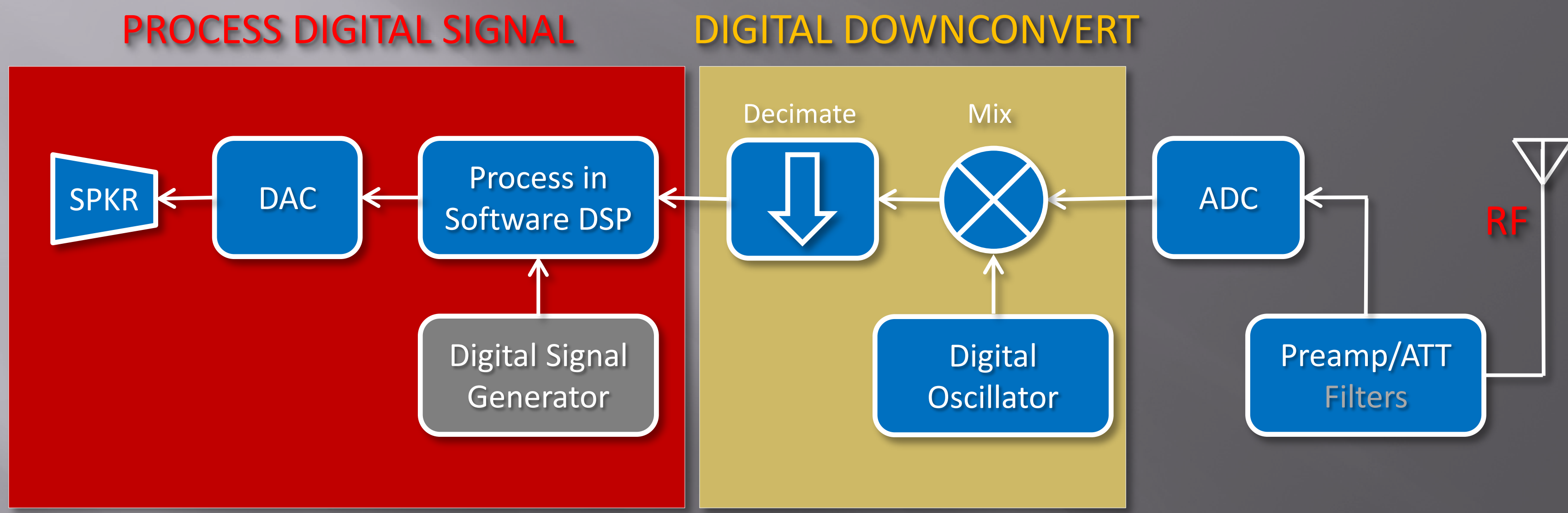
DIGITAL PREDISTORTION LINEARIZING OUR AMPLIFIERS

Dr. Warren C. Pratt, NR0V

HAM RADIO FRIEDRICHSHAFEN 2014

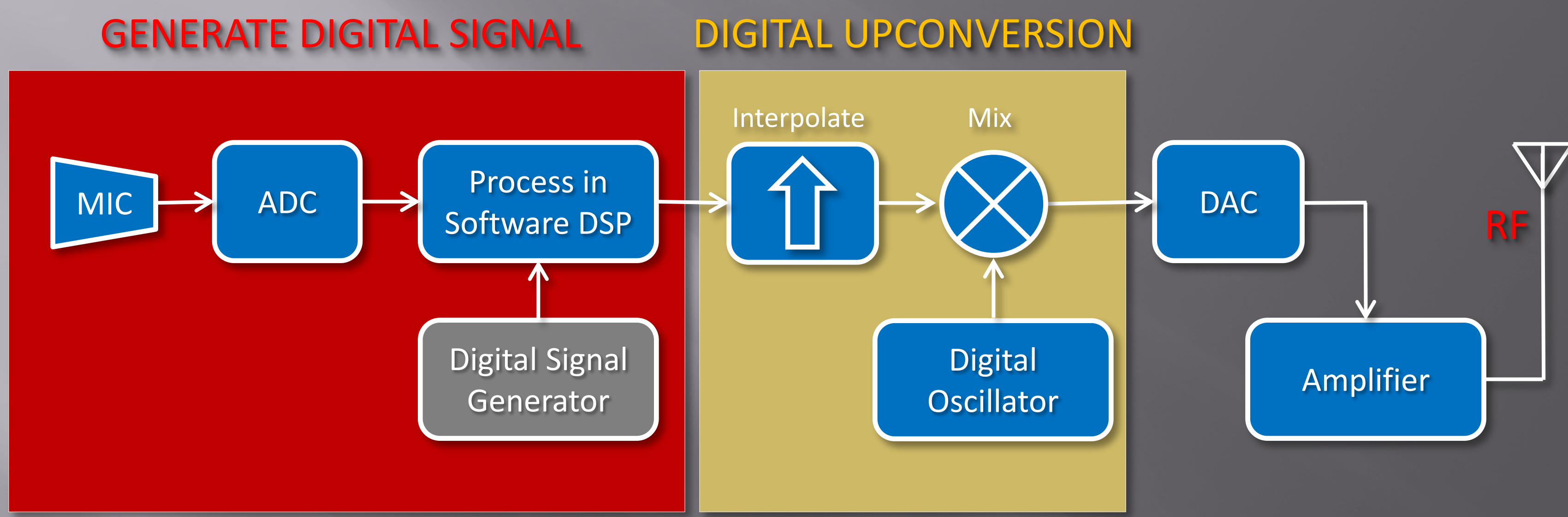
DIGITAL DOWN-CONVERSION RECEIVER
(DDC)



- 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)

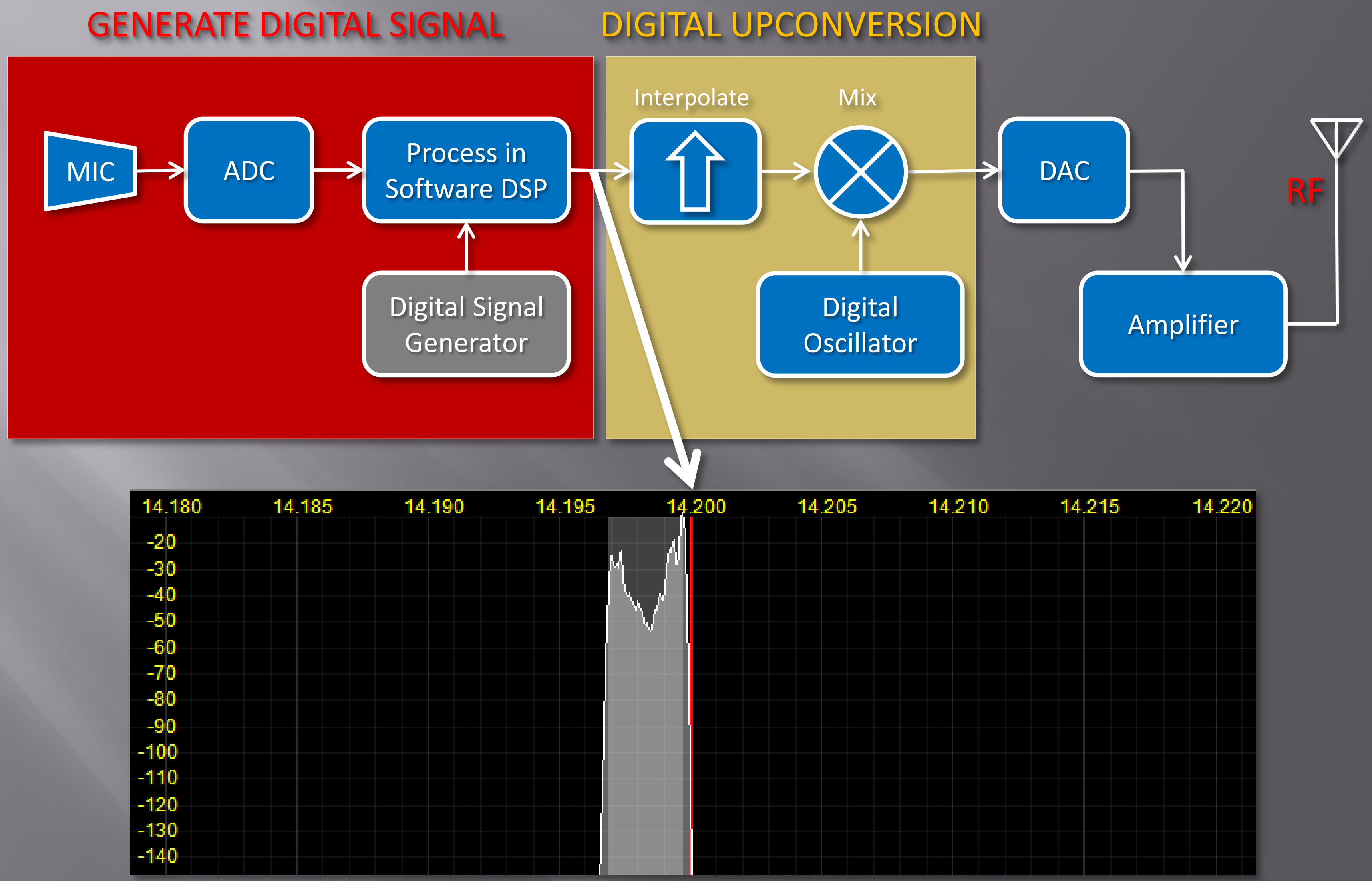
DIGITAL UP-CONVERSION TRANSMITTER
(DUC)



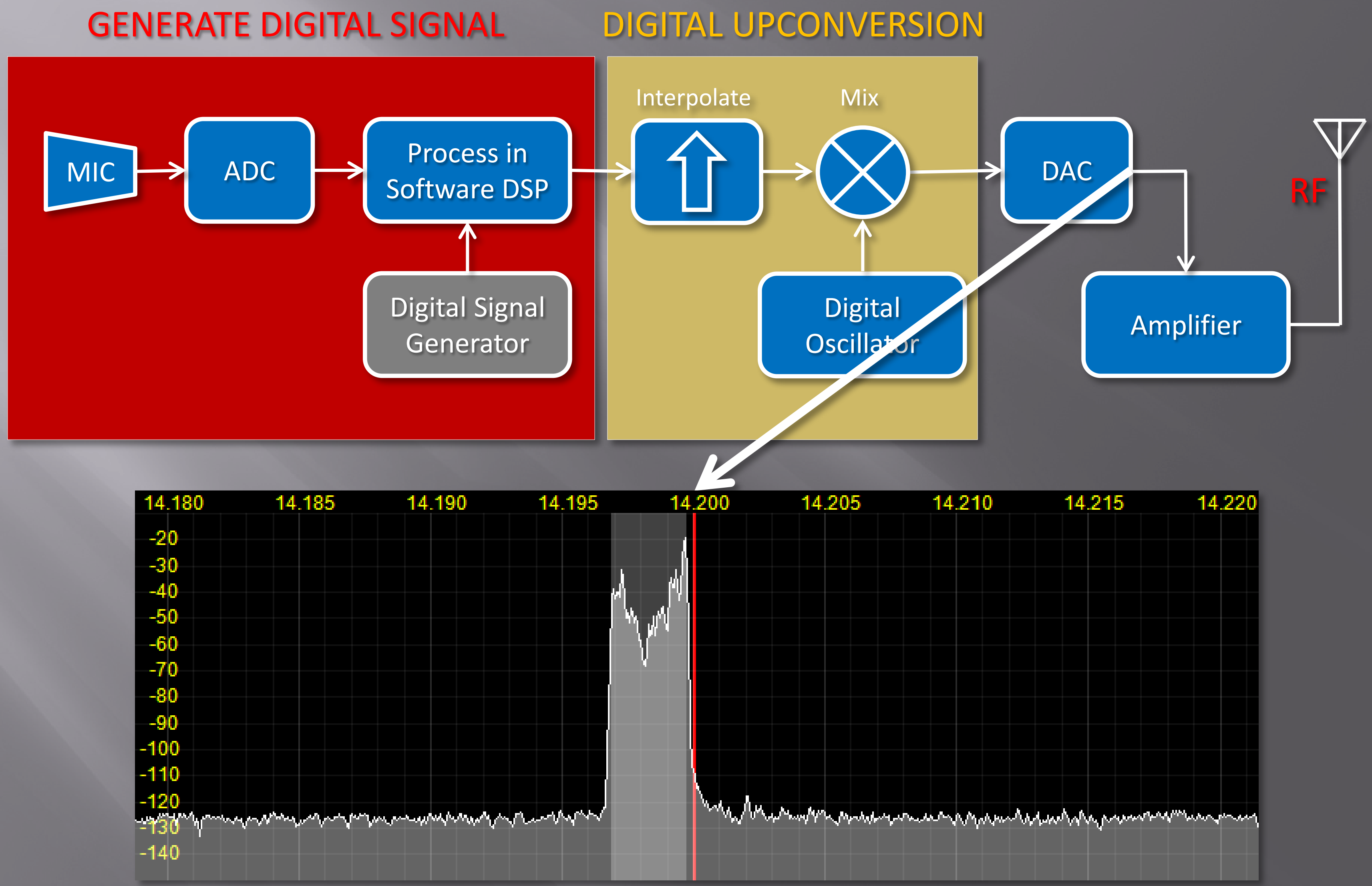
- Complex Digital Signal (I,Q) Generated From Audio Data
  - Sample rates are easily processed in software (48K – 384K)

- Interpolate Up To The Sample Rate Of The DAC & Oscillator (122.88 Mhz)
- Mix With Complex Oscillator To Generate The RF-Frequency Digital Signal

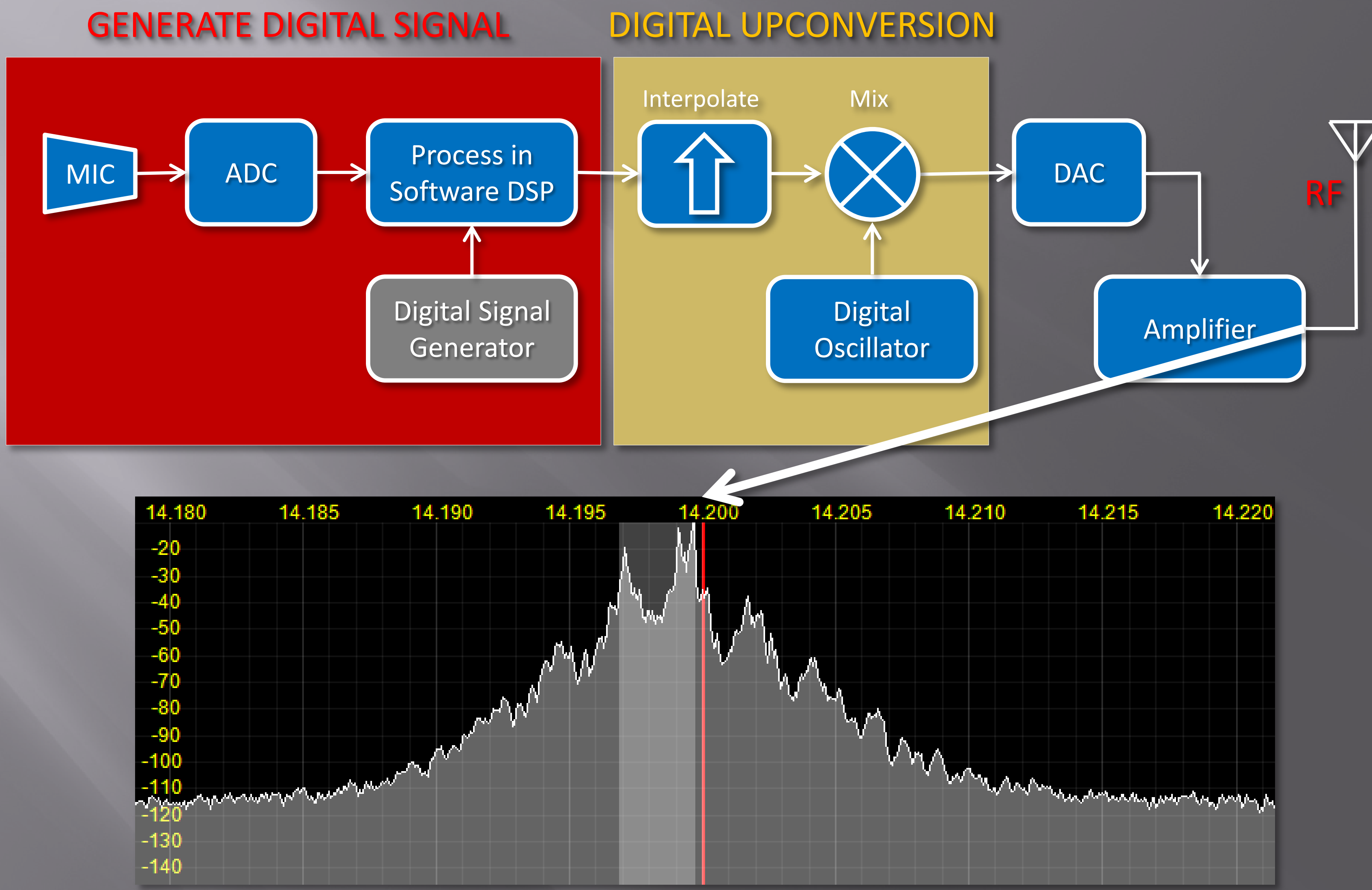
DIGITAL UP-CONVERSION TRANSMITTER
(DUC)



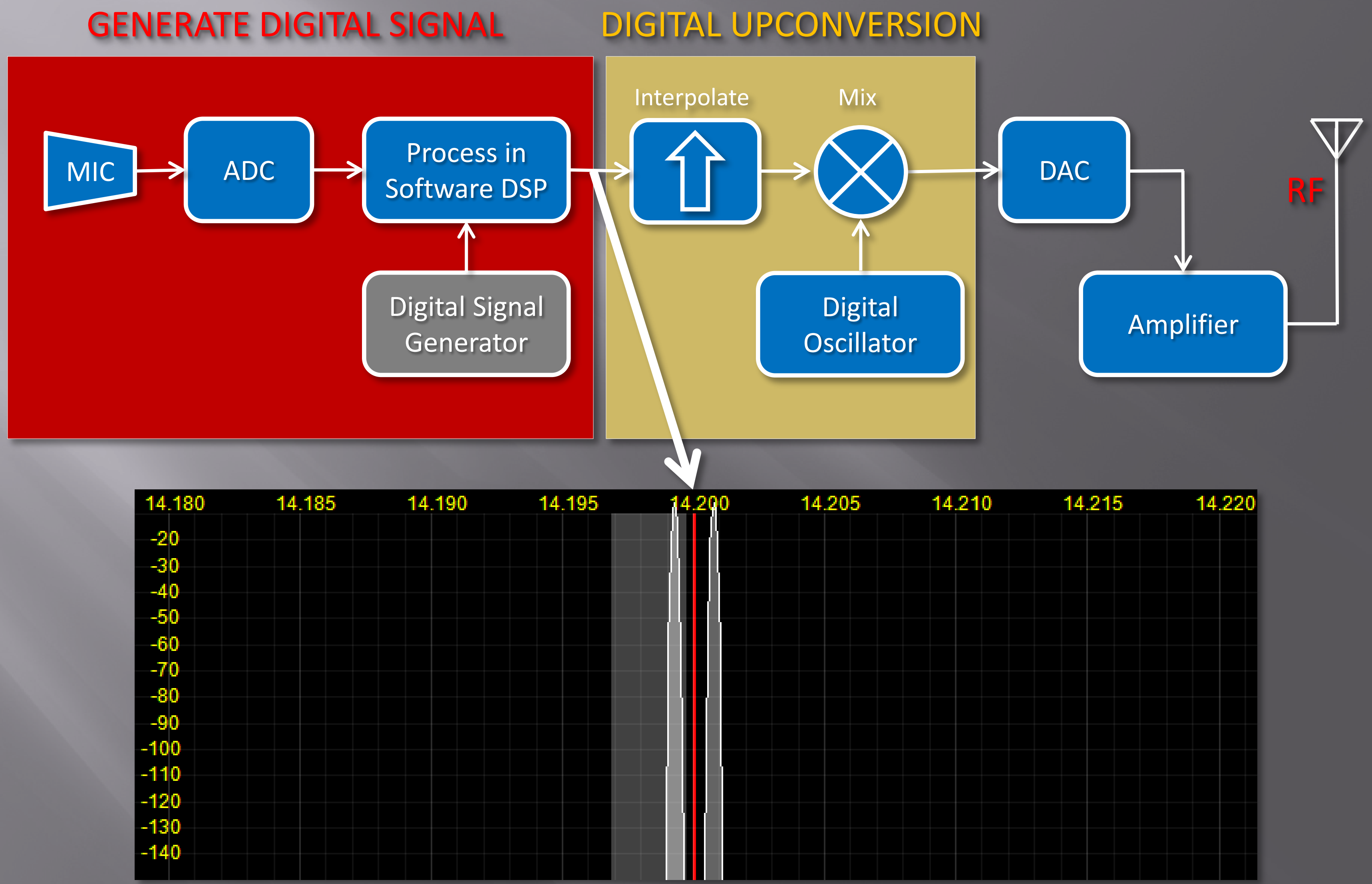
DIGITAL UP-CONVERSION TRANSMITTER
(DUC)



