Rôle des simulations dans le commissioning

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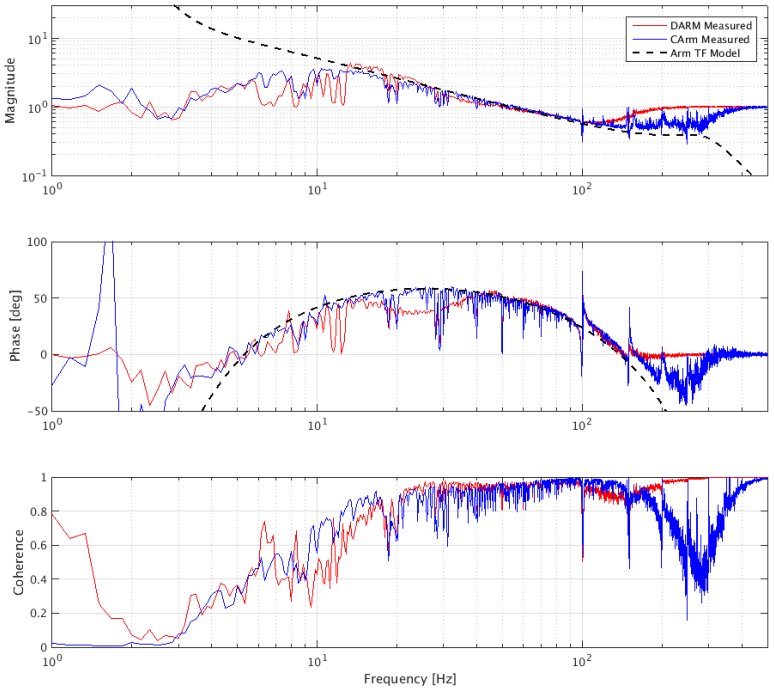
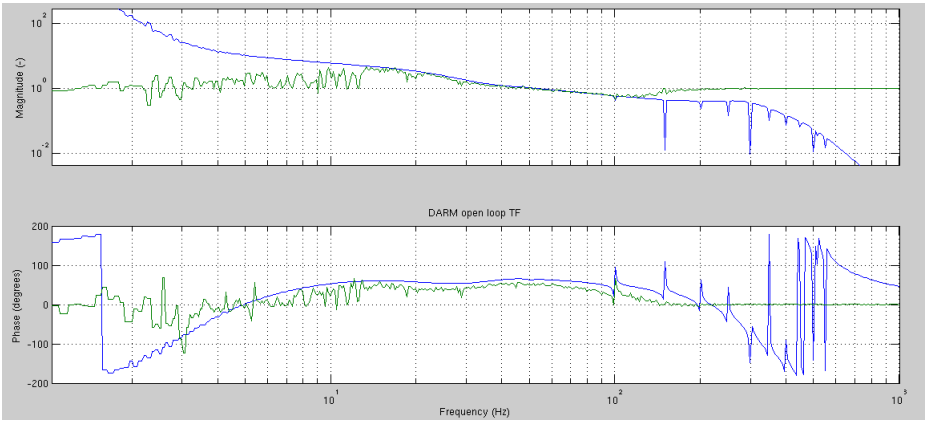
Simulations and commissioning

- Simulations provide the expected behavior of the interferometer
- Typical situation: simulations $\rightarrow$ commissioning
  - Predict expected behavior using simulations
  - Try to control interferometer based on expected behavior
  - Real interferometers are different from simulations
  - Empirically try other solutions until one works
- Less explored path: commissioning $\rightarrow$ simulations
  - Observe unexpected behavior in interferometer
  - Reproduce behavior in simulations
  - Understand the physics of the behavior
  - Solve the unexpected problem
  - In practice getting answer from simulations takes 1-2 months

