Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**Analysis of PHY waveform Peak to Mean Ratio and Impact on RF Amplification**
Date Submitted	**2001-03-06**
Source(s)	Paul Struhsaker Raze Technologies Inc. 2540 E. Plano Pkwy. Suite 188 Plano TX, 75023 Kirk Griffin Voice: 972-516-1240 Fax: 972-578-9081 mailto:paul@razetechnologies.com mailto:kgriffin@razetechnologies.com
Re:	This document provides additional analysis for evaluation of the PHY proposals
Abstract	This document provides a summary of peak to mean ratios of signal proposed in the current PHY proposals and provides Rapp model simulations for the RF PA back off required to meet the MMDS spectral mask.
Purpose	Provide additional technical information and simulation to better inform members as we evaluate the PHY proposals.
Notice	
Release	
Patent Policy and Procedures	

Analysis of PHY waveform Peak to Average Ratio and impact on RF Amplification

Paul Struhsaker & Kirk Griffin
Raze Technologies

Introduction

This paper provides the summary of simulations of the PHY layer modulations proposed in the PHY proposal submissions for the March session [1-3]. In addition to the waveforms described in the proposals, this paper also provides analysis of PI/4 offset QPSK, which offers a 0.6 dB improvement over traditional QPSK

In forming the IEEE 802.16.3 standard, TG3 must evaluate the system level impact of PHY layer modulation on the RF subsystems at basestation and, to a greater extent, at the subscriber.

The RF transmitter dominants power consumption and thermal generation at the subscriber. The digital portion of the subscriber will continue to see reductions in terms of cost and power consumption over time. The RF PA will see limited improvements due to both device physics and device packaging constraints. For subscriber systems that require power outputs in the 25 to 27 dBm range combined with a PA back off over 8 dB not only is the cost of PA at issue, the following secondary issues must be addressed:

- Cost of mechanical packaging for thermal dissipation of the PA
- Additional costs in AC/DC power conversion and battery requirements (If you live in California or countries with less than reliable power grids this is a serious consideration)
- Reliability of the subscriber due to PA failure (increased junction temperature of the PA device results in higher MTBF)

The peak to average ratio (PAR) of transmitted waveform determines the bias point and efficiency of the TX PA and the resulting amplifier efficiency. For a given required power output, the greater the peak to average ratio, the greater the PA back-off. A survey of RF PA device between 2 and 11 GHz shows a significant cost (~3x to 4x) when the P1 dB (1 dB compression point) or the PA is > than ~30 dBm.

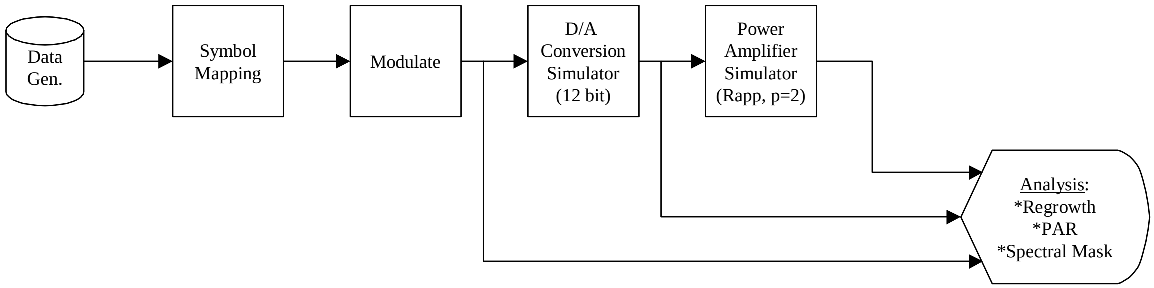
The simplest solution would be to select a constant modulus signal with highly efficient Class C amplification. This would result in the lowest possible cost, complexity, and thermal load for a subscriber. Unfortunately this would also end in the poorest possible spectrum efficiency. So, we are forced to make trade offs to maximize spectral efficiency. We do so by inducing greater cost and complexity into the transmitter. Given the cost sensitivity of the subscriber, these choices have to be weighed very carefully.

This paper should provide the reader a base line set of data to assist in making this choice.