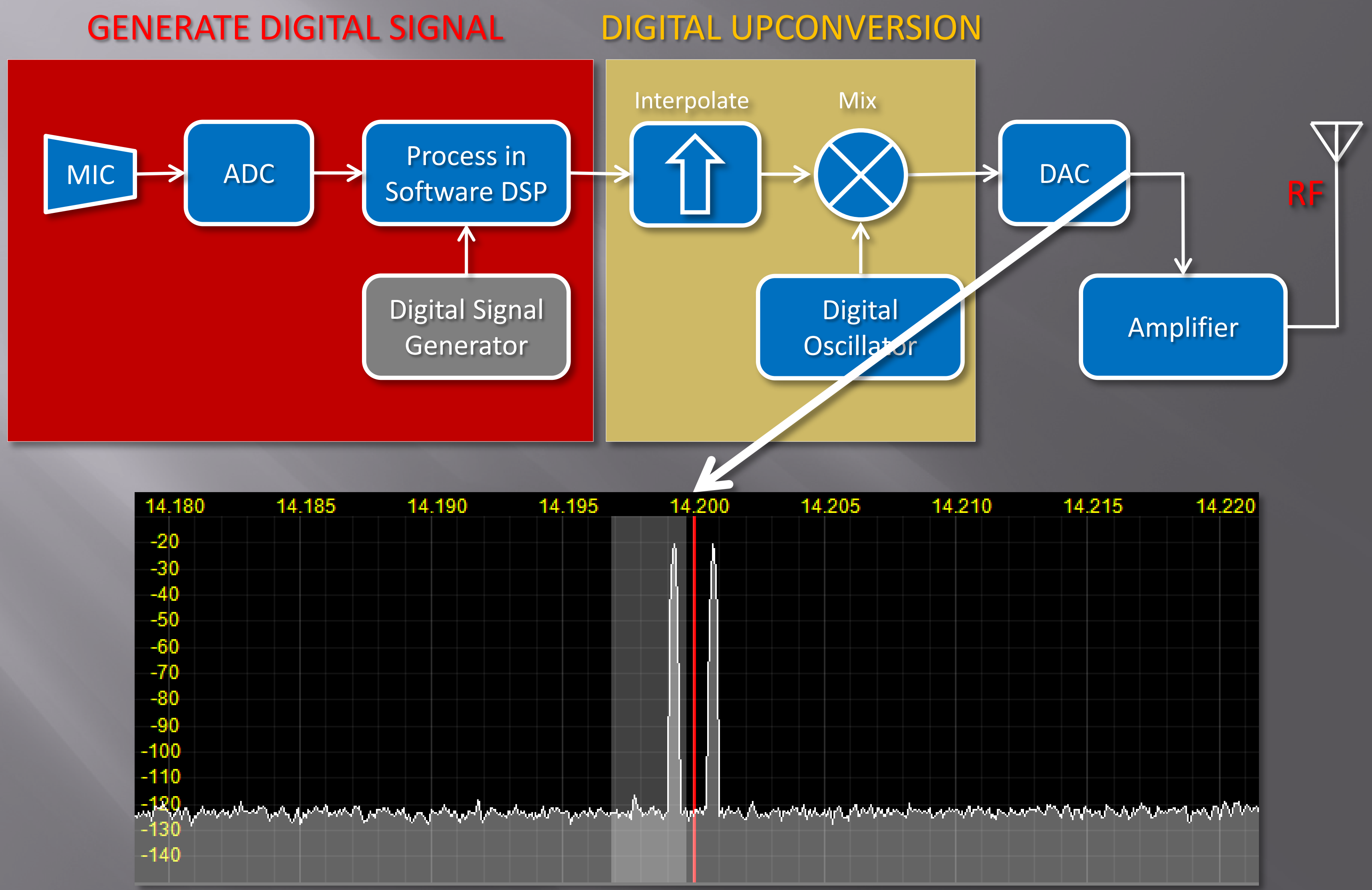
DIGITAL UP-CONVERSION TRANSMITTER
(DUC)



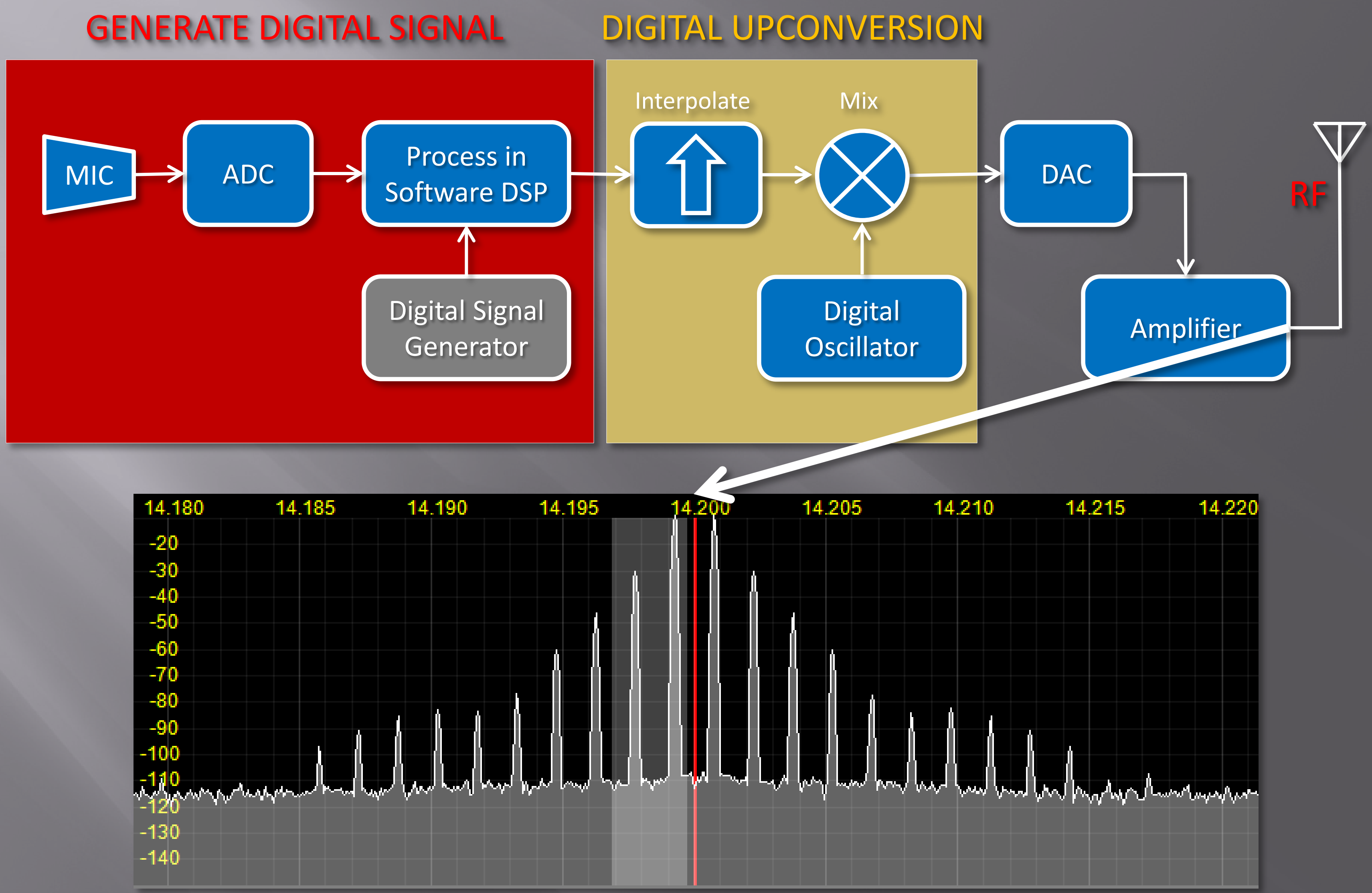
DIGITAL UP-CONVERSION TRANSMITTER
(DUC)



DIGITAL UP-CONVERSION TRANSMITTER
(DUC)



DIGITAL UP-CONVERSION TRANSMITTER
(DUC)

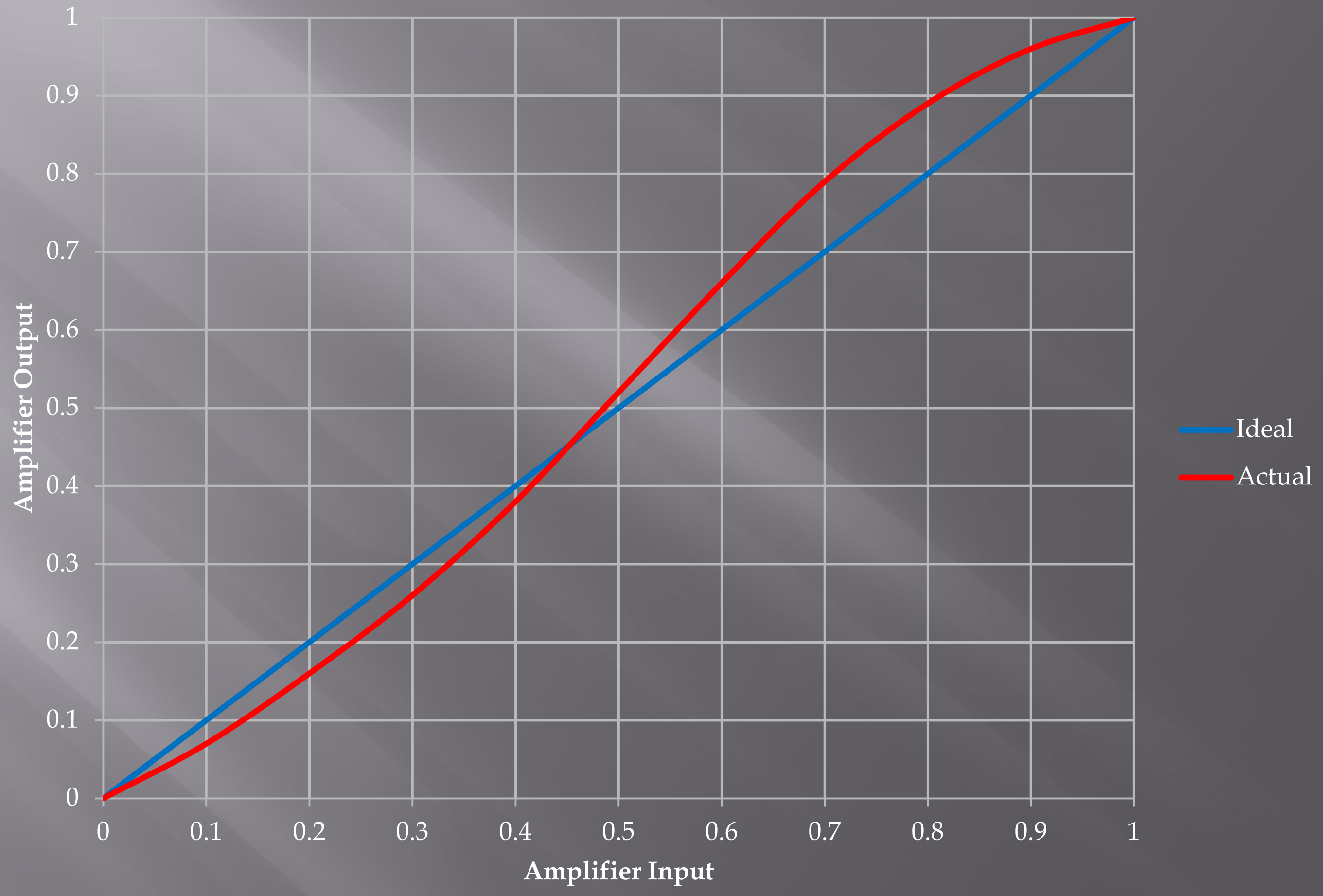


WHY ?

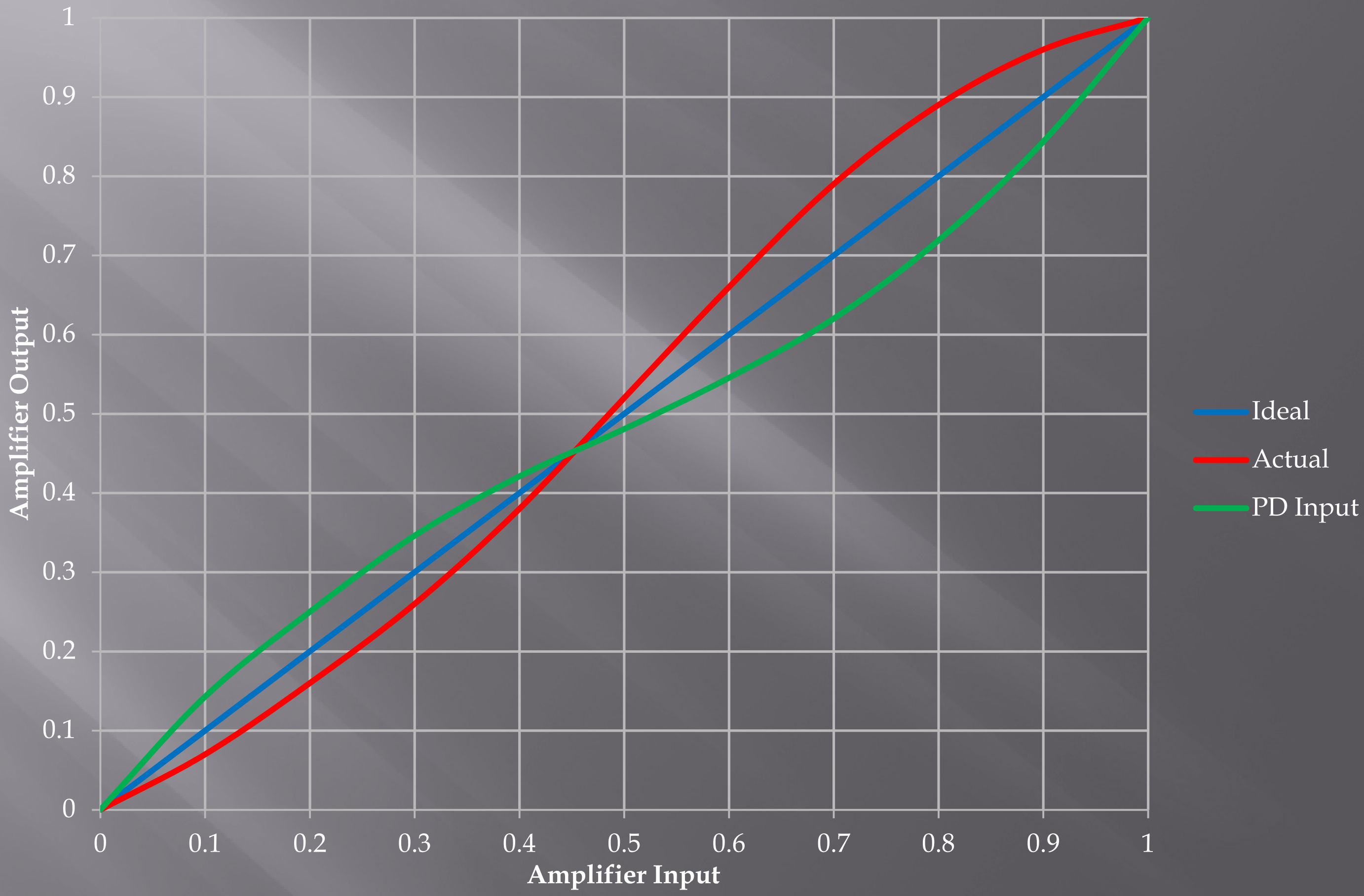
WHY ?

Because the amplifier is NOT perfectly linear!

