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FM/HD Radio Efficiency Improvement

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Agenda

- Efficiency Definitions
- Short history of FM transmitter efficiency
- Four Technology Improvements driving up efficiency:
  - SMPS (Switch Mode Power Supplies)
  - LDMOS devices
  - PAPR/Crest Factor reduction for HD Radio
  - Efficiency Optimization Routines
- Impact on HD Radio configurations (hybrid vs. separate)

Efficiency Definitions

- **PA or PLATE Efficiency** – Historically used by FCC to determine power by the Indirect Method:

  $$P_{OUT} / E_P \times I_P$$

  May be determined from transmitter internal metering.

- **AC to RF Efficiency** – Ratio of Power Output to AC Power Input, where AC Power Input = Line Voltage x Line Current x PF

  For three phase, use Line Voltage x Line Current x 1.73 x PF

  $$P_{OUT} / P_{IN}$$

  Usually CANNOT be determined with transmitter internal metering.

Historical Data

ANALOG:

- 1995-2010 – Solid State, Typical 63-65% AC to RF, at ***rated power***. Performance at less than rated power could be as much as 10% less.
  - Nautel did 'Q' Series at 68% but not frequency agile, not IBOC compatible.
- 1995-2010 – Tube, Typical 62-65% AC to RF. Grounded Grids had only "apparent" efficiency of 80%, true efficiency closer to 60%.

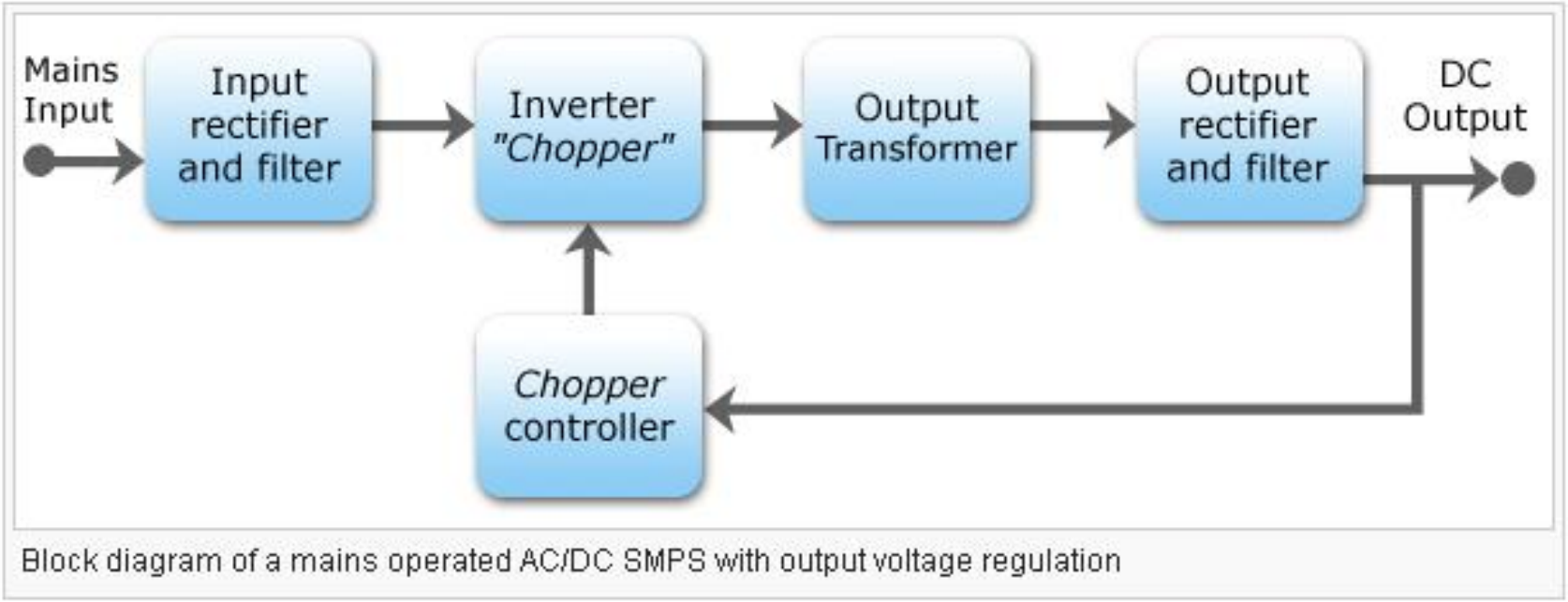
HD RADIO:

- Solid State, Typical 40-48% AC to RF, rated power, -20 dBc.
- Tube, Typical 37-48% AC to RF, rated power, -20 dBc.

