1500W Control system

M. Bawaj

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A.D. 1308 unipg
UNIVERSITÀ DEGLI STUDI DI PERUGIA

VIRGO

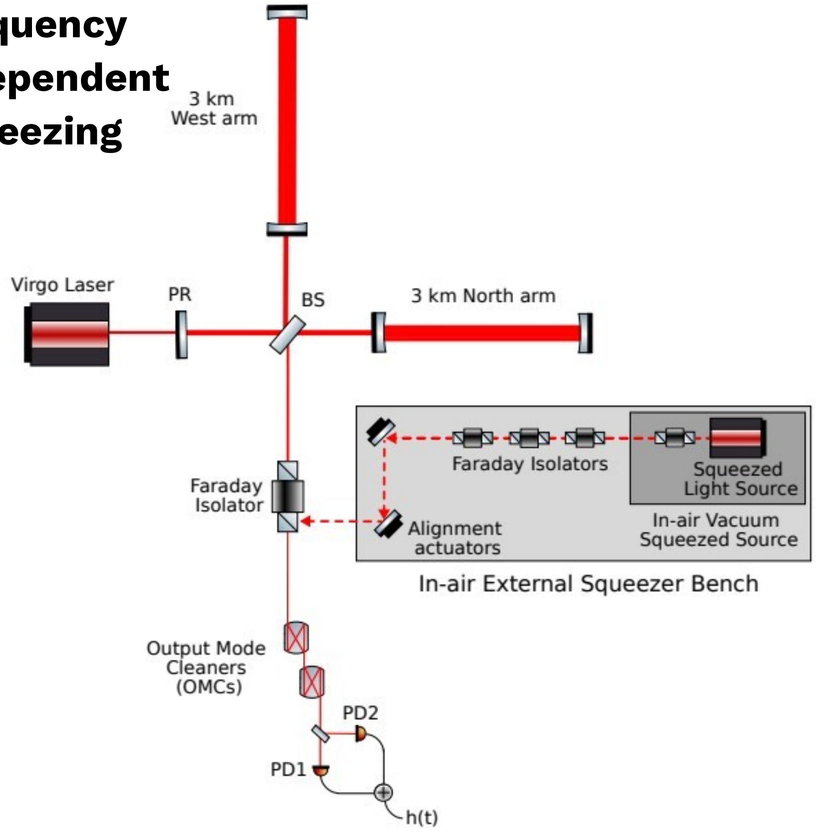
INFN Istituto Nazionale di Fisica Nucleare

Presentation plan

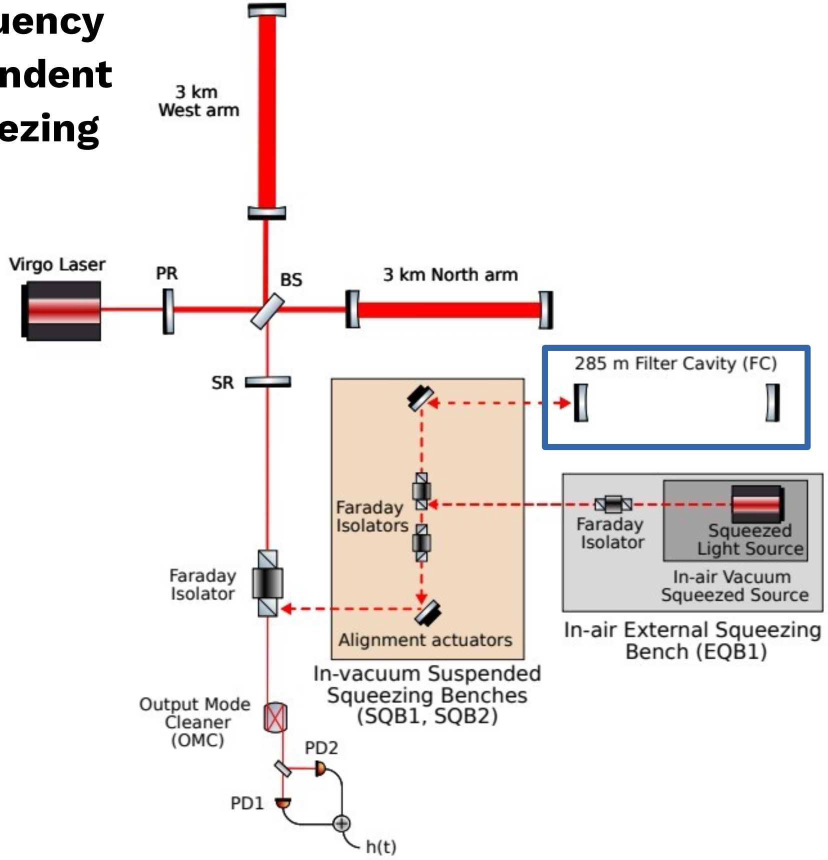
- Frequency dependent squeezing + EPR
- Optical bench
- Optical cavity lock
- Our finite state machine
- High level control software

