A heterodyne cross-correlator for phase noise measurement

C. ALEXANDRE, J.F. OLIVIER, A. ARISTIDE
Cedric (CNAM/ ENSIIE), Paris, France

G. SANTARELLI
LP2N (IOGS/Univ Bordeaux I), Bordeaux, France

Y. LE COQ, M.LOURS, J. PINTO
LNE-SYRTE (OP/CNRS/UPMC), Paris, France

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 dissemnation, optical clocks,…) (contact = Yann Le Coq)

Recent work in connection with such developments:

- Ultra low phase noise microwave genration with optical frequency combs:
  App. Phys. Lett. 96 211105 (2010), Optics Letters 36, 3654 (2011), Applied Physics B 106, 301 (2012), Optics Letters 39, 1204 (2014)

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.

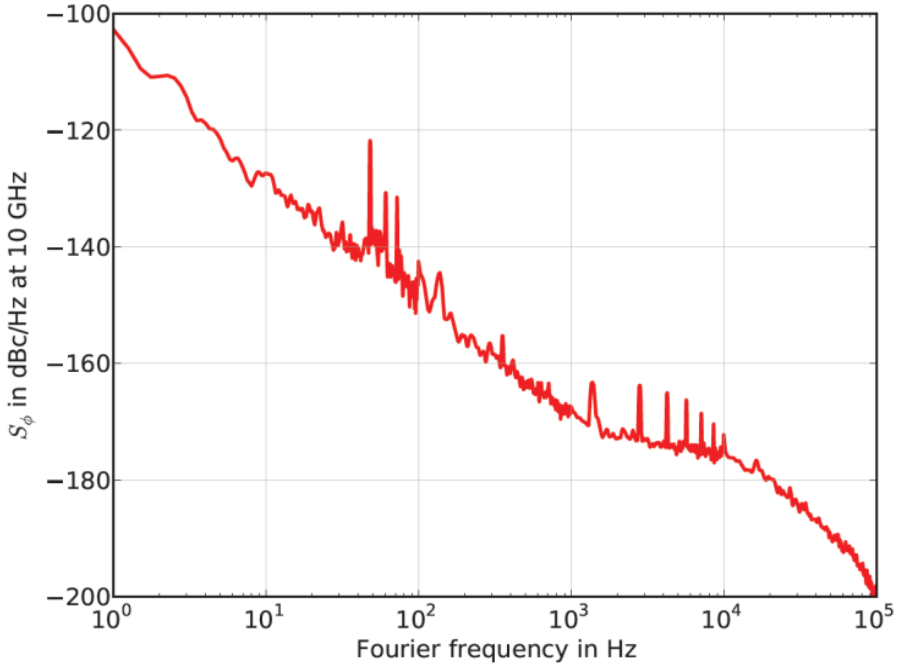
(contact = Christophe Alexandre)

Recent work in connection with such developments:

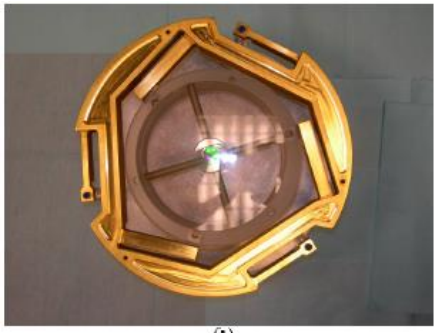
- Electronics of the Iliade ranging project (ANR) with OCA/ARTEMIS (Michel Lintz): https://artemis.oca.eu/spip.php?article311
- Electronics of the LUMINAR ranging project (EU) with LNE-CNAM/LCM (Jean-Pierre Wallerand): http://projects.npl.co.uk/luminar/the-project/

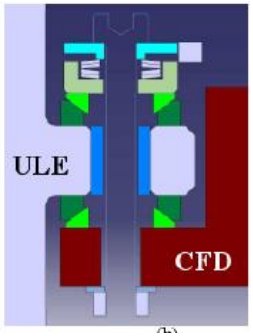
Context : ultra-low phase noise microwave generation with optical frequency combs

→ A robust 4.5×10^{-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

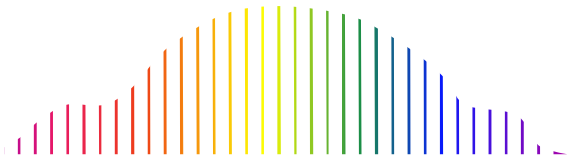


Φ-noise of a 10 GHz carrier obtained by frequency division of the space-prototype USL at 200THz (SODERN/CNES/SYRTE), by a frequency comb, assuming perfect division





