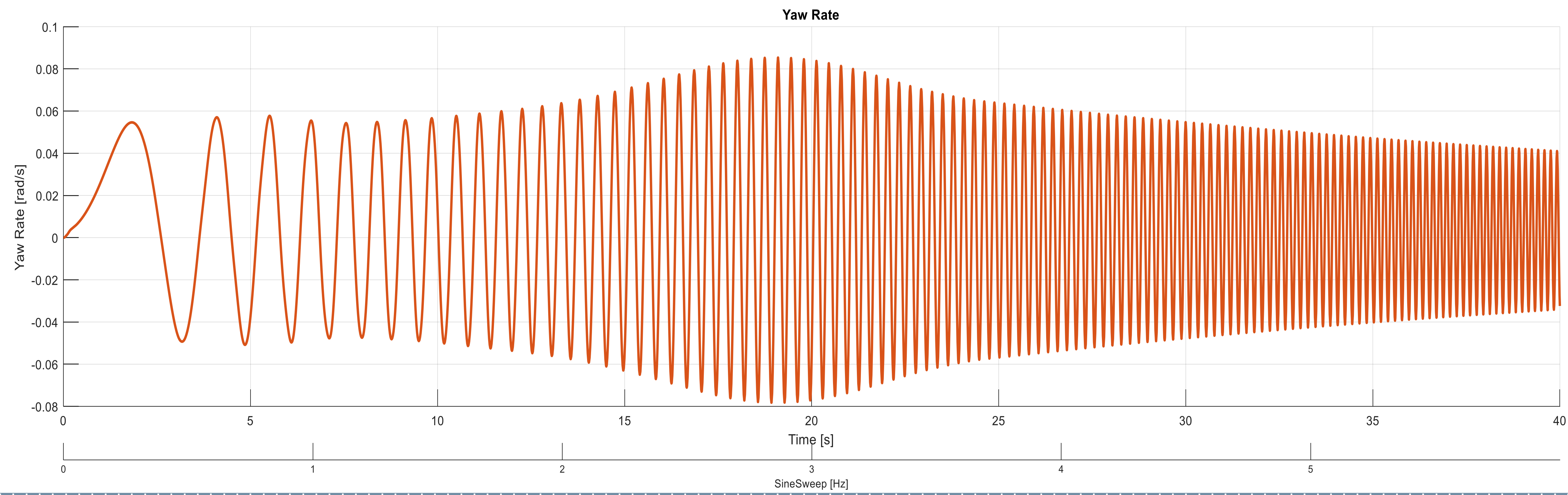


Model Identification and Data Analysis (MIDA) - Examples

AY 2019-2020

Prof. Sergio Matteo Savaresi
move.deib.polimi.it

Model Identification of engine-to-slip dynamics for a traction-control system using time-domain (State-Space) identification

The brake/traction control problem

Example of wheel lockup in braking

https://www.youtube.com/watch?v=SHODIsUrydU

https://www.youtube.com/watch?v=Isb2k8yEazA

Example of wheel overslip in traction, also affecting lateral dynamics

Definition of longitudinal slip of the wheel (lambda)

v: body speed
r: rolling radius
ω: angular wheel speed

$\omega r = v_w$ «wheel speed" [m/s] at the contact point

$$\lambda = \frac{|v - \omega r|}{\max\{v, \omega r\}}$$

If brake:

$$\boxed{\lambda := \frac{v - \omega r}{v}}$$

Free rolling

$$\boxed{0 \le \lambda \le 1}$$

Locked wheel

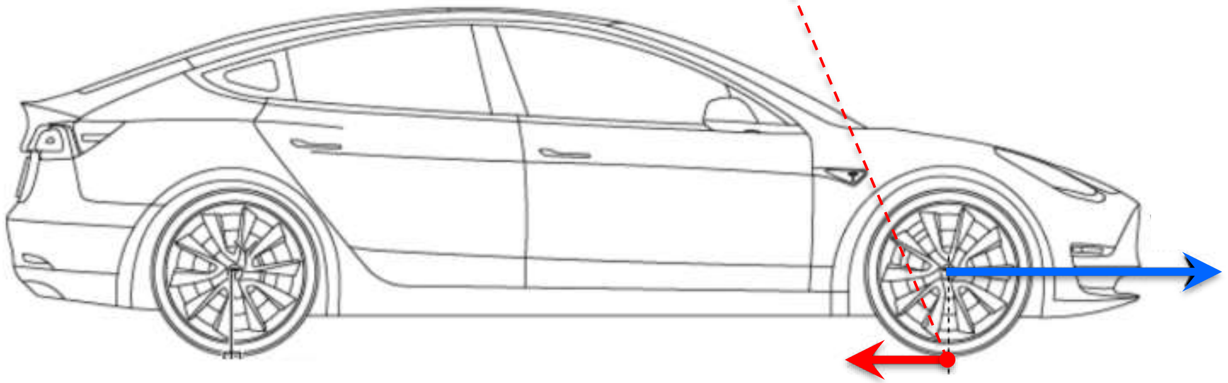
If traction:

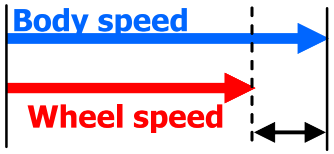
$$\boxed{\lambda = \frac{(\omega r - v)}{\omega r}}$$