Evolution in FM Design:

Use of High Efficiency Switched Mode Power Supplies

SMPS Theory



Block diagram of a mains operated AC/DC SMPS with output voltage regulation

SMPS Functional Blocks

- Input Rectifier and Filter – converts input to pulsed DC, often with Power Factor correction
- Inverter Chopper – converts DC to AC through multi-stage MOSFET power oscillator, operating typically at 20 kHz or more.
- Output transformer – Steps up/down power oscillator output for required voltage output. Due to high frequency, transformer can be physically small.
- Output Rectifier and Filter – Smooths and filters DC output and sends sample back to Chopper Controller for regulation.

80 PLUS Certification

- Voluntary certification program to promote efficient energy use in Communication and computer PSUs.
- Certifies PSUs that have more than 80% energy efficiency at 20%, 50%, and 100% of rated load, and
- Power Factor of 0.9 or greater at 100% load
- 2007 First 80 Plus Power Supplies
- 2008 added Bronze, Silver, and Gold certifications
- 2009 added Platinum
- 2012 added Titanium

Efficiency Level Certifications

80 Plus test type[4]	115V internal non-redundant				230V internal redundant			
Percentage of rated load	**10%**	**20%**	**50%**	**100%**	**10%**	**20%**	**50%**	**100%**
80 Plus		80%	80%	80%				
80 Plus Bronze		82%	85%	82%		81%	85%	81%
80 Plus Silver		85%	88%	85%		85%	89%	85%
80 Plus Gold		87%	90%	87%		88%	92%	88%
80 Plus Platinum		90%	92%	89%		90%	94%	91%
80 Plus Titanium	90%	92%	94%	90%	90%	94%	96%	91%

SMPS in Nautel Transmitters

NV and VS replacement

TECTROL

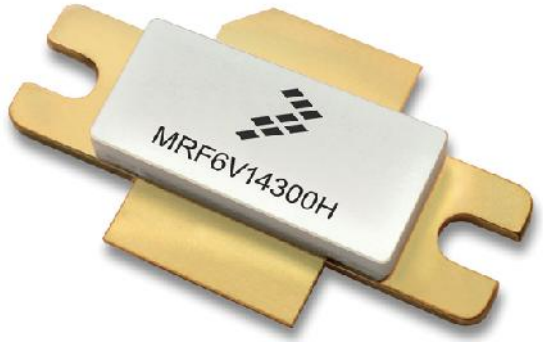
NV/LT and GV

LINEAGE POWER

nautel GVSeries

Evolution in FM Design:

50 Volt LDMOS



Drivers for LDMOS Development

- Cellular Industry
- Initially 28-32V devices back in 90’s
- 50V LDMOS enabled broadcast application, initially by Freescale.
- Two suppliers today:
  - Freescale
  - NXP

LDMOS – VMOS Comparison

Attribute	Si VMOS	28V RF-LDMOS	50V RF-LDMOS
CW eff. at P1dB	3	5	5
Power Gain	3	5	5
Thermal resistance	3	4	5
CW Packaged Power Density	3	3	4
High Intrinsic Zin / Zout (wideband)	3	3	4
On-Die Passives Integration	2	4	4
Variability / Performance spread	2	4	4
Technology Maturity	5	5	4
Reliability	4	5	5

Table 1: Comparison of RF Power attributes vs. device technology

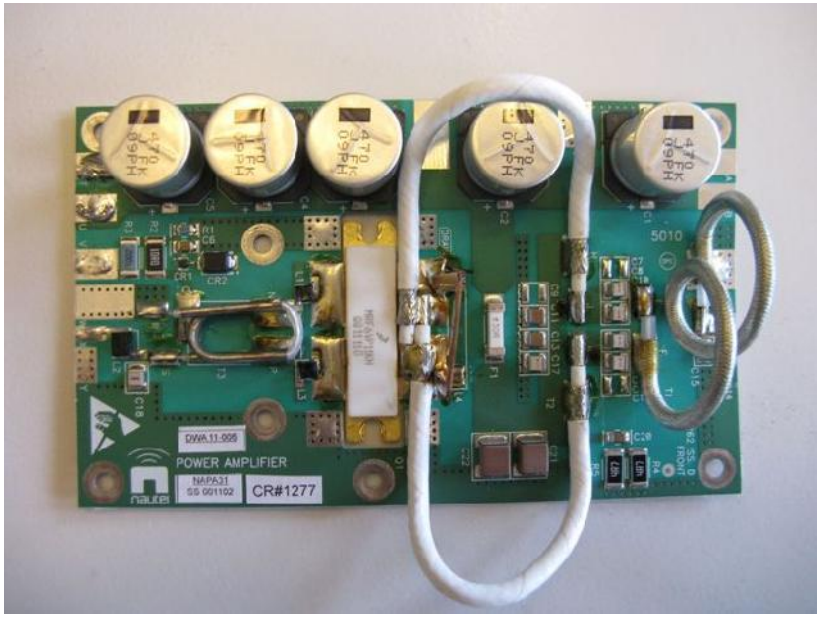
Benefits to FM Design

- Device output 800 to 1100w (2x VMOS)
- Higher gain (~ 23 dB)
- Improved drain efficiency (~ 85% vs 80%)
- So:
  - Eliminate IPA stage
  - Lower combining losses

- BUT, must still remove heat!