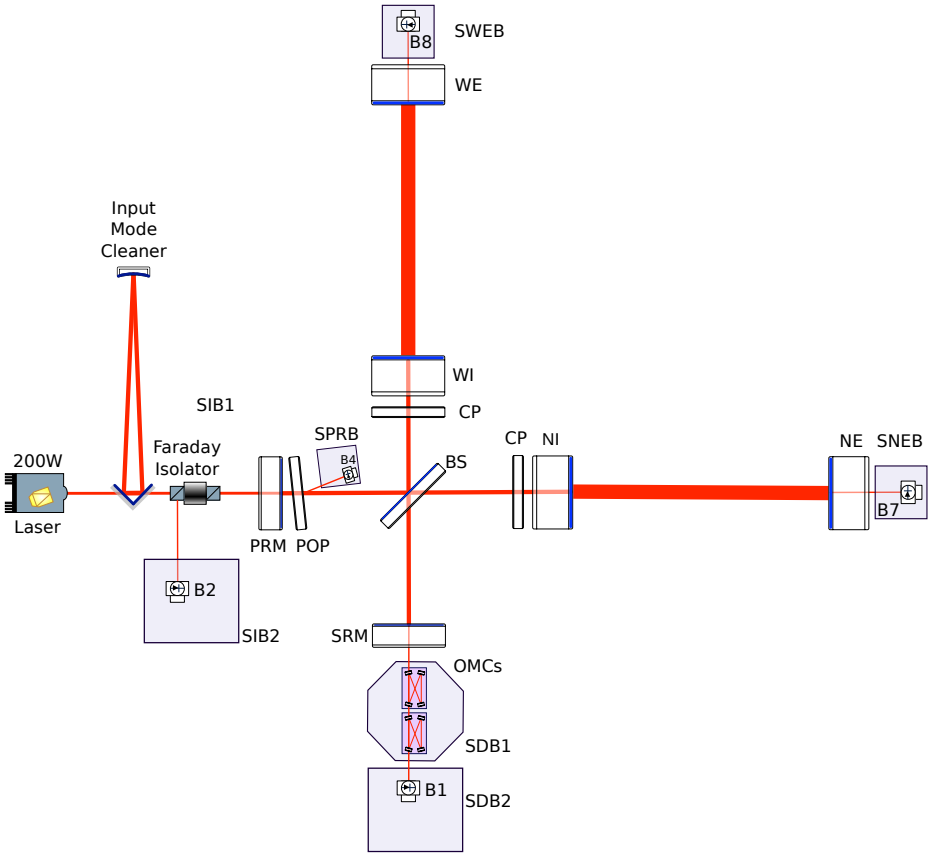
An example of unexpected behavior - VIR-0044A-17





- Not understood feature in the DARM control loop transfer function
- Same feature observed in plane wave simulations
- But physics of it never understood

Simulation problem



- Have a realistic model of the interferometer
- Simulations can never be a complete representation of real life
- Simplify physics or simplify model?
  - Simplify physics: plane wave, modal decomposition, simple pendulum suspension, ...
  - Simplify model: one arm cavity only, a couple cavity PR + arm, full interferometer without INJ/DET telescopes, ...
- Understanding the meaning of results is more important than the simulation itself

A missed problem - VIR-0258A-20

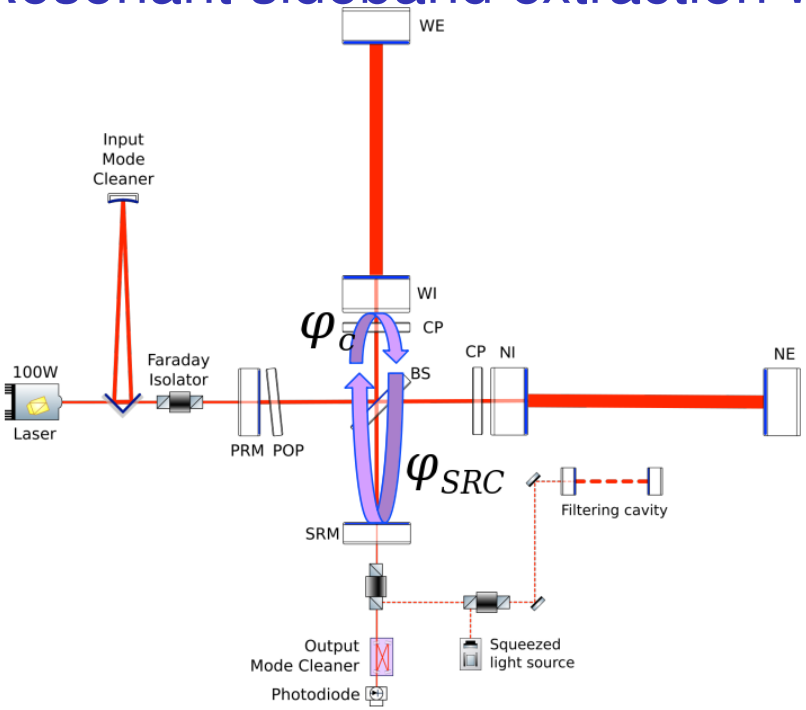
- Finesse simulation up to higher order mode 5

