DIGITAL PREDISTORTION
LINEARIZING OUR AMPLIFIERS

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HAM RADIO FRIEDRICHSHAFEN 2014
DIGITAL DOWN-CONVERSION RECEIVER
( DDC )

- 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)

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DIGITAL UP-CONVERSION TRANSMITTER (DUC)

- 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

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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
- 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

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DIGITAL UP-CONVERSION TRANSMITTER

(G DUC )

GENERATE DIGITAL SIGNAL

DIGITAL UPCONVERSION

MIC → ADC → Process in Software DSP → Interpolate → Mix → Digital Oscillator → DAC → Amplifier → RF

Digital Signal Generator

Process in Software DSP

Interpolate

Mix

Digital Oscillator

DAC

Amplifier

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Mix
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DIGITAL UPCONVERSION

Interpolate → Mix → Digital Oscillator → DAC → Amplifier → RF


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WHY?

Because the amplifier is NOT perfectly linear!
CORRECTION BY PREDISTORTION

Amplifier Input

Amplifier Output

0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

Ideal
Actual
PD Input

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ADAPTIVE BASEBAND PREDISTORTION

Basic Concept

Generate Signal

I, Q

GENERATE DIGITAL SIGNAL

MIC → ADC → Process in Software DSP → Digital Signal Generator

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ADAPTIVE BASEBAND PREDISTORTION
Basic Concept
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

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ADAPTIVE BASEBAND PREDISTORTION

SOFTWARE

Generate Signal

I,Q

Apply Correction

I,Q

Compare Signals & Calculate Correction

Correction

FIRMWARE

DUC

DAC

RF

HARDWARE

Amplifier

DDC

ADC

RF

 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

\[ \text{mag} = \sqrt{i^2 + q^2} \]
\[ g = \text{gain_correct} \left( \text{mag} \right) \]
\[ \varphi = \text{phase_correct} \left( \text{mag} \right) \]
\[ i_{\text{out}} = g \left( i \cos \varphi - q \sin \varphi \right) \]
\[ q_{\text{out}} = g \left( i \sin \varphi + q \cos \varphi \right) \]

Multiply by the gain correction

Rotate the phase
FOR EACH pair_of_iq_samples

\[ \text{in\_mag} = \sqrt{i_{\text{in}}^2 + q_{\text{in}}^2} \]

\[ \text{out\_mag} = \sqrt{i_{\text{out}}^2 + q_{\text{out}}^2} \]

\[ g = \text{scale} \times \left( \frac{\text{in\_mag}}{\text{out\_mag}} \right) \]

\[ \varphi = \arctan \left( \frac{-i_{\text{in}} \times q_{\text{out}} + q_{\text{in}} \times i_{\text{out}}}{i_{\text{in}} \times i_{\text{out}} + q_{\text{in}} \times q_{\text{out}}} \right) \]

save_gain_corrections

save_phase_corrections

“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

0.6 A.

High Temp.
Low Temp.
MEMORY EFFECTS
THE PREDISTORTION ENEMY!

EXAMPLE:
CLASS B AMPLIFIER

Drain Current
Device Temperature

High Temp.
Low Temp.

0.6 A.

Same Input Mag/Phase → Different Output Mag/Phase
Why? The amplifier “remembers” the past inputs!
USING PURE SIGNAL

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

![Graph showing magnitude and phase response with different lines representing Mag Amp, Phs Amp, Mag Corr, and Phs Corr.]

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PURESIGNAL 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

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PURESIGNAL RESULTS
Kurt, DL9SM

- PureSignal OFF
- IMD3 ~ -21dB

- PureSignal ON
- IMD3 ~ -51dB
PURESIGNAL RESULTS
Kurt, DL9SM

- PureSignal OFF
  - IMD ~ -31dB

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

ANAN-100D → 2M Xvtr → M^2 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!
PURESIGNAL 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

Hermes
Transceiver

Two P-P Stages
TI OPA2674C

Hercules
100W PA
(DJ8AY)

2x RD16HHF1 MOSFET
2x MRF492 BJT

LK 500 NTC

2x 3-500Z
(Grounded-grid)

MIXED TECHNOLOGY
• 80M, 900 Watts
• IMD3 -28 → -55 dBC
• IMD5 -34 → -70 dBC

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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!