200 THz (λ=1.5µm)



Opt. Freq. comb

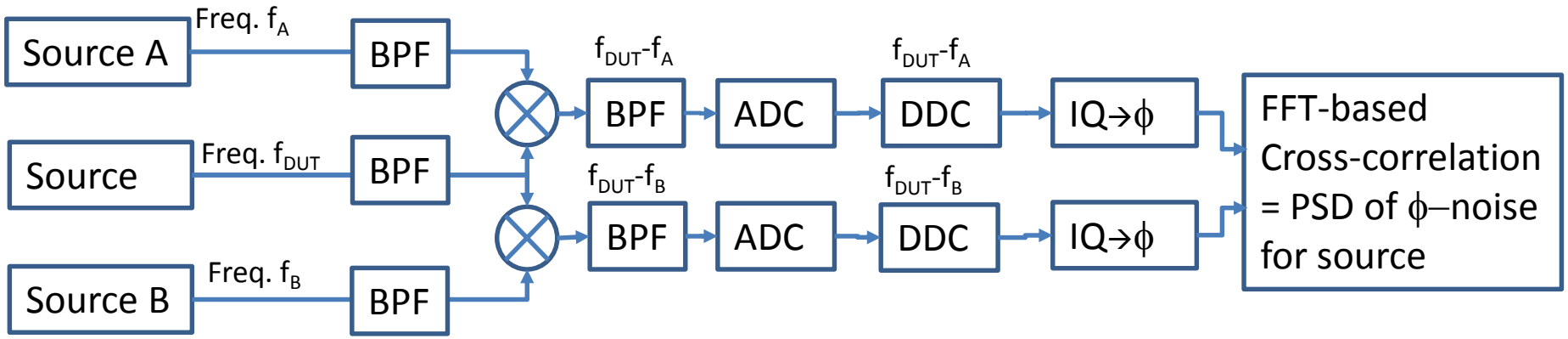
Φ-noise
→ -20.log(20000) = -86dB (!!!)

10 GHz

Argence et al. Opt. Express 20, 25409 (2012)

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

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



→ 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

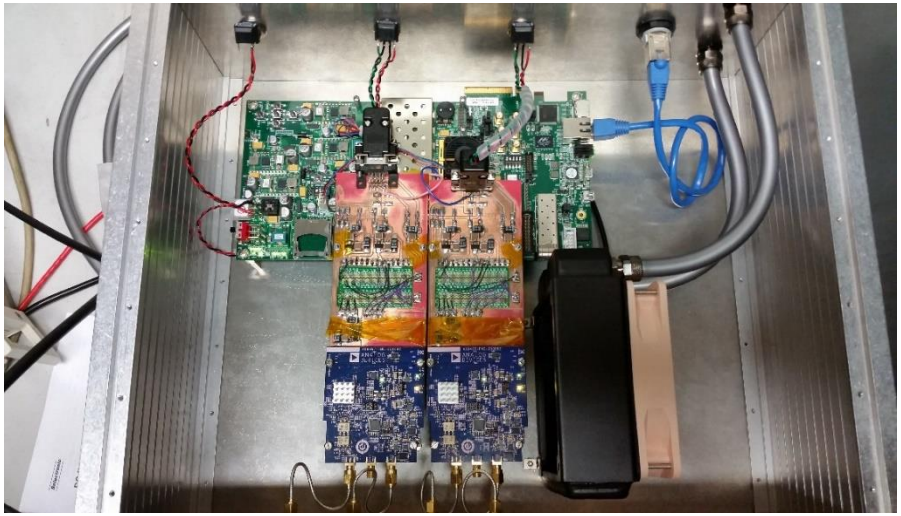


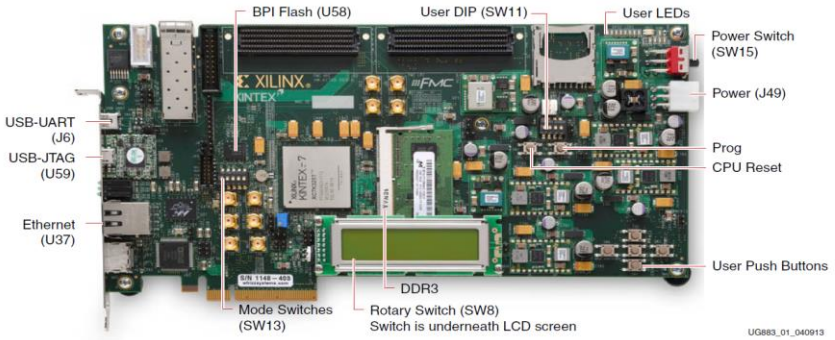
Photo of the FPGA motherboard and the 2 ADC daughter boards (with water-cooling system)

