PRESENTATION TITLE: RF Transmitter Amplifiers

June 2014
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TV Transmitter Amplifier designs
Performance (A discussion on SNR, EVM and MER)
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Amplifier Designs

- Tube technology was employed in first high power amplifiers.
  - Klystrons / Tetrodes / Diacrodies
    - Pulsed klystrons
  - MSDC klystrons
  - Klystrodes which became...
  - Inductive Output Tubes (IOT)

- Solid State
  - Increased in power capability
    - Initially VHF then moved to UHF
    - 5W (1960’s)
    - (LDMOS; laterally diffused metal oxide semiconductor)
    - 250-300 W per pallet (and up to 1kW per chassis)
  - One chassis can contain everything: protection, power supply and cooling
  - Liquid cooling typically doubles power density

- New Technology… *Doherty and Drain Modulation (Envelope Tracking)*
## Amplifier Designs

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<td>7</td>
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<td>40</td>
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<td>20</td>
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<td>42</td>
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<tr>
<td><strong>Maximum Power per device (KW)</strong></td>
<td>30</td>
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<td>24</td>
<td>30</td>
<td>50</td>
<td>48</td>
<td>50</td>
<td>0.3</td>
<td>0.3</td>
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<tr>
<td><strong>Typical average life (hours)</strong></td>
<td>50,000</td>
<td>1,000,000</td>
<td>15,000</td>
<td>50,000</td>
<td>30,000</td>
<td>15,000</td>
<td>30,000</td>
<td>1,000,000</td>
<td>1,000,000</td>
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</tbody>
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### Electrical Efficiency (ATSC Digital)

![Electrical Efficiency Graph](image)
Amplifier Designs

Amplifier Digital Efficiency*

- KLYSTRON: 6%
- TETRODE: 9%
- BI-POLAR TRANSISTOR: 10%
- TRADITIONAL IOT: 22%
- LDMOS TRANSISTOR: 26%
- MSDC INDUCTIVE OUTPUT TUBE (IOT): 50%
- LDMOS DOHERTY: 36%
- ENVELOPE MODULATION: 38%
- ENVELOPE-DOHERTY MODULATION: 45%*

* Estimate only
Changes in Amplifier design

- New amplifier types available
  - Dougherty modulation
  - Envelope modulation (Drain Modulation)
  - Combinations of above

- Typical efficiency improvement from 25% to > 40%

- Which to choose?
  - IOT
  - Traditional LDMOS
  - Doherty
  - Drain Modulation
  - ?
IOT Technology

- What is an IOT?
- High Vacuum Electron tube
- Water and Air cooled
- Cathode High Voltage, ion pump, filaments and focus power supply required
- Crowbar or similar protection system
- Gain 20 dB
- The efficiency of an IOT dramatically increased due to the introduction of the Multi-State Depressed Collector technology (taken from the MSDC klystron).
- Efficiencies in ATSC increased from 20% to 50%
- Still the most efficient amplifier on the market today
Doherty Modulation (or Doherty Power Amplifier DPA)

- William Doherty - 1936
- Bell Labs (Westin Electric)
- Successful developments by Continental Electronics (James B. Weldon / Joseph Sainton)
- 50kW AM transmitters
- Various version including parallel Class AB and C tubes (Continental 317C)
- 9 tubes versus RCA’s 32 tubes!
- Follow on development by NXP (Ex-Philips)
- LDMOS design using standard format two transistor pallet
- Current model BLF888D – 250W output (average power – UHF)
- 50% Drain Efficiency (at the transistor) –
- “Ultra Wide Band Doherty (NEW) Bandwidth approx. 200MHz i.e. Two types will cover the UHF Band
Amplifier Designs

Klystron

25-30,000 Volts

50 Volts

IOT

LDMOS Transistor 300W

LDMOS Amplifier 2.5kW

LDMOS Transmitter 30kW

TO SCALE
Amplifier Designs

Doherty Modulation (or Doherty Power Amplifier DPA)

