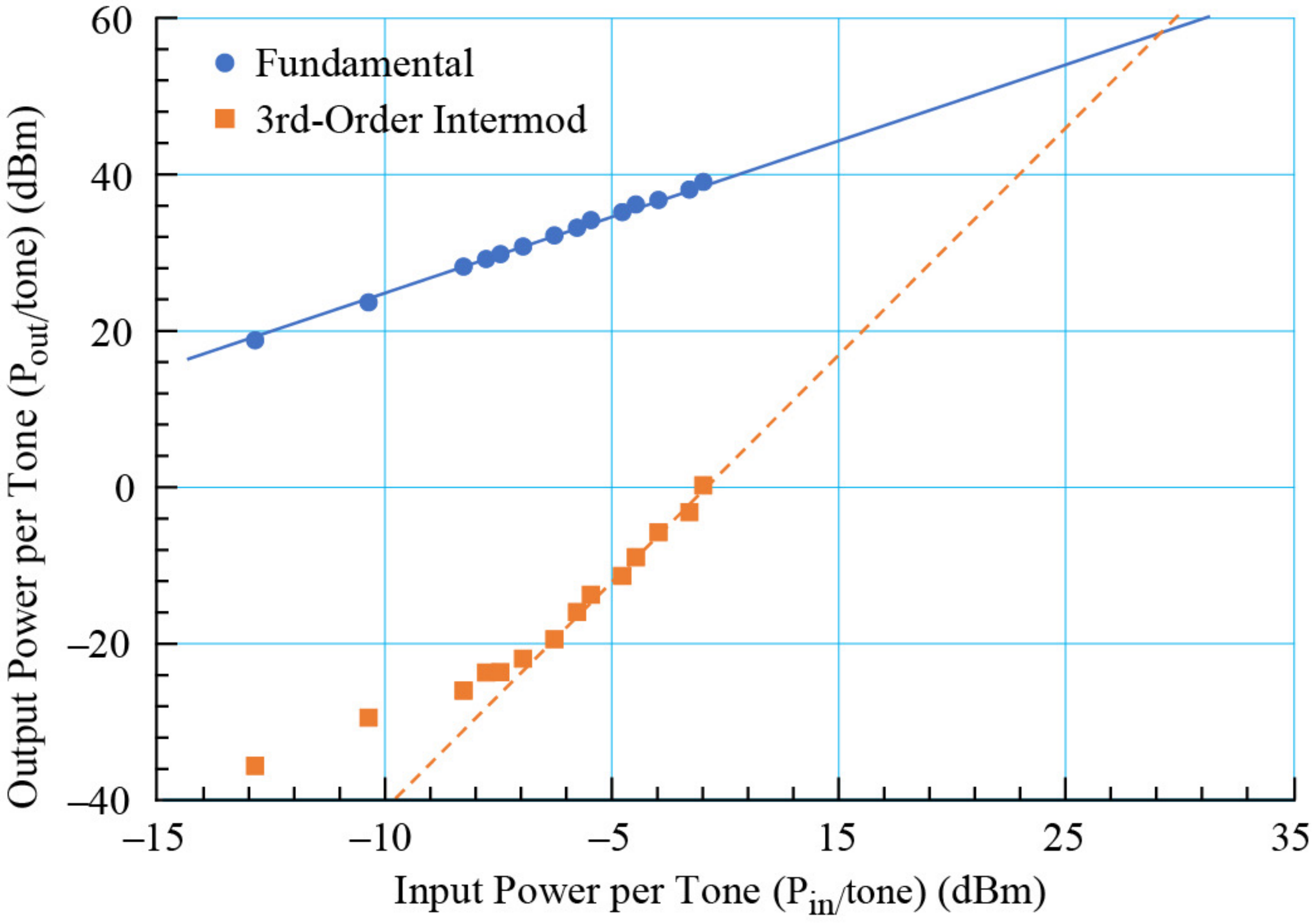
(Red solid line is the NTIA mask)



