

# Power Amplifier and Front End Module Requirements for IEEE 802.11n Applications

By David Guo  
RFMD

This article reviews PA performance for the newest WiFi specifications, and describes products offered by the author's company for this application

Customer demands for increased data bandwidth require WiFi Access Point (AP) and Customer Promise Equipment (CPE) to support IEEE 802.11n (11n) technology with peak

data rates up to 600 Mbps. According to market research reports, almost all new WiFi products have integrated 11n technology, and the forecast for shipments of 11n equipment in 2012 is one billion units. In order to improve the mobile data traffic, 11n will be one of the standard features in mobile phones to address the high data throughput service, such as streaming video and gaming. In this article, we examine 802.11g vs. 802.11n, focusing on the requirements for the power amplifier (PA) or integrated PA front end module (FEM) in 11n designs.

## IEEE 802.11n vs. 802.11g/a

In 11n, multiple input multiple output (MIMO) is an addition to the physical layer (PHY). MIMO is the use of more than one transmitter and more than one receiver on the same wireless device to increase data throughput. The IEEE 802.11n standard can support much faster data rates, up to 600 Mbps, compared to 802.11a/g which has a peak data rate of 54 Mbps. The 11n PHY supports a wide array of different data rates, called modulation coding scheme (MCS) rates, as listed in Table 1.

## 802.11n PA Selection Requirements

### 1. RF Radiated Power

The main specification of WiFi Access



WiFi customer products incorporate front-end modules like the RF5605 or stand-alone power amplifiers like the RF5652.

Point (AP) is shown in Table 2. [Tables 1 and 2 are on the following page.]

For most designs, the power levels desired at the antenna are the same for 11n as they were for earlier 11g platforms. The main stream MIMO products in current designs include 1x1 (1 transmit and 1 receive), 2x2, and 3x3 multi-stream solutions to provide the highest data rates possible.

### 2. Power Amplifier Linearity

As a critical component for Access Points, PA's performance dominates the performance of AP in coverage, battery life and data rate capability. A PA for 11n is required to provide higher linear power than 11g because the PAR (Peak-Average Ratio) of 11n modulation (MCS7) is about 0.5 to 1 dB higher than that of 11g (in 64 QAM, 54 Mbps) due to the higher coding rate and the wider modulation bandwidth.

MCS index	Spatial streams	Modulation type	Coding rate	Data rate (Mbit/s)			
				20 MHz channel		40 MHz channel	
				800 ns GI	400 ns GI	800 ns GI	400 ns GI
0	1	BPSK	1/2	6.50	7.20	13.50	15.00
1	1	QPSK	1/2	13.00	14.40	27.00	30.00
2	1	QPSK	3/4	19.50	21.70	40.50	45.00
3	1	16-QAM	1/2	26.00	28.90	54.00	60.00
4	1	16-QAM	3/4	39.00	43.30	81.00	90.00
5	1	64-QAM	2/3	52.00	57.80	108.00	120.00
6	1	64-QAM	3/4	58.50	65.00	121.50	135.00
7	1	64-QAM	5/6	65.00	72.20	135.00	150.00
8	2	BPSK	1/2	13.00	14.40	27.00	30.00
9	2	QPSK	1/2	26.00	28.90	54.00	60.00
10	2	QPSK	3/4	39.00	43.30	81.00	90.00
11	2	16-QAM	1/2	52.00	57.80	108.00	120.00
12	2	16-QAM	3/4	78.00	86.70	162.00	180.00
13	2	64-QAM	2/3	104.00	115.60	216.00	240.00
14	2	64-QAM	3/4	117.00	130.00	243.00	270.00
15	2	64-QAM	5/6	130.00	144.40	270.00	300.00
...	3	...	...	...	...	...	...
23	3	64-QAM	5/6	195.00	216.70	405.00	450.00
...	4	...	...	...	...	...	...
31	4	64-QAM	5/6	260.00	288.90	540.00	600.00

Table 1 · Modulation coding schemes and data rates.

Application	Power Level	Modulation	MIMO Configuration
Indoor Coverage	23dBm, 25dBm, 27dBm	11b, 11g, 11a, 11n	2T2R, 2T3R, 3T3R
Outdoor Coverage	27dBm, 30dBm	11b, 11g, 11a, 11n	2T2R, 2T3R, 3T3R

Table 2 · WiFi PA power level specification.

### 3. DC Supply

For design convenience and diversity, PA or FEM specifications request operation at different DC supply voltages, such as at 5.0 and 3.3 V (industry standard DC supplies voltages). The other advantage of a PA working with wide supply voltage range is the flexibility that designers have using the same part for different power output level designs.

