Linear Power Amplifiers for Point-to-Point Radio Applications

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There is a need to develop a new generation of highly linear, high frequency chipsets to address traffic congestion.

Microwave links in the range of 10 – 27 GHz are commonly used for point-to-point (P2P) connectivity. With the phenomenal increase of cell phone users and demand for high data rates, link traffic is getting congested. Since available channel bandwidth is limited and fixed, link manufacturers are addressing this traffic congestion by increasing spectral efficiency and are using a complex modulation scheme such as 4 – 1024 QAM.

In order to support this high order modulation scheme, there is a need to develop a new generation of highly linear, high frequency chipsets starting from baseband to antenna for Tx path and from antenna to baseband for Rx path.

RFMD has developed a new generation of chipsets as shown in Figure 1 in the frequency range of 10 – 27 GHz to address the growing issue of traffic congestion. This portfolio includes voltage-control oscillators (VCOs) featuring state-of-the-art phase noise, upconverters with best IP3, noise figure (NF), and LO leakage over 30 dB gain control range, and downconverters that have achieved very low NF and high IIP3 together in their class.

A key to the success of the Tx chain at a high frequency component level is the power amplifier. As the modulation rate is increased, the PA's output power is backed-off, or in other words, PA output power is dynamically adjusted during link operation. The PA should be capable of maintaining a high level of intermod suppression (C/I3) at varied output power. In addition, it needs to have a decent noise figure to minimize error vector magnitude, (EVM), especially when the PA input signal contains higher order modulations.

All RFMD PAs referenced in this article have been designed with these constraints and limitations in mind and they are packaged in a 6 x 6 QFN package. RFMD's 10 – 13 GHz linear PA (RFPA1002) covers 10, 11, and 13 GHz bands of point-to-point (P2P) link. This PA has a small signal gain of 26±1 dB, OIP3=37 dBm at 28 dBm/DCL (Vd=4V, 982mA) and 42 dBm (at Vd=7V, 1A). The P1dB of this PA is ~+33 dBm. It can also be used as a VGA by adjusting the gate control voltage. For gain dynamic range of 15 dB, Pdiss varies from 1.25 W to 6.0 W, worst case IM3 for entire gain dynamic range is >46 dBc at Pin = -15dBm.

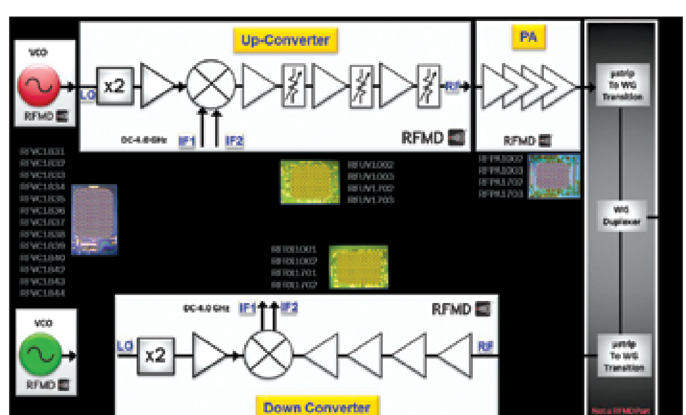

Figure 1 • RFMD's 10 – 27 GHz Chipset.

The RFPA1003 is a 14.4 - 15.4 GHz high linearity PA and it has been designed for 15 GHz band P2P link. It has 25 dB gain, IM3=50dBc at P_{OUT}=20dBm/DCL and 35dBc at P_{OUT}=28dBm/DCL. P1dB of this PA is +32.5 dBm and OIP3=42.5 dBm at P_{OUT}=28dBm/DCL.

The RFPA1702 is a 17.7 - 19.7 GHz linear PA. It is designed for 18 GHz P2P link. It has 25 dB gain, IM3=52dBc at P_{OUT}=20dBm/DCL and 32.5dBc at P_{OUT}=27dBm/DCL. P1dB of this PA is +31.0 dBm and OIP3=41dBm at P_{OUT}=28dBm/DCL. Its power dissipation is ~7.0 W and NF~7.0 dB. With over 15 dB gain control, it consumes 2 to 6W dc power and OIP3 varies from 20 to 40 dBm. The minimum IM3 is >55dBc for Pin=-15dBm/DCL. All of these PAs have been internally fabricated using 0.25μm PHEMT technology and packaged in a 6 x 6 QFN package.

