# Wideband GaN Power Amplifiers for Software-Defined Radios

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Software-Defined Radio (SDR) architectures are playing an increasingly important role in emerging radio configurations with requirements for supporting multi-band and multi-standard operation. They will be reconfigurable by software which allows improved spectral efficiency and faster deployment of new standards. SDRs have a wide range of applications such as Public Mobile Radios (PMR) used by law enforcement personnel and emergency responders, military communications (milcoms) such as Joint Tactical Radio System (JTRS) for military use, and cellular base station transceivers (BTSs) for commercial use.

## Software-Defined Radios

The Software-Defined Radio (SDR) architecture has been in existence for some time. Practical implementation on a larger scale has been made possible only recently due to the vast improvements in digital signal processing ICs and RF front end components. The components are similar to ones used in radio transceivers including modulator-demodulators, frequency convertors, low noise amplifiers, and power amplifiers. The difference is that operation frequency, modulation formats and encoding are purely determined by software. This offers the system the flexibility to adapt to the communication environment by scanning for available spectrum through software and optimizing the modulation format or radio standards to minimize interference. Significant cost savings are expected from increased spectral efficiency and from the ability to adapt to future standards.

The key enablers for SDR include wideband linear front end components such as the power amplifier (PA) and low noise amplifier (LNA), ADC and DACs for RF-to-digital-to-RF conversion, and a high speed DSP for dynamic signal processing. Wide bandwidth and linearity requirements are critical to the ability of the SDR to adapt to multiple bands, modulation formats, and radio standards. For systems like the JTRS and PMR, power amplifiers need to operate over multi-decade bandwidth covering VHF, UHF, and L-bands, and need to be highly efficient and compact, especially when the amplifier is used in a handheld or mobile unit. By using a single wideband PA instead of individual narrowband amplifiers for each band, significant cost savings are obtained

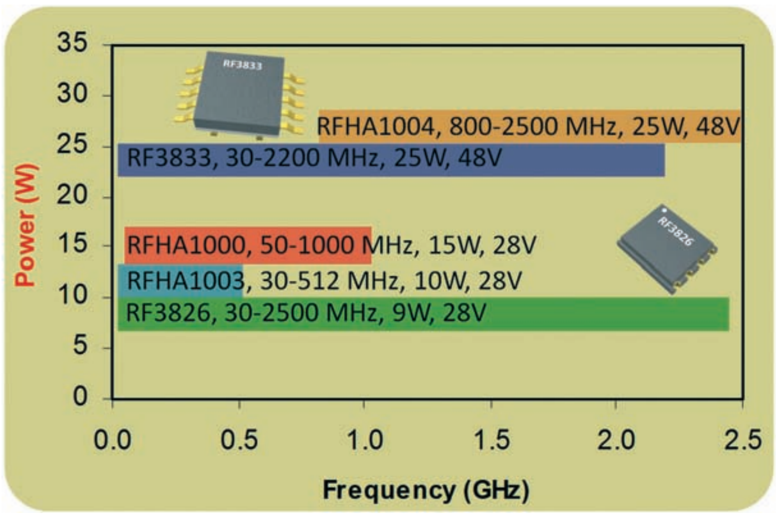


*Figure 1: Output power and instantaneous bandwidth of some of RFMD's GaN power ICs.*

