Transmission System –
Total Cost of Ownership

February 2013

Featuring GatesAir’s Geoff Mendenhall
Technology Advisor
Transmission System - Total Cost of Ownership

presented by:
Geoffrey N. Mendenhall, P.E.

Harris Broadcast
A Gores Portfolio Company

Deliver the moment™
INTRODUCTION

• High interest among broadcasters / RF network operators to reduce overall transmission facility cost of ownership

• Total Cost of Ownership (TCO) includes more than initial cost, energy cost, and maintenance of transmission equipment

• Acquisition, maintenance, operating, training costs of all required systems in transmission facility including cooling and floor space, must be considered to arrive at lowest TCO
TOPICS TO BE COVERED

• Definition of “Total Cost of Ownership” (TCO)

• All elements that determine the real, long term, “Total Cost of Ownership”

• Besides the reduction in direct operating costs, the benefits of reduced (TCO) include a reduction of carbon footprint in support of green technology.

• Comprehensive analysis is required including:
  – Trade off’s between air and liquid cooling systems
  – Impact on the overall facility, floor space requirements, size, and the thermal efficiency of the transmitter building

• New evaluation process / analysis tool to design transmission facility for lowest (TCO) (work in progress)

• Example of the findings from a real world, transmission site (TCO) analysis
WHAT IS TOTAL COST OF OWNERSHIP?

- Acquisition cost of transmission equipment
- Installation cost of transmission equipment
- Operating cost of transmission equipment
- Maintenance cost of transmission equipment

- Acquisition cost of facility cooling system (HVAC, etc.)
- Installation cost of facility cooling system (HVAC, etc.)
- Operating cost of facility cooling system (HVAC, etc.)
- Maintenance cost of facility cooling system (HVAC, etc.)
- Periodic replacement cost for facility cooling system (HVAC, etc.)

- Acquisition or recurring lease cost of floor space required
- Training costs
OTHER FACTORS AFFECTING TCO

• Average outside air temperature at facility location
• Cost of energy at facility location
• Size, construction, and thermal efficiency of facility
TRANSMITTER SELECTION IMPACT ON TCO

- Physical size and foot print ($\text{FT}^2$)
- Power density of transmitter (Watts / $\text{FT}^3$)
- Type of cooling – air or liquid
- Operating efficiency (AC to RF) of the transmitter
- AC power requirements – (1) phase or (3) phase (polyphase may be more expensive to bring to some sites)
- AC input voltage and voltage regulation requirements
- Maintainability – hot swappable modules, air or liquid filter replacement, and all other maintenance tasks
- Commonality of transmitter types – spares sharing, common training, and operational requirements
- N+1 transmitter system architecture can reduce number of backup transmitters required
TRANSMITTER SELECTION IMPACT ON TCO

- Choice between air or liquid cooling of transmission equipment makes a significant difference in TCO

- Initial purchase cost of liquid cooled transmitter is typically higher than an equivalent air cooled transmitter

- Elimination of most air conditioning costs make breakeven period short and provide significant long term operational savings

- Typical air conditioning units require ongoing maintenance and replacement on a 5 to 8 year cycle

- Liquid cooled transmitters have significantly lower energy consumption than combined energy consumption of air cooled transmitter and required air conditioning
TRANSMITTER EFFICIENCY OPTIMIZATION

- 50v LDMOS power amplifier technology
- 95% efficient power supplies
- Advanced Real Time Adaptive Correction (RTAC)
- Advanced Crest Factor Reduction
- Variable speed cooling system – air or liquid
- Sharing liquid cooling across multiple transmitters
FET TECHNOLOGY COMPARISON

Comparison of RF Power Attributes vs. Technology

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

Red = Poor
Yellow = Neutral
Green = Strength
(Scale 1 to 5)
**FET TECHNOLOGY COMPARISON**

Practical Pallet Gain 19dB in digital DVB-T operation and 21dB in FM operation

Typical efficiency of over 28% in DVB-T operation and 84% in FM operation

Flexiva (FAX) – High Power 5kW – 40kW

- Efficiency
  - 72% AC to RF Efficiency
  - Significantly better than competitive products (8 -10%)
  - Rivals tube-type transmitters at 30/40kW
Flexiva (FAX) – High Power – 5kW to 40kW

5k/10K

20K

30K

40K

FAX High Power (5kW – 40kW)
TCO ANALYSIS TOOL

• Harris has developed prototype tool to analyze and calculate TCO for a broadcast transmission facility

