The VLBI2010 Up/Down converter: Design and tests

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Downconversion

- Function:
  - Downconvert RF signals at 2-14 GHz to IF at ~0-2 GHz, prior to Nyquist zone filtering.
- General specifications:
  - Reject out-of-band (e.g., image) signals by >70 dB.
  - Flexible LO tuning
    - Avoid RFI
    - Useful for system testing
  - LO frequency offset from N × pulse cal repetition rate
    - Aids rejection of phase cal spurious signals & harmonics
  - Coherence loss from LO phase noise <1%
  - High dynamic range
    - Reduces SNR loss from RFI-induced intermod products
Downconverter architectures: updown converter

- Updown converter (UDC) has best features of other two architectures:
  - Tunable LO to downconvert different input RF ranges to fixed IF frequencies.
  - Fixed-frequency filter.
  - Strong image rejection possible.
- The devil is in the design details:
  - Avoiding LO spurious signals in passband.
  - Avoiding higher-order mixing products.
  - Etc.
Haystack UDC

- Designed by Alan Rogers of Haystack Observatory.
- Primary characteristics:
  - 1-13 GHz input frequency range
  - 0.5-2.5 GHz output frequency range
  - Net USB downconversion
  - Total LO frequency = 4 x (5.75-8.25 GHz Luff synth. freq.) − 22.5 GHz
    = 0.5 − 10.5 GHz
  - 30-60 dB conversion gain

\[ f_{RF} + 22.5 - 4f_{Luff} = f_{IF} \]

22 Oct 2012
VLBI2010 TecSpec Workshop
Haystack UDC - image reject filter \(|S21|\)
To:      Mark 5 Group  
From:    Alan E.E. Rogers  
Subject: Performance characteristics of Updown converter

Performance results based on the block diagram of figure 1 are as follows:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input frequency range</td>
<td>1-13 GHz</td>
</tr>
<tr>
<td>Up conversion L.O. range</td>
<td>23-33 GHz</td>
</tr>
<tr>
<td>Up conversion L.F. range</td>
<td>20-22 GHz</td>
</tr>
<tr>
<td>Down Conversion L.O.</td>
<td>22.5 GHz</td>
</tr>
<tr>
<td>L.F. range prior to Nyquist filters</td>
<td>0.5-2.5 GHz</td>
</tr>
<tr>
<td>Output Frequency</td>
<td>22.5 - 4x luff + input GHz</td>
</tr>
<tr>
<td>Luff frequency range</td>
<td>5.75 - 8.25 GHz</td>
</tr>
<tr>
<td>Minimum step size</td>
<td>100 kHz</td>
</tr>
<tr>
<td>Bandpass ripple</td>
<td>4 dB peak to peak</td>
</tr>
<tr>
<td>Minimum size for repeatable phase</td>
<td>1 MHz</td>
</tr>
<tr>
<td>Nominal input power</td>
<td>-30 dBm</td>
</tr>
<tr>
<td>Spurious rejection (excluding L.O. Sidebands)</td>
<td>-70 dB</td>
</tr>
<tr>
<td>Spurious signals (Luff 3\text{rd} harmonic)</td>
<td>-50 dB</td>
</tr>
<tr>
<td>Spurious signals (excluding luff 3\text{rd} harmonic)</td>
<td>-70 dB</td>
</tr>
<tr>
<td>Conversion gain (atten. 0 dB)</td>
<td>60 dB</td>
</tr>
<tr>
<td>Conversion gain (atten. 30 dB)</td>
<td>30 dB</td>
</tr>
<tr>
<td>Noise figure</td>
<td>8 dB</td>
</tr>
<tr>
<td>Cross-talk between pol. Channels</td>
<td>~50 dB</td>
</tr>
<tr>
<td>Coherence loss due to phase noise</td>
<td>~0.5% (~5° rms)</td>
</tr>
</tbody>
</table>
To: Mark 5 Group  
From: Alan E.E. Rogers  
Subject: Temperature sensitivity of Updown converter

The Updown converter (see Mk5 Memo #059) uses a Luff (TLSD57508250/100K) digital local oscillator to shift input up to an I.F. center frequency of 21 GHz and then shifted down with a second Luff (SCSM3-11250) oscillator at a fixed 11.25 GHz and doubled to 22.5 GHz. The conversion is net upper sideband. A positive phase delay shift in the first local oscillator results in a negative phase delay shift in the signal and a positive delay shift results in a positive phase delay in the signal so that if identical synthesizers were used for the LOs their phase shifts would cancel.

