Ennes Workshop Series
Columbia University

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A New Approach to Solid-State High-Power FM Amplifiers

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INTRODUCTION

- New FM RF power amplifier technology offering major improvements over what is current available
  - Significantly higher output power density
  - More compact, space efficient transmitters
  - Greater power and cooling efficiency
  - Lower purchase and operating costs
  - Improved RF performance
  - Improved Robustness

POWER DENSITY AND COST

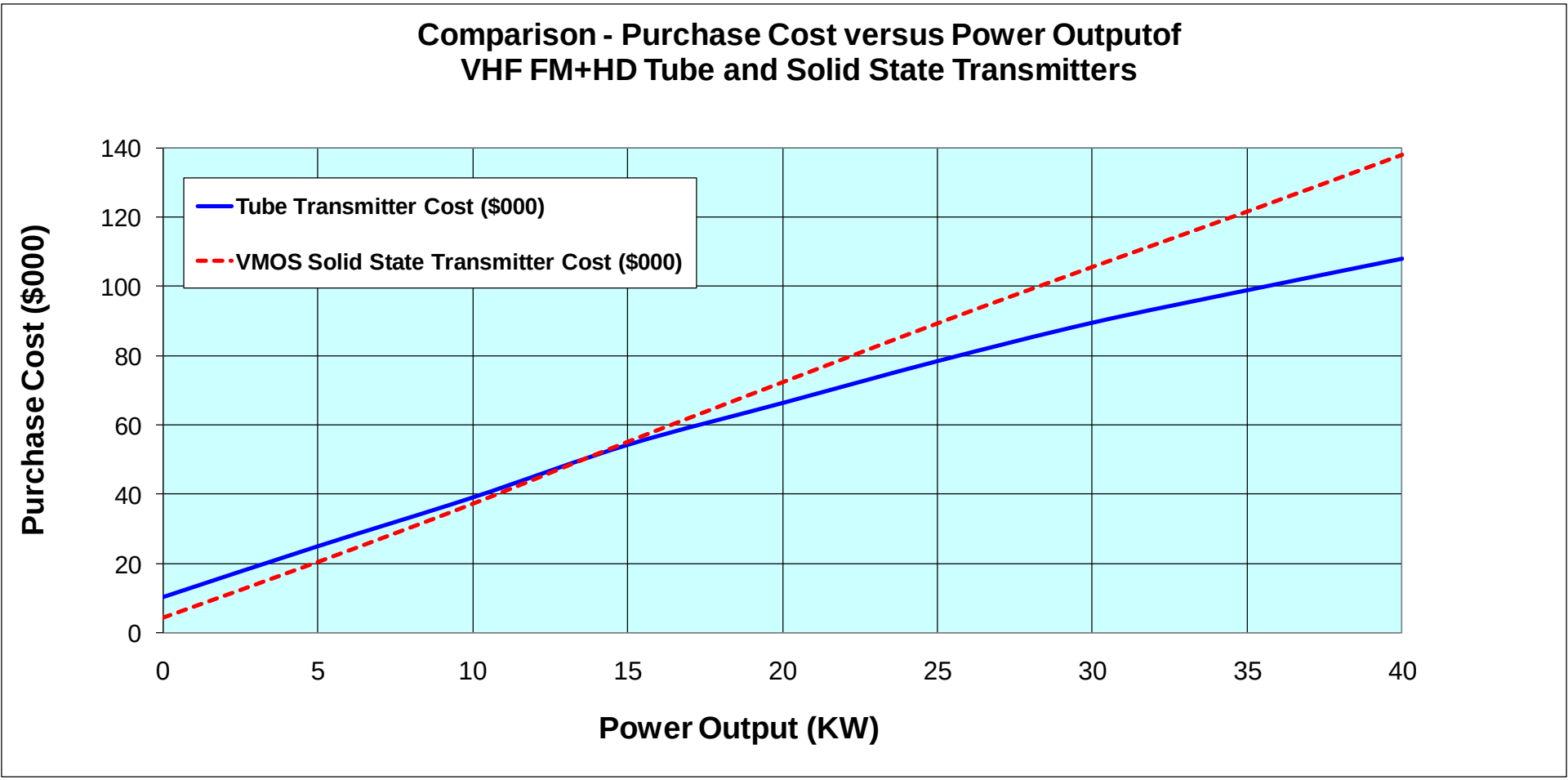
Increased power solid-state comes at a premium when compared to tube based transmitters

The cost increase of higher power in solid-state transmitters is linear

- 1:1 ratio of power vs. cost. Doubling the power output requires:
  - Doubling the size or number of power supplies
  - Doubling the size or number of output modules
  - Doubling the size or number of combiner ports used
  - Doubling the manufacturing and acquisition costs.

TUBE VS. SOLID-STATE COST COMPARISON

The cost of tube based transmitters flattens at higher powers levels exceeding 15kW with the current technology.



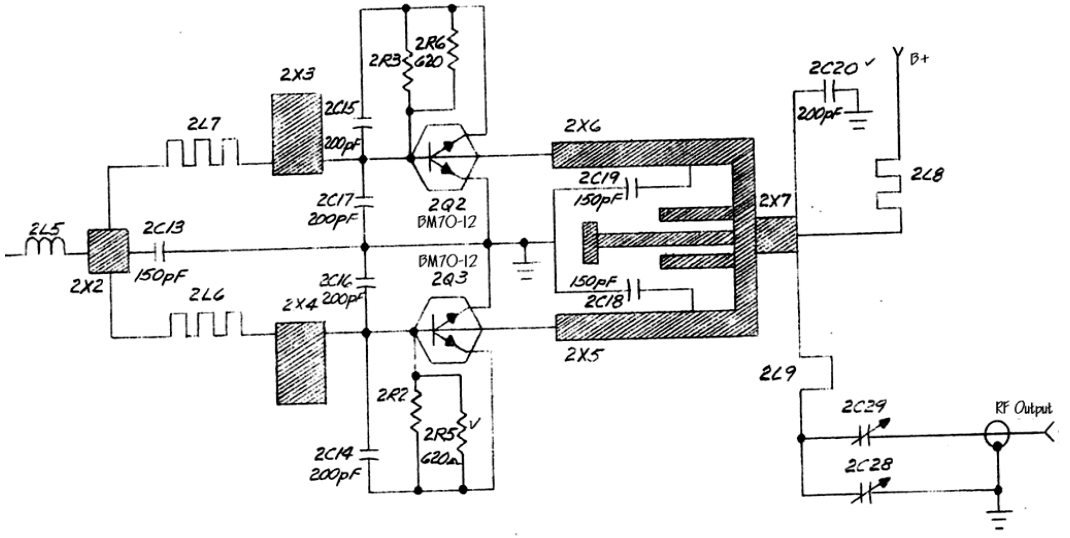
TUBE VS. SOLID-STATE

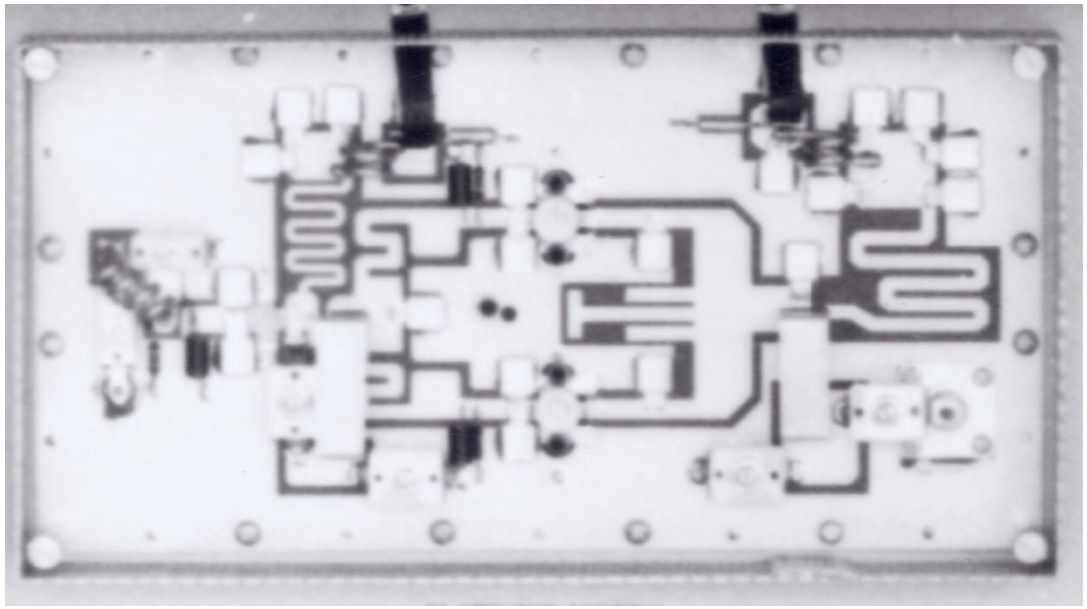
- **Solid-state power amplification advantages**
  - Redundancy
  - Soft failure modes
  - Lower maintenance
- **Tube based power amplification advantages**
  - Lower purchase price
  - Lower long term operating cost
  - Robustness against catastrophic abuses
  - Maintain efficiency over wide range of power and frequency
  - Up to 30% more efficient at higher power

EARLY FM SOLID-STATE

- The first solid-state FM transmitter was introduced at the 1974 at NAB
  - Sparta's Model 600B - **250 Watts** using 2 combined 150 Watt amplifiers
  - 58% PA efficiency - 38% AC-RF
  - $6,500 List ($28,500 today) dollars,
- A bargain at less than $100/Watt.

