Benefits of Liquid Cooling for High Power FM
Digital Transmitters

WBA Broadcasters Clinic
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GatesAir Manager, Radio Product Development

SBE CHAPTER 24, Inc., MADISON WISCONSIN USA
Issues Customers are Facing

Rising Cost of Energy

- World electricity prices have increased by an average of 6.6% per year for the past 5 years
- Projected to continue to rise throughout the world - 60% increase by 2030

Electricity Prices Hit all Time High

- Some countries are imposing taxes based on energy usage, example Australia from 2012-14:

<table>
<thead>
<tr>
<th>Financial Year</th>
<th>Price* (USD $)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012–13</td>
<td>23.00</td>
</tr>
<tr>
<td>2014</td>
<td>24.15</td>
</tr>
<tr>
<td>1 July 2014 onwards</td>
<td>Revoked</td>
</tr>
</tbody>
</table>

Source: Clean Energy Regulator - per ton of emitted CO$_2$
Issues Customers are Facing

Pressure to Reduce Operating Expenses

- **Opex** (people, plant, spares, energy) = 5x the cost of initial investment in the transmitter over the system lifetime
  - Purchase price is only 20% of the cost to deliver services
- Deploying people to a site is costly
- Aging technology is very costly to maintain – parts and people/skills harder to find
Factors Affecting TCO

- When purchasing, or replacing a transmitter, Total Cost of Ownership is more important than just the purchase price alone

- Some of the items that must be considered:
  - **Equipment acquisition cost (inc. taxes/duties/shipping, etc.)**
  - **Financing/Loan/Payment Terms (if applicable)**
  - **Building space requirements (own, lease, purchase)**
  - **Shipping to site, Installation and commissioning costs**
  - **Operational cost of the equipment, including:**
    - AC power costs
    - Personnel training
    - Routine maintenance costs / site visits
    - Repair costs
    - Upgrades
    - Warranty and other factors
TCO versus Efficiency

- **TCO is what is really important to a transmission operator:**
  - It’s the total cost to own and operate the transmitter system over time
  - Includes initial equipment cost and delivery
  - Includes the installation/commissioning cost
  - Includes routine and unscheduled maintenance costs
  - Repair/replacement and other operational costs

- **AC power consumed by the transmitter is important**
  - However, other factors also affect the system efficiency:
    - AC transformers and voltage regulators
    - Heat load to the room (HVAC costs)
    - RF system losses (often significant)
    - RF feeder losses
      - ex: 100.1MHz, 500ft, 3-1/8” Heliax, energy loss = 15%
      - Non-optimal antenna pattern (throwing RF energy away)
At GatesAir we are constantly updating designs to improve efficiency and lower TCO:

- Higher Efficiency RF Devices & PA Module design
- Higher Efficiency Power Supplies
- Optimized Energy Efficient Cooling Systems
- Broadband, future-proof designs
- Improved up-time and reduced maintenance costs
- Modular designs with Faster MTTR (Mean Time To Repair)
- Higher Power Density for reduced floor space
- User-friendly designs, easier to understand and operate
What is **PowerSmart®**?  

**PowerSmart®** is the on-going GatesAir design initiative to create the most efficient transmitter designs and products. GatesAir leverages the most sophisticated tools to develop cost, energy, and space efficient solutions.

### Television

The Maxiva™ family of UHF transmitters led this initiative with the first 50V LDMOS device-driven transmitter in the industry setting a new benchmark for power density and efficiency.

### Radio

The Flexiva™ family of FM transmitters set new benchmarks with operating efficiencies of up to 72%, the first FM design to use 50V LDMOS devices, and the smallest footprint at 10kW and higher power levels.
Power Supply Technology

- Improvements in Power density/weight
- Very high conversion efficiency
  - 96.3% versus 84% only a few years ago
- With 48-50V DC requirement, can leverage the Telecomm industry:
  - Very high MTBF (900,000hrs)
  - High volume part
  - Widely available Worldwide
- Versatile
  - Use same part in FM and TV products

<table>
<thead>
<tr>
<th>Reliability (calculated)</th>
<th>900,000</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tr>
</tbody>
</table>

At ambient of 25°C at full load per Telcordia SR-332, issue 2, Reliability Prediction for Electronic Equipment, Method I Case III.
Every Part of The Transmitter Matters

