

1500W Control system

M. Bawaj

meeting 30.06.2025 – Virgo Cascina



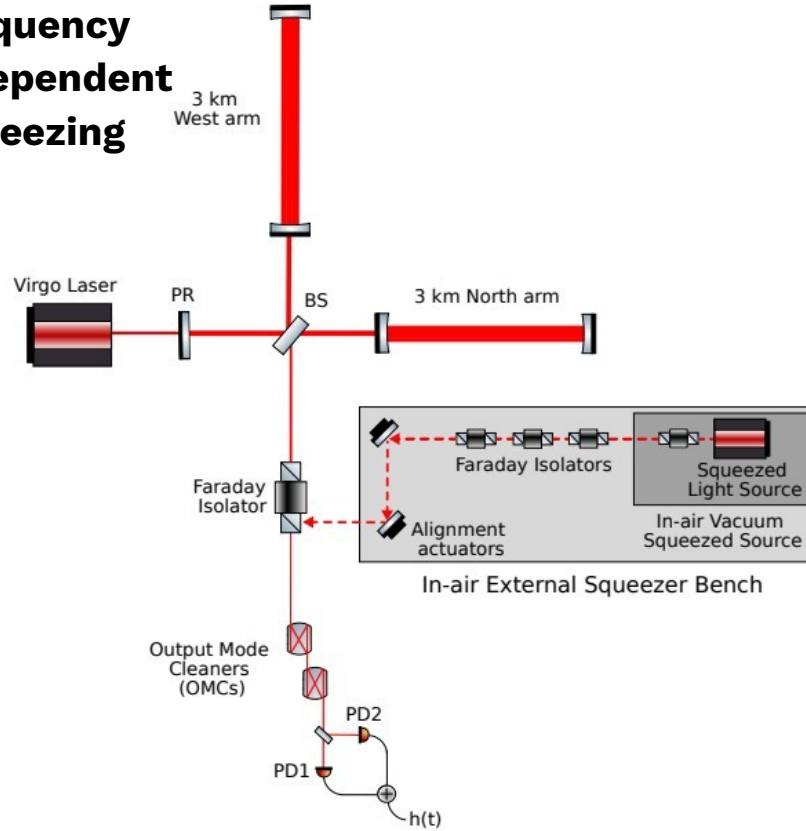
Presentation plan

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

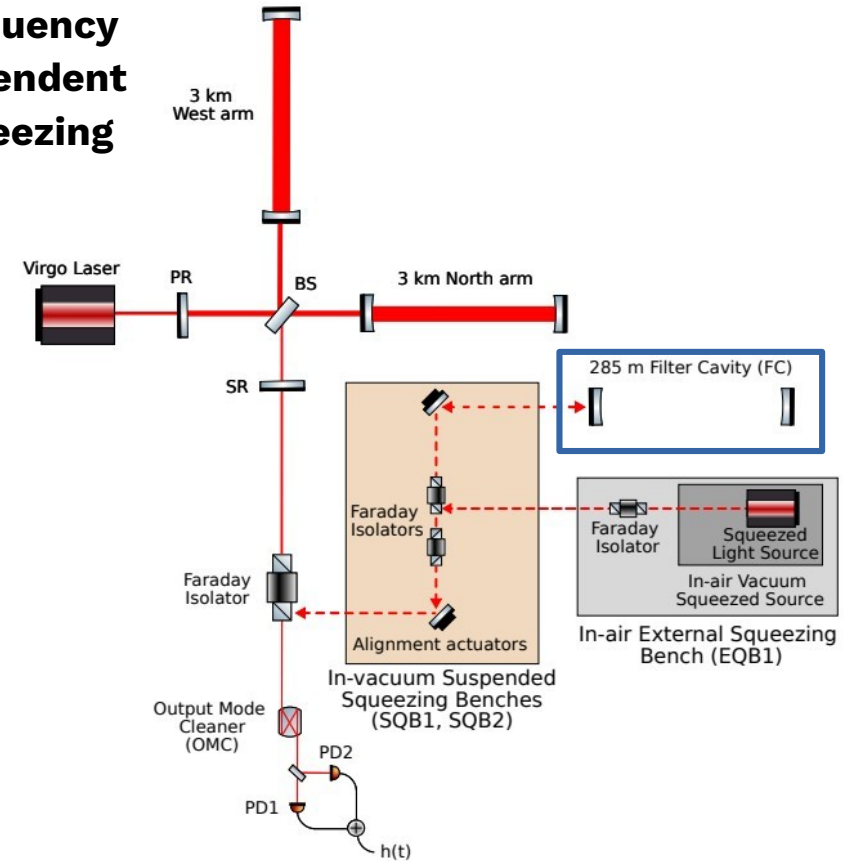


From FIS to FDS

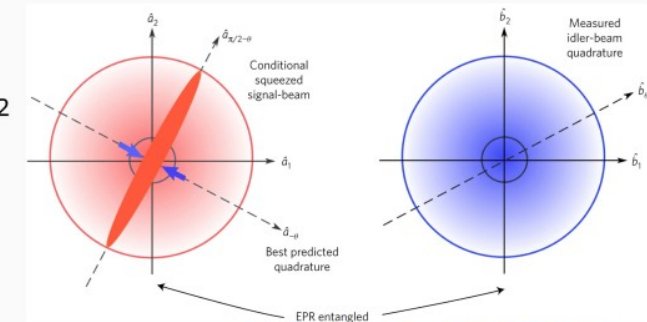
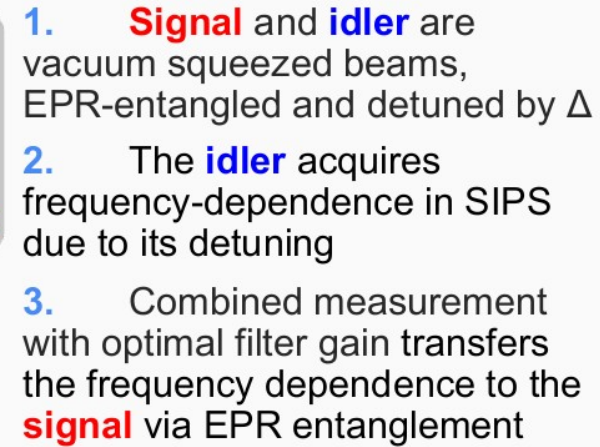
Frequency Independent Squeezing