Circuit Design

The key to circuit design is the device model. This model should be able to accurately predict small and large signal behavior including P1dB and IM3. The model, which is developed using DC-IV and [S]-parameter over various bias voltages, accurately predicts DC, [S]-parameters, P1dB and Psat performance. Such models usually over predict IM3, and its contours are sometimes severely dislocated on the Smith Chart compared to measured contours. RFMD's PAs are designed based on a combination of measured load-pull data and modified device models to properly incorporate IM3 behavior and device scaling based on IM3.

A good technique to PA design is to partition the spec into number of stages and then decide the device size for each stage that should provide required gain, power, and IM3 per stage and inter-stage drive ratio. To design a linear power amplifier one should look for high gain and best possible IM3 for specified output power and each device should be biased for a little higher Idss compared a saturated power amplifier design. Normally a saturated power amplifier is biased close to deep class AB condition. Agilent's ADS and Momentum have been used to design power amplifiers discussed here. Voltage and current probes have been used at all parallel nodes feeding and combining signal and power to active device. This helped to determine to maintain close to identical impedances at all similar nodes and thus minimize odd-mode problem. Due to inter-coupling among feed network, impedance mismatch occurs that cause odd-mode stability issues. To suppress odd-mode insta-

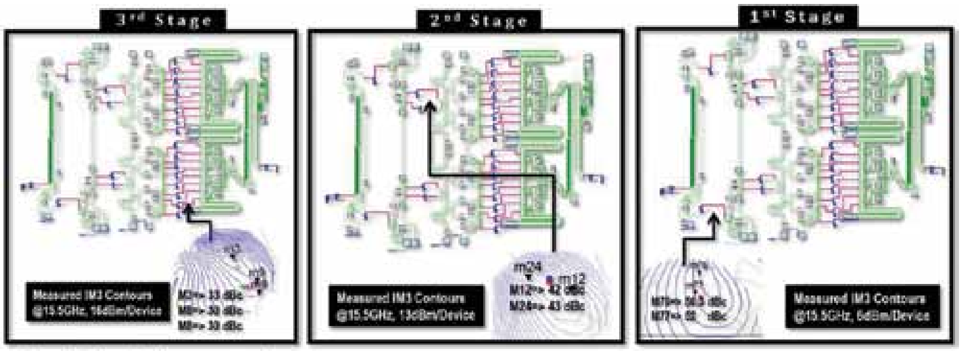

Fig. 2: Simulation example

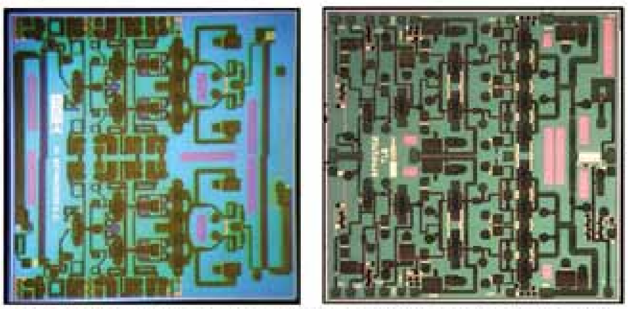

Fig. 3a: Die photographs of 10, 11, 13, and 18GHz band PAs

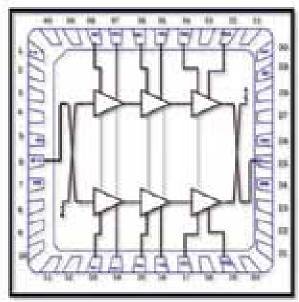

Fig. 3b: PA package outline

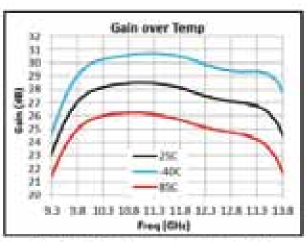

Fig. 4a: Over temp. measured gain

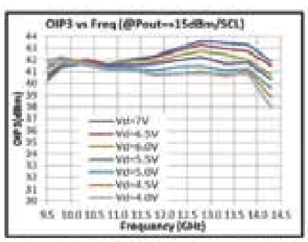

Fig. 4b: Variation of OIP3 vs. freq. at Vd=4-7V

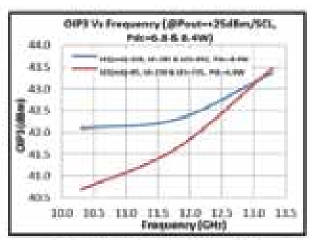

Fig. 4c: Variation of OIP3 with Pdc

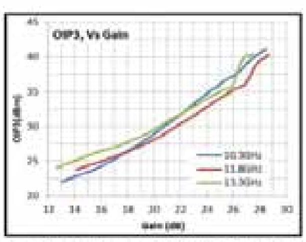

Fig. 4d: Variation of OIP3 with gain (VGA)