$$\boxed{0 \le \lambda \le 1}$$

Free rolling

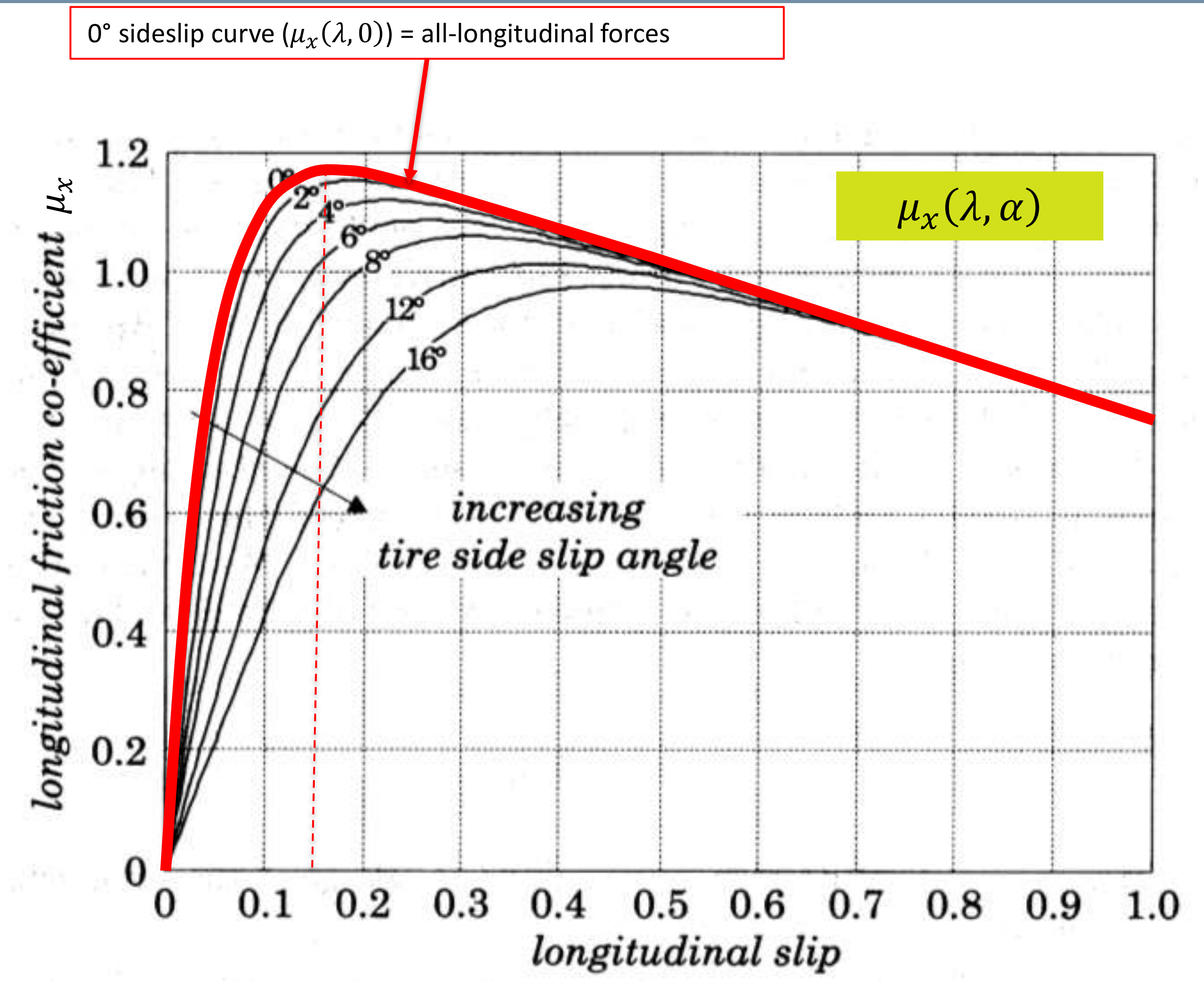
«Burnout»





'SLIP" $\lambda = \dfrac{\text{Body speed} - \text{Wheel speed}}{\text{Body speed}}$

Contact forces: longitudinal friction coefficient



Example of dry-asphalt, with high-grip tire

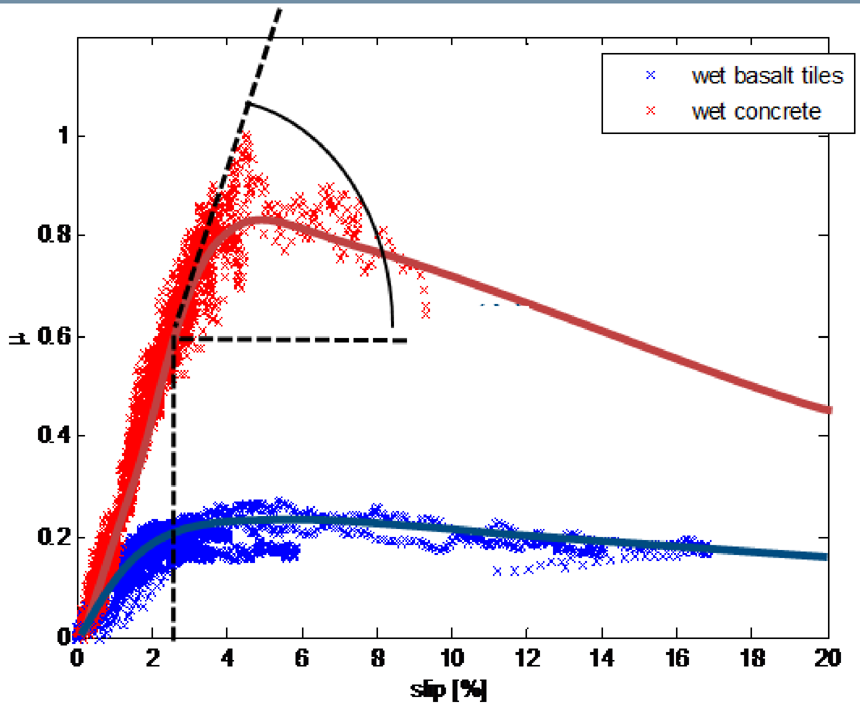
If there is no slip, the longitudinal force is zero

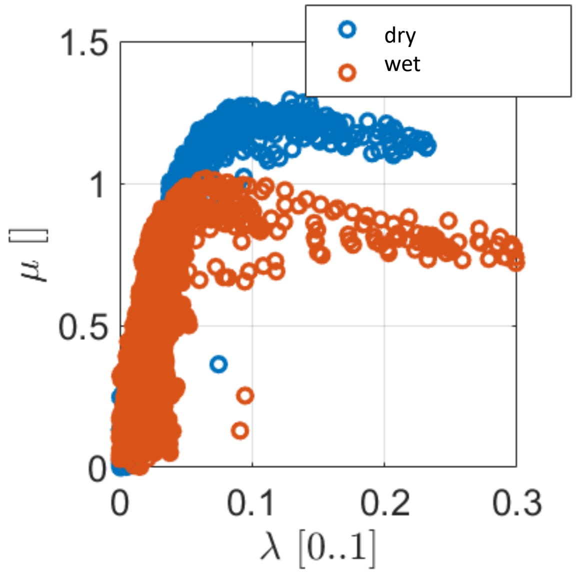
Force increases linearly up to values of λ of about 0.1-0.15

Beyond the maximum: **slope sign changes (!)**

Increasing side-slip angle:
- Reduction of longitudinal force
- The maximum point moves forward

Example of estimation of longitudinal friction curve from experimental data





Longitudinal-dynamics control: traction control (TC)

Remark on motorcycles: Traction Control (TC) generations...

