DIGITAL PREDISTORTION
LINEARIZING OUR AMPLIFIERS

Dr. Warren C. Pratt, NROV

HAM RADIO FRIEDRICHSHAFEN 2014
• Mix With Complex Oscillator To Generate Baseband (0 Hz IF) Signal
• Decimate Down From The Sample Rate Of The Oscillator & ADC (122.88 Mhz)

• Process The Complex Digital Signal (I,Q) To Generate Audio
  • Sample rates are easily processed in software (48K – 384K)
• Complex Digital Signal (I,Q) Generated From Audio Data
  • Sample rates are easily processed in software (48K – 384K)
  • Interpolate Up To The Sample Rate Of The DAC & Oscillator (122.88 Mhz)
  • Mix With Complex Oscillator To Generate The RF-Frequency Digital Signal
DIGITAL UP-CONVERSION TRANSMITTER (DUC)

**GENERATE DIGITAL SIGNAL**
- MIC
- ADC
- Process in Software DSP
  - Digital Signal Generator

**DIGITAL UPCONVERSION**
- Interpolate
- Mix
  - Digital Oscillator
- DAC
- Amplifier

RF

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DIGITAL UP-CONVERSION TRANSMITTER (DUC)

**Generate Digital Signal**
- MIC
- ADC
- Process in Software DSP
- Digital Signal Generator

**Digital Upconversion**
- Interpolate
- Mix
- Digital Oscillator
- DAC
- Amplifier
- RF
DIGITAL UP-CONVERSION TRANSMITTER (DUC)

GENERATE DIGITAL SIGNAL

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DIGITAL UPCONVERSION

- Interpolate
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DIGITAL UP-CONVERSION TRANSMITTER (DUC)

GENERATE DIGITAL SIGNAL

MIC ➔ ADC ➔ Process in Software DSP

Digital Signal Generator

DIGITAL UPCONVERSION

Interpolate ➔ Mix

Digital Oscillator

DAC ➔ Amplifier

RF

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DIGITAL UP-CONVERSION TRANSMITTER (DUC)

GENERATE DIGITAL SIGNAL
- MIC
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DIGITAL UPCONVERSION
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RF
DIGITAL UP-CONVERSION TRANSMITTER (DUC)

- **Generate Digital Signal**
  - MIC → ADC → Process in Software DSP → Digital Signal Generator

- **Digital Upconversion**
  - Interpolate
  - Mix
  - Digital Oscillator
  - DAC → Amplifier

- RF
WHY?
WHY?

Because the amplifier is NOT perfectly linear!
AMPLITUDE NON-LINEARITY

[Graph showing amplifier output vs. input with two curves: Ideal and Actual.]
CORRECTION BY PREDISTORTION

Amplifier Output

Amplifier Input

Ideal

Actual

PD Input
ADAPTIVE BASEBAND PREDISTORTION

Basic Concept

1, Q

Generate Signal

GENERATE DIGITAL SIGNAL

MIC → ADC → Process in Software DSP

Digital Signal Generator

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ADAPTIVE BASEBAND PREDISTORTION
Basic Concept

DIGITAL DOWNCONVERT
- Generate Signal
- I,Q
- Correction
- Decimate
- Mix
- Digital Oscillator

DIGITAL UPCONVERSION
- DUC
- Interpolate
- Mix
- Digital Oscillator
ADAPTIVE BASEBAND PREDISTORTION

Basic Concept

• Apply Correction to the out-bound signal
• Calculate Correction by Comparing the Input & Output of the Amplifier
  • BASEBAND – I,Q Before Up-Conversion / I,Q After Down-Conversion
  • ADAPTIVE – Repeat the process to Adapt to Changing Conditions
ADAPTIVE BASEBAND PREDISTORTION

