Standardization training program
E-60 discipline: Control

Gyro terminology and performance specification standard

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European Space Agency

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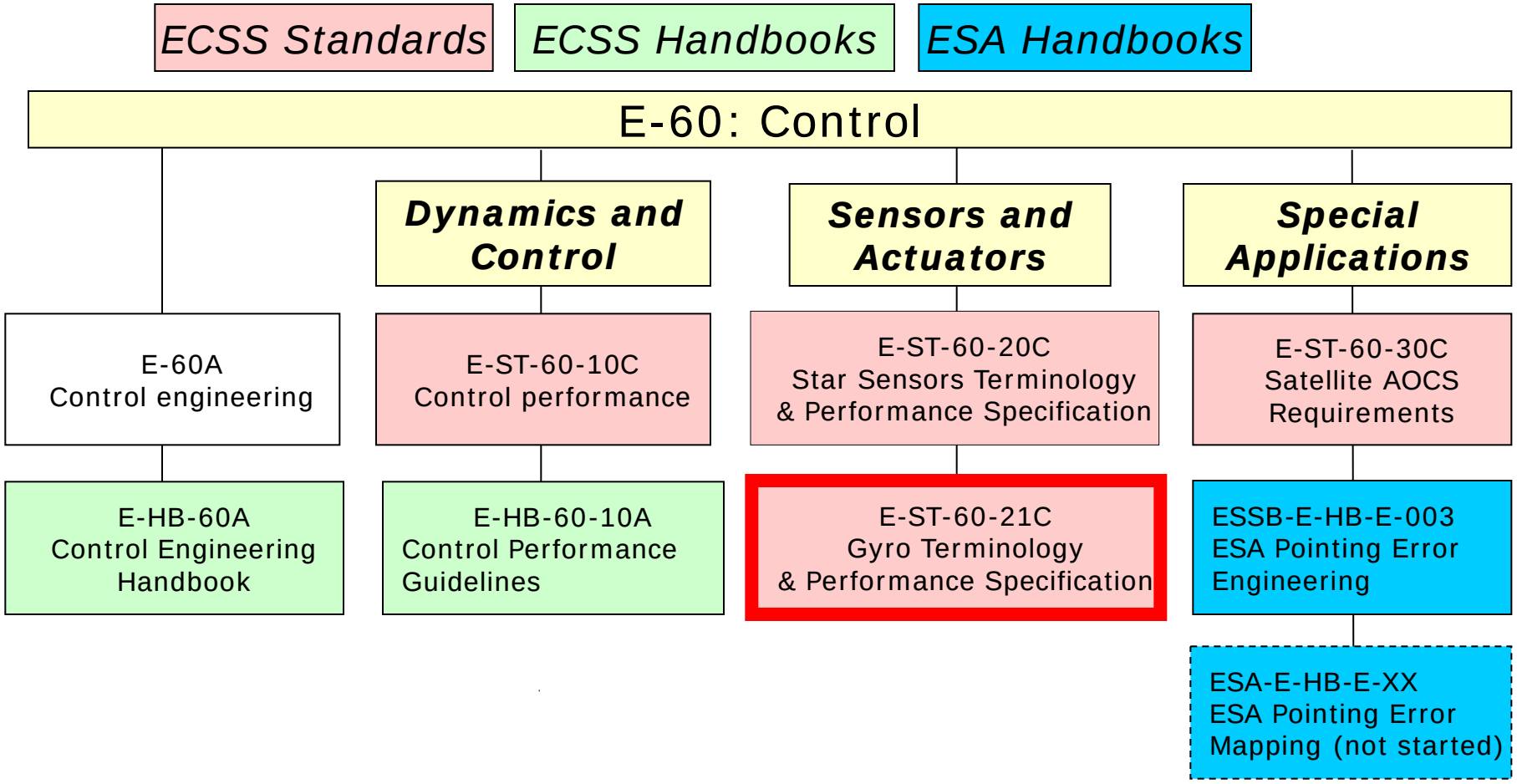