AMPLITUDE NON-LINEARITY

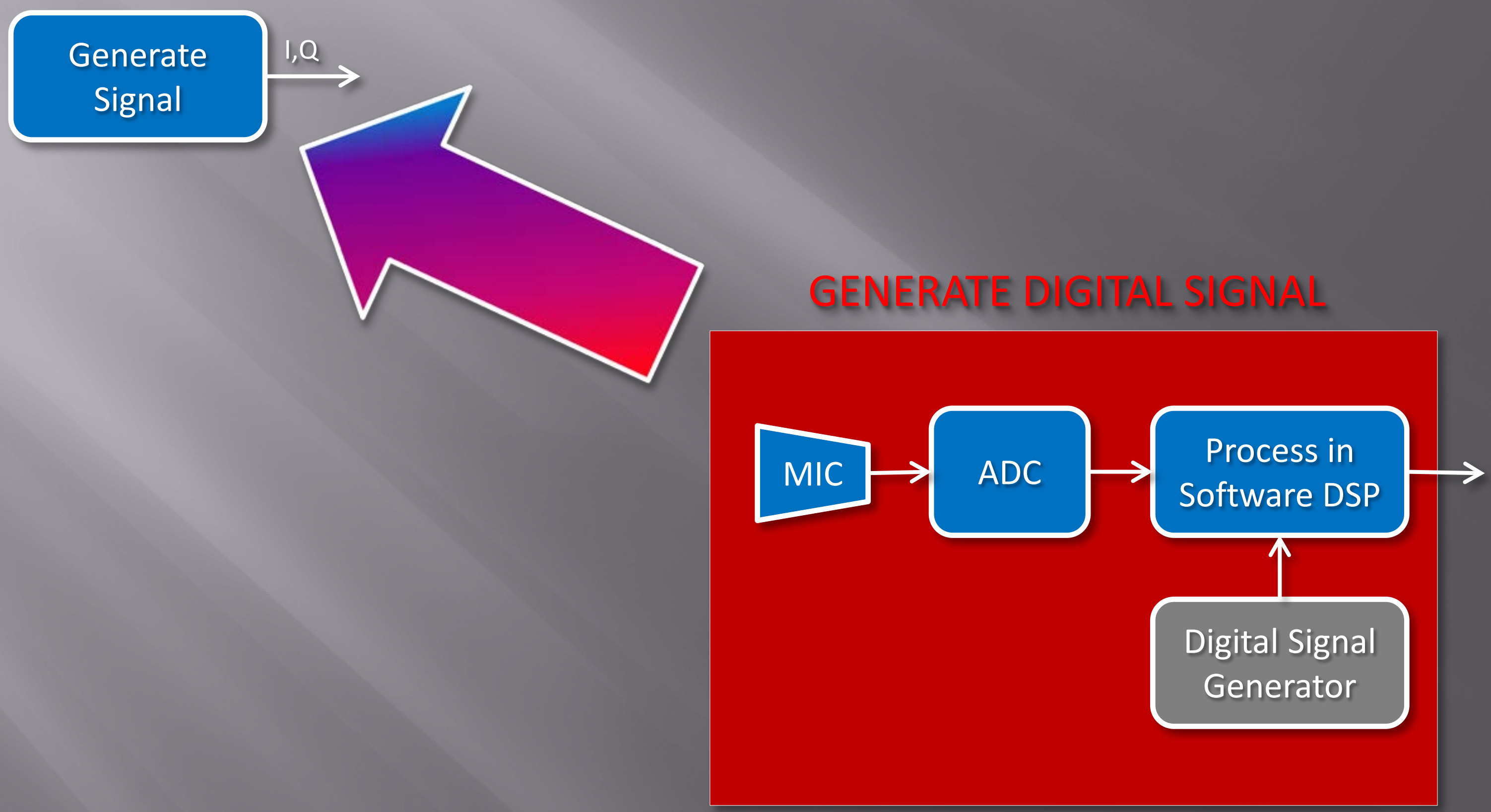


CORRECTION BY PREDISTORTION



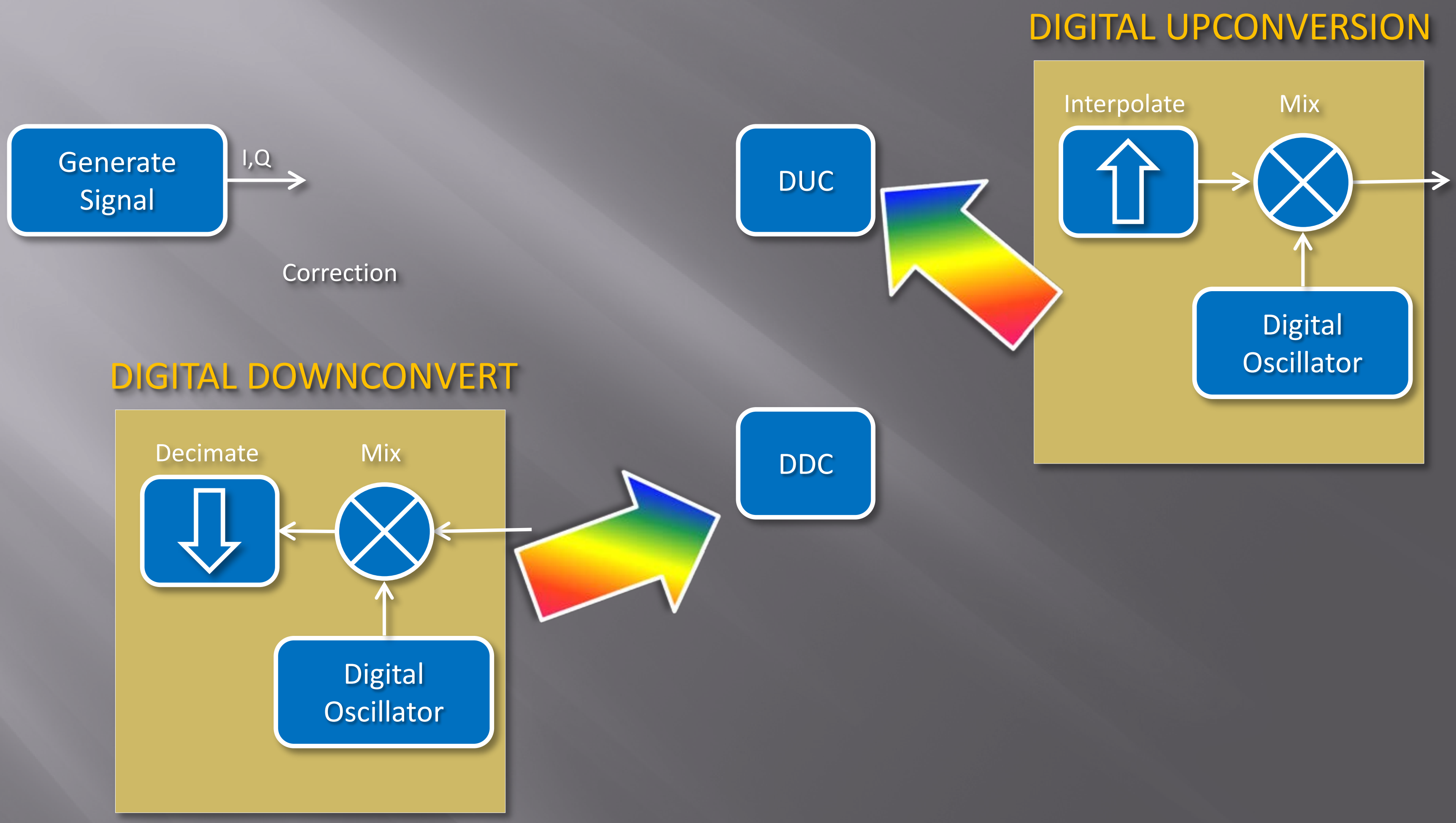
ADAPTIVE BASEBAND PREDISTORTION

Basic Concept



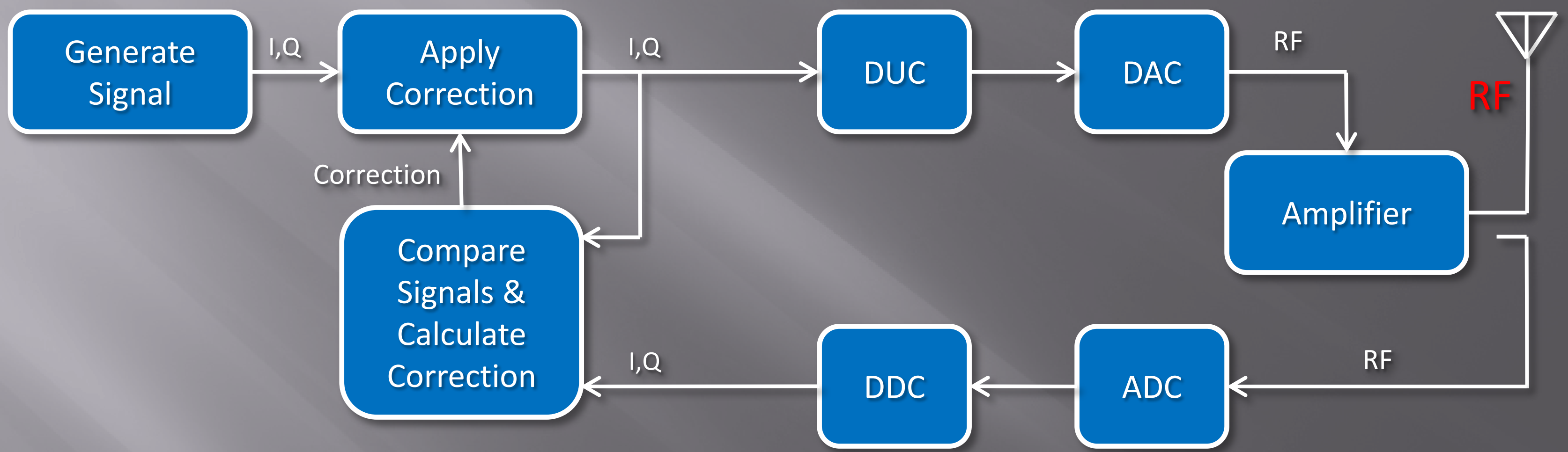
ADAPTIVE BASEBAND PREDISTORTION

Basic Concept



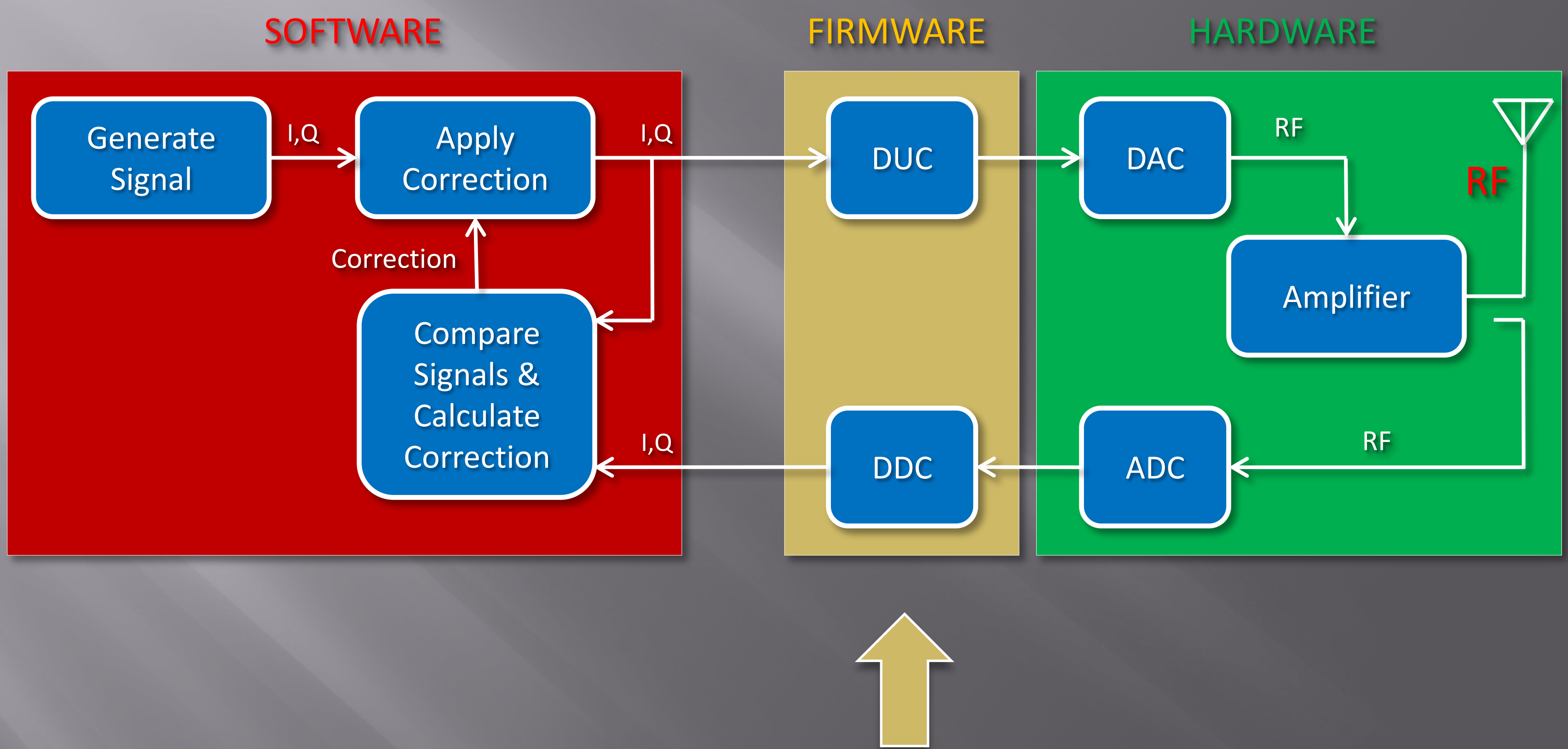
ADAPTIVE BASEBAND PREDISTORTION

Basic Concept



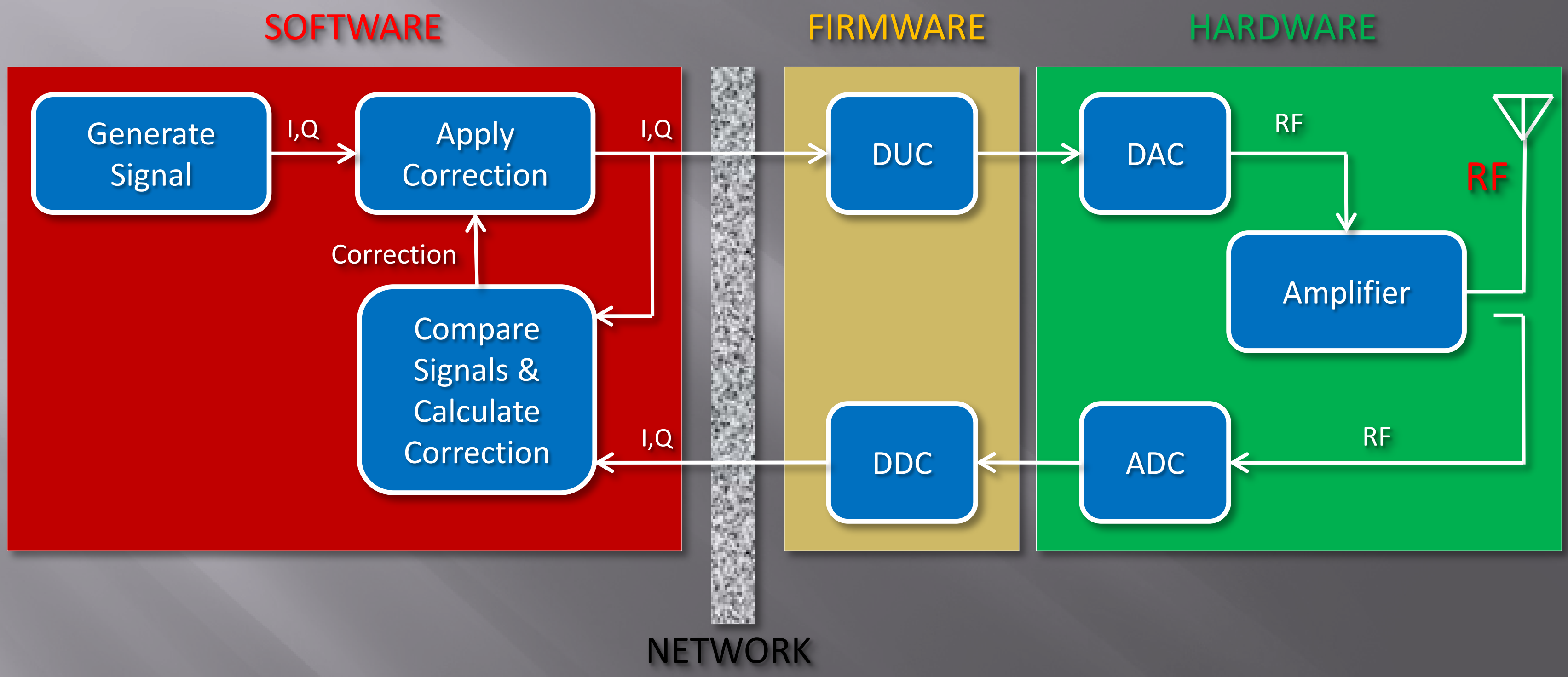
- Apply Correction to the out-bound signal
- Calculate Correction by Comparing the Input & Output of the Amplifier
  - BASEBAND – I,Q Before Up-Conversion / I,Q After Down-Conversion
  - ADAPTIVE – Repeat the process to Adapt to Changing Conditions

ADAPTIVE BASEBAND PREDISTORTION



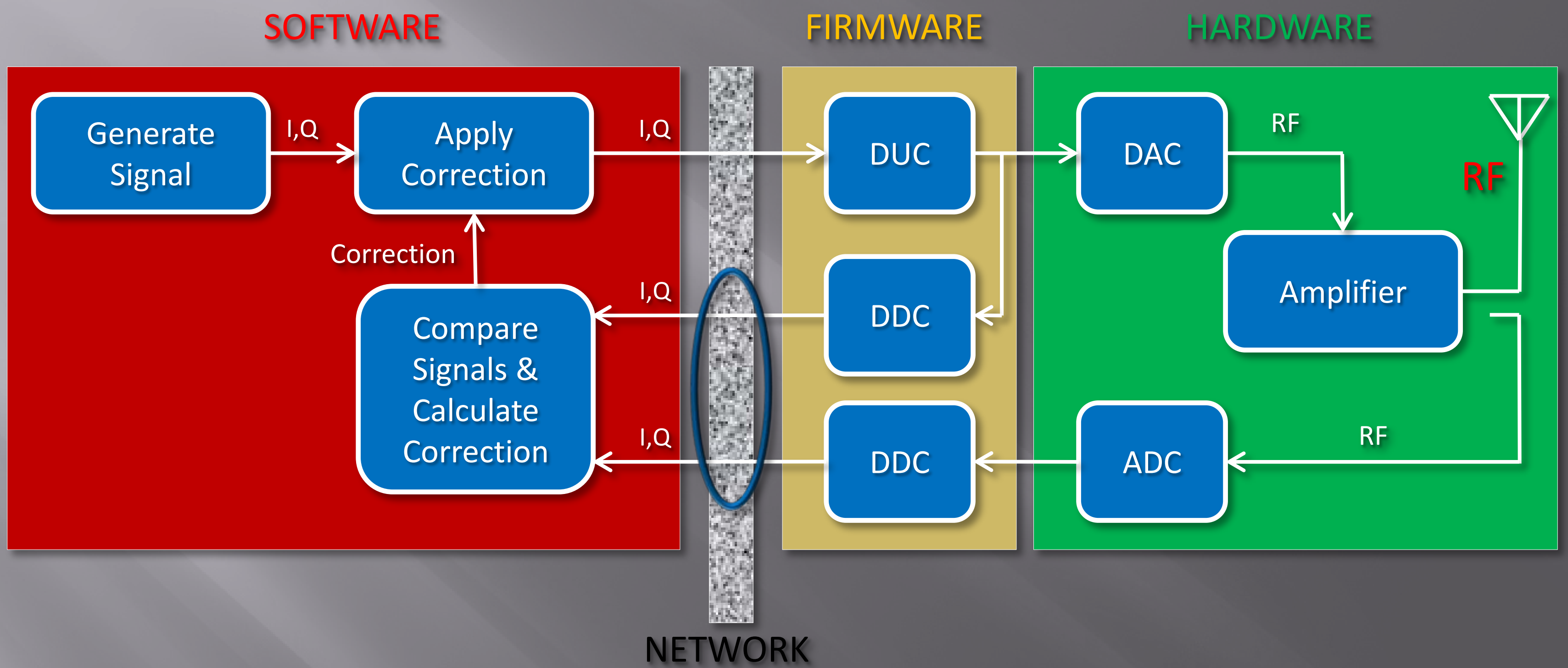
VERY flat frequency response!

ADAPTIVE BASEBAND PREDISTORTION



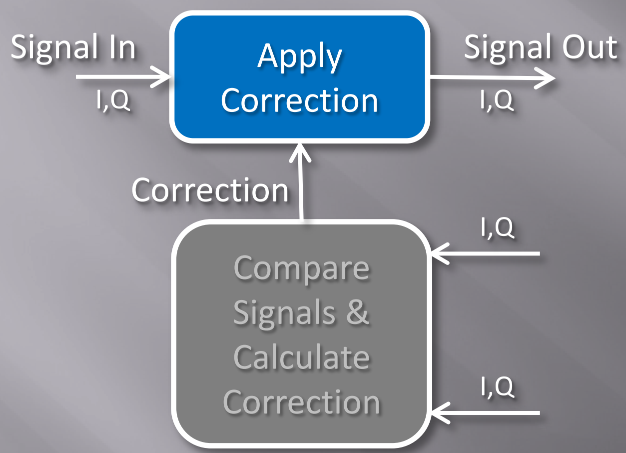
- Samples from the amplifier Input and Output must be matched in time
- Network delays create variability in timing of amplifier Output samples

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

ADAPTIVE BASEBAND PREDISTORTION
APPLYING CORRECTION



FOR EACH iq_sample

$mag = sqrt(i^2 + q^2)$

$g = gain\_correct (mag)$

$\varphi = phase\_correct (mag)$

$i\_out = g * (i * \cos(\varphi) - q * \sin(\varphi))$

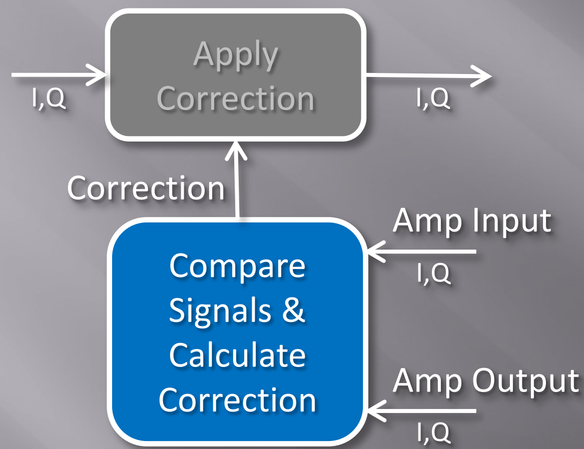
$q\_out = g * (i * \sin(\varphi) + q * \cos(\varphi))$

Multiply by the gain correction

Rotate the phase

ADAPTIVE BASEBAND PREDISTORTION

CALCULATING CORRECTION



FOR EACH pair_of_iq_samples

$$in\_mag = sqrt\ (i_{in}^2 + q_{in}^2)$$
$$out\_mag = sqrt\ (i_{out}^2 + q_{out}^2)$$
$$g = scale * (\ in\_mag\ /\ out\_mag\ )$$
$$\varphi = \arctan\ (\ (-\ i_{in} * q_{out} + q_{in} * i_{out}) \ / \ (\ i_{in} * i_{out} + q_{in} * q_{out}\ )\ )$$

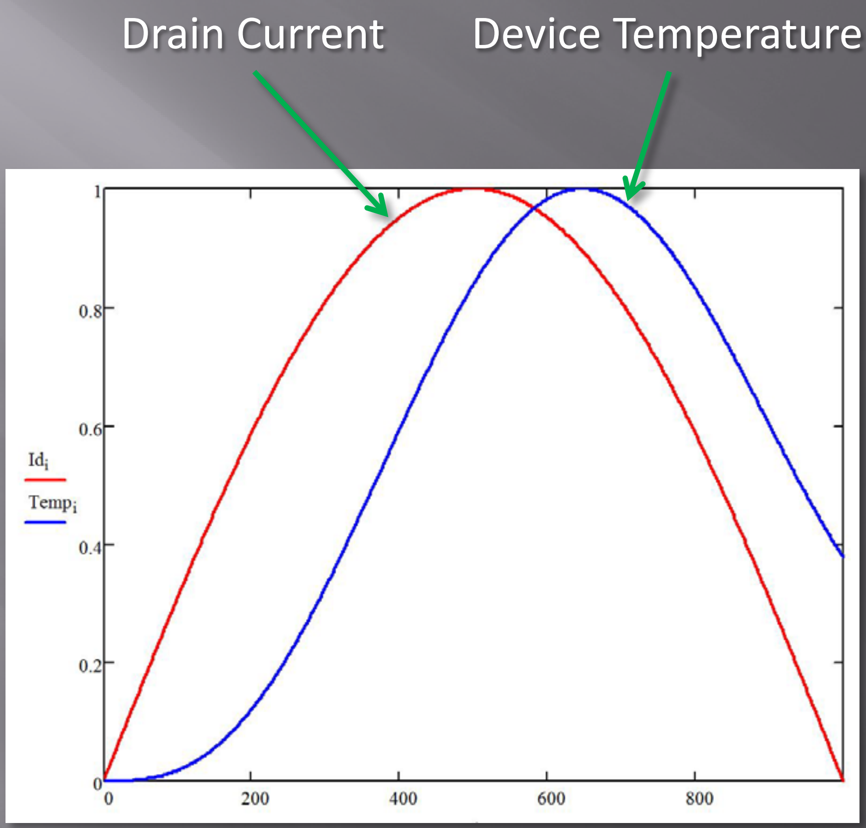
save_gain_correction

save_phase_correction

“scale” compensates for amplifier gain and feedback attenuation

MEMORY EFFECTS
THE PREDISTORTION ENEMY !