SOFTWARE

Generate Signal
Apply Correction
Compare Signals & Calculate Correction

FIRMWARE

DUC
DDC

HARDWARE

DAC
Amplifier
ADC

VERY flat frequency response!
ADAPTIVE BASEBAND PREDISTORTION

• Samples from the amplifier Input and Output must be matched in time
• Network delays create variability in timing of amplifier Output samples
ADAPTIVE BASEBAND PREDISTORTION

- Samples from the amplifier Input and Output are synchronized
- The Input I,Q and Output I,Q are interleaved in network packets

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FOR EACH iq_sample
\[
\text{mag} = \sqrt{i^2 + q^2}
\]
\[
g = \text{gain\_correct}(\text{mag})
\]
\[
\phi = \text{phase\_correct}(\text{mag})
\]
\[
i_{out} = g \times (i \times \cos(\phi) - q \times \sin(\phi))
\]
\[
q_{out} = g \times (i \times \sin(\phi) + q \times \cos(\phi))
\]
FOR EACH pair_of_iq_samples

\[ \text{in}_\text{mag} = \sqrt{i_{\text{in}}^2 + q_{\text{in}}^2} \]
\[ \text{out}_\text{mag} = \sqrt{i_{\text{out}}^2 + q_{\text{out}}^2} \]
\[ g = \text{scale} \times \left( \frac{\text{in}_\text{mag}}{\text{out}_\text{mag}} \right) \]
\[ \phi = \arctan \left( \frac{-i_{\text{in}} \times q_{\text{out}} + q_{\text{in}} \times i_{\text{out}}}{i_{\text{in}} \times i_{\text{out}} + q_{\text{in}} \times q_{\text{out}}} \right) \]

save_gain_correction
save_phase_correction

“scale” compensates for amplifier gain and feedback attenuation
MEMORY EFFECTS
THE PREDISTORTION ENEMY!

EXAMPLE:
CLASS B AMPLIFIER

Drain Current
Device Temperature
MEMORY EFFECTS
THE PREDISTORTION ENEMY!

EXAMPLE:
CLASS B AMPLIFIER

Drain Current
Device Temperature

High Temp.
Low Temp.

0.6 A.
MEMORY EFFECTS
THE PREDISTORTION ENEMY!

EXAMPLE:
CLASS B AMPLIFIER

Drain Current
Device Temperature

0.6 A.

High Temp.
Low Temp.

Same Input Mag/Phase ➔ Different Output Mag/Phase
Why? The amplifier “remembers” the past inputs!
USING PURESIGNAL

1. Install your coupler.
2. Click “Linearity” to open the PureSignal form.
USING PURE SIGNAL

1. Click AutoCalibrate to activate PureSignal
2. Transmit audio or turn on the two-tone generator.
3. Adjust your attenuators for a GREEN Feedback Level indication.
4. If desired, adjust other controls per the “Information” document.
5. (Optional) Relax and click AmpView just to see what’s happening.
USING AMPVIEW
PURE SIGNAL RESULTS
Kurt, DL9SM

- Hermes Transceiver
- SD2918 Class A
- NXP, 2x BLF578

- 50V LDMOS Final
- Low Idq = 0.7A/device
- >1200W Capability

- 80M, 1 KW
- Low memory effects visible
PURESIGNAL RESULTS
Kurt, DL9SM

- PureSignal OFF
  - IMD3 ~ -31dBt

- PureSignal ON
  - IMD3 ~ -53dBt
PURESIGNAL RESULTS
Kurt, DL9SM

- PureSignal OFF
- IMD ~ -30dB
- PureSignal ON
- IMD ~ -52dB
PURESIGNAL RESULTS
Kurt, DL9SM

Hermes Transceiver → SD2918 Class A → NXP, 2x BLF578

- 50V LDMOS Final
- Low Idq = 0.7A/device
- >1200W Capability

- 20M, 1 KW
- Most non-linear band for this amp
- Low memory effects visible
- Should correct well
PURESIGNAL RESULTS
Kurt, DL9SM