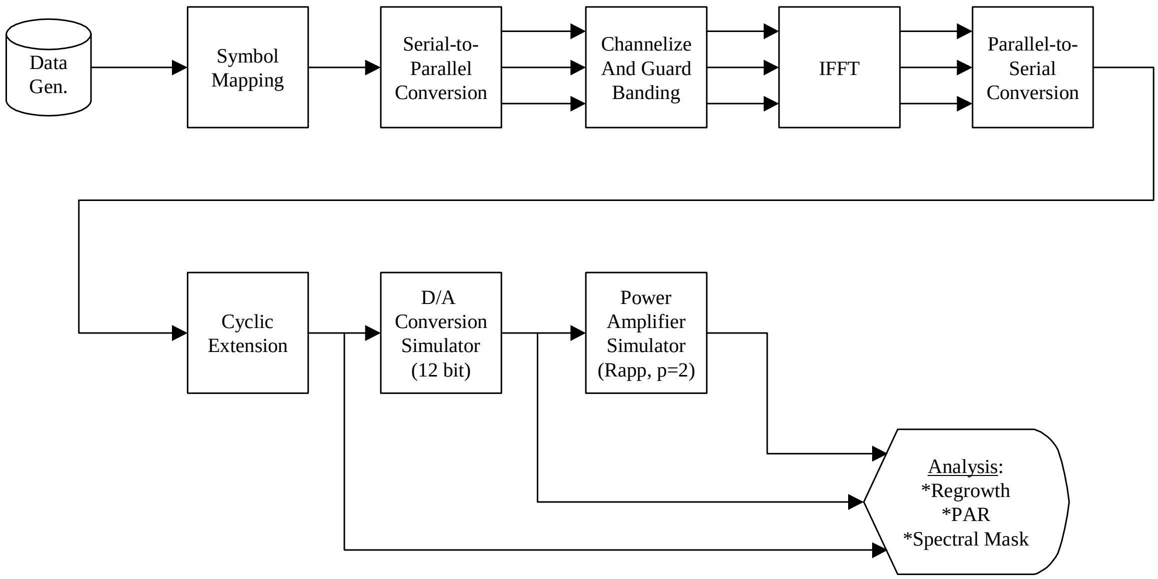
Simulation Framework

PHY modulation simulations were conducted in Matlab. PHY parameters were selected for MMDS 6 MHZ spectral occupancy. A DSS/NCO was used to place the complex baseband signal on a 12 MHz carrier for evaluation of the single sided real spectrum.

The following diagram illustrates the single carrier simulation flow.



The following diagram illustrates the OFDM simulation flow. Windowing of OFDM word transmission is used and does provide slight improvement in PAR performance.



By using a common simulation framework, we can readily compare results between all the proposed modulation formats.

Summary of Peak to Average Ratio

The following table provides representative PAR (peak to average ratio) values for the simulated waveforms:

OFDM	64 point FFT	256 point FFT	512 point FFT
QPSK	13.3	12.0	11.9
16QAM	13.3	12.0	12.0
64QAM	13.4	12.3	12.5

*Number of actual carriers is 75% of indicated in column headers.

Single Carrier	PAR
QPSK	7.5
PI/4 DQPSK	7.0
OQPSK	4.8
16QAM	9.4
64QAM	10.5

*RRC Alpha of 0.25.