Frequency Dependent Squeezing



courtesy of F. De Marco



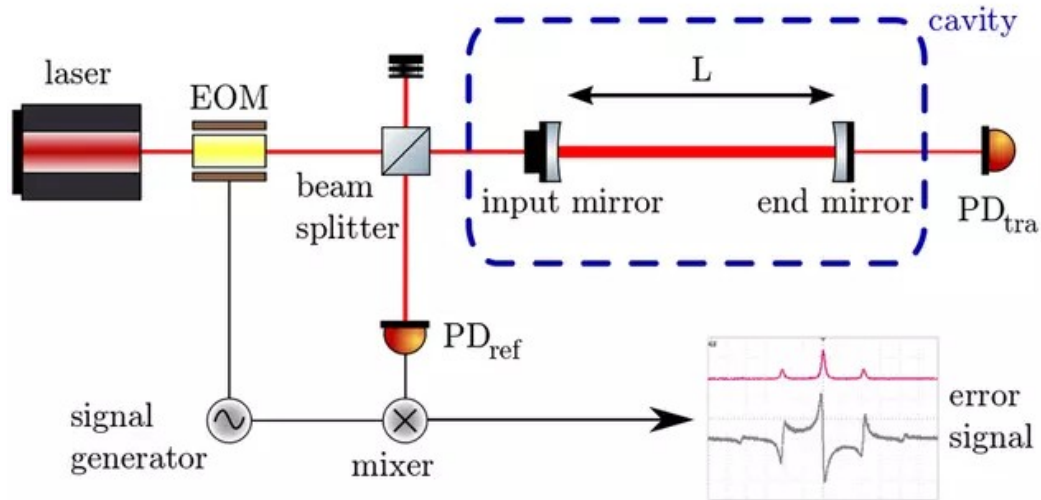
Credits: [Ma et al. - Nature Phys 13, 776–780 \(2017\)](#)

Cons:

- More compact and cheaper
- More flexible vs SR
- Avoids FC optical losses
- 2 squeezed beams to be handled
- 3 dB penalty w.r.t. optimal squeezing rotation ellipse

