SIESTA
A General Purpose Simulation Program for the VIRGO Experiment

Frédérique MARION
LAPP, BP 110, F-74941 Annecy-le-Vieux CEDEX, France

for the VIRGO Collaboration:

B.Caron, D.Castellazzi, M-L.Dedieu, L.Derome, A.Dominjon, C.Drezen, R.Flaminio, X.Grave, F.Marion, L.Massonnet, C.Mehmel, R.Morand, B.Mours, V.Sannibale, M.Yvert
Laboratoire de Physique des Particules (LAPP), Annecy-Le-Vieux, France

E.Bougleux, M.Mazzoni, P.Pelfer, R.Stanga
Dipartimento di Fisica dell'Universitá e INFN sezione di Firenze, Italy

D.Babusci, S.Bellucci, S.Candusso, G.Giordano, G.Matone
Laboratori Nazionali dell'INFN, Frascati, Italy

J-M.Mackowski, L.Pinard
Université Claude Bernard, IPNL, Villeurbanne, France

F.Barone, E.Calloni, L. Di Fiore, M.Flagiello, F.Garufi, A. Grado, M.Longo, M.Lops, S.Marano, L.Milano, S.Solimeno
Dipartimento di Scienze Fisiche dell'Università e INFN Sezione di Napoli, Italy

V.Brisson, F.Cavalier, M.Davier, P.Hello, P.Heusse, P.Mann, L.Matone
Laboratoire de l'Accélérateur Linéaire, Université Paris-Sud, Orsay, France

Y.Acker, M.Barsuglia, B.Bhawal, F.Bondu, A.Brillet, F.Cleva, H.Heitmann, J-M. Innocent, L.Latrach, C.N. Man, M. Pham-Tu, E.Tournier, M.Taubmann, J-Y. Vinet
Groupe Laser Optique, Université Paris-Sud, Orsay, France

C.Boccara, Ph.Gleyzes, V.Loriette, J-P.Roger
Laboratoire de Spectroscopie en Lumière Polarisée, Ecole Supérieure de Physique et Chimie Industrielle, Paris, France

G.Cagnoli, L.Gammaitoni, J.Kovalik, F.Marchesoni, M.Punturo
Dipartimento di Fisica dell'Università e INFN Sezione di Perugia, Italy

M.Beccaria, M.Bernardini, S.Braccini, C.Bradaschia, G.Cella, A.Ciampa, E.Cuoco, G.Curci, R.Del Fabbro, R.De Salvo, A.Di Virgilio, D.Enard, I.Ferrante, F.Fidecaro, A.Giassi, A.Giazotto, L.Holloway, P.La Penna, G.Losurdo, S.Mancini, F.Palla, H-B.Pan, D.Passuello, R.Poggiani, A.Vicerè,Z. Zhang
Dipartimento di Fisica dell'Università, INFN Sezione di Pisa e Scuola Normale Superiore, Italy

V.Ferrari, E.Majorana, P.Puppo, P.Rapagnani, F.Ricci
Dipartimento di Fisica dell'Università "La Sapienza" e INFN Sezione di Roma 1, Italy

ABSTRACT

The simulation program developped for the VIRGO collaboration is designed as a general purpose tool for detector design, detector commissioning and data analysis. It allows to simulate in an integrated way some expected gravitational wave signals as well as many aspects of the detector response. The general structure and contents of the simulation program are described, as well as a typical application example.

1. Introduction

The development of an integrated, general purpose simulation program for the VIRGO experiment has been going on for several years.[1] One of the goals of the SIESTA software was to provide a tool for the detector design and commissioning, especially as far as the control of the interferometer is concerned. To reach this goal, a global simulation of the interferometer operation is needed, not only for the case when the interferometer is around its working point but also for the lock acquisition phase. The other major goal of SIESTA is to provide simulated data for data analysis, in order to develop search and trigger algorithms. Moreover, attention has been paid to make the software modular enough so that some pieces may be used in connection with other VIRGO softwares. These motivations have led to the main features of the software design.

One of the choices has been to perform the simulation in the time domain. This is important for data analysis since it allows to produce the same type of simulated data as real data. It is also useful when non-linear effects have to be taken into account, such as non-linearities in the interferometer optical response or in the electronics.

