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 currently 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.
The cost of tube based transmitters flattens at higher powers levels exceeding 15kW with the current technology.
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
The first solid-state FM transmitter was introduced at the 1974 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.
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 2\textsuperscript{nd} harmonic notch filter as part of the output matching network.
**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.
EVOLUTION OF SOLID-STATE AMPLIFIERS

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.

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

This provides 2\textsuperscript{nd} 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 (2x 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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Comparison - Purchase Cost versus Power Output of VHF FM+HD Tube and Solid State Transmitters

- Tube Transmitter Cost ($000)
- VMOS Solid State Transmitter Cost ($000)
Comparison - Purchase Cost versus Power Output of VHF FM+HD Tube and Solid State Transmitters

- Tube Transmitter Cost ($000)
- VMOS Solid State Transmitter Cost ($000)
- LDMOS Solid State Transmitter Cost ($000)
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
## HYBRID CREST FACTOR REDUCTION

<table>
<thead>
<tr>
<th>HD Operating Mode</th>
<th>HD Carrier Injection (dBc)</th>
<th>PAR (dB) @ 0.01% with SCFR</th>
<th>PAR (dB) @ 0.01% with HCFR</th>
<th>PA Utilization Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>MP1</td>
<td>-20</td>
<td>1.49</td>
<td>1.11</td>
<td>+9%</td>
</tr>
<tr>
<td>MP3</td>
<td>-20</td>
<td>1.65</td>
<td>1.22</td>
<td>+10%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MP1</td>
<td>-14</td>
<td>2.64</td>
<td>2.04</td>
<td>+15%</td>
</tr>
<tr>
<td>MP3</td>
<td>-14</td>
<td>2.87</td>
<td>2.22</td>
<td>+16%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MP1</td>
<td>-10</td>
<td>3.75</td>
<td>2.58</td>
<td>+31%</td>
</tr>
<tr>
<td>MP3</td>
<td>-10</td>
<td>3.96</td>
<td>2.72</td>
<td>+33%</td>
</tr>
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</table>
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.
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.
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.
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 CO² 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

Highest efficiency >70% AC > RF
Most Compact – 10 kW in 16 RU
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
High-Power – FAX 20K / FAX 40K

- **FAX 20K**
  - 22,000 W
  - 44 RU
  - Flexstar HD Radio™ Exciter
  - Power Block Control w/ optional FAX300 Exciter
  - 2 x FAX 10K 10kW Power Blocks

- **FAX 40K**
  - 42,000 W
  - 2 x 44 RU
  - 4 x FAX 10K 10kW Power Blocks
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 (including cable and plexus exciters), broadcast (analog and digital), aeronautical and radio/land mobile applications. They are unmatched input and output designs allowing wide frequency range utilization, between 1.8 and 800 MHz.

- Typical Performance: $V_{DS} = 50$ Volts; $I_{DS} = 100$ mA

<table>
<thead>
<tr>
<th>Signal Type</th>
<th>$P_{out}$ (W)</th>
<th>$f_{max}$ (MHz)</th>
<th>$R_{DS}$ (ohms)</th>
<th>$V_{PP}$ (%)</th>
<th>IRL (bits)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulsed (100 usec, 20% Duty Cycle)</td>
<td>1250 Peak</td>
<td>230</td>
<td>24.0</td>
<td>74.0</td>
<td>16</td>
</tr>
<tr>
<td>CW</td>
<td>1250 CW</td>
<td>230</td>
<td>22.0</td>
<td>74.6</td>
<td>-16</td>
</tr>
</tbody>
</table>

- 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 usec
- 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 to a Maximum of 50 $V_{DS}$ 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. 88 Suffix = 150 Units. 56 mm Tape Width, 13 inch Reel. For RS Tape and Reel options, see p. 12.