Generation 1
(BMW) [2007]

Mainly (only) safety-oriented

Generation 2 (Ducati 1098)
[2008]

Performance-oriented

Very simple roll-angle detection (yes/no)

Generation 3
(Aprilia RSV4 and BMW S1000) [2010]

Full **roll-angle estimation**

Ride-by-wire

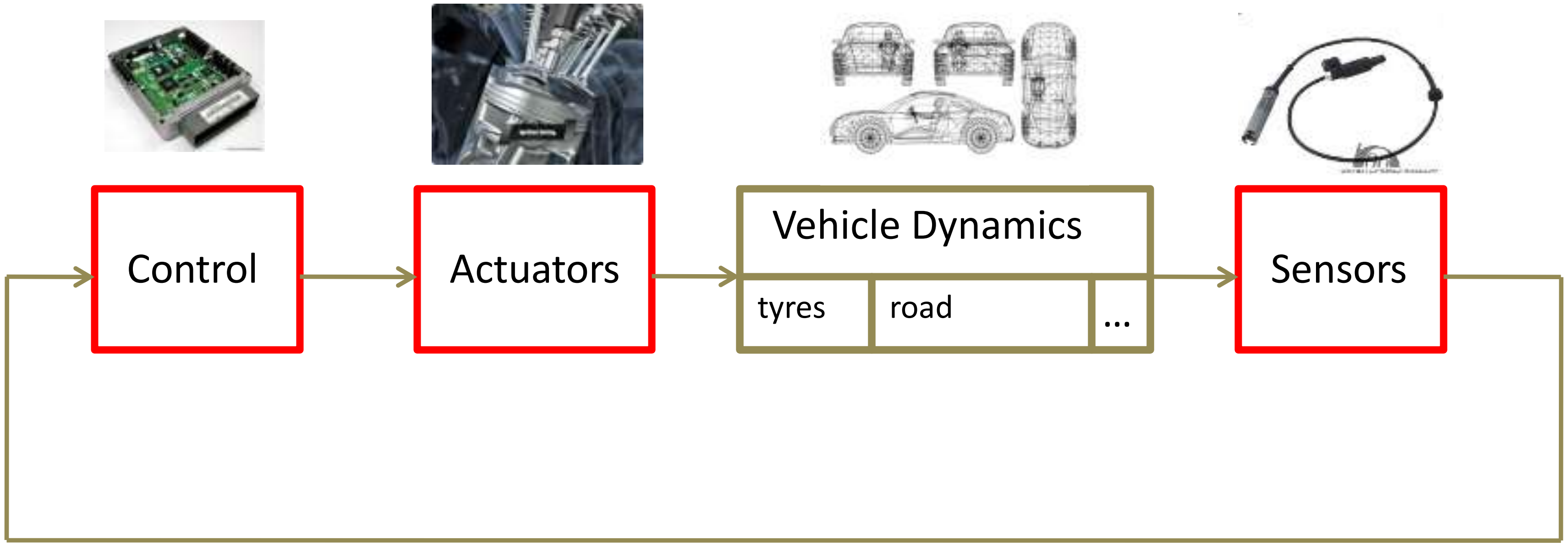
+ “Gadgets” (wheelie, launch...)

Generation 3+; Yamaha R1
MY 2015

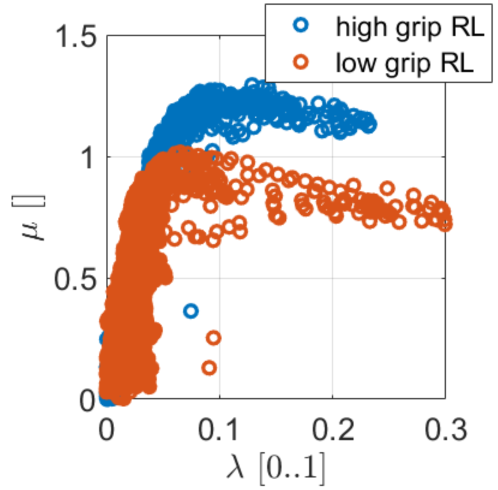
Includes **rear wheel sideslip monitoring**

