Transmitter choices for the next digital roll out...

What technology is the best fit for your station?
Key factors for the Engineering Manager:

- Signal Quality – SNR/MER
- Cost of Operation – Efficiency
- Reliability
- Maintenance
- Obsolescence
Contents

- Quick look at SS device progression
- Signal Quality – The Key Ingredients
- Cost of Operation – Transmitter Efficiency
  Comparisons versus Power Output
- Reliability & Maintenance – System Complexity
- Obsolescence – Device stability
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Quick look at SS device progression

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- Space considerations
How “in” efficient is your “green” transmitter?

A Brief History….. Of transmitter devises & efficiencies
Contents

➢ Quick look at SS device progression
➢ **Signal Quality – The Key Ingredients**
➢ Cost of operation – Transmitter Efficiency Comparisons versus Power Output
➢ Reliability & Maintenance – System Complexity
➢ Obsolescence – Device stability
➢ Space considerations
Signal Quality – Root Causes of Problems

There are several SNR degradations in the link between the transmitter and the receiver starting… with the transmitter

- **At the TX Site**
  - Intermodulation and cross-modulation products with the transmitter
  - Noise due to the issues between transmitter and antenna.
- **Propagation**
  - Various propagational Interference, natural & man made
- **At the home**
  - Co-channel & Adjacent channel interference
  - Receiver equalizer adds white noise

ALL POTENTIALLY DEGRADE THE RECEIVED SNR and DECREASE COVERAGE
Signal Quality – Quantitative Definition

As Transmitter Signal to Noise Ratio (T-SNR) decreases the ability to pick up a received signal drops proportionally.

- “Good” >66% >26dB
- “Bad” > 33% >17dB
- “Ugly” 33% <17dB
Signal Quality – Correction Techniques

Look for these technologies in your Exciter

To obtain a balance between maximum efficiency and maximum signal quality:

➢ Drive the amplifier into saturation to obtain the best efficiency and …

➢ Correct the signal using the latest correction techniques

➢ Digital Pre-Distortion with “PA modeling”

➢ Crest Factor Reduction (CFR)

➢ Memory Error Correction (MEC)
New Digital Pre-distortion algorithms significantly improve IMD and SNR
- Mathematical PA modeling
- Crest Factor Reduction
- Memory Error Correction
- Significantly improves IMD and SNR

These techniques can almost DOUBLE the efficiency of a modern transmitter

Couple this with new Amplifier design techniques and you very efficient transmitter options
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Cost of operation – Efficiency

- Best choice of technology varies with application
  - One size does NOT fit all
- SS options include:
  - 50V device designs – great for low power applications
  - Doherty Modulation – best suited for HP up to 30 kW
    - Paralleling two amplifiers devices; first operating in Class AB which amplifies the average power level, and the second operates in Class C amplifying just the peaks of the waveform. Output of two devices are combined with a matched transformer.
  - Drain Modulation (or Envelope Tracking) - complex
    - Operates by modulating the DRAIN of a FET amplifier with the input signal so that the Power Supply voltage follows the level of the input signal. The amplifier operates near the high-efficiency saturation point over a significant portion of the envelope depth.
- IOT – most efficient for most stations above 30kW
Doherty Modulation

**DOHERTY** Amplifier design was invented by William Doherty in 1934 by Bell Labs.

**Carrier amplifier:** Class AB (saturates at high power input)
**Peak Amplifier:** Class C (Turns on at high power input)

**DOHERTY** Configuration improves linearity at the high power input by complementing the saturation of the carrier amplifier with the turn on characteristics of the peak amplifier.

NXP semiconductors and Freescale both have released transistors “optimized” for Doherty amplifier applications.
Efficiency Comparisons

- CEA
- ESCIOT
- Conventional IOT

Efficiency vs. 8VSB Average Power (kW)
Efficiency Comparisons

Constant Efficiency IOT vs. Daugherty Solid State

![Graph comparing Constant Efficiency IOT and Daugherty Solid State with power output on the x-axis and final stage efficiency on the y-axis.]
## Cost of Operation – Efficiency Comparison at 10kW

<table>
<thead>
<tr>
<th>Amplifier Type</th>
<th>32V</th>
<th>50V</th>
<th>Doherty / Drain</th>
<th>MSDC-IOT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmitter Power Output - kW</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Amplifier Efficiency</td>
<td>18%</td>
<td>27%</td>
<td>42%</td>
<td>50%</td>
</tr>
<tr>
<td>Transmitter Efficiency</td>
<td>15%</td>
<td>21%</td>
<td>35%</td>
<td>26%</td>
</tr>
<tr>
<td>Transmitter Consumption</td>
<td>66.7</td>
<td>47.6</td>
<td>28.6</td>
<td>38.5</td>
</tr>
<tr>
<td>Cost of Energy at $/kW/Hr</td>
<td>$ 0.10</td>
<td>$ 58,400</td>
<td>$ 41,714</td>
<td>$ 25,029</td>
</tr>
</tbody>
</table>