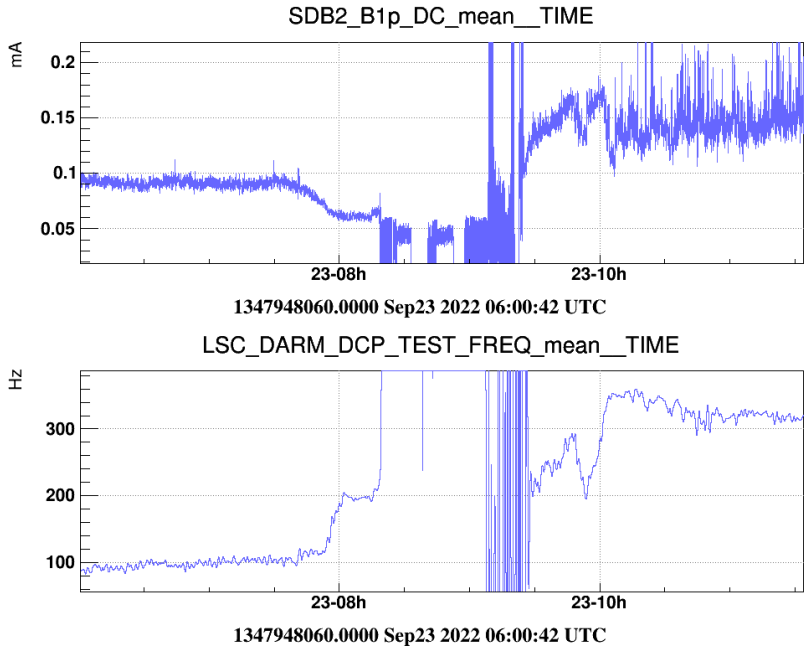
Starting parameters	No SR	SR
Recycling gain	38.2	38.3
DF power	0.54 µW	4µW
TEM_{00} power	1.7e-9 W	2.8e-10 W

ΔRoC = 10 (on NE)	No SR	SR
Recycling gain	37.2	32.9
DF power	28mW	190mW
TEM_{00} power	10µW	6mW

- Power due to arm cavity differential mode mismatch amplified by factor 7 with SR
- Nobody understood that it is a fundamental problem of degenerate signal recycling