Nautel LDMOS Architecture

10 kW Tx	NV	GV & NV/LT
Exciter	(1)	(1)
IPA	4	None
PA pallets per PB	8	4
Power Blocks per tx	4	4
Total pallets	36	16



Evolution in FM Design:

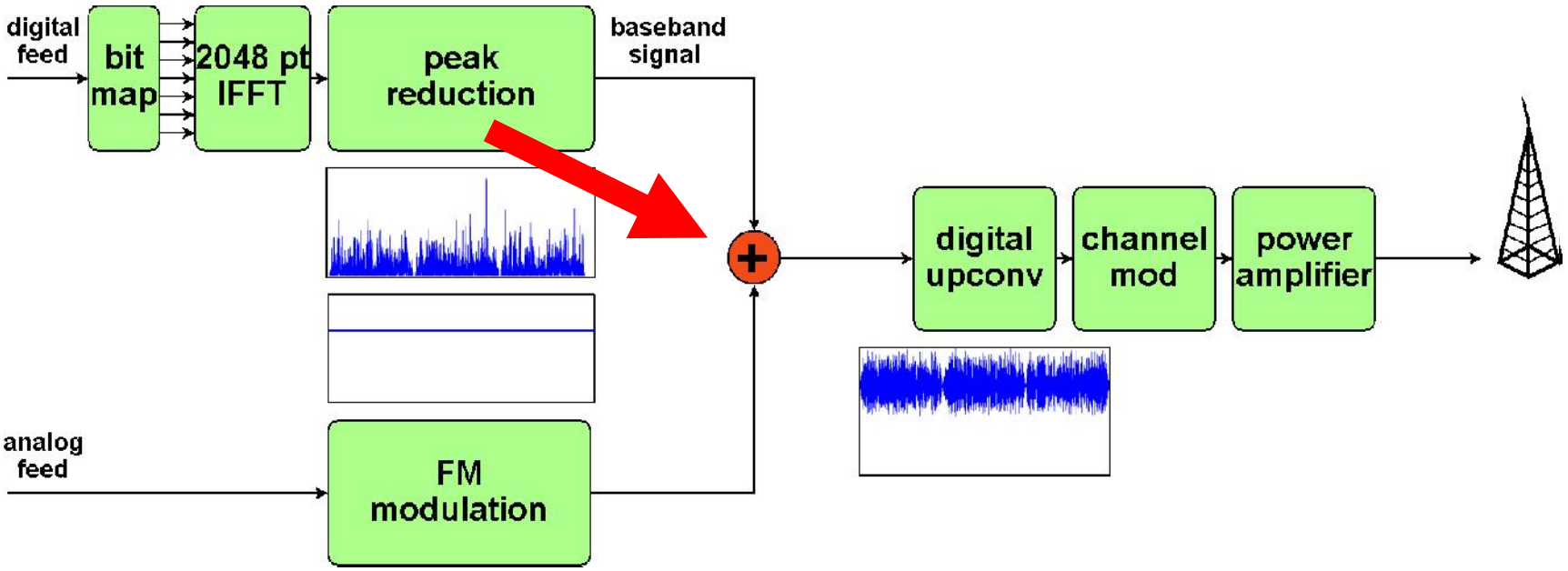
Peak to Average Power Reduction for HD Radio Modes

PAPR /CFR/PAR1&2/PB

- PAPR – Peak to Average Power Reduction, also known as Crest Factor Reduction (CFR)
- PAR1 –iBiquity implementation that only performed reduction on the ***digital*** portion of hybrid waveform.
- PB – Nautel PowerBoost that performs reduction on the ***combined hybrid*** waveform.
- PAR2 – iBiquity implementation that will perform reduction on the combined hybrid waveform.