From FIS to FDS

Frequency Independent Squeezing

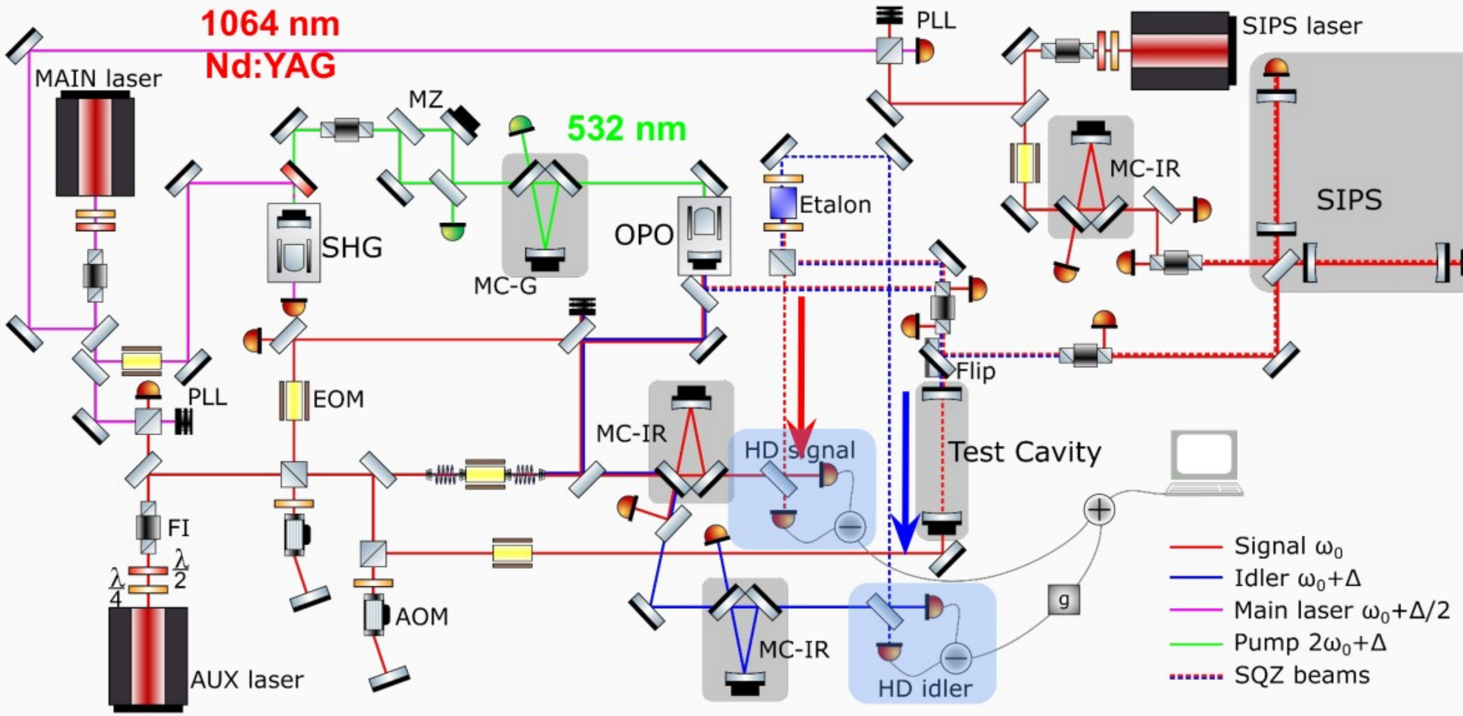


Frequency Dependent Squeezing

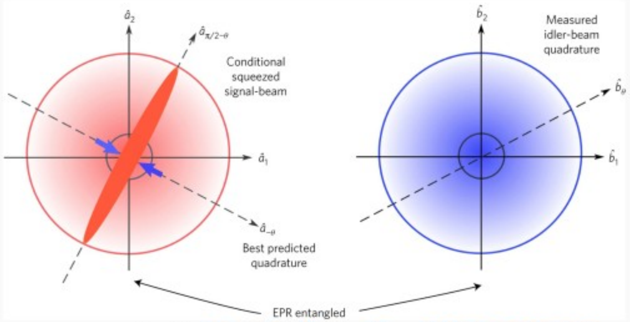


EPR working principle

courtesy of F. De Marco



1. **Signal** and **idler** are vacuum squeezed beams, EPR-entangled and detuned by Δ
2. The **idler** acquires frequency-dependence in SIPS due to its detuning
3. Combined measurement with optimal filter gain transfers the frequency dependence to the **signal** via EPR entanglement



Credits: Ma *et al.* - Nature Phys 13, 776–780 (2017)

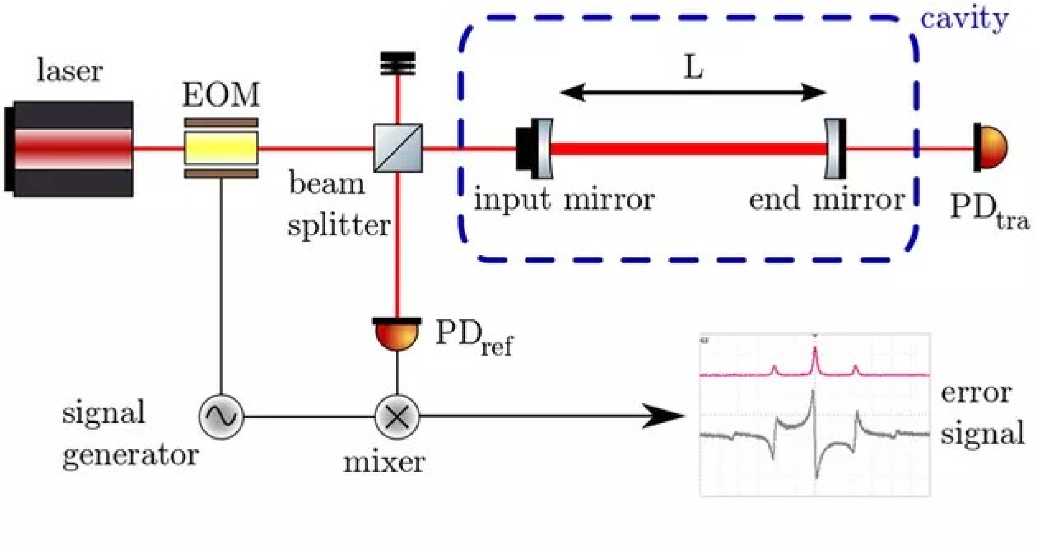
Pros:

- More compact and cheaper
- More flexible vs SR
- Avoids FC optical losses

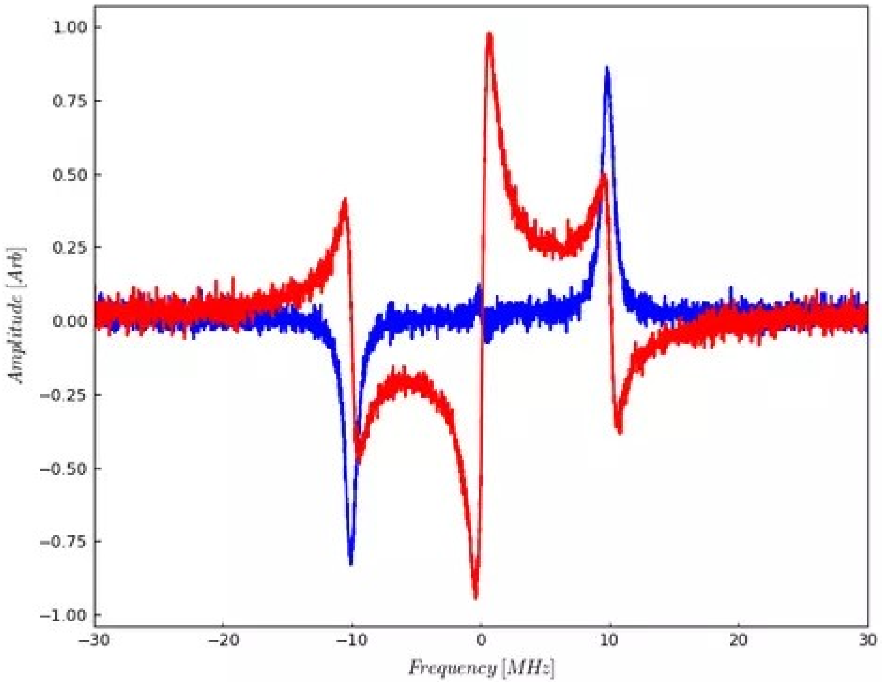
Cons:

- 2 squeezed beams to be handled
- 3 dB penalty w.r.t. optimal squeezing rotation ellipse

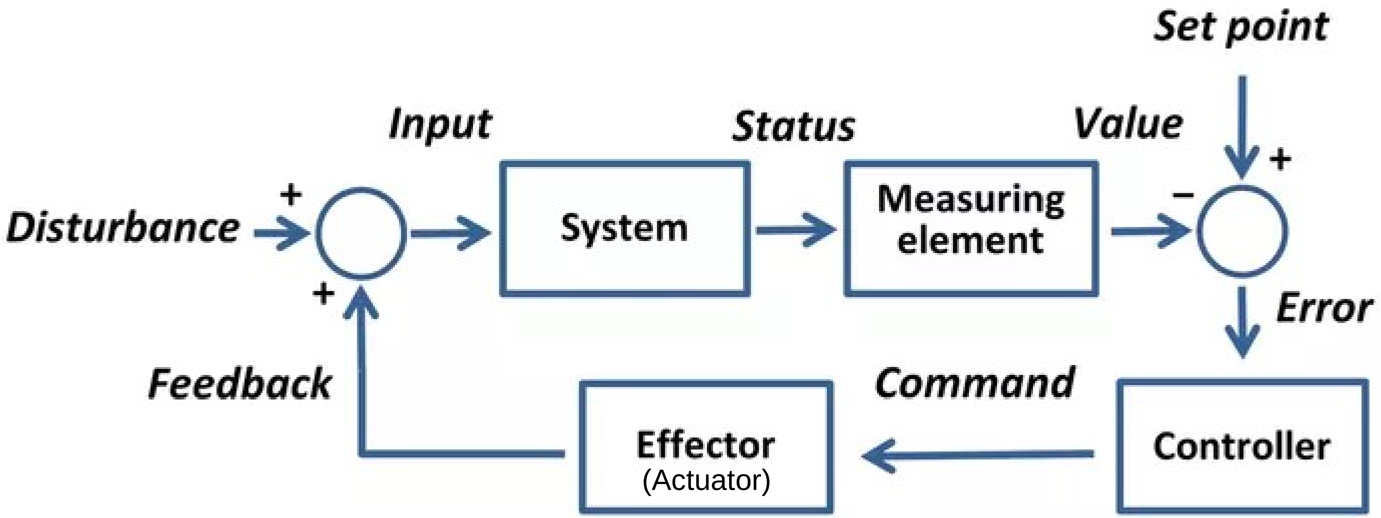
Pound-Drever-Hall error signal generation



PD_{ref} demodulation:
– right phase (quadrature)
– orthogonal phase (complementary)