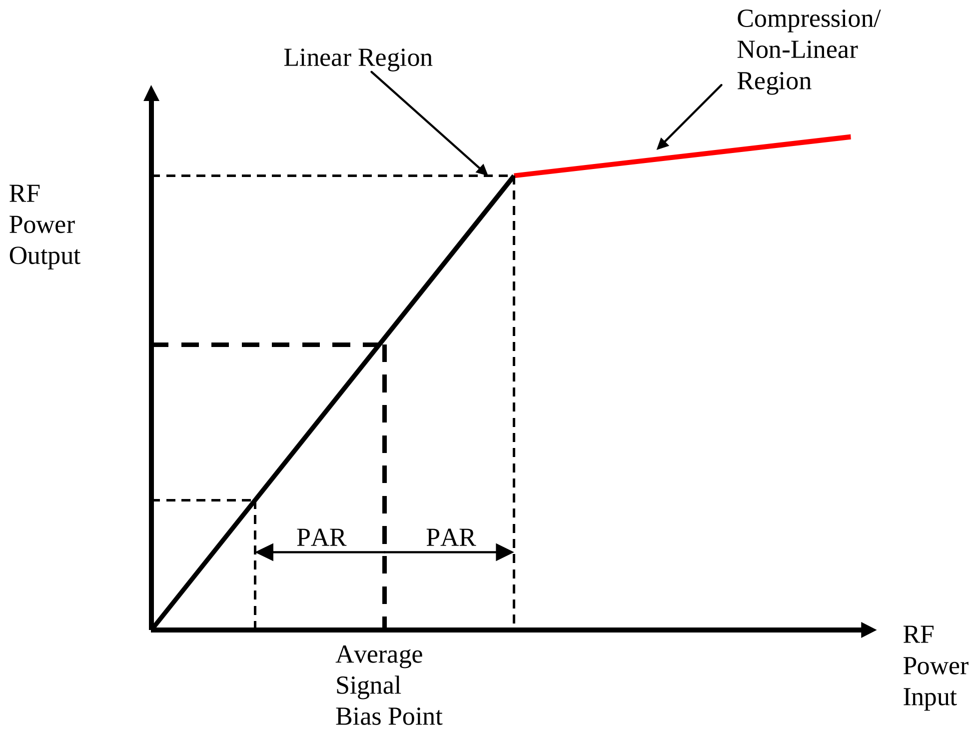
While it may seem counter intuitive, the PAR of the 64 point OFDM is actually worse than the larger OFDM word sizes. This can be attributed to the higher probability and more frequent occurrence of the peak deviation (the alignment of all carriers).

If we consider the subscriber up-link which will typically be limited to QPSK or 16 QAM modulations in SC or OFDM we see the following:

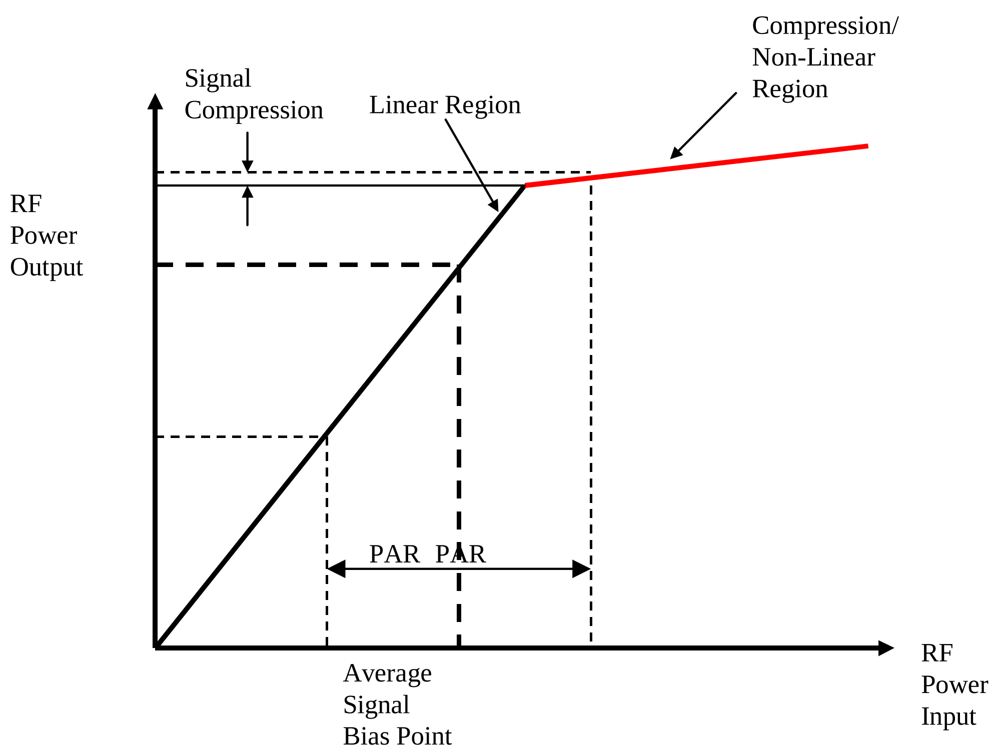
- 4.5 to 5 dB lower PAR for SC vs OFDM 256/512 using QPSK or PI/4 offset QPSK
- 2.6 dB lower PAR for SC vs OFDM 256/512 with 16 QAM

Transmit Power Amplifier Back Off

The following diagram illustrates the input to output power transfer function of a typical power amplifier that is properly biased. The amplifier is biased to operate point in the linear region of the transfer function. The bias point is selected so that the peak amplitudes of the input waveform experience a limited amount of clipping/compression in the non-linear region of the amplifier. This bias point back-off (i.e. PA back-off) is selected based on the waveform(s) that are to be transmitted, their associated peak to average ratio, and the amount of spectral re-growth of the filtered side lobes of the amplified signal .