- PureSignal OFF
- IMD3 ~ -21dB

- PureSignal ON
- IMD3 ~ -51dB
PURE SIGNAL RESULTS
Kurt, DL9SM

• PureSignal OFF
  • IMD ~ -31dB

• PureSignal ON
  • IMD ~ -51dB
PURESIGNAL RESULTS
Clyde, K2UE

ANAN-100D → 2M Xvtr → M² 2M-1K2

- ANAN Low-Pwr Xvtr Output
- Full-duplex Transverter
- 1200W 2M Amplifier

- 2M Amplifier is VERY non-linear
- LDMOS, Very low memory effects
- Should be very correctable!
PURE SIGNAL RESULTS
Clyde, K2UE

- PureSignal OFF
- IMD3 ~ -16dBt

- PureSignal ON
- IMD3 ~ -48dBt
PURESIGNAL RESULTS
Helmut, DC6NY

- Push-Pull LDMOS
- 1.8 – 70 Mhz.
- 300+ Watts
- Class AB or Class B

- 40 Meters
- Class B Operation
- \( I_{dq} = 20 \text{ mA} \)
- Drain efficiency = 80%

Hermes Transceiver
Freescale MRFE6VP6300HR5
PURESIGNAL RESULTS
Helmut, DC6NY

- 40 Meters, Class B
- PureSignal OFF
  - IMD3 = -16 dBc
  - IMD5 = -28 dBc

- PureSignal ON
  - IMD3 = -51 dBc
  - IMD5 = -64 dBc
  - ~ 35 dB Improvement
PURESIGNAL RESULTS
Focko, DJ5JB

Two P-P Stages
TI OPA2674C

2x RD16HHF1 MOSFET
2x MRF492 BJT

Hermes Transceiver

Hermes 100W PA (DSP)

LK-500 NTC

2x 3-500Z (Grounded-grid)

MIXED TECHNOLOGY
• 80M, 900 Watts
• IMD3 -28 → -55 dBc
• IMD5 -34 → -70 dBc
What’s Next?

• Exploration of algorithms to actively correct memory effects
  • Probably difficult for modes such as SSB and AM
  • Probably requires a different mathematical formulation than is currently used in Telecom
  • Some simulation already in place
  • More days and hours required!
WHO WORKS ON MEMORY EFFECTS?
WHO WORKS ON MEMORY EFFECTS?

What do they look like?
WHO WORKS ON MEMORY EFFECTS?

What do they look like?

• Italian Mathematician
• Developed the Volterra Series
  • The Taylor Series approximates the response of
    a nonlinear system
  • The Volterra Series incorporates memory effects!

Dr. Vito Volterra
WHO WORKS ON MEMORY EFFECTS?

What do they look like?

Dr. Vito Volterra

Dr. Warren Pratt

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PURESIGNAL – THE SECRET INFO PANEL

Ctrl-Alt-i
PURESIGNAL RESULTS
Bert, PA2XHF

- Push-Pull LDMOS
- 1.8 – 50 Mhz.
- 200W Driven from Hermes

- 80M Operation
- Very Linear @ 200W
- No memory effects visible
PURESIGNAL RESULTS
Bert, PA2XHF

- PureSignal OFF
  - IMD3 ~ -36dBt
  - IMD5 ~ -45dBt

- PureSignal ON
  - IMD3 ~ -72dBt
  - IMD5 ~ -82dBt
PURESIGNAL RESULTS
Bert, PA2XHF

- Hermes Transceiver
- Freescale MRFE6V6300HR5
  - Push-Pull LDMOS
  - 1.8 – 50 Mhz.
  - 200W Driven from Hermes
  - 6M Operation
  - Typical Linearity @ 200W
  - No memory effects visible

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PURESIGNAL RESULTS
Bert, PA2XHF

