The Digital Transceiver ADT-200A
The Principle of a Digital Receiver
  AD Converter
  The Problem with IP3
  The Direct Conversion Rx

The Functional Units of ADT-200A
  DSP Module
  PA Module
  Preselector Module

The Operating Concept of ADT-200A

Where do we go from here?
The Principle of a Digital Receiver

Signal Flow in a fully digital Receiver

Tasks of the DDC:
- Quadrature Mixer with an IF ≈ 0Hz (Homodyne Receiver), **NOT** a Sampler
- Sample Rate Reduction by Decimation
- Improvement of S/N by Integration

RF in 0...30MHz → BP → Digital Down Converter (DDC) → DSP → DA-Converter

73Msps * 14Bit = 1.02Gbit/s
2 * 32ksps * 24Bit = 1.536Mbit/s

D = 2304

$t = 31.25\text{us} \rightarrow 9600\text{ Instructions at 300MIPS}$
The Dynamic Range of an AD-Converter

Example: 14Bit AD-Converter AD6645 from Analog Devices:

Dynamic Range (ideal) = 86dB ( = SNR of fullscale input signal )
Dynamic Range (real) = 75dB → 12 effective Bits (ENOB)

Max. Input Power = \((0.78\text{Vrms})^2 / 1000\Omega\) = -2.2dBm
Noise Floor = -2.2dBm - 75dB = -77.2dBm

Minimum Input Voltage at 50Ω = 30.8µV
The Dynamic Range of an AD-Converter

Process Gain:

\[ G_p = 10 \cdot \log_{10} \left( \frac{f_s}{2 \cdot B} \right) \]

For \( B = 2.4\text{kHz} \) and \( f_s = 73\text{Msps} \):
\( G_p = 44.8\text{dB} \rightarrow \text{SNR} = 119.8\text{dB} \)

Noise Floor in 50Ω = 0.22µV
The Calculation of Receiver Performance

- **Noise Figure**
  \[ \text{F}_{\text{ges}} = 11.4 \text{dB} \]

- **Sensitivity**
  \[ \text{MDS} = -129 \text{dBm} \text{ @ } B=2.4\text{kHz} \text{ (0.08uV)} \]

- **Dynamic Range**
  \[ \text{DR} = 117 \text{dB} \]

- **IM3 free Dynamic Range**
  \[ \text{DR}_3 = 101 \text{dB} \]

- **Max. Input Power**
  \[ \text{P}_{\text{max}} = -11.4 \text{dBm} \]
The Problem with Intercept Point (IP3) Measurement

**IP3 from an analog Amplifier**

- IM3 product increases 3dB per 1dB of signal

**IP3 from AD-Converter AD6645**

- IM3 product is nearly independent of signal
Principle of the Digital Receiver

The Problem with Intercept Point (IP3) Measurement

![Graph showing IM3 behaviour of an analogue receiver]

- IM3-free dynamic range = 94 dB
- IP3 = 20 dBm
Principle of the Digital Receiver

The Problem with Intercept Point (IP3) Measurement

Excerpt from ARRL Lab Test Report
The Problem with Intercept Point (IP3) Measurement

Measurement of IM3 - Product with and without Dithering

-130 -120 -110 -100 -90 -80 -70 -60 -50 -40 -30 -20 -10 0

IM3 [dBm]

Input Power [dBm]

-130 -120 -110 -100 -90 -80 0

w/o Dith.  with Dith.
The Principle of a Digital Receiver

Principle of Direct Conversion Receiver

\[ S(t) = A(t) \cdot e^{j\omega t} = A(t) \cdot [\cos(\omega t) + j \cdot \sin(\omega t)] \]
The Direct Conversion (Quadrature) Receiver

I-Channel: $\times$  
Q-Channel: $\times$  
TP  
-90°  
AF out  
N(t)

RF in

LO  
90°  
$\sin$  
$\cos$

Broadband Phase shifter!