- ✓ The HPA spectral efficiency for a fixed bandwidth (135 MHz) increases from 2bits/s/Hz (OQPSK) to 5bits/s/Hz (32APSK), which can be exploited by cognitive radios to enhance throughput
- ✓ The spectrum and consequently the HPA is compliant with the NTIA mask requirements

Measured 3rd-Order Intermodulation Distortion (IMD) vs. Input Power per Tone at F_0 = 27.5 GHz

(Tone spacing is 5 MHz and Tone frequencies are 27.5 GHz ± 2.5 MHz)



✓ The high OIP3 on the order of 56 dBm demonstrated that the 3rd-order IMD products generated by the HPA is small. Therefore, the interference signals generated within the cognitive radio channel bandwidth due to HPA nonlinearity is also small

TABLE I: OUT-OF-BAND SPECTRAL REGROWTH

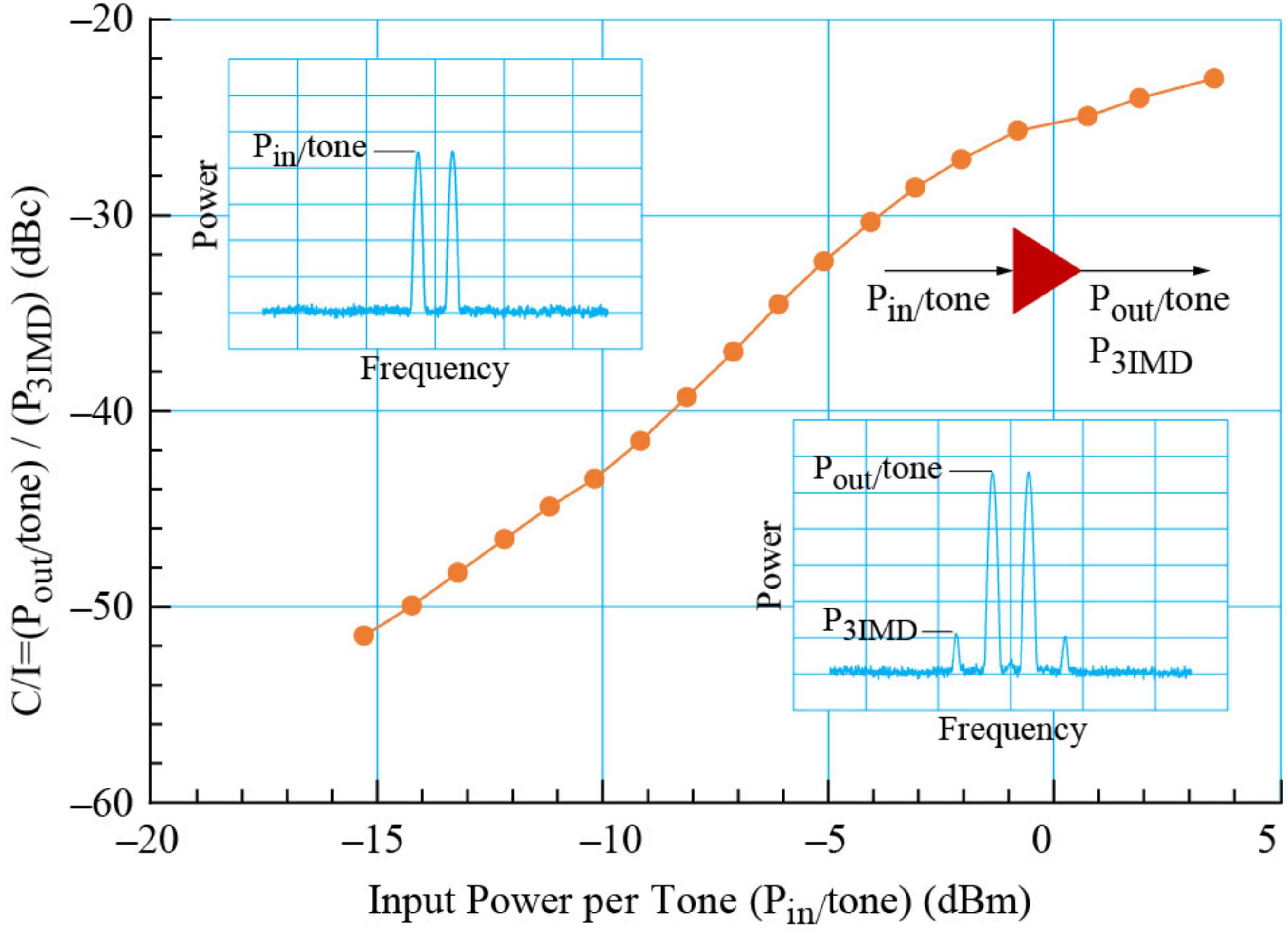
✓ The out of band spectral regrowth is measured at 1-symbol rate (100 MHz) away from the center frequency or carrier frequency for all four waveforms and the results are summarized below