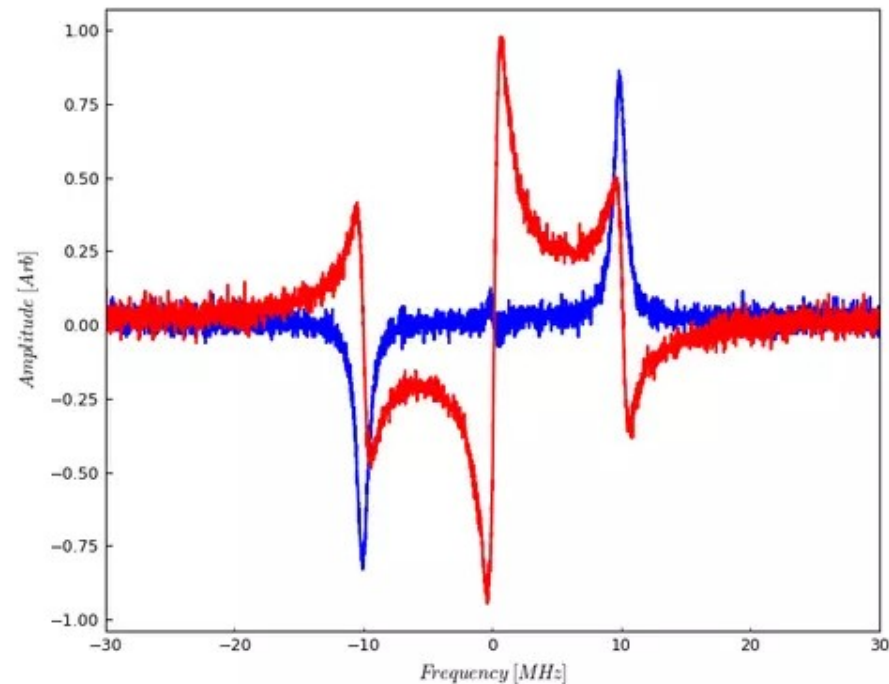


Pound-Drever-Hall error signal generation



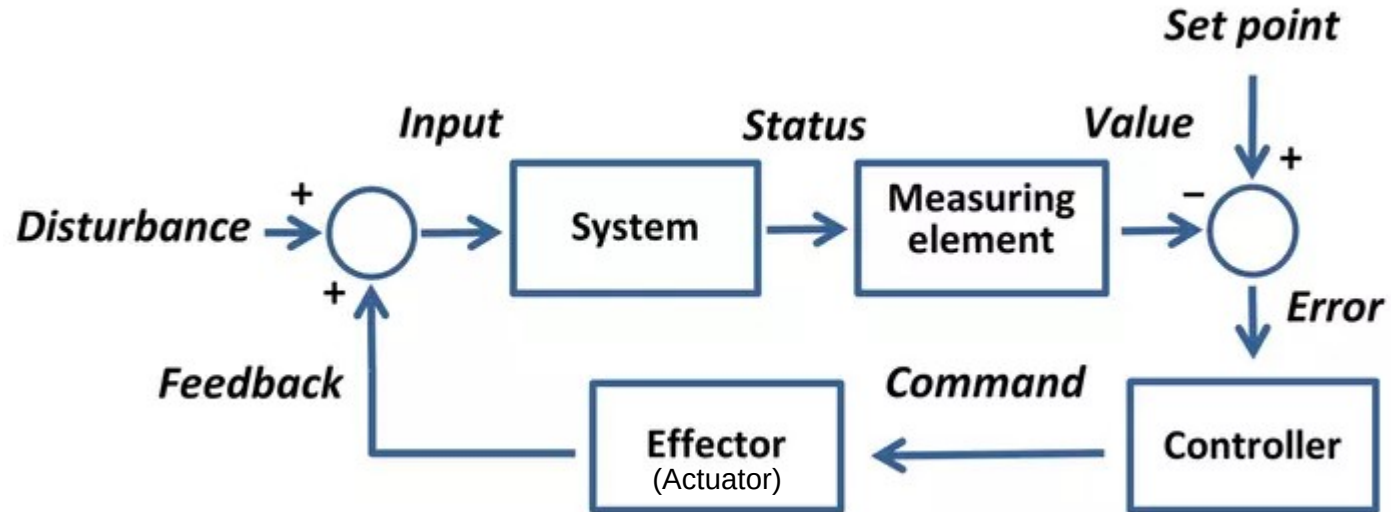
PD_{ref} demodulation:

- right phase (quadrature)
- orthogonal phase (complementary)