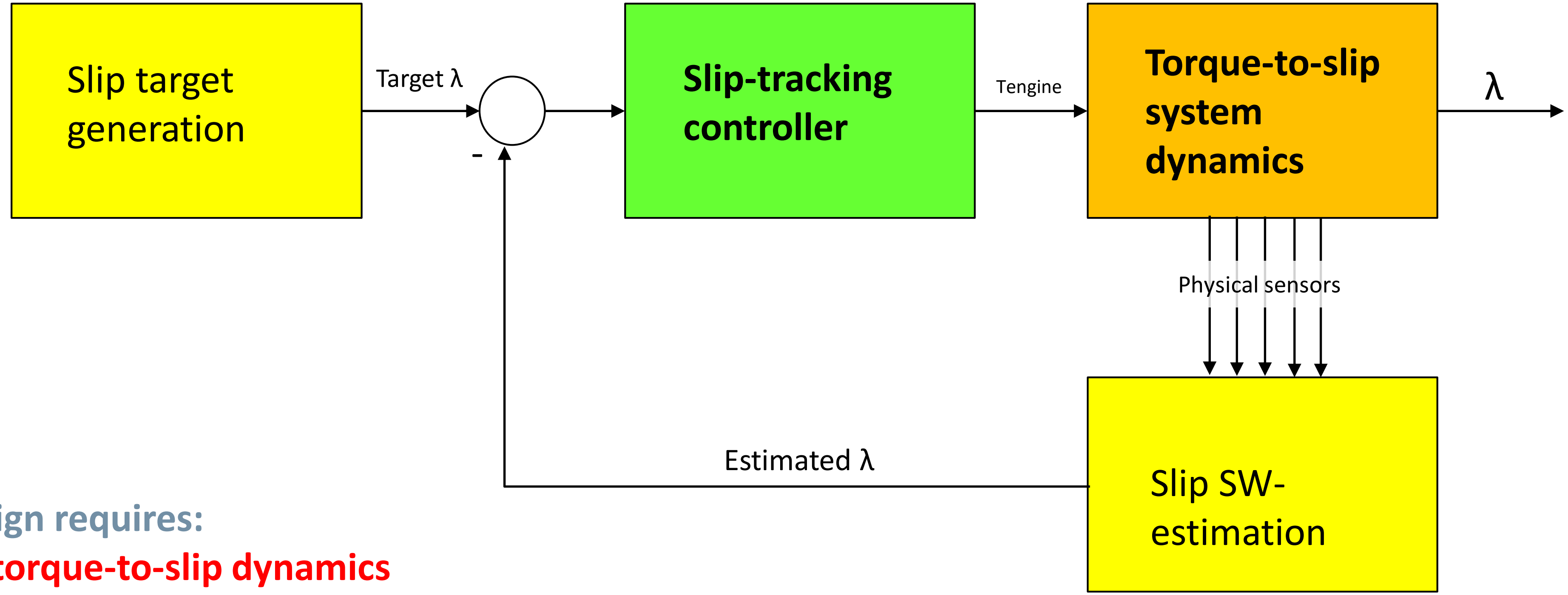
Introduction to Traction Control (TC) system

TC is a **closed-loop electronic control system**



Introduction to TC DESIGN: sub-problems



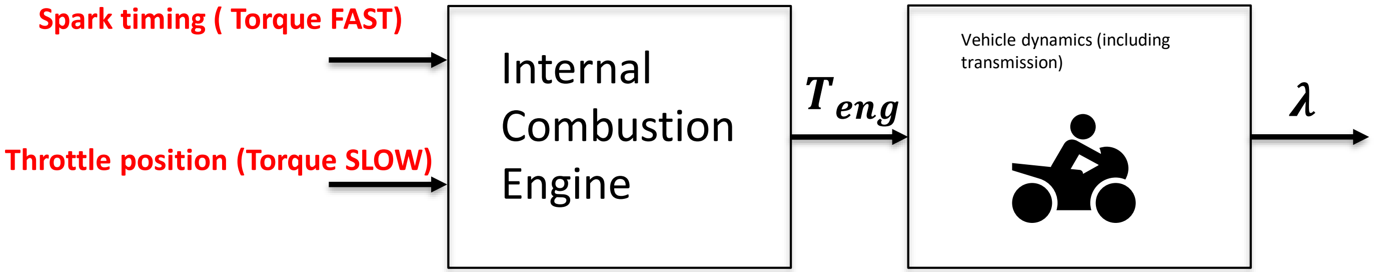


The complete control design requires:

- **Modelling the Engine-torque-to-slip dynamics**
- **Design the slip-tracking control algorithm**
- **Design an estimator for the slip (SW-sensing)**
- **Design a slip-target generation algorithm**

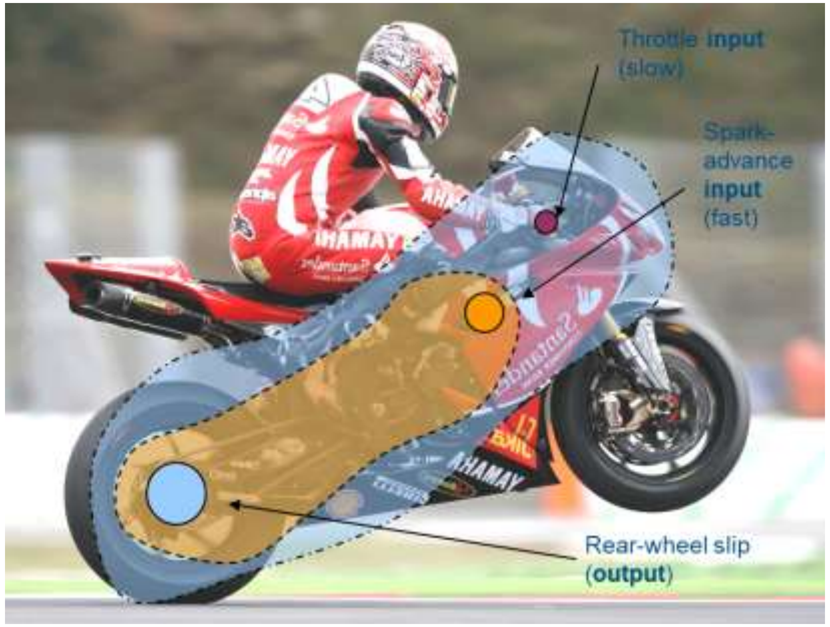
Classic (most common) actuator: Torque of the Internal Combustion Engine (ICE)

In a Spark Ignited Internal Combustion Engine, there are two variables that can be used to change the delivered torque