Compared to Doherty: $ (8,664)
Compared to 50V Basic: $ 16,686 $ 8,022
Compared to 32V: $ 16,686 $ 33,371 $ 24,708

CAPEX: N/A $ 280,000 $ 300,000 N/A

Over 5 Years: $ 83,429 $ 166,857 $ 123,538
# Cost of Operation – Efficiency Comparison at 20kW

<table>
<thead>
<tr>
<th>Amplifier Type</th>
<th>32V</th>
<th>50V</th>
<th>Doherty / Drain</th>
<th>MSDC-IOT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmitter Power Output - kW</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Amplifier Efficiency</td>
<td>18%</td>
<td>27%</td>
<td>42%</td>
<td>57%</td>
</tr>
<tr>
<td>Transmitter Efficiency</td>
<td>15%</td>
<td>21%</td>
<td>35%</td>
<td>37%</td>
</tr>
<tr>
<td>Transmitter Consumption</td>
<td>133.3</td>
<td>95.2</td>
<td>57.1</td>
<td>54.1</td>
</tr>
<tr>
<td>Cost of Energy at $/kW/Hr</td>
<td>$ 0.10</td>
<td>$ 116,800</td>
<td>$ 83,429</td>
<td>$ 50,057</td>
</tr>
</tbody>
</table>

- **Compared to Doherty**: $2,706
- **Compared to 50V Basic**: $33,371, $36,077
- **Compared to 32V**: $33,371, $66,743, $69,449

<table>
<thead>
<tr>
<th>CAPEX</th>
<th>N/A</th>
<th>$ 400,000</th>
<th>$ 470,000</th>
<th>$ 525,000</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Over 5 Years</strong></td>
<td>$ 166,857</td>
<td>$ 333,714</td>
<td>$ 347,243</td>
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</tbody>
</table>
## Cost of Operation – Efficiency Comparison at 30kW

<table>
<thead>
<tr>
<th>Amplifier Type</th>
<th>32V</th>
<th>50V</th>
<th>Doherty / Drain</th>
<th>MSDC-IOT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmitter Power Output - kW</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Amplifier Efficiency</td>
<td>18%</td>
<td>27%</td>
<td>42%</td>
<td>57%</td>
</tr>
<tr>
<td>Transmitter Efficiency</td>
<td>15%</td>
<td>21%</td>
<td>35%</td>
<td>43%</td>
</tr>
<tr>
<td>Transmitter Consumption</td>
<td>200.0</td>
<td>142.9</td>
<td>85.7</td>
<td>69.8</td>
</tr>
<tr>
<td>Cost of Energy at $/kW/Hr</td>
<td>$ 0.10</td>
<td>$ 175,200</td>
<td>$ 125,143</td>
<td>$ 75,086</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$ 61,116</td>
<td></td>
</tr>
</tbody>
</table>

Compared to Doherty

<table>
<thead>
<tr>
<th>Compared to Doherty</th>
<th>$ 13,969</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compared to 50V Basic</td>
<td>$ 50,057</td>
</tr>
<tr>
<td>Compared to 32V</td>
<td>$ 50,057</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CAPEX</th>
<th>N/A</th>
<th>N/A</th>
<th>$ 670,000</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>$ 550,000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Over 5 Years

|       | $ 250,286 | $ 500,571 | $ 570,419 |
# Cost of Operation – Efficiency Comparison at 40kW

<table>
<thead>
<tr>
<th>Amplifier Type</th>
<th>32V</th>
<th>50V</th>
<th>Doherty / Drain</th>
<th>MSDC-IOT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmitter Power Output - kW</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Amplifier Efficiency</td>
<td>18%</td>
<td>27%</td>
<td>42%</td>
<td>57%</td>
</tr>
<tr>
<td>Transmitter Efficiency</td>
<td>15%</td>
<td>21%</td>
<td>35%</td>
<td>48%</td>
</tr>
<tr>
<td>Transmitter Consumption</td>
<td>266.7</td>
<td>190.5</td>
<td>114.3</td>
<td>83.3</td>
</tr>
<tr>
<td>Cost of Energy at $/kW/Hr</td>
<td>$ 0.10</td>
<td>$ 233,600</td>
<td>$ 166,857</td>
<td>$ 100,114</td>
</tr>
</tbody>
</table>