• Visited Riverview ATC site to test tool

• Consider all elements in power consumption budget

• Transmitter make / model

• Transmitter cooling – air vs. liquid

• Cooling system percent of total cost

• Transmitter percent of total cost

• Payback period (OPx vs. CAPx)
### TCO ANALYSIS TOOL

<table>
<thead>
<tr>
<th>Transmitter</th>
<th>Model</th>
<th>Total Transmitter Acquisition Cost</th>
<th>HVAC Acquisition Cost</th>
<th>HVAC Installation Cost</th>
<th>Annual HVAC Maintenance (Per Ton)</th>
<th>Heat Is Ducted?</th>
<th>HVAC SEER Level</th>
<th>Annual Rental Fee</th>
<th>Annual Preventative Maintenance No. of Visits</th>
<th>per visit Rate for Preventive Maintenance</th>
<th>First Year Training Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maxiva ULX ATSC</td>
<td>ULX-2400ATi</td>
<td>$153,600.00</td>
<td>$500.00</td>
<td>$2,500.00</td>
<td>$150.00</td>
<td>No</td>
<td>12</td>
<td>$0.00</td>
<td>$400.00</td>
<td>$2,000.00</td>
<td>$2,000.00</td>
</tr>
</tbody>
</table>

**Installation**
- Commissioning: $11,200.00
- Unit Cost: $120,000.00

**Unit Cost**
- $22,400.00
- $11,200.00
- $2,000.00

**USA**
- Price Per kW/h: $0.065

**Source** - IEA "Electricity Information 2010"

---

<table>
<thead>
<tr>
<th>Region</th>
<th>Country/State</th>
<th>Unit Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>Texas</td>
<td>$120,000.00</td>
</tr>
</tbody>
</table>

---

**Product Description**
Liquid-Cooled UHF Multimedia TV Transmitter

---

**Model Specifications**

### First Year TCO (includes acquisition costs & training)
- **Annual OPEX**: $7,290.32
- **Five Year TCO**: $195,051.60
- **Ten Year TCO**: $231,503.21
- **Fifteen Year TCO**: $267,954.81
- **Twenty Year TCO**: $304,406.41

**Model**
- **Transmitter**: Maxiva ULX ATSC
- **Model**: ULX-2400ATi

**TX Power Output**
- Before Filter: 2,500 W
- Typical Power Consumption: 9,617 W

**TX Typical Power Consumption**: 26.00%

### Air Cooling

- **Total Heat Output**: 7,117 W
- **Heat Output Indoors**: 7,117 W
- **Annual Air Cooling Requirement (kW-Hr)**: 52.47
- **Total Cooling Needed (BTU/H)**: 5,458.88
- **Annual Cooling Needed (Tons)**: 5,458.88
- **Annual Cooling (100% AC)**: $150.00
- **Annual Cooling Costs (var. AC)**: $0.00
- **Annual HVAC Maintenance Costs**: $0.00

### Liquid Cooling

- **Total Heat Output**: 4,717 W
- **Heat Output Indoors**: 4,717 W
- **Annual Cooling Requirement Liquid +HVAC**
  - Energy Consumption: 52.47
  - Total Cooling Needed (BTU/H): 5,458.88
  - Annual Cooling Needed (Tons): 5,458.88
  - Annual Cooling (100% AC): $150.00
  - Annual Cooling Costs (var. AC): $0.00
  - Annual HVAC Maintenance Costs: $0.00

### Consumption

- **Annual Total Electrical Usage**: 87,452 kW-Hr
- **Annual Carbon Emissions (tons)**: 52.47
- **How Many Cars on the Road**: 9.9
- **Annual Transmitter Consumption Cost**: $5,458.88
- **Annual Electricity Costs (100% AC)**: $5,666.86
- **Annual Electricity Costs (var. AC)**: $5,458.88

### Dimensions

- **Height (RU)**
  - cm: 450.3
  - in: 176.4
- **Width**: 648.0 cm (25.5 in)
- **Depth**: 682.3 cm (26.8 in)
- **Volume (m³/ft³)**
  - Indoor: 1194.0
  - Outdoor: 1550.52
- **Efficient Volume (m³/ft³)**
  - Indoor: 403.08
  - Outdoor: 43524.58
- **Power Density (KW per m²/ft²)**
  - Indoor: 0.00
  - Outdoor: 77.37
- **Footprint (m²/ft²)**
  - Indoor: 77.37
  - Outdoor: 1754.45

### Service

- **MTBF**: 125548
- **Rental Costs**: $0.00
- **Annual Service & Maintenance Costs**: $1,600.00

---

**Product Description**
Liquid-Cooled UHF Multimedia TV Transmitter

---

**Source** - IEA "Electricity Information 2010"
# TCO COMPARISON TOOL

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Harris #1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transmitter</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maxiva UAX Digital</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UAX-2000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Harris #2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transmitter</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maxiva ULX ATSC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ULX-2400ATi</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Competitor A</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RF Output Before Filter</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2,500 W</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power Consumption</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13,820 W</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Competitor B</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RF Output Before Filter</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2,500 W</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power Consumption</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14,000 W</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$135,000.00 $155,600.00