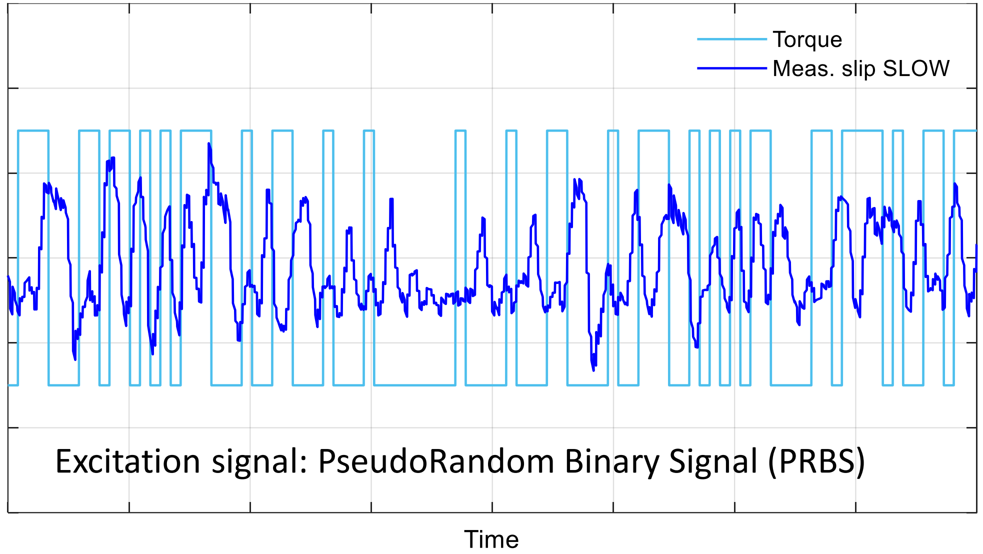


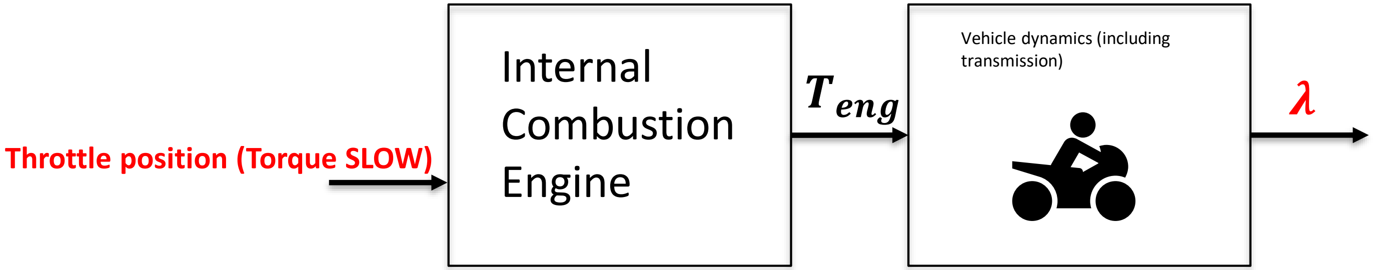
Spark-timing has a «fast» action on T_{eng}

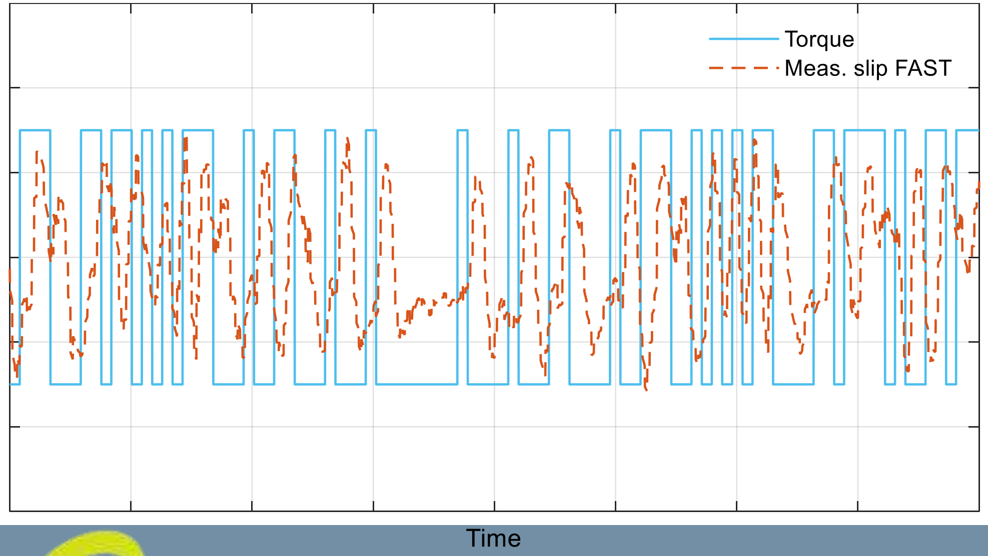
Throttle position has a «slow» action on T_{eng}