TP = Low-Pass Filter
Mathematical Background of a Direct Conversion Receiver

The Principle of a Digital Receiver

\[ \frac{1}{2} \sin((\omega_2 - \omega_{LO})t) + \frac{1}{2} \sin((\omega_1 - \omega_{LO})t) = \frac{1}{2} \sin(x) - \frac{1}{2} \sin(y) \]

\[ \frac{1}{2} \cos((\omega_2 - \omega_{LO})t) + \frac{1}{2} \cos((\omega_1 - \omega_{LO})t) = \frac{1}{2} \cos(x) + \frac{1}{2} \cos(y) \]

\[ \sin(x) = A_p(t) \sin((\omega_2 - \omega_{LO})t) \]

\[ \frac{1}{2} \sin(x) + \frac{1}{2} \sin(y) = \frac{1}{2} \sin(x) + \frac{1}{2} \sin(y) \]

\[ TP = \text{Low-Pass Filter} \]
Principle of the Direct-Conversion Receiver

The Image Rejection Ratio \( IRR \)

\[
IRR = \frac{1 - 2(1 + \epsilon)\cos \theta + (1 + \epsilon)^2}{1 + 2(1 + \epsilon)\cos \theta + (1 + \epsilon)^2}
\]

\( \epsilon \): Gain Error [-]
\( \Theta \): Phase Error [°]
\( \epsilon = 20 \times \log(\epsilon) \)

\( e = 0.1 \text{dB} \)
\( e = 0.03 \text{dB} \)
\( e = 0.01 \text{dB} \)
\( e = 0.003 \text{dB} \)
\( e = 0.001 \text{dB} \)
How does SDR technology benefit the radio amateur?

- A radio which can be retrofitted with new features at any time
- Characteristics which are largely independent of tolerances and ageing
- Accuracy approaching that of measuring instruments
- Special features such as Antennascope, Audio Recorder, Remote Operation etc.
- A future-oriented technology, which is implemented with a fraction of the components utilized in current radio equipment
- This technology lends itself to automated manufacturing, with a corresponding cost savings
Functional Blocks of ADT-200A

Chipset of DSP Module
Functional Blocks of ADT-200A

Signal Processing on DSP (per Channel)
/*****************************************************************************/
**  FM_Demodulator  
*****************************************************************************/

FM_Demodulator:

/*  first, we calculate the squared absolut carrier value */

F3 = F1 * F1;   /* F1  -> I channel input */  
F4 = F2 * F2;   /* F2  -> Q channel input */  
F12 = F3 + F4;   /* F12 -> I^2 + Q^2 */  
F13 = RSQRTS F12;  /* F13 -> 1/SQR(I^2 + Q^2) */  
F1 = F1 * F13;   /* normalize F1 */  
F2 = F2 * F13;   /* normalize F2 */

/*  then, we get the phase info by delay modulation */

F5 = DM(last_I);  
F5 = F1 - F5;   /* build d/dt -> I' */  
F5 = F5 * F2;   /* product -> I'* Q */  
F6 = DM(last_Q);  
F6 = F2 - F6;   /* build d/dt -> Q' */  
F6 = F6 * F1;   /* product -> Q'* I */  

DM(last_I) = F1;  /* save normalized last_I */  
DM(last_Q) = F2;  /* save normalized last_Q */  

F1 = F5 - F6;   /* I'*Q - Q'*I */  
CALL ARCSIN;  
DM(FM_out) = F3;
Functional Blocks of ADT-200A

The TRX3C DSP Module

- Digital Downconverter
- AD-Converter
- LP Filter 30MHz
- Preamplifier
- Master Clock
- Dig. Upconverter
- Tx-DAC
- USB-IF
- DSP
- Audio-Codec

Preamplifier | LP Filter 30MHz | AD-Converter | Digital Downconverter
The Power Amplifier

Linearity at f = 7MHz

Pin [dBm]  Pout [dBm]  Eta [-]

0  0.0
5  5.0
10  10.0
15  15.0
20  20.0
25  25.0
30  30.0
35  35.0
40  40.0
45  45.0
50  50.0