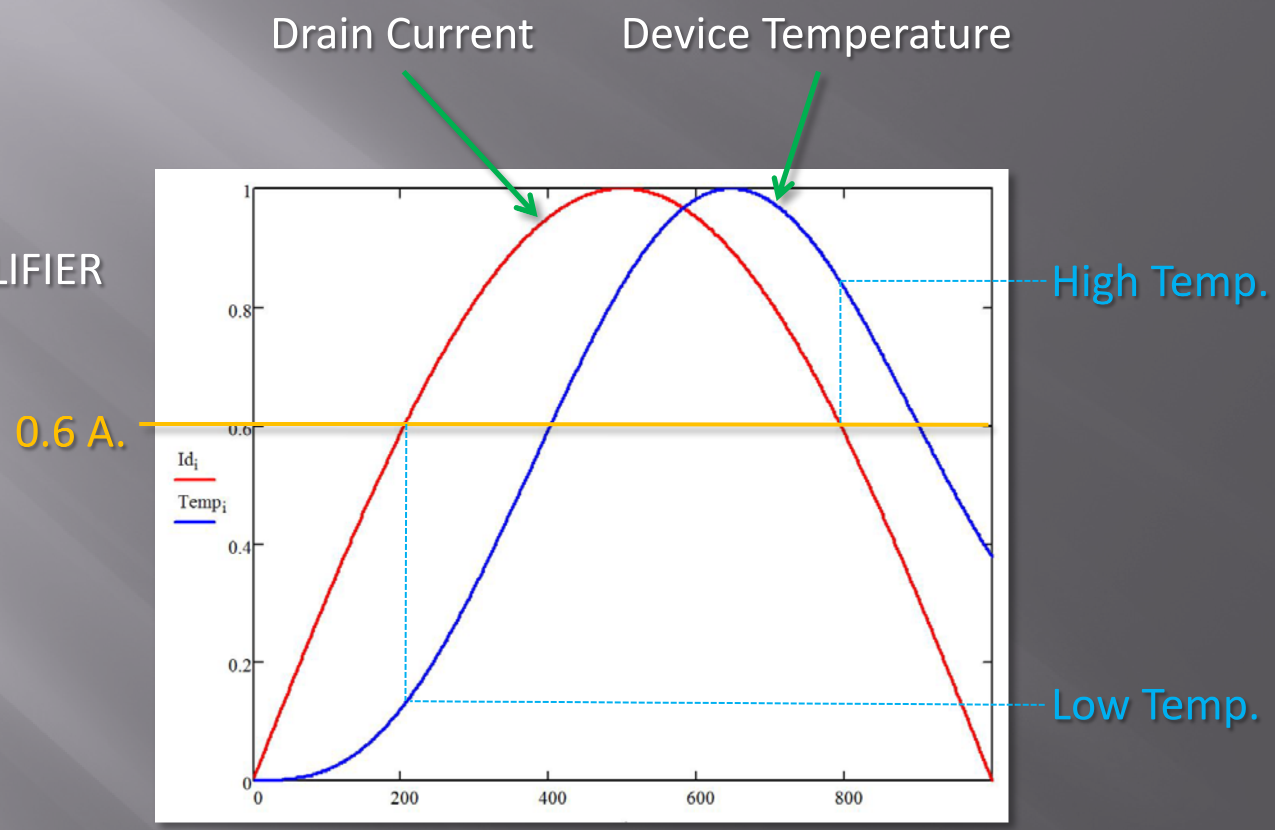
EXAMPLE:
CLASS B AMPLIFIER



MEMORY EFFECTS

THE PREDISTORTION ENEMY !

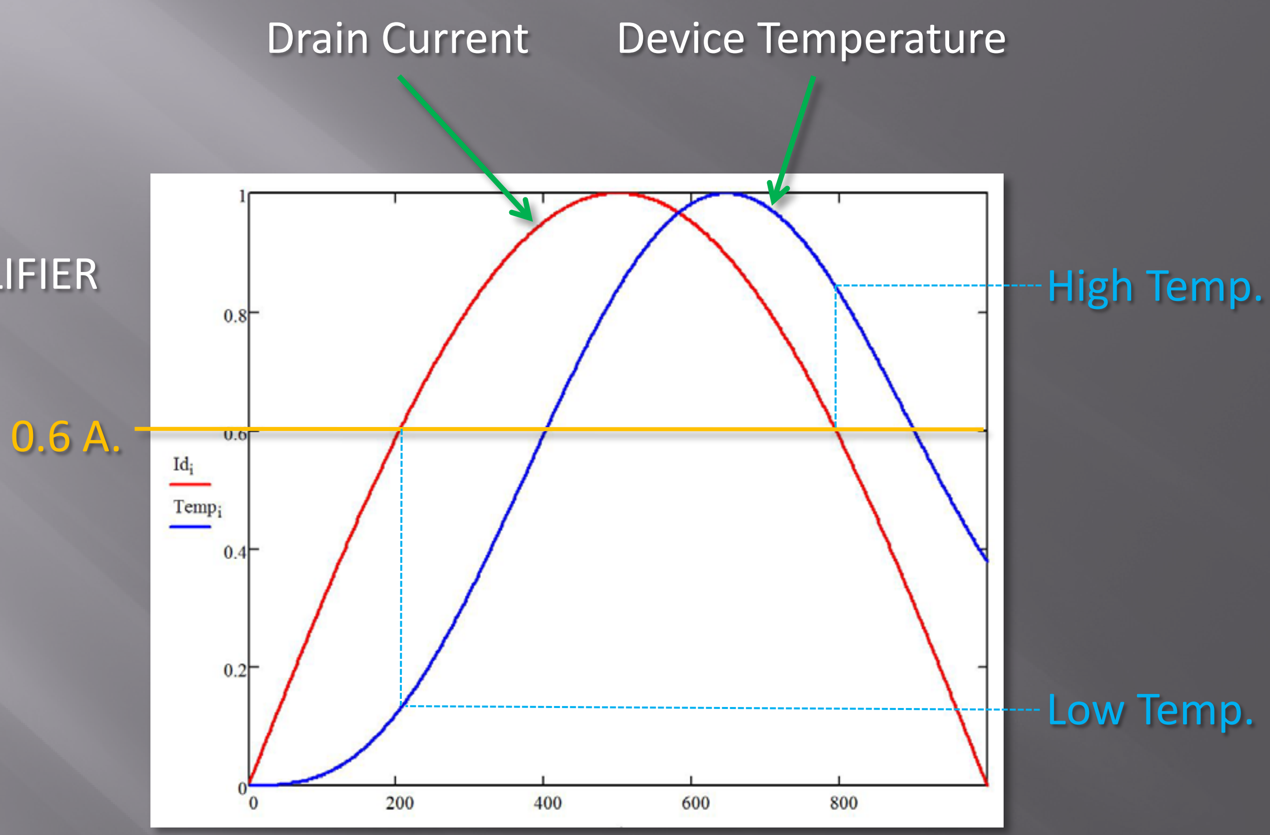
EXAMPLE:
CLASS B AMPLIFIER



MEMORY EFFECTS

THE PREDISTORTION ENEMY !

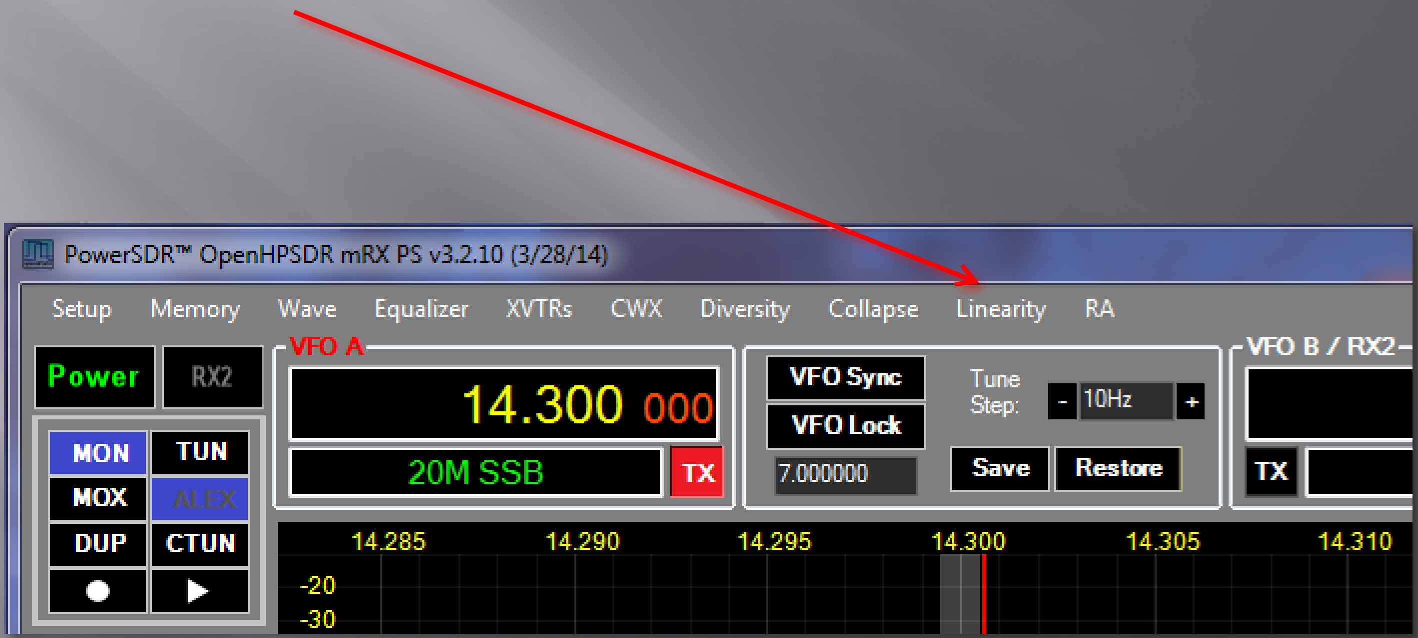
EXAMPLE:
CLASS B AMPLIFIER



Same Input Mag/Phase → Different Output Mag/Phase
Why? The amplifier "remembers" the past inputs!

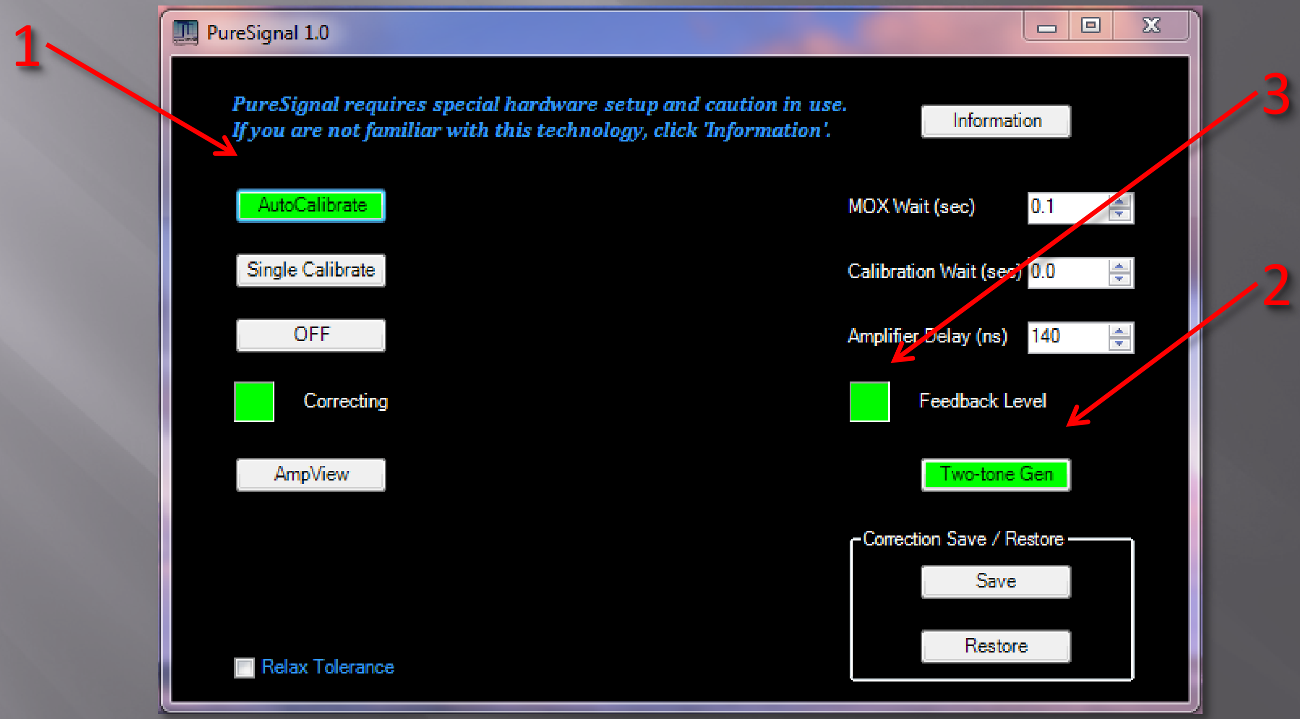
USING PURESIGNAL

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

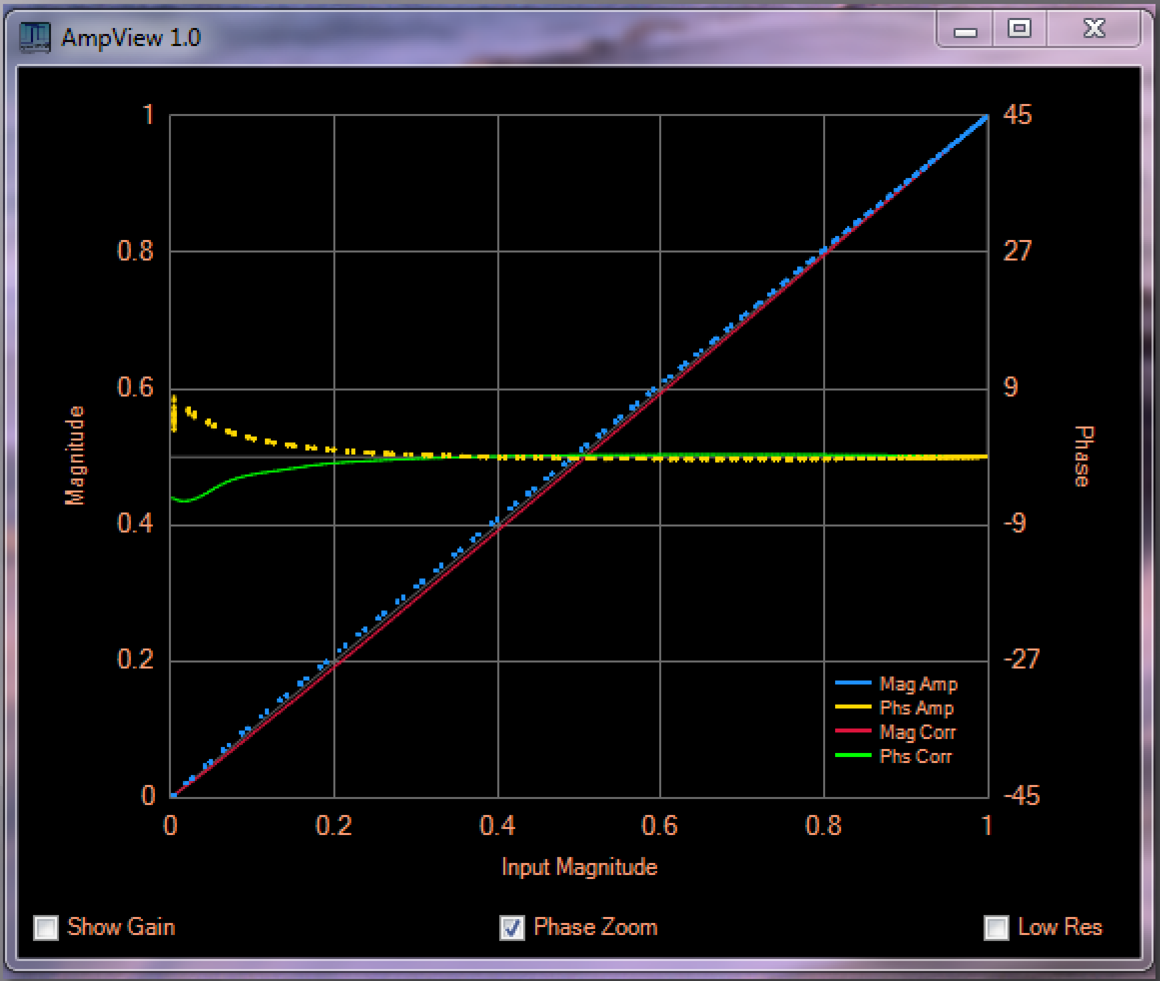


USING PURESIGNAL

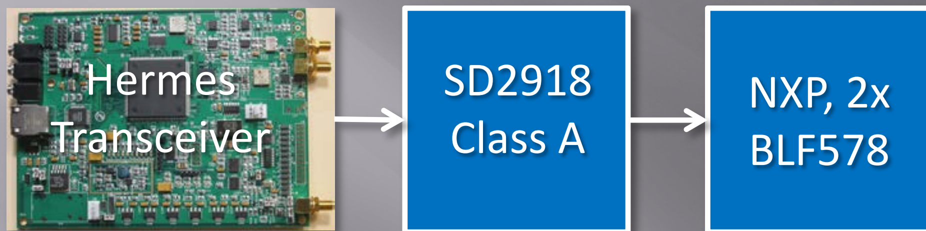
1. Click AutoCalibrate to activate PureSignal
2. Transmit audio or turn on the two-tone generator.
3. Adjust your attenuators for a GREEN Feedback Level indication.
4. If desired, adjust other controls per the “Information” document.
5. (Optional) Relax and click AmpView just to see what’s happening.