Main PA = Class A/B Carrier Amplifier

Peak PA = Class C (Peeking amplifier)

Wilkinson Splitter

~ 36-40% Efficiency
Amplifier Designs

Doherty Modulation (or Doherty Power Amplifier DPA)

Class A/B

Efficiency 28%
Temperature 75° C

Class A/B

Average Junction temperature 140 ° C

Class A/B

Class C

Efficiency 43%
Temperature 66° C

Class A/B

Average Junction temperature 117° C
Amplifier Designs

Doherty Modulation (or Doherty Power Amplifier DPA)

Summary:

- Average Drain Efficiency over UHF band = 42% versus 25% for standard Class AB;

- Transmitter energy consumption savings
  - (for a 5kW transmitter, efficiency improves from 24% to 34%);

- Less heat dissipated on transistors => Higher MTBF and thus higher reliability
  - A reduction of 20 degrees C in junction temperature represents four times more in reliability

- Broadband through a new design by NXP that almost covers the entire UHF band

- Extra savings due to simpler cooling system and less internal fans
Amplifier Designs

Envelope Modulation (Drain Modulation)

- Energy Dissipated as Heat
- Transmitted Radio Signal
Amplifier Designs

Envelope Modulation (Drain Modulation)

Modulator/Exciter

V_{DC}

Class A/B Amplifier

~ 25% Efficiency
75% Wasted energy as heat

Energy Dissipated as Heat
Amplifier Designs

Envelope Modulation (Drain Modulation)

Modulator/Exciter → V_{DC} → DC-DC Converter → Class A/B Amplifier

Average Power Tracking

~ 30% Efficiency
70% Wasted energy as heat

Energy Dissipated as Heat
Amplifier Designs

Envelope Modulation

Envelope Detector → Supply Modulator → Class A/B Amplifier

Envelope doesn’t track to zero

Envelope Power Tracking

~ 40% Efficiency
60% Wasted energy as heat
Amplifier Designs

Doherty Modulation (or Doherty Power Amplifier DPA)

Drain Modulated

Efficiency 46%
Temperature 62° C

Drain Modulated

Average Junction temperature 112° C
Amplifier Designs

Envelope Modulation or Drain Modulation

Summary:

- Average Drain Efficiency over UHF band = 48% versus 30% for standard Class AB and 42% for Doherty

- Transmitter energy consumption savings
  - (for a 5kW transmitter, efficiency improves from 24% to 38%);

- Less heat dissipated on transistors => Higher MTBF and thus higher reliability
  - A reduction of 20 degrees C in junction temperature represents four times more in reliability

- Extra savings due to simpler cooling system and less internal fans
Amplifier Designs

Envelope Modulation
- Efficient 48%
- Broadband
- Complex (PSU)

Doherty Modulation
- Efficient 42%
- Ultra Wide band transistors from NXP still drop off in power at high and low frequencies
- Significant reduction in efficiency as power level moves away from maximum

**Warning**
- As transmitter power is reduced from maximum efficiency does not stay the same
- It is an important factor when deciding on technology
Amplifier Efficiency as a % of Maximum Power
Amplifier Designs

LDMOS – Performance versus Output Power reduction

** Without re-correction
Comparison of High Efficiency (HE) transmitters versus Standard LDMOS (Fixed Drain)

**POWER CONSUMPTION COST HIGH EFFICIENCY VERSUS STANDARD LDMOS**

**Based On:** 24 hour/365 day operation, $0.07 kW/h, 25% LDMOS Efficiency, 38% Doherty Efficiency
Amplifier Designs

Comparison of High Efficiency (HE) transmitters versus Standard LDMOS (Fixed Drain)

** Based On: 24 hour/365 day operation, $0.07 kW/h, 25% LDMOS Efficiency, 38% Doherty Efficiency and 10% premium on capital investment
Comparison of High Efficiency (HE) transmitters versus Standard LDMOS (Fixed Drain)

