University of Rome “Tor Vergata”
Department of Industrial Engineering

Bachelor's Degree in Engineering Sciences

Synchronization control of DC motors through adaptive disturbance cancellation

-Implementation issues-

Candidate: **C. Valentini**

Supervisor: **C.M. Verrelli**
Thesis Advisor: **M. Tiberti**

July, the 26th, 2016

A brief abstract...

- A different interpretation of a ***mater/slave controller***
- Description of the ***implementation of the algorithm***
- Presentation of the ***experimental results***

The model of the ***DC motor***

$$\dot{\theta}(t) = \omega(t)$$

$$\dot{\omega}(t) = -\frac{F}{J}\omega(t) - c_1 - c_2\theta(t) + \frac{k_M}{J}i(t)$$

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"Reconstruction" action

***"Stabilizing"** action*

The control signal in the Laplace domain...

$$\mathcal{L}\{i\}(s) = -\bar{b}\frac{(s + \frac{k_1 l_\omega}{\bar{b}})}{s + l_\omega}\mathcal{L}\{\tilde{\theta}\}(s) + \mathcal{L}\{v\}(s)$$

$$\bar{b} = k_1 + k_2 l_\omega$$

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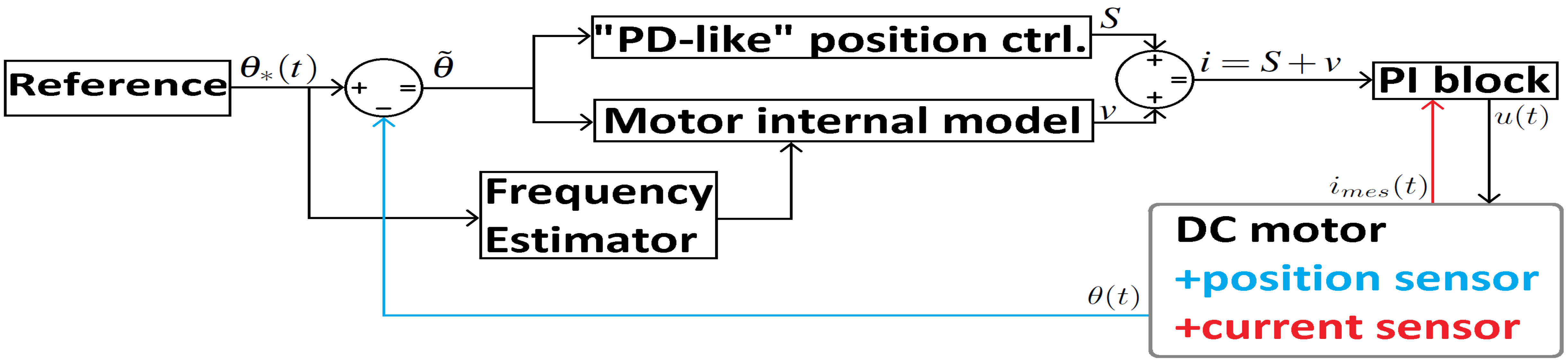
Block diagram of the controller



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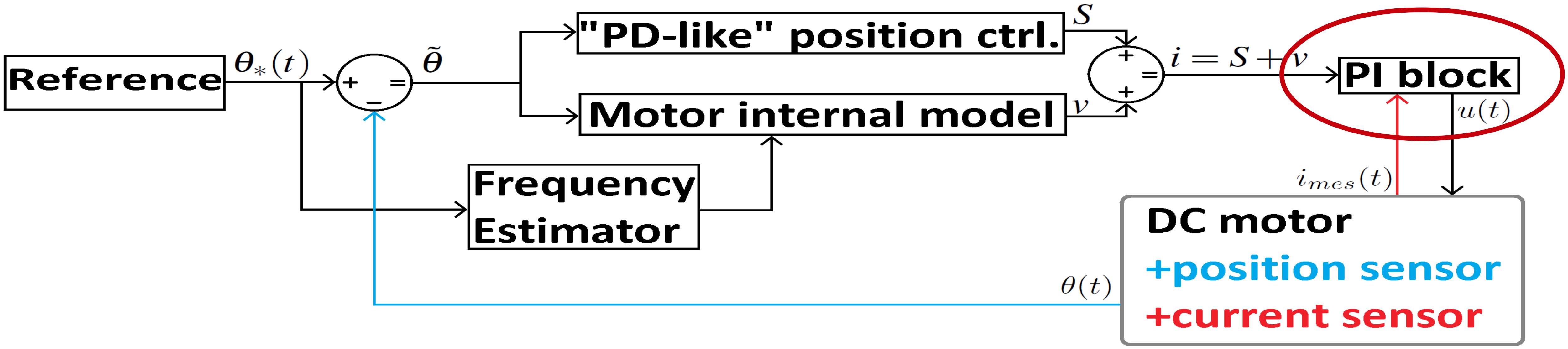