$5,200.00 $500.00

$7,500.00 $2,500.00

No No

Air Liquid

$0.00 $0.00

$1,600.00 $1,600.00

$150.00 $150.00

$0.065

12
## TCO COMPARISON TOOL

<table>
<thead>
<tr>
<th></th>
<th>Harris</th>
<th>Harris</th>
<th>Competitor A</th>
<th>Competitor B</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RF Output Before Filter</strong></td>
<td>2,500 W</td>
<td>2,500 W</td>
<td>2,500 W</td>
<td>2,500 W</td>
</tr>
<tr>
<td><strong>TX Power Consumption</strong></td>
<td>12,437 W</td>
<td>9,617 W</td>
<td>13,820 W</td>
<td>14,000 W</td>
</tr>
<tr>
<td><strong>Annual Transmitter Consumption</strong></td>
<td>108,948 kW-Hr</td>
<td>84,242 kW-Hr</td>
<td>121,063 kW-Hr</td>
<td>122,640 kW-Hr</td>
</tr>
<tr>
<td><strong>Efficiency</strong></td>
<td>20.1%</td>
<td>26.0%</td>
<td>18.1%</td>
<td>17.9%</td>
</tr>
<tr>
<td><strong>Cooling Method</strong></td>
<td>Air</td>
<td>Liquid</td>
<td>Air</td>
<td>Air</td>
</tr>
<tr>
<td><strong>Ducted Heat Output</strong></td>
<td>0 W</td>
<td>0 W</td>
<td>0 W</td>
<td>0 W</td>
</tr>
<tr>
<td><strong>Heat Output Indoors</strong></td>
<td>9,937 W</td>
<td>550 W</td>
<td>11,320 W</td>
<td>11,500 W</td>
</tr>
<tr>
<td><strong>Liquid Cooling</strong></td>
<td>0 kW-Hr</td>
<td>1,840 kW-Hr</td>
<td>0 kW-Hr</td>
<td>0 kW-Hr</td>
</tr>
<tr>
<td><strong>Air Cooling</strong></td>
<td>24,752 kW-Hr</td>
<td>1,370 kW-Hr</td>
<td>28,197 kW-Hr</td>
<td>28,645 kW-Hr</td>
</tr>
<tr>
<td><strong>Btu/H Tons</strong></td>
<td>33906</td>
<td>1877</td>
<td>38625</td>
<td>39240</td>
</tr>
<tr>
<td><strong>HVAC Maintenance</strong></td>
<td>$423.83</td>
<td>$23.46</td>
<td>$548.82</td>
<td>$490.50</td>
</tr>
<tr>
<td><strong>Annual Cooling</strong></td>
<td>24,752 kW-Hr</td>
<td>3,210 kW-Hr</td>
<td>28,197 kW-Hr</td>
<td>28,645 kW-Hr</td>
</tr>
<tr>
<td><strong>Total Annual Power Consumption</strong></td>
<td>133,700 kW-Hr</td>
<td>87,452 kW-Hr</td>
<td>149,260 kW-Hr</td>
<td>151,285 kW-Hr</td>
</tr>
<tr>
<td><strong>Annual Cooling Costs</strong></td>
<td>$1,603.91</td>
<td>$207.98</td>
<td>$1,827.14</td>
<td>$1,856.19</td>
</tr>
<tr>
<td><strong>Carbon Emissions (Tons)</strong></td>
<td>80.22</td>
<td>52.47</td>
<td>89.56</td>
<td>90.77</td>
</tr>
<tr>
<td><strong>Annual Transmitter Consumption Costs</strong></td>
<td>$7,059.84</td>
<td>$5,458.88</td>
<td>$7,844.90</td>
<td>$7,947.07</td>
</tr>
<tr>
<td><strong>Annual OPEX</strong></td>
<td>$10,687.58</td>
<td>$7,290.32</td>
<td>$11,754.85</td>
<td>$11,893.76</td>
</tr>
<tr>
<td><strong>First Year TCO</strong></td>
<td>$158,387.58</td>
<td>$165,890.32</td>
<td>$152,912.56</td>
<td>$148,109.63</td>
</tr>
<tr>
<td><strong>5 Year TCO</strong></td>
<td>$201,137.90</td>
<td>$195,051.60</td>
<td>$199,931.97</td>
<td>$195,684.67</td>
</tr>
<tr>
<td><strong>10 Year TCO</strong></td>
<td>$254,575.80</td>
<td>$231,503.21</td>
<td>$258,706.23</td>
<td>$255,153.46</td>
</tr>
<tr>
<td><strong>15 Year TCO</strong></td>
<td>$308,013.70</td>
<td>$267,954.81</td>
<td>$317,480.49</td>
<td>$314,622.26</td>
</tr>
</tbody>
</table>
TCO COMPARISON TOOL