Using the set-up shown in Figure 1 the phase delay sensitivity to temperature was measured. The table below shows the change in output phase measured with oscilloscope for a temperature change from 86 to 96 °F.

<table>
<thead>
<tr>
<th>Input freq GHz</th>
<th>Luff syn GHz</th>
<th>Cycles change</th>
<th>TempCo ps/degC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.75</td>
<td>-0.5</td>
<td>-90</td>
</tr>
<tr>
<td>5</td>
<td>6.75</td>
<td>-0.3</td>
<td>-11</td>
</tr>
<tr>
<td>9</td>
<td>7.75</td>
<td>-0.2</td>
<td>-4</td>
</tr>
</tbody>
</table>

The negative sign indicates that the phase delay through the UpDown converter decreases with increased temperature. The tempCo is computed using the input frequency.
Test set-up for measurement of phase delay change with temperature
To: Mark 5 Development Group  
From: A.E.E. Rogers  
Subject: Updown converter notes  
This memo updates the characteristics given in memo #059  

1] Spurious signals  
A full scan of the first L.O. was made with the spectrum analyzer looking at the I.F. from 0.5 to 2.5 GHz. The following spurs were noted with the 2nd L.O. at 22.5 GHz from the “max hold” on the analyzer:

   a. Spur at 22.5-3 \times \text{Luff} falls in the I.F. range with Luff from 6.6667 to 7.3337 GHz corresponding to an input frequency range from 4.7 to 9.3 GHz.

   b. Spur at 4 \times \text{Luff} - 22.5 falls in the I.F. range with Luff from 5.75 to 6.25 corresponding to input range of 1 to 5 GHz.

   c. Spur at 3.5 \times \text{Luff} - 22.5 falls in the I.F. range with Luff from 6.57 to 7.14 corresponding to input range from 4.28 to 8.56 GHz.

All of these spurs are more than 50 dB below the normal total power. Spurs a) and c) could be reduced with additional filtering of the first L.O. multiplier chain. Spurs b) are the result of the L.O. signal leaking around the 21 GHz cavity filter and could be reduced by better shielding and/or the use of some microwave absorbing material. None of these spurs should pose a serious problem unless a spur falls on a frequency being used as a phase cal tone. This can be avoided by appropriate setting of the MHz digit of the Luff synthesizer. For example if the MHz digit is one the spurs will never fall on a harmonic of 5 of 10 MHz. If necessary the 100 kHz resolution of the Luff TLSD57508250/100 K synthesizer can be used in order to set an L.O. offset.
2] Compression and distortion
The 1 dB compression point of the updown converter occurs at input level of -20 dBm provided the output level is less than +12 dBm. If the attenuation is set less than 30 dB and there is a strong RFI signal within the Nyquist bandpass the output may saturate before the first mixer stage. The IP2 and IP3 points are at +20 and +10 dBm respectively referred to the input and again these intercept points are reduced if the attenuation is less than 30 dB and the RFI is within the Nyquist bandpass so that the intermodulation occurs first in the output amplifier. Saturation and intermodulation in the first mixer referred to the updown input:

<table>
<thead>
<tr>
<th>1 dB compression</th>
<th>-20 dBm</th>
</tr>
</thead>
<tbody>
<tr>
<td>IP2</td>
<td>+ 20 dBm</td>
</tr>
<tr>
<td>IP3</td>
<td>+10 dBm &lt; 5 GHz + 6 dBm &gt; 5 GHz</td>
</tr>
</tbody>
</table>
To: Mark 5 Development Group

From: A.E.E. Rogers

Subject: Phase calibrator pulse distortion in UDC

1] Distortion of phase cal pulses vs peak power in pulse

If the pulses from the phase calibrator are too strong they can be distorted in the Updown converter (UDC). The 1 dB compression point of the UDC is -10 dBm (see memo #70). The phase calibration distortion for various levels was measured by offsetting the UDC first LO by +100 kHz so that the spurious signals produced by the UDC are now offset from the phase calibration rails by +400 kHz. The results of the measurements are given in the table below:

<table>
<thead>
<tr>
<th>UDC 1st LO MHz</th>
<th>Pcal peak power dBm</th>
<th>Tone freq. GHz</th>
<th>Distortion dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>5750.1</td>
<td>0</td>
<td>1.1</td>
<td>-20</td>
</tr>
<tr>
<td>5750.1</td>
<td>-10</td>
<td>1.1</td>
<td>-30</td>
</tr>
<tr>
<td>5750.1</td>
<td>-20</td>
<td>1.1</td>
<td>-40</td>
</tr>
<tr>
<td>6750.1</td>
<td>-10</td>
<td>5.1</td>
<td>-31</td>
</tr>
<tr>
<td>7750.1</td>
<td>-10</td>
<td>9.1</td>
<td>-30</td>
</tr>
</tbody>
</table>

Notes:

1. The peak power is measured at the input of the UDC.
2. Distortion is the relative level of the 400 kHz sidebands on the phase cal rails.
3] Recommend peak pulse power

I recommend the peak pulse power at the input of the UDC be less than -10 dBm. At this level the -30 dB distortion should keep the variation of phase cal voltage with L.O. phase under 3% and a corresponding error in the extracted phase cal phase under 2 degrees.
Haystack UDC - measured performance

> 70 dB  image rejection (and rejection of other unwanted responses)
< -60 dB  spurious signals (excluding Luff 3\textsuperscript{rd} harmonics) relative to -40 dBm input
< - 40 dB  spurious signals from Luff 3\textsuperscript{rd} harmonics relative to -40 dBm input
-18 dBm  input 1-dB comp. pt. with all power in NZ passband (gain = 30 dB)
-10 dBm  input 1-dB comp. pt. with flat 12-GHz-wide input spectrum
+20 dBm  input IP2 with gain = 30 dB
~ +8 dBm  input IP3 with gain = 30 dB
~ -50 dB  cross-talk between polarization channels
~5° rms  LO phase noise (\(\rightarrow\) ~0.5% coherence loss)
8 dB  noise figure
4 dB pk-pk  bandpass ripple
10-30° / °C  total LO phase temperature sensitivity (frequency dependent)
  or about -4 to -90 ps/ °C  in phase delay
  (temperature sensitivity is smaller)
It is very important to be sure UDC has a pure reference. This plot shows a significant pedestal when the reference is via a serial of older 5 MHz buffers – which cleans up with better buffers.
Haystack UDC - further characteristics

- 5 or 10 MHz input reference frequency for LO
- 100 kHz minimum Luff synthesizer step → 400 kHz total LO quantization
  - Non-integer-MHz step aids in reducing saturation-induced pcal spurious signals generated after 1st UDC mixer.
- An upgrade to the LO circuit to support 1-17 GHz input RF range has been designed but not yet tested.
- Two sets of RF-to-IF electronics with a common LO, to support two polarizations.
- Includes one NZ signal chain plus a splitter that could feed a second.
- 0-31.5 dB programmable attenuator with 0.5-dB steps in NZ channel.
- Remote (via USB port) and local monitor/control of LO and attenuator settings.
Simplified block diagram for connectorized up/down converter for DBE

Notes:
1) Luff needs min. of +5.8v direct from power supply
2) For 5 MHz input Wenzel doubler precedes buffer
3) +5 to ADA-0410A and HMC-033 run separately to avoid coupling
4) Ferrite beads on these modules
5) Cables marked with * should be solid semi-rigid for minimum leakage
CURRENT DESIGN

R.F. input
1-12 GHz

ZX80-14012L
+12
Markl M2-0243LP
Lorch 11E77-21000/20000-S/S

IF
other polarization
+23-33 GHz

21 GHz cavity filter

7E77-20000/10000-S/S
BPF +5
+ 5
dB
P bend

7E77-14000/6000-S/S
BPF
11.5-16.5 GHz

Issues:
1) 3rd. harmonics of ADA-0410A and HMC-C033 may require coax switches to select filters. or YIG tracking filter
2) No data on ZX80-14012L above 14 GHz – may need different amplifier.

EXPANDED COVERAGE

R.F. input
1-17 GHz

+12
70ma

No data > 14 GHz

7E77-30500/15000-S/S
BPF +5
+ 5
dB
P bend

7E77-15250/7500-S/S
BPF
11.5-19.0 GHz

Extending the frequency range of the UDC

acee 23 Feb 2011
Haystack UDC - Nyquist zone filter \(|S21|\)
END