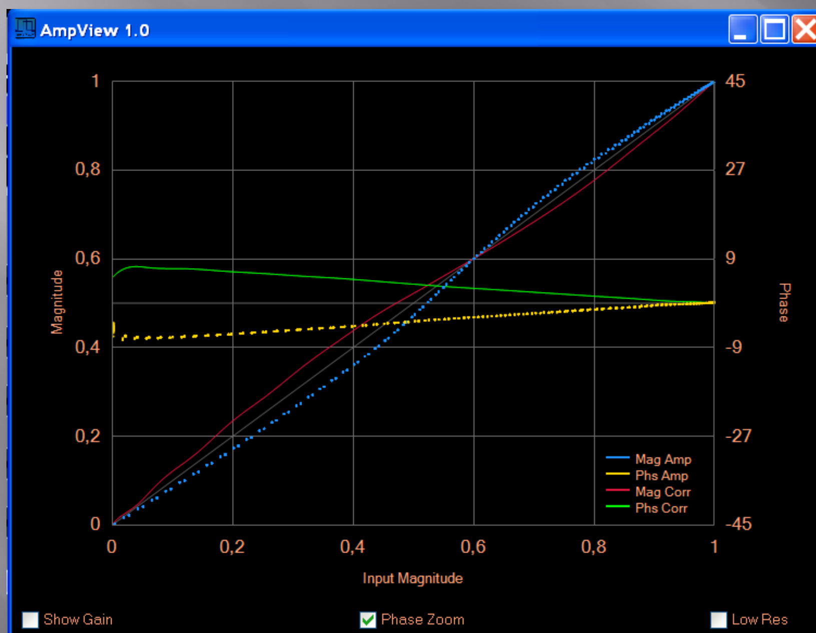
USING AMPVIEW



PURESIGNAL RESULTS
Kurt, DL9SM



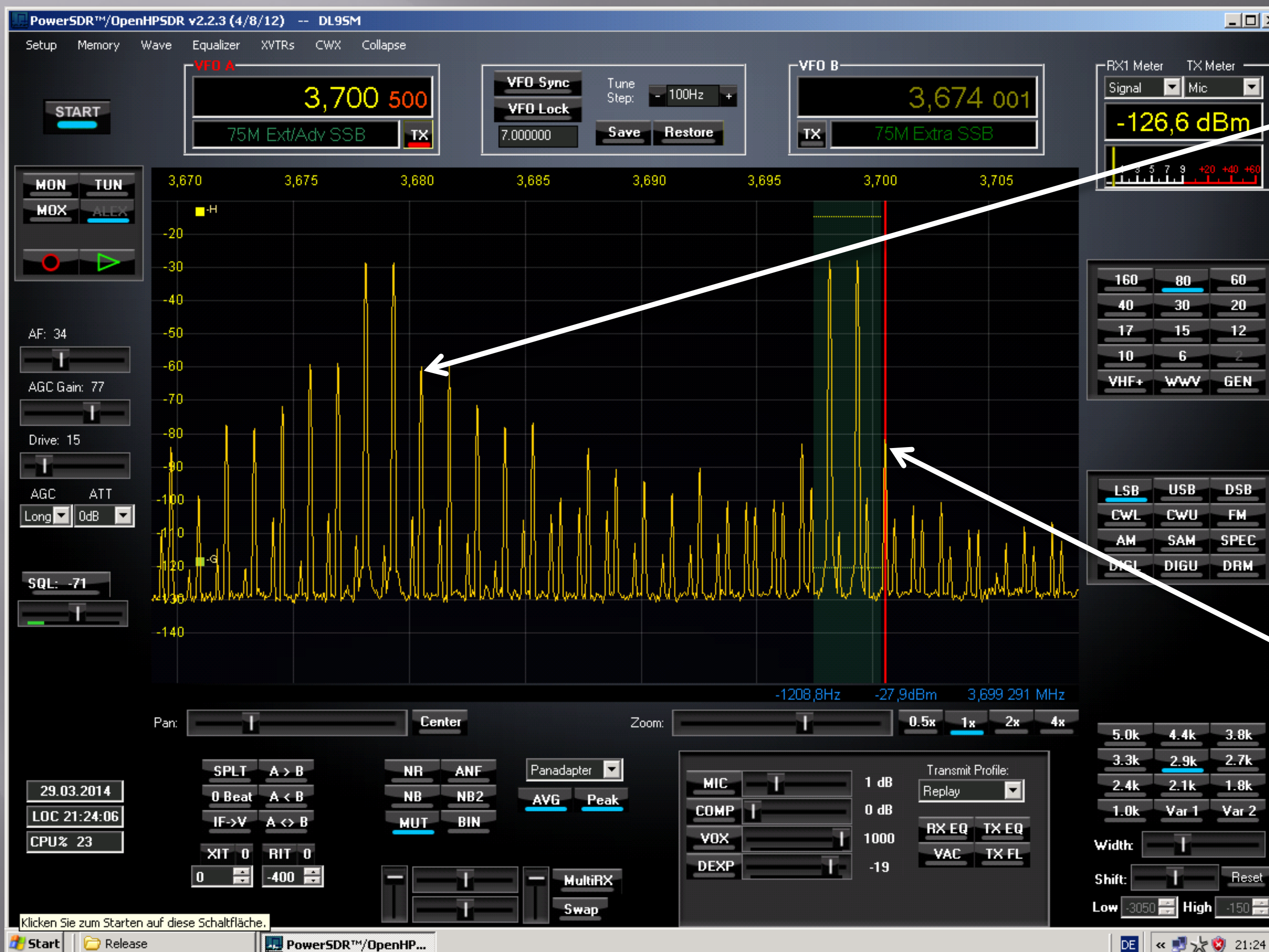
- 50V LDMOS Final
- Low Idq = 0.7A/device
- >1200W Capability



- 80M, 1 KW
- Low memory effects visible

PURESIGNAL RESULTS

Kurt, DL9SM



- PureSignal OFF
- IMD3 ~ -31dBt

- PureSignal ON
- IMD3 ~ -53dBt

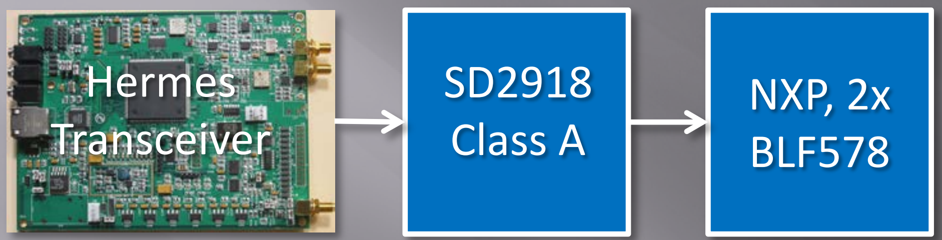
PURESIGNAL RESULTS

Kurt, DL9SM

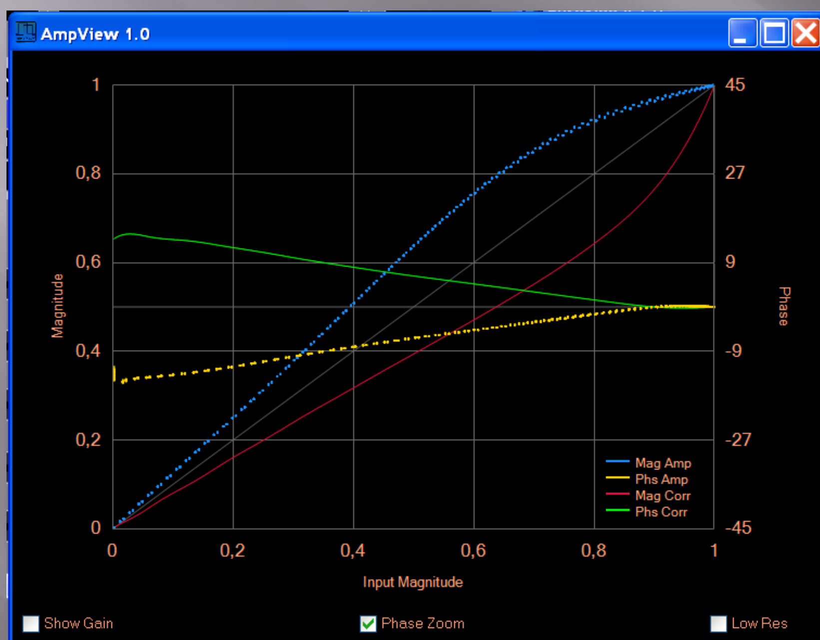
- PureSignal OFF
- IMD ~ -30dB

- PureSignal ON
- IMD ~ -52dB

PURESIGNAL RESULTS
Kurt, DL9SM



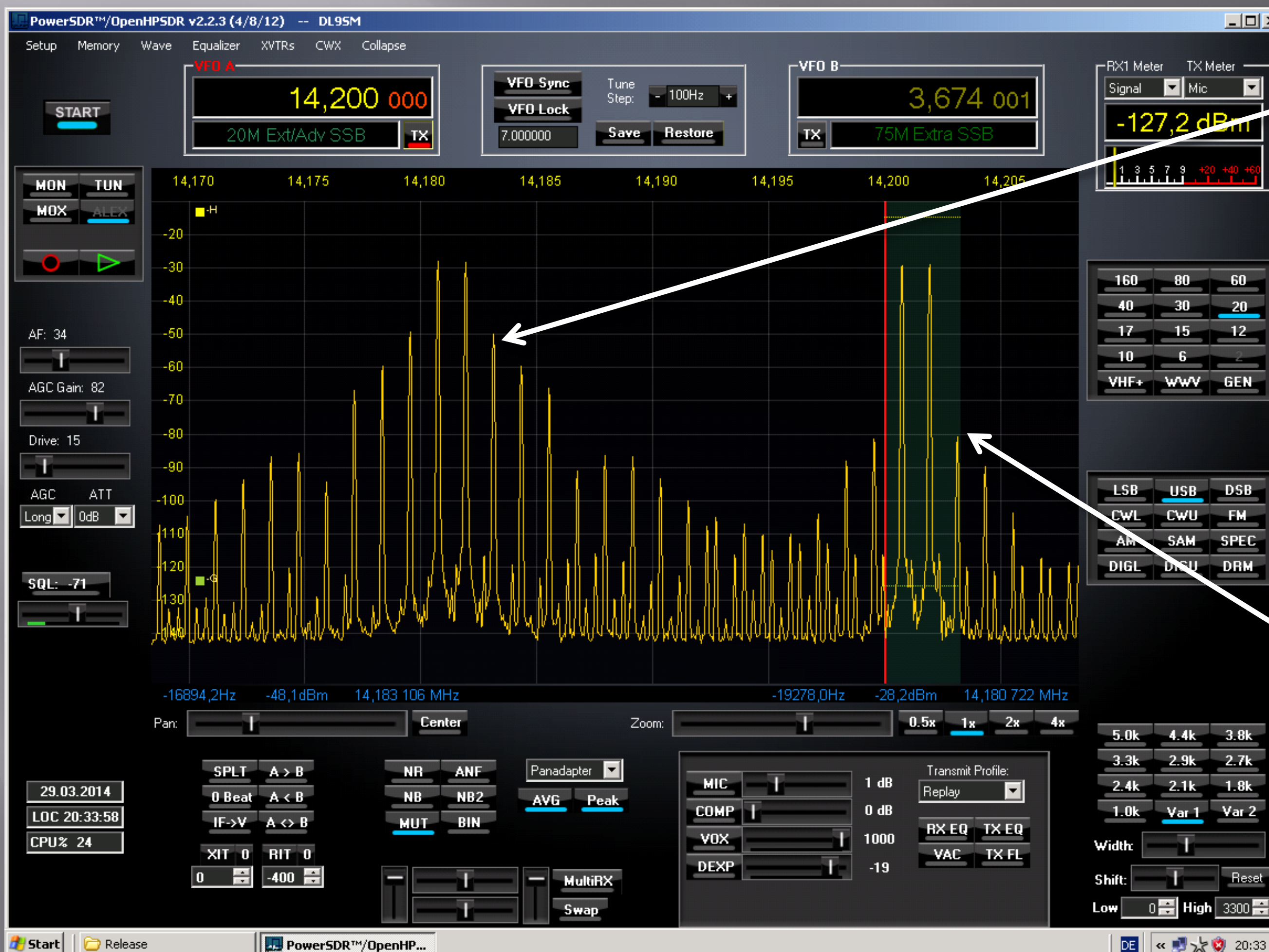
- 50V LDMOS Final
- Low Idq = 0.7A/device
- >1200W Capability



- 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

PURESIGNAL RESULTS
Kurt, DL9SM

- PureSignal OFF
- IMD ~ -31dB

- PureSignal ON
- IMD ~ -51dB

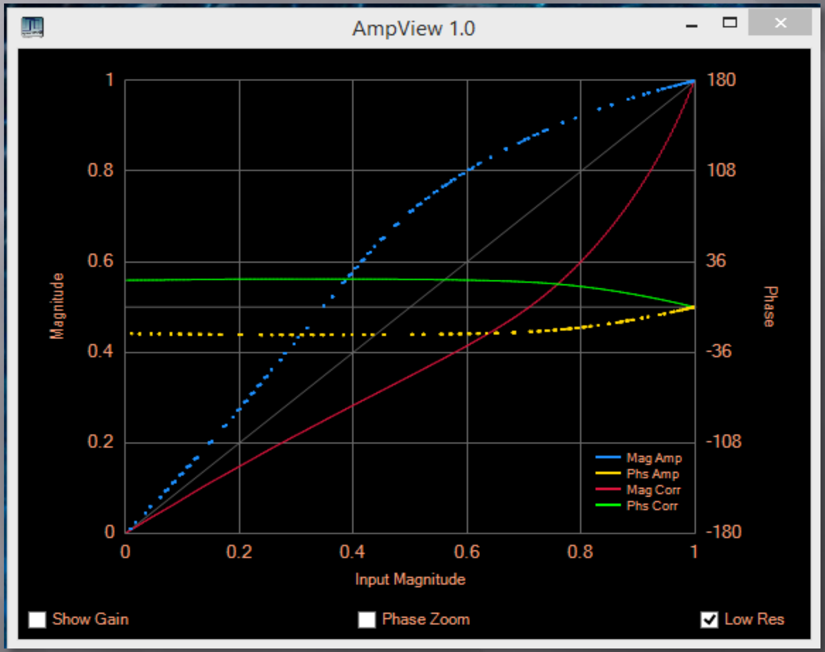
PURESIGNAL RESULTS
Clyde, K2UE

ANAN-100D

2M Xvtr

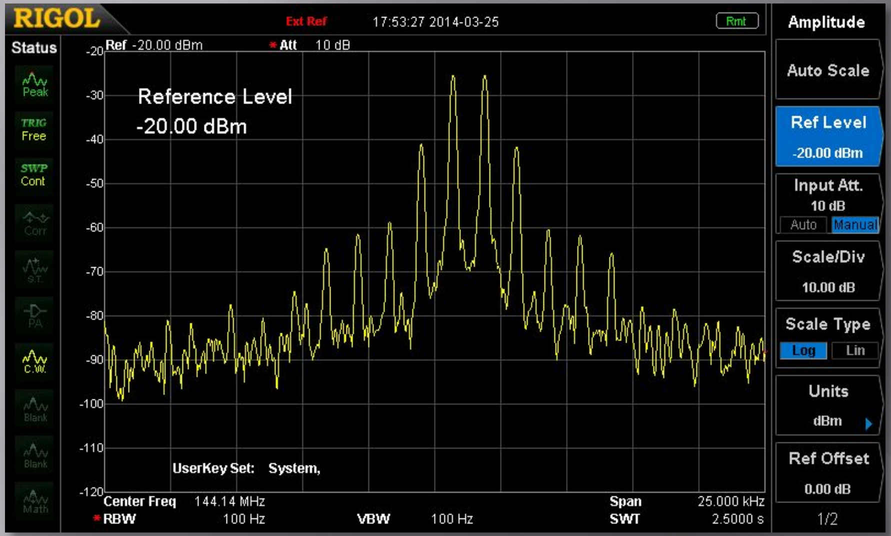
M² 2M-1K2

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

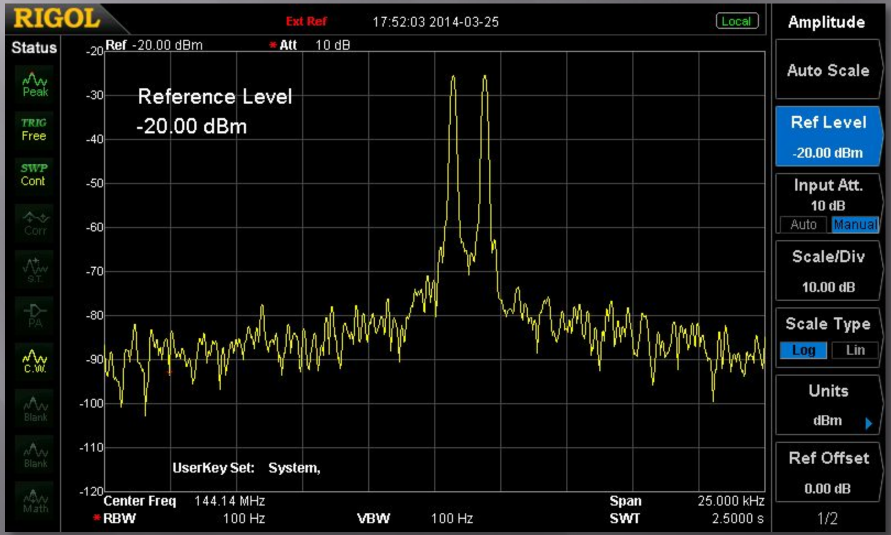


- 2M Amplifier is VERY non-linear
- LDMOS, Very low memory effects
- Should be very correctable!

PURESIGNAL RESULTS
Clyde, K2UE

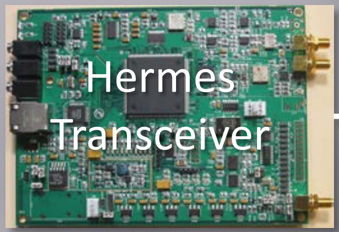


- PureSignal OFF
- IMD3 ~ -16dBt

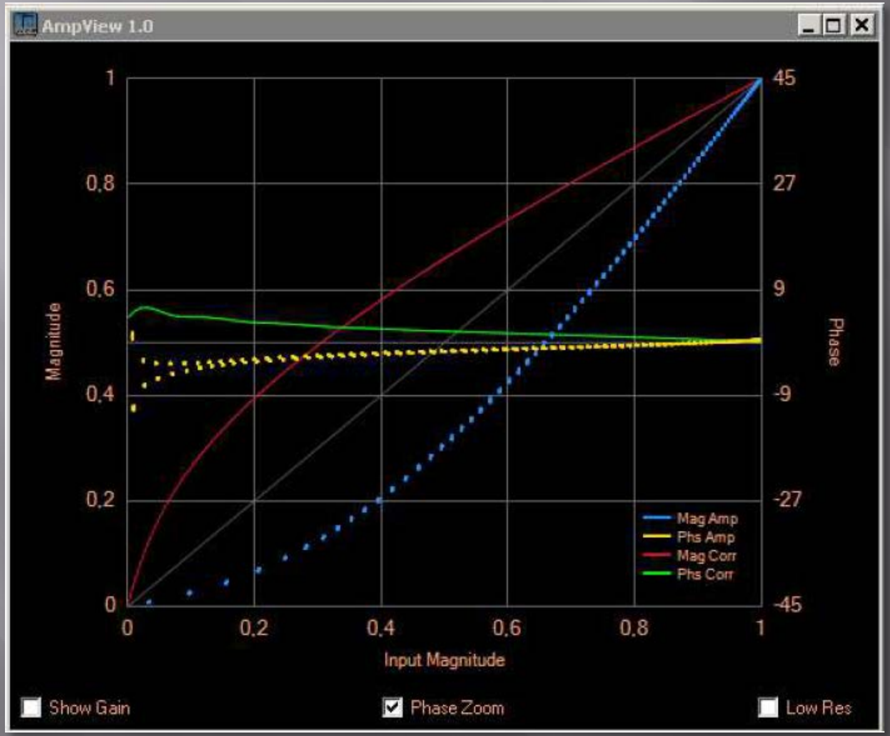


- PureSignal ON
- IMD3 ~ -48dBt

PURESIGNAL RESULTS
Helmut, DC6NY



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



- 40 Meters
- Class B Operation
- Idq = 20 mA
- Drain efficiency = 80%

PURESIGNAL RESULTS
Helmut, DC6NY

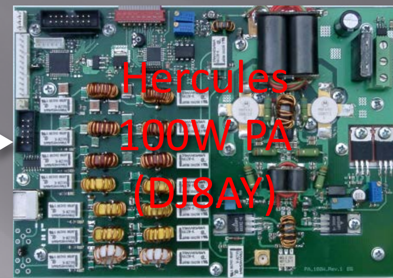
- 40 Meters, Class B
- PureSignal OFF
- IMD3 = -16 dBc
- IMD5 = -28 dBc

- 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

2x 3-500Z
(Grounded-grid)

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

PURESIGNAL

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?