Effect of power supply efficiency on overall system efficiency

<table>
<thead>
<tr>
<th></th>
<th>Tx with older PS</th>
<th>Tx with new High Eff. PS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RF Power Output (kW)</strong></td>
<td>10.00</td>
<td>10.00</td>
</tr>
<tr>
<td>Power Amplifier Efficiency</td>
<td>76%</td>
<td>76%</td>
</tr>
<tr>
<td>DC Power to PA's</td>
<td>13.16</td>
<td>13.16</td>
</tr>
<tr>
<td><strong>Power Supply Efficiency</strong></td>
<td><strong>84%</strong></td>
<td><strong>96%</strong></td>
</tr>
<tr>
<td>AC Power to PA's</td>
<td>15.59</td>
<td>13.65</td>
</tr>
<tr>
<td>Power Supply Loss</td>
<td>2.43</td>
<td>0.49</td>
</tr>
<tr>
<td>Drivers</td>
<td>0.60</td>
<td>0.60</td>
</tr>
<tr>
<td>Exciter</td>
<td>0.14</td>
<td>0.14</td>
</tr>
<tr>
<td>Control</td>
<td>0.12</td>
<td>0.12</td>
</tr>
<tr>
<td>Cooling</td>
<td>0.75</td>
<td>0.75</td>
</tr>
<tr>
<td>Total AC Input (kW)</td>
<td>19.63</td>
<td>15.75</td>
</tr>
<tr>
<td><strong>Overall Tx Efficiency</strong></td>
<td><strong>51%</strong></td>
<td><strong>63%</strong></td>
</tr>
</tbody>
</table>

Distribution of Power Usage with Older Technology Power Supplies

Distribution of Power Usage with High Efficiency Power Supplies

Power Supplies make 13% difference!
RF Device Technology

- New 50V LDMOS devices introduced that dramatically increase power density, efficiency and reliability
  - 1400W peak power
  - High Gain (> 22dB)
  - High DC-RF Efficiency (> 82%)
  - Improved thermal transfer
  - Rugged
  - Very High MTF (> 20K years)

BLF188XR Features and benefits (from data sheet):
- High power
- High power gain
- High efficiency
- Designed for broadband operation (HF to 600 MHz)
- Excellent ruggedness (VSWR > 65 : 1 through all phases)
- Excellent thermal stability
- Integrated ESD protection
- Internal input matching for ease of use
- Designed for broadband operation (HF to 600 MHz)
Three Ways to Cool the Transmitter

1. Air-cooling using outside air
   - Small HVAC Unit
   - Minimal heat load to room
   - ~ 88% of heat goes outside via liquid
   - Outdoor Heat Exchanger

2. Air-cooling using inside air and Air-Conditioning
   - Large HVAC Unit
   - Cool air
   - Warm exhaust air
   - Outdoor A/C Unit

3. Liquid-cooling
# Cooling Comparison

<table>
<thead>
<tr>
<th>Item</th>
<th>Air-Cooled (outside air)</th>
<th>Air-Cooled (HVAC)</th>
<th>Liquid Cooled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy cost</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Maintenance</td>
<td>Very High</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Installation cost</td>
<td>High</td>
<td>Medium</td>
<td>Medium/Low</td>
</tr>
<tr>
<td>Site visits</td>
<td>Frequent</td>
<td>Infrequent</td>
<td>Infrequent</td>
</tr>
<tr>
<td>Humidity control</td>
<td>None</td>
<td>Excellent</td>
<td>Excellent</td>
</tr>
<tr>
<td>Dust &amp; dirt</td>
<td>Filter dependent</td>
<td>Excellent</td>
<td>Excellent</td>
</tr>
<tr>
<td>Reliability</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium/Excellent</td>
</tr>
<tr>
<td><strong>TCO Rank</strong></td>
<td><strong>3</strong></td>
<td><strong>2</strong></td>
<td><strong>1</strong></td>
</tr>
</tbody>
</table>
NEW! Flexiva™ FLX Liquid-Cooled FM Transmitters

- 88% overall heat dissipation to liquid transfer efficiency
- Internal or external redundant pump modules
- Two 10kW transmitters with dual exciters, in a single rack
- 20kW with dual exciters in a single rack
Flexiva™ FLX Liquid-Cooled FM Transmitters

Scalable 10kW - 80kW Liquid Cooled
Liquid Cooling
Power & Heat Load Discussions
Maximum Power Available Optimized for Best Efficiency

Best efficiency is established by adjusting the PA Voltage to the lowest achievable (44V) while maintaining acceptable peak-to-average-power-ratio (PAPR) and pre-correct-ability at ~2dB PA saturation.