EARLY FM SOLID-STATE





The Sparta 600B amplifiers each used two parallel driven BM70-12, 12 volt bipolar transistors made by Communications Transistor Corporation.

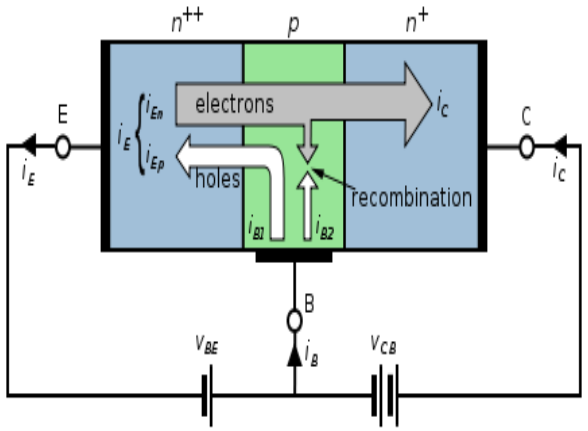
The two devices are run as separate common emitter, zero-bias class-C amplifiers

The outputs of the two amplifiers are in-phase combined

Required a 2nd harmonic notch filter as part of the output matching network

EVOLUTION OF SOLID-STATE AMPLIFIERS

- Bipolar Transistors (BJT)
  - Earliest solid-state FM transmitters used 12 volt BJTs such as the CTC BM70-12



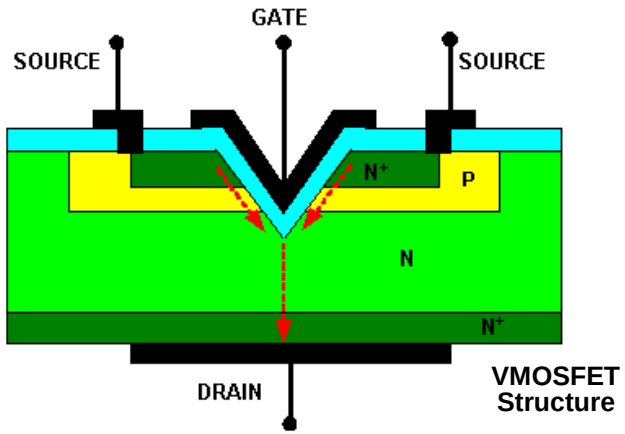
•Bipolar Junction Transistors work as current-controlled current regulators restricting the amount of current passed from the emitter to the collector (NPN) according to a small, controlling current applied to the base.

Vertically-Diffused Metal–Oxide-Semiconductor Field-Effect Transistor (VMOS-FET)

Nearly all today's solid-state FM transmitters use VMOS-FET devices

As RF amplifiers, VMOS-FETs have greatly superior characteristics when compared to BJTs:

- Thermal stability
- Frequency stability
- Improved linearity
- Higher gain (~14dB)
- Increased ruggedness
- Lower noise
- Lower feedback capacitance
- Simpler bias circuitry
- More easily matched input impedance
- Better IMD performance
- Lower thermal resistance



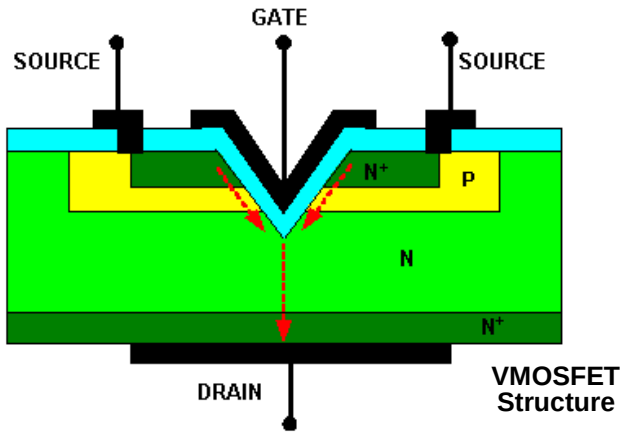
The VMOS-FET is named after the V-shaped groove architecture.

The increased gate surface area provides higher current handling and blocking voltage capability, better reliability and improved stability in the presence of severe mismatch.

Vertically-Diffused Metal–Oxide-Semiconductor Field-Effect Transistor (VMOS-FET)

Harris' Platinum Z and ZX lines of FM transmitters have used the Freescale MRF-151 and later, the NXP BLF-177 VMOS device since the early 1990s.

Other manufacturers use similar VMOS – FET devices such as the ST-Micro SD2942, or the Macom MRF151G



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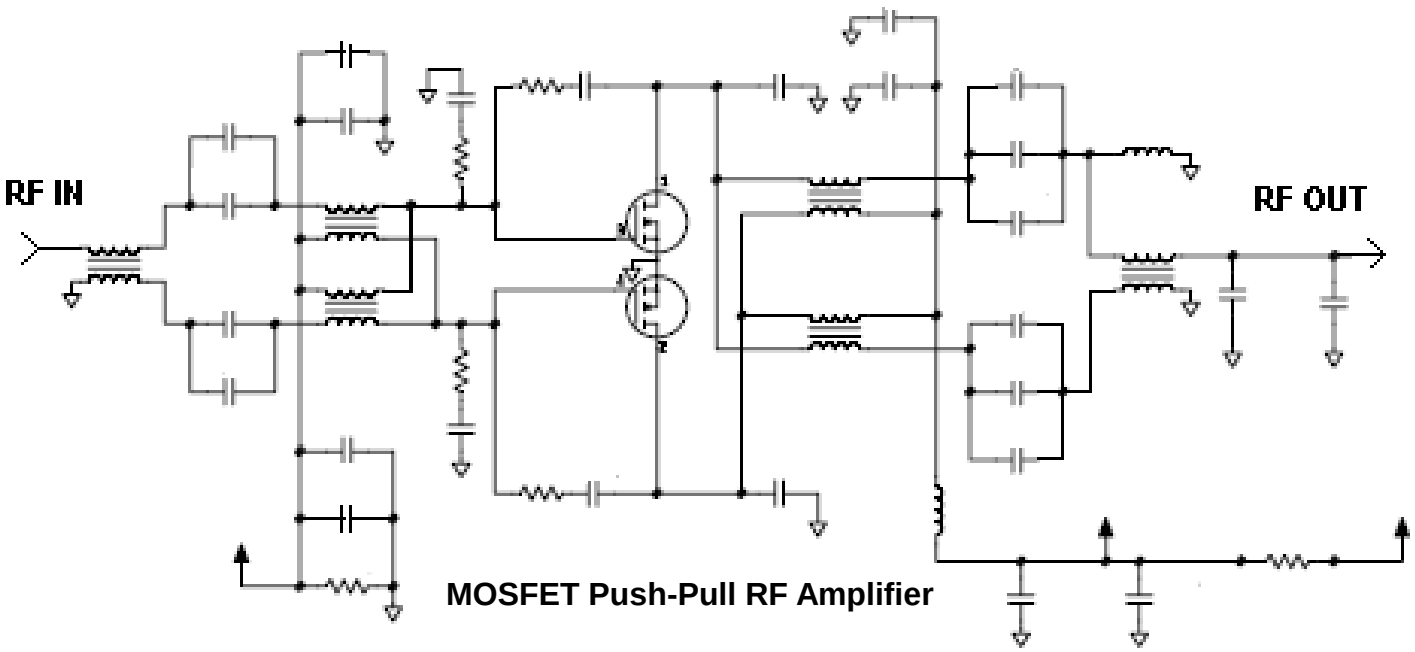
MODERN MOSFET PA



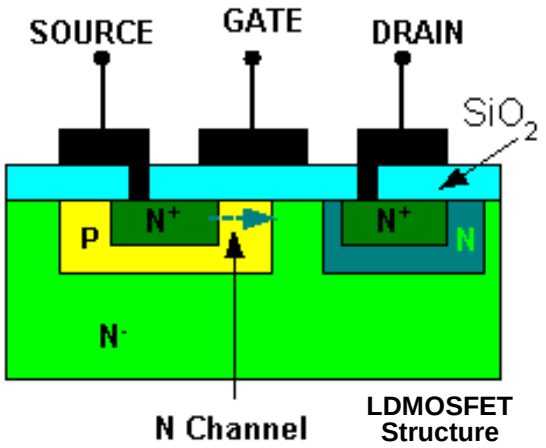
Using a pair of MOSFETS, higher input and output impedances make possible a wide bandwidth, push-pull architecture.