Dr. Vito Volterra

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

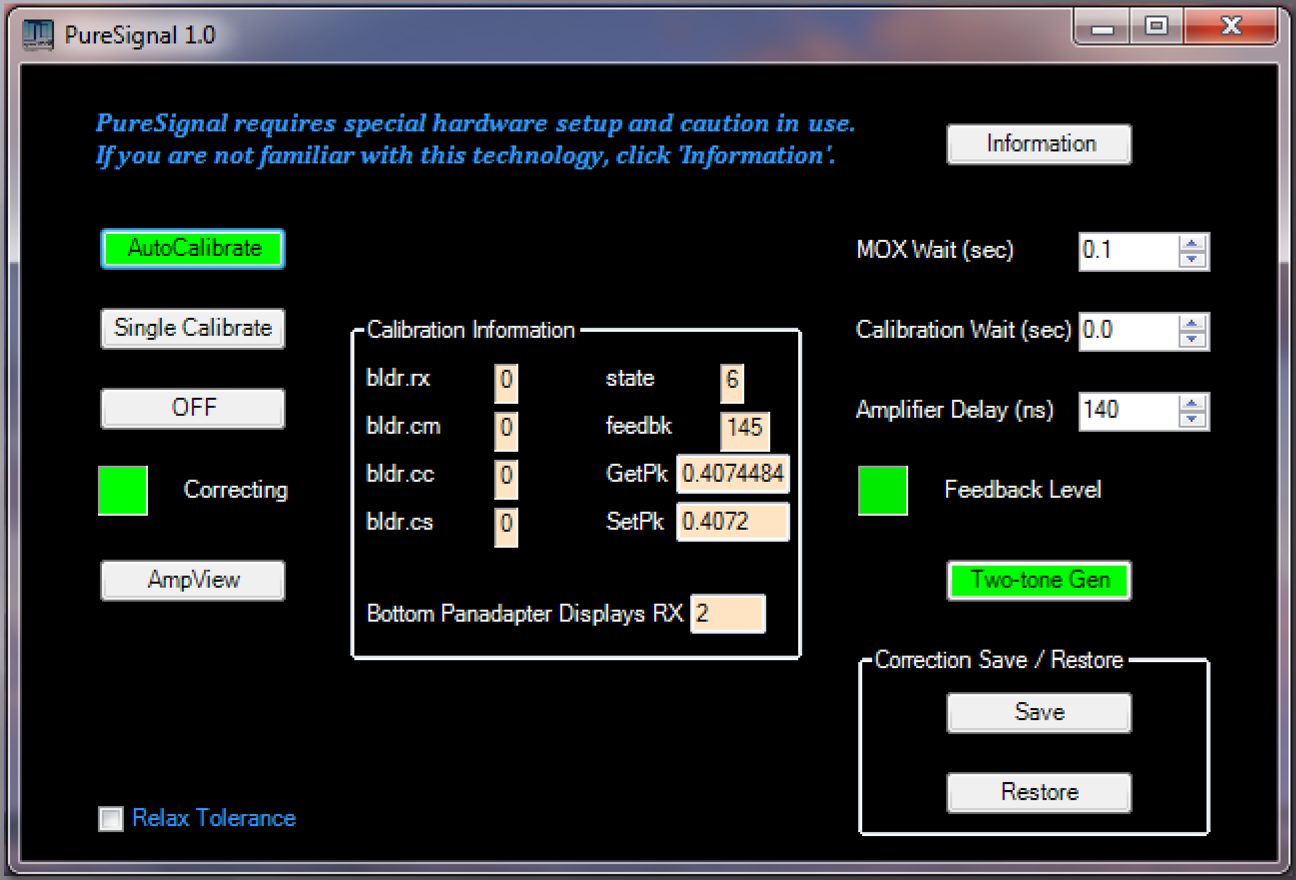
WHO WORKS ON MEMORY EFFECTS?

What do they look like?

Dr. Vito Volterra

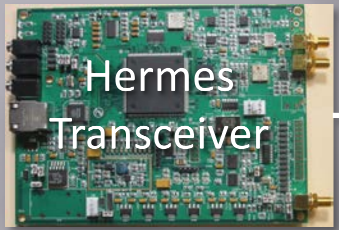
Dr. Warren Pratt

PURESIGNAL – THE SECRET INFO PANEL



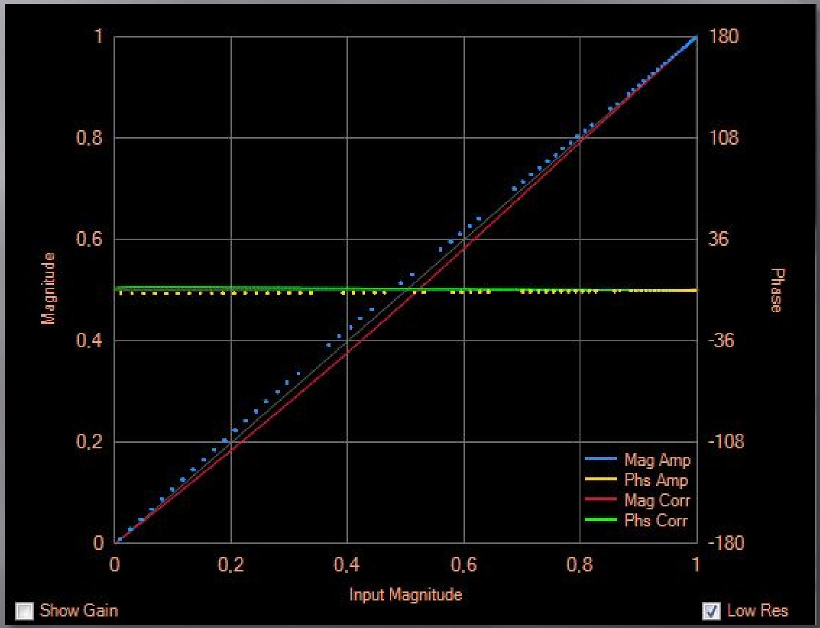
Ctrl-Alt-i

PURESIGNAL RESULTS
Bert, PA2XHF



Freescale
MRFE6VP6300HR5

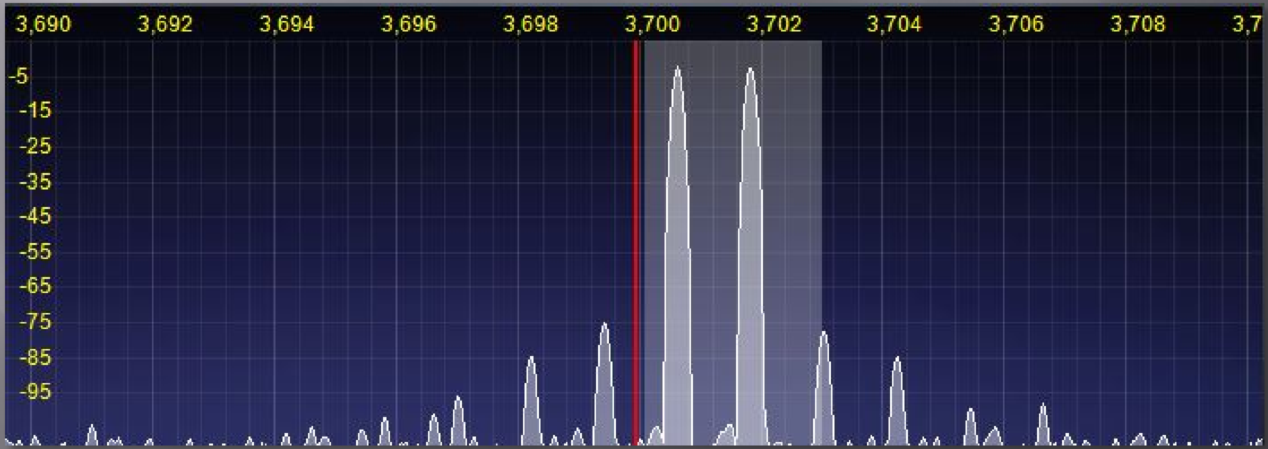
- Push-Pull LDMOS
- 1.8 – 50 Mhz.
- 200W Driven from Hermes



- 80M Operation
- Very Linear @ 200W
- No memory effects visible

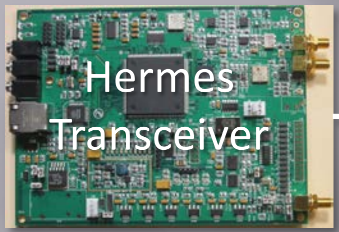
PURESIGNAL RESULTS
Bert, PA2XHF

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



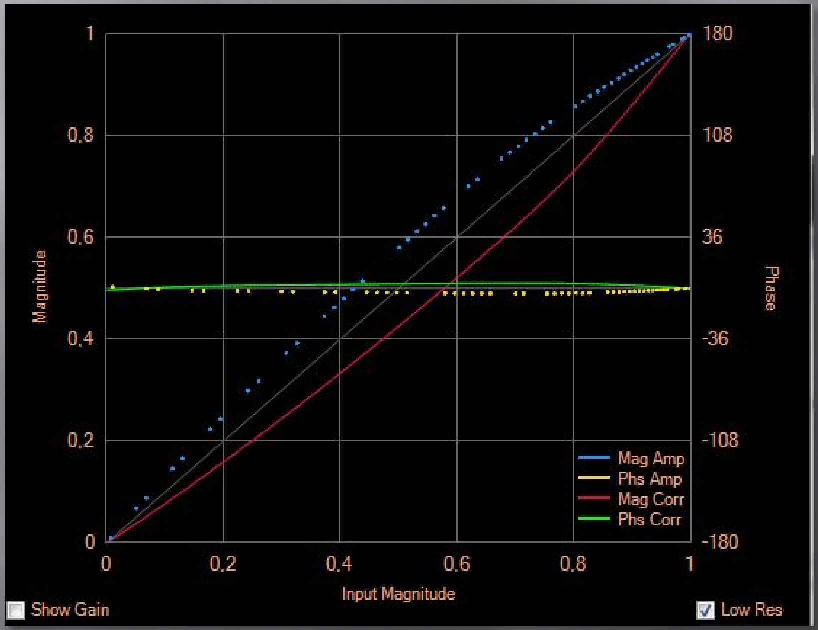
- PureSignal ON
- IMD3 ~ -72dBt
- IMD5 ~ -82dBt

PURESIGNAL RESULTS
Bert, PA2XHF



→ Freescale MRFE6V6300HR5

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

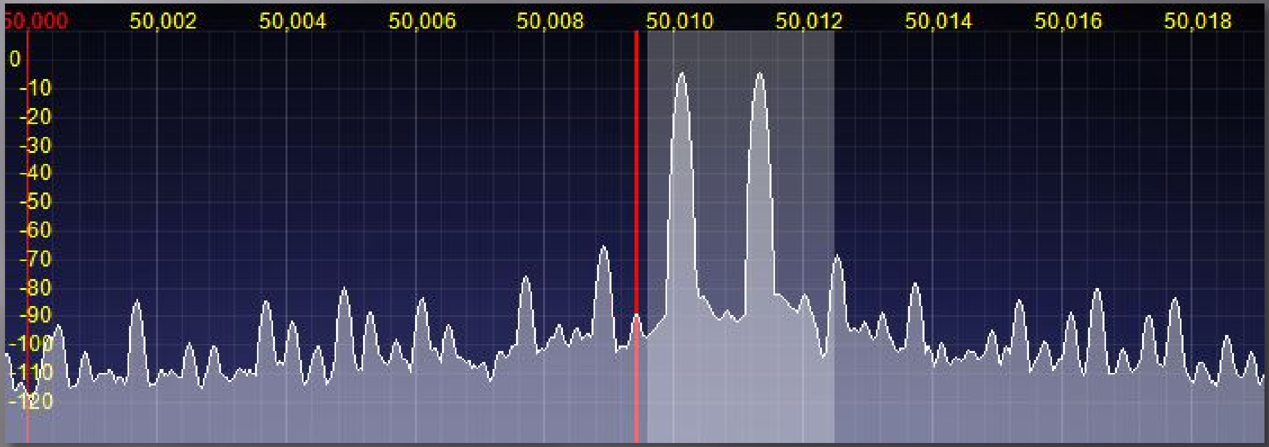


- 6M Operation
- Typical Linearity @ 200W
- No memory effects visible

PURESIGNAL RESULTS

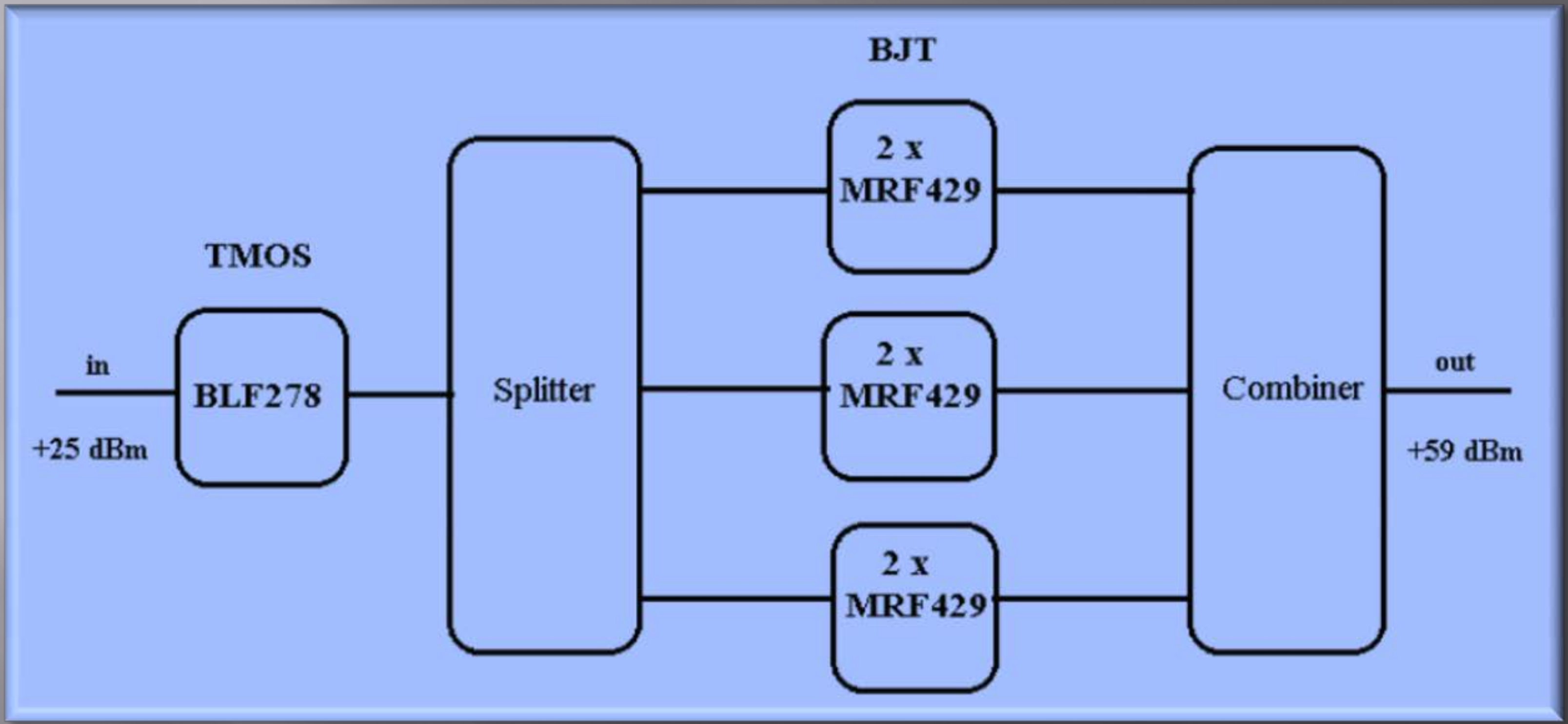
Bert, PA2XHF

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



- PureSignal ON
- IMD3 ~ -60dBt
- IMD5 ~ -70dBt

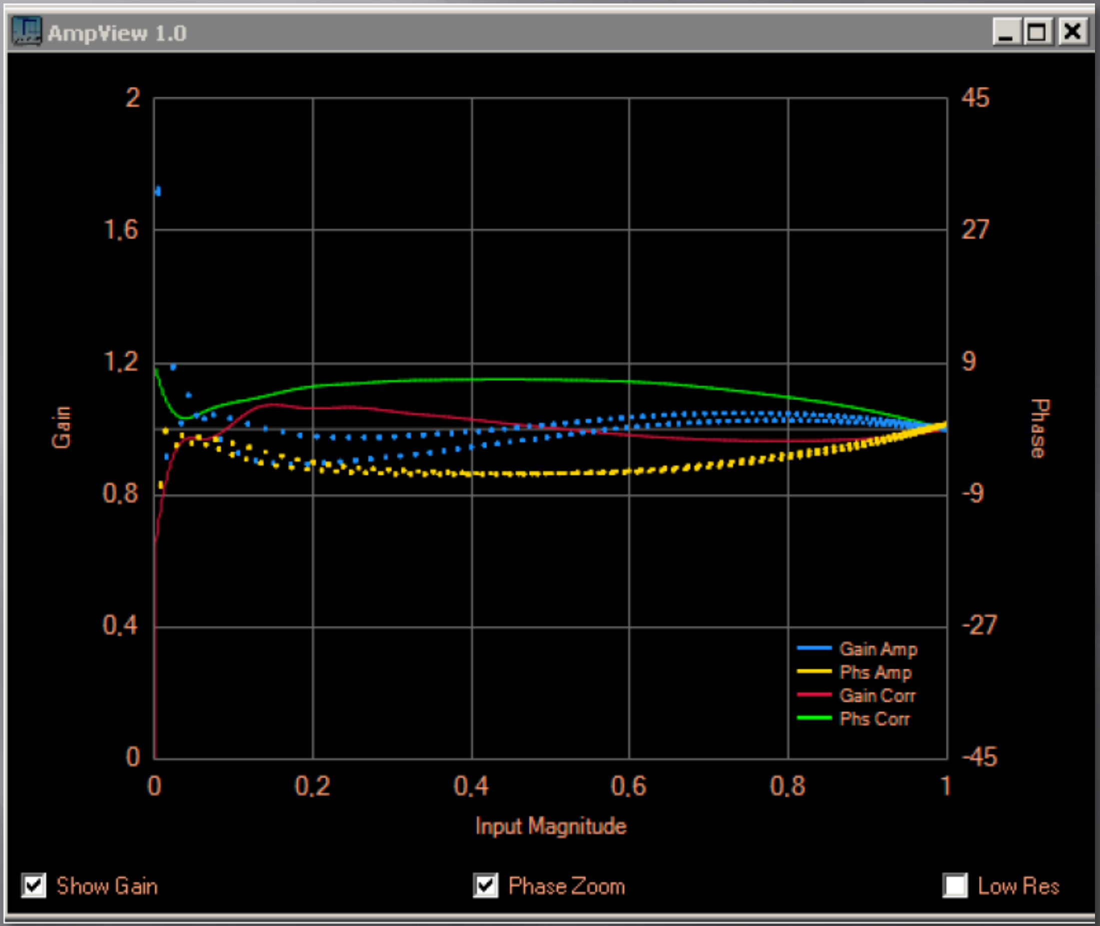
PURESIGNAL RESULTS
Helmut, DC6NY



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

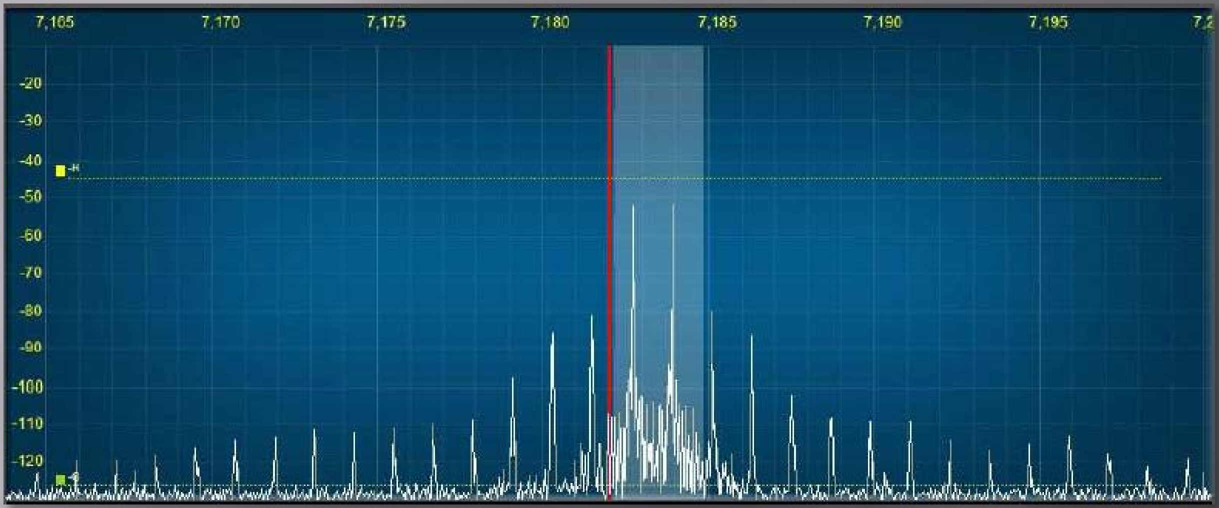
- Saturation Power: 1035 Watts
- 1 dB Compression: ~ 800 Watts

