DDCs and DUCs for Wireless Communications

1998 ISART SYMPOSIUM

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WHY DIGITAL INSTEAD OF ANALOG?

- Moves many traditionally analog functions into digital
- Easier manufacturing and maintenance (no trimming needed)
- Higher performance
- For narrow channels, smaller, lower power and cost
  - (for this purpose “NARROW” gets wider as a function of time).

FLEXIBILITY

HISTORY

- Prior to 1985 used in military/government
  - Multiple circuit boards, kWatts, <5MSPS, $200k each
- 1985-1990 proprietary chip sets
  - Proprietary 2-3 chips per DDC, 2-6Watts, 10-50MSPS, $500, $1,000 each, military customers
- 1990-1995 commercial chips
  - Single chip, Graychip & Harris, 1Watt, 50-70 MSPS, $100 each, commercial uses
  - 0.25Watt/channel, 50-70 MSPS, $10/channel, commercial use dominates
- Future (2000)
  - Wider bandwidths (support for WCDMA, LMDS, MCNS, etc.), better SFDR (for GSM)
MOST BASIC FORM

- BASED ON WEAVER DEMODULATION

\[ e^{-jw_0 t} \]

\[ x(t) \rightarrow \text{MIXER} \rightarrow \text{LOW PASS FILTER} \rightarrow y(t) \]

INPUT SPECTRUM

Translated down

Positive image is

Translated down and filtered out

NEGATIVE IMAGE IS

OUTPUT SPECTRUM

COMPLEX MIX DOWN AND THEN LOW PASS FILTER

OPTIONS

- IMPULSE BLANKER
- SYNCHRONIZATION
- RESAMPLER
- NARROW BAND MIXER
- CARTESIAN TO POLAR
- FM DISCRIMINATOR
- LOOP CLOSURE FOR DEMODULATION
- CORRELATORS
- FRONT END SWITCHING
DDC KEY SPECIFICATIONS

- **NCO**
  - TUNING RESOLUTION
  - SPUR FREE DYNAMIC RANGE - some cellular systems want > 110 dB
  - PHASE OFFSETS AND SYNCHRONIZATION - critical for beamforming

- **FILTERING AND DECIMATION**
  - FILTERING STOPBAND
  - DECIMATION RANGE
  - FILTERING STAGES
  - MAXIMUM OUTPUT BANDWIDTH

- **ADDITIONAL FUNCTIONS**
  - RESAMPLING - allows oversampled output, independence of input and output rates
  - DEMODULATION SUPPORT - rectangular to polar conversion, FM discrimination, etc.
  - SYNCHRONIZATION - especially for beamforming
  - FRONT-END SWITCHING - to allow visibility to multiple ADC’s
  - IMPULSE BLANKING - especially for HF environment
## A COMPARISON OF VARIOUS DDCs

<table>
<thead>
<tr>
<th>Model</th>
<th>Fin Max</th>
<th>Max BW Out</th>
<th>SFDR</th>
<th>Dec Range</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>GC1011A</td>
<td>70</td>
<td>0.875</td>
<td>75</td>
<td>64-64k</td>
<td>Introduced 1989</td>
</tr>
<tr>
<td>GC1012A</td>
<td>70</td>
<td>28</td>
<td>75</td>
<td>2-64</td>
<td>Power of two decimation</td>
</tr>
<tr>
<td>HSP50214</td>
<td>65</td>
<td>0.657</td>
<td>98</td>
<td>4-16k</td>
<td>+ resampler, rectangular to polar conversion, FM discriminator</td>
</tr>
<tr>
<td>GC9001</td>
<td>5</td>
<td>0.25</td>
<td>100</td>
<td>16-16k</td>
<td>+ resampler, CORDIC, NB mix, transmitter</td>
</tr>
<tr>
<td>GC4014</td>
<td>62.5</td>
<td>1.563</td>
<td>95</td>
<td>32-64k</td>
<td>four channels</td>
</tr>
<tr>
<td>AD6620</td>
<td>65</td>
<td>~0.4</td>
<td>100</td>
<td>?-16k</td>
<td>can also do 2 channel diversity at 1/2 rate</td>
</tr>
</tbody>
</table>

### Not released yet

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<tbody>
<tr>
<td>GC1016</td>
<td>500</td>
<td>20</td>
<td>90</td>
<td>4-168</td>
<td>Coarse frequency resolution</td>
</tr>
<tr>
<td>GC4016</td>
<td>70</td>
<td>4.5</td>
<td>115</td>
<td>12-32k</td>
<td>Four channels + resampler</td>
</tr>
<tr>
<td>GC1116</td>
<td>300</td>
<td>30</td>
<td>90</td>
<td>4-512k</td>
<td>can do 2 channels at 1/2 rate</td>
</tr>
</tbody>
</table>

Many DDCs allow a trade-off between stopband and maxBWOut. Here maxBWOut is estimated for a 130 tap decimate by four final filter, bandwidth is 80% sample rate.