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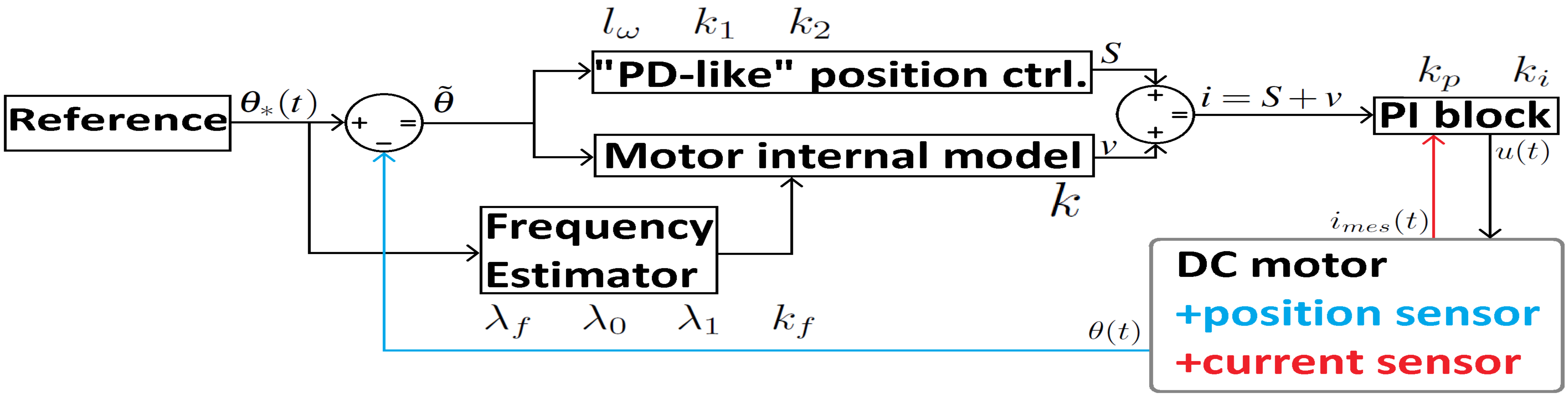