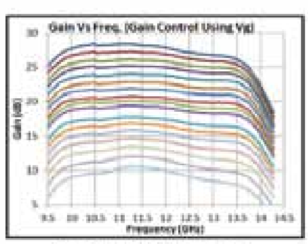

Fig. 4e: RFPA1002 as VGA, gain variation with Vg

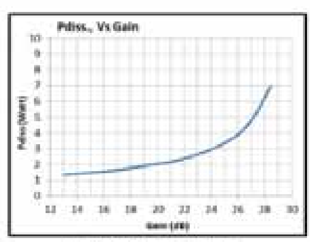

Fig. 4f: Pdc versus gain

RFPA1002 (10-13GHz Linear Power Amplifier)					
Vd	Id1(mA)	Id2(mA)	Id3(mA)	Id(Total)	Pdiss.(W)
7.0	88	231	742	1061	7.4
6.5	87	227	732	1047	6.8
6.0	84	220	723	1028	6.2
5.5	82	212	713	1007	5.5
5.0	77	203	702	982	4.9
4.5	74	193	687	954	4.3
4.0	70	183	673	926	3.7

Note;
SCL=Single Carrier Level
Total Power (dBm) =SCL+3
DCL =(Double Carrier Level) =Total Power

Table 1: PAs power dissipation at drain voltages 4-7V step 0.5V, corresponds to OIP3 of Fig 4b.

bility, proper value resistors have been added at gates and drains. ADS S-probe method has been used to check inter-stage stability. Figure 2 is an example of the design steps used for design of these PAs. Figure 3a shows die photographs of 10, 11, 13, 15, and 18 GHz band PAs. Figure 3b shows PA outline package drawing. The main objective of PA design was to get the best possible IM3 performance at P_{OUT} (total) =28 dBm. Better BW or Psat can be achieved if IM3 is not the main design criterion.

Performance of 9.8 - 13.3 GHz Linear Power Amplifier (RFPA1002)

Figures 4a - 4f show measured performance of RFPA1002. This PA covers 10, 11, and 13 GHz bands of P2P application. All the measurements are taken at Vd=6.5, Id (total) =1.07A unless otherwise noted. Figures 4d - 4f show some of the important performance plots of this PA. Figure 4a shows gain versus frequency behavior over temperature and Figure 4b shows OIP3 versus frequency at drain voltage from 4 to 7V, 0.5 step for single carrier level (SCL) P_{OUT} = 17dBm (or 20 dBm total power).

Table 1 shows DC power dissipation corresponding to Figure 4b. Figure 4c shows OIP3 improvement with the increase in DC power dissipation from 6.8 W to 8.5 W, it shows > 1.5 dBm improvement in OIP3 especially at lower frequency and for P_{OUT} = 25dBm/SCL. The main reason for this improvement could be due to slightly mismatched IM3 loadline between simulation and measured device output load. Figures 4d - 4f show measured performance of the PA as a VGA. PA gain has been varied using gate bias. Figure 4d shows variation of OIP3 versus gain, total gain was varied about 15 dB and OIP3 was measured at constant input power=-15dBm/DCL. Figure 4e shows how gain varies with Vg. A >15dB gain dynamic range has been achieved by adjusting gate bias. Figure 4f shows change in DC power dissipation with variation of