Background and motivation

IF YOU ASK 10 PEOPLE WHAT BIAS IS, YOU GET 11 ANSWERS

- Gyros are used on almost all spacecraft, often in mission-critical functions:
  - Detumble and rate damping
  - Safe mode, Sun acquisition mode
  - High accuracy gyrostellar estimation
  - Star tracker blinding coverage

- Different technologies exist:
  - Optical gyros (Ring Laser Gyro, Fibre Optic Gyro)
  - Coriolis Vibratory Gyros (Hemispherical Resonating Gyro, Tuning Fork Gyro,…)
  - Mechanical gyros (single-axis/dual-axis mechanical gyro, Dynamically Tuned Gyro,…)
  - MEMS gyros

- Despite the different technologies, a common understanding of the performance of gyros is needed.

- Often the IEEE standards were referred to.

Gyro terminology & performance specification overview

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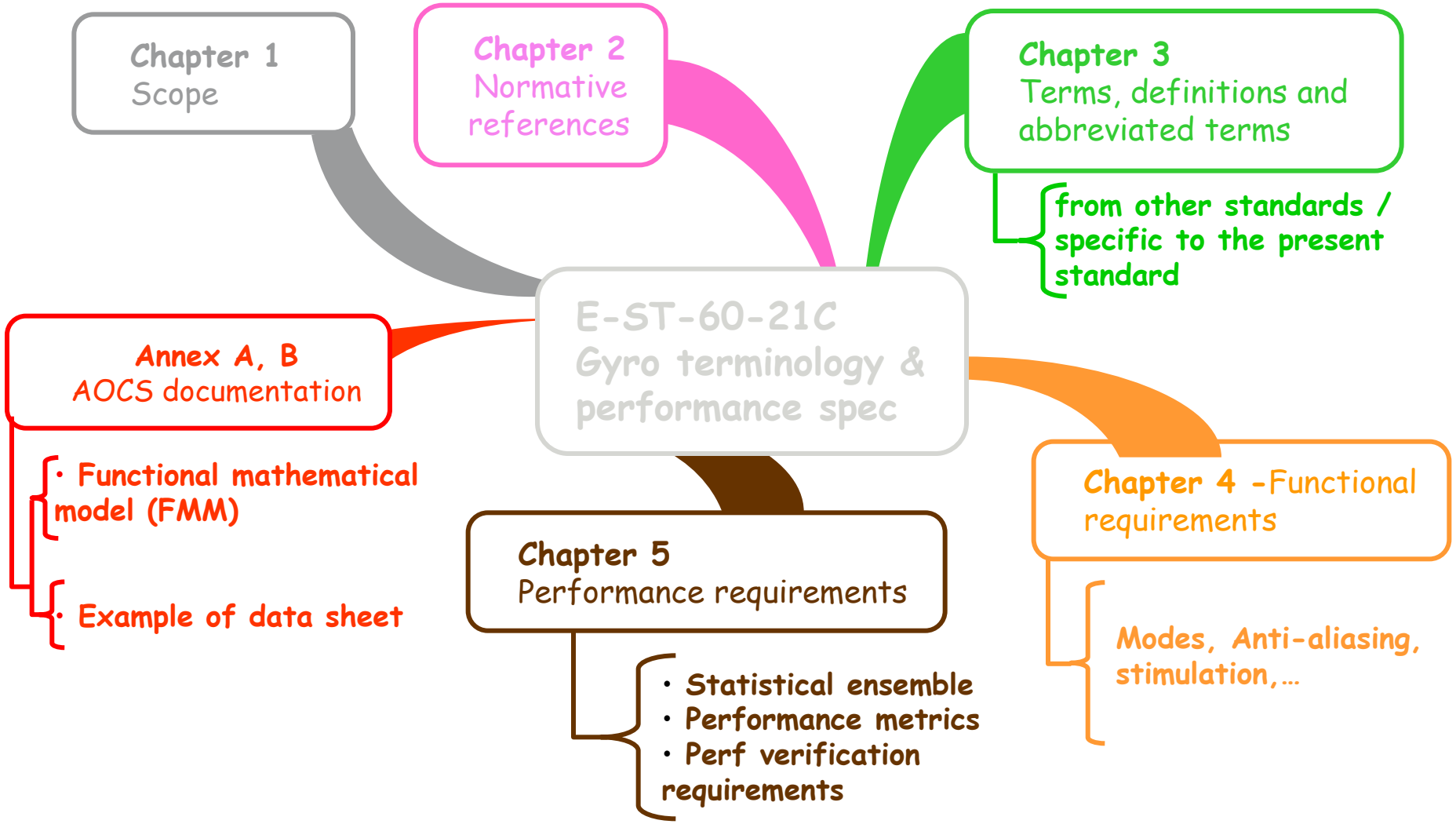