Waveform	Spectral Regrowth (dBc) (@27.6 GHz)
Offset-QPSK	-35.1
8PSK	-34.1
16APSK	-32.8
32APSK	-31.5

✓ The data indicate that the spectral regrowth is less than –30 dBc, which demonstrates low adjacent channel interference or adjacent channel power ratio (ACPR). A cognitive radio with this capability enables roaming and interoperability

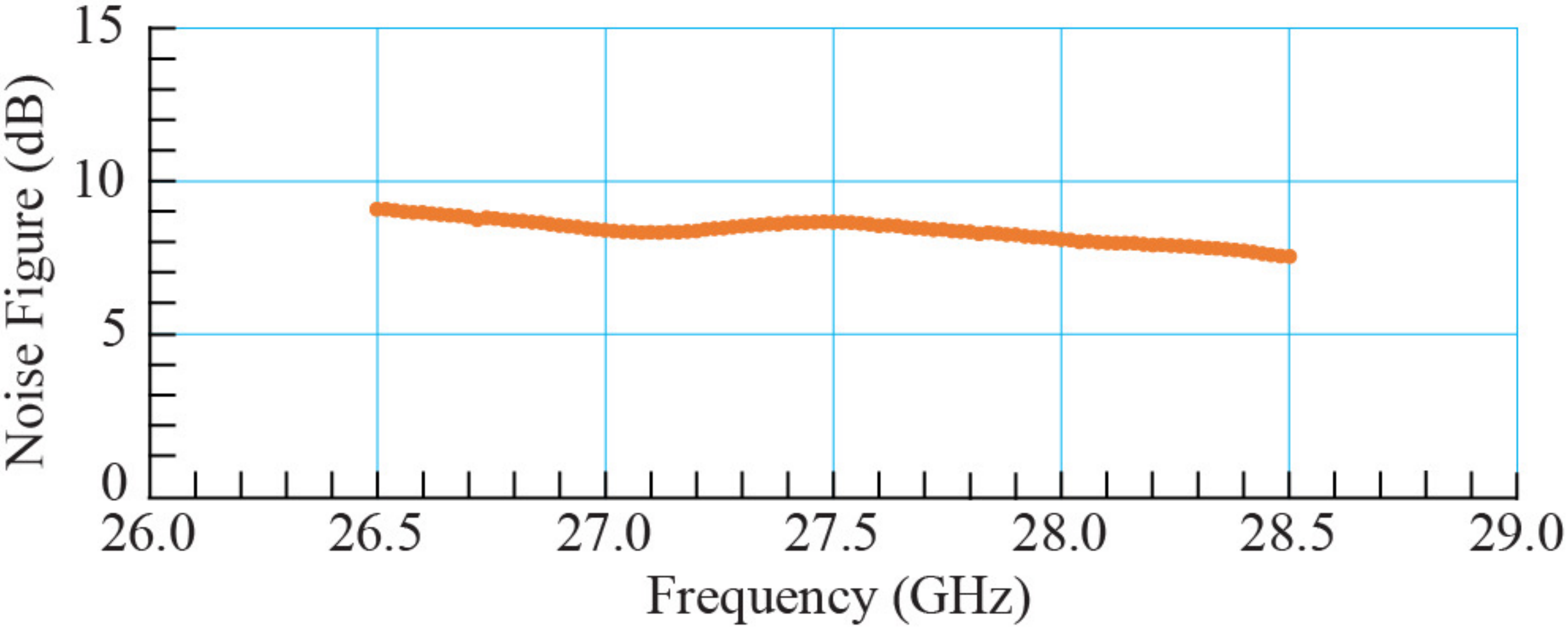
Measured C/I vs. Input Power per Tone at F_0 = 27.5 GHz

