A heterodyne cross-correlator for phase noise measurement

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People involved

The LNE-SYRTE (CNRS/UPMC/Observatoire de Paris) is acting as the national metrology institute in France for time and frequency metrology (primary frequency standards, time and frequency dissemination, optical clocks,...) (contact = Yann Le Coq)

Recent work in connection with such developments:

- Ultra low phase noise microwave generation with optical frequency combs:

The LP2N (CNRS/IOGS, Univ. Bordeaux I) is a recently created laboratory which includes a unit for industry collaboration about low noise optics and electronics. (Contact = Giorgio Santarelli)

The CEDRIC/LAETITIA (EA 4629) laboratory of CNAM Paris is specialized in signal processing for telecommunication and electronic systems optimization. (contact = Christophe Alexandre)

Recent work in connection with such developments:

- Electronics of the Iliade ranging project (ANR) with OCA/ARTEMIS (Michel Lintz): https://artemis.oca.eu/spip.php?article311
- Electronics of the LUMINAR ranging project (EU) with LNE-CNAM/LCM (Jean-Pierre Wallerand): http://projects.npl.co.uk/luminar/the-project/
Context: ultra-low phase noise microwave generation with optical frequency combs

→ A robust $4.5 \times 10^{-16}$ (@1s) level USL cavity (designed following space industry standards and methods)
→ 10cm long cavity with rings
→ Prototype designed for transport +/-10g and operation at zero-2g
→ Currently existing lab prototype

$\Phi$-noise of a 10 GHz carrier obtained by frequency division of the space-prototype USL at 200THz (SODERN/CNES/SYRTE), by a frequency comb, assuming perfect division

$200 \text{ THz} (\lambda=1.5\mu\text{m})$

$\Phi$-noise
→ $-20 \cdot \log(20000)$
   = $-86 \text{dB}$ (!!!)

Development/Design of microwave absolute phase noise measurement systems of extremely high performance

One of our measurement techniques: cross-correlation (heterodyne version)

Source A → BPF → f_{DUT}-f_A → BPF → ADC → DDC → IQ→φ
Source → BPF → f_{DUT}-f_B → BPF → ADC → DDC → IQ→φ
Source B → BPF → f_{DUT}-f_B → BPF → ADC → DDC → IQ→φ

→ No need to assume extreme performance on Source A and Source B noise, except statistical independence
→ Usefull for detecting very low noise at high Fourier frequencies (>10kHz)
→ Very usefull for caracterizing one very good oscillator against two (moderatly) good ones
→ The heterodyne version is expected to be largely insensitive to AMPM conversion from mixers if used at high enough IF
→ Home-made system: can hope to control/understand every (or at least most) part of it...
Physical implementation

Photo of the FPGA motherboard and the 2 ADC daughter boards (with water-cooling system)

Photo of the frequency chain generating 2 ~statistically independant 250MHz clock signals (but f-locked at low Fourier frequencies

ADC : AD9467 (Analog Device)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
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</thead>
<tbody>
<tr>
<td>Conversion rate + resolution</td>
<td>250 Msp</td>
</tr>
<tr>
<td>Effective Number Of Bits (ENOB) à 5 MHz</td>
<td>12.4</td>
</tr>
<tr>
<td>Spurious-Free Dynamic Range (SFDR) à 5 MHz</td>
<td>97 dBFS</td>
</tr>
<tr>
<td>Aperture Jitter</td>
<td>60 fs rms</td>
</tr>
</tbody>
</table>

FPGA : Xilinx KC705

Clock sources :
2 home-made frequency chains based on 2xRakon LNO100

Guaranteed low phase noise @ 100 MHz:
-165 dBC/Hz @ 1kHz offset
-178 dBC/Hz @ 100kHz offset
2 independent clocks at 250MHz
/125 decimation ratio to 2MSPS
Output data format: I1 Q1 I2 Q2 with 32 bits
total data rate = 32MBytes/s
FPGA implementation

Detail of the Digital Down Converter

- DDS 24 bits, SFDR = 138 dB
  - Spectre corrigé par série de Taylor

Characteristics of FIR low pass filter

- FIR low pass filter frequency response: 180dB rejection
Current results at 10 MHz input signals

Phase noise measured on input 1
Phase noise measured on input 2

1500s averaging cross-correlation
Current results at 100MHz input signals

5000s averaging cross-correlation