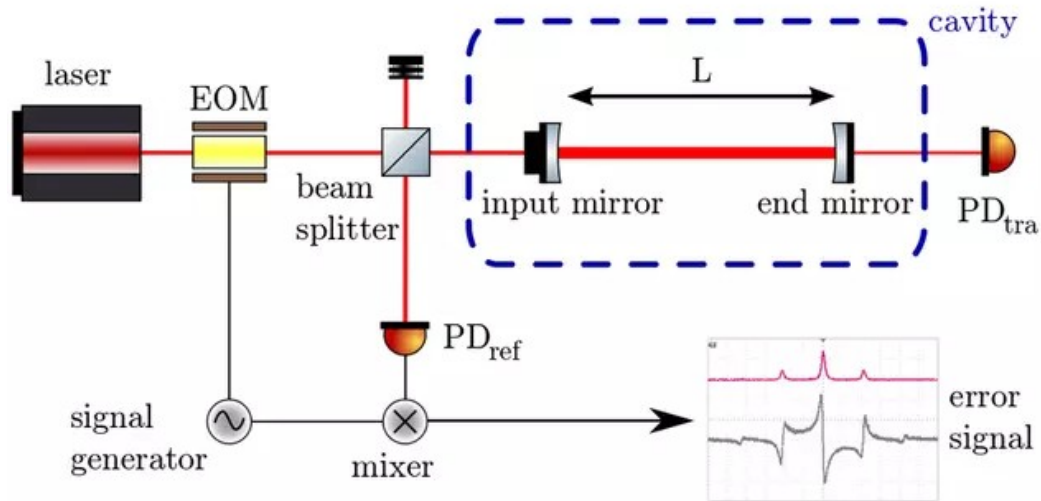


Negative feedback loop



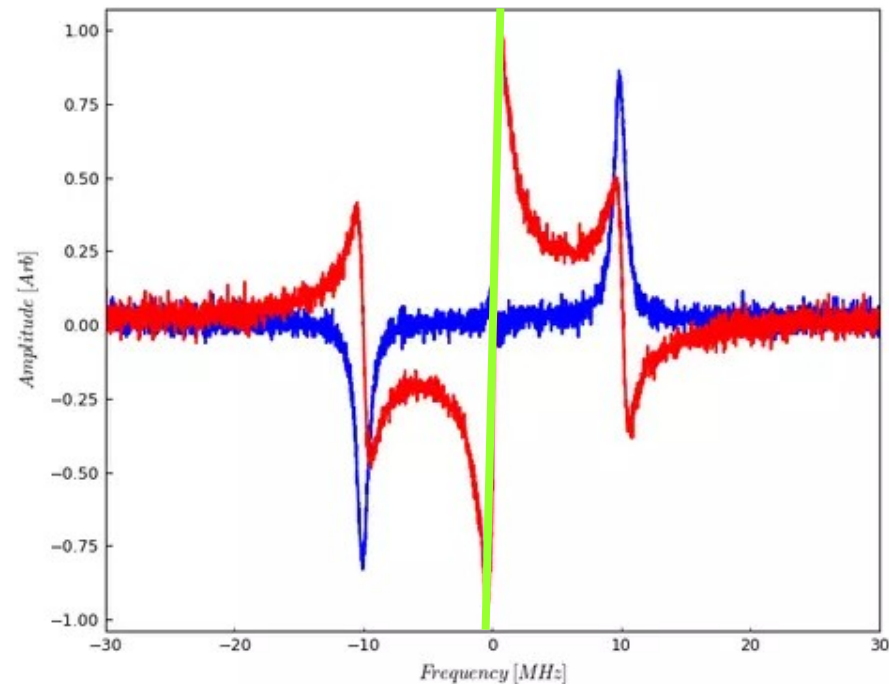


Pound-Drever-Hall error signal generation



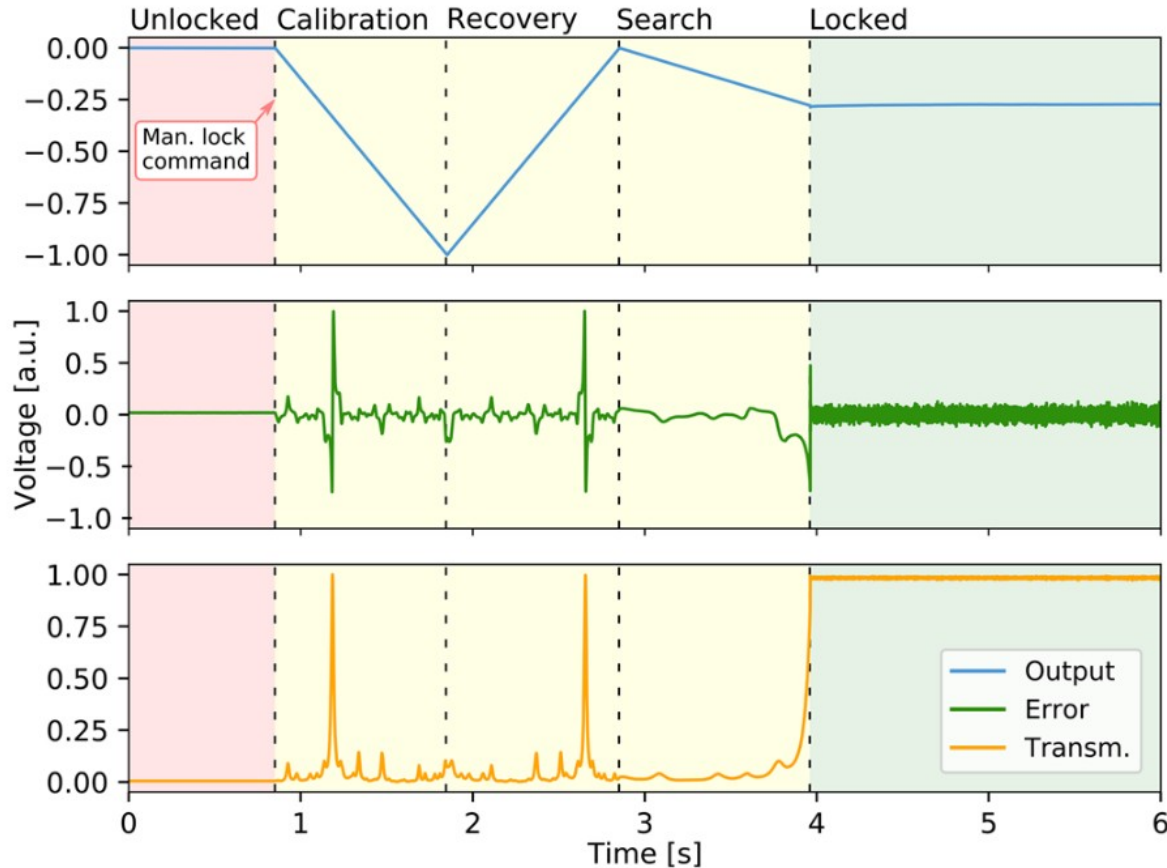
PD_{ref} demodulation:

- right phase (quadrature)
- orthogonal phase (complementary)





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 crate communicate via back panel.

Each unit can become a TOLM.