**Efficiency vs. HD Injection at Max Power**

<table>
<thead>
<tr>
<th>Flexiva FLX (NXP BLF188XR) PA</th>
<th>FLXT10K</th>
<th>FLXT20K</th>
<th>FLXT30K</th>
<th>FLXT40K</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Analog Only (44v)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max Power</td>
<td>11,000</td>
<td>22,000</td>
<td>33,000</td>
<td>44,000</td>
</tr>
<tr>
<td>Typical Efficiency</td>
<td>66%</td>
<td>65%</td>
<td>65%</td>
<td>65%</td>
</tr>
<tr>
<td><strong>Analog @-20 dBc HD (44v)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max Power</td>
<td>10,578</td>
<td>21,156</td>
<td>31,734</td>
<td>42,312</td>
</tr>
<tr>
<td>Typical Efficiency</td>
<td>63%</td>
<td>65%</td>
<td>65%</td>
<td>65%</td>
</tr>
<tr>
<td><strong>Analog @-14 dBc HD (44v)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max Power</td>
<td>8,230</td>
<td>16,460</td>
<td>24,690</td>
<td>32,920</td>
</tr>
<tr>
<td>Typical Efficiency</td>
<td>58%</td>
<td>58%</td>
<td>58%</td>
<td>58%</td>
</tr>
<tr>
<td><strong>Analog @-12 dBc HD (44v)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max Power</td>
<td>7,350</td>
<td>14,700</td>
<td>22,050</td>
<td>29,400</td>
</tr>
<tr>
<td>Typical Efficiency</td>
<td>56%</td>
<td>56%</td>
<td>56%</td>
<td>56%</td>
</tr>
<tr>
<td><strong>Analog @-10 dBc HD (44v)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max Power</td>
<td>6,200</td>
<td>12,400</td>
<td>18,600</td>
<td>24,800</td>
</tr>
<tr>
<td>Typical Efficiency</td>
<td>53%</td>
<td>53%</td>
<td>53%</td>
<td>53%</td>
</tr>
</tbody>
</table>

**Published Flexiva FAX Freescale PA**

<table>
<thead>
<tr>
<th>FLXT10K</th>
<th>FLXT20K</th>
<th>FLXT30K</th>
<th>FLXT40K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Power</td>
<td>11000</td>
<td>22000</td>
<td>33000</td>
</tr>
<tr>
<td>Typical Efficiency</td>
<td>68%</td>
<td>68%</td>
<td>68%</td>
</tr>
<tr>
<td>Max Power</td>
<td>10000</td>
<td>20000</td>
<td>30000</td>
</tr>
<tr>
<td>Typical Efficiency</td>
<td>67%</td>
<td>67%</td>
<td>67%</td>
</tr>
<tr>
<td>Max Power</td>
<td>8985</td>
<td>17970</td>
<td>26955</td>
</tr>
<tr>
<td>Typical Efficiency</td>
<td>57%</td>
<td>57%</td>
<td>57%</td>
</tr>
<tr>
<td>Max Power</td>
<td>7750</td>
<td>15500</td>
<td>23250</td>
</tr>
<tr>
<td>Typical Efficiency</td>
<td>55%</td>
<td>55%</td>
<td>55%</td>
</tr>
<tr>
<td>Max Power</td>
<td>6534</td>
<td>13068</td>
<td>19602</td>
</tr>
<tr>
<td>Typical Efficiency</td>
<td>52%</td>
<td>52%</td>
<td>52%</td>
</tr>
</tbody>
</table>
Best Power is established by adjusting the PA Voltage to either the maximum available or the lowest practical value where maximum power can still be achieved at reasonable efficiency while maintaining acceptable peak-to-average-power-ratio (PAPR) and pre-correct-ability at ~2dB PA saturation.
Power, Cooling and efficiency

<table>
<thead>
<tr>
<th>FLX Power Cooling &amp; Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Mode:</td>
</tr>
<tr>
<td>TPO</td>
</tr>
<tr>
<td>PAV</td>
</tr>
<tr>
<td>Dissipation</td>
</tr>
<tr>
<td>AC &gt; RF Eff</td>
</tr>
<tr>
<td>Heat &gt; Liquid</td>
</tr>
<tr>
<td>Heat &gt; Air</td>
</tr>
<tr>
<td>Total Heat</td>
</tr>
<tr>
<td>Heat &gt; Liquid Eff</td>
</tr>
</tbody>
</table>