SIESTA is written in the C language, and is based on an object-oriented structure that is most suitable to build an integrated simulation involving many different aspects. The implemented framework allows to integrate the generation of gravitational wave events with the simulation of the most relevant aspects of the detector operation: behavior of suspended mirrors, interferometer optical response, control, DAQ (see Figure 1). Since the level of accuracy needed for some aspects of the simulation may vary according to the issue investigated, various models are made available as options whenever possible.

Not all the simulation developments carried out in VIRGO have been integrated into SIESTA. Very specific issues such as the problem of scattered light or the needed requirements on the mirror surface quality have been addressed through dedicated simulation tools that need not be integrated in the general software.

2. Contents of the simulation

In this section, we review briefly the contents of the different modules building up SIESTA.

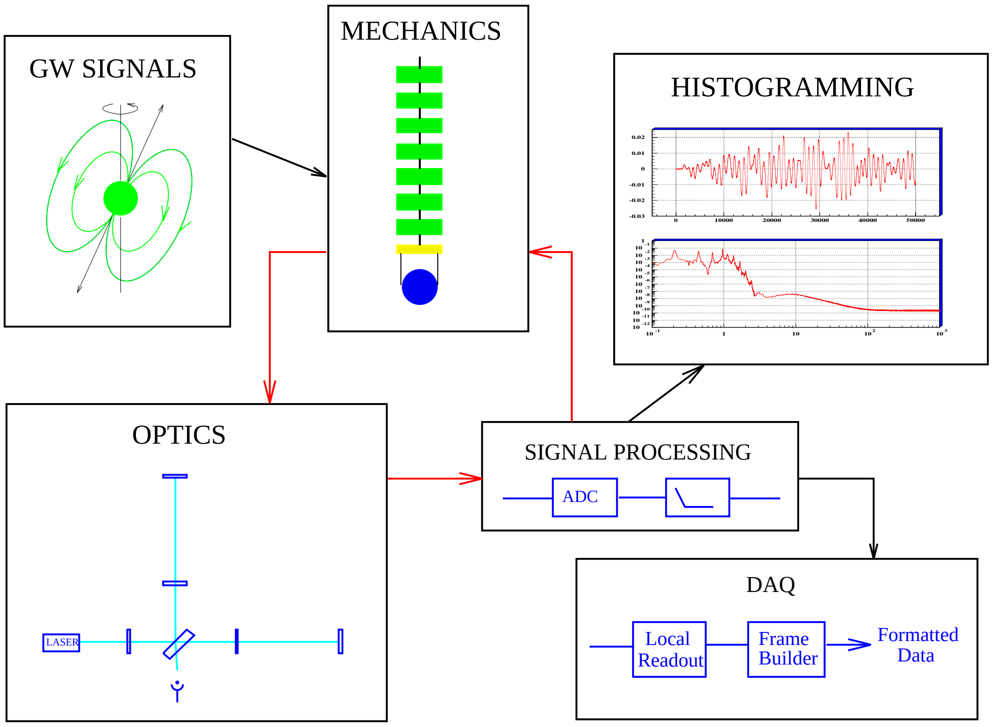

Figure 1: Illustration of the different modules integrated into SIESTA.

2.1. Gravitational wave event generator

This module simulates the signal emitted by a source and translates it into a signal at the detector level taking into account Doppler effect as well as amplitude and phase modulation due to Earth rotation.[2] As far as sources are concerned, a basic generator is available for pulsars and binary coalescences (up to first post-Newtonian order).

2.2. Simulation of suspended mirrors

This module allows to compute the position of a suspended mirror as a function of time taking into account the action of seismic noise, thermal noise, and feedback forces that may be applied on the mirror from its reference mass or from the marionette. The simulation is based on a numerical resolution of the motion equation of a chain of massive pendula in one dimension. The angular degrees of freedom are not yet taken into account. The injection of seismic and thermal noise is made by generating random sequences with white frequency distribution and filtering them in order to get the proper frequency spectrum.