Negative feedback loop



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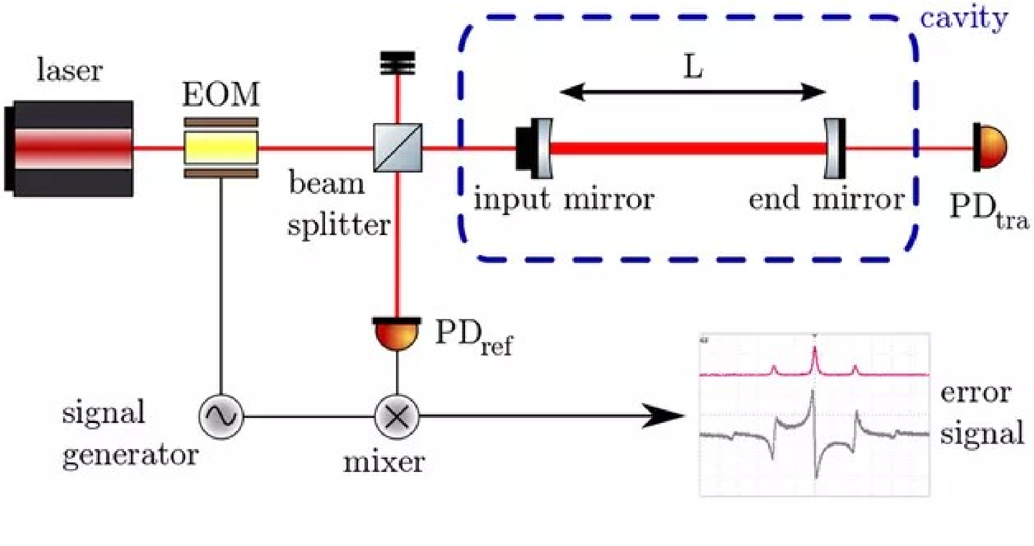

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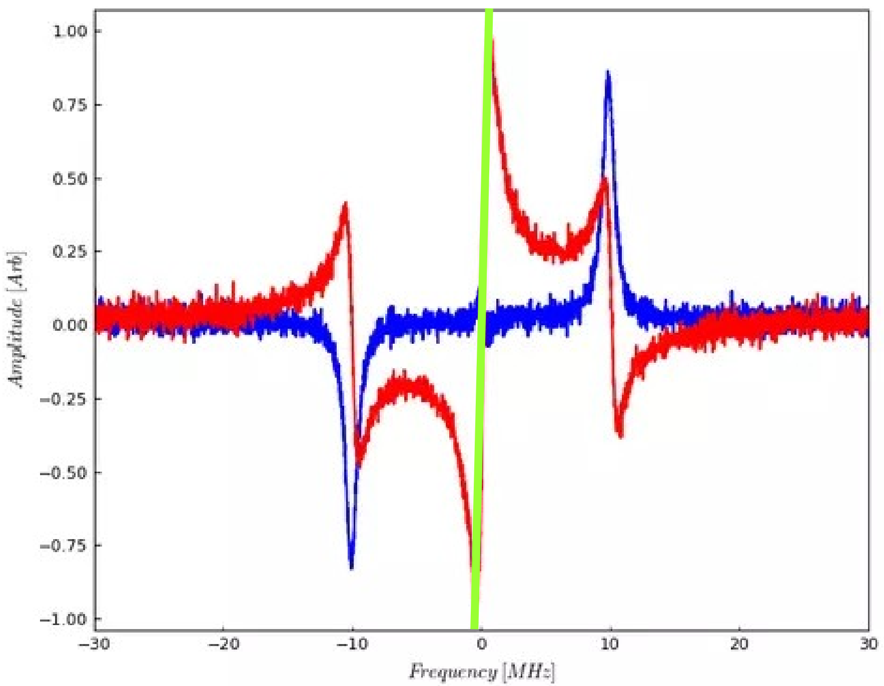
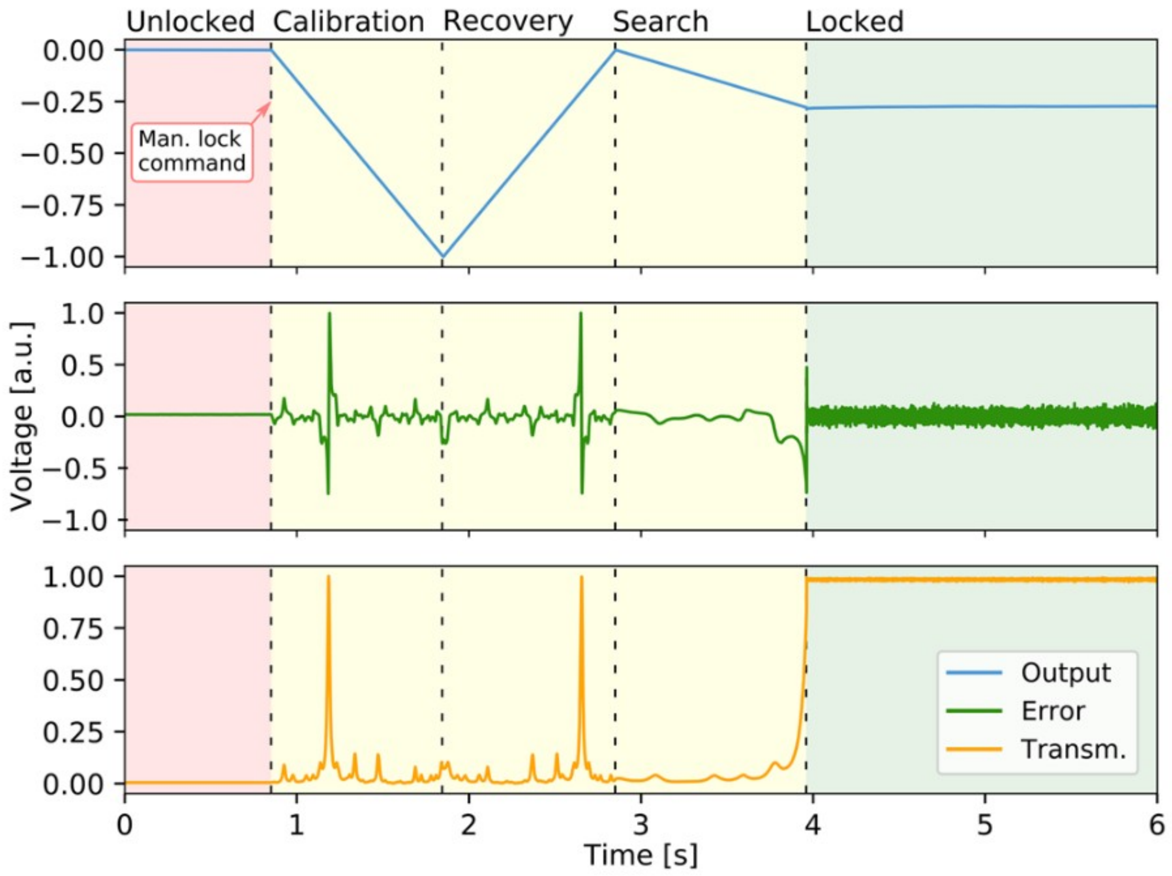