Resonant sideband extraction with a degenerate SRC





- Resonant sideband extraction - TEM00 anti-resonant in signal recycling cavity

$$\varphi_c^{00} + \varphi_{\mathrm{SRC}} = (2n+1)\pi$$

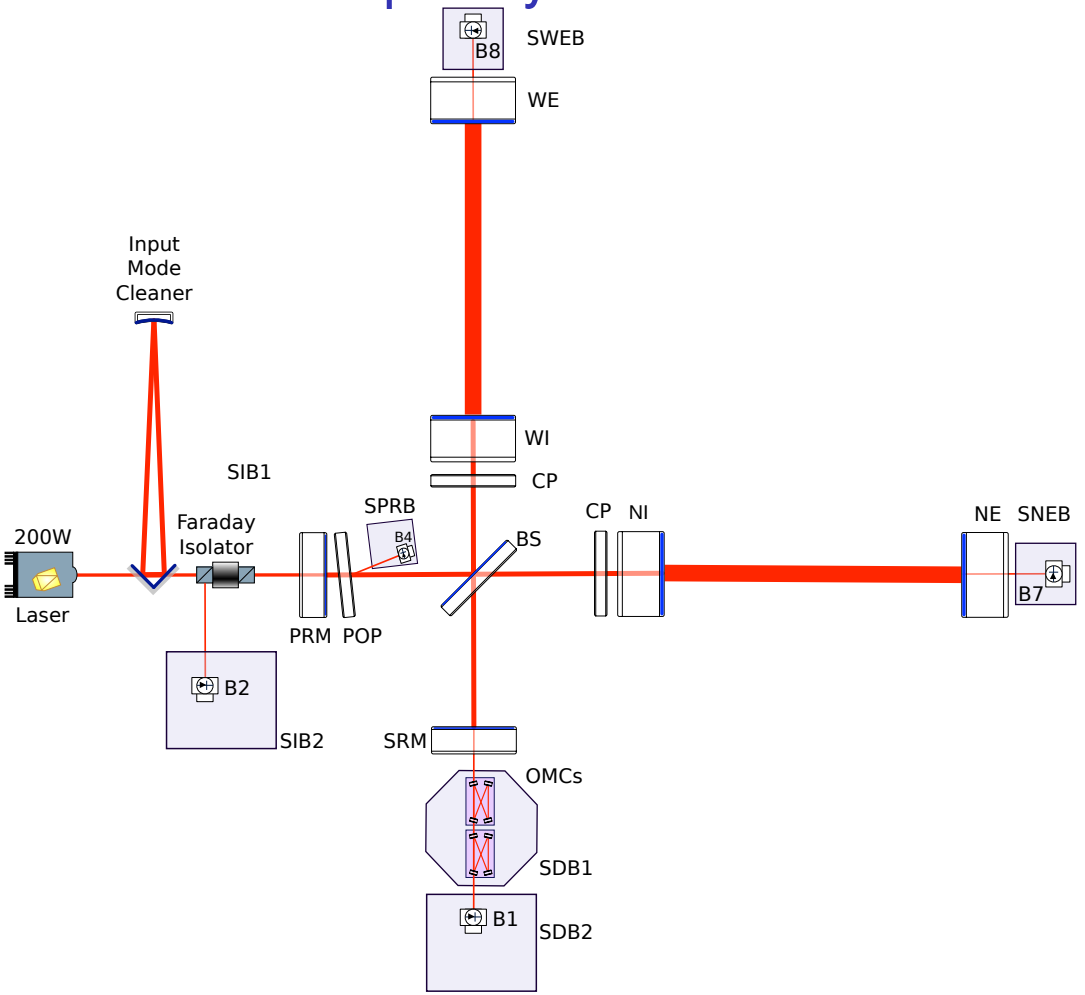
- Higher order mode resonance conditions
  - stable arm cavities $\Rightarrow$ HOM not resonant in the arms $\quad \varphi_c^{mn} = \varphi_c^{00} + \pi$
  - SRC degenerate $\rightarrow$ φ_{SRC} same for all modes $\quad \varphi_c^{mn} + \varphi_{\mathrm{SRC}} = 2n\pi$

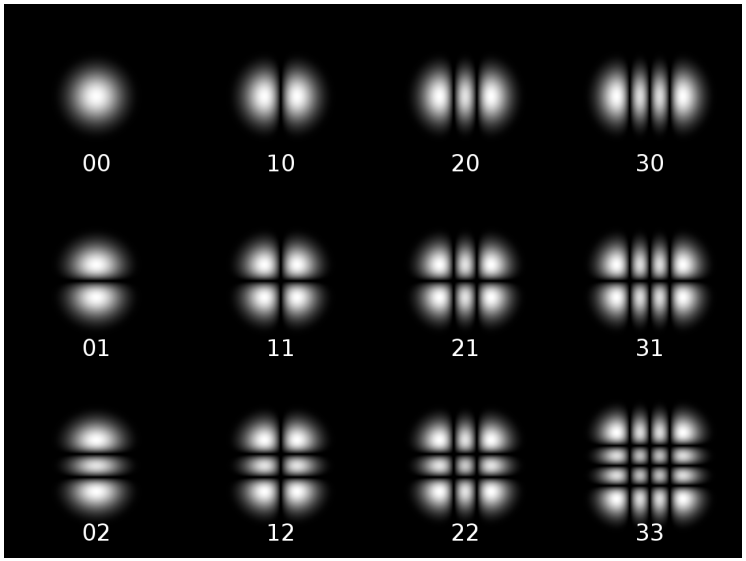
  $\Rightarrow$ Signal recycling acts as defect amplifier