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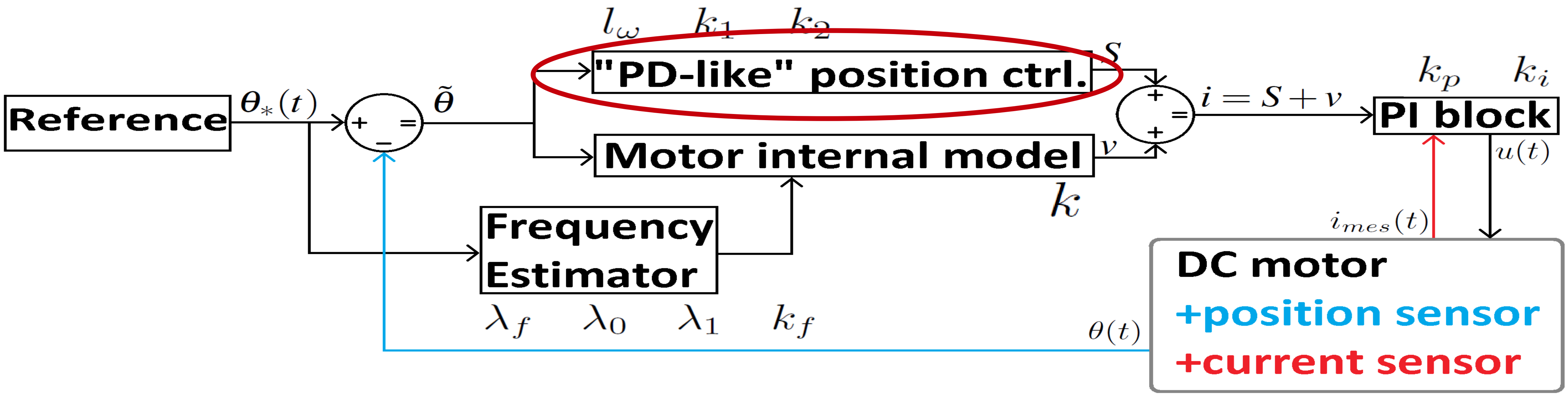

Stabilizing action: a “PD-like” interpretation...

$$S = -k_1 \tilde{\theta} - k_2 \hat{\tilde{\omega}}$$

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$$\hat{\tilde{\omega}} = l_\omega\tilde{\theta} + \psi_\omega$$

with $l_\omega \in \mathbb{R}_+$

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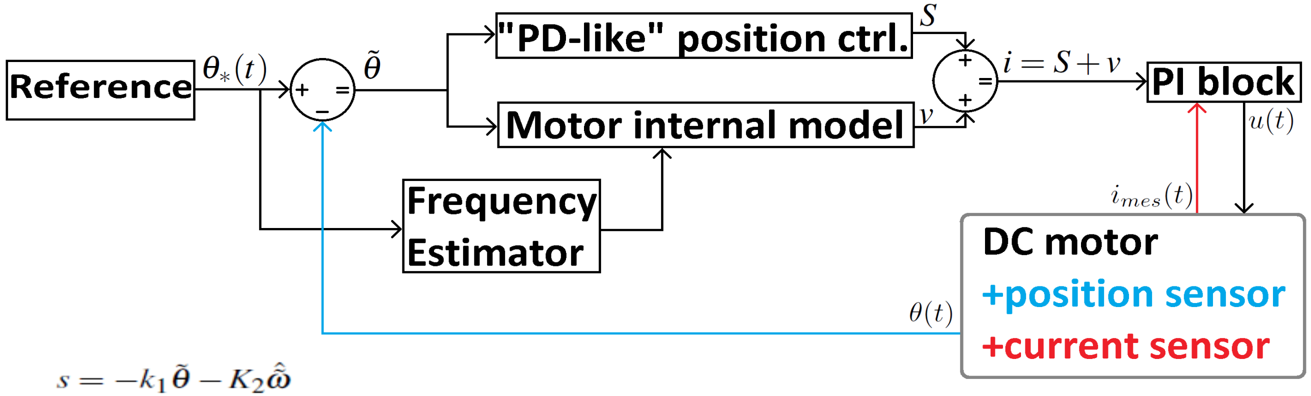
with $l_\omega \in \mathbb{R}_+$