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



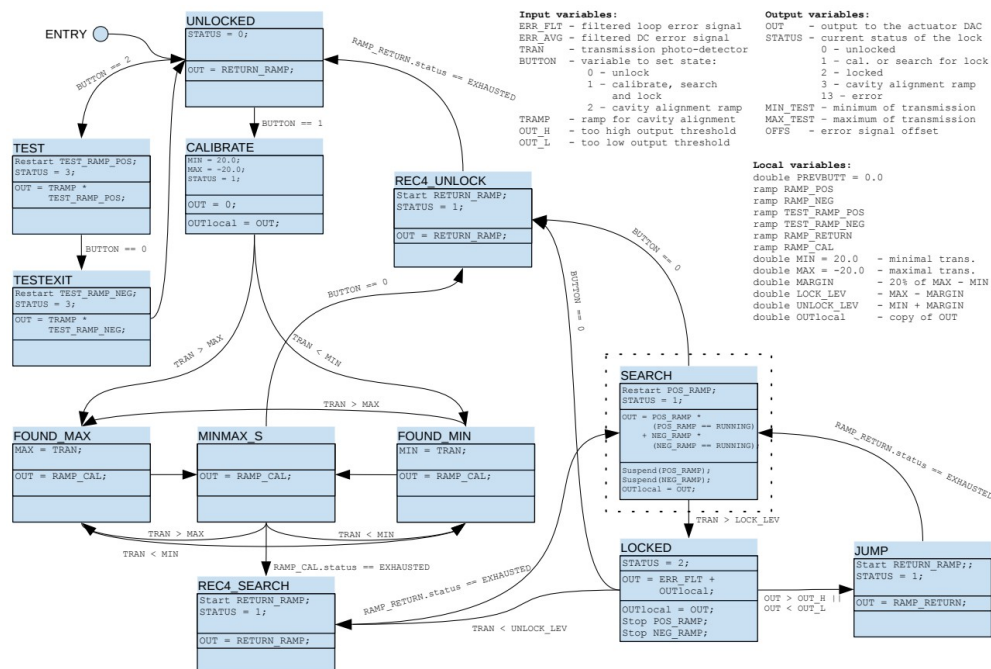
UDSPT unit boards in a μ TCA chassis. On the right there is the NAT-MCH switch. Entire crate has ~800 GFLOPS of computing power available.



Suspension Control System DSP

Software:

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



```
Terminal
File Edit View Search Terminal Help
Level: Top
Virgo Inertial damping on [ 172.16.2.98 ] Page 1

Hardware implementation
operative.hrd

Ramp Time [10.00] Downsampling Factor [1]
Sampling Frequency [160000.000] Oversampling Factor [1]

Input Output Filename GUARD Gain Gname @Frequency When
From Tango
ADD TRAMP_F no 20 trian_freq
ADD TRAMP_0 no 0 trian_off
General variables
ADD OUT_H no 1
ADD OUT_L no -1
SIG_GEN TRAMP RAMP no 0.4 trianAmpl
=== SHG ===
Input variables SHG
FEED S_OFFS NULL no -1
ADD TRAMP NULL no 0
ADC2 S_TRAN NULL no -1
ADC1 S_ERR NULL no 1
ADD S_TRAN no 0
ADD S_BUTTON no 0 SHG_on
Error signal filtering
S_ERR S_ERR_FLT SHG_filter.flt no 1 SHG_gain 1 after
S_ERR S_ERR_AVG AVG_filter.flt no 1 0.001 after
Finite state machine
F_S_M SHG.fsm
Output variables
ADD S_STATUS no 0
ADD S_MIN_TEST no 0
ADD S_MAX_TEST no 0
ADD S_OFFS no 0

Quit ^Add ^Ins ^Del Modify Up Down Compile Save Title Load Hrd_setup Page
```