### 4. Power-Down Function and Transient Response

11n is a TDD (Time-Division Duplex) system. When an AP works in receive mode, to save DC power consumption, the PA can be shut off to save total DC power consumption. A competitive PA or FEM should have power down function and low quiescent current capabilities.

In an 11n system, a fast turn on/off of PA or FEM is essential for system operating in duty cycles versus continuous wave (CW) operation. Based on an 11n modulation scheme, the Guard Interval (GI) between bursts are defined as 800 and 400 ns and will require the turn on/off time of PA or FEM to be as short as 400 ns.

### 5. EVM in Burst Mode

Linearity is the key specification of an 11n PA or FEM. Currently, in an AP system, System-on-Chip (SOC) solutions with integrated baseband, modulator/demodulator and amplifier buffers are widely used. Most designers are struggling to get adequate EVM from SOC integrated solution alone, requiring improved linearity from the PA to meet system EVM specifications. Typically, a PA is

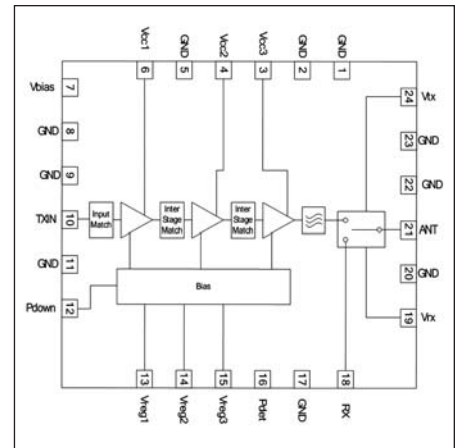


Figure 1 · RF5605 front-end module (FEM) functional block diagram.

required to have less than 3% EVM typical at rated power.

In MIMO mode, the transmitter can operate in duty cycle ranging from 90% to as low as 30%. The consistency of a PA's EVM in this condition is a must to meet system EVM requirement for highest data rate performance. The dynamic EVM performance [5] is a key PA or FEM design spec for which EVM is measured at 50% duty cycle. The higher the EVM in low duty-cycle operation of the PA or FEM, the more the system performance will be degraded.

### 6. Harmonics Emission

Harmonics emission is another design parameter to be considered for PA or FEM requirement. For the China market, the harmonics emission is defined to be -30 dBm/MHz [6] as maximum. For the North American market, FCC lists -41.3 dBm/MHz [1] as the maximum allowed emission power. Other countries have differing requirements.

### 7. Easy to Implement

The 11n system operates in both the 2.4 and 5.8 GHz bands. Designers prefer to choose PAs or FEMs with fewer external components, with the benefit being simplified RF matching, improved performance optimization for mass production and fast time-to-

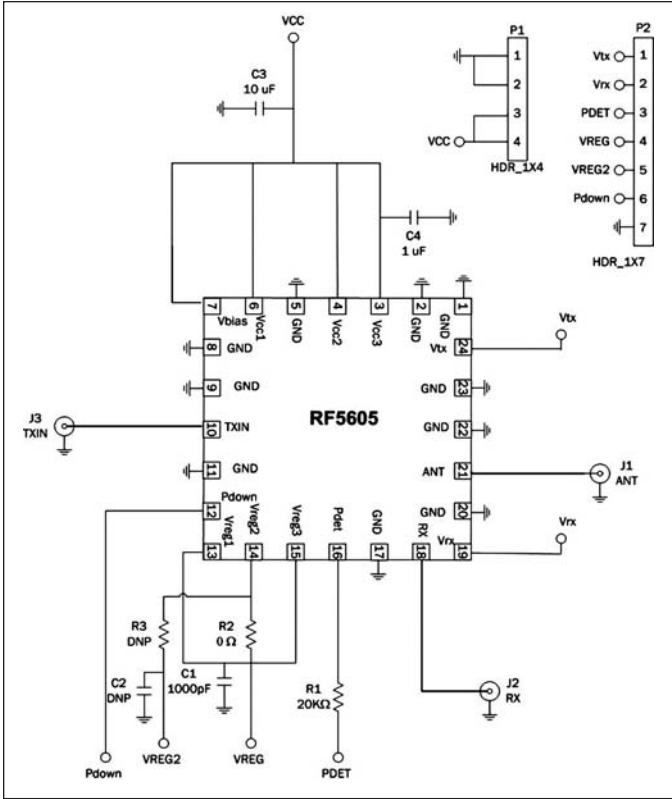


Figure 2 · RF5605 application schematic.

market. FEM integrates sensitive RF matching components in the package, which improves the production yield of end customer products.