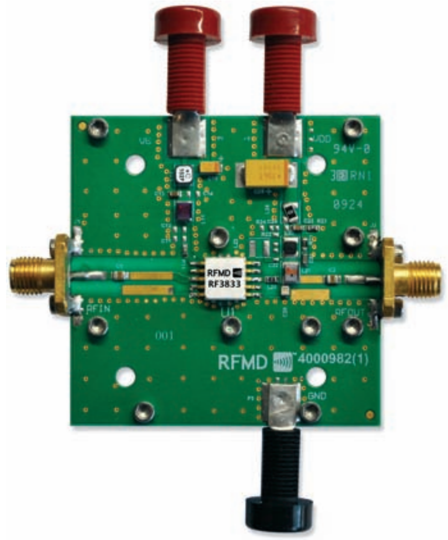


*Figure 2: Typical 50Ω matched 30 to 2500 MHz band application circuit.*

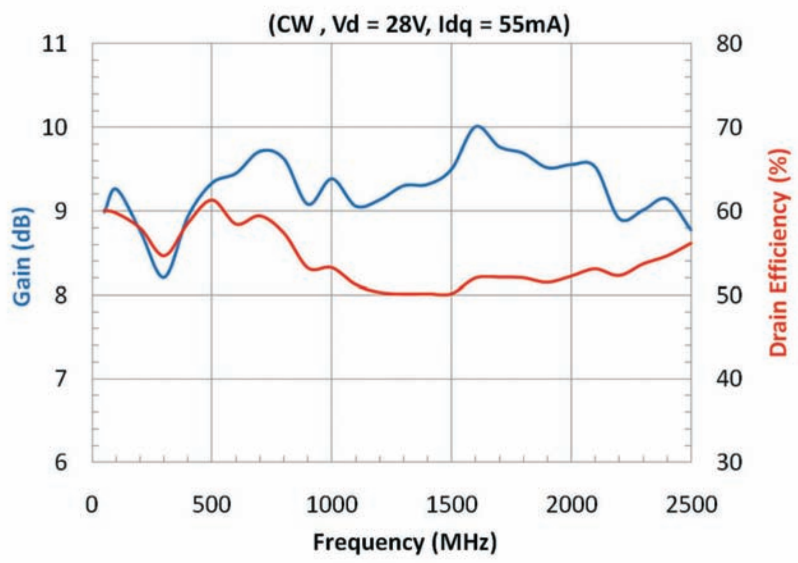


*Figure 3: RF3826 gain and drain efficiency over 30 to 2500 MHz band at an output power of 9 W.*

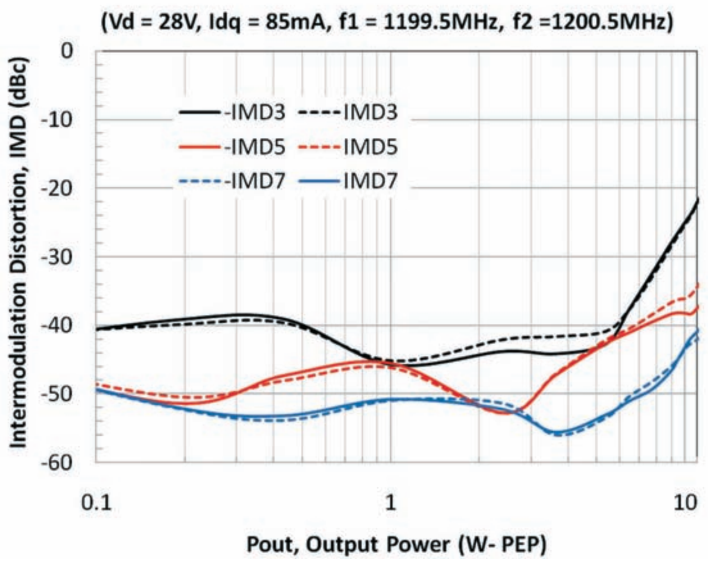


*Figure 4: RF3826 two-tone intermodulation performance at a carrier frequency of 1200 MHz and 1 MHz tone spacing.*

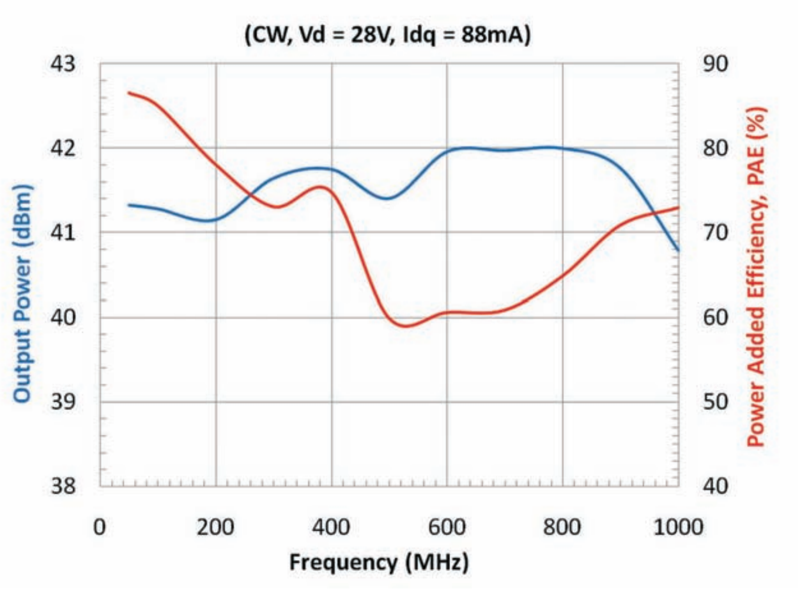


*Figure 5: RFHA1000 output power and power-added efficiency over 50 to 1000 MHz at an input power of 27 dBm.*