** Based On: 24 hour/365 day operation, $0.07 kW/h, 25% LDMOS Efficiency, 38% Doherty Efficiency and 10% premium on capital investment
Amplifier Designs

So which high power device to choose

- IOT’s
  - Still the highest efficiency… but
  - High Voltage
  - Complex
  - Less redundancy

- Envelope Tracking or Drain Modulation
  - High redundancy
  - Higher efficiency than Doherty
  - Complex

- Doherty
  - Lowest efficiency that all, but
  - Simpler and easier to implement
  - Band limited but easy enough to change if necessary

- PRICE…. ALL about the same!
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TV Transmitter Amplifier designs

Performance (A discussion on SNR and MER)

Distortions in TV Transmitters

About Anywave

Q&A
S/N is the ratio of ideal signal power to all other signal contributions (such as noise and distortion products). Data is taken only from the I channel (that is the real axis; in phase with the pilot) at each symbol time.

\[
S/N = 20 \log \left( \frac{\sqrt{\sum_{j=1}^{N} (I_j^2)}}{\sqrt{\sum_{j=1}^{N} (\delta I_j^2)}} \right)
\]

Where:

- \( S/N \) = Signal to Noise Power Ratio in dB.
- \( I_j \) = Ideal received I-channel signal.
- \( \delta I_j \) = Error in the actual received I-channel signal.
EVM is the square root of the mean of the squares (RMS) of the magnitudes of the real axis symbol error vectors, divided by the magnitude of the real (in-phase) part of the outermost ideal constellation state.

The symbol error is the difference between the received real axis symbol and its ideal value. EVM is often expressed as a percent.

Error Vector Magnitude (EVM) is defined by the following formula:

\[
EVM_{RMS} = \sqrt{\frac{1}{N} \sum_{j=1}^{N} \delta I_j^2 \frac{S_{max}^2}{\delta I_j^2}} \times 100\%
\]

Where:

- \(EVM_{RMS}\) = Error Vector Magnitude (%).
- \(\delta I_j\) = The error in the real axis received signal value.
- \(S_{max}\) = Magnitude of the real (in-phase) part of the vector to the outermost state of the constellation.

EVM can also be expressed in terms of dB, where \(EVM_{dB} = 20 \times \log\left(\frac{100}{EVM\%}\right)\). Note that the ratio is intentionally inverted to make the value in dB positive.
Complex Modulation Error Ratio (Complex MER) is a complex form of the S/N measurement that is made by including Q (quadrature) channel information in the ideal and error signal power computations, similar to EVM. MER is defined by the following formula:

\[
MER = 20 \log \left( \frac{\sqrt{\sum_{j=1}^{N} \left( I_j^2 + Q_j^2 \right)}}{\sqrt{\sum_{j=1}^{N} \left( \delta I_j^2 + \delta Q_j^2 \right)}} \right)
\]

Where:

- MER = Modulation error ratio.
- \( I_j \) and \( Q_j \) = Ideal I-channel and Q-channel symbols.
- \( \delta I_j \) and \( \delta Q_j \) = Errors between received and ideal I-channel and Q-channel symbols.
SNR, MER and EVM

- SNR is defined in real domain: only approximate relationship between MER, SNR and EVM can be obtained. MER and EVM differ from each other, only by the reference value.