This provides 2nd and even order harmonic suppression eliminating the need for harmonic notch filtering

Laterally Diffused Metal–Oxide-Semiconductor Field-Effect Transistor (LDMOS-FET)

LDMOS-FETs have significant advantages over VMOS-FETs for RF amplifiers:

- Higher current handling
- Higher breakdown voltage
- Increased power density (2 x VMOS)
- Increased maximum power output
- Improved linearity
- Higher gain (~21dB) (less drive required)
- Improved efficiency
- Lower thermal resistance
- Increased ruggedness – Can tolerate extreme VSWR reflections of up to 65:1 pulsed at full rated power, at all phase angles



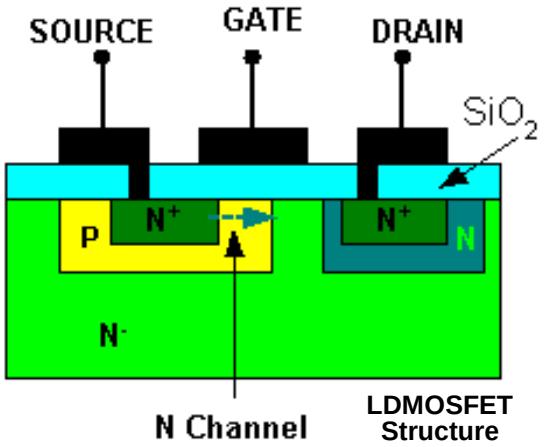
The LDMOS-FET is an asymmetric MOSFET designed for low on-resistance, higher blocking voltage and current handling capability than their VMOS counterpart.
Combined with a short channel length superior thermal performance and high breakdown voltage, these characteristics make them very attractive for high power RF amplifiers in many applications.

Laterally Diffused Metal–Oxide-Semiconductor Field-Effect Transistor (LDMOS-FET)

LDMOS-FET power amplifiers are used extensively in communication base stations, cellular systems, wireless communications and radar systems.

Harris has had a great deal of experience with LDMOS the Maxiva™ UHF and VHF television transmitters, as well as the Platinum™ series L-band television transmitters.

Recent developments in 50-volt VHF Band II LDMOS device technology have resulted in dramatic improvements in power density per device, and maximum power output as well as linearity and efficiency.



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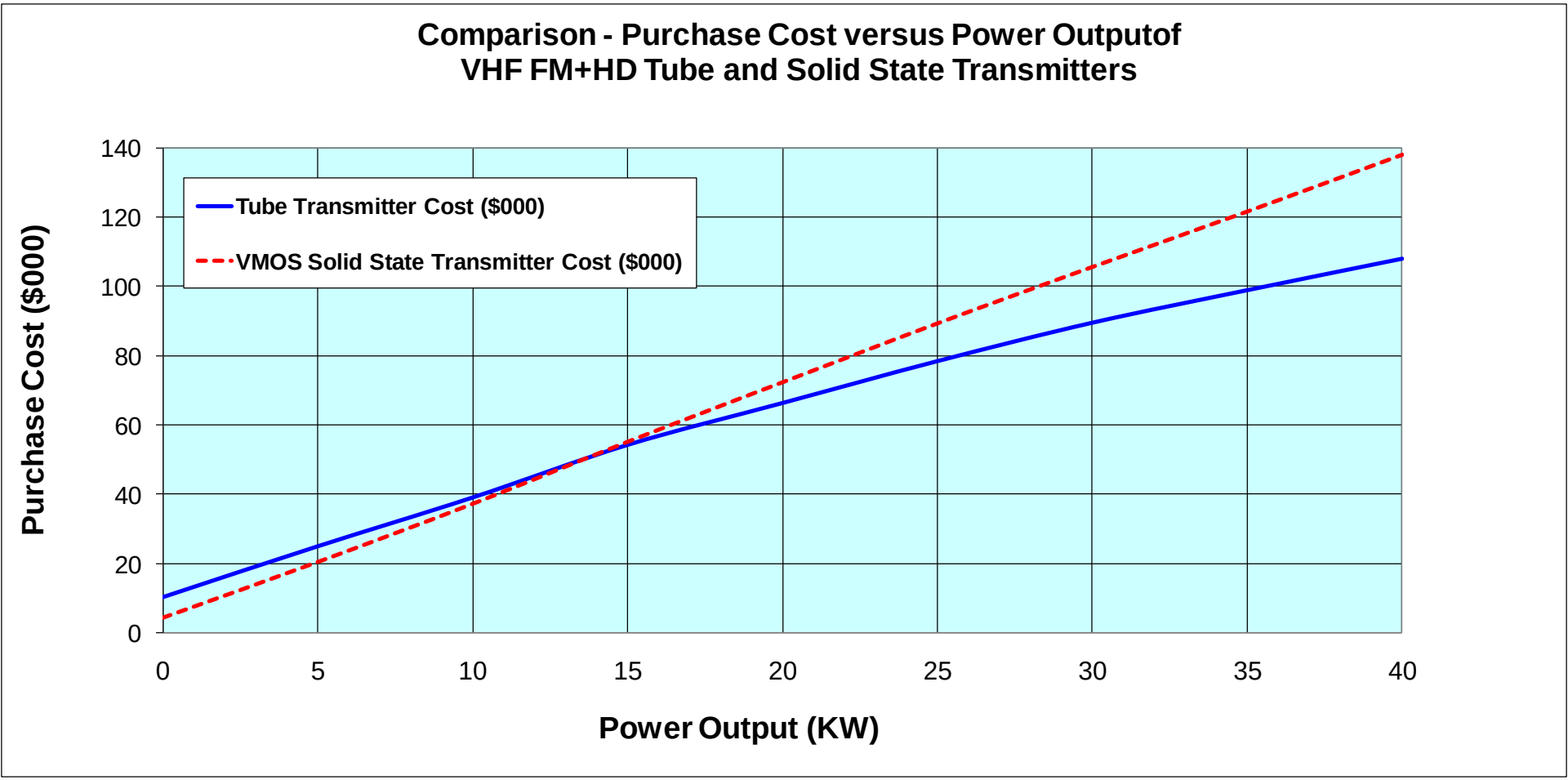
POWER DENSITY Vs. COST



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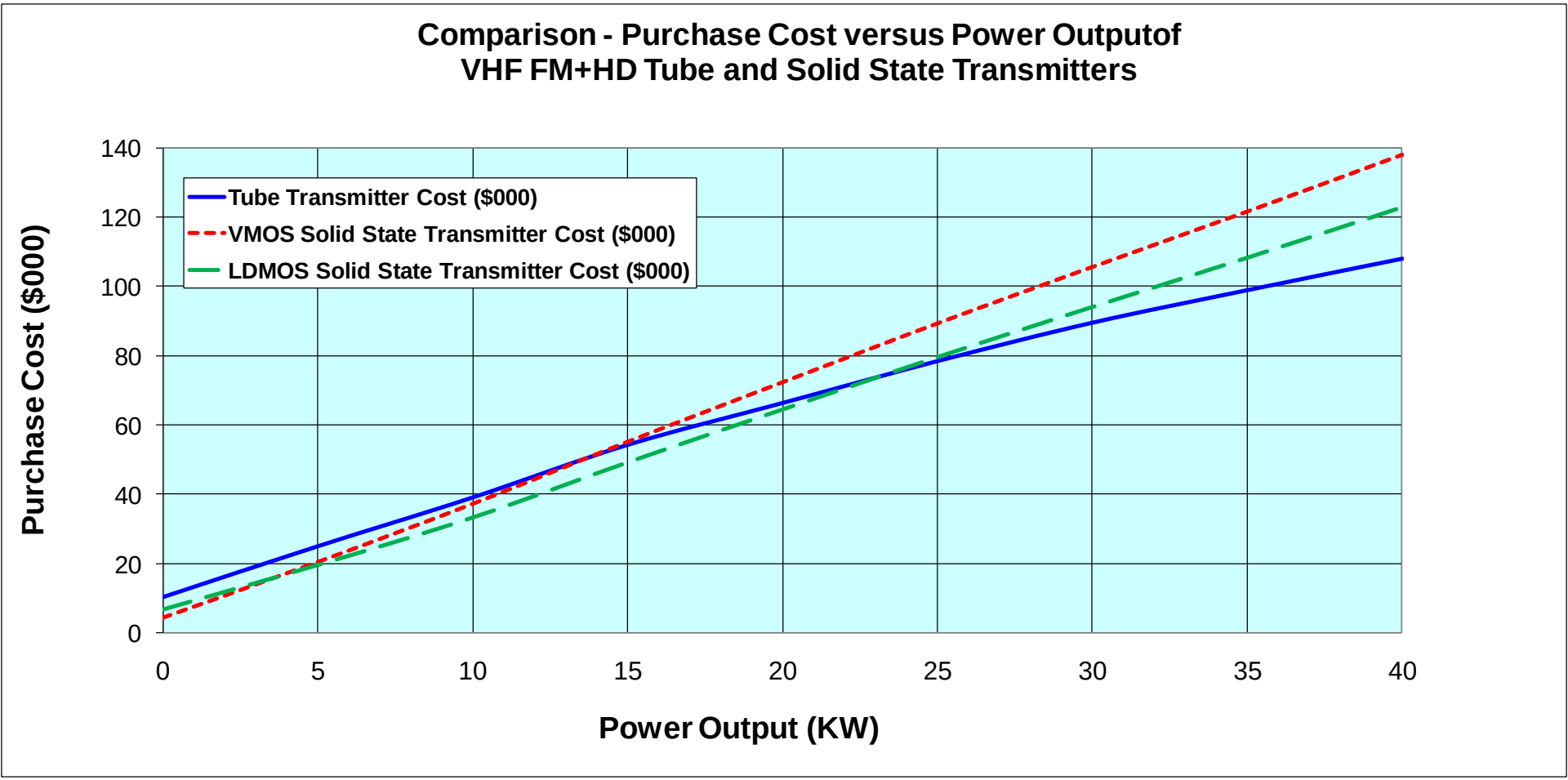