PURESIGNAL RESULTS
Helmut, DC6NY



- 40 Meters; 800 Watts PEP
- Significant Memory Effect
- Best-fit Correction

PURESIGNAL RESULTS
Helmut, DC6NY

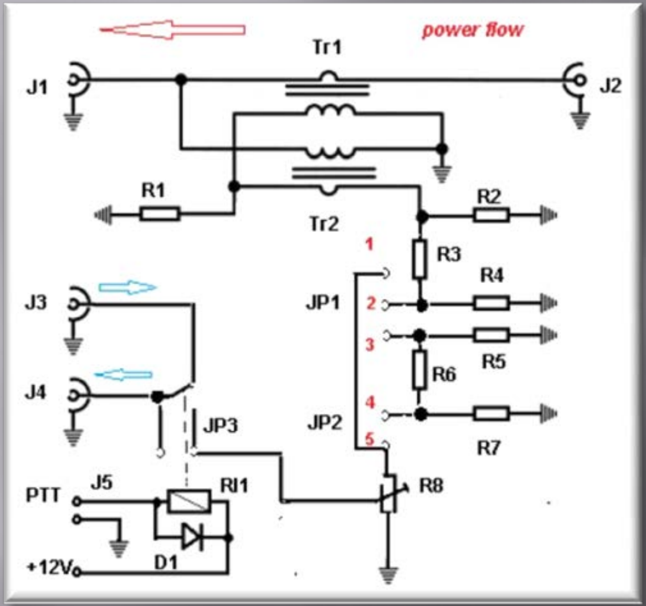


- PureSignal OFF
- IMD3 -28 dBc
- IMD5 -33 dBc

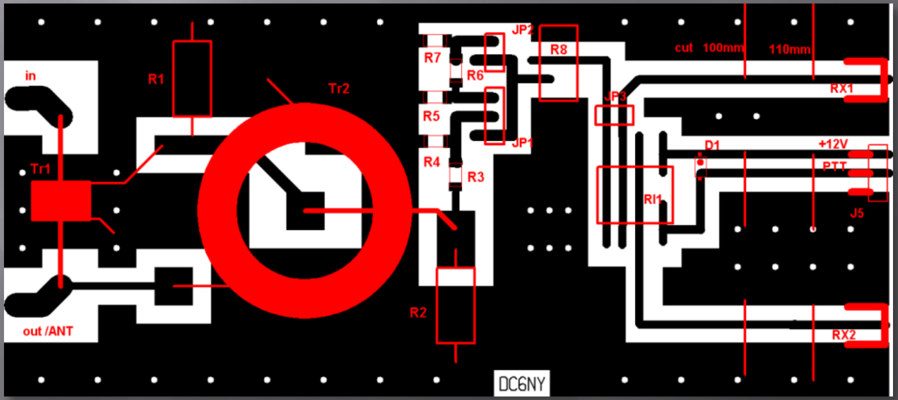
- PureSignal ON
- IMD3 -48 dBc
- IMD5 -53 dBc

DC6NY RF SAMPLER

Schematic

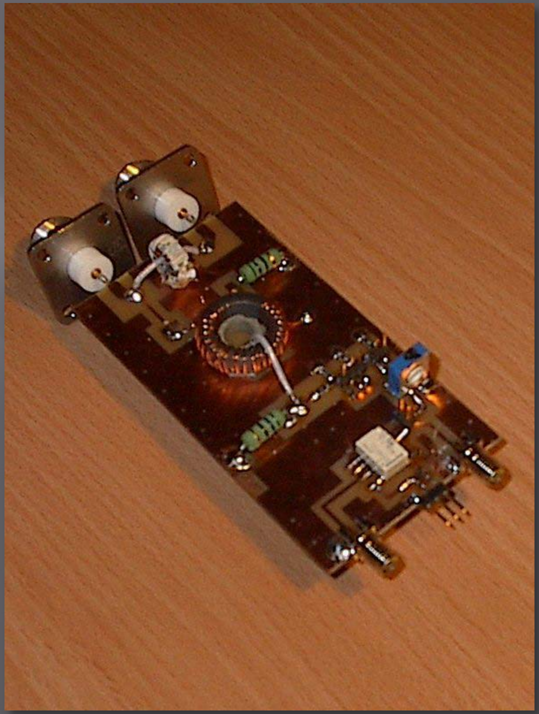


Printed Circuit Board



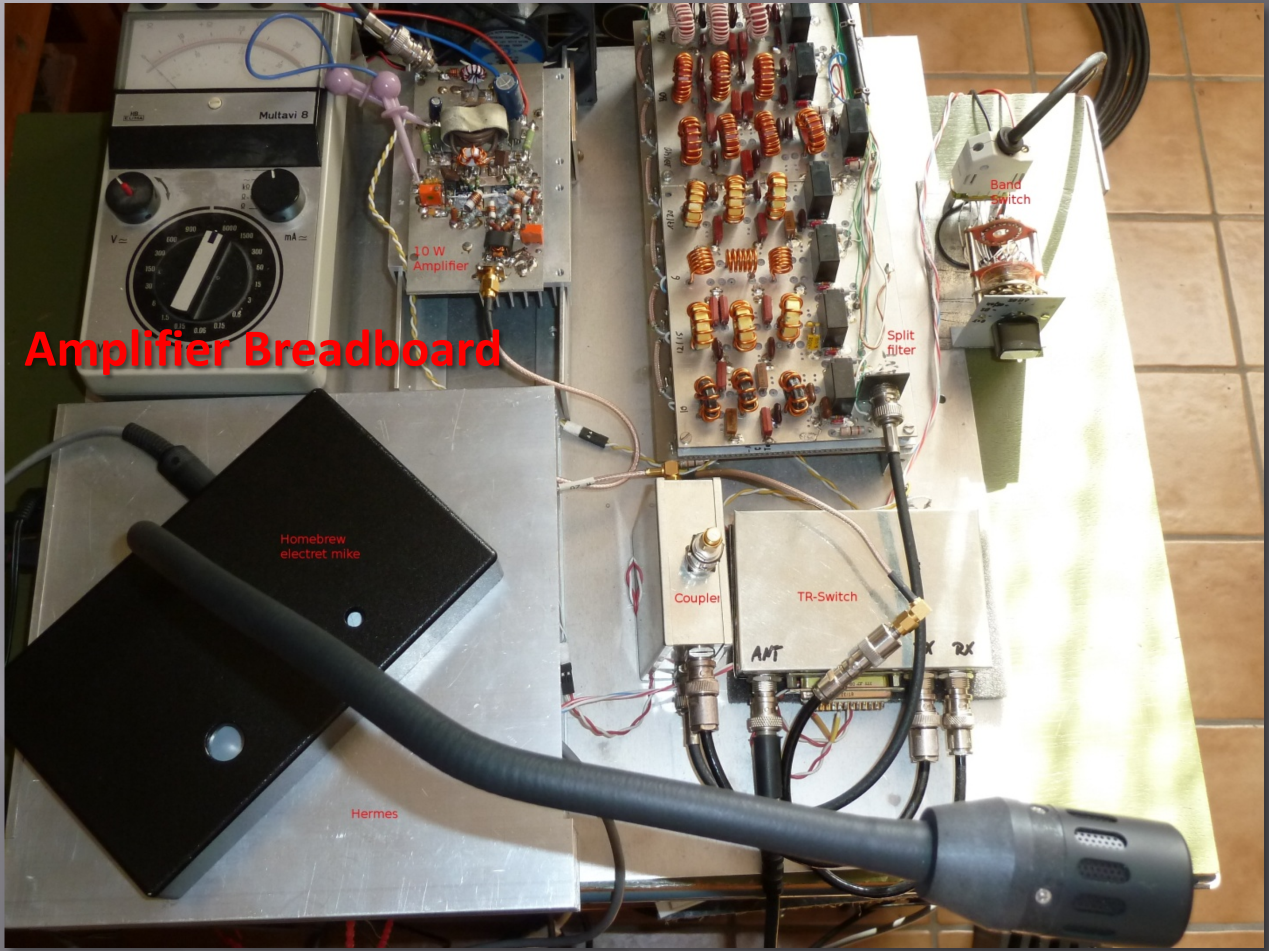
- Designed by Helmut, DC6NY
- Posted on hamsdr.com
- Designed-in flexibility
- PCB group-buy was done by Steve, G1YLB

Prototype



PURESIGNAL RESULTS
Peter, DK7SP

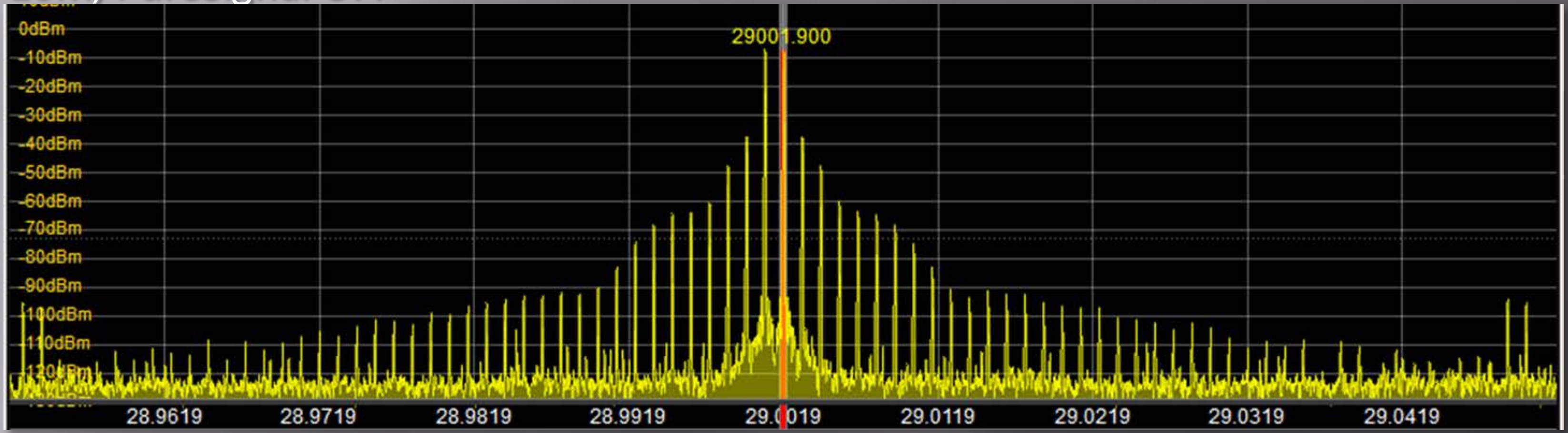
Careful design can produce excellent results with 13.8V MOSFETS!



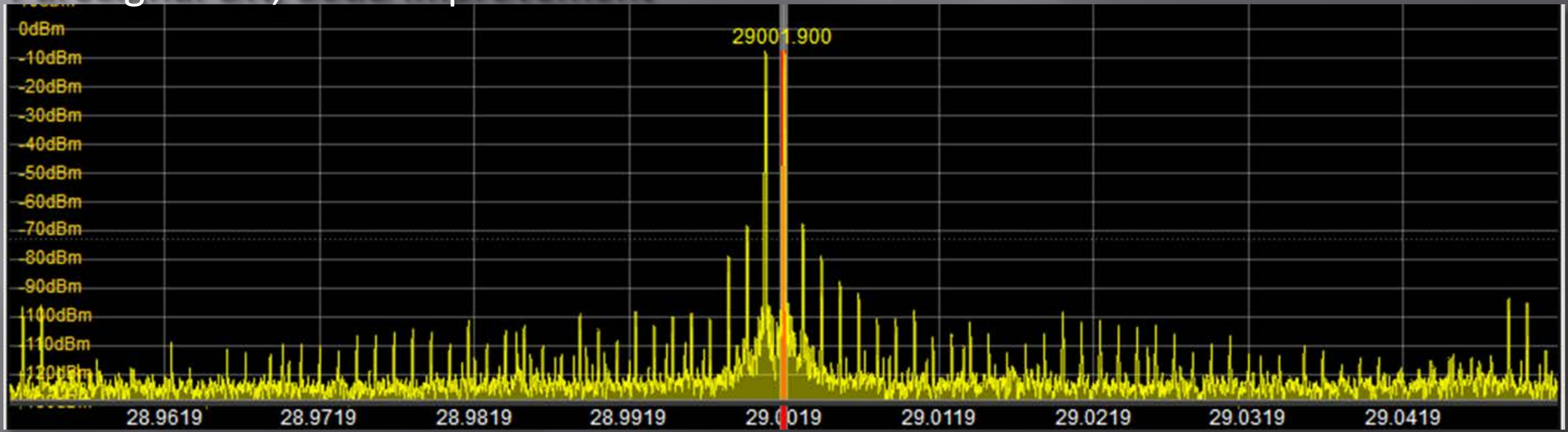
- 10W, Single-stage P-P
- 2x RD16HHF1
- Low Idq, 175mA/dev
- Optimized Z-matching
- Voltage Feedback