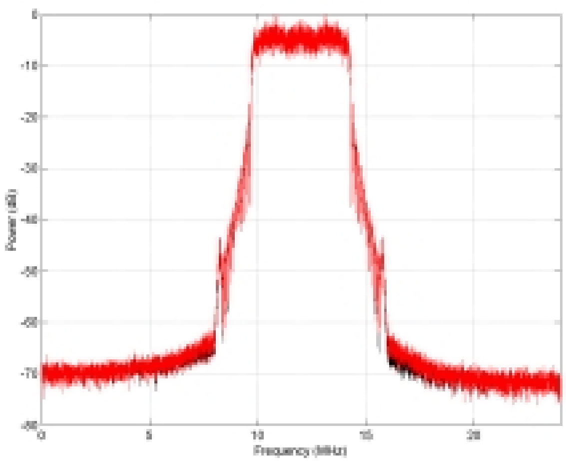


When the PA is biased too aggressively to improve average power output, compression/clipping occur as illustrated in the following diagram.

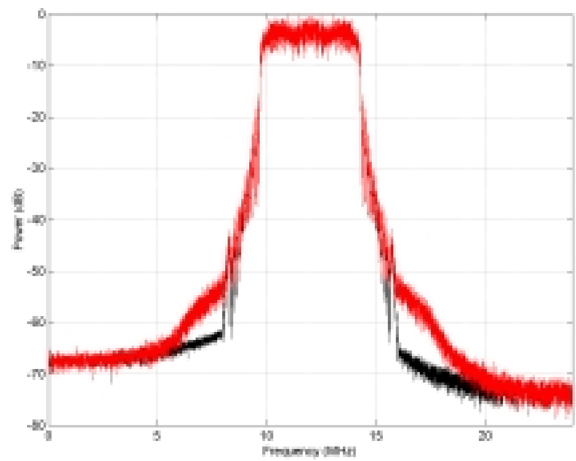


The RF amplifier exhibits a non-linear transfer function. A combination of simulation and implementation are required to evaluate the amount of back-off required. What should be clear is that the higher the PAR, the less RF PA power output will be generated for a give PA with a given P1 dB power output. To maintain a given power output large and more expensive PA devices must be selected to support higher complexity waveforms.

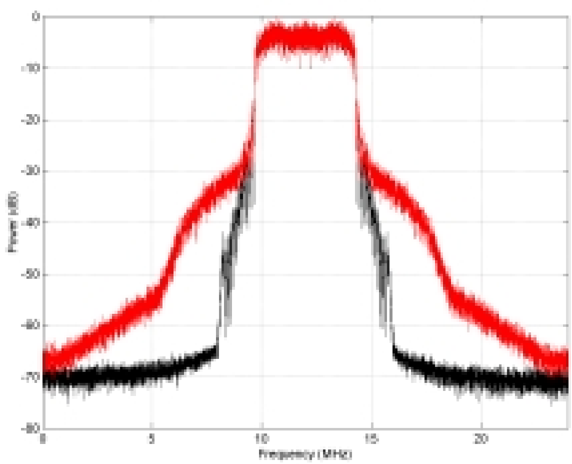
The following diagrams illustrate the amplifier back off and spectral re-growth that was exhibited by QPSK single carrier and OFDM modulated waveforms for PA back-off of 20, 15, 10 and 5 dB from the 1 dB compression point of the amplifier.