Dynamics of the ***reduced order observer***

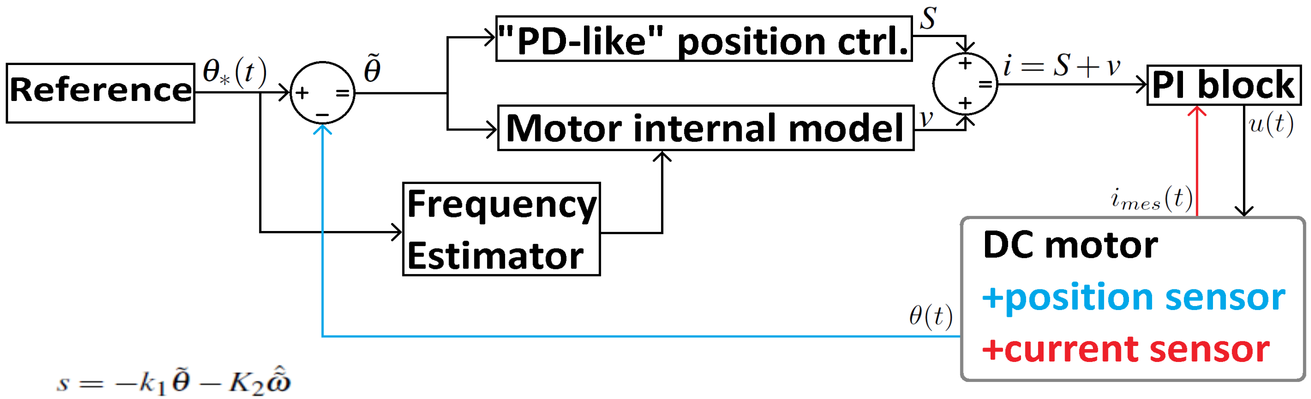
$$\dot{\psi}_\omega = -l_\omega\psi_\omega - l_\omega^2\tilde{\theta}$$

From the ***mathematical description*** of the algorithm to its ***actual implementation***



$$
\begin{aligned}
s &= -k_1\tilde{\theta} - K_2\hat{\omega} \\
\dot{\hat{\omega}} &= l_\omega\tilde{\theta} + \psi_\omega \\
\dot{\psi}_\omega &= -l_\omega\psi_\omega - l_\omega^2\tilde{\theta} \\
\dot{\xi}_f &= -\lambda_f\xi_f - \theta_* \\
\dot{\hat{\theta}}_* &= \hat{\eta}_f + \lambda_f\theta_* + \frac{\hat{\theta}_0}{\lambda_f} + \xi_f\hat{\theta}_1 + k_f(\theta_* - \hat{\theta}_*) \\
\dot{\hat{\eta}}_f &= -\lambda_f\hat{\eta}_f - \lambda_f^2\theta_* \\
\dot{\hat{\theta}}_0 &= \lambda_0(\theta_* - \hat{\theta}_*) \\
\dot{\hat{\theta}}_1 &= \lambda_1\xi_f(\theta_* - \hat{\theta}_*) \\
v &= -\dot{\hat{w}}_0 - \dot{\hat{w}}_1 \\
\dot{\hat{w}}_0 &= k\tilde{y} \\
\dot{\hat{w}}_1 &= \hat{w}_2 + k\tilde{y} \\
\dot{\hat{w}}_2 &= -\hat{\theta}_1\hat{w}_1 \\
i &= s + v
\end{aligned}
$$

From the *mathematical description* of the algorithm to its *actual implementation*