For 3Tx3Rx and 4Tx4Rx MIMO products, a front end module is a must for designs that require limited PCB size.

**RFMD RF5605 FEM Performance**

The RF5605 (Figure 1) is a 1x1 MIMO FEM module that is intently specified to address IEEE 802.11b/g/n

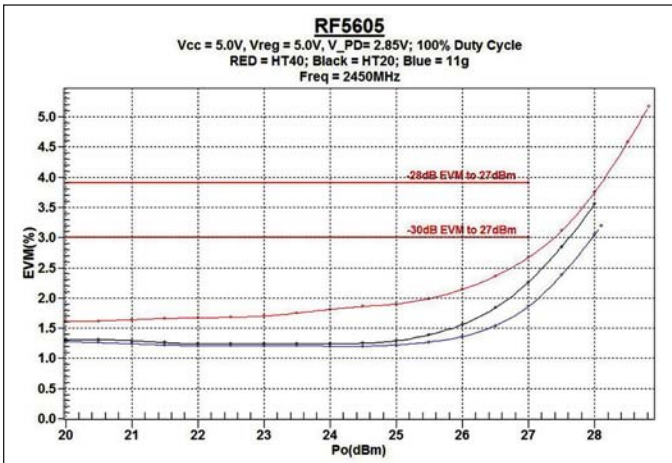


Figure 4 · EVM plot for 11g vs. 11n.

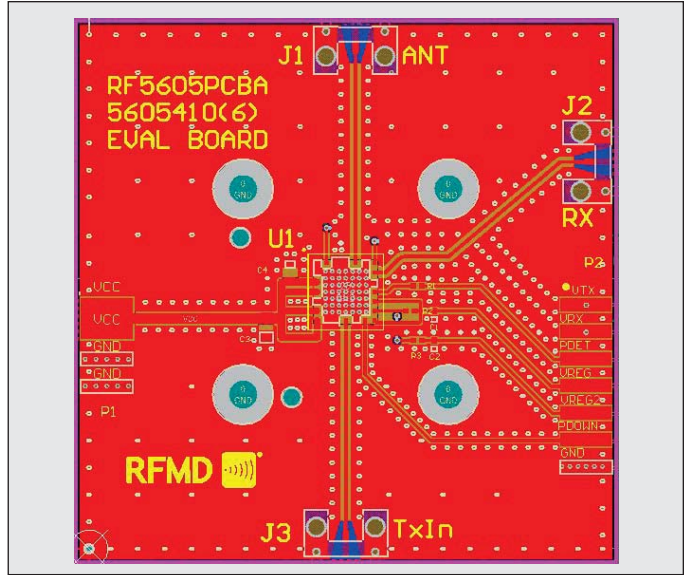


Figure 3 · The RF5605 evaluation board PCB; top layer on FR4.

WiFi 2.4 to 2.5 GHz consumer premise equipment (CPE) applications. As shown in Figure 1, the module has an integrated three-stage linear PA, TX harmonics filtering and a SPDT switch. The RF5605 is fully matched input and output for 50 ohm systems, incorporating matching networks optimized for linear output power and efficiency. This module requires a DC supply voltage (5.0 V typical) to PA, and a 2.85 V to set Icq (quiescent current) for optimized linearity performance. Also, there is a power down (PN) pin available to shut down the PA when operating in RX mode. Applying a PD voltage of 2.2 to 3 V to turn the PA on; and PD < 0.2 V to turn the PA off.

At 5.0 V DC supply, the RF5605 has 34 dB typical gain and is capable of 27 dBm 11n HT20 linear power for EVM <3% at the ANT port of the FEM. With its built-in harmonics filter, the harmonics at the ANT port is <-35 dBm.

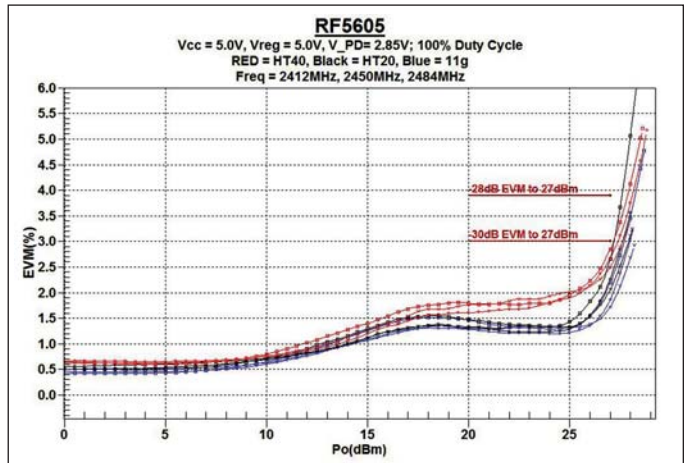


Figure 5 · EVM plot in 100% duty cycle.