Compared to Doherty: $ 27,114
Compared to 50V Basic: $ 66,743, $ 93,857
Compared to 32V: $ 66,743, $ 133,486, $ 160,600

CAPEX: N/A, N/A, $ 915,000, $ 850,000

Over 5 Years: $ 333,714, $ 667,429, $ 803,000
## Cost of Operation – Efficiency Comparison at 60kW

<table>
<thead>
<tr>
<th>Amplifier Type</th>
<th>32V</th>
<th>50V</th>
<th>Doherty / Drain</th>
<th>MSDC-IOT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmitter Power Output - kW</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Amplifier Efficiency</td>
<td>18%</td>
<td>27%</td>
<td>42%</td>
<td>62%</td>
</tr>
<tr>
<td>Transmitter Efficiency</td>
<td>15%</td>
<td>21%</td>
<td>35%</td>
<td>54%</td>
</tr>
<tr>
<td>Transmitter Consumption</td>
<td>400.0</td>
<td>285.7</td>
<td>171.4</td>
<td>111.1</td>
</tr>
<tr>
<td>Cost of Energy at $/kW/Hr</td>
<td>$ 0.10</td>
<td>$ 350,400</td>
<td>$ 250,286</td>
<td>$ 150,171</td>
</tr>
</tbody>
</table>

- Compared to Doherty: $ 52,838
- Compared to 50V Basic: $ 100,114 $ 152,952
- Compared to 32V: $ 100,114 $ 200,229 $ 253,067

<table>
<thead>
<tr>
<th>CAPEX</th>
<th>N/A</th>
<th>N/A</th>
<th>$ 1,200,000</th>
<th>$ 920,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Over 5 Years</td>
<td>$ 500,571</td>
<td>$ 1,001,143</td>
<td>$ 1,265,333</td>
<td></td>
</tr>
</tbody>
</table>
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Reliability & Maintenance

- **Reliability ~ All HP DTV transmitters will have failures!!!**
  - Solid State requires on average 1 replacement PA module per year
  - MSDC-IOT expected device life of >87,600 hours (10 years)
  - Normal wear items affect both (fans, pumps, etc.)

- **Maintenance ~ All HP DTV transmitters require maintenance!!!**
  - Air cooling (not typically used >5kW) has to be kept clean and cool
  - Liquid cooling systems need the coolant monitored, flushed periodically
  - Long term stability of new SS designs not yet known

- **IOT based transmitters have specific needs and skill sets:**
  - The HV compartment needs to be kept clean / safety considerations
  - Safety interlocks should be checked
  - Filament management for the highest device life expectancy
## Reliability & Maintenance – System Complexity Comparison

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Fixed DRAIN</th>
<th>DOHERTY</th>
<th>MSDC-IOT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency Amplifier</td>
<td>28 - 30%</td>
<td>44 - 46%</td>
<td>57 - 62%</td>
</tr>
<tr>
<td>Efficiency Transmitter</td>
<td>20 - 22%</td>
<td>28 - 29%</td>
<td>37 - 54%</td>
</tr>
<tr>
<td>Broadband</td>
<td>YES</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>Reliability</td>
<td>GOOD</td>
<td>VERY GOOD *</td>
<td>GOOD **</td>
</tr>
<tr>
<td>Complexity</td>
<td>GOOD</td>
<td>Unknown*</td>
<td>AVERAGE</td>
</tr>
<tr>
<td>Active Redundancy</td>
<td>GOOD</td>
<td>MEDIUM</td>
<td>GOOD **</td>
</tr>
<tr>
<td>Performance at Reduced Power</td>
<td>MEDIUM</td>
<td>POOR</td>
<td>EXCELLENT</td>
</tr>
</tbody>
</table>

* Adequate field data is still being complied by vendors
** Assumes a dual HPA IOT design used
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Solid State devices continue to evolve and improve:
- Bipolar to LDMOS
- Higher supply voltages (28, 32, 38, 50 VDC….)
- Higher power capability per transistor
- Higher efficiencies (<10% → >35%)

As devices evolve, older series quickly become obsolete….

Where are you on the technology curve?
Tube based amplifiers had 3 major evolutions

- Klystron $\rightarrow$ IOT $\rightarrow$ MSDC-IOT
  - Klystrons not used in DTV
  - IOT and MSDC-IOT both widely used and available
- Tube Vendors continue to support traditional IOT
- Tube Vendors continue to service and sell Klystrons for the Scientific / Medical / Industrial markets
THANK YOU

More information?

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