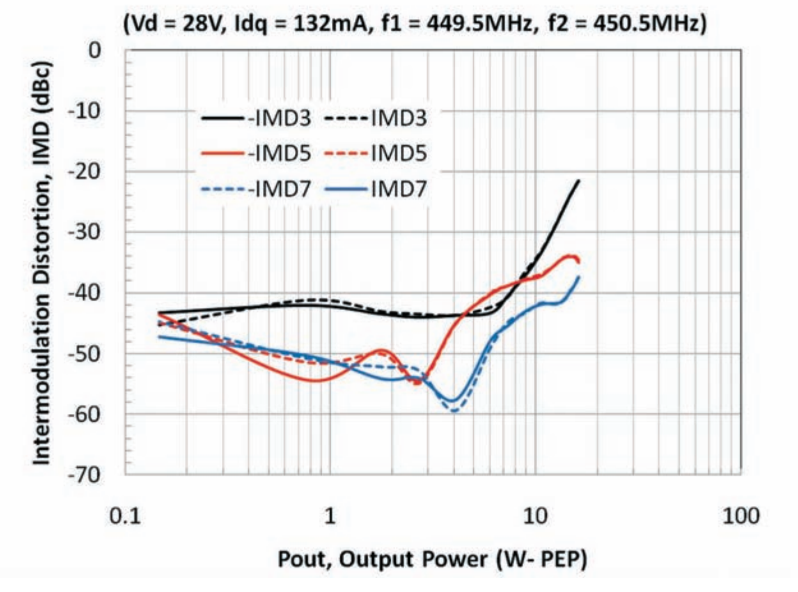


*Figure 6: RFHA1000 two-tone intermodulation performance at a carrier frequency of 450 MHz and 1 MHz tone spacing.*

through reduced component count by eliminating multiple PAs and its supporting bias, matching, switch and filter circuitry, further saving board real estate and reducing overall size. The PA requirements for portable and mobile SDR platforms range in power from a few watts to hundreds of watts, covering multi-octave and even multi-decade bandwidth while maintaining high efficiency.

## Incumbent Technology

Today's communication radios are relatively narrowband and use gallium arsenide (GaAs) and silicon (Si) based PAs to deliver low to high wattages of power covering the RF carrier frequency for that radio standard. There are inherent limitations in extending these PAs to cover wider multi-decade bandwidth. High power devices have large periphery and hence large device capacitances that limit bandwidth. In addition, the large periphery devices have low optimal load impedances that limit the maximum power that can be driven into a 50Ω system without broadband impedance transformation. Losses in the transformation network further limit output power and efficiency which then impact battery operating life and increase power dissipation in both portable and mobile systems. Next generation radios such as SDR will need to embrace new PA semiconductor technology and packaging solutions capable of addressing the RF electrical and mechanical requirements.

## RFMD GaN Technology

RFMD, using its leadership in the design and manufacture of multi-band power amplifiers for cellular handsets, has developed an advanced GaN process that facilitates development of next generation broadband power amplifiers for emerging applications. This technology benefits greatly from RFMD's industry-leading scale with wafer fabrication in the world's largest III-IV factory. These fabs start ~25% of the world's GaAs wafers and have demonstrated a 78% learning curve for cost reduction. GaN manufacturing is co-located with this high volume GaAs line and utilizes many of the same process steps, techniques, and expertise. Full technology and initial product qualification for the first- and second-generation GaN process is completed and foundry services are available as well.