$\Rightarrow$ SR increases HOM power by factor ~ 7 when well aligned
- $\sim$ 100 mW during O3
- $\sim$ 700 mW at present

VIR-0923A-22

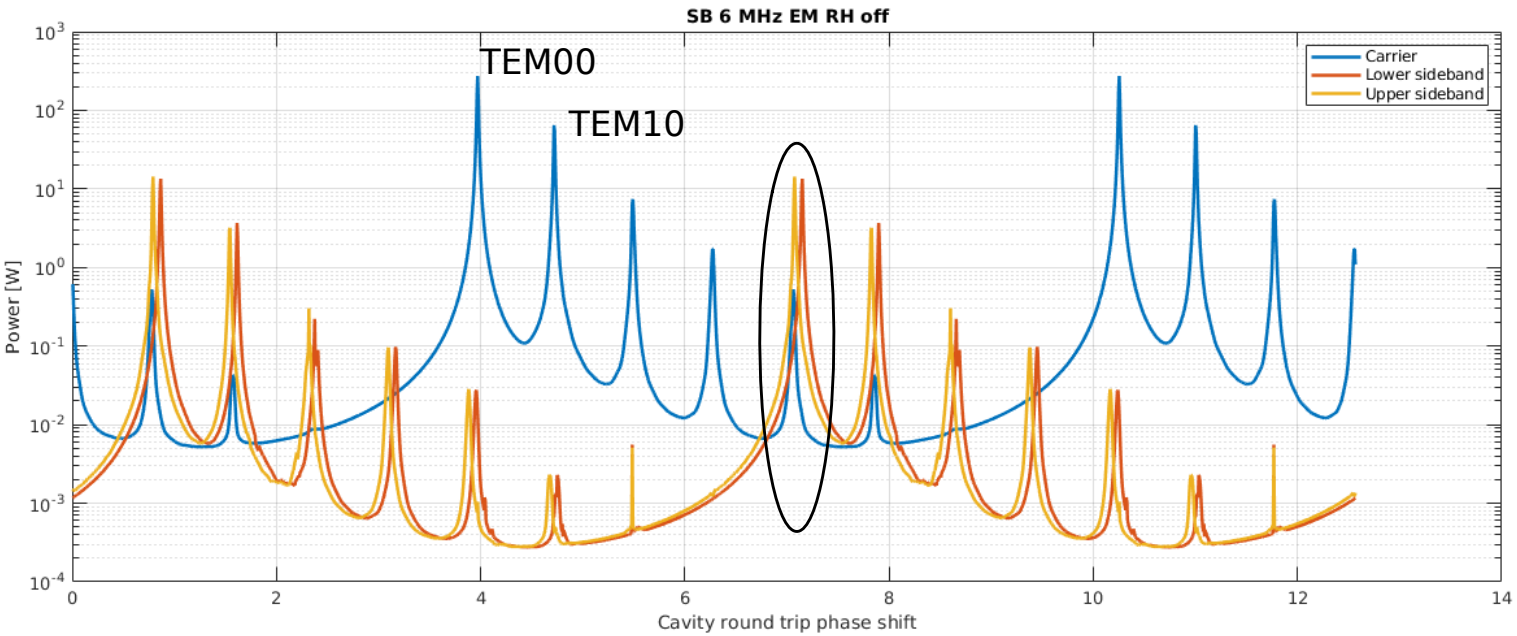
Simulation complexity





- Analytical computation - can be understood by a person
- Plane wave simulation - simplest form of longitudinal control
- order 0 and 1 simulation - first level of angular control
- order 0, 1 and 2 simulation - first level of thermal compensation simulation
- FFT simulation - often the longitudinal or angular control impact is lost
- Mirror maps - low order (low angle) scattering and defects
- Mirror rugosity - higher order (high angle) scattering

Higher order mode can matter



- Position of higher order modes and sidebands as function of arm length
- One free spectral range
- Superposition of 4th order carrier and fundamental of 56 MHz sideband