- $EVM\ (dB) = MER\ (dB) + 3.679\ dB$

- $SNR = 39.3 - 20 \times \log_{10} (EVM\%)\ dB$
Constellation and Eye Diagrams

- The “Constellation” Measurement
- 8 Vertical Lines (virtual)
- Thinner the vertical line, better the signal

- The “Eye Diagram” Measurement
- 8 Cross over points (8VSB)
- The bigger the “eyes” the better the signal.
Bowed lines indicate amplitude error: such as clipping or non-linear distortion (AM-AM distortion)

S shaped lines indicated phase errors (AM-PM distortion)

Lines frayed at edges indicate phase noise problems
Constellation

SNR: 34 dB

SNR: 24 dB
Eye Diagram

SNR: 37 dB

SNR: 19 dB
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Distortions in TV Transmitters

Two types of distortion that causes SNR

- **LINEAR (AM-PM)**
  - Caused by filters, combiners etc.
  - **MER/SNR**
    - GOOD = 36dB
    - MINIMUM = 27dB
    - POOR = <24dB

- **NON-LINEAR (AM-AM)**
  - Caused by saturation of an RF amplifier
  - **PAPR**
    - GOOD = 55dB
    - MINIMUM = 47dB
    - POOR = <44dB
Distortions in TV Transmitters

What is automatic and or adaptive linear and non-linear pre-correction?

Let the amplifier Gain be described as a polynomial

\[ v_o(t) = a_1v_i + a_2v_i^2 + a_3v_i^3 + ... = F_{NL}(v_i(t)) \]

Linear gain requires

\[ v_{oL}(t) = a_1v_i(t) \]

If we find another function G, and pass the signal through first, so that

\[ v_o(t) = F(G(v_i(t))) = a_1v_i(t) \]
Distortions in TV Transmitters

What is automatic and or adaptive linear and non-linear pre-correction?

We get Linear Gain, but we do not get anymore power, and we get sharper saturation.
What is automatic and or adaptive linear and non-linear pre-correction?

Note: The input bandwidth is increased.

Key is not to increase it too much.
Distortions in TV Transmitters

What is automatic and or adaptive linear and non-linear pre-correction?

The Modulator / Exciter pre-distortion:

- Increases the peak-to-average power ratio of the signal input to the PA
  - Which is the “gain expansion” characteristic of the Exciter

- Increases the bandwidth of the signal that is input to the PA
  - Distortion components are added to the signal to cancel out the distortion of the PA
Distortions in TV Transmitters

The **FOUR FUNDAMENTAL (CRITICAL) MEASUREMENTS**

- **TS OK**
- **SNR**
- **IMD**
- **OUTPUT POWER**

**TRANSPORT STREAM:**
19.39 MB/s
Distortions in TV Transmitters

About linear correction

- **Internally** caused by filter, combiners (anything with phase changing characteristics)

- **Externally** caused by transmission line, antennas (transmit and receive), propagation effects...

- Internal is far less than external

- Equalization inside receivers DOES compensate for LINEAR distortion

- If Linear Distortion is not minimized then the more harmful Non-linear Distortion components may go unnoticed because the linear distortion tends to dominate SNR.

**VERY GOOD SNR/MER (36.5 dB)**

**VERY BAD SNR/MER (19.3 dB)**
Distortions in TV Transmitters

About non-linear correction

- Caused by 3rd Harmonic Distortion (re-insertion of side bands)
- ICPM / LF linearity (in Analog) Manifested by non-linear in band and out of band IMD products
- Amplitude/Gain change within amplifier due to input level
- Reduces receivers ability to automatically correct for linear distortion
- No mechanism to correct these errors in the receiver

VERY GOOD SHOULDERS (53 dB)

VERY BAD SJPI: DERS (25 dB)
Distortions in TV Transmitters

About non-linear correction

Receiver sees this noise

Shoulders of 32dB

Which relates to

SNR of about 19dB

(32 – 11 – 3 = 19 dB)
Distortions in TV Transmitters

About non-linear correction

Shoulder height difference indicates that the amplifier gain is dependent on frequency (time), and hence has a memory.