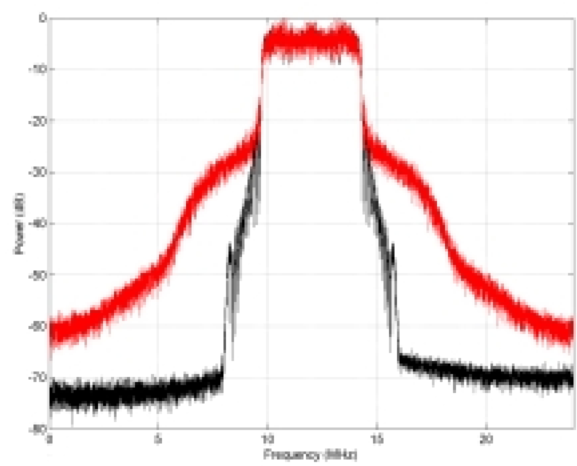


(c)



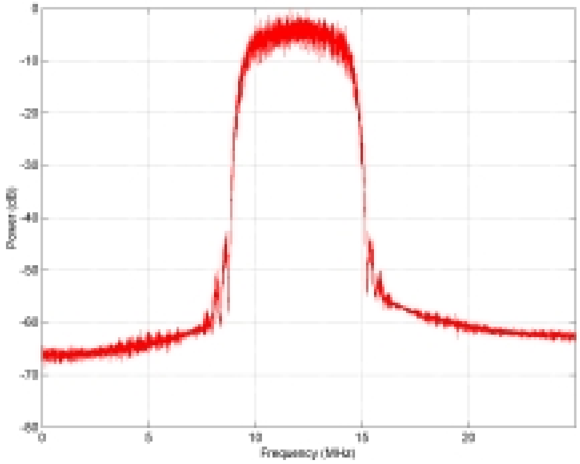
(d)



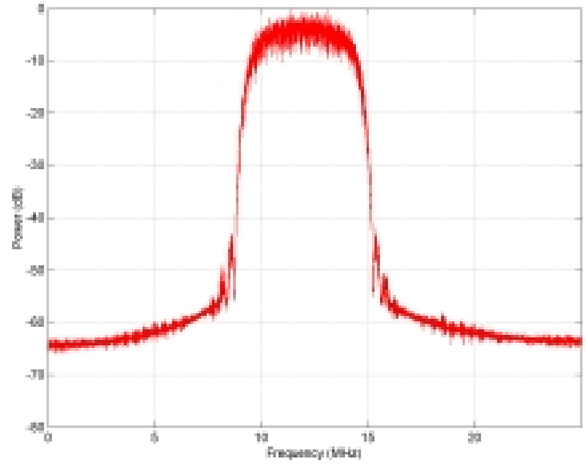


(e)

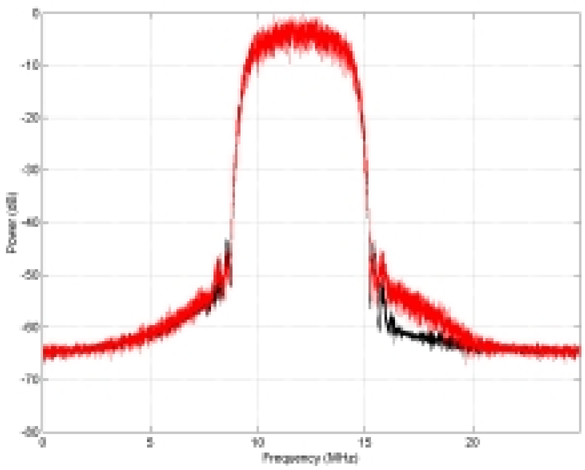
QPSK OFDM Signals (48 carriers) through PA (Rapp, p=2): (a) 20 dB backoff, (b) 15 dB, (c) 10 dB, (d) 5 dB



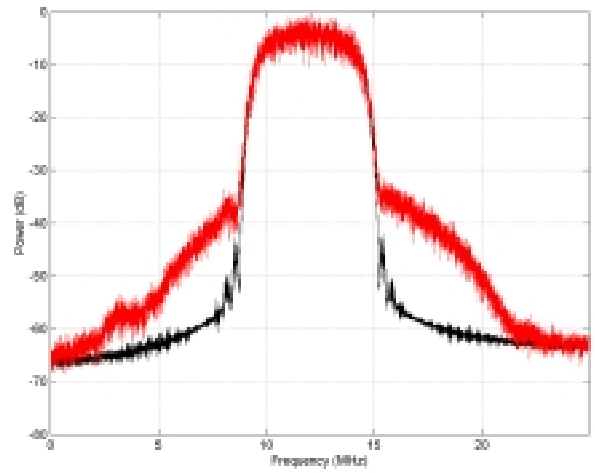
(a)



(b)



(c)



(d)

QPSK Single Channel Signal through PA (Rapp, p=2): (a) 20 dB backoff, (b) 15 dB, (c) 10 dB, (d) 5 dB

As would be expected, the plots illustrate the spectral re-growth from amplifier saturation that is aligned with the modulation PAR.