POWER LEVEL REQUIREMENTS

- A wide range of power levels is required today
- Digital RF waveforms require higher average power, higher peak power, lower thermal resistance and higher efficiency
- Common amplification systems must have additional peak power capability to pass PAR of combined, hybrid signal
- New LDMOS devices, with a peak envelope power rating of 1.25kW running at an average power of 850 Watts have the additional headroom required for the PAR of digital waveforms

HYBRID CREST FACTOR REDUCTION

- PAR required depends on mix ratio of HD with the FM
- Standard Crest Factor Reduction (CFR) applied to (OFDM) signal within Exgine doesn't take into account downstream vector summation of FM added to HD in common amplification transmitter
- Hybrid Crest Factor Reduction (HCFR) can be applied to the digital signal accounting for vector addition of FM analog signal
- Depending on the ratio of HD power combined with the FM
  - **Up to 33% improvement in average transmitter power output at -10dBc**
  - **Up to 16% improvement at a -14dBc injection level**
- HCFR applies only to common amplification – not digital only
- HD Radio carrier injection level should be increased to make-up for RMS power removed by HCFR
- Imposes further stress on the PA and reduces the overall net gain in PA utilization

• NAB BEC April 11th 2010

HYBRID CREST FACTOR REDUCTION

HD Operating Mode	HD Carrier Injection (dBc)	PAR (dB) @ 0.01% with SCFR	PAR (dB) @ 0.01% with HCFR	PA Utilization Improvement
MP1	-20	1.49	1.11	+9%
MP3	-20	1.65	1.22	+10%
MP1	-14	2.64	2.04	+15%
MP3	-14	2.87	2.22	+16%
MP1	-10	3.75	2.58	+31%
MP3	-10	3.96	2.72	+33%

• NAB BEC April 12th 2010

ASB, HCFR, MER IMPLEMENTATION

- Asymmetrical HD Sidebands, Hybrid Crest Factor Reduction, and MER calculations are currently being implemented outside the Exgine modulation process
- Inefficient to apply a second layer of HCFR to OFDM sidebands that have already had digital only CFR applied
- Inefficient to introduce sideband asymmetry downstream using digital filters after OFDM modulation
- Harris and others currently offering these functions outside Exgine as near term solution
- More efficient and cost effective to integrate these functions with the ODFM modulation process within the Exgine

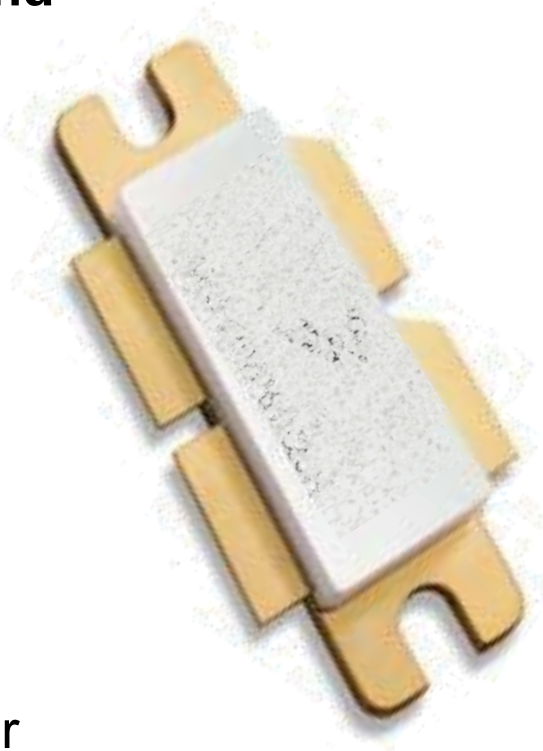
ASB, HCFR, MER IMPLEMENTATION

- Optimum solution is to integrate crest factor reduction into OFDM modulation process where sideband asymmetry and MER impact can be taken into account
- Doing this signal processing within the Exgine is more accurate and efficient than applying processing downstream as a second layer outside the Exgine
- Harris is working with iBiquity to add these signal processing features to the next generation Exgine

POWER DENSITY

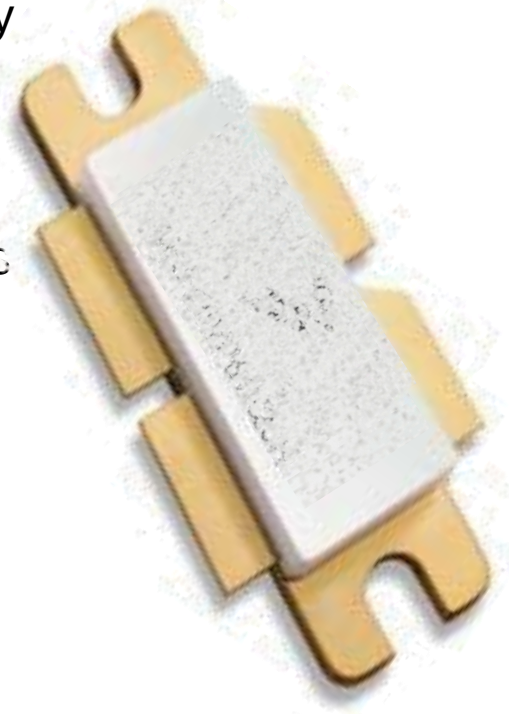
Amplifier power density is the key to reducing both the size of the transmitter and the cost of manufacturing and purchase.

- Contemporary solid-state 10kW FM transmitter designs can achieve about 625 Watts per cubic foot at a cost of around $8.00/Watt in a single 19” rack
- *50 Volt LDMOS makes possible fewer devices in a more compact and lower cost transmitter package*
- New transmitter systems designed around these higher per-device power levels can now achieve 20 kW in the same 19” rack or around 1250W per cubic foot at a cost of less than $5.00/Watt



HIGHER POWER DENSITY

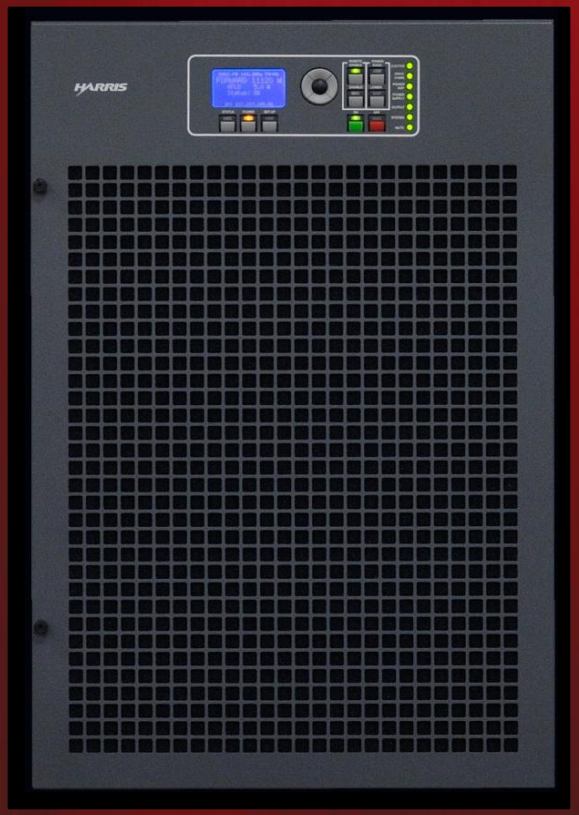
- Several LDMOS devices evaluated for the new high-power FM module.
- Selection criteria: Power Density, Gain, Efficiency & Robustness.
- Used in industrial, scientific and medical (ISM) markets such as CO^2 lasers, plasma generators and magnetic resonance imaging (MRI) scanners
- The LDMOS device ultimately selected for incorporation into Harris' next generation FM module passed all of stress tests and performed flawlessly.