$$
\begin{aligned}
s &= -k_1\tilde\theta - K_2\hat{\tilde\omega}\\
\hat{\tilde\omega} &= l_\omega\tilde\theta + \psi_\omega\\
\dot\psi_\omega &= -l_\omega\psi_\omega - l_\omega^2\tilde\theta\\
\dot\xi_f &= -\lambda_f\xi_f - \theta_*\\
\dot{\hat\theta}_* &= \hat\eta_f + \lambda_f\theta_* + \frac{\hat\theta_0}{\lambda_f} + \xi_f\hat\theta_1 + k_f(\theta_* - \hat\theta_*)\\
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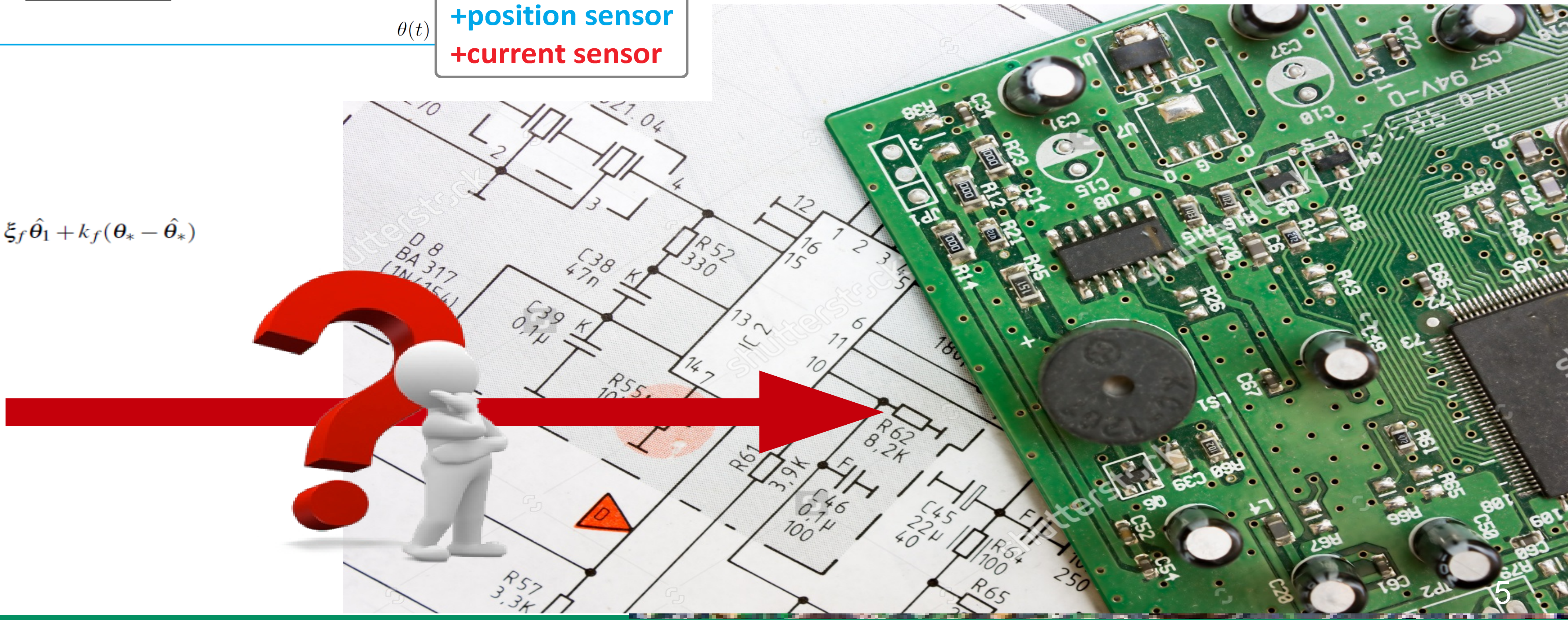

NI *myRIO* device

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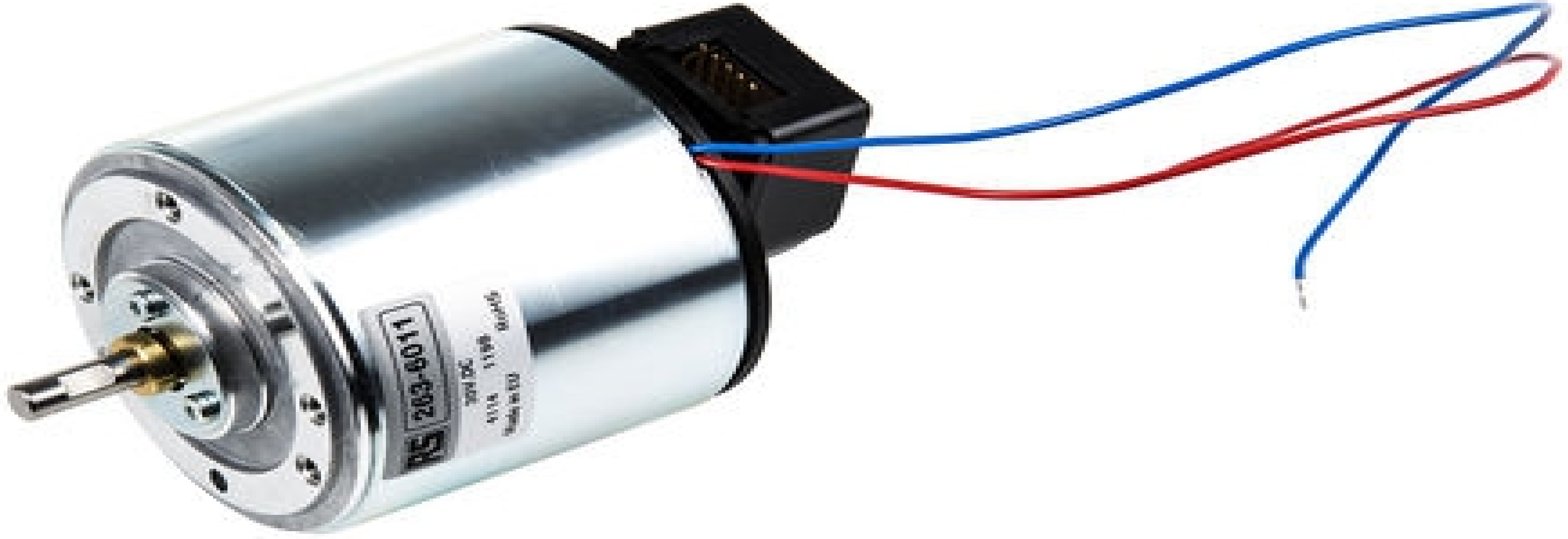
The ***FPGA*** chip