Generic controller



Four automated phases:

- Calibration
- Recovery
- Search
- Locked

Additional mode:

- Scan

Nguyen, C., et al. "Automated Source of Squeezed Vacuum States Driven by Finite State Machine Based Software." Review of Scientific Instruments 92, no. 5 (May 1, 2021): 054504. https://doi.org/10.1063/5.0046317

Suspension Control System DSP

Each UDSPT unit contains:

- 6 analog-to-digital and 6 digital-to-analog converters (24-bit, 1MSPS);
- FPGA and DSP.

Units in the same create communicate via back panel.

Each unit can become a TOLM.

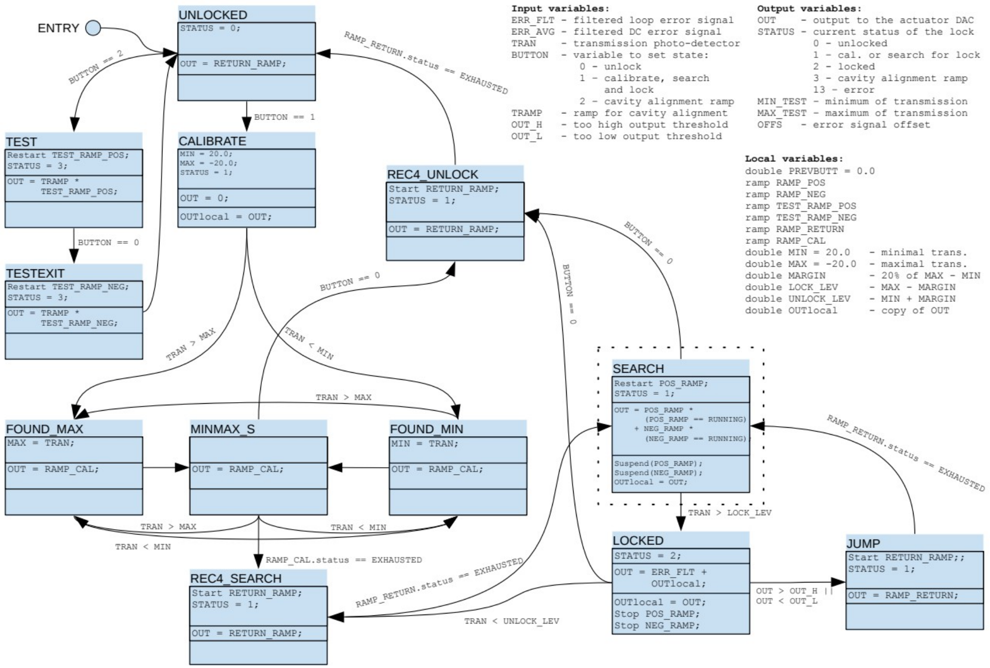
There are 20 crates in Advanced Virgo, that means ~200 UDSPT boards in total.

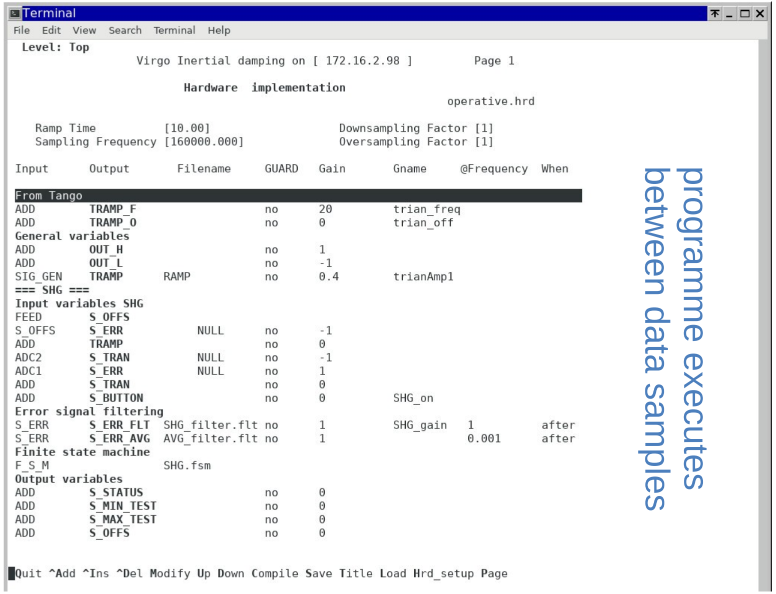
UDSPT unit boards in a μTCA chassis. On the right there is the NAT-MCH switch. Entire crate has ~800 GFLOPS of computing power available.