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

ADC : AD9467 (Analog Device)

Conversion rate + resolution	250 Msps 16 bits
Effective Number Of Bits (ENOB) à 5 MHz	12.4
Spurious-Free Dynamic Range (SFDR) à 5 MHz	97 dBFS
Aperture Jitter	60 fs rms

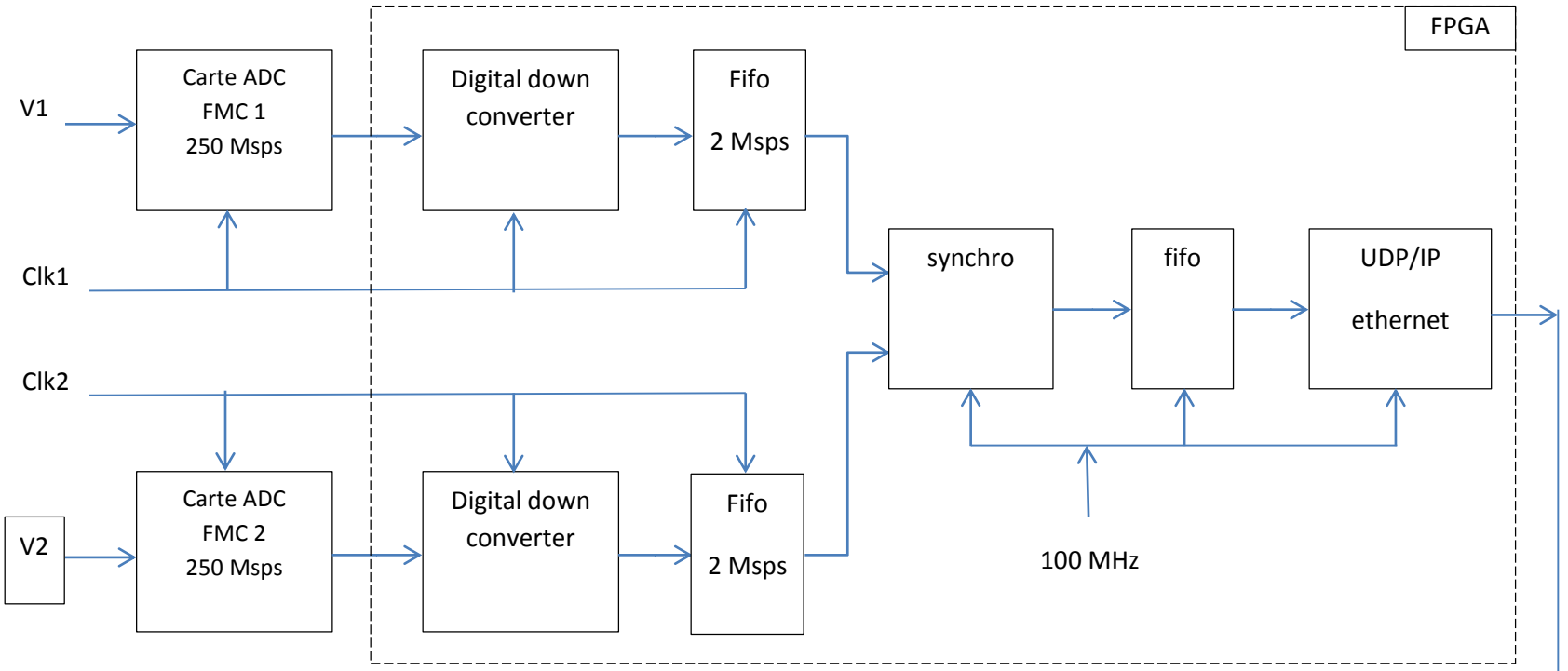
FPGA : Xilink KC705



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