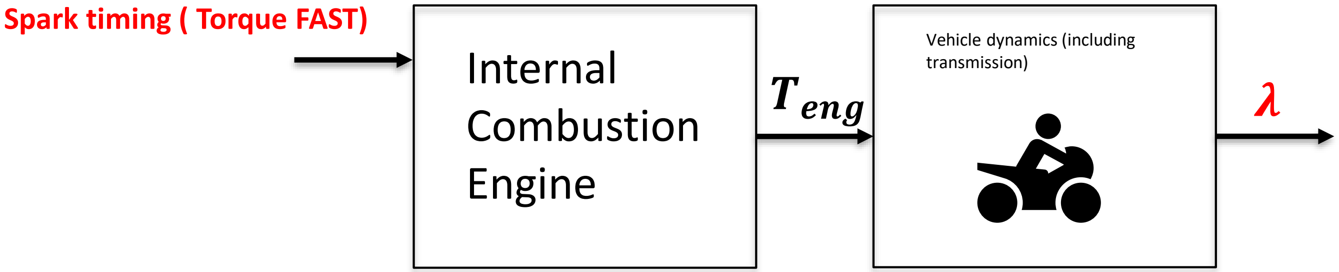


Experimental I/O relationship from the two inputs

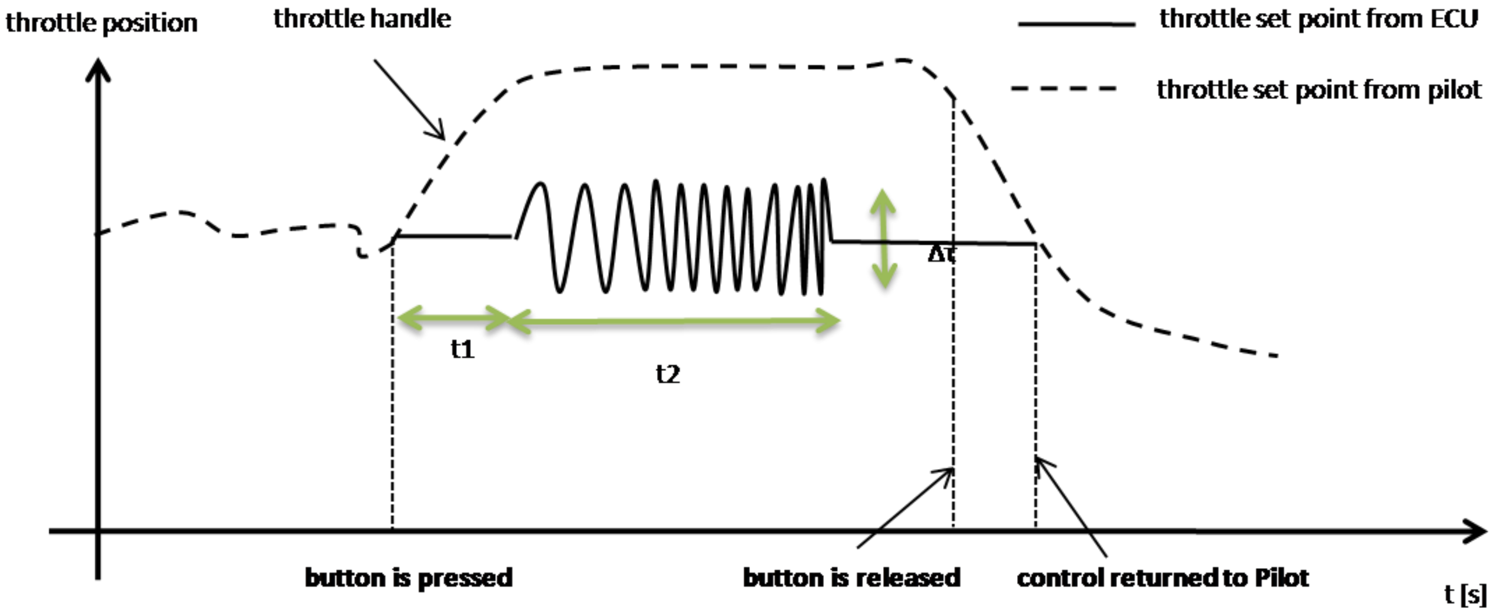








Remark on experiment design

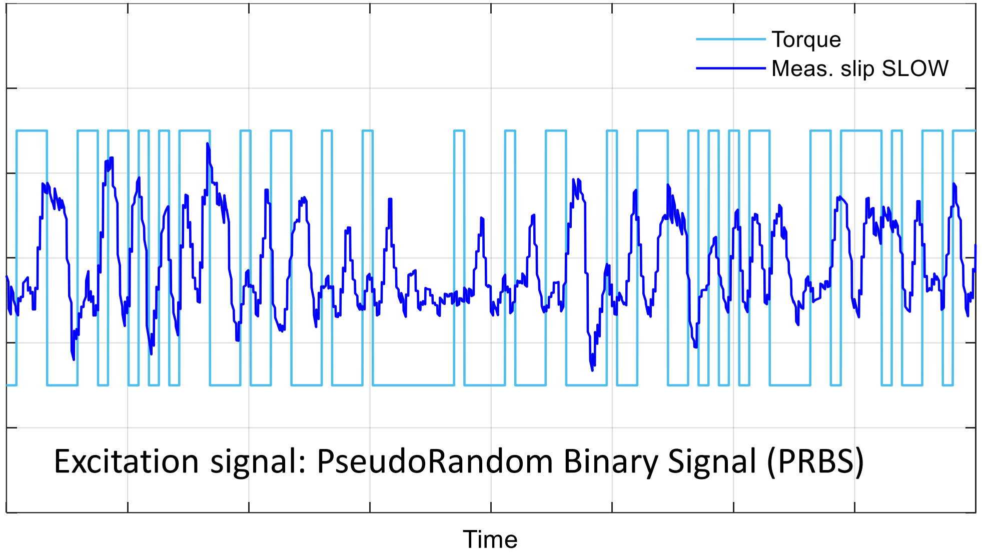


Tests on a long (3 km) straight road:

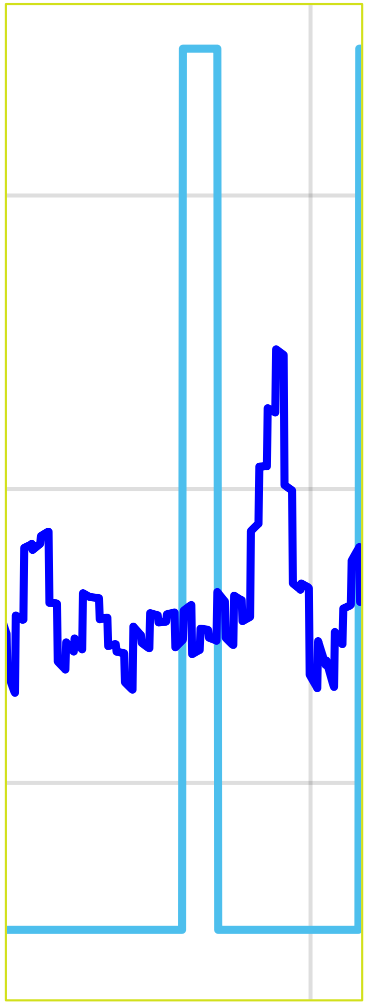
1) the rider is asked to Trim the motorcycle to constant speed
2) the test is trigged by the driver with a button: At that point the ECU completely command overrides the driver, and the excitation signal is applied around the neighborhood of the initial condition.

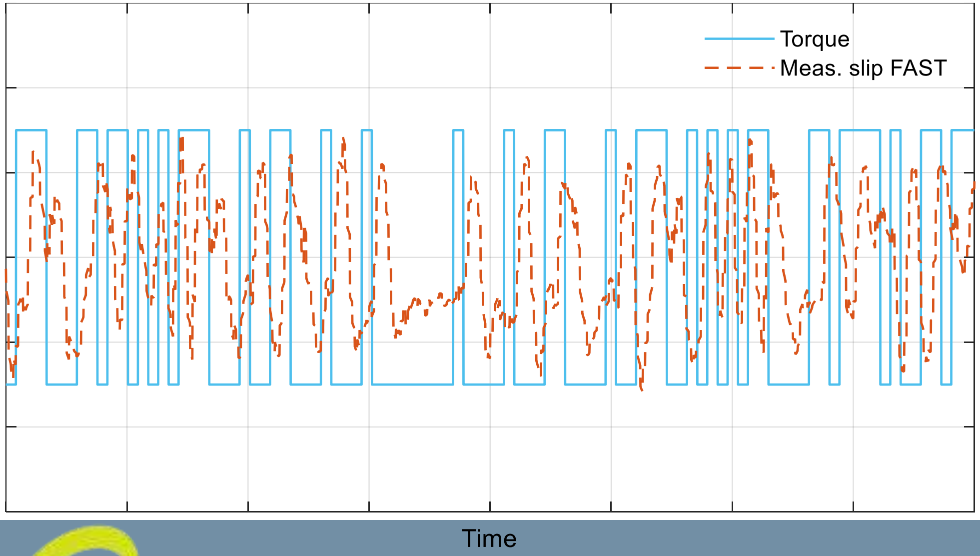
This experiment is non-trivial, but has the major advantage of **being repeatable and providing the real dynamic behavior of the motorbike** (And rider), on a real test-track (**Whereas test-rig Typically experiments are flawed by non-realistic conditions)**.