Suspension Control System DSP

Software:

- Programming language (~ASM)
- Digital FIR filters
- Data exchange between units
- Finite State Machine





programme executes between data samples

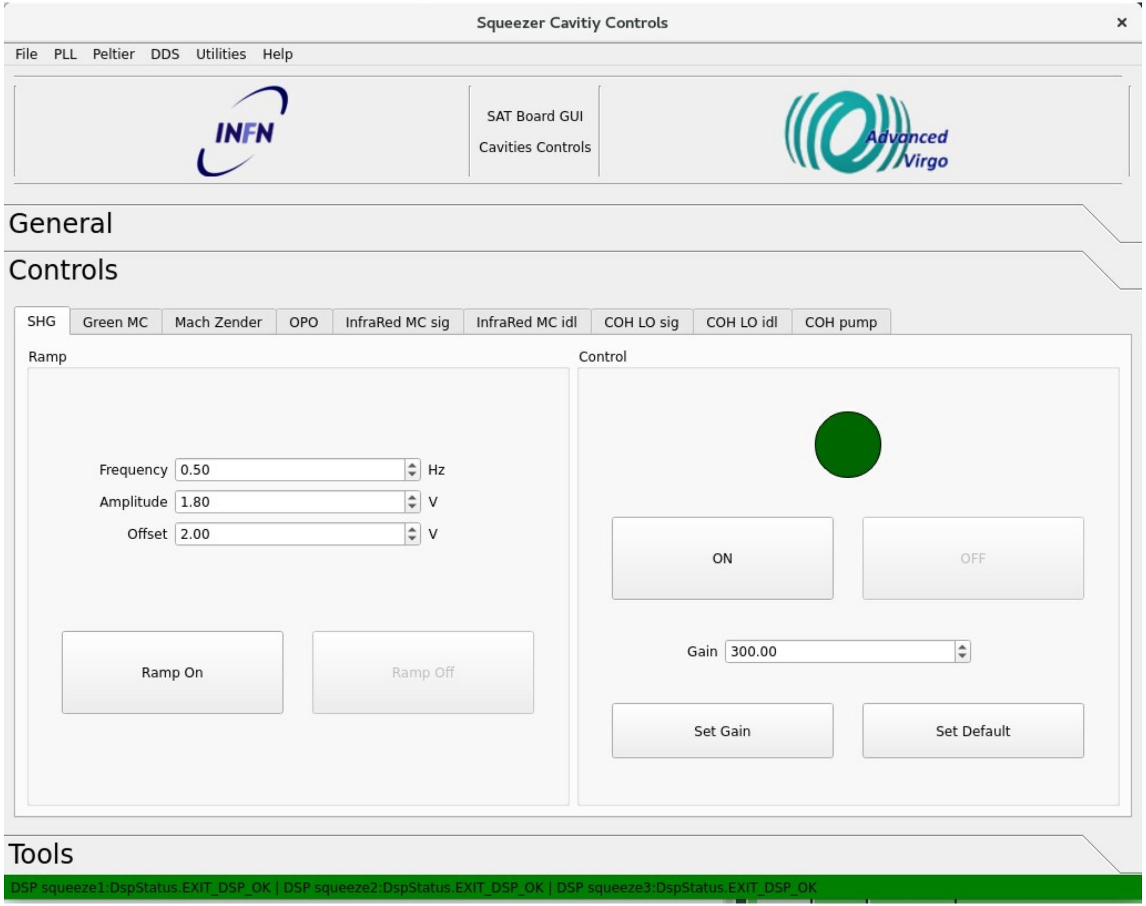
execution rate 160kHz

Suspension Control System DSP

Graphical User Interface

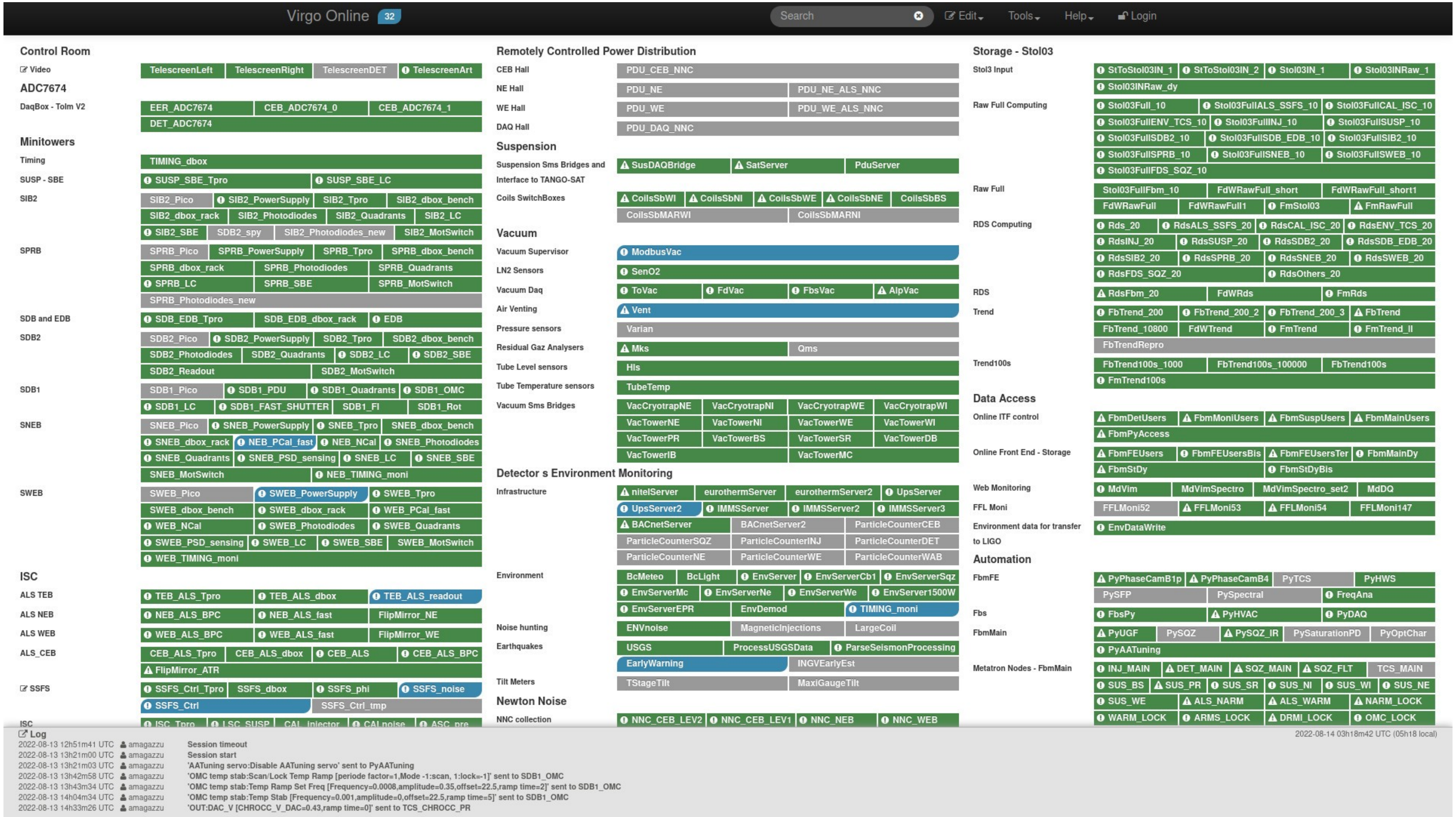
