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

- AD-Converter
  - RF in 0...30MHz
  - Digital Down Converter (DDC)
  - DA-Converter

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

- D = 2304
- t = 31.25us -> 9600 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 50\( \Omega \) = 0.22\( \mu \text{V} \)
The Principle of a Digital Receiver

The Calculation of Receiver Performance

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**Noise Figure**
\[ F_{ges} = 11.4\, \text{dB} \]

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

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

**IM3 free Dynamic Range**
\[ DR3 = 101\, \text{dB} \]

**Max. Input Power**
\[ P_{\text{max}} = -11.4\, \text{dBm} \]

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**Gain**
- Preselector: -2dB
- Preamplifier: 14dB
- Antialiasing-Filter: -1dB
- Transformer 1:4: Zin/Zout = 1:16, Gain = -0.5dB
- AD-Converter: U_{\text{inmax}} = 2.2\, \text{Vpp}, Z_{\text{in}} = 800\, \text{Ohm}, F = 20.8\, \text{dB}

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**Preamplifier Transformer 1:4 AD-Converter**

**AD6645**

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22.06.07 / HB9CBU
The Problem with Intercept Point (IP3) Measurement

**IP3 from an analog Amplifier**

- Pout [dB] vs. Pin [dB]
- IP3 [dBm] vs. Pin [dB]

**IP3 from AD-Converter AD6645**

- Pout [dBFS] vs. Pin [dBFS]
- IP3 [dBm] vs. Pin [dBFS]

IM3 product increases 3dB per 1dB of signal

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

The Problem with Intercept Point (IP3) Measurement

IM3 behaviour of an analogue receiver

IP3 = 20dBm

IM3-free dynamic range = 94 dB
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

![Graph showing IM3 measurement with and without dithering](image-url)
Principle of Direct Conversion Receiver

\[ S(t) = A(t) \cdot e^{j\omega t} = A(t) \cdot \left[ \cos(\omega t) + j \cdot \sin(\omega t) \right] \]
The Principle of a Digital Receiver

The Direct Conversion (Quadrature) Receiver

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

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

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

\( A_p(t) = A_s(t) = 1 \)

\( \omega_1 < \omega_{LO} \)

\( \omega_2 > \omega_{LO} \)

TP = Low-Pass Filter
Principle of the Direct-Conversion Receiver

The Image Rejection Ratio  IRR

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

\(\varepsilon\) : Gain Error [-]

\(\Theta\) : Phase Error [°]

\(e = 20 \times \log(\varepsilon)\)
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
Signal Processing on DSP (per Channel)
Signal Processing Example

/****************************************************************************
**   FM_Demodulator
****************************************************************************/

FM_Demodulator:
/* first, we calculate the squared absolute 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;
The TRX3C DSP Module

Functional Blocks of ADT-200A
The Power Amplifier

Linearity at f = 7MHz

Pout [dBm] vs Pin [dBm] graph with two curves:
- Blue curve for Pout [dBm]
- Red curve for Eta [-]

Eta [-] vs Pout [dBm] graph with two points:
- Eta [-] at 50 dBm
- Eta [-] at 20 dBm
The Transmitter Power Amplifier

Principle of Adaptive Predistortion

- PA Transfer Characteristic
- Deviation from Linearity
- Compensated Amplitude Response
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
Transmitted spectrum measured over 1 kHz

ATT: 30.00 dB
BW VIDEO: 0.30 kHz
BW RES: 0.30 kHz
MARKER: -6.78 dBm, 14.0002 MHz
Functional Blocks of ADT-200A

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

Pre = 10dB  Pre = 0dB  ATT = 10dB  ATT = 20dB  ATT = 25dB

ATT = 0dB  ATT = 10dB  ATT = 20dB  ATT = 25dB

Preamplifier  Attenuator

Attenuator  0dB  10dB  20dB  30dB  35dB

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

-13dBm  -3dBm  +7dBm  +17dBm  +20dBm
The Concept of Transceiver Control

- Front-Panel
- PC
- Web-Server
- Data Base
- TRX

Audio Signals

Internet

one Data Segment for each Rx Channel

UDP/IP

SPI

USB

The Operational Interface of ADT-200A
The Concept of Transceiver Control

- **VFO 1**
  - Configuration Set 1
  - Configuration Set
  - Configuration Set
  - Configuration Set

- **Function Keys**
  - Rx1 Frequency (VFO1)
  - Tx1 Frequency (VFO5)
  - Rx2 Frequency (VFO2)
  - Rx2 Frequency (VFO6)
  - Rx3 Frequency (VFO3)
  - Rx3 Frequency (VFO7)
  - Rx4 Frequency (VFO4)
  - Rx4 Frequency (VFO8)

- **Tuning Knob**
  - Rx1 Volume
  - TX1 Sidetone
  - RX2 Volume
  - TX2 Sidetone
  - RX3 Volume
  - TX3 Sidetone
  - RX4 Volume
  - TX4 Sidetone

- **AF Gain Control**
The Concept of Transceiver Control
The Concept of TRX Control
The Menu Structure

The Operational Interface of ADT-200A

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
- STDNRD
- 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