Device and Thermal Analysis Examples

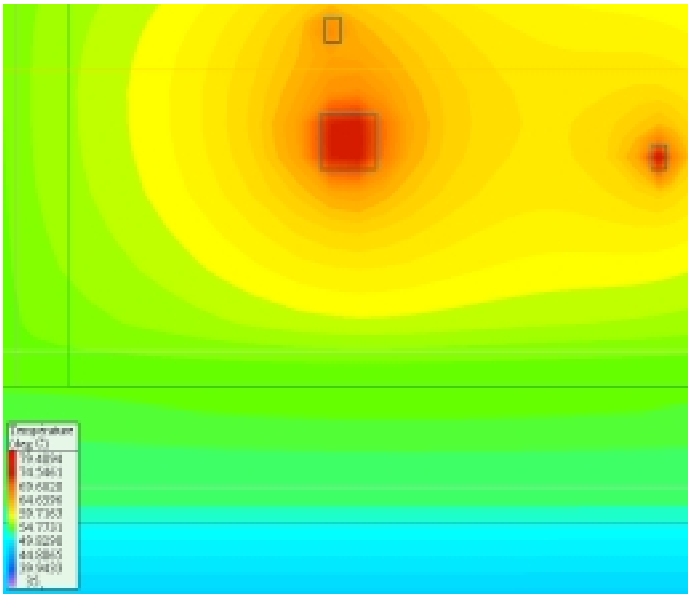
The following table provides a list of example PA devices for the MMDS band.

Manufacture	Part Number	Price per 5K (approx.)	P1 dB
RF Micro Devices	RFM-2163	$2.77	30 dBm
AMCOM	AM072MX-QG	$9.00	31.5 dBm
Stellex	PA1177R	$87.00	33 dBm
NEC	NE6500496	$75.00	35.5 dBm

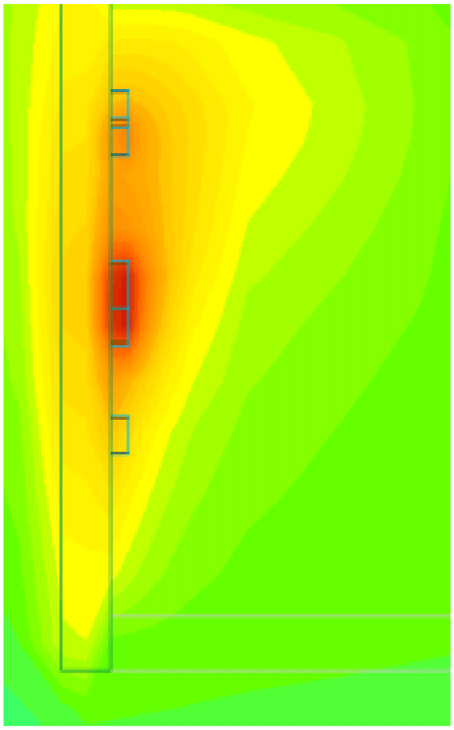
Once the requirements move significantly over 30 dBm for P1 dB, the cost of the rise considerably due to advanced packaging needed to provide adequate thermal management.

The following thermal simulations of the low cost devices (RF-2163, and AMO072MX-QC) illustrate thermal mechanical design issues.

These simulations were conducted at 35 deg C. All boards were oriented vertically (typical for subscriber mechanical configuration). There are no fans or other for of forced air. While not shown in the diagrams, manufacture recommended heat sinking is applied to each device. 1 oz copper layers are used on the PCB. The AM072MX part had the additional benefit of copper filled thermal vias.