Chapter 4 : Functional requirements

- Operating Modes
  - Measurement mode
  - Auxiliary modes (test mode, programming mode,…)
- Start-up, Warm-up
- Alignment and scale factor
- Anti-aliasing filter
- Stimulation
- Lifetime and duty cycle

Perf. Req. Chapter 5.1, 5.2, 5.3: Statistical Ensemble, Verification req.

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- Statistical interpretation
  - Variation in time → temporal interpretation (e.g. noise), use worst-case sensor
  - Variation from sensor-to-sensor → ensemble interpretation (e.g. switch-on bias)
  - Mixed interpretation (do not use this as a default)

- Confidence level is to be agreed with the customer for each of the error source
  - (1σ, 2σ or 3σ only applies for Gaussian distributions)

- Performance verification
  - To be specified whether this applies to compensated (calibrated) or uncompensated measurements
  - Adequate test equipment is required
  - Earth rotation rate (approx. 15°/h) shall be taken into account

- Performance requirements shall indicate conditions:
  - EOL vs BOL
  - Environmental effects
  - Warm-up effects
  - Acceleration, 1g 0g effects
  - Temperature effects

Perf. Req. Chapter 5.4: Performance metrics

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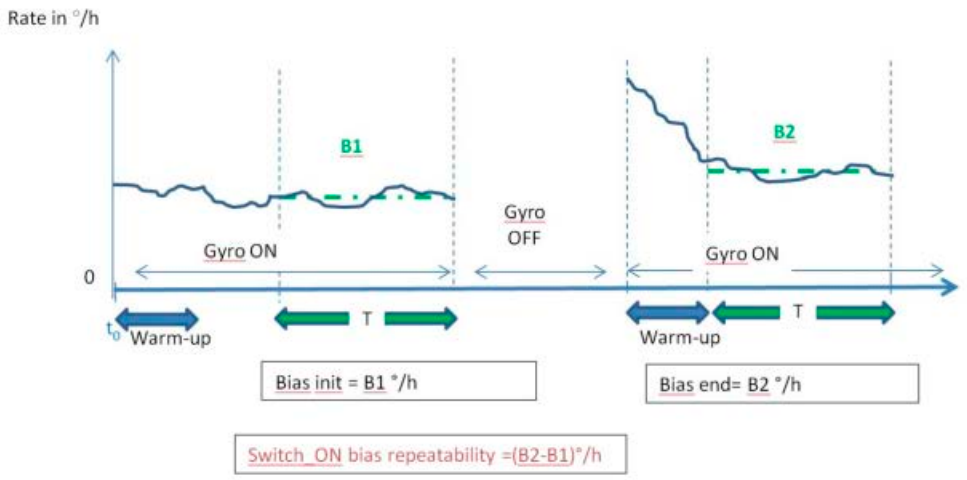
→ BIAS

- Bias **repeatability**
  - Switch-on to switch-on repeatability
  - Repeatability before and after mechanical environment
  - Repeatability before and after thermal vacuum cycling
  - Repeatability before and after radiation
- Bias **stability**
  - E.g. maximum over life, time intervals to be specified
  - See also: rate random walk, flicker noise, long term drift, bias drift
- Bias **thermal sensitivity**
  - Before calibration or residual after calibration
  - Sensitivity to thermal gradient (spatial or temporal) to be specified
- Other bias **sensitivity**:
  - Magnetic flux density
  - Specific force (non-gravitational acceleration)
  - Vibration
  - …
- **Verification**: on marble block