22.06.07 / HB9CBU
Functional Blocks of the ADT-200A

The Transmitter Power Amplifier
Principle of Adaptive Predistortion

PA Transfer Characteristic
Deviation from Linearity
Compensated Amplitude Response
Functional Blocks of ADT-200A

Spectrum of Output Signal without and with Adaptive Predistortion

2-Tone Modulation with 1100Hz and 1900Hz Test Tones

without predistortion

with predistortion (optimally tuned)
Functional Blocks of ADT-200A

Spectrum of Output Signal without and with Adaptive Predistortion

2-Tone Modulation with 1100Hz and 1900Hz Test Tones

without predistortion  
with wideband predistortion

22.06.07 / HB9CBU Translation: VA7OJ
Transmitted spectrum measured over 1 MHz

ATT: 30.00 dB
BW VIDEO: 0.30 kHz
BW RES: 0.30 kHz

MARKER: -6.78 dBm, 14.0002 MHz
The Power Amplifier Module PAM2A

- electronic Rx/Tx-Switch
- Directional Coupler
- Log Detectors
Specifications of PA:
Max. Output Power 50W
Min. Output Power 100mW
Spurious and Harmonics >70dBc

Extras:
• Adaptive Predistortion
• Power-Meter for full Range of 0.1 ... 50W
• VSWR-Meter with high Dynamic even for 0.1W
• Antennascope determines the complex impedance of an Antenna, either on the TRX or on the Feed Point (optional)
The Preselector

- Attenuator, 0...35dB in 5dB-Steps
- Half Octave Filters, switched by High Current FET’s
- VLF-Front End, for 60, 75, 77.5 and 137kHz
The Half-Octave Filters in the Preselector
The Preselector

Simultaneous reception in the 80m and 30/20m bands

ATT: 20.00 dB
BW VIDEO: 300.00 kHz
BW RES: 248.29 kHz

MARKER: -36.36 dBm, 30.0454 MHz
The Preselector

Simultaneous reception in the 40m and 30/20m bands

ATT: 20.00 dB
BW VIDEO: 300.00 kHz
BW RES: 248.29 kHz
MARKER: -0.4 dBm, 6.0876 MHz
Concept of Input Attenuators

Dynamic Range = 117 dB

Preamp = 10dB
ATT = 0dB

ATT = 10dB
ATT = 20dB
ATT = 25dB

-13dBm
-3dBm
+7dBm
+17dBm
+20dBm

-130dBm
-120dBm
-110dBm
-100dBm
-95dBm

Attenuator
0dB 10dB 20dB 30dB 35dB
The Concept of Transceiver Control

Front-Panel → SPI → IF
PC → USB → IF
Web-Server → SPI → IF
Internet → UDP/IP → IF

Data Base

one Data Segment for each Rx Channel

Audio Signals → TRX
### The Concept of Transceiver Control

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22.06.07 / HB9CBU Translation: VA7OJ
The Concept of Transceiver Control
The Concept of TRX Control
The Operational Interface of ADT-200A

The Menu Structure

Top Menu

- BAND
- MODE
- FILTER
- OPTION
- VFO

OPTION

- AGC
- ATT
- P-AMP
- M-SPEC
- VOX

Mode specific
Mode: SSB

- ON
- 3dB
- 9dB
- -6dB
- PBT
- EQ-LOW
- EQ-MID
- EQ-HI
- BACK

Mode specific
Mode: CW

- ON
- STDND
- 50bpm
- SMI-BK
- OFF
- BFO
- KEYER
- SPEED
- QSK
- DECODE
The Menu Structure
Where do we go from here?

Availability of first units: from January 08

ADT-200 price: approx. CHF 4500 (USD 3800)

Optional add-on features:

• Antennascope

• Web-server module for web-based remote control of an ADT-200A

• User interface for control via a PC

• Spectrum analysis

• 2m/70cm transceiver module with $P_o \approx 10W$ on each band

• Diversity reception