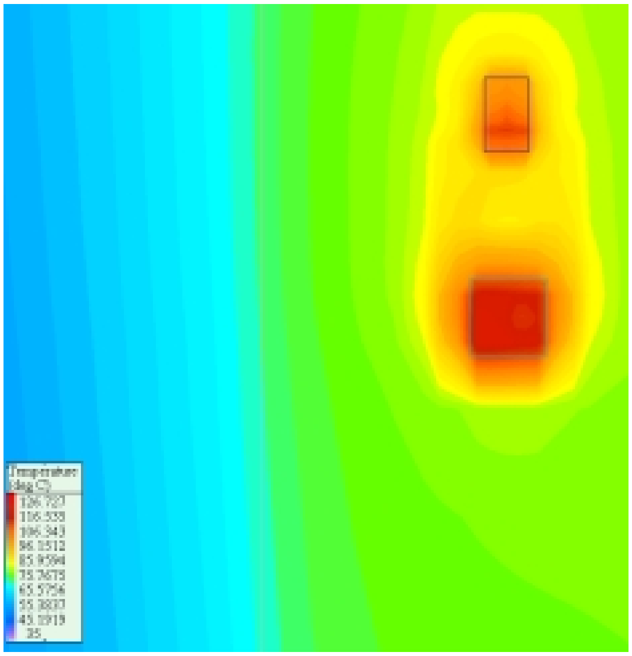


RFM-2163 Top View

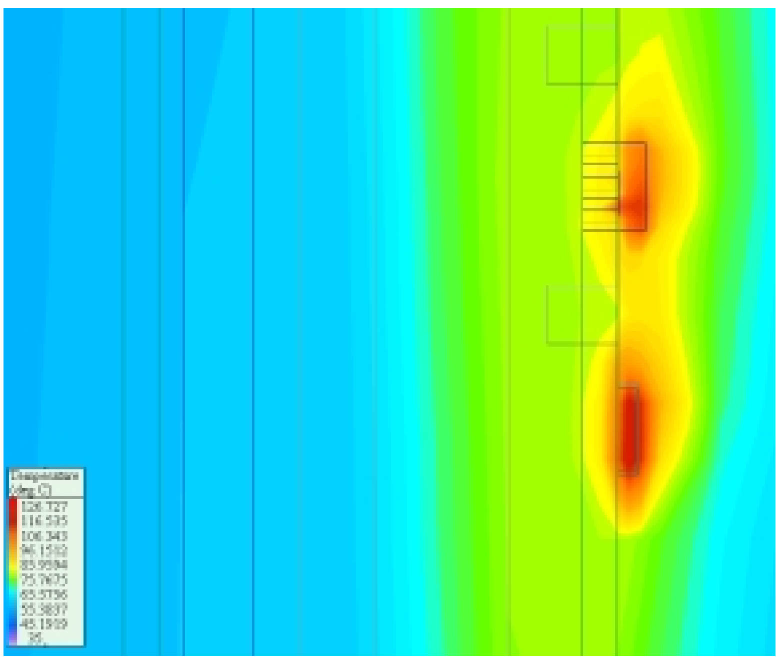


RFM-2163 Side View

At 35 deg C. the device has junction temperature of 79.5 deg C. In practice, a subscriber that meets ETSI requirements will experience 45 deg C maximum ambient temperature with an additional 15 deg C solar load. This is equivalent to the addition of 25 degree to the junction temperature or 105 deg C junction temperature (a good value for component reliability)



AM072MX-QG (smaller device) Top View



AM072MX-QG (with thermal vias) Top View

At 35 deg C. the AM072MX-QG has junction temperature of 110 deg C. In practice, a subscriber that meets ETSI requirements will experience 45 deg C maximum ambient temperature with an additional 15 deg C solar load. This is equivalent to the addition of 25 degree to the junction temperature or 135 deg C junction temperature (this is a problem for component reliability).

As there simulations illustrate, there is a direct connection between the selection of the PHY modulation and the following parameters:

- PA back-off to meet out of band emissions
- PA device for required Power Output with the back-off
- Thermal management for reliable operation of the PA device

Once the Amplifier is above ~ 30 dBm P1 dB, costs and thermal issues will dominate the design complexity.

References

[1] 802.16.3c-01/33 IEEE 802.16.3 OFDM PHY proposal for the 802.16.3 PHY layer

[2] 802.16.3c-01/32 SC-FDE PHY Layer System Proposal for Sub 11 GHz BWA (An OFDM Compatible Solution)

[3] 802.16.3c-01/31 PHY Layer System Proposal for Sub 11 GHz BWA Having SC-FDE and OFDM Modes

[4] Rapp, C. "Effects of HPA non-linearity on 4 DPSK/OFDM Signal for Digital Sound broadcasting System" Proceedings of the Second European Conference on Satellite Communications, Liege Belgium pp. 179-184 Oct 22-24 1991.