FPGA implementation



2 independant clocks at 250MHz

/125 decimation ratio to 2MSPS

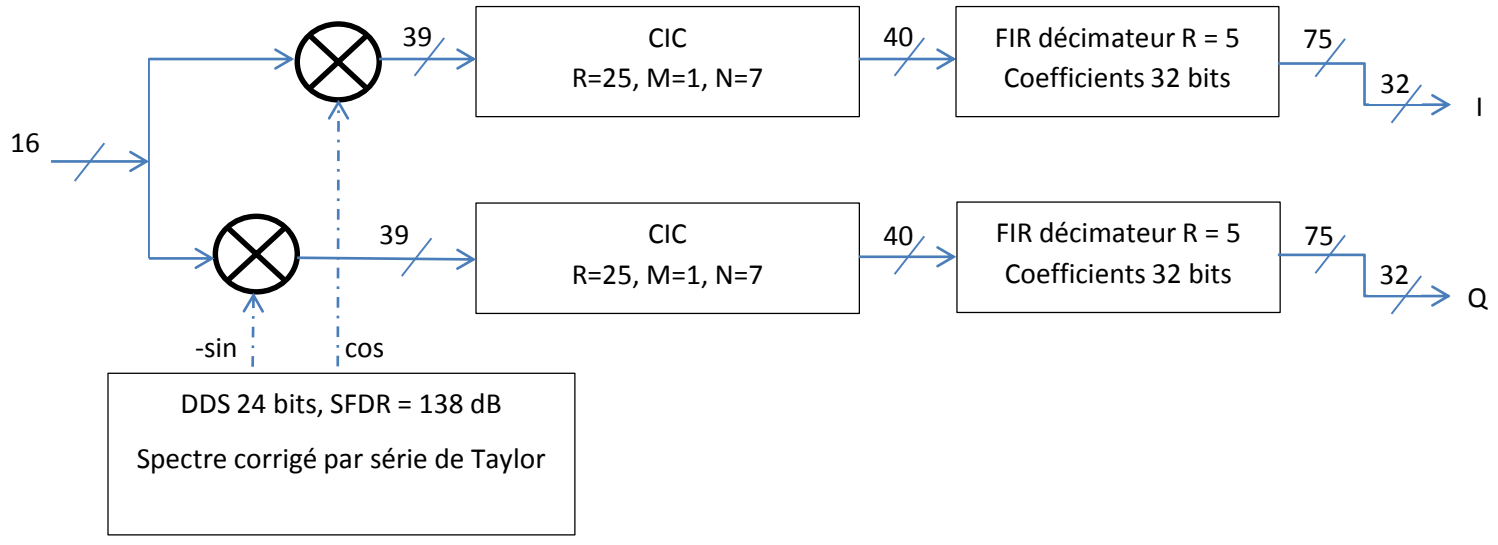
Output data format : I1 Q1 I2 Q2 with 32 bits
total data rate = 32MBytes/s

To PC

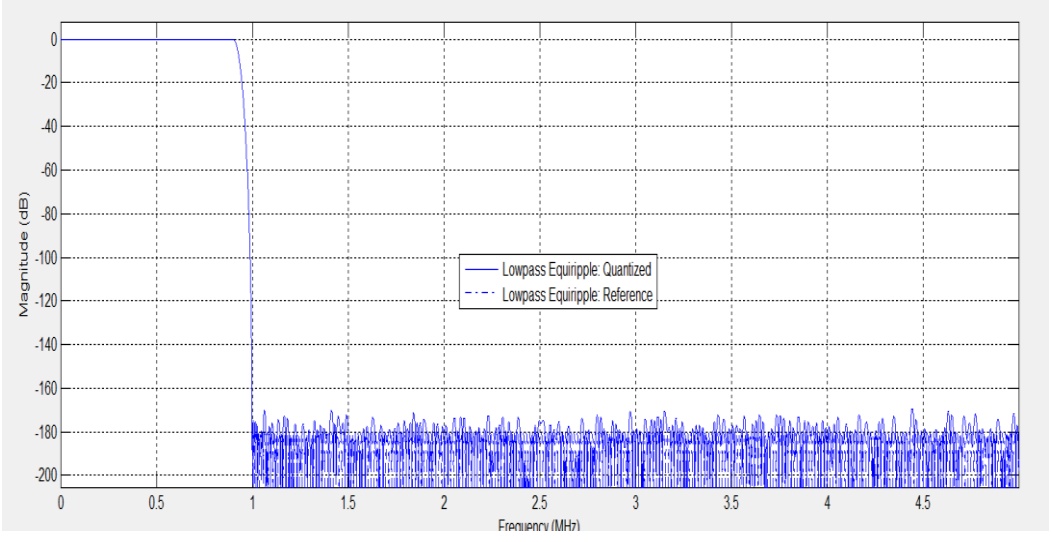
program in C for fast acquisition and writing I1,Q1, I2, Q2 to SSD
+ program in Matlab or Python for real time analysis from SSD data