programme executes
between data samples

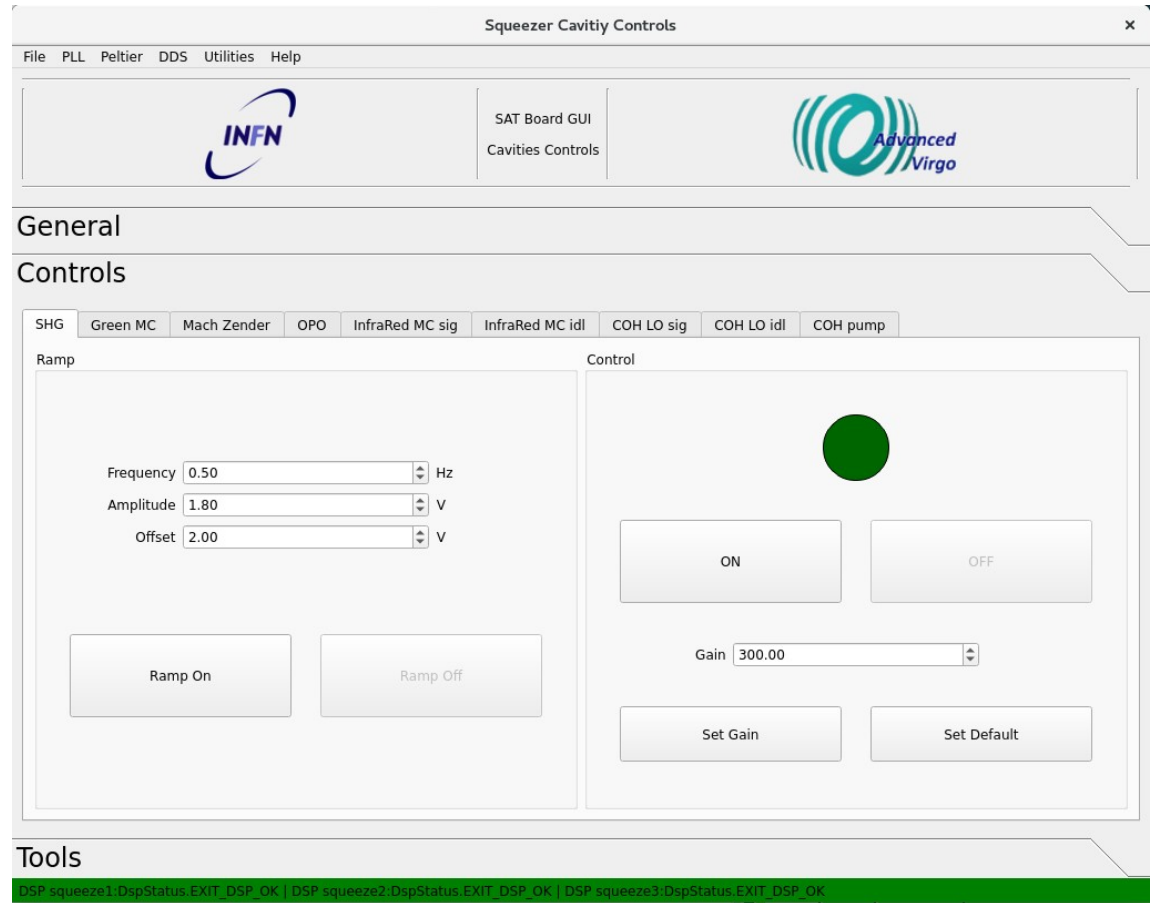


Suspension Control System DSP

Graphical User Interface

Software:

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





Virgo Process Monitoring (VPM)

Virgo Online 32

Search

Edit

Tools

Help

Login

Control Room

AD7674

DaqBox - ToIn V2

Minitowers

Timing

SUSP - SBE

SIB2

SPRB

SDB and EDB

SDB2

SDB1

SNEB

SWEB

ISC

ALS TEB

ALS NEB

ALS WEB

ALS_CEB

SSFS

ISC Log

TelescreenLeft

TelescreenRight

TelescreenDET

TelescreenArt

EER_ADC7674

CEB_ADC7674_0

CEB_ADC7674_1

DET_ADC7674

TIMING_dbox

SUSP_SBE_Tpro

SUSP_SBE_LC

SIB2_Pico

SIB2_PowerSupply

SIB2_Tpro

SIB2_dbox_bench

SIB2_dbox_rack

SIB2_Photodiodes

SIB2_Quadrants

SIB2_LC

SIB2_SBE

SDB2_spy

SIB2_Photodiodes_new

SIB2_MotSwitch

SPRB_Pico

SPRB_PowerSupply

SPRB_Tpro

SPRB_dbox_bench

SPRB_dbox_rack

SPRB_Photodiodes

SPRB_Quadrants

SPRB_LC

SPRB_SBE

SPRB_MotSwitch

SPRB_Photodiodes_new

SDB_EDB_Tpro

SDB_EDB_dbox_rack

EDB

SDB2_Pico

SDB2_PowerSupply

SDB2_Tpro

SDB2_dbox_bench

SDB2_Photodiodes

SDB2_Quadrants

SDB2_LC

SDB2_SBE

SDB2_Readout

SDB2_MotSwitch

SDB1_Pico

SDB1_PDU

SDB1_Quadrants

SDB1_OMC

SDB1_LC

SDB1_FAST_SHUTTER

SDB1_FI

SDB1_Rot

SNEB_Pico

SNEB_PowerSupply

SNEB_Tpro

SNEB_dbox_bench

SNEB_dbox_rack

NEB_PCal_fast

NEB_NCal

SNEB_Photodiodes

SNEB_Quadrants

SNEB_PSD_sensing

SNEB_LC

SNEB_SBE

SNEB_MotSwitch

NEB_TIMING_moni

SWEB_Pico

SWEB_PowerSupply

SWEB_Tpro

SWEB_dbox_bench

SWEB_dbox_rack

WEB_PCal_fast

WEB_NCal

SWEB_Photodiodes

SWEB_Quadrants

SWEB_PSD_sensing

SWEB_LC

SWEB_SBE

SWEB_MotSwitch

WEB_TIMING_moni

TEB_ALS_Tpro

TEB_ALS_dbox

TEB_ALS_readout

NEB_ALS_BPC

NEB_ALS_fast

FlipMirror_NE

WEB_ALS_BPC

WEB_ALS_fast

FlipMirror_WE

CEB_ALS_Tpro

CEB_ALS_dbox

CEB_ALS

CEB_ALS_BPC

FlipMirror_ATR

SSFS_Ctrl_Tpro

SSFS_dbox

SSFS_phi

SSFS_noise

SSFS_Ctrl

SSFS_Ctrl_tmp

ISC_Tpro

ISC_SUSP

CAL_injector

CAL_noise

ASC_pre

Session timeout

Session start

'AATuning servo:Disable AATuning servo' sent to PyAATuning

'OMC temp stab:ScanLock Temp Ramp [periodic factor=1,Mode=1,scan,1,locks=1]' sent to SDB1_OMC