This chart is extrapolated from data taken by measuring air and liquid flows and temperature deltas to compute heat to air and heat to liquid transfer and comparing this numbers with the theoretical model.
Power, Cooling and efficiency

| FLX Power Cooling & Efficiency |
|-------------------|---|---|---|---|---|
| **Operating Mode:** | **FM** | **-20** | **14** | **-10** | **HD** |
| **TPO** | 11,000 | 11,000 | 10,500 | 9250 | 5,500 |
| **PAV** | 43V | 43V | 46.9V | 49.8V | 49.8V |
| **Dissipation** | 16,176 | 17,590 | 18,470 | 17,870 | 12,680 |
| **AC > RF Eff** | 68% | 63% | 57% | 52% | 43% |
| **Heat > Liquid** | 3,832 | 4,709 | 6,231 | 7,105 | 6,140 |
| **Heat > Air** | 1,145 | 1,681 | 1,539 | 1,315 | 840 |
| **Total Heat** | 4,976 | 6,390 | 7,770 | 8,420 | 6,980 |
| **Heat > Liquid Eff** | 77% | 74% | 80% | 84% | 88% |

This chart is extrapolated from data taken by measuring air and liquid flows and temperature deltas to compute heat to air and heat to liquid transfer and comparing this numbers with the theoretical model.
Conclusions

- As PA efficiency increases, the ratio of heat-to-liquid vs. heat-to-air efficiency decreases.
- As TPO decreases, efficiency decreases as well as overall dissipation BUT, heat to liquid transfer efficiency increases.
- FM mode at full power being most efficient, exhibits lowest overall dissipation BUT, the worst case heat-to-liquid efficiency resulting in the highest room heat load.
  - FM+HD @ -14 is the worst case number that should be used to calculate Air Conditioning sizing.
  - Air Conditioning and TX system power consumption should be calculated based on the intended operating mode and TPO for TCO calculations.
Flexiva FLX Liquid Cooled Transmitter
System Architecture
FAX Air Cooled PA Module
FLX Liquid Cooled PA Module with Chiller Plate
Flexiva High Power FM Transmitters

**10kW Power Block**

- Integrated IPA switching (Automatic drive chain redundancy)
- Hot-Swappable, Hot Pluggable 2750W High Efficiency PS
- 1 to 1 PS to PA Ratio
- Hot Pluggable Dual IPA module Same module as PA
- Seven Hot-Pluggable, Hot Swappable 1750 Watt PA modules for redundancy
- Hardware based controller with backup controller & life-support maintains basic functions and provides system operation without reliance on the microprocessor

Microcontroller for Local Display, Remote Web Interface, SNMP Support

Integrated IPA switching (Automatic drive chain redundancy)
Liquid cooled 14-Way Splitter & ISO-Loads

Liquid Cooling Distribution System
Flexiva™ FLX Liquid-Cooled FM Transmitters

Glycol distribution system
Chiller plate for Combiner reject loads
Variable speed flushing fans reduced from 4 to 2
Input/output from pump modules
Flexiva™ FLX Liquid-Cooled FM Transmitters
COOLING SYSTEM BLOCK DIAGRAM

Note: System air purger must be at the highest point in the system.
10kW Transmitter System
Total Annual Power Consumption

- **Air Cooled**
  - Transmitter: \[\text{VALUE}\] kW/H
  - Cooling System: \[\text{VALUE}\] kW/H
  - Total: 158,798 kW

- **Liquid Cooled**
  - Transmitter: 136,335 kW
  - Cooling System: \[\text{VALUE}\] kW/H
  - Total: \[\text{VALUE}\] kW/H
High Efficiency Pump Module

- GatesAir design and manufacture
- 3rd generation – Optimized for High Efficiency
- Small physical size
- 2 Pumps, with auto/manual changeover
  - Low-noise, high efficiency pumps
  - Replace a pump during on-air operation!
- Low maintenance, closed-loop pressurized system
- Quiet – Designed for indoor installation
- Pump speed adjustable to optimize flow rate and efficiency
High Efficiency Heat Exchanger

- GatesAir manufacture
- Dual fans - on-air replacement
- Low noise, high-efficiency fan blades
- Speed controlled for maximum efficiency

- Vertical or horizontal airflow (mounting can be adapted on site for either configuration)
- Two sizes available 20kW & 50kW heat dissipation

Vertical Air Flow

Horizontal Air Flow
FLX10K Transmitter

Xmtr Size
- 23.51 wide
- 71.00 tall
- 45.75 deep with doors
- 44.43 deep without doors
FLX20K Transmitter

Xmtr Size
- 23.51 wide
- 83.25 tall
- 45.75 deep with doors
- 44.43 deep without doors
FLX40K Transmitter

Supply/Return

PWA, Pump
Diode Gating

Xmtr Size
- 47.09 wide
- 83.25 tall
- 45.75 deep
  with doors
- 44.43 deep
  without doors
FLX40K Transmitter
Thank you!

Questions?