Software:

- Python based
- Minimizes parameters
- Speeds up interaction with loops
- Provides feedback on the status



execution rate 160kHz

Virgo Process Monitoring (VPM)



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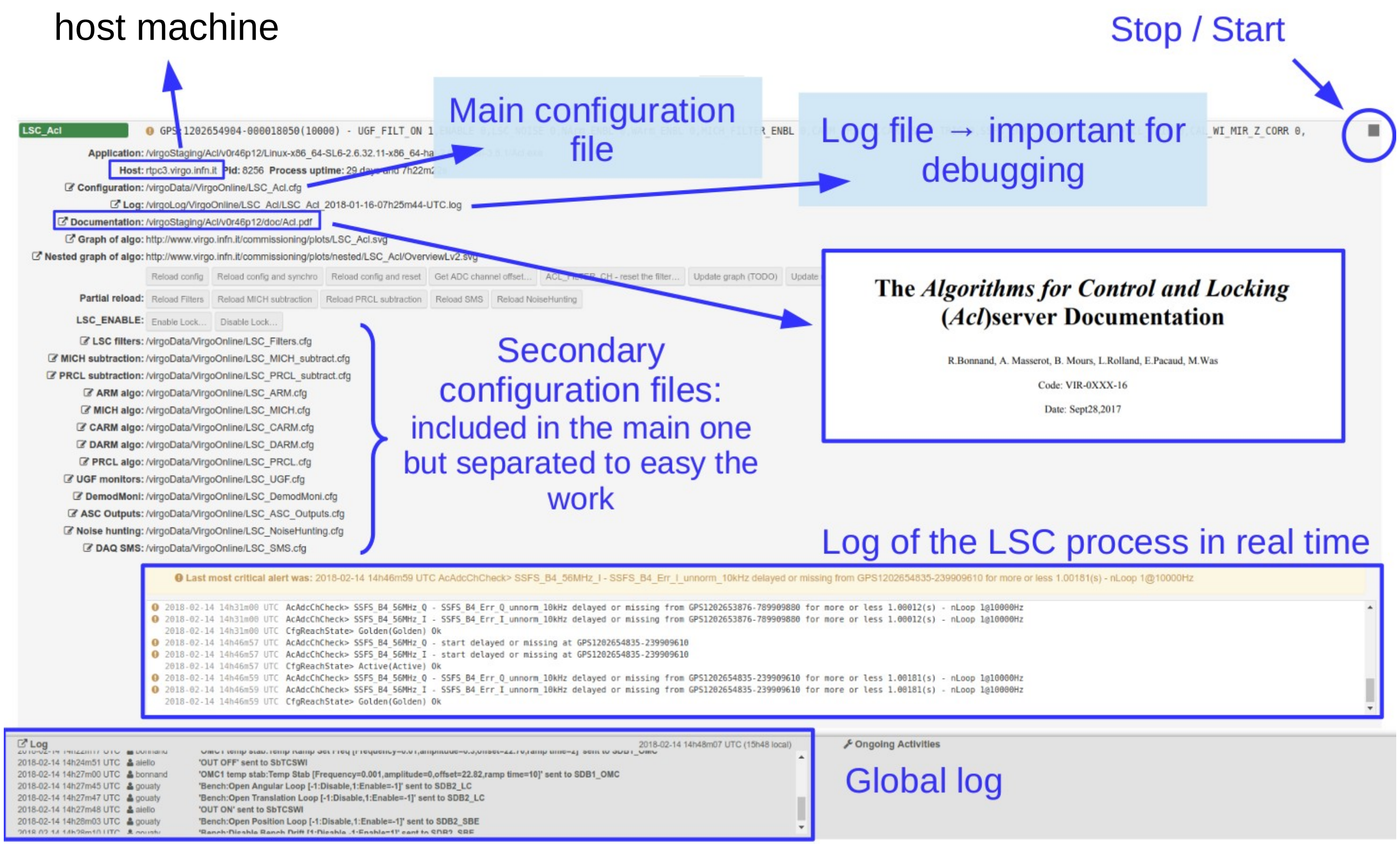
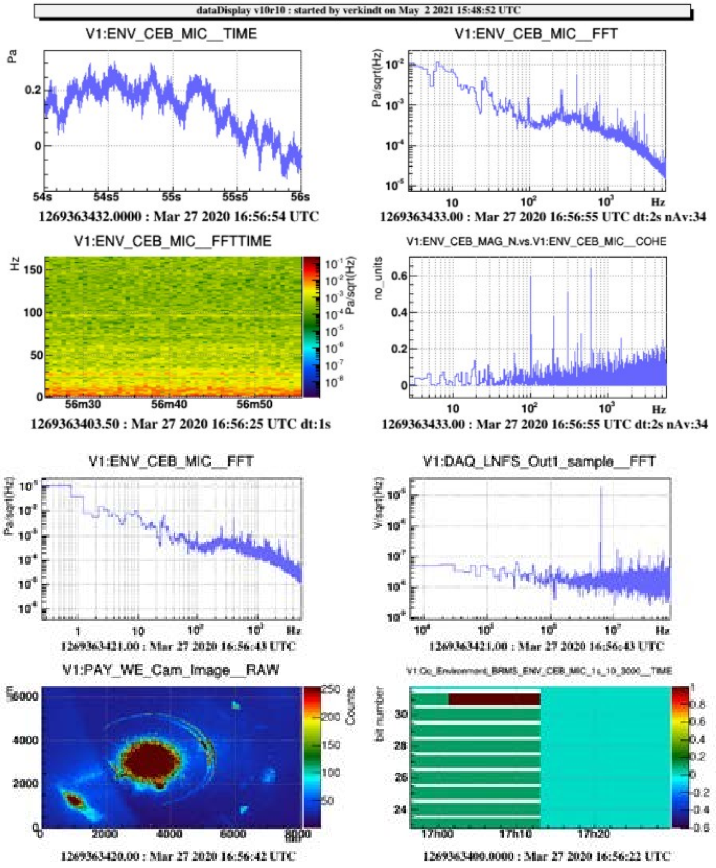