Remark: delay



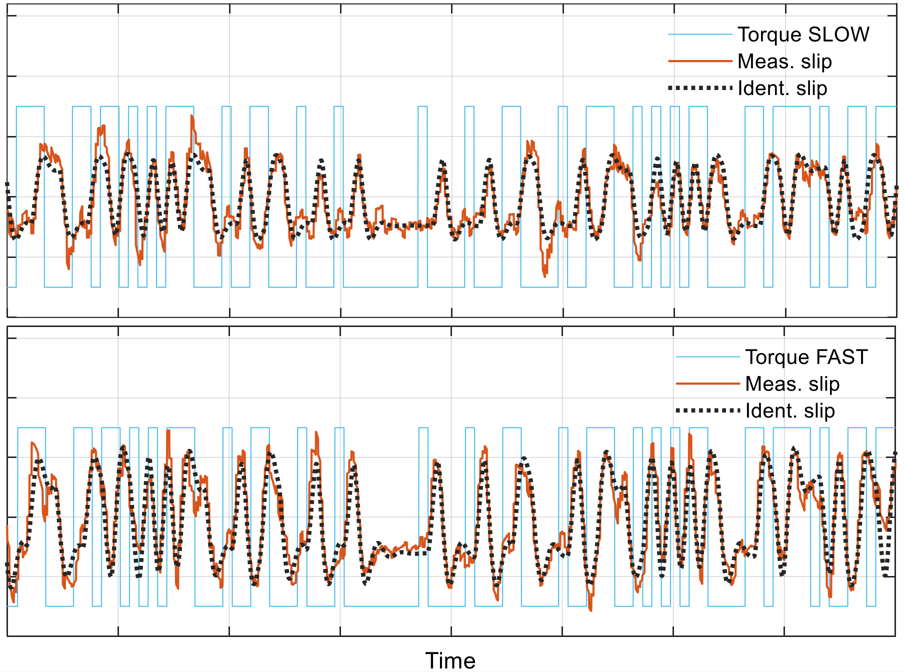
Estimated delay: 5 steps at 20ms sampling time

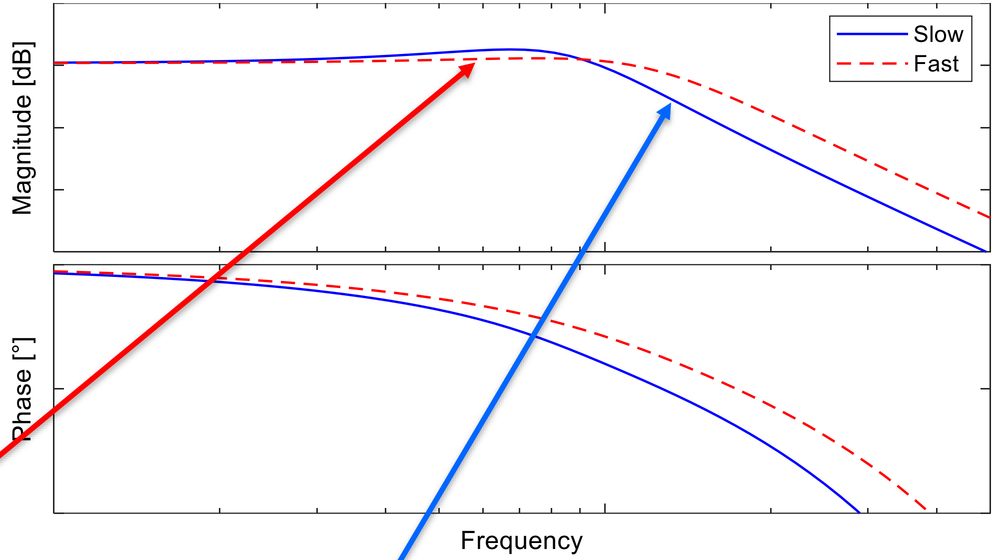




Estimated delay: 4 steps at 20ms sampling time

Experimental (Black-Box) identification of I/O relationships from the two inputs





Sampling time: Ts=20ms (0.02s)

$$\text{Ffast}(z) = \frac{0.01412\, z + 0.01412}{z^2 - 0.2876\, z + 0.1988}\ (z^{-3})$$

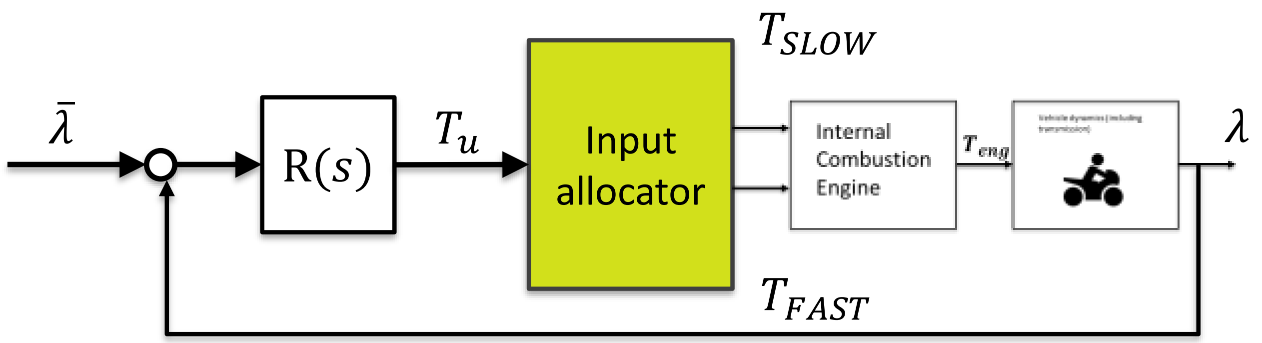
$$\text{Fslow}(z) = \frac{0.01116\, z + 0.01116}{z^2 - 0.7237\, z + 0.4002}\ (z^{-4})$$

Obtained with 4SID identification

2nd-order (only!) TF, with delays

SISO design with input-allocator

An effective controller is a SISO controller, flanked by a proper "Input Allocator" (IA).