(Tone spacing is 5 MHz)



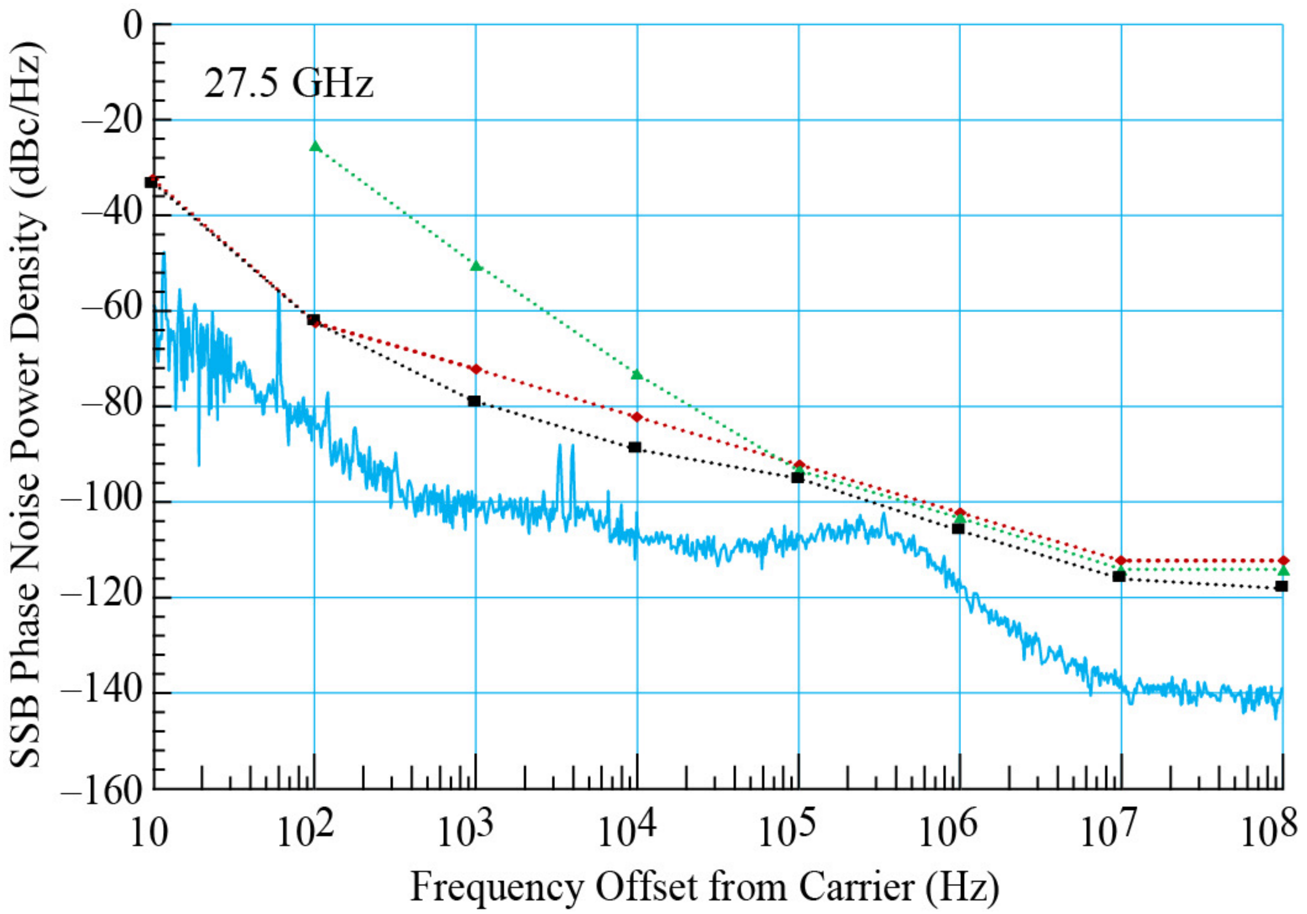
✓ The C/I is less than –50.0 dBc initially and gradually increases to about –20.0 dBc as the HPA is driven from small signal to the 1-dB compression point and beyond. This feature enables roaming without needing complex lookup tables to prevent adjacent band interference