Nautel's **PowerBoost**

Standard PAR1 reduction only considers the IBOC signal …

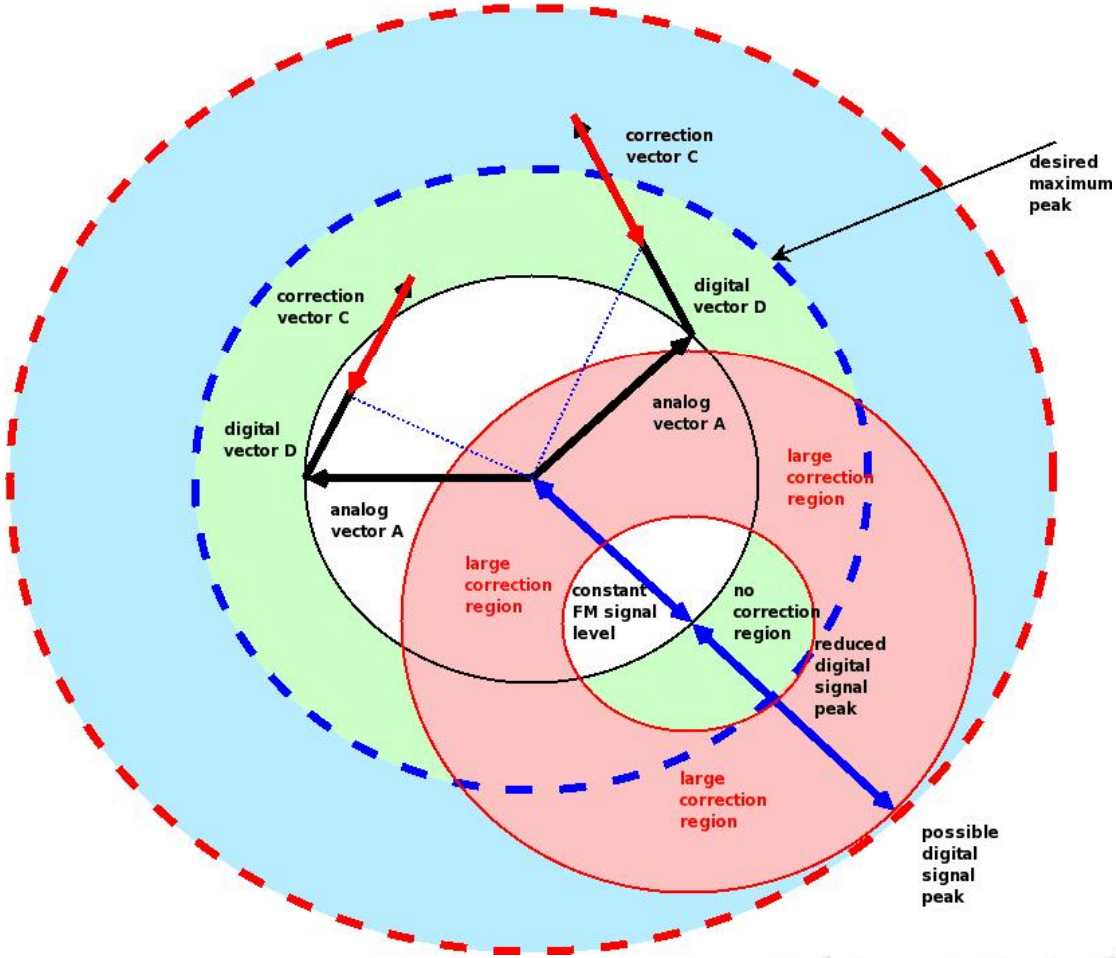


...what if we considered both the analog and digital signals together?

