Stabilized High-Power Lasers for the Einstein Telescope

Benno Willke

16 June 2021 (ET Laser Work Package kick-off meeting)

most current ET design information

- most current ET design information can be found in

Design Report Update 2020 for the Einstein Telescope

- info concerning the stabilized laser system in

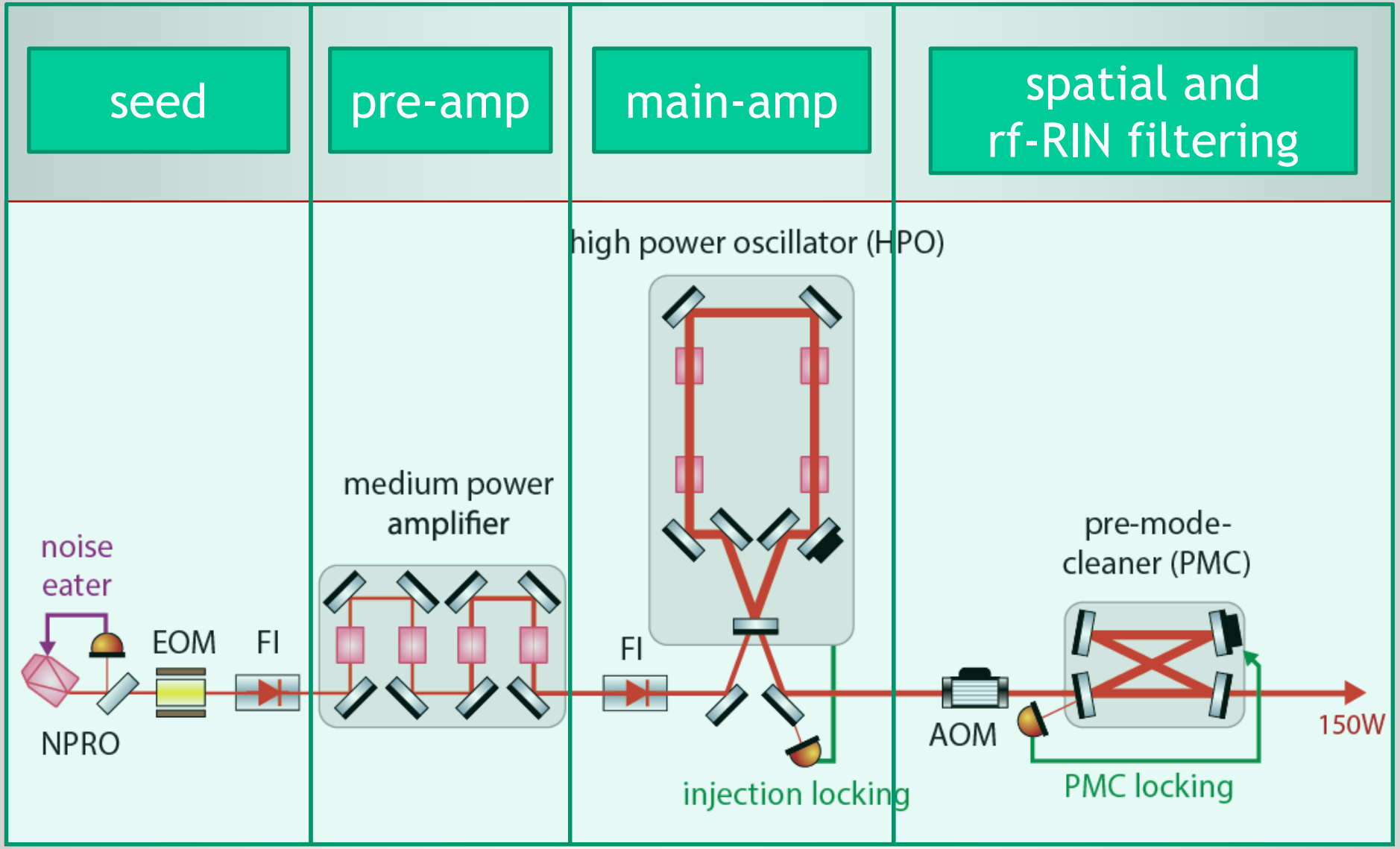
Chapter 6.4: Light sources

url:https://apps.et-gw.eu/tds/?content=3&r=17245

General Requirements

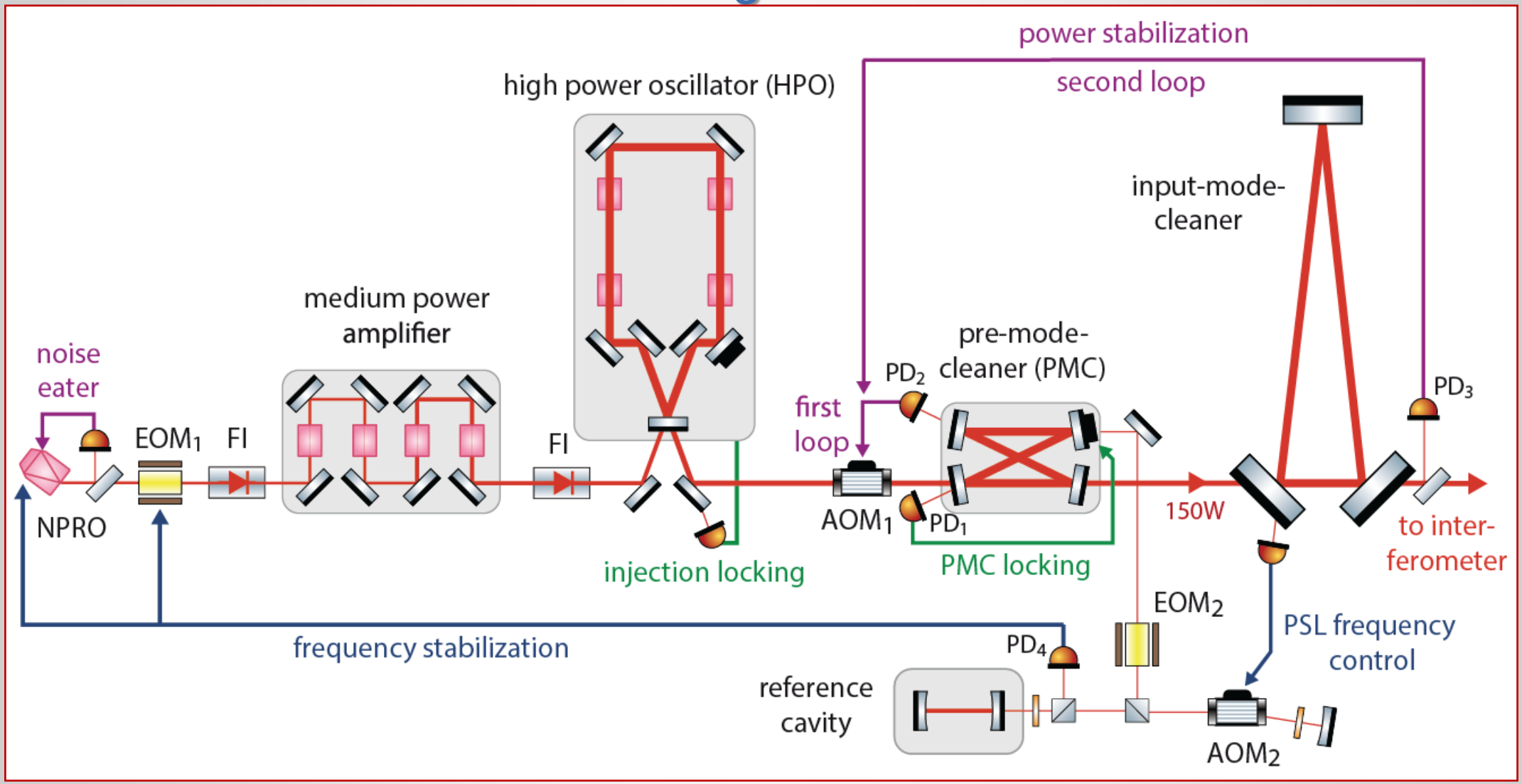
- 700 Watt power at 1064nm (cw, single-frequency, linearly-polarized)
  - To enable high circulating power in interferometer arms
- 5 Watt power at 1550nm (cw, single-frequency, linearly-polarized)
- High spatial purity and low beam jitter
  - Good coupling to input-mode-cleaner
  - Low shot noise on sensors for laser and input-mode-cleaner stabilization
- Low free running noise (in laser power and frequency)
  - Acceptable stabilization effort (loop gain and cross-couplings)
- Low-noise sensors (for laser power and frequency)
  - To achieve required stability for light entering the input mode-cleaner
- Fast actuators (for laser power and frequency) with large range
  - To allow for required loop gain in stabilization control loops
- High robustness and reliability with low maintenance requirements

Typical GWD Laser Design (example aLIGO)



Kwee et. al, Opt. Express (2012)