GaN HEMT devices with high breakdown voltage and high power density capability offer several advantages for broadband high power amplifiers. They have larger optimal load impedance, smaller device periphery and lower capacitances for a given power level compared to other technologies. RFMD's AlGaN/GaN HEMT devices further employ a source-connected field modulation plate that enables operation from 14 V to 50 V drain voltage. RFMD's first-generation process is optimized for peak power and peak efficiency. The second-generation GaN process offers improved linearity in exchange for lower power density, while maintaining high efficiency. Both RFMD GaN processes offer advantages over incumbent technology targeting SDR applications.

## RFMD GaN Power ICs

**Figure 1** shows a sample of broadband GaN Power IC amplifiers available from RFMD targeting SDR applications. A variety of devices with instantaneous bandwidth from 30 to 512 MHz and extending through 30 to 2500 MHz, and from power levels of 9 to 25 W is available. The device inputs are internally matched to 50Ω and designed to be unconditionally stable with flat gain down to low frequencies. Unlike competing solutions that use unmatched transistors, where the user has to struggle with matching the device over a broadband while trying to keep it stable over multi-decade bandwidth, the internal match and stability circuits in RFMDs GaN power ICs ensures ease of use while minimizing board area.

The Power ICs employ a multi-chip module (MCM) approach consisting of GaN on SiC active die in combination with a GaAs die containing the integrated passive circuits (IPCs). This approach offers an optimal tradeoff between performance and cost in this frequency range by minimizing the SiC die area compared to an MMIC design. The passive chip includes matching circuitry, stabilization circuit, and bias decoupling components. The space consuming passive circuitry is located on a lower cost substrate, while keeping the overall amplifier size compact. The short turnaround time of the high volume GaAs foundry and utilization of common GaN die enables very short design cycles for MCMs of this type.

An 8-pin AlN 5 mm x 6 mm leadless LCC package which matches the SO8 footprint is used for the lower power parts, and a 10-pin 7 mm x 8 mm leaded Copper package is used for the higher power parts. The packaged devices are soldered to an evaluation board and tested. For the application circuit, (**Figure 2** shows an example), the input is fully matched to 50Ω within the package. At the output a lumped two-element match is used, which offers the flexibility to optimize the performance for linearity, output power, or efficiency as needed for the application. This flexibility allows for a single power IC device to be used in multiple systems incorporating the same PCB layout but with a changing BOM. Broadband DC-blocking capacitors, DC

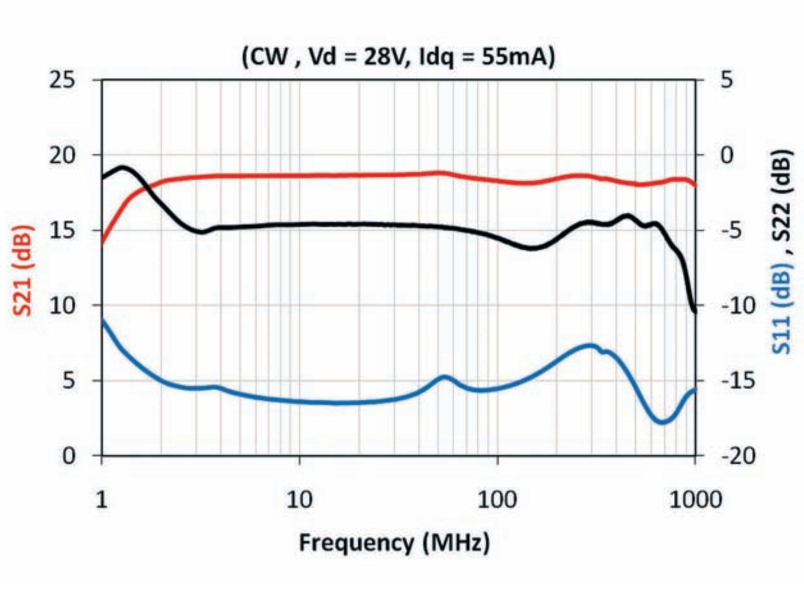


*Figure 7: RFHA1003 small-signal parameters showing 18 dB gain over 2 to 512 MHz.*