Making Digital Radio **Work.**

iBiquity PAR1 Reduction

Standard PAR1 reduction applied to ONLY IBOC signal



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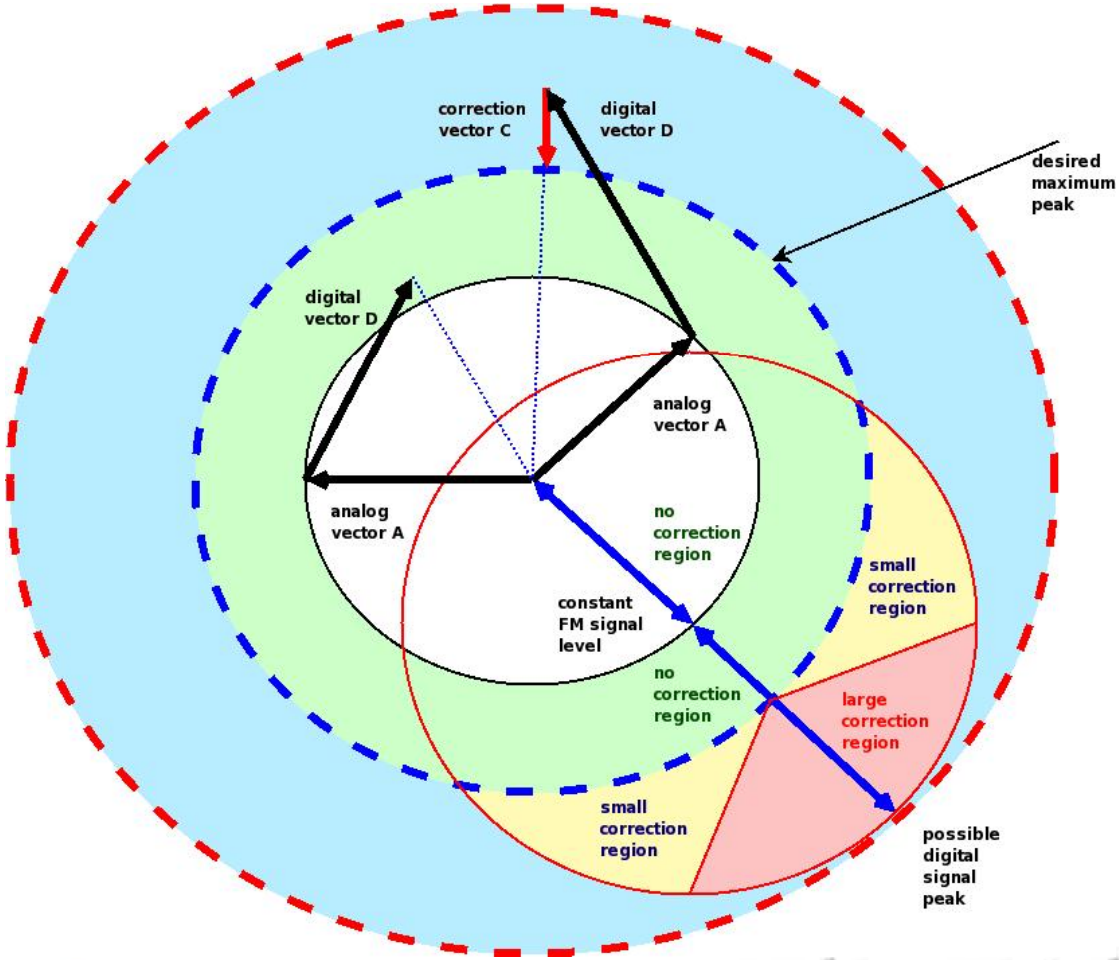
Making Digital Radio Work.

PowerBoost and iBiquity PAR2

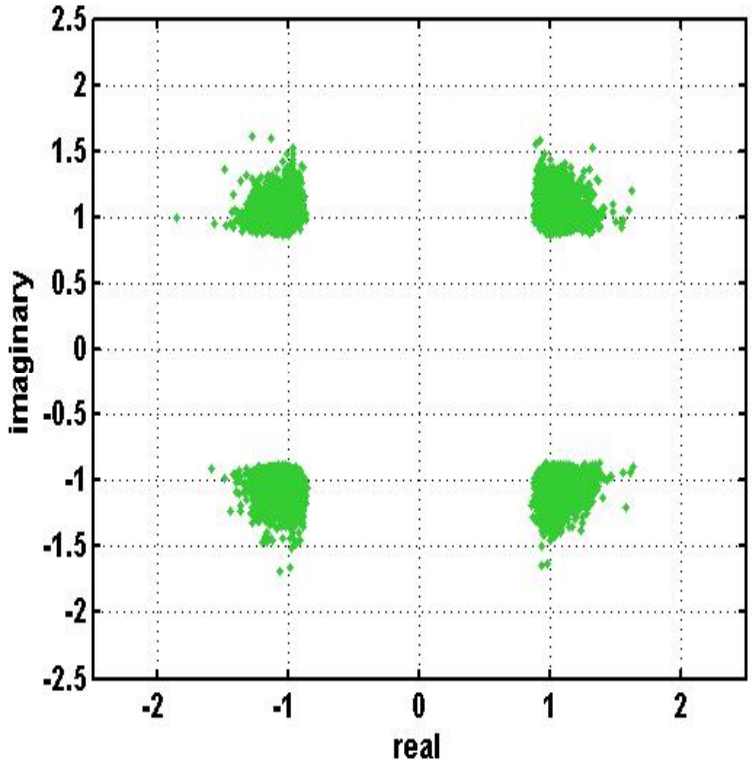
PAR2 reduction applied to hybrid FM+IBOC signal