Advanced LIGO Pre-Stabilized High-Power Laser



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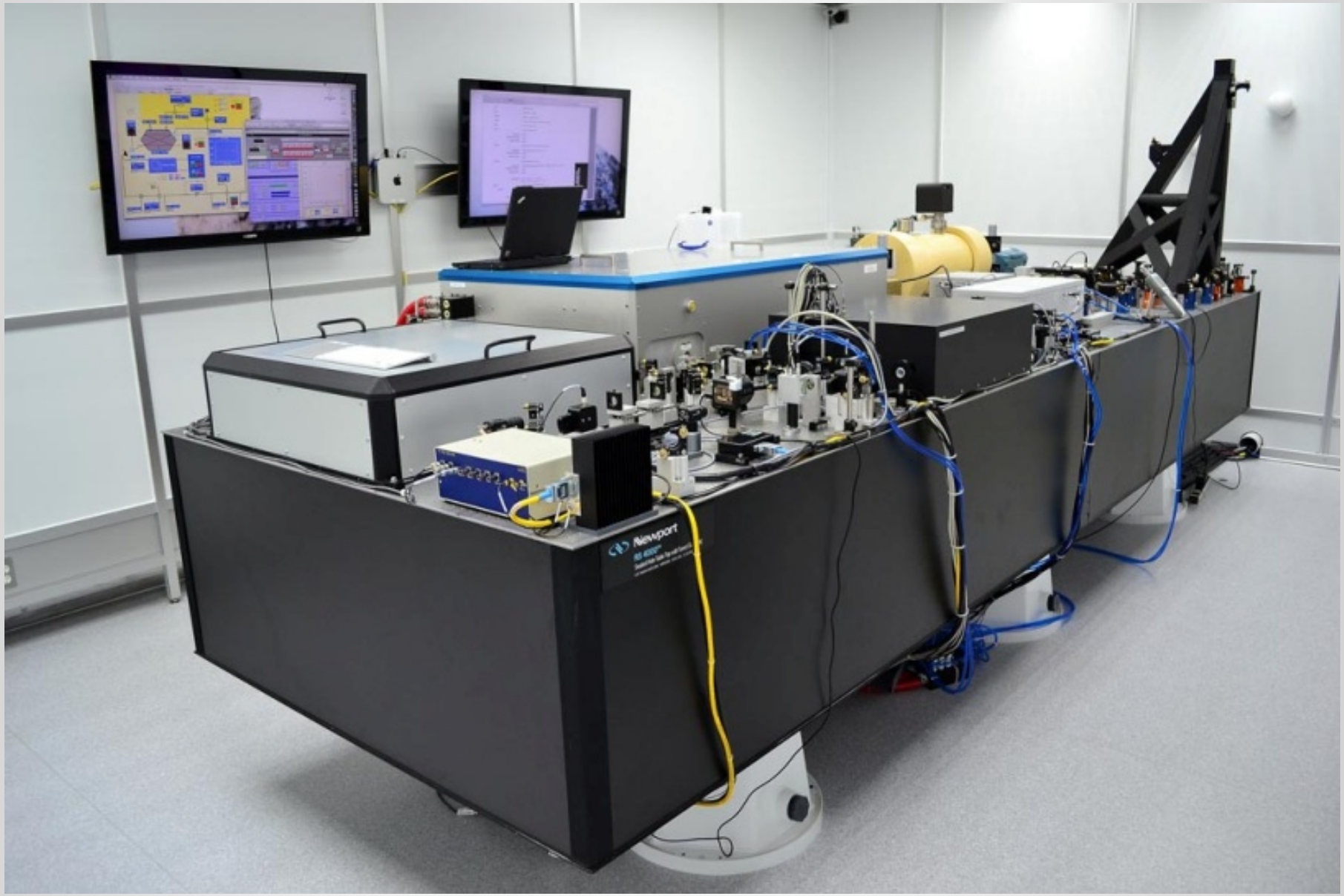
Advanced LIGO Pre-Stabilized High-Power Laser



Laser Requirements for ET

- cw, single-frequency, linearly-polarized with 700W @ 1064 and 5W @ 1550nm
- less than 10% higher order spatial mode content
- polarization purity > 1/10
- low free-running noise (equal or better than aLIGO and Advanced Virgo lasers)
  - power noise
  - frequency noise
  - beam pointing
  - polarization fluctuations
- power and frequency actuator
  - range larger than free running noise
  - speed sufficient to achieve $RIN < 2 \cdot 10^{-10}\ 1/\sqrt{\mathrm{Hz}}$ and $\Delta\nu < 10\ \mu\mathrm{Hz}/\sqrt{\mathrm{Hz}}$
- low drift of DC parameters and stable noise level
- robust and reliable 24/7 operation for years
- digital monitoring and control capabilities

Stabilization Requirements

- Filter Resonator (pre-modecleaner)
  - higher order spatial mode reduction
  - beam pointing reduction
  - rf-power noise reduction
- power noises sensor
  - with shot-noise limited performance equivalent to 10 Watt
- power stabilization feed-back control system
  - relative electronic input noise of less than $10^{-10}\ 1/\sqrt{\mathrm{Hz}}$
  - high enough unity-gain frequency to achieve $RIN < 2 \cdot 10^{-10}\ 1/\sqrt{\mathrm{Hz}}$ at 10 Hz
- frequency stabilization feed-back control system
  - high dynamic range of more than 9 orders of magnitude at 10 Hz
  - high enough unity-gain frequency to achieve $\Delta\nu < 10\ \mu\mathrm{Hz}/\sqrt{\mathrm{Hz}}$
- digital control and monitoring system

Competences Required in the ET Laser Group

- design and fabrication of
  - lasers at $1064\ \mathrm{nm}, 1550\ \mathrm{nm}$ and $2\mu\mathrm{m} - 2.1\ \mu\mathrm{m}$
  - vacuum compatible electro-optical modulators and Faraday Isolators with high optical quality for high power levels
  - power noise sensors with noise below the shot-noise of several Watts
  - fast vacuum compatible power actuator for high power levels
- simulation and design of feed-back control systems
  - low noise coherent beam combination at $1064\ \mathrm{nm}$
  - noise analysis of stabilized laser system including cross couplings
  - fast low-noise analog feed-back control electronic
- digital control and monitoring