⇒ Interferometer control fails

- Mirror radius of curvature changes due to laser absorption
- Superposition condition changes when locking interferometer

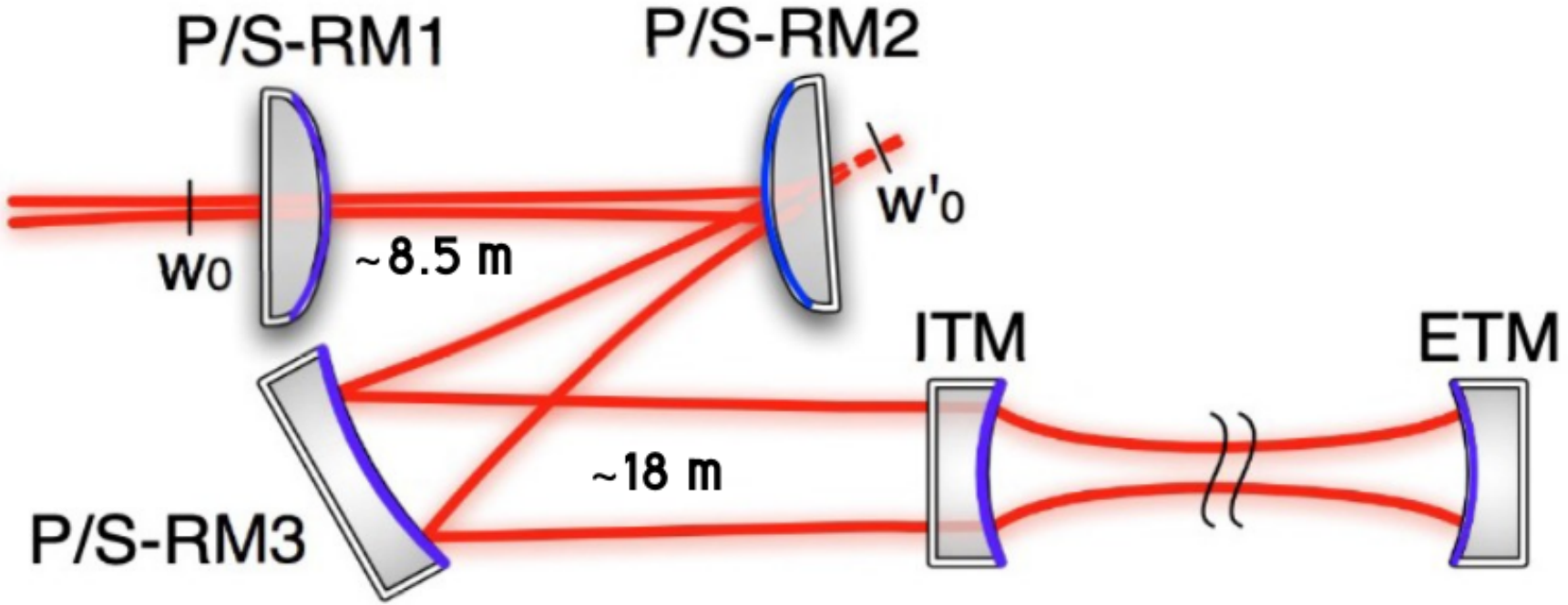
VIR-0232A-22

Simulation for commissioning

simulations $\longleftrightarrow$ commissioning

- Need a two person team: simulation expert and interferometer expert
  - Running the interferometer is complicated
  - Running a simulation is complicated
- Simulation model needs to be developed before commissioning starts
  - And tested on some example of potential problems
  - Establish a good communication between the two person team
- Once commissioning starts
  - New questions from interferometer expert will appear
  - Simulation expert need to be reactive and try to find answers
  - Taking more than 1 week to provide an answer is not useful

Some first questions for Virgo stable recycling cavities



- How to do the initial mirror positioning and alignment?
  - How to get from $\sim$ mm/mrad installation errors to $\sim$ um/urad alignment needed for cavity resonance
- How to make a precise automatic alignment of recycling cavities with 3 mirrors instead of 1 mirror
- How to do the mode matching of recycling cavities
  - Distance between RM2 and RM3 is critical
- Goal should be to commission interferometer in simulation before commissioning real hardware