Measured Noise Figure vs. Frequency



✓ In a cognitive radio while transmitting a HPA with low noise figure (≤9.0 dB) implies less S/N ratio degradation of the adjacent channels and while receiving less deviation of the constellation points from their desired locations

Measured SSB Phase Noise Spectral Power Density vs. the Frequency Offset from the Carrier Frequency of 27.5 GHz



The red, green, and black dotted lines are the MIL-STD-188-164C & DVB-S2X aggregate Phase Noise & Professional Services Masks, respectively

- ✓ The HPA phase noise spectrum is compliant with the standards
- ✓ Low HPA phase noise implies less rotation of the waveform constellation points which improves BER performance of the cognitive radio

Table II: Test Result Summary

Parameter	Measured Value
Frequency (f_0) (GHz)	27.5
Output Power (P_{sat}) (dBm)	41.2 (13.2 W)
Small Signal Gain (dB)	30.4
Peak PAE (%)	19.25
Return Loss (dB)	< –10.0
RMS EVM Offset-QPSK, 8PSK, 16APSK, and 32APSK (Drive at 1-dB compression point)	≤ 6%
Out-of-Band Spectral Regrowth (dBc), @ 27.6 GHz	< –30.0 dBc
OIP3 (dBm)	56
Noise Figure (dB)	< 9.0
SSB Phase Noise Power Density (dBc/Hz) (Drive at 1-dB compression point)	Compliant with the MIL-STD Mask

Potential Use Cases for Cognitive Radio Platforms with Wideband HPA

- **Wide Tunable Bandwidth**
  - Enables interoperability between several space network service providers especially in the near-Earth domain
    - This flexibility can be leveraged by an intelligent agent that resides onboard to optimize the selection of a provider by trading several factors, such as cost, latency, and peak data rates, and considering real-time and learned performance, such as weather, availability, and interference
- **Higher-Order Modulation Waveform Amplification**
  - Capable of amplifying higher-order modulation waveforms with low EVM of ≤6%
    - This is significant because it allows standards such as DVB-S2 to allow frame-by-frame selection of modulation from QPSK to 32APSK, allowing the onboard intelligent agent to trade reliability vs. throughput and spectral efficiency
- **Low Intermodulation Distortion Interference**
  - Output OIP3 is on the order of 56 dBm and C/I is ≤-50 dBc initially and gradually increases to -20 dBc when driven from small signal to the 1-dB compression point
    - This characteristic is important for a lunar relay satellite that is transmitting data to several user assets on the lunar surface using FDMA technique. An intelligent agent on the relay satellite could determine which of the several users are within the wide service area that needs to be contacted at any given time

CONCLUSIONS

- The design, architecture & advantages of a Ka-band GaN HEMT MMIC based balanced HPA are presented
- The architecture is validated by characterizing the HPA. The measured output power, gain, PAE, RMS EVM for Offset-QPSK, 8PSK, 16APSK, and 32APSK waveforms, spectral efficiency, 3rd-order IMD products, spectrum, spectral regrowth, NF, & phase noise are presented
- The measured performance characteristics indicates that the HPA meets NTIA, military, and commercial spectral mask requirements & hence enables user terminals that can interoperate and roam. In addition, the benefits of the above performance characteristics toward the design & implementation of cognitive radio platforms is also discussed
- Lastly, as examples, three potential use cases that exploit AI and ML techniques for cognitive radios with an integrated wideband balanced HPA are discussed