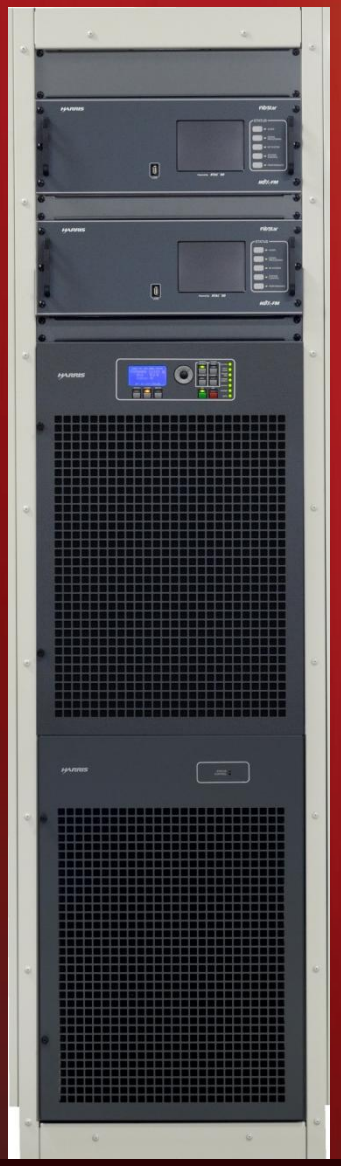


Introducing Flexiva™

A New Family of Air-Cooled FM Transmitter for Worldwide Analog and Digital Standards

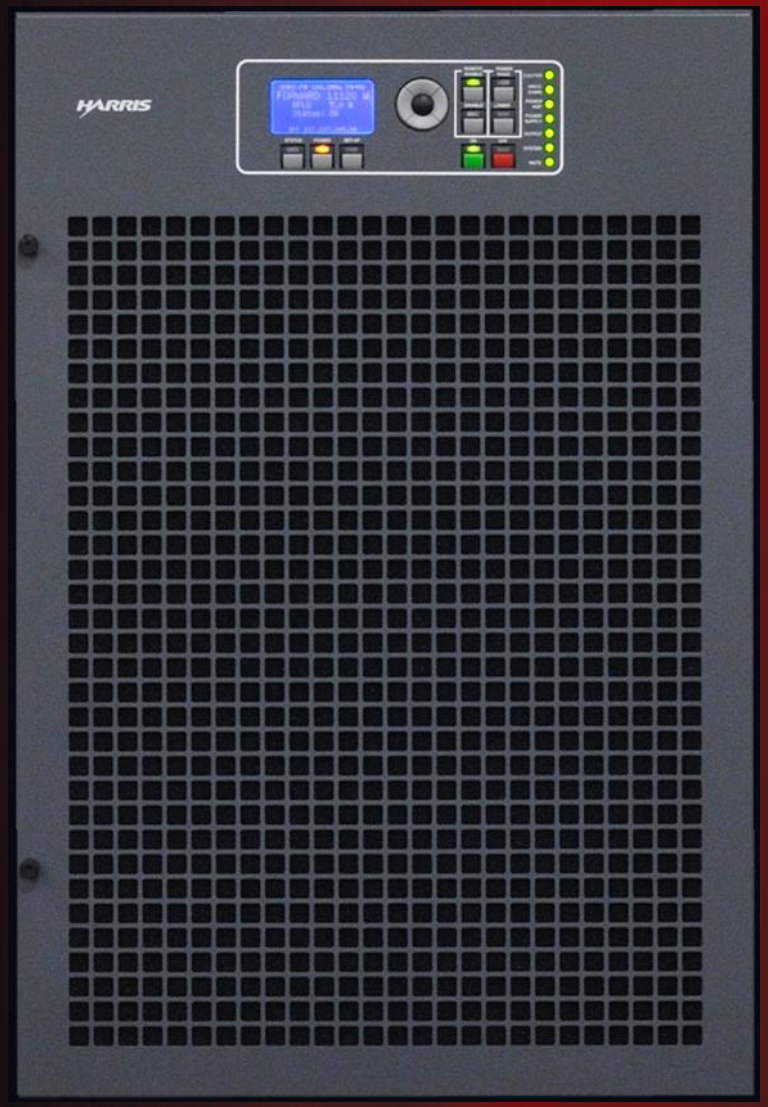
PowerSmart™





Highest efficiency >70% AC > RF
Most Compact – 10 kW in 16 RU

High-Power 10 KW



- 16 RU Compact Transmitter
  - FAX 5K 6,200 W
  - FAX 10K 11,000 W
- Optional Internal Flexiva Exciter
  - Self contained
  - Input for External Exciter
  - Auto switching Main/Alt Exciters
- 10 kW Block - Scalable up to 40kW

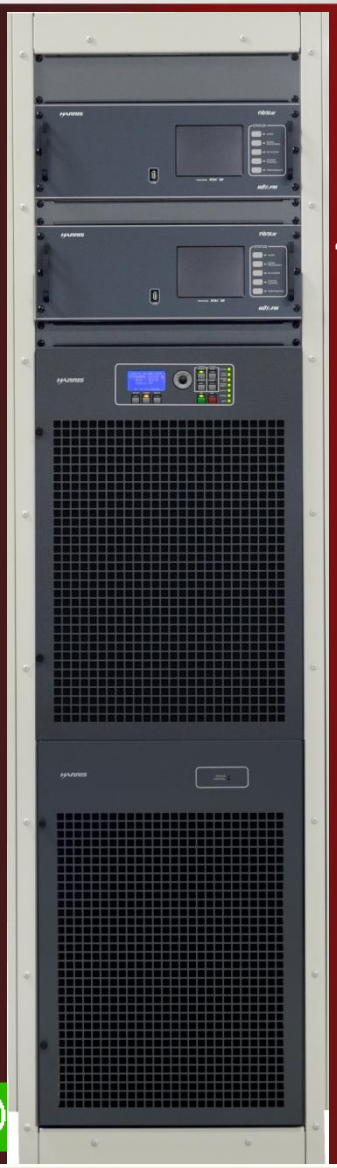
PowerSmart™

Flexiva™ High-Power – FAX 20K / FAX 40K

Flexstar HD Radio™ Exciter

Power Block Control w/ optional FAX300 Exciter

2 x FAX 10K 10kW Power Blocks



FAX 20K
22,000 W
44 RU

4 x FAX 10K 10kW Power Blocks

FAX 40K
42,000 W
2 x 44 RU

PowerSmart™

AMPLIFIER PALLET DESIGN

Freescale Semiconductor
Technical Data

RF Power Field Effect Transistors

High Ruggedness N-Channel
Enhancement-Mode Lateral MOSFETs

These high ruggedness devices are designed for use in high VSWR i... (including laser and plasma exciters), broadcast (analog and digital), aerosp... and radio/land mobile applications. They are unmatched input and outp... designs allowing wide frequency range utilization, between 1.8 and 600 MHz.

- Typical Performance: V_{DD} = 50 Volts, I_{DQ} = 100 mA

Signal Type	P_{out} (W)	f (MHz)	G_{ps} (dB)	η_D (%)	IRL (dB)
Pulsed (100 µsec, 20% Duty Cycle)	1250 Peak	230	24.0	74.0	-1...
CW	1250 CW	230	22.9	74.6	-15

- Capable of Handling a Load Mismatch of 65:1 VSWR, @ 50 Vdc, 230 MHz, at all Phase Angles, Designed for Enhanced Ruggedness, 1250 Watts Pulsed Peak Power, 20% Duty Cycle, 100 µsec
- Capable of 1250 Watts CW Operation

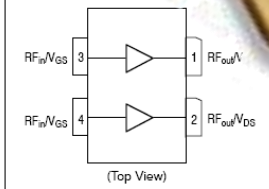
Features

- Unmatched Input and Output Allowing Wide Frequency Range Utilization
- Device can be used Single-Ended or in a Push-Pull Configuration
- Qualified Up to a Maximum of 50 V_{DD} Operation
- Characterized from 30 V to 50 V for Extended Power Range
- Suitable for Linear Application with Appropriate Biasing
- Integrated ESD Protection with Greater Negative Gate-Source Voltage Range for Improved Class C Operation
- Characterized with Series Equivalent Large-Signal Impedance Parameters
- RoHS Compliant
- In Tape and Reel. R6 Suffix = 150 Units, 56 mm Tape Width, 13 inch Reel. For R5 Tape and Reel options, see p. 12.

Table 1. Maximum Ratings

Rating	Symbol	Value	Unit
Drain-Source Voltage	V_{DSS}	-0.5, +125	Vdc
Gate-Source Voltage	V_{GS}	-6.0, +10	Vdc
Storage Temperature Range	T_{stg}	-65 to +150	°C
Case Operating Temperature	T_C	150	°C
Total Device Dissipation @ T_C = 25°C Derate above 25°C	P_D	1333 6.67	W W/°C
Operating Junction Temperature (1,2)	T_J	225	°C

CASE 375E-04,
NI-1230
MRFE6VP61K25
PARTS Ar...