The ***DC motor*** used in the experiments



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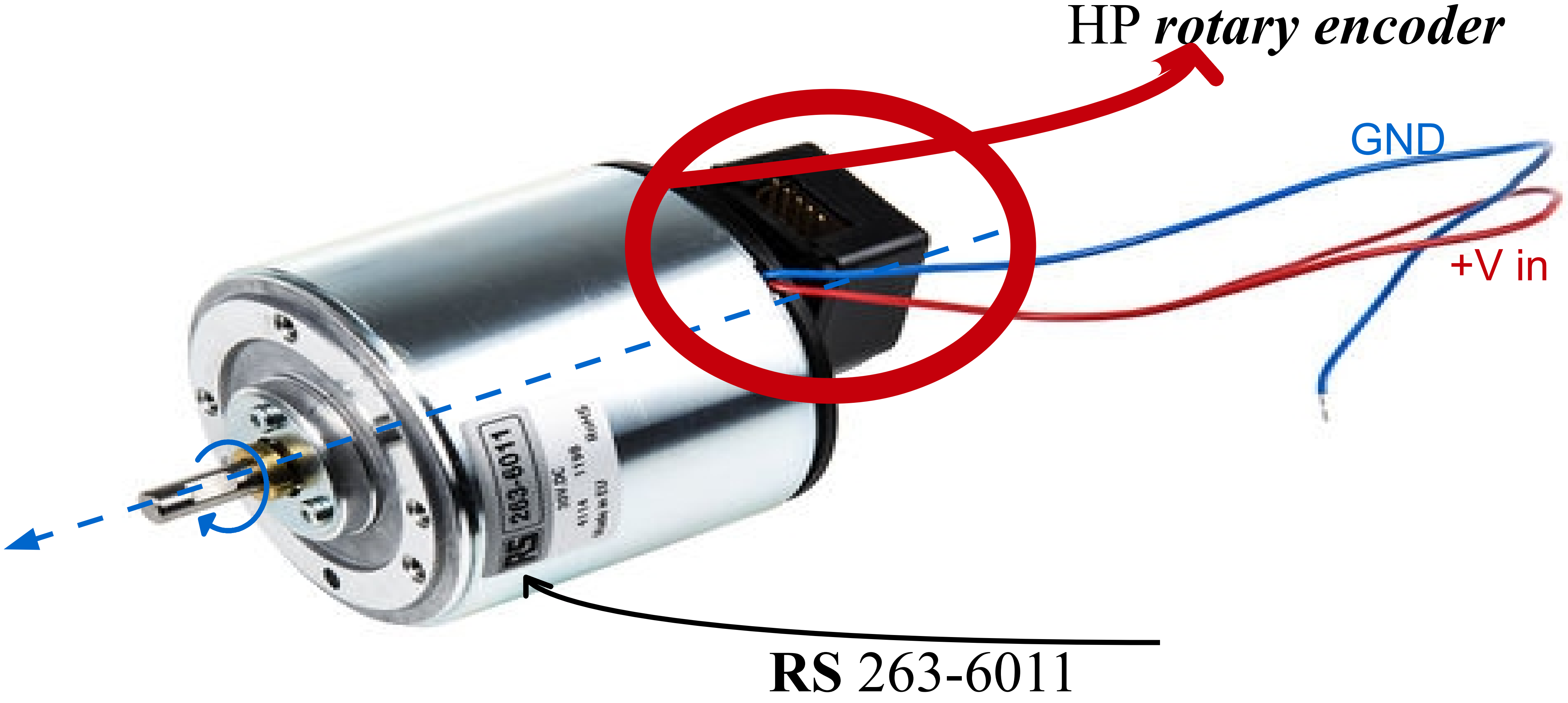