Table 1. Maximum Ratings

<table>
<thead>
<tr>
<th>Rating</th>
<th>Symbol</th>
<th>Value</th>
<th>Unit</th>
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<tbody>
<tr>
<td>Drain-Source Voltage</td>
<td>$V_{DS}$</td>
<td>-0.5, +125</td>
<td>Vdc</td>
</tr>
<tr>
<td>Gate-Source Voltage</td>
<td>$V_{GS}$</td>
<td>-8.0, +10</td>
<td>Vdc</td>
</tr>
<tr>
<td>Storage Temperature Range</td>
<td>$T_{S}$</td>
<td>-65 to +150</td>
<td>°C</td>
</tr>
<tr>
<td>Case Operating Temperature</td>
<td>$T_{C}$</td>
<td>150</td>
<td>°C</td>
</tr>
<tr>
<td>Total Device Dissipation @ $T_{C} = 25$°C</td>
<td>$P_{D}$</td>
<td>1383</td>
<td>W</td>
</tr>
<tr>
<td>Duty above 25°C</td>
<td>$P_{D}$</td>
<td>5.67</td>
<td>W/°C</td>
</tr>
<tr>
<td>Operating Junction Temperature</td>
<td>$T_{J}$</td>
<td>220</td>
<td>°C</td>
</tr>
</tbody>
</table>

Figure 1. Pin Connections

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

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

New RF Module
Conservative
1720 Watts
Power Supply Modules

- 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
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
**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
  - Input for External Exciter
  - Auto switching Main/Alt Exciters
- 10 kW Block - Scalable up to 40kW
Inside Flexiva

Seven 2750W High Efficiency power supplies
One per PA Module. Summed for IPA, control and cooling

IPA/Exciter switching provides automatic drive chain redundancy

Space for optional internal digital exciter

Hardware based Transmitter controller with backup controller
Maintains basic functions and provides system life support without need for microprocessor

Transmitter control and display board

Five 6” high-efficiency, Variable speed exhaust fans for redundant, quiet operation

Dual IPA module for redundancy. Same as PA module, reduces sparing requirements

Seven Dual 1750 Watt PA modules (14 875 Watt amplifiers) for redundancy.

Microcontroller for Display, SNMP and Web server

Washable/reusable air filter
Inside Flexiva

- Combiner
- Low Pass Filter
- Harmonic Filter
- Directional Coupler
- Reject Loads And Heatsink
- RF Output
- Drive Chain Switching
- Customer I/O Interface
- AC Entrance
## Flexiva™ High-Power

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<thead>
<tr>
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<tbody>
<tr>
<td>FAX50</td>
<td>1 - 65</td>
<td>47</td>
<td>37</td>
<td>28</td>
<td>22</td>
<td>20</td>
<td>17</td>
</tr>
<tr>
<td>FAX150</td>
<td>10 - 175</td>
<td>127</td>
<td>100</td>
<td>76</td>
<td>48</td>
<td>42</td>
<td>37</td>
</tr>
<tr>
<td>FAX300</td>
<td>30 - 330</td>
<td>240</td>
<td>188</td>
<td>144</td>
<td>120</td>
<td>116</td>
<td>100</td>
</tr>
<tr>
<td>FAX500</td>
<td>50 - 550</td>
<td>413</td>
<td>314</td>
<td>267</td>
<td>200</td>
<td>195</td>
<td>170</td>
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<tr>
<td>FAX1K</td>
<td>100 - 1100</td>
<td>852</td>
<td>630</td>
<td>480</td>
<td>400</td>
<td>388</td>
<td>340</td>
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<tr>
<td>FAX2K</td>
<td>200 - 2200</td>
<td>1,704</td>
<td>1,256</td>
<td>1,068</td>
<td>800</td>
<td>776</td>
<td>684</td>
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<tr>
<td>FAX3K</td>
<td>300 - 3300</td>
<td>2,475</td>
<td>1,770</td>
<td>1,440</td>
<td>1,200</td>
<td>1,164</td>
<td>1,020</td>
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<tr>
<td>FAX5K</td>
<td>500 - 5500</td>
<td>4,000</td>
<td>3,600</td>
<td>2,400</td>
<td>2,000</td>
<td>1,940</td>
<td>1,700</td>
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<tr>
<td>FAX10K</td>
<td>1,000 - 11,000</td>
<td>8,530</td>
<td>6,430</td>
<td>5,450</td>
<td>3,640</td>
<td>3,265</td>
<td>3,120</td>
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<tr>
<td>FAX20K</td>
<td>2,000 - 22000</td>
<td>17,040</td>
<td>13,600</td>
<td>11,524</td>
<td>7,280</td>
<td>6,530</td>
<td>6,240</td>
</tr>
</tbody>
</table>
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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Need customer feedback
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

Dimensions:

- 40.1" (1,018mm)
- 48.5" (1,232mm)
- 21.0" (533mm)
- 27.1" (687mm)
- 29.7" (755mm)
Questions?

A New Approach to Solid-State FM Amplifiers

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