



Annual report

Name and surname: Marco Toffano

Cycle and a.a.: XL / 2024-2025

Supervisor: M. Bellato, J. P. Zendri

- Research activity carried out during the year

VIRGO, as well as LIGO and future Einstein Telescope (ET), all rely on precise timing of the various actuators of the detector (electromechanical, electrothermal, optoelectrical etc.) for active noise compensation, allowing accurate measurement of spatial displacement. Even tiny fluctuations of the reference frequency carriers result in an overall worsened sensitivity curve. Despite recent advances in microelectronics, integrated commercial solutions favour the development of high-end characteristics in terms of spectral purity within the frequency range typical of the world of telecommunications, resulting in very low noise floors “far from the carrier”, i.e. from a frequency offset of about 1 MHz on. Considering this fact, and the objective of enhancing sensitivity in the lower portion of the spectrum, a dedicated solution is envisaged.

During this first year of the Tech-FPA PhD program, I carried out some comprehensive foundational work that can be coarsely divided into the following packages:

- 1) **Literature review of existing methodologies for ultra-stable frequency reference generation**, mainly exploring latest developments in time and frequency metrology. The scarcely documented approach of “translation/offset loops” was identified as a promising candidate to experiment with, and procurement of a dedicated evaluation board and other RF components has been engaged with the aim of jumpstarting a demonstrator prototype. The core idea was presented at the 3rd ET meeting in Warsaw.
- 2) **Analysis and characterization of the currently employed RF-generation system**, developed at INFN Padova. Several measurements have been collected at VIRGO experimental facility, so to better grasp current limitations and novel requirements for the new electronics. This activity could not have been overlooked since, at the present time, there is no unanimous consent on the direction of electronics development for ET, and specifications needed to be set as accommodating as possible. The inner workings of the detector were also explored, with particular attention to the generation of squeezed light for quantum noise reduction.
- 3) **“Digitization” of a phase-noise reduction loop on optical signal confined in monomodal fibres**: starting from an already working feedback system integrating optical and electronic components, the legacy analog RF generator was substituted with a 12-bit direct digital synthesizer (DDS). The regulation loop was closed on a development board, performing the mapping from continuous phase deviation signal to 32-bit instantaneous frequency setting, plus the necessary loop shaping and ADC/DDS interfacing. Some preliminary results were presented at the Electronics Workshop @INFN in Torino. This experience was critical to understand that a versatile, almost-continuous modulation capability is essential for the final synthesizer realization, orienting the choice of a high-performance 16-bit DAC with user-selectable DSP functions as the internal RF source for the translation loop demo. Currently, the influence of environmental factors on noise rejection is under investigation, and a shift at VIRGO is planned to specifically quantify the change in light polarization (up to now neglected) over the squeezing optical bench, aiming to understand and possibly compress the observed “random walk” tendency of optical phase’s Allan variance.



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**PhD course of National Interest in Technologies for
Fundamental Research in Physics and Astrophysics**

• **List of attended courses and passed exams**

- Design of readout integrated circuits for particle detectors (prof. Loddo - INFN Bari) → Passed
- Cabling and shielding for low noise applications (prof. Aloisio - UniNA Federico II) → Attended
- Microelectronics for radiation detectors II (prof. Mazza - INFN Torino) → Exam planned
- Advanced FPGA design and management techniques (prof. Biesuz – INFN Ferrara) → Ongoing

• **List of attended conferences, workshops and schools, with mention of the presented talks**

- 3rd Einstein Telescope Annual Meeting: Nov 12-15, 2024, Warsaw → Poster
(<https://indico.ego-gw.it/event/764/overview>)
- Tech-FPA PhD Retreat: Feb 17-21, 2025, Gran Sasso National Laboratories
(<https://agenda.infn.it/event/43840/>)
- Workshop on Electronics for Physics Exp. Applications @INFN: Mar 5-7, 2025, Torino → Poster
(<https://agenda.infn.it/event/44098/>)
- XV ET Symposium: May 26-30, 2025, Bologna → Poster
(<https://indico.ego-gw.it/event/819/>)
- 14th White Rabbit Workshop: Jun 25-26, 2025, CERN
(<https://indico.cern.ch/event/1524513/>)
- European Time and Frequency Seminar (EFTS): Jun 30 - Jul 4, 2025, FEMTO-ST Institute in Besançon
(https://efts.eu/dokuwiki/doku.php?id=current:00_start)

• **List of published papers/proceedings**

- “FPGA-Based RoCEv2-RDMA Readout Electronics for the CTAO-LST Advanced Camera” → Coauthor

• **Thesis title (even temporary)**

Development of a low phase noise frequency synthesizer for Gravitational Wave Detectors

Date, 10/09/2025

Signature

Marco Toffano

Seen, the supervisor

M. Bellini
Jean-Louis Taq.