• PureSignal OFF
  • IMD3 ~ -26dBt
  • IMD5 ~ -40dBt

• PureSignal ON
  • IMD3 ~ -60dBt
  • IMD5 ~ -70dBt
PURESIGNAL RESULTS
Helmut, DC6NY

- Frequency Range: 1.8 – 30 Mhz
- Vdd = 48 Volts

- Saturation Power: 1035 Watts
- 1 dB Compression: ~ 800 Watts
PURESIGNAL RESULTS
Helmut, DC6NY

- 40 Meters; 800 Watts PEP
- Significant Memory Effect
- Best-fit Correction
PURESIGNAL RESULTS
Helmut, DC6NY

- PureSignal OFF
- IMD3 -28 dBc
- IMD5 -33 dBc

- PureSignal ON
- IMD3 -48 dBc
- IMD5 -53 dBc
DC6NY RF SAMPLER

• Designed by Helmut, DC6NY
• Posted on hamsdr.com
• Designed-in flexibility
• PCB group-buy was done by Steve, G1YLB

Schematic

Printed Circuit Board

Prototype
PURESIGNAL RESULTS
Peter, DK7SP

Careful design can produce excellent results with 13.8V MOSFETS!

- 10W, Single-stage P-P
- 2x RD16HHF1
- Low Idq, 175mA/dev
- Optimized Z-matching
- Voltage Feedback

Amplifier Breadboard
PURESIGNAL RESULTS
Peter, DK7SP

10M, PureSignal OFF

PureSignal ON, 30dB Improvement
PURESIGNAL RESULTS
Peter, DK7SP

PureSignal OFF

PureSignal ON, 30+dB Improvement
PURESIGNAL RESULTS
Bill, KC9XG

ANAN-100D

- Two Push-Pull Stages TI OPA2674C
- Push-Pull Mitsubishi RD15HV1F MOSFETs
- Push-Pull Mitsubishi RD100HVF1 MOSFETs
- 13.8V Design, Typical of Modern Transceivers
PURESIGNAL RESULTS
Mike, N1JEZ

• Extensive 6 Meter Testing
• Paper & Presentation – 40th Eastern VHF/UHF Conference, April 2014
  “LDMOS RF Amplifier Linearization using PowerSDR mRX Pure Signal”
• Class AB and Class B Testing of Homebrew LDMOS Amplifier
• Testing of ANAN-100 with ACOM–1006 (4CX800A / GU74B, 1 KW)
Mike, N1JEZ

1 KW, 6M Amplifier
NXP BLF-178

- Class AB
- 740W PEP
- IMD3 -38 → -54 dBC
- IMD5 -42 → -65 dBC
- Higher-order Down Significantly
PURESIGNAL RESULTS
Mike, N1JEZ

1 KW, 6M Amplifier
NXP BLF-178

- Class B, $I_{\text{bias}}=100\text{mA}$
- 740W PEP
- IMD3 $-22 \rightarrow -56\text{ dBC}$
- IMD5 $-28 \rightarrow -63\text{ dBC}$
- Higher-order Down Significantly

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<th>Delta Freq</th>
<th>Delta Pwr</th>
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<td>-26.13 dBm</td>
<td>-3600 kHz</td>
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PURESIGNAL RESULTS
Mike, N1JEZ

Waterfall Testing, SSB, Class B

PureSignal OFF

PureSignal ON

1 KW, 6M Amplifier
NXP BLF-178

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PURESIGNAL RESULTS
Mike, N1JEZ

ANAN-100

ACOM-1006

IMD3 -52.69 dBC
IMD5 -63.48 dBC

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<th>Ref</th>
<th>Delta</th>
<th>Ref Freq</th>
<th>Ref Amp</th>
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<td>50.140 091 MHz</td>
<td>-21.00 dBm</td>
<td>-3.000 kHz</td>
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<td>50.141 091 MHz</td>
<td>-21.58 dBm</td>
<td>-3.500 kHz</td>
<td>-63.48 dB</td>
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