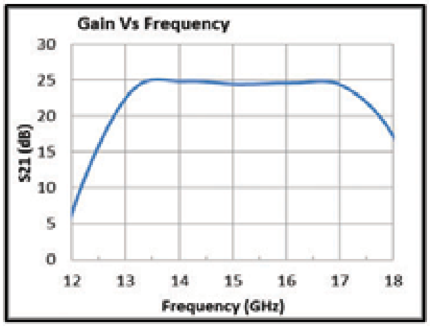

Fig. 5a: Variation of gain over frequency

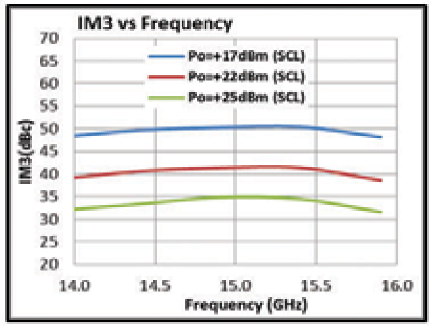

Fig. 5b: Variation of IM3 over various POUT

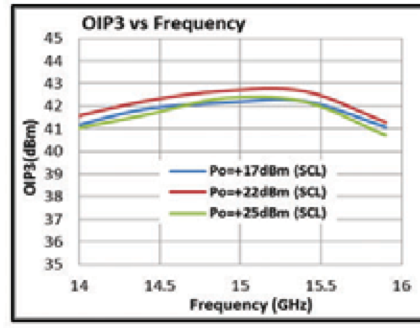

Fig. 5c: Variation of OIP3 over various POUT

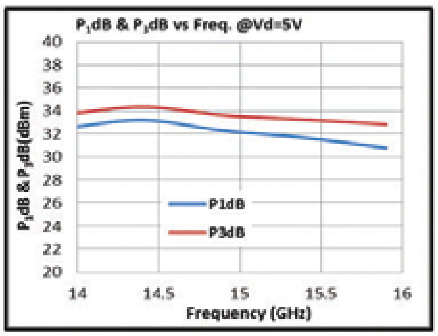

Fig. 5d: Variation of P1dB and p3dB with freq.

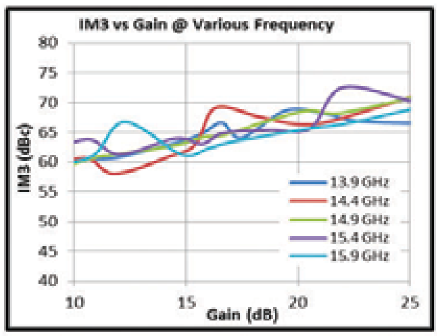

Fig. 5e: Variation of IM3 with gain (VGA)

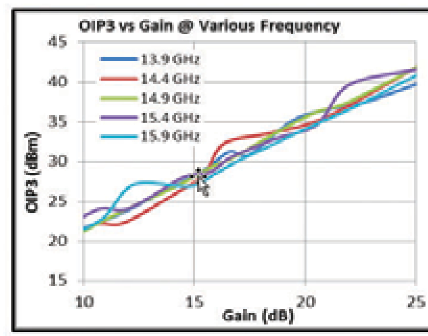

Fig. 5f: Variation of OIP3 with gain (VGA)

gain or drain current. Since Vg is varied to get VGA function, drain current varies with Vg.

Performance of 14.4 - 15.4 GHz Linear Power Amplifier (RFPA1003)

Figures 5a - 5f show measured performance of RFPA1003. This is designed for 15 GHz band applications. All the measurements are taken at Vd=7.5, Id (total) =1.05A unless otherwise noted. Figure 5a shows gain versus frequency performance and for entire band ~25dB gain has been achieved. Figure 5b shows IM3 plots with frequency for P_{OUT} = 17/22 and 25dBm SCL. This PA demonstrates very high IM3 ~50dBc at P_{OUT} = 17dBm/SCL and >32dBc at P_{OUT} = 25dBm/SCL, which is a key parameter for a linear PA. Figure 5c shows OIP3 versus frequency at P_{OUT}=17/22/25dBm/SCL. Figure 5d is a plot of P1dB and P3dB versus frequency for PA when PA bias was tuned for best IM3 or OIP3. If the PA

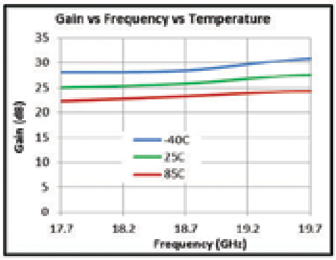

Fig. 6a: Over temp. measured gain

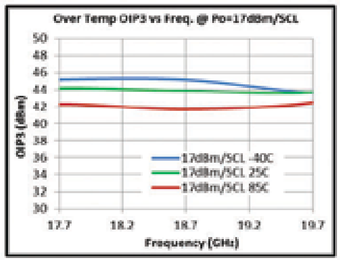

Fig. 6b: Over temp. OIP3 at P_{OUT}=17dBm/SCL

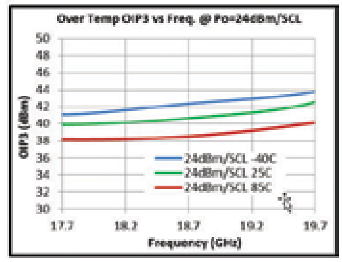

Fig. 6c: Over temp. OIP3 at P_{OUT}=24dBm/SCL

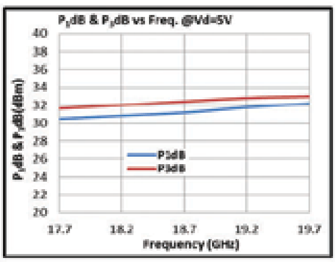

Fig. 6d: Variation of P_1dB and P_3dB with freq.