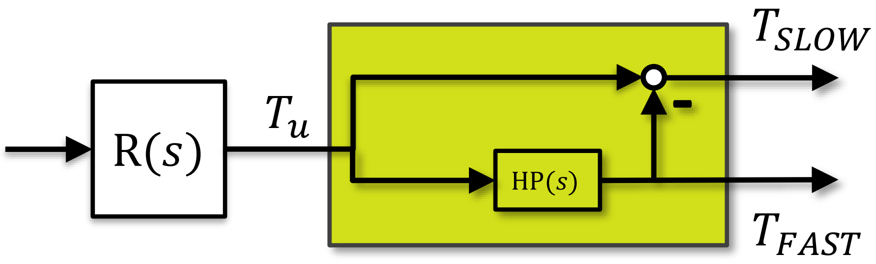
The IA must satisfy the following requirements:

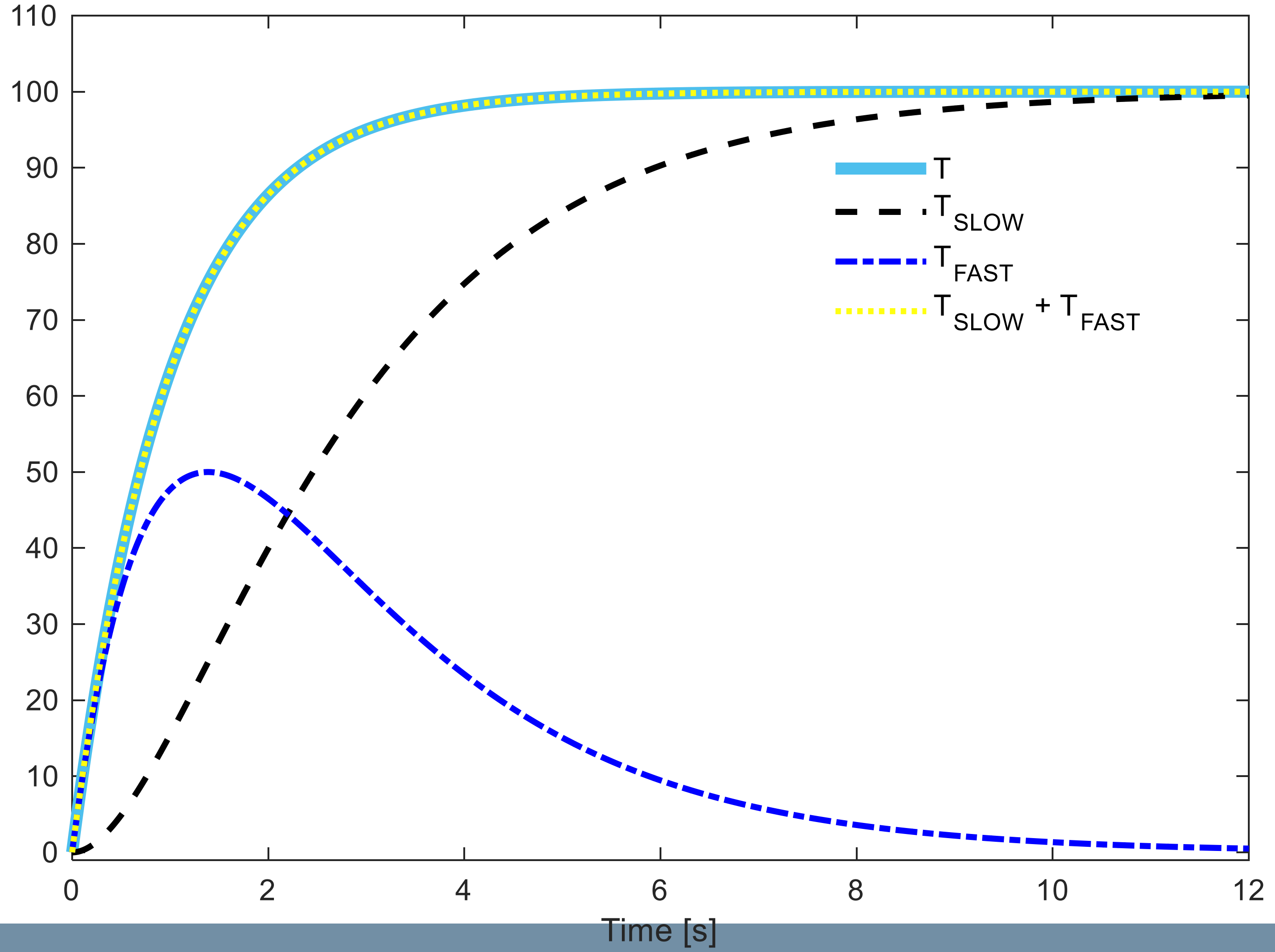
1. Be "transparent" with respect to the regulator, meaning that the TOTAL engine torque should match exactly the torque requested by the regulator. This allows a SISO approach for the controller design

2. Allocate the torques according to their specific features:
    1. The high frequency torque should be delivered through the "FAST" channel
    2. The low frequency torque should be delivered through the "SLOW" channel

Input-allocator (frequency-split)

The Input Allocator makes a frequency-split of the Torque requested by the slip-regulator





Example:

$$HP(s) = \frac{s}{s+0.5}$$

Two examples of advaced TC for high-performance motorcycles («superbike» class)

https://www.youtube.com/watch?v=8a9LWlGkjbA