2.3. Optics module

The part of SIESTA that deals with optical simulation is designed as a toolkit that provides some general methods to simulate any user defined configuration together with more specific models dedicated to the case of a VIRGO-like interferometer. The generic simulation may be performed using either a wavefront computation technique using FFT for propagation,[3] or a method based on an eigenmode expansion of the field and using simple algebra for propagation and reflection.[4]

The specific models provide a variety of tools to perform fast quasistatic simulations as well as dynamic simulations both in the linear and in the non-linear domain (i.e. when cavities are close to resonance or not) and taking into account misalignment effects. As a matter of example, this allows us to extract the transfer functions between the vibration modes of the interferometer and the different signals collected on the photodiodes, or to model the signals observed in case a cavity sweeps through resonance with high velocity.

2.4. Signal processing

A SIESTA module is dedicated to signal processing, namely digital filtering and simulation of analog to digital conversion. This allows us to simulate control loops explicitely in the time domain. A typical application example is shown in more details in the next section.

3. An application example

A typical application of SIESTA involving most of its contents is the simulation of the interferometer longitudinal control, as summarized on Figure 2. This kind

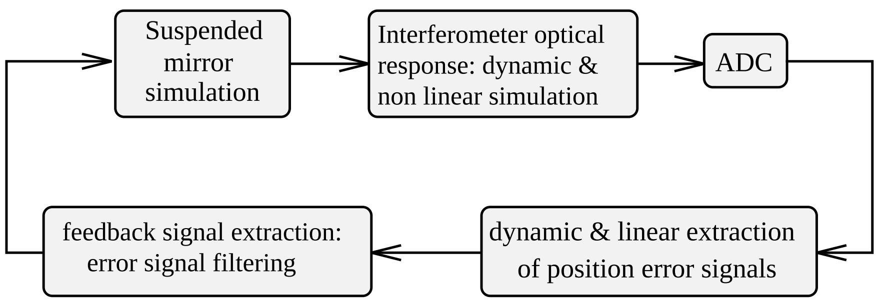

Figure 2: Principle of a typical simulation involving the longitudinal control of the interferometer.

of simulation involves the simulation of the suspended mirrors, the simulation of the interferometer response accounting for non-linearities and frequency dependence, the conversion of the signals collected on the photodiodes, the (frequency dependant) extraction of the mirror position error signals, and the processing to extract correction forces fed back to the mirrors. Figure 3 shows the spectrum obtained from a FFT of an observed sequence of values of the main signal at the antisymmetric port of the interferometer for a given choice of control strategy. To translate this spectrum into a sensitivity spectrum, a pseudo calibration can be performed by measuring the transfer function between the differential vibration mode of the interferometer and the observed signal. This transfer function can then be used to unfold the detector response in the spectrum considered. This spectrum is shown as a matter of example and illustrates how such a simulation gives us the possibility to evaluate the strategy choices for the control and their robustness, as well as the possible effect of the limited dynamics of the converters or the influence of residual mirror misalignments, etc.

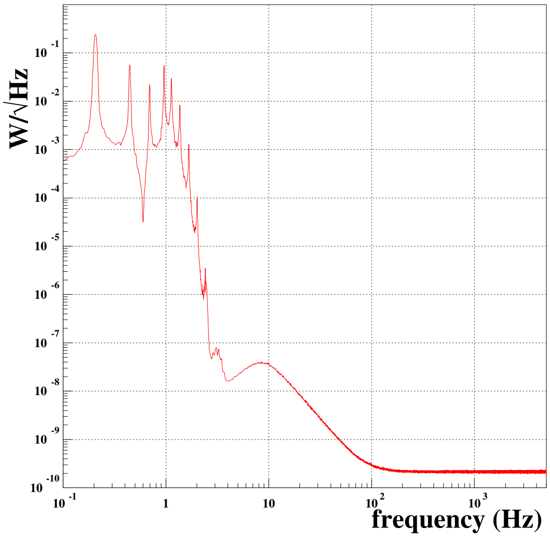

Figure 3: Spectrum of the antisymmetric port signal derived as the Fourier transform of a sequence of values obtained from a simulation in the time domain involving the longitudinal control of the interferometer.

4. Conclusion

The SIESTA software provides a tool for an integrated simulation of the VIRGO interferometer. Its main current application fields are the design of the interferometer control system and the production of simulated data to develop data analysis algorithms.

The software developments are steadily going on. The mid term efforts should concern the simulation of the suspended mirrors - with the implementation of the angular degrees of freedom - and the development of the gravitational wave generator.

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