AD6620 is publicity shy. Information is based on preliminary datasheet.
UP CONVERTER OVERVIEW

- BASED ON WEAVER MODULATION

LOW PASS FILTER

MIXER

\[ y(t) \xrightarrow{\text{RE}[\cdot]} x(t) \]

\[ e^{-jw_0 t} \]

Translated down

- INPUT SPECTRUM

\[ y(t) \]

\[ -F \quad -w_0 \quad +F \quad +w_0 \]

Signal is mixed up by \( w_0 \)

\[ x(t) \]

- OUTPUT SPECTRUM

\[ -F \quad -w_0 \quad +F \quad +w_0 \]

Negative image is created by saving real part

- OPTIONS

  SUPPORT FOR FM/FSK/GMSK

  RESAMPLING

  SYNCHRONIZATION

  SUMIN/OUT

- OPPOSITE OF THE DEMODULATOR
### A COMPARISON OF VARIOUS DUCs

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<tr>
<td>GC9001</td>
<td>5</td>
<td>0.25</td>
<td>90</td>
<td>16-16k</td>
<td>+ receiver, NB mix, resampler</td>
</tr>
<tr>
<td>GC4114</td>
<td>62.5</td>
<td>1.56</td>
<td>85+</td>
<td>32-64k</td>
<td>Four channels. Two channels can be slaved for double bandwidth.</td>
</tr>
<tr>
<td>HSP50215</td>
<td>52</td>
<td>0.4</td>
<td>85+</td>
<td>4-?</td>
<td>Resampling architecture. Estimated 400 kHz at 80dB stop, 800kHz at 65dB stop.</td>
</tr>
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**Not released yet**

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<tr>
<td>GC1116</td>
<td>300</td>
<td>30</td>
<td>90</td>
<td>4-512k</td>
<td>can do 2 channels at 1/2 rate. Can do higher BW at a lower rate.</td>
</tr>
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First filter data input span of 31 samples for GC9001, GC4114, and GC1116. The span is 16 for HSP50215.
DIGITAL BASE STATION ARCHITECTURE

BEAMFORMED “WIDEBAND RADIO” DOWN-CONVERTER ARCHITECTURE

- SINGLE WIDEBAND ANALOG RADIO PER ANTENNA DOWN-CONVERTS COMPLETE CELLULAR FREQUENCY BAND
- 10 TO 100 DIGITAL RECEIVERS EXTRACT INDIVIDUAL CALLS FROM THE WIDEBAND RADIO OUTPUT
- ADVANTAGES:
  - FREQUENCY ALLOCATION ON DEMAND OPTIMIZES CELL USE.
  - BETTER FIDELITY, SMALLER, LESS POWER, LOW MAINTENANCE
  - CAN BE USED FOR ALL CELLULAR FORMATS (GSM, AMPS, CDMA, etc.)
  - LOWER MOBILE TRANSMIT POWER REQUIRED, BETTER FREQUENCY REUSE
HIGHER INTERMEDIATE FREQUENCIES

- HIGHER RECEIVER IF CAN BE PROCESSED USING UNDERSAMPLING IF THE A/D FRONT-END IS WIDE ENOUGH W/O LOSING TOO MUCH PERFORMANCE

- HIGHER DUC SAMPLE RATE OUT IS DESIRED
  - TRANSMITTER IF REQUIRES HIGHER DIGITAL SAMPLE RATE
  - OVERSAMPLED DATA INTO D/A TO IMPROVE SPUR PERFORMANCE

  ✦ GC1116 WILL BE SUITABLE FOR THIS PURPOSE
  - TYPICALLY 1/2 GC1116 PER D/A.
  - MAY ALSO ALLOW PREDISTORTION FOR POWER AMP.
- **UP TO 500 MSPS INPUT** (ECL, PECL, LVECL, CMOS)
- **UP TO 25 MSPS COMPLEX OUTPUT**
- **TARGETED FOR RADAR APPLICATIONS**
GRAYCHIP
DSP CHIPS AND SYSTEMS

GC4016 UPCOMING QUAD DDC

- FOUR FULLY INDEPENDENT DDC’s IN 100TQFP
- FOUR NARROW BAND OUTPUTS, TWO WIDER BAND OUTPUTS, OR ONE WIDE BAND OUTPUT
- RESAMPLING FOR ARBITRARY OUTPUT RATES AND OVERSAMPLING
- ~175 mW / CHANNEL for GSM @ 61.75 MSPS
- SUPPORTS GSM, IS136/TDMA, AMPS, NMT
- SUPPORTS FOUR IS95@2x, TWO IS95@4x OR ONE IS95@8x
- SUPPORTS WCDMA, MCNS
- OPTIONAL PARALLEL OUTPUT

ONE CHANNEL OF FOUR

- 12-16 bits
- 16 or 20
- 20
- 118 bit phase
- 115 SFDR
- Shift EXP
- Scale and shift
- TUNING FREQUENCY
- PHASE OFFSET
- Input Format
- Shift Down
- 5 Stage Equalization
- 4k to 4
- Coarse Gain
- Coarse Delay
- Coarse Filters
- Delay
- Decimate by 12
- Decimate by 2
- Decimate by 38
- Resampler
- Final Gain
- Output Formatter
- 8, 16, or 24