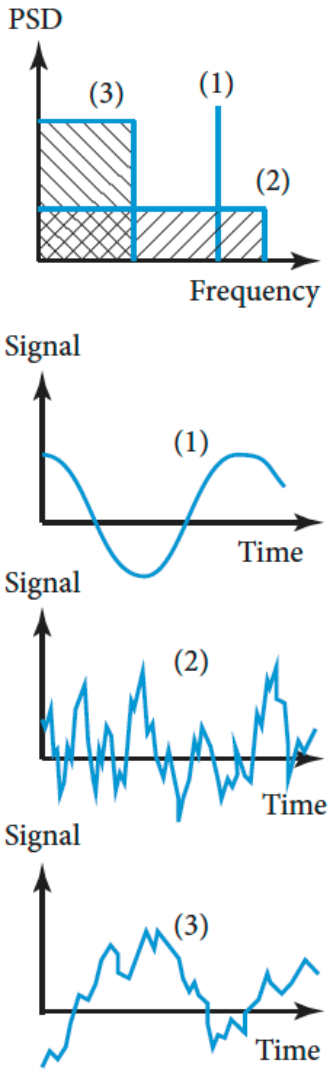
Noise: Power Spectral Density (PSD) introduction

- Power spectral density (PSD) describes the frequency content of a random process
- The mean square value of the signal is equal to the integral under the PSD curve:

$$E[x^2] = \int_0^\infty S_x(f)df$$

- White noise has a flat PSD curve
- Propagation through a transfer function H:

$$S_y(\omega) = |H(i\omega)|^2 S_x(\omega)$$



Perf. Req. Chapter 5.4: Performance metrics

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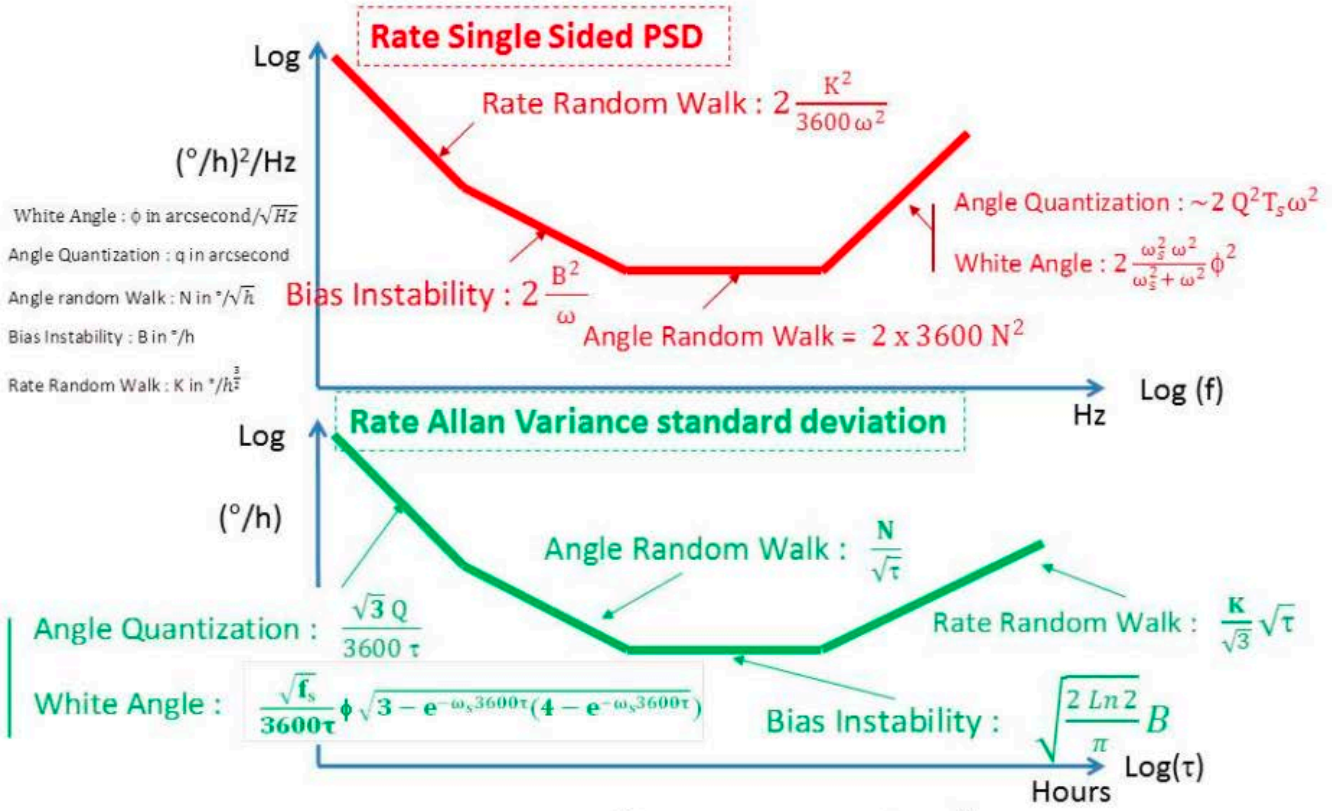
→ NOISE