Making Digital Radio **Work.**

PowerBoost Animation

Impact of Peak Reduction

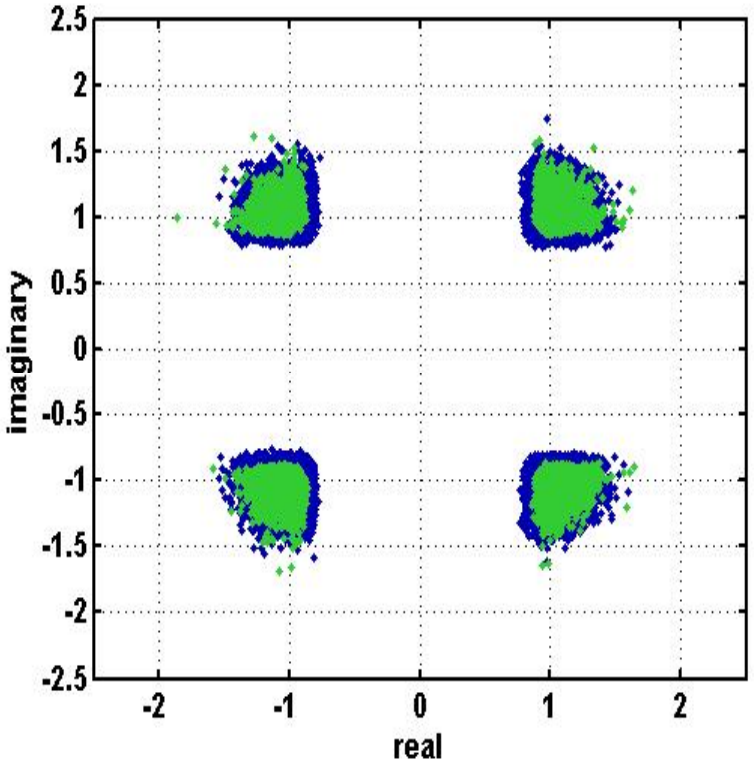


Nautel HD Power Boost
soft peak reduction

IBOC injection: -10 dBc
Transmitter: 20 kW
Output Power: 12.8 kW
Peak to Average: 3.6 dB
DC-RF Efficiency: 56.8%
Data MER: 24.5 dB
Coverage Reduction:~0.1 dB

Making Digital Radio **Work.**

Impact of Peak Reduction

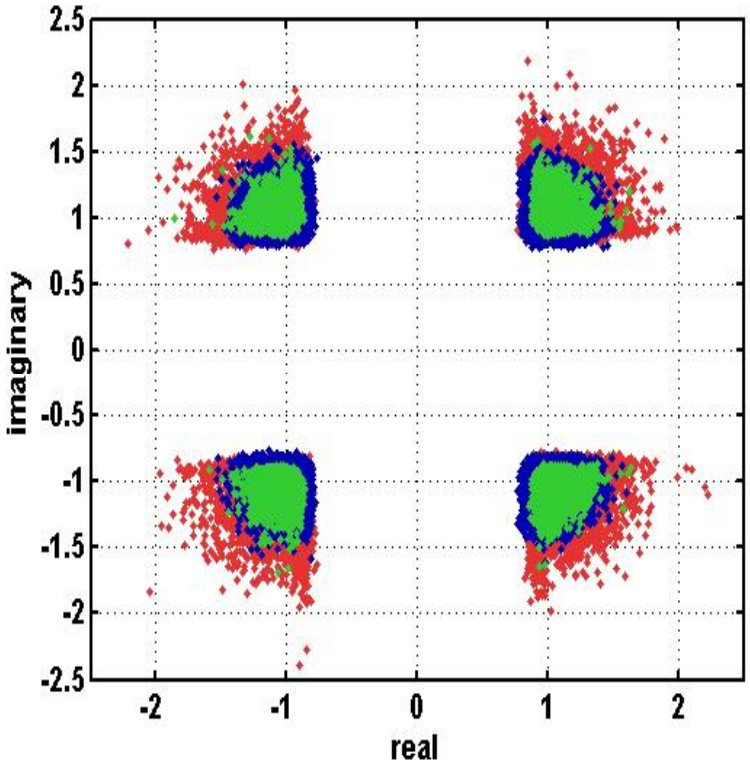


Nautel HD Power Boost
typical peak reduction

IBOC injection: -10 dBc
Transmitter: 20 kW
Output Power: 13.8 kW
Peak to Average: 3.1 dB
DC-RF Efficiency: 58.7%
Data MER: 19.1 dB
Coverage Reduction: 0.2 dB

Making Digital Radio **Work.**

Impact of Peak Reduction



Nautel HD Power Boost
hard peak reduction

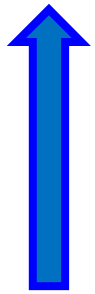
IBOC injection: -10 dBc
Transmitter: 20 kW
Output Power: 15.0 kW
Peak to Average: 2.7 dB
DC-RF Efficiency: 60.9%
Data MER: 16.4 dB
Coverage Reduction: 0.28 dB

Making Digital Radio **Work.**

Evolution in FM Design:

Efficiency Optimization Routines

Effect of PA Voltage Adjustment

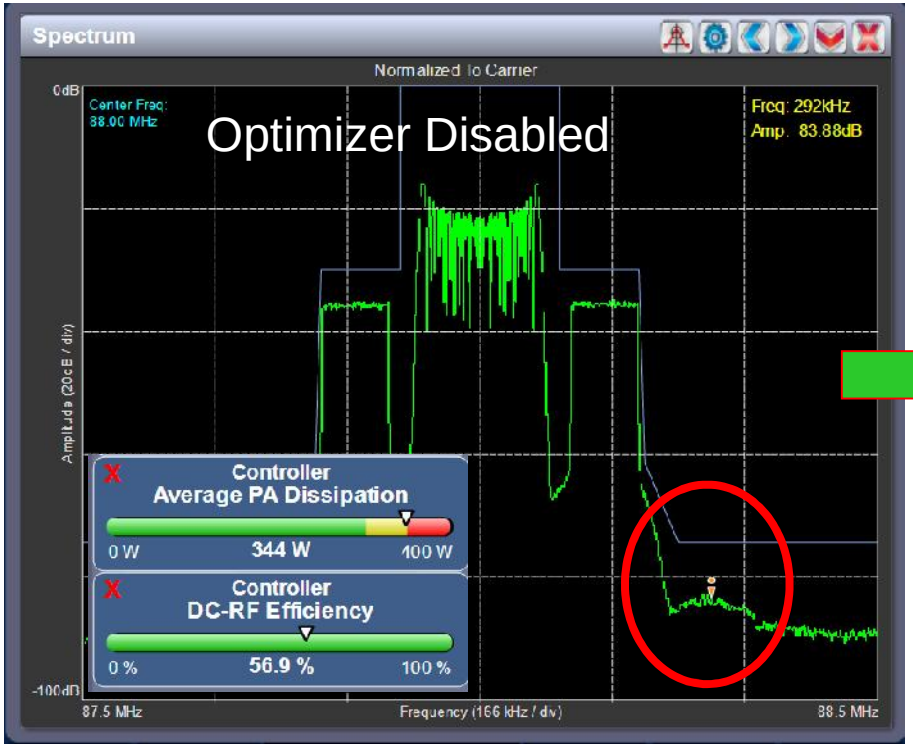


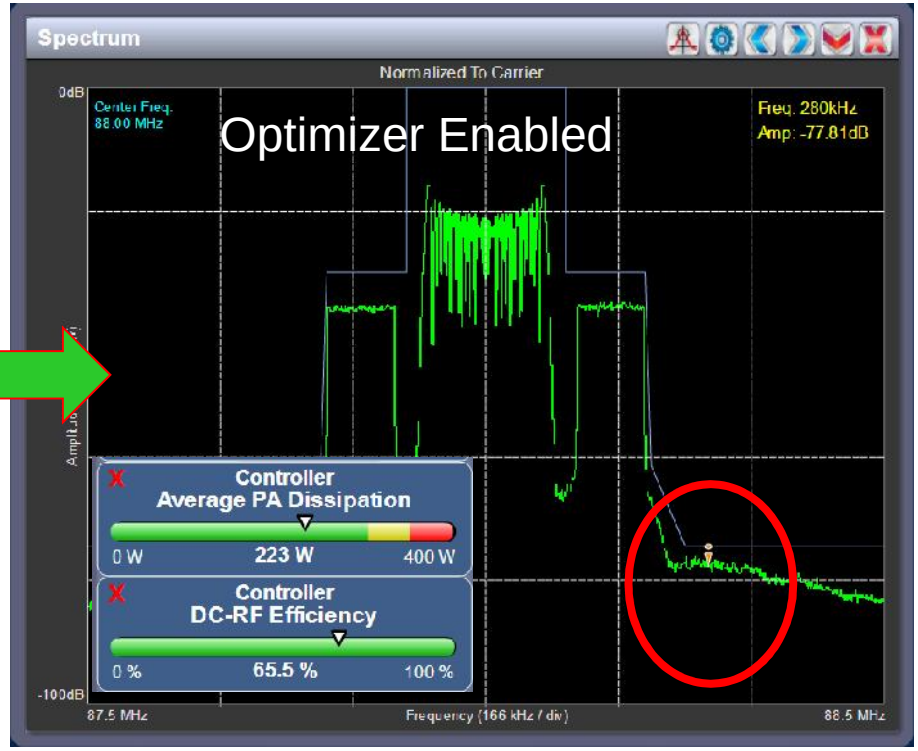
- As the PA voltage is ***raised***, more peaks can pass through the amplifier without being clipped, so third order intermodulation products are, in turn, reduced, resulting in a cleaner spectrum, and better mask performance. However, the device may not be in full saturation, resulting in more losses and lower efficiency.