'OMC temp stab:Temp Ramp Set Freq [Frequency=0.0008,amplitude=0.35,offset=22.5,ramp time=2]' sent to SDB1_OMC

'OMC temp stab:Temp Stab [Frequency=0.001,amplitude=0.05,offset=22.5,ramp time=5]' sent to SDB1_OMC

'OUT_DAC_V [CHROCC_V_DAC=0.43,ramp time=0]' sent to TCS_CHROCC_PR

Remotely Controlled Power Distribution

CeB Hall

NE Hall

WE Hall

DAQ Hall

Suspension

Suspension Sms Bridges and Interface to TANGO-SAT

Coils SwitchBoxes

Vacuum

Vacuum Supervisor

LN2 Sensors

Vacuum Daq

Air Venting

Pressure sensors

Residual Gaz Analysers

Tube Level sensors

Tube Temperature sensors

Vacuum Sms Bridges

Detector s Environment Monitoring

Infrastructure

Environment

Noise hunting

Earthquakes

Tilt Meters

Newton Noise

NNC collection

PDU_CEB_NNC

PDU_NE

PDU_NE_ALS_NNC

PDU_WE

PDU_WE_ALS_NNC

PDU_DAO_NNC

SusDAQBridge

SatServer

PduServer

CoilsSbMWI

CoilsSbNI

CoilsSbWE

CoilsSbNE

CoilsSbBS

CoilsSbMARWI

CoilsSbMARNI

ModbusVac

SenO2

ToVac

FdVac

FbsVac

AlpVac

Vent

Varian

Mks

Oms

His

TubeTemp

VacCryotrapNE

VacCryotrapNI

VacCryotrapWE

VacCryotrapWI

VacTowerNE

VacTowerNI

VacTowerWE

VacTowerWI

VacTowerPR

VacTowerBS

VacTowerSR

VacTowerDB

VacTowerIB

VacTowerMC

nitelServer

eurothermServer

eurothermServer2

UpsServer

UpsServer2

IMMServer

IMMServer2

IMMServer3

BACnetServer

BACnetServer2

ParticleCounterCEB

ParticleCounterSQZ

ParticleCounterINJ

ParticleCounterDET

ParticleCounterNE

ParticleCounterWE

ParticleCounterWAB

BcMeteo

BcLight

EnvServer

EnvServerCb1

EnvServerSqz

EnvServerMc

EnvServerNe

EnvServerWe

EnvServer1500W

EnvServerEPR

EnvDemod

TIMING_moni

ENVnoise

MagneticInjections

LargeCoil

USGS

ProcessUSGSData

ParseSeismonProcessing

EarlyWarning

INGVEarlyEst

TStageTilt

MaxGaugeTilt

NNC_CEB_LEV2

NNC_CEB_LEV1

NNC_NEB

NNC_WEB

Storage - StoI03

StoI3 Input

Raw Full Computing

Raw Full

RDS Computing

RDS

Trend

Trend100s

Data Access

Online ITF control

Online Front End - Storage

Web Monitoring

FFL Moni

Environment data for transfer to LIGO

Automation

FbmFE

Fbs

FbmMain

Metatron Nodes - FbmMain

StToStoI03IN_1

StToStoI03IN_2

StoI03IN_1

StoI03INRaw_dy

StoI03Full_10

StoI03FullALS_SSFS_10

StoI03FullCAL_ISC_10

StoI03FullENV_TCS_10

StoI03FullINJ_10

StoI03FullSUSP_10

StoI03FullSDB2_10

StoI03FullSDB_EDB_10

StoI03FullSIB2_10

StoI03FullSPRB_10

StoI03FullSNEB_10

StoI03FullSWEB_10

StoI03FullFDS_SQZ_10

StoI03FullFbm_10

FdWRawFull_short

FdWRawFull_short1

FdWRawFull1

FmStoI03

FmRawFull

Rds_20

RdsALS_SSFS_20