TCO Comparison

- UAX-2000
- ULX-2400ATi
- Competitor A
- Competitor B

First Year TCO  |  5 Year TCO  |  10 Year TCO  |  15 Year TCO
---|---|---|---
$0.00 | $0.00 | $0.00 | $0.00
$50,000.00 | $50,000.00 | $50,000.00 | $50,000.00
$100,000.00 | $100,000.00 | $100,000.00 | $100,000.00
$150,000.00 | $150,000.00 | $150,000.00 | $150,000.00
$200,000.00 | $200,000.00 | $200,000.00 | $200,000.00
$250,000.00 | $250,000.00 | $250,000.00 | $250,000.00
$300,000.00 | $300,000.00 | $300,000.00 | $300,000.00
$350,000.00 | $350,000.00 | $350,000.00 | $350,000.00
$400,000.00 | $400,000.00 | $400,000.00 | $400,000.00
HVAC - AIR COOLED TRANSMITTER

• Pros
  - Familiar technology
  - Simplicity - No concern about liquid spills

• Cons
  - Higher initial cost of A/C equipment
  - Higher total energy cost
  - Higher maintenance cost
  - High replacement cost of A/C equipment – shorter life cycle
LIQUID COOLED TRANSMITTER

• Pros
  - Lower overall energy cost
  - Less floor space – higher power density
  - Lower initial cost of heat exchanger – no duct work
  - Lower maintenance cost – no air filters to clean
  - Less frequent replacement cost – longer life cycle
  - Much lower noise level
  - Ratio of heat transported by liquid vs. heat liberated into air
  - Can be integrated into facility cooling loop or geothermal cooling loop
  - Highly evolved and desired in DTV installations

• Cons
  - Less familiar technology to radio broadcasters
  - Higher initial cost of transmitter – quickly offset by power savings
  - Concern about liquid spills – unlikely with new technology
LIQUID COOLED UHF PA MODULE

Module weight < 20kg

AC-DC Converters (8)

RF Pallets (4)

Coolant blind mate connectors

Output RF Connector

Output Power Combiner

Cold Plate

Harris Broadcast
A Gores Portfolio Company
MAXIVA LIQUID COOLED UHF PA MODULE

User replaceable sub-assemblies shown

AC-DC Converter Module

RF Pallet

50V LDMOS Device with Heat Spreader

Diagnostic Port

Status LED’s
MAXIVA ULX - FRONT VIEW

- Apex M2X Exciters
- TCU System Controller
- Redundant Pre-Drivers
- Liquid Cooled PA's (up to 8)
- Liquid Cooled Redundant IPA's
- Liquid Cooled PA's (up to 8)
MAXIVA ULX - REAR VIEW

- AC Distribution
- RF Output Feeder
- PA Circuit Breakers
- 2-Way Output Combiner
- Redundant Cabinet Blowers (2)
- I/O Panel (on top)
- Coolant In/Out Hoses
- Liquid Cooled Upper 8-way Combiner
- Liquid Cooled Upper 8-way Power Divider
- Liquid Cooled Final Reject Load
- Liquid Cooled Lower 8-way Power Divider
- Liquid Cooled Lower 8-way Combiner
Note: System air purger must be at the highest point in the system.
HIGH EFFICIENCY PUMP MODULE

- Liquid Out
- Liquid In
- Pump/Fan Speed Controllers
- Circuit Breakers
- Expansion Tank
- Pumps
LIQUID TO AIR HEAT EXCHANGER

- Compact size (Two sizes available, Tx dependent)
- Two Configurations – Horizontal or Vertical airflow
- Redundant variable speed fans

(50kW Dissipation unit shown, 12kW system is smaller)
TCO - OPTIMIZATION SUMMARY

• Selection of transmission equipment

• Consider all acquisition, operating and maintenance costs

• Consider all elements in power consumption budget

• Cooling technology used in transmitter has large impact on TCO

• Volume and floor space of transmission equipment affects TCO

• Building efficiency
ACKNOWLEDGEMENTS:

• Ed Allen – Cox Media
• Roz Clark – Cox Media
• Stefan Wallner - Harris Corporation
• Victor Fenix - Harris Corporation
• Tim Anderson - Harris Corporation
• Rich Redmond - Harris Corporation
• Monica Collins - Harris Corporation
Questions?

Geoffrey N. Mendenhall, P.E.
Harris Broadcast
email: gmendenh@harris.com
Visit our website at:
http://www.harrisbroadcast.com/