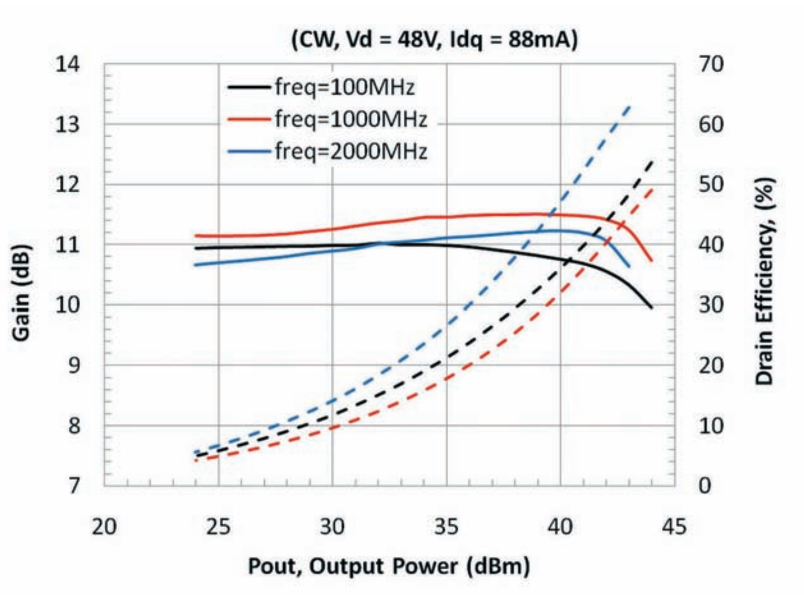


*Figure 8: RF3833 gain and drain efficiency on CW drive up at frequencies of 100, 1000, and 2000 MHz.*

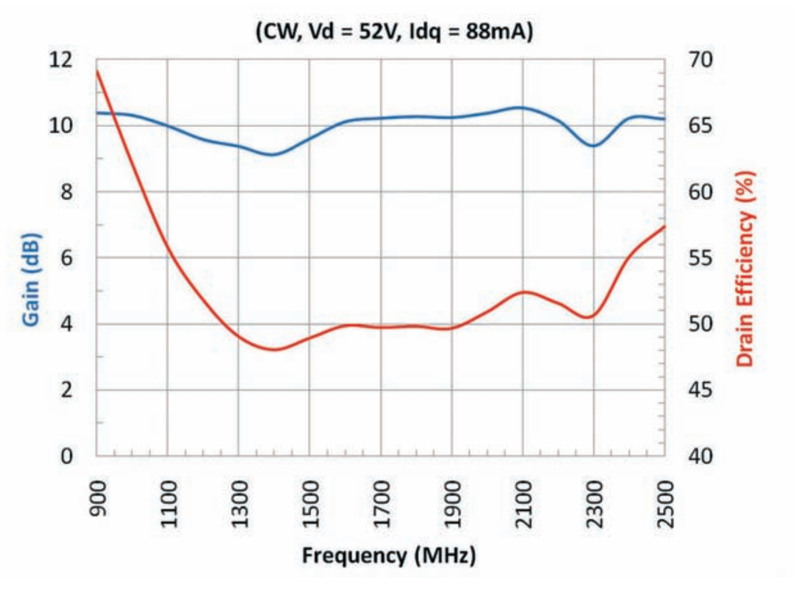


*Figure 9: RFHA1004 gain and drain efficiency over 900 to 2500 MHz band at an output power of 25 W.*

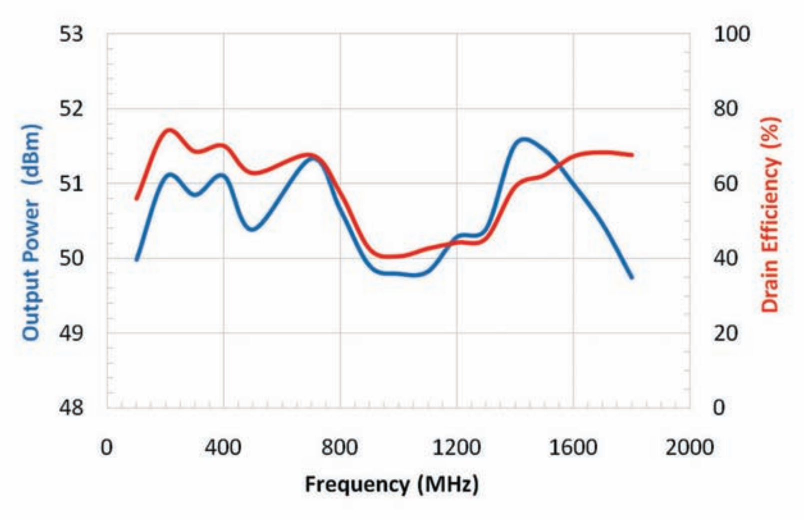


*Figure 10: Output power and efficiency of the 100 W module that combines four RF3833 GaN Power ICs.*

bias chokes, and decoupling capacitors are located on the evaluation board.