RdsCAL_ISC_20

RdsENV_TCS_20

RdsINJ_20

RdsSUSP_20

RdsSDB2_20

RdsSDB_EDB_20

RdsSIB2_20

RdsSPRB_20

RdsSNEB_20

RdsSWEB_20

RdsFDS_SQZ_20

RdsOthers_20

RdsFbm_20

FdWRds

FmRds

FbTrend_200

FbTrend_200_2

FbTrend_200_3

FbTrend

FbTrend_10800

FdWTrend

FmTrend

FmTrend_IL

FbTrendRepro

FbTrend100s_1000

FbTrend100s_100000

FbTrend100s

FmTrend100s

FbmDetUsers

FbmMoniUsers

FbmSuspUsers

FbmMainUsers

FbmPyAccess

FbmFEUsers

FbmFEUsersBis

FbmFEUsersTer

FbmMainDy

FbmSiDy

FbmSiDyBis

MdVim

MdVimSpectro

MdVimSpectro_set2

MdDQ

FFLMoni52

FFLMoni53

FFLMoni54

FFLMoni147

EnvDataWrite

PyPhaseCamB1p

PyPhaseCamB4

PyTCS

PyHWS

PySFP

PySpectral

FreqAna

FbsPy

PyHVAC

PyDAQ

PyUGF

PySQZ

PySQZ_IR

PySaturationPD

PyOptiChar

PyAATuning

INJ_MAIN

DET_MAIN

SQZ_MAIN

SQZ_FLT

TCS_MAIN

SUS_BS

SUS_PR

SUS_SR

SUS_NI

SUS_WI

SUS_NE

SUS_WE

ALS_NARM

ALS_WARM

NARM_LOCK

WARM_LOCK

ARMS_LOCK

DRML_LOCK

OMC_LOCK

2022-08-14 03h18m42 UTC (05h18 local)



Virgo Process Monitoring (VPM)

host machine

Stop / Start

The screenshot shows the Virgo Process Monitoring (VPM) web interface. Annotations include:

- Main configuration file**: Points to the `Host: rtpc3.virgo.infn.it` field in the application header.
- Log file → important for debugging**: Points to the `Log: /var/log/VirgoOnline/LSC_Act_2018-01-16-07h25m44-UTC.log` field.
- Secondary configuration files: included in the main one but separated to easy the work**: Points to a list of files under the `LSC_ENABLE` section, including `LSC_filters`, `MICH subtraction`, `PRCL subtraction`, `ARM algo`, `MICH algo`, `CARM algo`, `DARM algo`, `PRCL algo`, `UGF monitors`, `DemodMoni`, `ASC Outputs`, `Noise hunting`, and `DAQ SMS`.
- The Algorithms for Control and Locking (AcL)server Documentation**: Points to a box containing the title, authors (R. Bonnand, A. Masserot, B. Mours, L. Rolland, E. Pacaud, M. Was), code (VIR-0XXX-16), and date (Sept28,2017).
- Log of the LSC process in real time**: Points to a large log window showing real-time status updates, such as `AcAdcChk> SSFS_B4_50MHz_0 - SSFS_B4_Err_0_unorm_10kHz delayed or missing from GPS1202654835-239909610 for more or less 1.00181(s) - nLoop 1@10000Hz`.
- Global log**: Points to a bottom log window showing system events, such as `*OUT OFF* sent to SbTCSW` and `*OMC1 temp stab Temp Stab [Frequency=0.001,amplitude=0,offset=22.82,ramp time=10] sent to SDB1_OMC`.



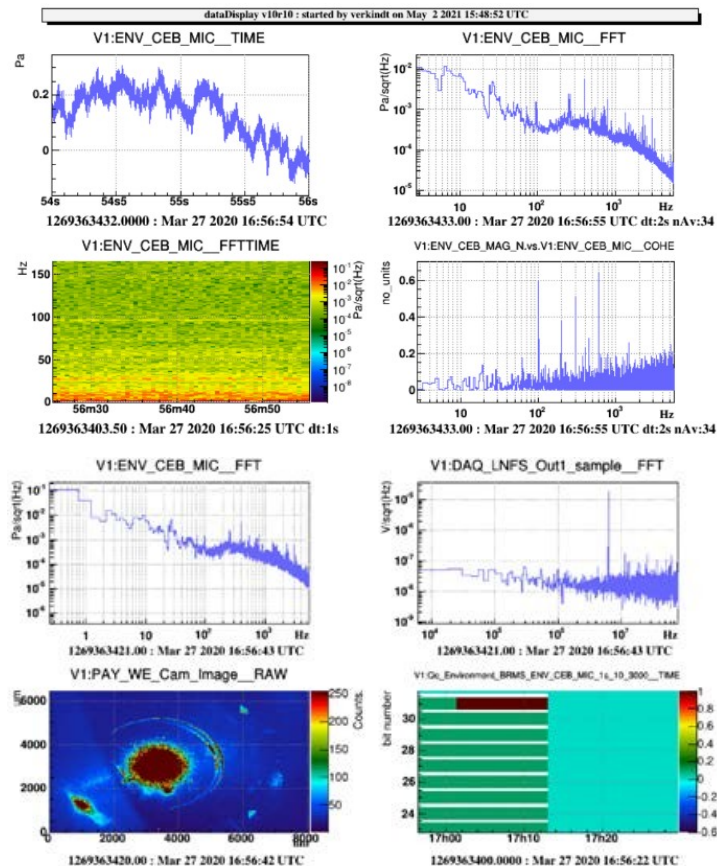
DataDisplay

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!