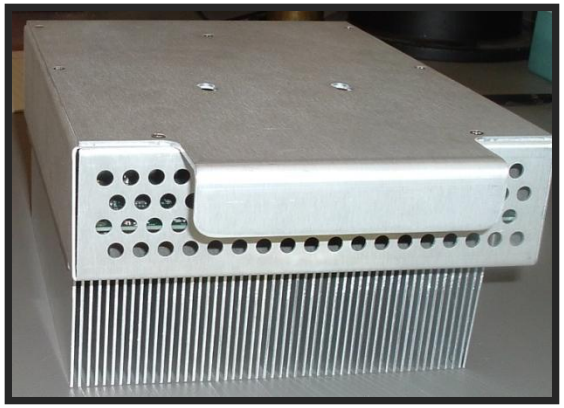


(Top View)

Figure 1. Pin Connections

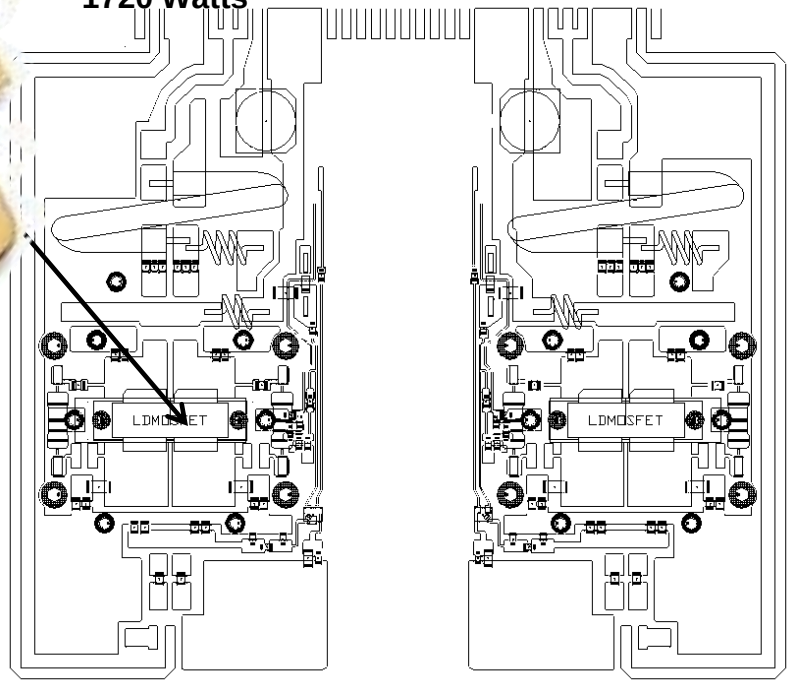
New RF Device

50V LDMOSFET
1275W / Device
82% Efficiency
21.5 dB Gain



New RF Module

Conservative
1720 Watts



Part of the new highly successful LDMOS Family used in all current TV and DMB products

Power Supply Modules

LINEAGE POWER

- Over-temperature warning and protection
- Redundant, parallel operation with active load sharing and redundant +5V Aux power
- Remote ON/OFF
- Hot insertion/removal (hot plug)
- Four front panel LED indicators
- UL* Recognized to UL60950-1, CAN/ CSA† C22.2 No. 60950-1, and VDE‡ 0805-1 Licensed to IEC60950-1
- CE mark meets 2006/95/EC directive§
- Internally controlled Variable-speed fan
- RoHS 6 compliant

Compact Power Line

CP2725AC54TE High Efficiency Front End PS

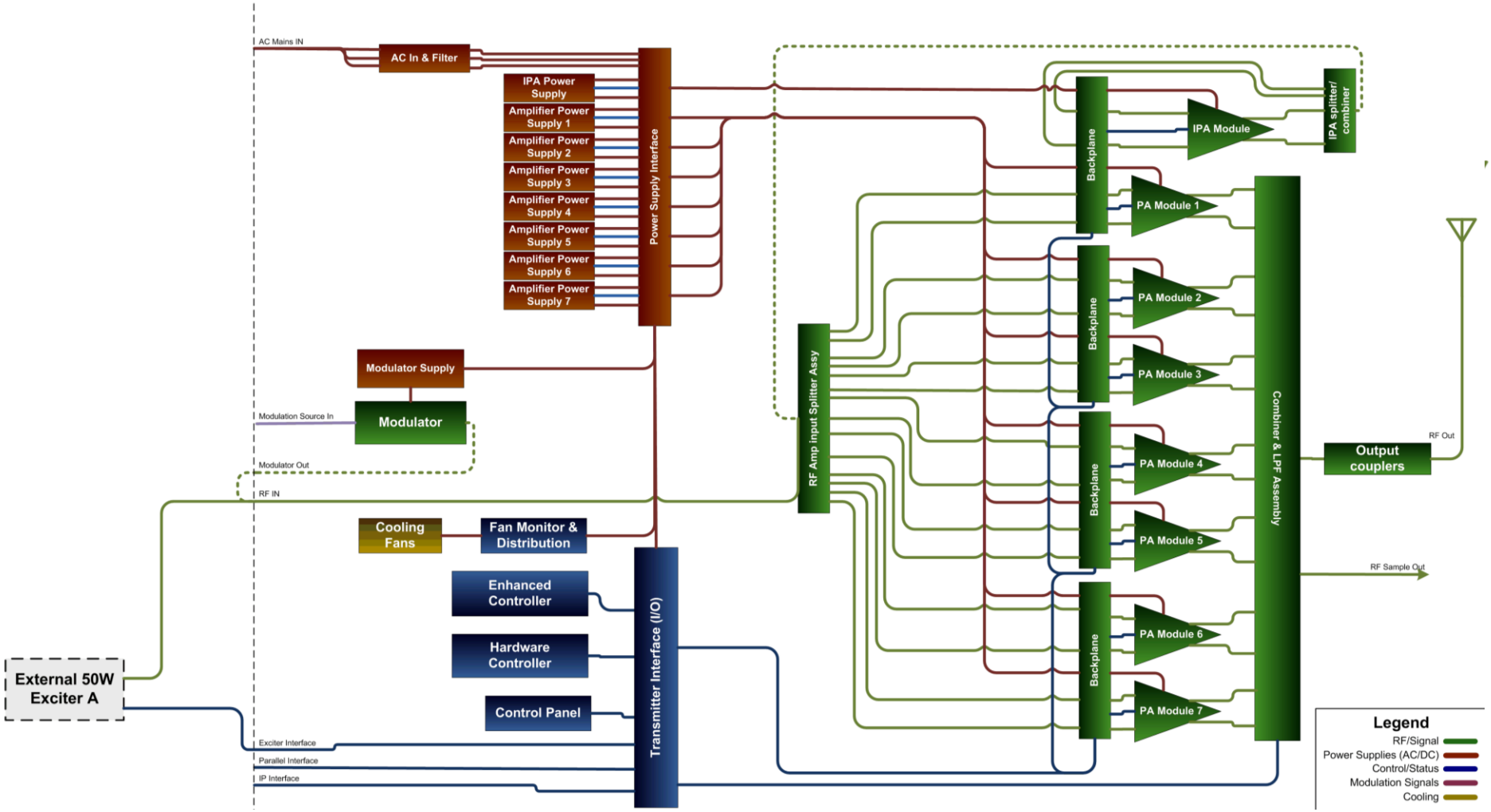
Input: 100-120/200-277 Vac; Default Output: ±54 Vdc @ 2725W; 5 Vdc @ 4W

- 2725 Watt Switching Power Supply Modules
- 1 Power supply per dual PA Module
- 96% Efficiency
- Wide operating voltage range