### RF3826: 9 W, 30 to 2500 MHz

RF3826, packaged in an 8-pin AlN 5 mm x 6 mm leadless LCC package, is a 9 W PA with an instantaneous bandwidth of 30 to 2500 MHz operating at 28 V and designed for milcom and PMR-type applications. On CW drive up to 9 W the device obtains about 9 dB gain and 50 to 62 % drain efficiency over the band (**Figure 3**). The two-tone linearity performance of the PA at a carrier frequency of 1200 MHz with 1 MHz tone spacing (**Figure 4**) shows 7 W output power with better than ~-35 dBc IMD3. When the output match is optimized for WiMAX applications, the device obtains better than 3% EVM measured at 32 dBm output power and 24.1% PAE over the 2.1 to 2.5 GHz band.

### RFHA1000: 15 W, 50 to 1000 MHz

RFHA1000, packaged in an 8-pin AlN 5 mm x 6 mm leadless LCC package, is a 15 W PA with an instantaneous bandwidth of 50 to 1000 MHz operating at 28 V and designed for milcom and PMR applications. On CW drive up the device obtains about 15 dB gain and 15 W of power with >60 % drain efficiency over the band (**Figure 5**). The two-tone linearity performance of the PA at a carrier frequency of 450 MHz with 1 MHz tone spacing (**Figure 6**) shows 10 W output power with better than about -35 dBc IMD3.

### RFHA1003: 10 W, 30 to 512 MHz

RFHA1003, packaged in an 8-pin AIN 5 mm x 6 mm leadless LCC package, is a 10 W PA with an instantaneous bandwidth of 30 to 512 MHz operating at 28 V and designed for milcom and PMR applications. On CW drive up the device obtains about 15 dB gain and 10 W of power with >65 % drain efficiency over the band. The lower cutoff frequency could be further extended down to 2 MHz (**Figure 7**) by using a suitable choice of external bias network.

### RF3833: 25 W, 50 to 2200 MHz

RF3833, packaged in a 10-pin 7 mm x 8 mm leaded copper package, is a 25 W PA with an instantaneous bandwidth of 50 to 2200 MHz operating at 48V and designed primarily for milcom and PMR mobile applications. On CW drive up the device obtains 10 to 11 dB gain and 50 to 63% efficiency (**Figure 8**) at 25 W of output power.

### RFHA1004: 25 W, 800 to 2500 MHz

RFHA1004, packaged in a 10-pin 7 mm x 8 mm leaded copper package, is a 25 W PA with an instantaneous bandwidth of 800 to 2500 MHz operating at 52 V and designed primarily for milcom and PMR mobile applications. On CW drive up the device obtains about 10 dB gain and 48 to 68% efficiency over the band at 25 W of output power (**Figure 9**).

These 50Ω matched GaN power ICs also offer a practical solution for scaling to higher power over broad bandwidth. As a demonstration [1], we combined four RF3833 devices within a 2 inch x 2 inch board area to obtain 100 W output power over 100 to1800 MHz with 41 to 74% efficiency over the band (**Figure 10**).

## Summary

RFMD is rapidly commercializing broadband GaN power amplifiers for SDR platforms by utilizing its design expertise, proven high volume advanced III–V semiconductor fabrication facilities, and high throughput assembly and packaging channels. RFMD's Power IC GaN product family provides cost effective solutions that reduce system size and complexity while addressing the need for wideband power with efficiencies exceeding typical solutions used today. Further advances in RFMD's GaN technology and packaged Power ICs will provide future-proof solutions able to meet linearity requirements of more complex modulation waveforms envisioned with next generation multi-band, multi-standard portable and mobile SDRs.

## References

[1] K. Krishnamurthy et. Al., "A 0.1-1.8 GHz, 100 W GaN HEMT Power Amplifier Module", 2010 IEEE CSICS. Dig., Session-O.2, 3-6 Oct. 2010.