- Noise performance requirements (from high-frequency to low frequency)
  - Angle White noise (AWN)
  - Angular Quantization Noise (AQN)
  - Angle Random Walk (ARW)
  - Bias instability (flicker, 1/f noise)
  - Rate Random Walk (RRW)
  - Rate Ramp
- PSD versus Allan Variance



$\omega = 2\pi f$

with f = frequency in Hz

$\omega_s = 2\pi f_s = \frac{2\pi}{T_s}$

with f_s = sampling frequency in Hz

$Q = \frac{q}{\sqrt{12}}$

with q= angle quantization in arcsecond

Perf. Req. Chapter 5.4: Performance metrics

→ SCALE FACTOR ERRORS

- Scale factor **initial value**
- **Deadband** (no Δ-value specified in ECSS), **non-linearity** and non-linearity error
- Scale factor **repeatability**
  - Switch-on to switch-on
  - Mechanical environment
  - Thermal vacuum
  - Radiation
- Scale factor **stability**
  - Time period to be specified
- Scale factor **thermal sensitivity**
- Verification:
  - Rate table
  - After bias compensation
  - Axis alignment errors
  - Noise effects must be <10% of scale factor error requirement

Perf. Req. Chapter 5.4: Performance metrics

→ MISALIGNMENT

- Absolute/relative **alignment** error
  - Absolute: angular error of sensitive axes wrt theoretical orientation
  - Relative: angular error between sensitive axes (non-orthogonality)
- Absolute/relative alignment **knowledge** error
  - Launch, micro-gravity, outgassing, moisture release, thermo-elastics,…
- Absolute/relative alignment **repeatability**
  - Mechanical environment
  - Thermal vacuum cycling
- Absolute/relative alignment **stability**
  - Specified time period
- Absolute/relative alignment **thermal sensitivity**
  - Operating temperature range and/or customer-specified temperature range

Perf. Req. Chapter 5.4: Performance metrics

→ OTHER PERFORMANCE METRICS

- Measurement **datation and latency**
  - Datation accuracy (jitter) → verified by analysis
  - Latency: between measurement date and availability date on databus
- **start-up** performances
  - Max rate error or angle increment error during start-up period
- **Warm-up** performances
  - Bias
  - Noise
  - Scale factor error
  - Misalignment error
- Measurement output **bandwidth**
- **Anti-aliasing** filter (DC gain, max phase at frequency, max overshoot, max attenuation, min attenuation, sample frequency,...)
- Data **quantization**
- **Failure detection** efficiency
- **Stimulation**

Annex A:
Functional Mathematical Model (FMM)