PURESIGNAL RESULTS
Peter, DK7SP

10M, PureSignal OFF



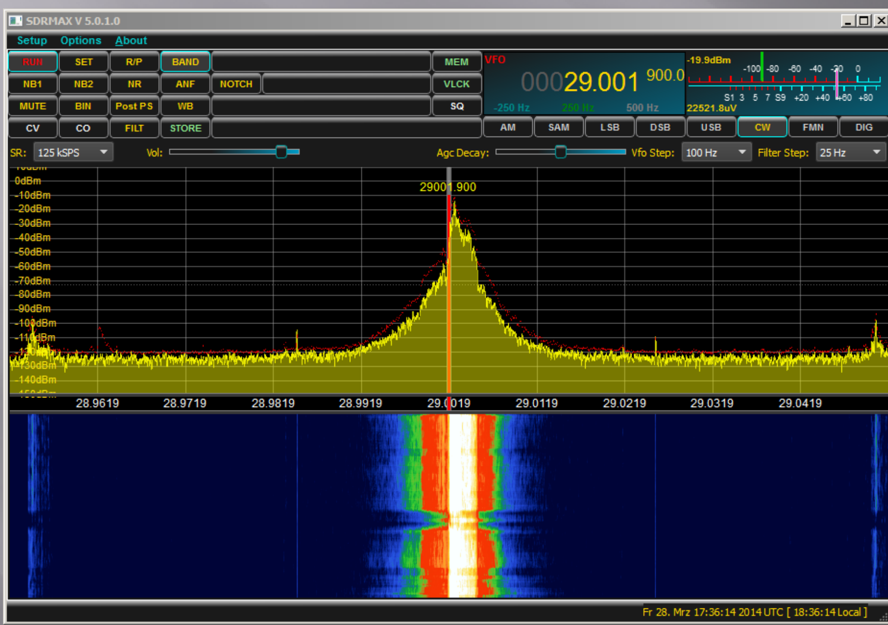
PureSignal ON, 30dB Improvement



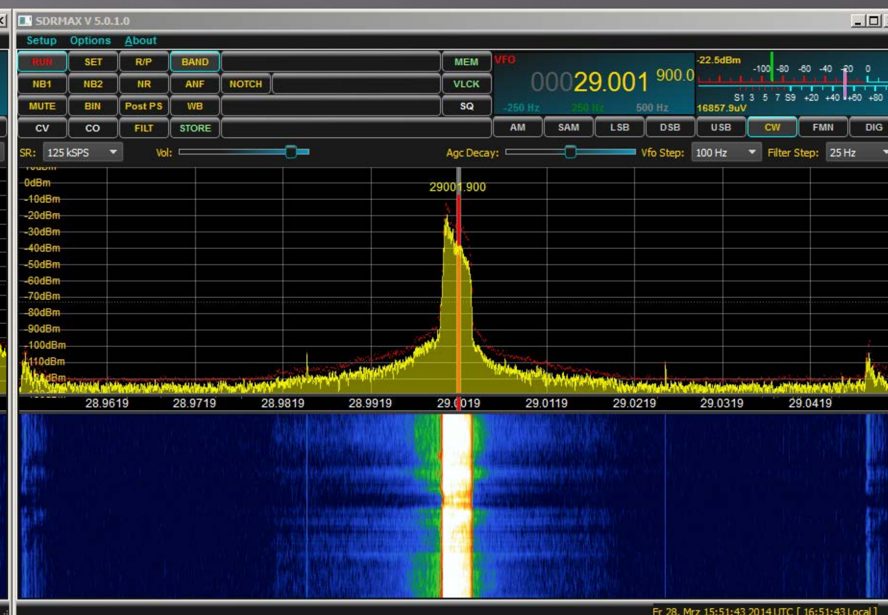
PURESIGNAL RESULTS

Peter, DK7SP

PureSignal OFF

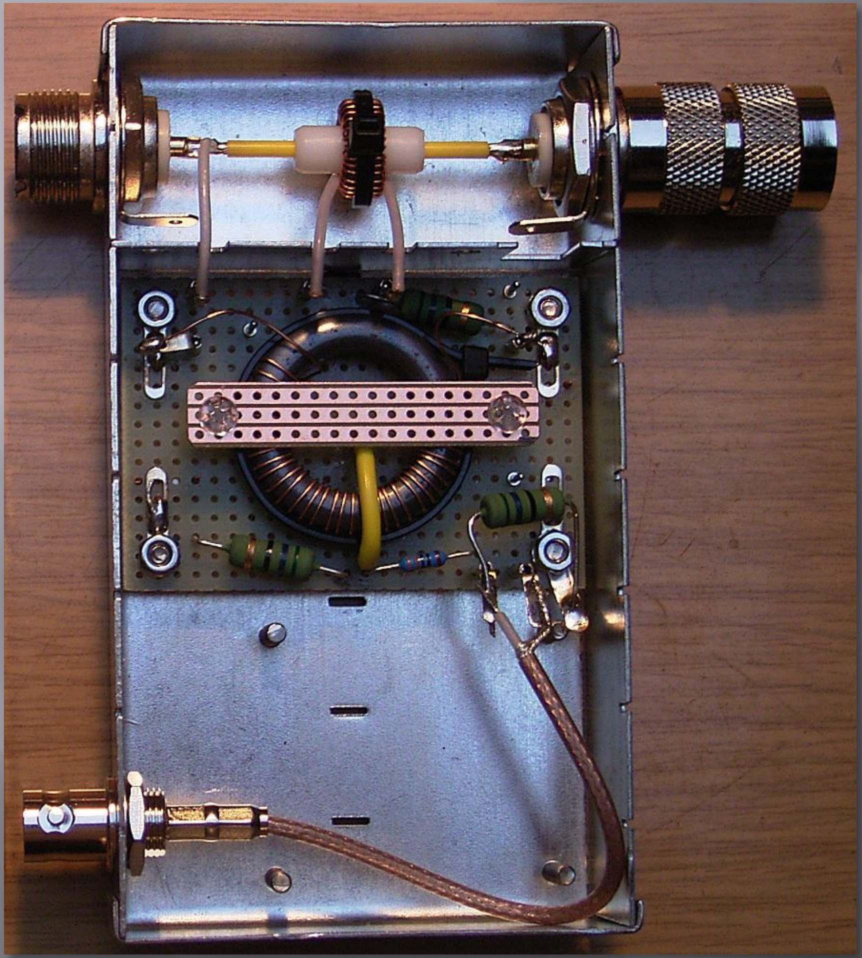


PureSignal ON, 30+dB Improvement

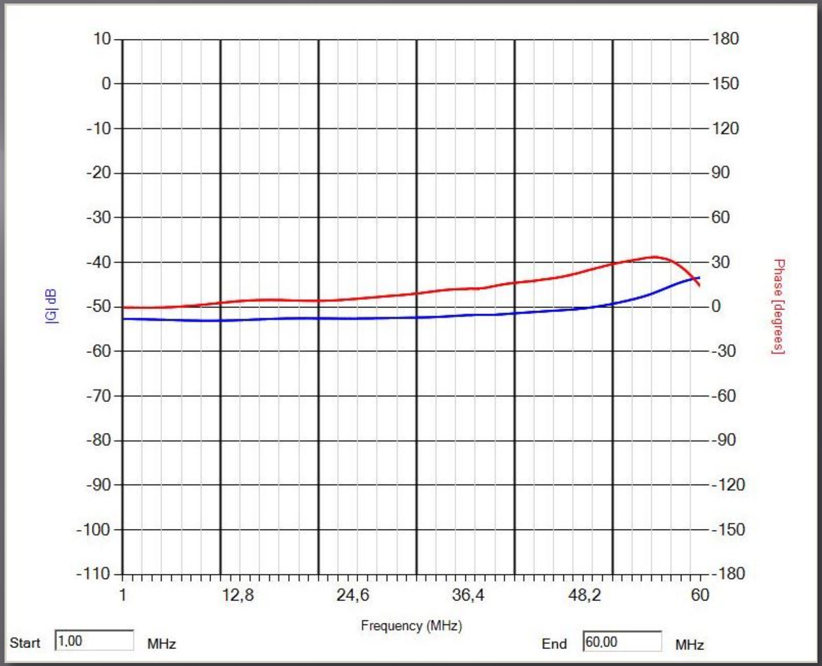


PURESIGNAL RESULTS
Focko, DJ5JB

Sampler



Frequency Response

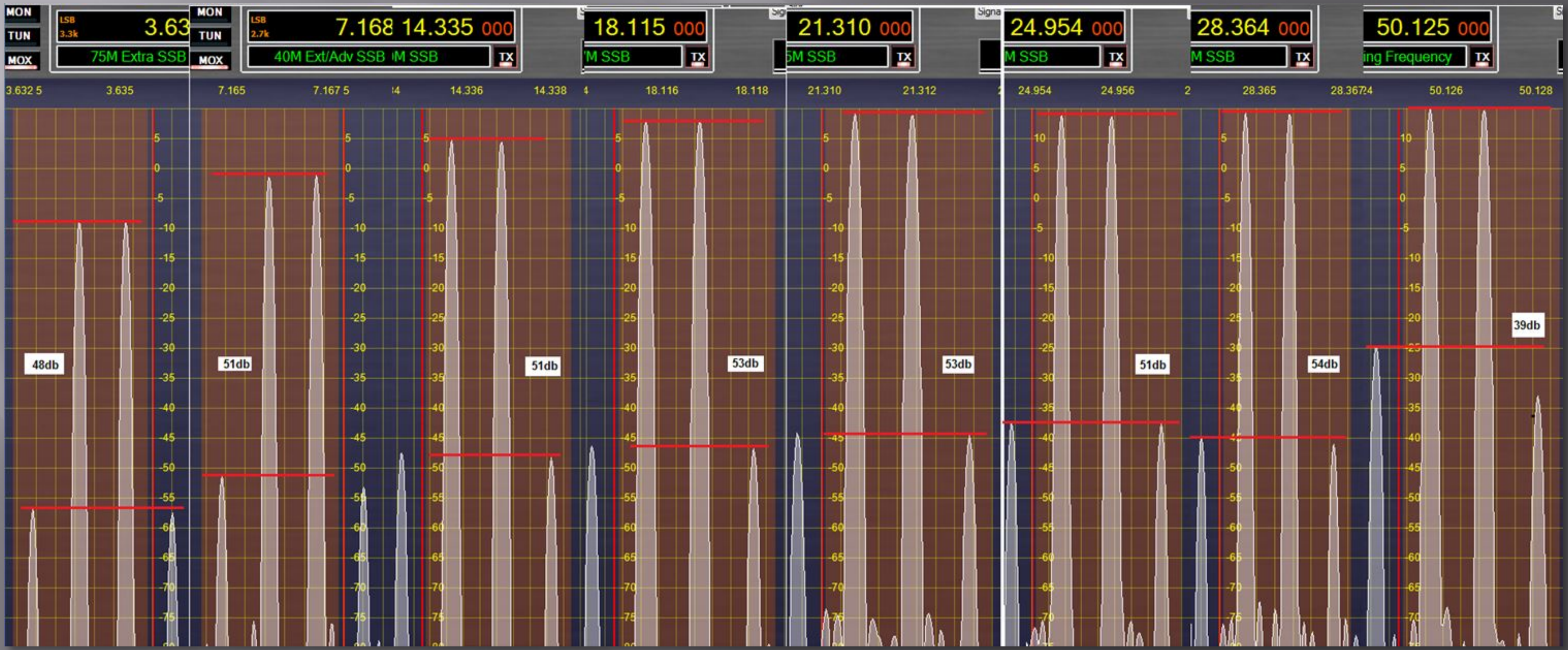


PURESIGNAL RESULTS

Bill, KC9XG

ANAN-100D

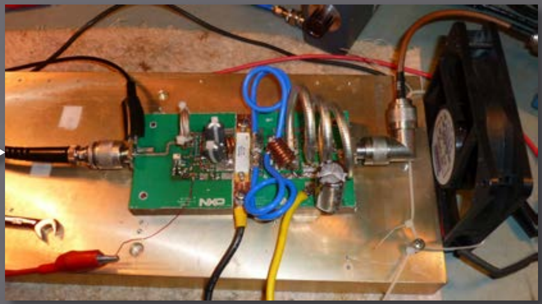
- Two Push-Pull Stages TI OPA2674C
- Push-Pull Mitsubishi RD15HVF1 MOSFETs
- Push-Pull Mitsubishi RD100HHF1 MOSFETs
- 13.8V Design, Typical of Modern Transceivers



PURESIGNAL RESULTS
Mike, N1JEZ

Hermes
Transceiver

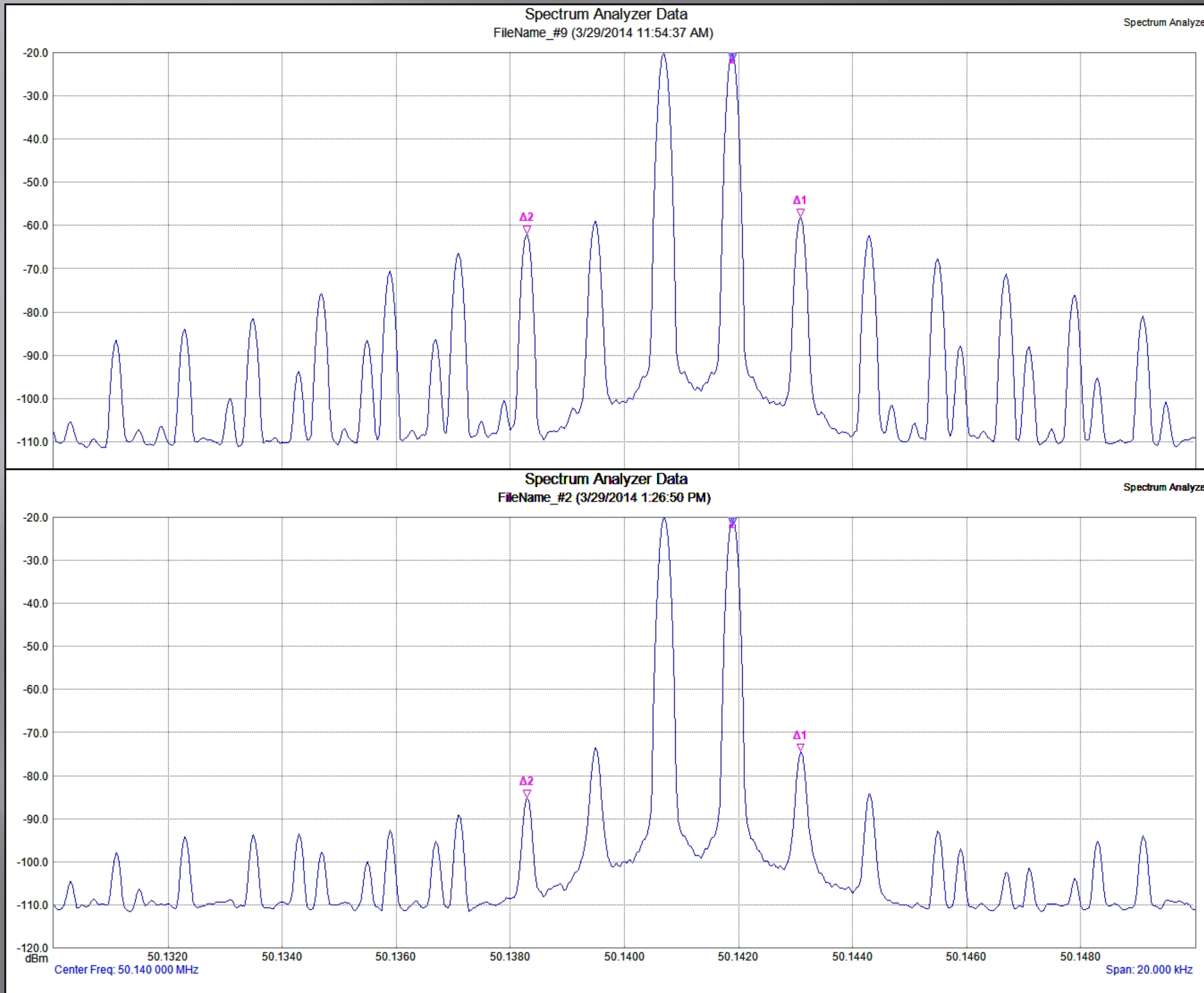
Class A Driver
Modified HARDROCK-50



1 KW, 6M Amplifier
NXP BLF-178

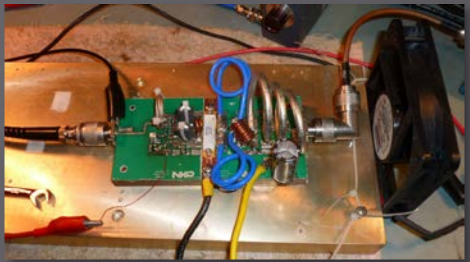
- Extensive 6 Meter Testing
- Paper & Presentation – 40th Eastern VHF/UHF Conference, April 2014
  "LDMOS RF Amplifier Linearization using PowerSDR mRX Pure Signal"
- Class AB and Class B Testing of Homebrew LDMOS Amplifier
- Testing of ANAN-100 with ACOM–1006 (4CX800A / GU74B, 1 KW)

PURESIGNAL RESULTS
Mike, N1JEZ



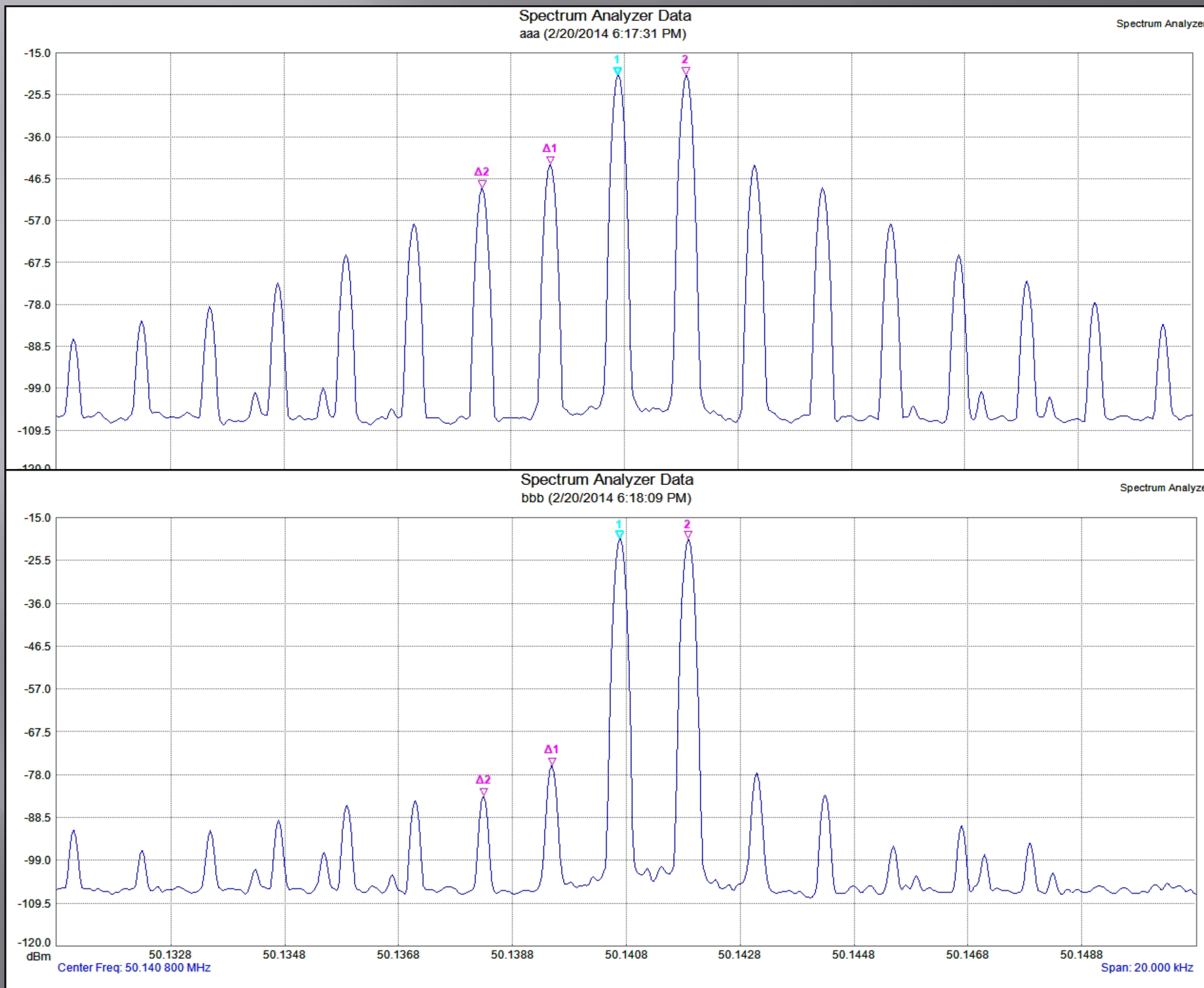
Mkr	Ref	Delta	Ref Freq	Ref Amp	Delta Freq	Delta Amp
1			50.141 891 MHz	-19.93 dBm	1.200 kHz	-54.48 dB
2			50.141 891 MHz	-19.93 dBm	-3.600 kHz	-65.18 dB

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



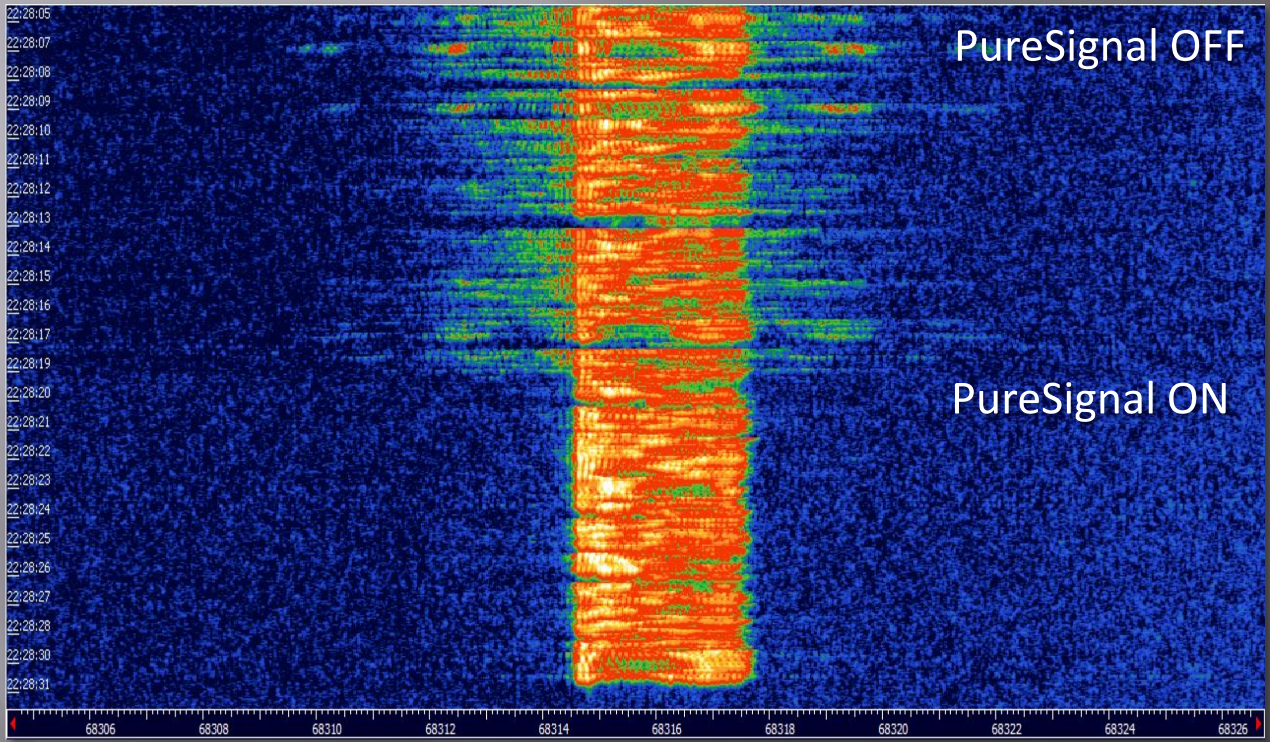
Mkr	Ref	Delta	Ref Freq	Ref Amp	Delta Freq	Delta Amp
1	■	■	50.140 691 MHz	-20.11 dBm	-1.200 kHz	-55.57 dB
2	□	□	50.141 891 MHz	-20.13 dBm	-3.600 kHz	-63.04 dB

1 KW, 6M Amplifier
NXP BLF-178

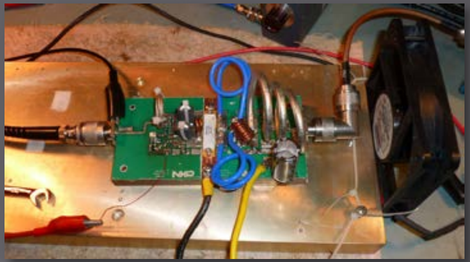
- Class B, I_{bias}=100mA
- 740W PEP
- IMD3 -22 → -56 dBc
- IMD5 -28 → -63 dBc
- Higher-order Down Significantly

PURESIGNAL RESULTS
Mike, N1JEZ

Waterfall Testing, SSB, Class B



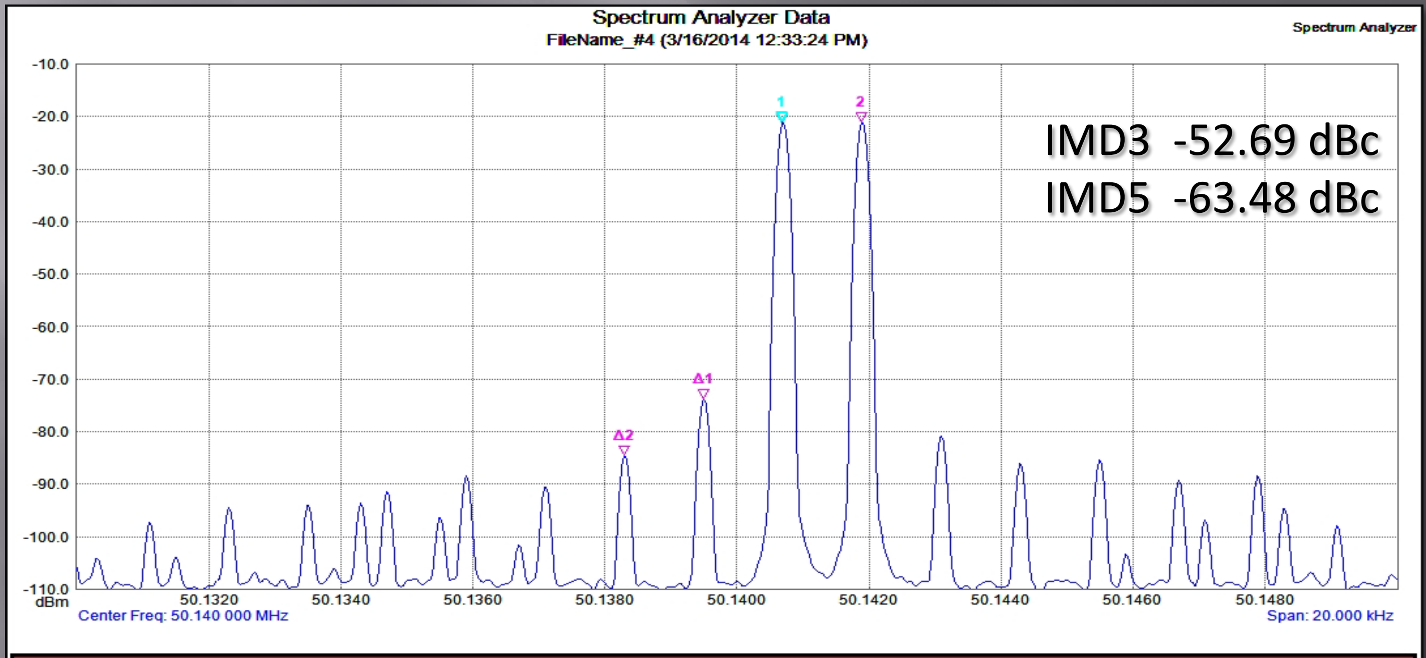
1 KW, 6M Amplifier
NXP BLF-178



PURESIGNAL RESULTS
Mike, N1JEZ

ANAN-100

ACOM-1006



Mkr	Ref	Delta	Ref Freq	Ref Amp	Delta Freq	Delta Amp
1	■	■	50.140 691 MHz	-21.00 dBm	-1.200 kHz	-52.69 dB
2	□	□	50.141 891 MHz	-21.00 dBm	-3.600 kHz	-63.48 dB