Such an amplifier would benefit from Memory Error correction (MEC).
Distortions in TV Transmitters

Power Output

- Power Fluctuation does not really affect coverage.
- A good AGC and or ALC is wise in terms of protecting other equipment and staying within your legal power limits.
- 1dB power reduction (-20%) would see about a 1 mile reduction in coverage (in UHF).
- However, the same change in power could cause an SNR reduction by up to 6dB, which in some circumstances could be many 10’s of miles of loss of coverage.
Distortions in TV Transmitters

Other techniques to improve linear and non-linear distortion

- Standard Non-linear and linear correction process through pre-distortion
  - Improved algorithms
    - Initial designs provided 5-6dB improvement
    - Current designs > 15dB
  - Adjusting the characteristics of the amplifier to be optimized at full power
    - Offers 1-2dB improvement

  - Memory Error Correction (MEC)

  - Crest Factor Reduction (CFR)
Other techniques to improve linear and non-linear distortion

- **Memory Error Correction** (MEC) algorithms improve linear and non-linear correction by up to 3dB.
  - Developed for the Cell phone industry to improve coverage through improved SNR
  - MEC compensates for dynamic errors in the amplifiers due to the thermal “memories of the transistor device”

- **Crest Factor Reduction** reduces the peaks of the amplified waveform allowing for less “crushing” of the signal and the generation of odd order harmonics (IMD)
  - CFR reduces IMD at the cost (compromise) of SNR.
  - CFR can only be applied if SNR is high enough to be reduced. i.e. above 36dB.
  - Another feature of CFR is that is “protects” sensitive amplifiers from “spikes”
Distortions in TV Transmitters

Ideal characteristics of a exciter correction system

- The ability to correct for both linear and Non-linear distortions by measuring after the filter and generating a “pre-distortion” that is equal and opposite to that of the output distortion, in order when they are added together a “almost perfect” output is produced with minimal Linear and Non-Linear distortion.

- IDEAL linear and non-liner correction requirements:
  - different algorithms for different amplifier devices
    - IOT
    - LDMOS
    - Doherty LDMOS
  - Fully adaptive
  - Separate Non-Linear and Linear correction
  - Separate Memory Error Effects (MEC) correction
  - Correction On/Off
  - Does not effect On-Air operation
  - Can be operated remotely or automatically
Distortions in TV Transmitters

Conclusion

- Monitor the four fundamental measurements (TS, SNR, IMD and Power)
- Measure performance often (annually); phase noise, frequency stability, pilot level, symbol rate
- LDMOS for power levels up to 4-6kW
- Doherty or Drain Modulation for higher power levels
- Future is a combination of both?
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About Anywave

Q&A
The main products of the company include:

- Exciters: ATSC/MH, CMMB, CTTB, DVB-T/T2, ISDB-T
- High Efficiency RF Power Amplifiers
- Transmitters: UHF Band IV and V, VHF Band I and III:
- RF Signal Processing Series technology
About Anywave

**Exciters/Translators**

Model: ACT-2X, 5X, 8X and 9X (NEW) Series

Power Range: -20dBm - +5dBm

**Stand-alone Amplifiers**

Model: ACT LPTV Series

Power Range: 2W – 1kW
About Anywave

Modular TV Transmitters

Model: ACT-LPTV Series
Power Range: 2W – 560W

Transmitter Systems - Air

Model: MPTV Series
Power Ranges: 1kW – 2.5kW
About Anywave

Transmitter Systems - Liquid

Model: ACT-HPTV Series

Power Range: 3kW – 30kW
About Anywave

RF Filters and Components

Filters
- Band Pass Filters
  - 6 Pole
  - UHF and VHF

Cable and Connectors
- Most sizes and styles
About Anywave

Digital Encoders

Specialized Design

Encoders
- Transcoders
- MPEG-2
- MPEG-4
- Multi-program
- Statistical multiplexing

R&D
- MPEG
- Transmission
- Modulation
- Control and Monitoring
About Anywave

Multimedia devices

- IP encoders
- Low Bit Rate Encoders
- Multiplexers
- Receivers
- IP Gateways
- ASI Distribution
- IP-ASI Adaptors
- DVB-S to DVB-C
  Transmodulators
- Decoders
- IRD’s
- DVB-C modulators
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