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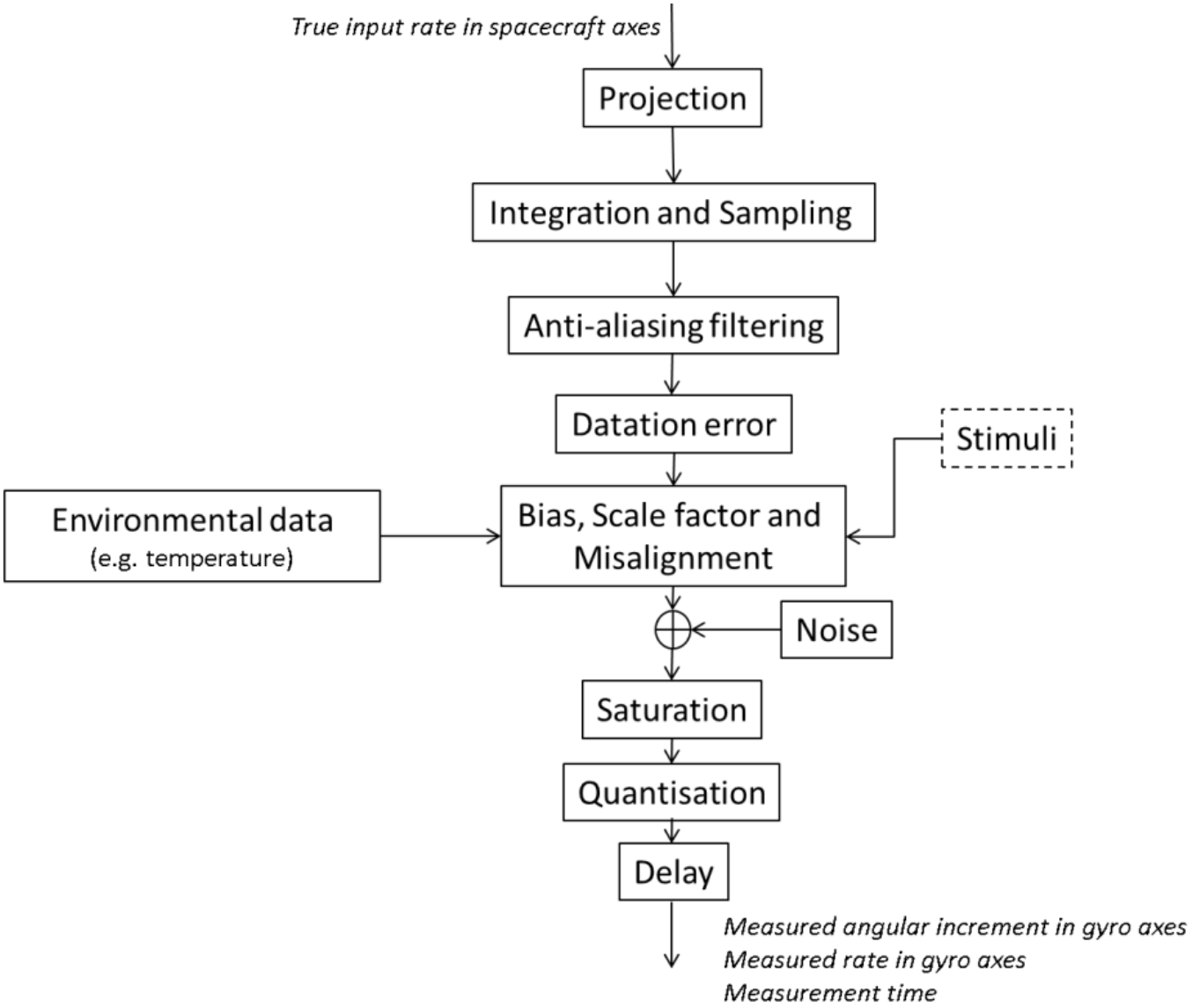

Conclusions and way forward

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- A common terminology, performance specification and test methodology is specified for all gyro technologies to be used for spacecraft
- Gyro performance specification contains, at least:
  - Bias (repeatability, thermal, stability, sensitivity)
  - Noise (quantization, ARW, flicker, RRW)
  - Scale factor (repeatability, deadband, thermal sensitivity, stability)
  - Misalignment (absolute/relative, knowledge, repeatability, stability)
  - Others (datation and latency, bandwidth, start-up, warm-up,…)
- Not a specification for gyros for launchers (not treating e.g. coning effects, depressurization effects, transfer function, structural damping,….)
- A similar terminology and performance specification standard can be proposed for accelerometers (no working group formed yet)

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