WiFi PA REQUIREMENTS

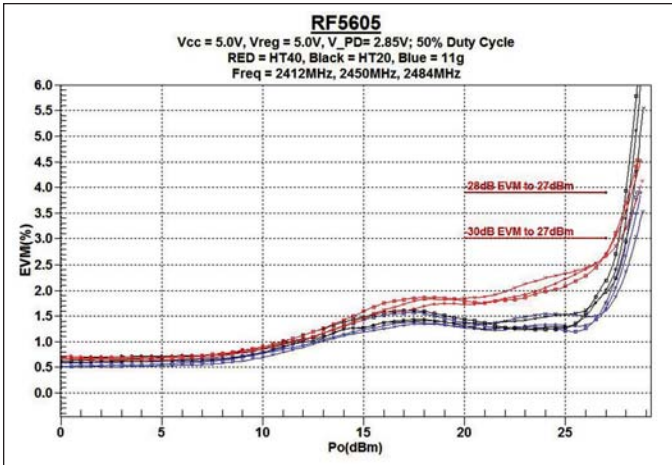


Figure 6 · EVM in 50% duty cycle.

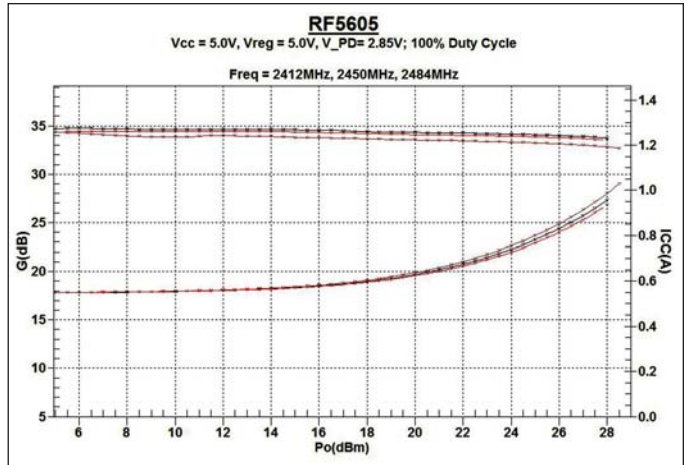


Figure 7 · RF5605 gain and Icc plot.

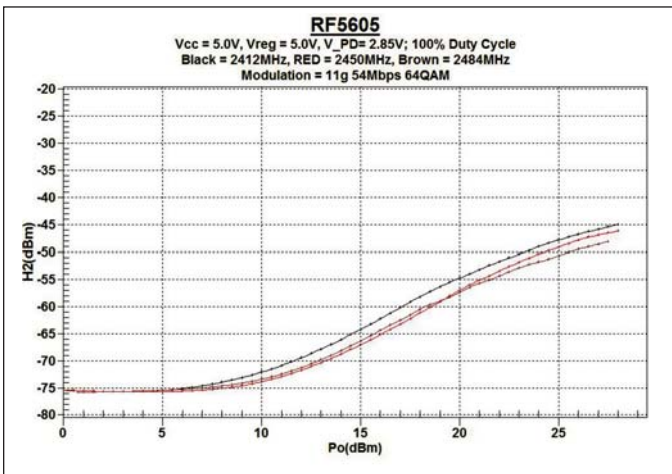


Figure 8 · RF5605 2nd harmonic plot.

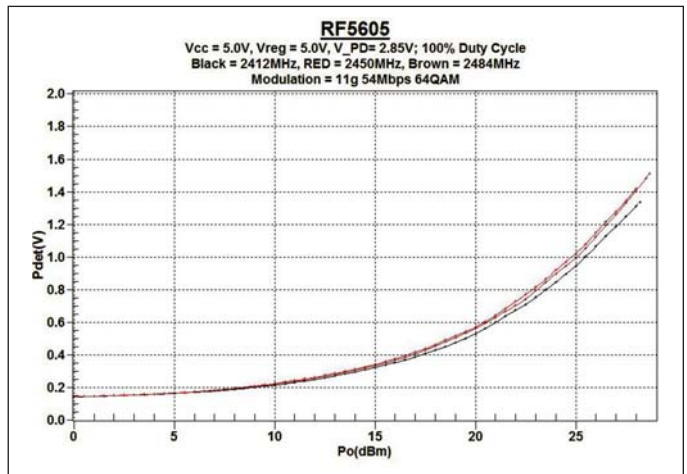


Figure 9 · RF5605 Pdet plot.