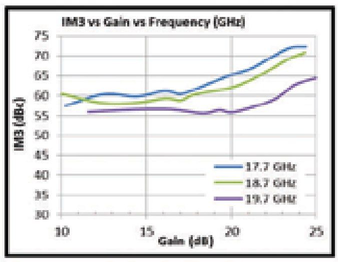

Fig. 6e: Variation of IM3 with gain (VGA)

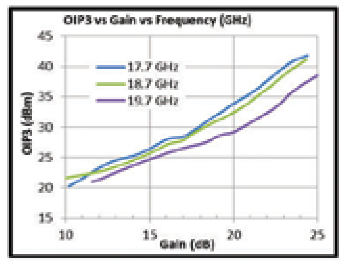

Fig. 6f: Variation of OIP3 with gain (VGA)

needs to be used as a saturated amplifier, P1dB and P3dB performance can be improved by tuning bias condition as a saturated amplifier. Figures 5e and 5f show performance of the PA as a VGA. PA gain has been varied using gate bias.

Performance of 17.7 - 19.7 GHz Linear Power Amplifier (RFPA1702)

Figures 6a - 6f show measured performance RFPA1702. This PA covers 18 GHz band of P2P radio application. All the measurements are taken at Vd=5.5, Id (total) =1.3A unless otherwise noted. Figures 6a - 6c show the PAs gain and OIP3 (at P_{OUT}=+15 and +24dBm/SCL) versus frequency behavior over temperature. Figure 6c shows P1dB and P3dB behavior of the PA when biased to achieve best IM3 performance. Figures 6e - 6f show performance of the PA as a VGA. PA gain has been varied using gate bias.

Conclusion

The performance of RFMD's linear power amplifiers is summarized in Table 2. These PAs demonstrate high gain and high IM3/OIP3 values at high P_{OUT} (total) = 28 dBm for 10, 11, 13, and 15 GHz band applications. For 18, 23, and 26 GHz bands, the IM3/OIP3 was measured at P_{OUT} (total) = 27 and 26 dBm. These PAs show very good performance as VGAs and, by adjusting gate bias, a gain dynamic range of >15 dB can be achieved. These PAs maintain decent IM3/OIP3 performance, a much desired feature to dynamically adjust power consumption of a PA. IM5 performance of the PAs is >60 dBc at P_{OUT} = 22/21 and 20 dBm for the various bands. P1dB and Psat was measured under best IM3 tuned case, if the amp needs to be used as a saturated amplifier a different biasing scheme can be used for better P_{OUT} performance at the cost of IM3/OIP3. All PA designs incorporate on-chip package compensation networks for good I/O match and are packaged in a low-cost 6 x 6 ceramic package for better thermal performance. Due to superior IM3/OIP3 performance of these PAs, they are well suited for high data rate and complex modulation systems.

About the Authors:

The authors work at RFMD, where Sushil Kumar is Director, Engineering; Kent Story is a Staff Design Engineer; Ron Kielmeyer is a Staff Design Engineer; Tariq Lodhi is a Senior Design Engineer; and Ian Hardcastle is a Staff Design Engineer.

References:

1. http://www.rfmd.com/CS/Documents/RFPA1002DS.pdf
2. http://www.rfmd.com/CS/Documents/RFPA1003DS.pdf
3. http://www.rfmd.com/CS/Documents/RFPA1702DS.pdf

Parameter	Units	RFPA1002	RFPA1003	RFPA1702	RFPA1703
RF Frequency	GHz	9.8 to 13.3 GHz	14.4 -15.4	17.7-19.7	21.2-26.5
Gain	dB	27	25	25	23
Gain Dynamic Range*	dB	≥15	≥15	≥15	≥15
OIP3	dBm	41 @Po=+25dBm (SCL)	42 @Po=+25dBm (SCL)	>40.5 @Po=+24dBm (SCL)	38 @Po=+23dBm (SCL)
IM5	dBc	>60 @Po=22dBm (SCL)	>62 @Po=22dBm (SCL)	68 @Po=21dBm (SCL)	60 @Po=20dBm (SCL)
OP_1dB	dBm	~+33	+32	+31.5	+30
RL (Input)	dB	10	8	12	10
RL (Output)	dB	14	15	8	10
NF	dB	5	7	7	7
Bias	V/A	6.5V/1.07A	7.5V/1.0A	5.5V/1.3A	5V/1.4A
Package Type		6x6 QFN	6x6 QFN	6x6 QFN	6x6 QFN

* Using Gate Bias

Table 2 • Summary of RFMD's Linear Power Amplifiers.