FPGA implementation

Detail of the Digital Down Converter

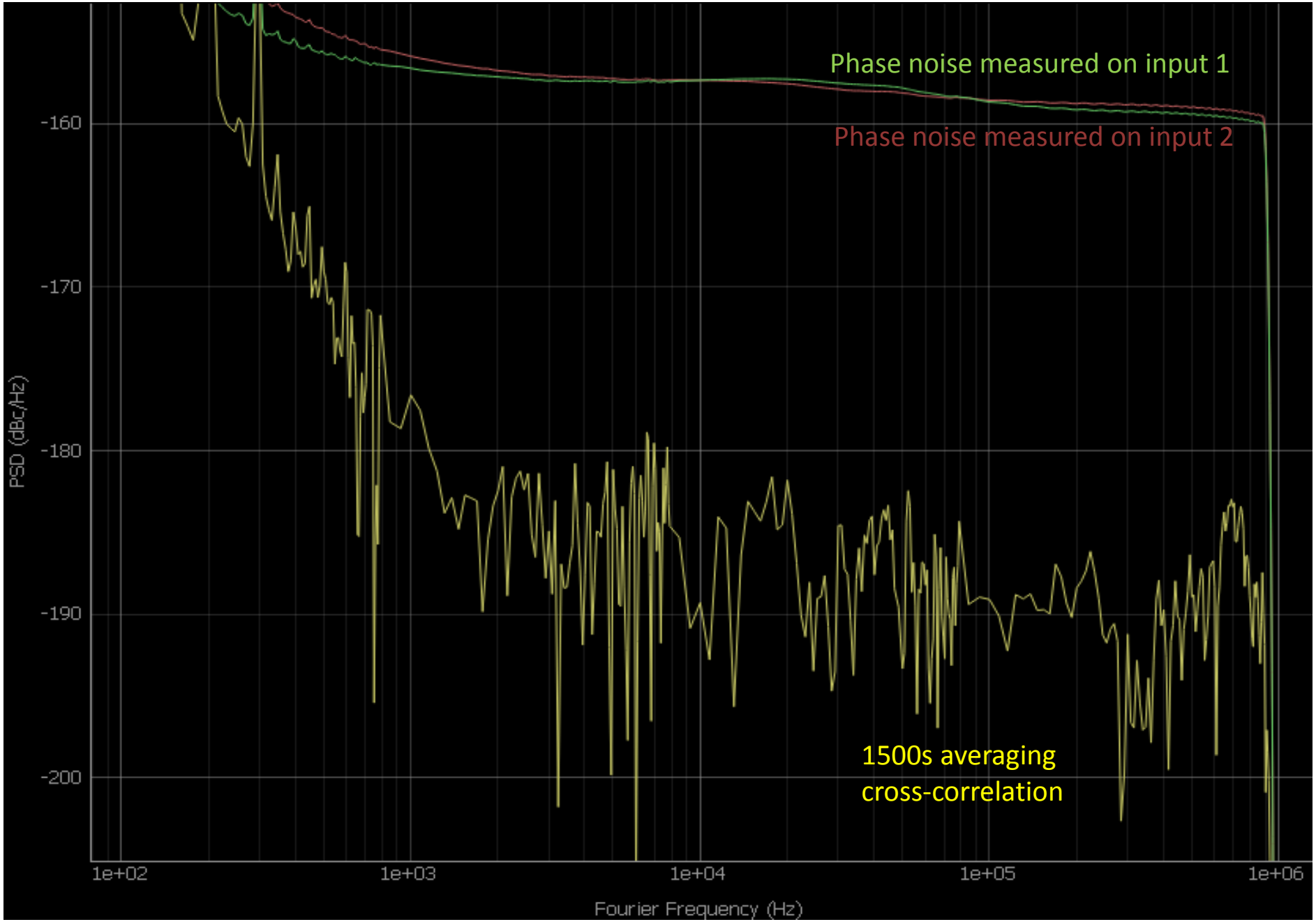


Characteristics of FIR low pass filter



FIR low pass filter frequency response :
180dB rejection

Current results at 10 MHz input signals



Current results at 100MHz input signals