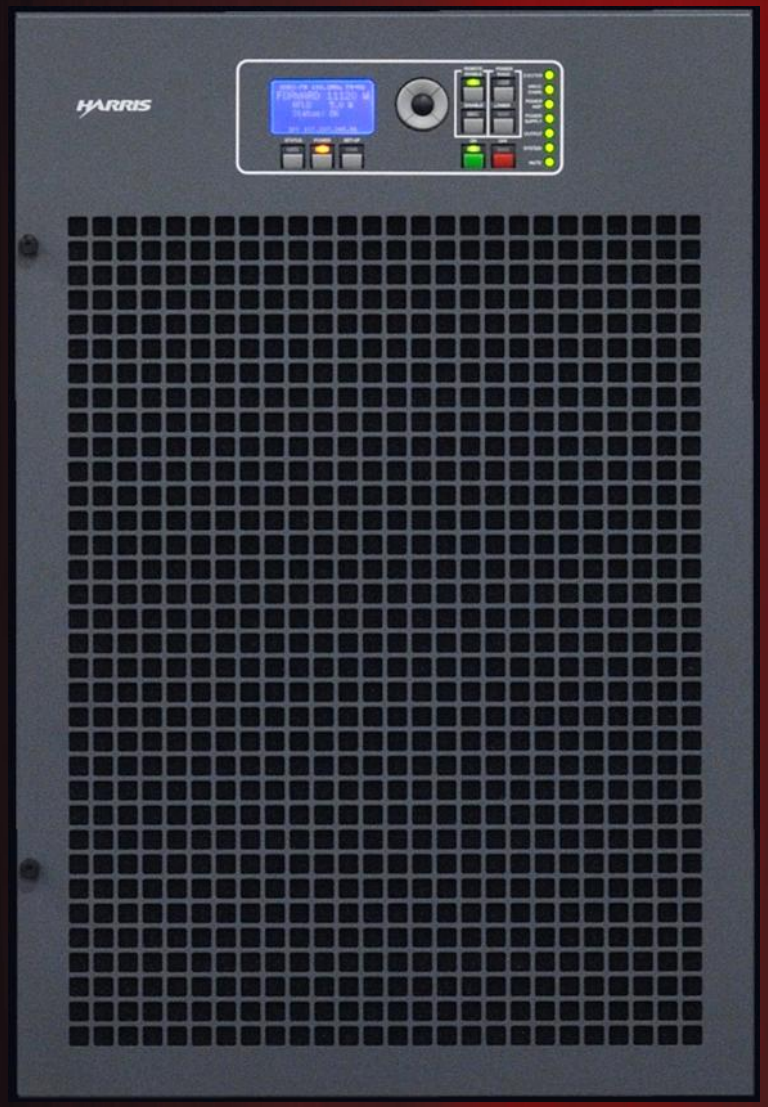
DISSIPATION AND COOLING

- Temperature is the silent killer for solid-state devices
- The higher efficiency of the LDMOS devices reduces the overall power dissipation
  - Achieves PA Efficiency of >82% in FM analog
  - Constant efficiency and power output across FM band
- Lower thermal resistance reduces the junction operating temperature making the device easier to cool
- Designing for the worst dissipation conditions, we must not only consider maximum ambient temperature, but also maximum VSWR at which the device may be operated at full power

NEW ARCHITECTURE FOR HIGHER POWER



High-Power 10 KW



- 16 RU Compact Transmitter
  - FAX 5K 6,200 W
  - FAX 10K 11,000 W
- AC-RF Efficiency > 70%
- Optional Internal Flexiva Exciter
  - Self contained
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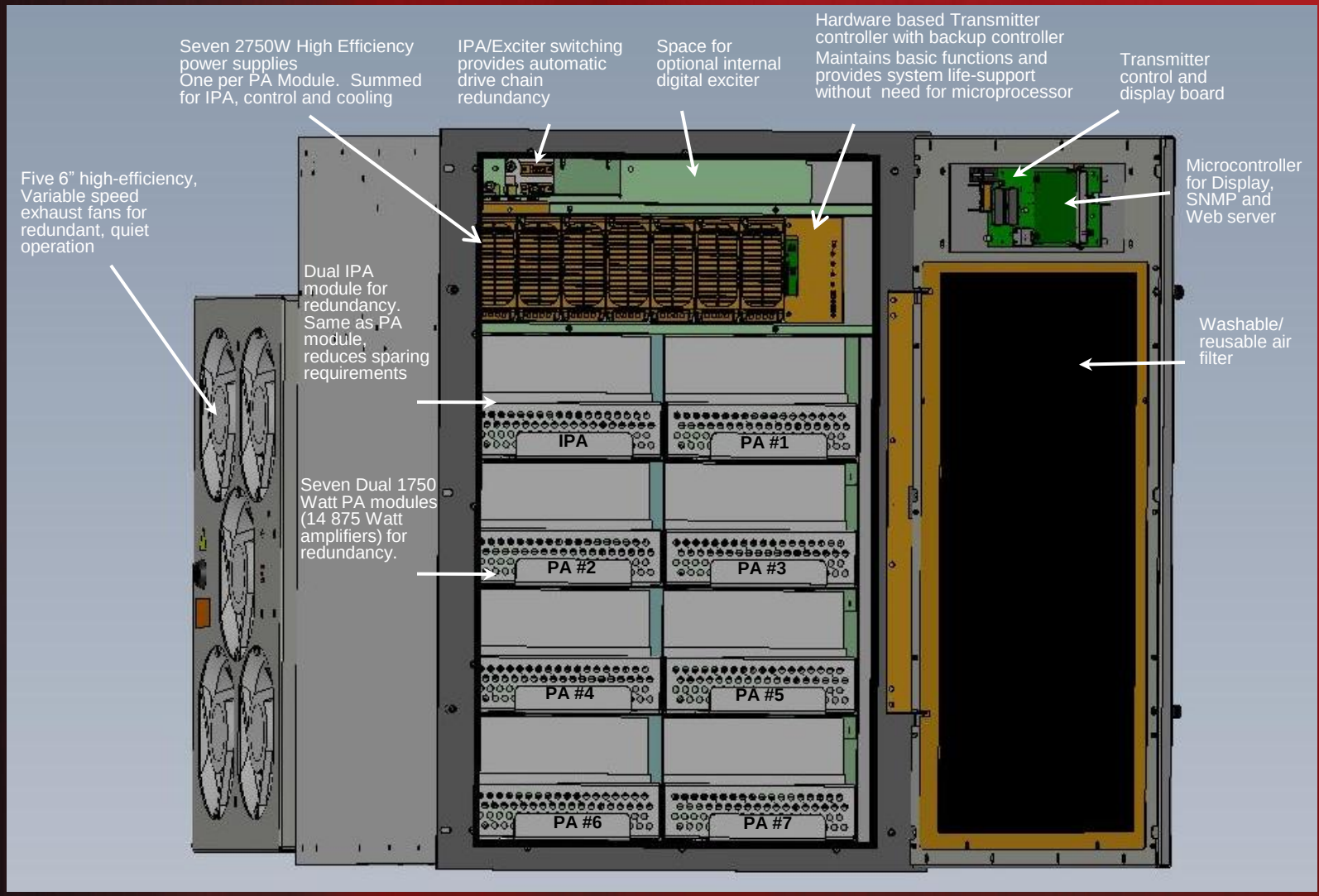
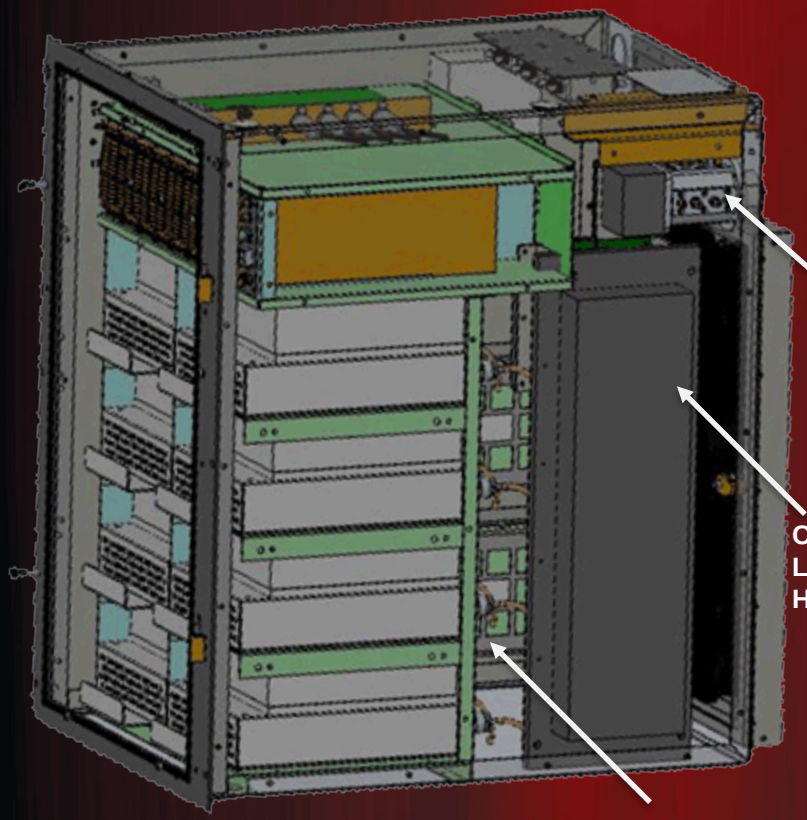
- 10 kW Block - Scalable up to 40kW