The RF5605 integrates a power detector at the PA output that can be used for system RF power monitoring (for open loop operation).

The RF5605 is in a 6 × 6 mm laminate package. Only three external DC decoupling capacitors are required for operation, greatly reduc-

ing the PCB area of the PA and simplifying implementation by the customer. With RFMD's 100% RF test in production, the FEM improves end-of-line production yields.

Part #	Functionality	Minimum 11g Pout (dBm)	Typical 11g EVM (%)	Minimum 11n Pout HT20 (dBm)	Typical 11n EVM (%)	Supply Voltage (V)	Gain (dB)	Package Size (mm)
RF5652	Unmatched PA	30	3	29.5	3	5	34	5x5
RF5632	Unmatched PA	28	3	27.5	3	5	34	4x4
RF5605	FEM	27.5	3	27	3	5	33	6x6
RF5602H	Unmatched PA in Hybrid	29	3	28.5	3	5	33	3x3
RF5602	Unmatched PA	26	3	25.5	3	5	34	3x3
RFFM4200	FEM	25	3	24.5	3	5	34	6x6

Table 3 · A list of RFMD PA and FEM product solutions for IEEE 802.11n.

RF5605 11g vs. 11n performance

Due to the modulation difference, 11n (MCS7) in a single stream operation has a higher coding ratio than 11g at 54 Mbps, both in using 64 QAM modulation. In theory, the estimated PAR of 11n MCS7 in HT20 (20 MHz BW) is about 0.5 dB higher than that of 11g at 54 Mbps; and 11n in MCS7 HT40 (40 MHz BW) has slightly higher PAR than that of HT20. In other words, to meet the same EVM level for 11n, it requires

the PA to have a higher linear power range than 11g. On an EVM plot, it will show less linear  $P_{OUT}$  at the same EVM line to the same PA.

Figure 4 is the plot of RF5605 tested in different modulations at the same biasing conditions and with the same test instrument. The plot shows the linear power delta of approximately 0.5 dB between 11g and 11n HT20 at EVM = 3%; and about 0.25 dB delta between 11n HT20 and HT40.

A typical RF5605 on an evaluation board was tested at  $V_{cc} = 5.0$  V,  $V_{reg} = 2.85$  V and  $V_{PD} = 2.85$  V, and at room temperature. The EVM plots in duty cycles of 100% and 50% were depicted separately. For EVM = 3%, the RF5605 can provide greater than 27 dBm linear power at the ANT port of the FEM. At lower duty cycle, 50% as an example, the EVM has not changed considerably compared to that at 100% duty cycle.

The gain of RF5605 is at 34 dB. At 27 dBm output linear power, the operation current to the PA is 860 to 930 mA across the frequencies.

The 2nd Harmonics were better than -35 dBm, tested with 11g modulation 64QAM 54 Mbps. The Pdet voltage in output power range of 0 to 28 dBm is 0.14 to 1.5 V.

### Summary

RFMD has designed many PAs or FEMs to address the 11n market demands for differing RF power levels. Table 3 lists the released PAs and FEMs and the power level and EVM specifications. For more information of RFMD 11n PA and FEM solutions, please check on RFMD website: <http://www.RFMD.com>

### About the Author

David Guo is the Staff Applications Engineer in RFMD WCBU. He can be reached by email at [DAGuo@RFMD.com](mailto:DAGuo@RFMD.com). The author would like to thank all of his colleagues who have contributed to this article.

### References

1. IEEE 802.11n Standard: IEEE 802.11n-2009.
2. RF5605DS datasheet, available at [www.RFMD.com](http://www.RFMD.com)
3. RF5652DS datasheet, available at [www.RFMD.com](http://www.RFMD.com)
4. RF5602DS datasheet, available at [www.RFMD.com](http://www.RFMD.com)
5. Sang-Woong Yoon, "Static and Dynamic Error Vector Magnitude Behavior of 2.4-GHz Power Amplifier," IEEE MTT-55, April 2007, pp. 643-647.
6. GB15629.11-2003: The Chinese National Standard for Wireless LANs.