- As the PA voltage is ***lowered***, more clipping occurs, resulting in increased clipping products (third order intermodulation products), and a deterioration of the mask performance. But full saturation of the LDMOS FETs occurs, i.e. higher “on” duty cycle, and this improves efficiency.

GV Series – Spectrum/Eff. Optimizer

- Automatically adapts to environmental changes (e.g. antenna VSWR or temperature) or transmitter configuration updates (e.g. HD injection or TPO)





E.g. GV20 @ 88MHz 16kW FM+HD -14dBc Injection MP3 mode

With Optimizer: less 120W Pdiss/FET and more than 8% higher efficiency

Making Digital Radio Work.

GV Series – Spectrum/Eff. Optimizer

Benefits :

- Lower semiconductor device dissipation (100W/device or more) and lower junction temperature; higher MTBF
- PA efficiency improvement of up to 8% or more
- Dynamic (on GV) – adapts to changing power, injection, ambient temp, VSWR, etc.
- Configurable for user specified mask clearance (default: 1 dB)
- Non compliance configurable alarm email notification
- Manual adjustment on NV, Auto on GV

2014 Performance
AC to RF Efficiency

- Analog – 71%, 72%
- Hybrid@ -20 dBc, 70%
- Hybrid @ -14 dBc, 57%
- Hybrid @ -10 dBc, 52%
- HD Only @ -14 dBc, 50%
- HD Only @ -10 dBc, 44%

Implications for HD Methods

- Does improved transmitter efficiency change the case for hybrid vs. separate transmitters?
- Traditionally, at medium to high TPO levels, separate HD and analog transmitters cost more in ***initial cost***, but were lower in ***operational cost.***
- What are the variables and tipping points?
- Sample calculation and analysis

Variables to Consider

- Age and condition of existing analog transmitter
- Age and condition of existing antenna
- Tower accommodation of new antenna (wind load, aperture, etc.)
  - Structural study, if needed, on tower
  - Tower upgrade costs
  - Rent or own tower
  - Tower rent if new or additional antenna
- Cost of new antenna and transmission line
- Building space
- Business decision: Is capital cost or operational cost more important?

Sample Analysis:
Step 1-Operating Cost

18 kW analog TPO, -14 dBc (720w digital):

Hybrid Operating Cost: 32.8 kW x 0.10 kwH x 8760 hrs/yr = $28,733 / yr.

Separate Operating Cost: (25 kW+1.8 kW) x 0.10 kwH x 8760 hrs/yr = $23,476 / yr.

Operational Savings: About $5,000 per year. Benchmark for ROI.

Step 2: Initial Tx Cost

Hybrid: Init Cap Cost*: GV20D, Importer , Exporter $110,000

Separate: Init Cap Cost*:NV20LT Analog + VS2.5HD, +I/E: $111,000

Must still add cost of external combining…..

** These are costs for illustrative purposes only, and may be more or less than actual quoted prices.*

nautel GVSeries

Step 2 –Antenna Costs

- Add cost of antenna
- Add cost of transmission line(s)
- Installation cost
- Add cost of structural study
- Add cost of tower mods
- Add incremental RENT !

All of the above, spread over 10 years, must be < $5,000 per year to realize a payback (this example only).

"Your mileage may vary!"

Variations on the Model

- If done 5 years ago, operational cost differential would have been larger, thus easier to justify separate configuration.
- At lower power levels, the operational cost differential is smaller, making it harder to justify the initial additional antenna costs.
- At higher power levels, easier to justify initial additional costs.
- At kwH rates above or below $0.10 kwH can help or hinder payback justification.

Step 2 –Antenna Costs

- Add
- Ac st of tra line(s)
- In lation c
- A cost ructura dy
- Ac tower m
- Add T !

All of the above, spread over 10 years, must be < $6,000 per year to realize a payback (this example only).

What about an ERI 788 All Pass Combiner?

ERI 788 Combiner Model

- KNOWN upfront cost (about $65,000)
- Eliminates risks and variables of “combining on the tower”
- Investment ROI may work for 10 year period
- Makes more sense for higher power levels and/or high electric rates
- May not be viable for < 20 kW TPO
- Must take into account injection losses (0.5 dB analog, 1.4 dB digital).
- Consider additional costs of switching

Summary

- Analog FM overall AC to RF efficiency now surpasses tubes at about 72%, thanks to advances in SMPS and LDMOS.
- HD Radio efficiency is aided by more advanced Peak Control algorithms, and by Efficiency Optimization routines.
- HD Radio separate amplifiers are still operationally lower cost, but investment ROI may take longer than previous.
- Newer combining techniques may be more attractive than “on the tower” combining, particularly at high TPO levels.

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