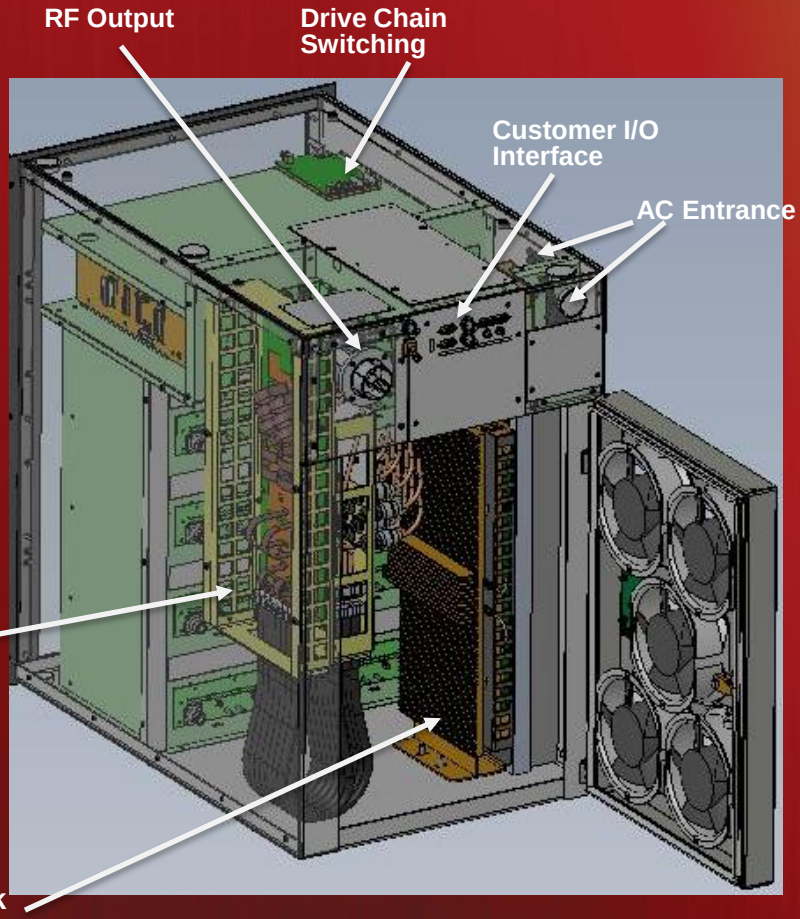
PowerSmart™

Inside Flexiva



Inside Flexiva





Flexiva™ High-Power

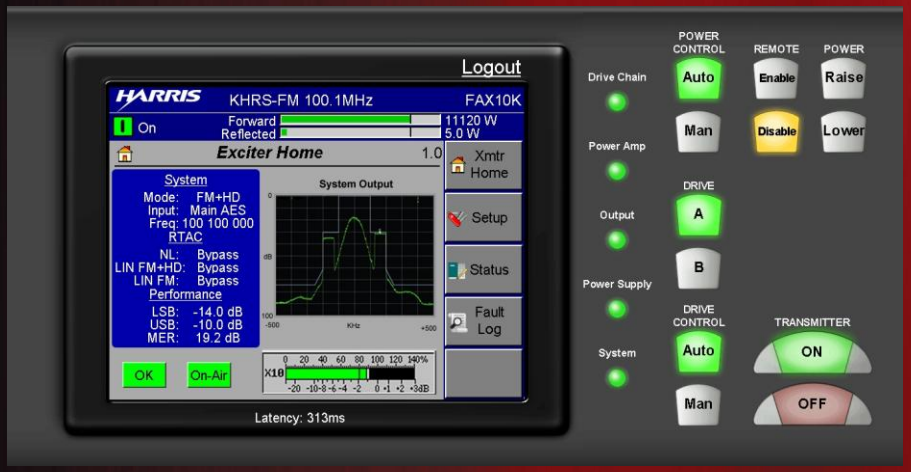
Model	Analog FM Power Range Watts	FM+HD -20dBc Power W	FM+HD -14dBc Power W	FM+HD -10dBc Power W	HD Only -20dBc Power W	HD Only -14dBc Power W	HD Only -10dBc Power W
FAX50	1 - 65	47	37	28	22	20	17
FAX150	10 - 175	127	100	76	48	42	37
FAX300	30 - 330	240	188	144	120	116	100
FAX500	50 - 550	413	314	267	200	195	170
FAX1K	100 - 1100	852	630	480	400	388	340
FAX2K	200 - 2200	1,704	1,256	1,068	800	776	684
FAX3K	300 - 3300	2,475	1,770	1,440	1,200	1,164	1,020
FAX5K	500 - 5500	4,000	3,600	2,400	2,000	1,940	1,700
FAX10K	1,000 - 11,000	8,530	6,430	5,450	3,640	3,265	3,120
FAX20K	2,000 - 22000	17,040	13,600	11,524	7,280	6,530	6,240

Front Panel User Interface

Simple – Powerful Front Panel Controls

- Easy to Read LCD Screen
- Finger friendly buttons for navigation and control
- Bright colored LED's for status and fault monitoring

Flexiva™ Web GUI



- Feature-rich and intuitive *Advanced Graphical User Interface* allows Flexiva to be controlled from anywhere in the world via the World-Wide-Web
- Front panel RJ45 allows instant access with a PC for detailed diagnostics, control and monitoring
- Works with any PC based browser or Smartphone
- Remote alarms are generated automatically in the event of a fault and are sent via SNMP or E-Mail with the connection to a network.
- Password protection

20-40 KW SOLID STATE TRANSMITTER

- Considering liquid cooled 40KW architecture
- Advantages:
  - 4 x power density of current air cooled
  - 40KW possible in a single 19” rack
  - Quiet and more efficient cooling = lower operating cost
  - Less impact on HVAC requirements
  - Well proven in DTV transmitters
- Disadvantages:
  - Additional cost of cooling components
  - Somewhat more complex installation
- Need customer feedback

Liquid Cooled High Power?

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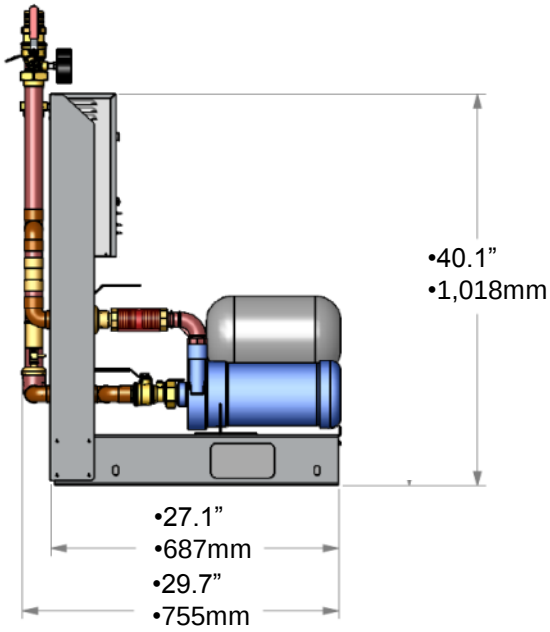
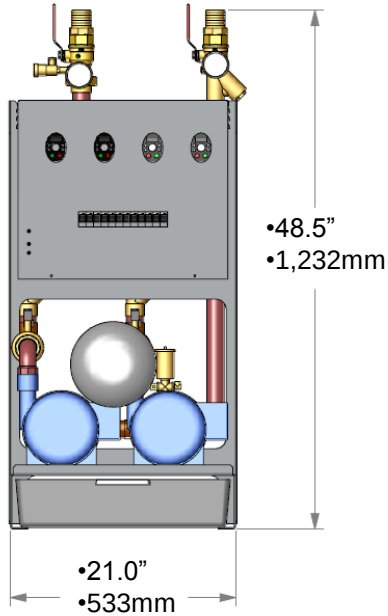
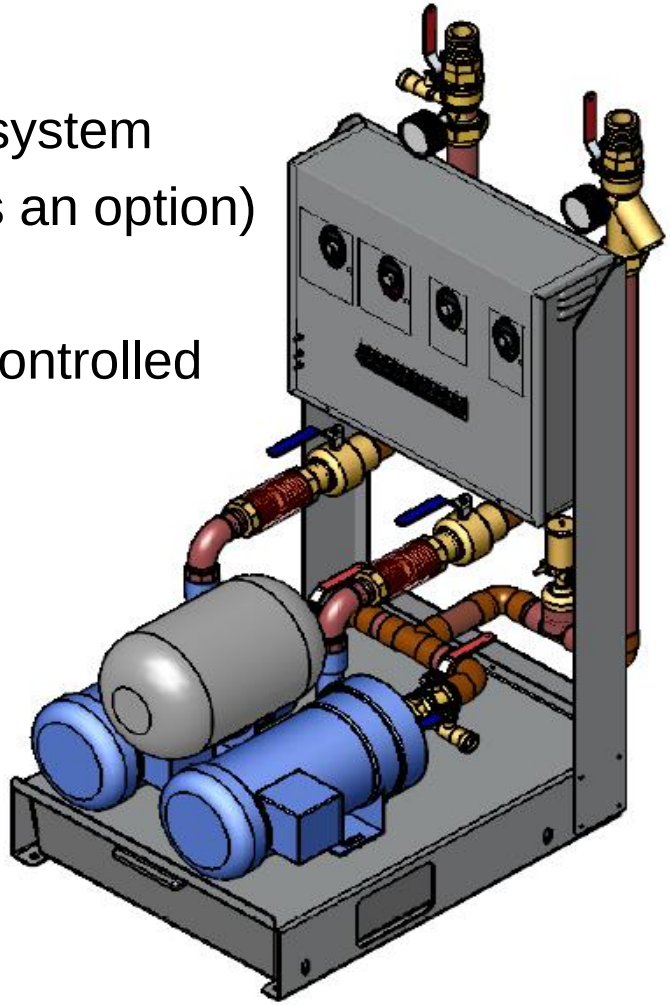
PowerSmart™

New Harris Pump Module

- Small physical size
- 2 Pumps, with auto changeover
- Low maintenance, closed-loop pressurized system
- Indoor design (outdoor qualified available as an option)
- No fill pump required
- Optimized Efficiency, pump speed inverter controlled







Questions?

A New Approach to Solid-State FM Amplifiers

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