DataDisplay

dataDisplay plots



Real-time Virgo data plot at real sampling frequency

Features:

- time series plot
- averaging and overlaying
- spectrum with spectral density computation plot
- spectrum waterfall
- reference
- zoom
- data export
- coherence between two channels
- transfer function between two channels

Verkindt, D. “ Advanced Virgo+ dataDisplay. Users Manual”, Technical note, Virgo, 2022. https://tds.virgo-gw.eu/?content=3&r=20688.

PyALP / PyServer

PyALP and PyServer are two similar concepts based on python implementation.

```
from virgotools import cm_send, AclServer
import logging
import numpy as np

def setup(state, frame, outputs):
    # produced channel
    outputs.add_channels('ON', prefix='SQZ')

    outputs.ON = 0
    log.info("Init done")

def loop(state, frame, outputs):  # every each second
    outputs.ON = 1

    err_signal = np.mean(frame.LFC_SC_PD_RF_11MHz_I_CAL)

    # perform the action every 2 seconds
    if frame.gps % aom_actuation_time == 1:
        # do the job

    outputs.info = ('ON: {}').format(outputs.ON)
```

- has direct access to data

```
from pyserver import *
from virgotools import *
import os, time
import configparser
config = configparser.ConfigParser()

@cm_handler
def handle_command(message, sender, _):
    sender = pvt_utils.native_str(sender)
    logger.info('Received a message from %s', sender)
    try:
        message = cm_lib.parse_cm_message(message)
        logger.info('Parsed message*: %r', message)
    except:
        logger.exception('Error')
    # do the handling procedure
    return cm.CmMessageOk

def init():
    logger.info("Doing init")
    cm.CmMessageInstallHandler(handle_command, 'my_cmd')
    return None

def worker():  # every each second
    data = do_the_worker_job()
    return data

run_server(worker, init=init)
```

- has **no** direct access to data
- based on asyncio

References

1) Acernese, et al. “The Advanced Virgo Longitudinal Control System for the O2 Observing Run.” Astroparticle Physics 116 (March 2020): 102386. https://doi.org/10.1016/j.astropartphys.2019.07.005.

2) Berni, F., “DMS help manual”, Technical note, Virgo, 2020. https://tds.virgo-gw.eu/?content=3&r=17053.

3) Evers, E., et al. “On Frequency Response Function Identification for Advanced Motion Control.” arXiv, June 18, 2020. http://arxiv.org/abs/2006.10373.

4) Nguyen, C., et al. “Automated Source of Squeezed Vacuum States Driven by Finite State Machine Based Software.” Review of Scientific Instruments 92, no. 5 (May 1, 2021): 054504. https://doi.org/10.1063/5.0046317.

5) Acernese, F., et al. “Increasing the Astrophysical Reach of the Advanced Virgo Detector via the Application of Squeezed Vacuum States of Light.” Physical Review Letters 123, no. 23 (December 5, 2019): 231108. https://doi.org/10.1103/PhysRevLett.123.231108.

6) Verkindt, D. “ Advanced Virgo+ dataDisplay. Users Manual”, Technical note, Virgo, 2022. https://tds.virgo-gw.eu/?content=3&r=20688.

Thank you for your attention!