“*Flow*” of the experiment

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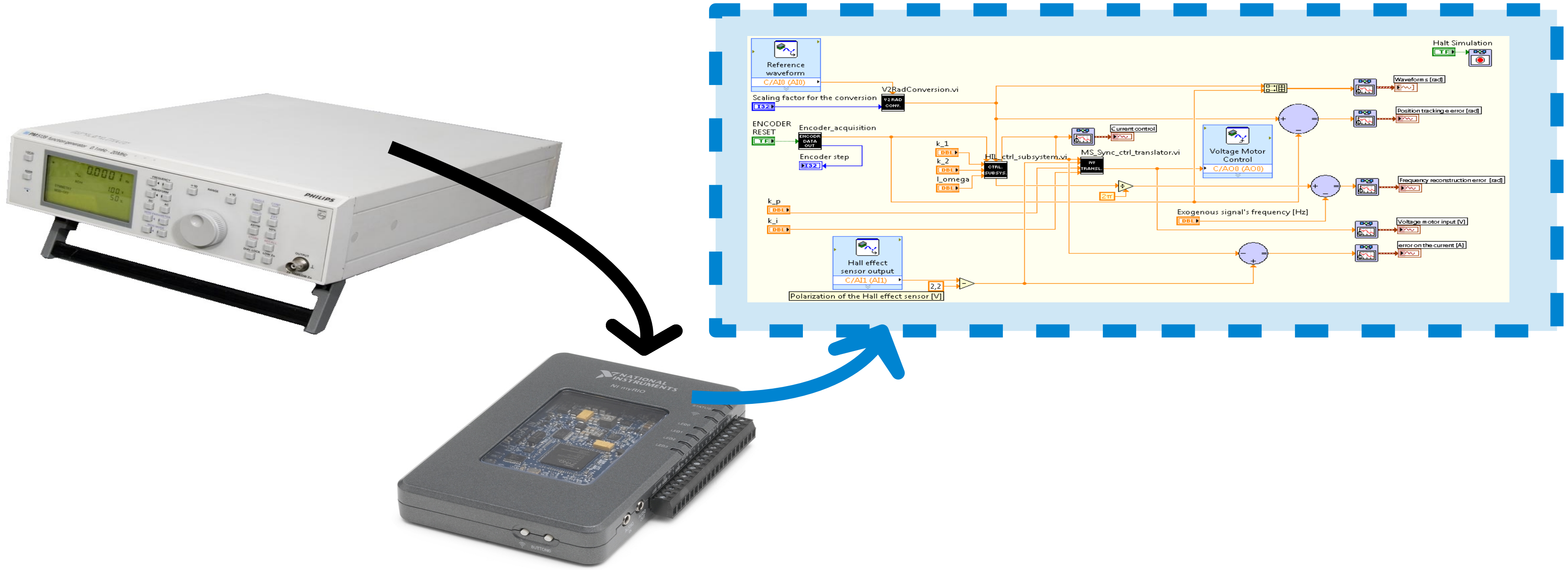

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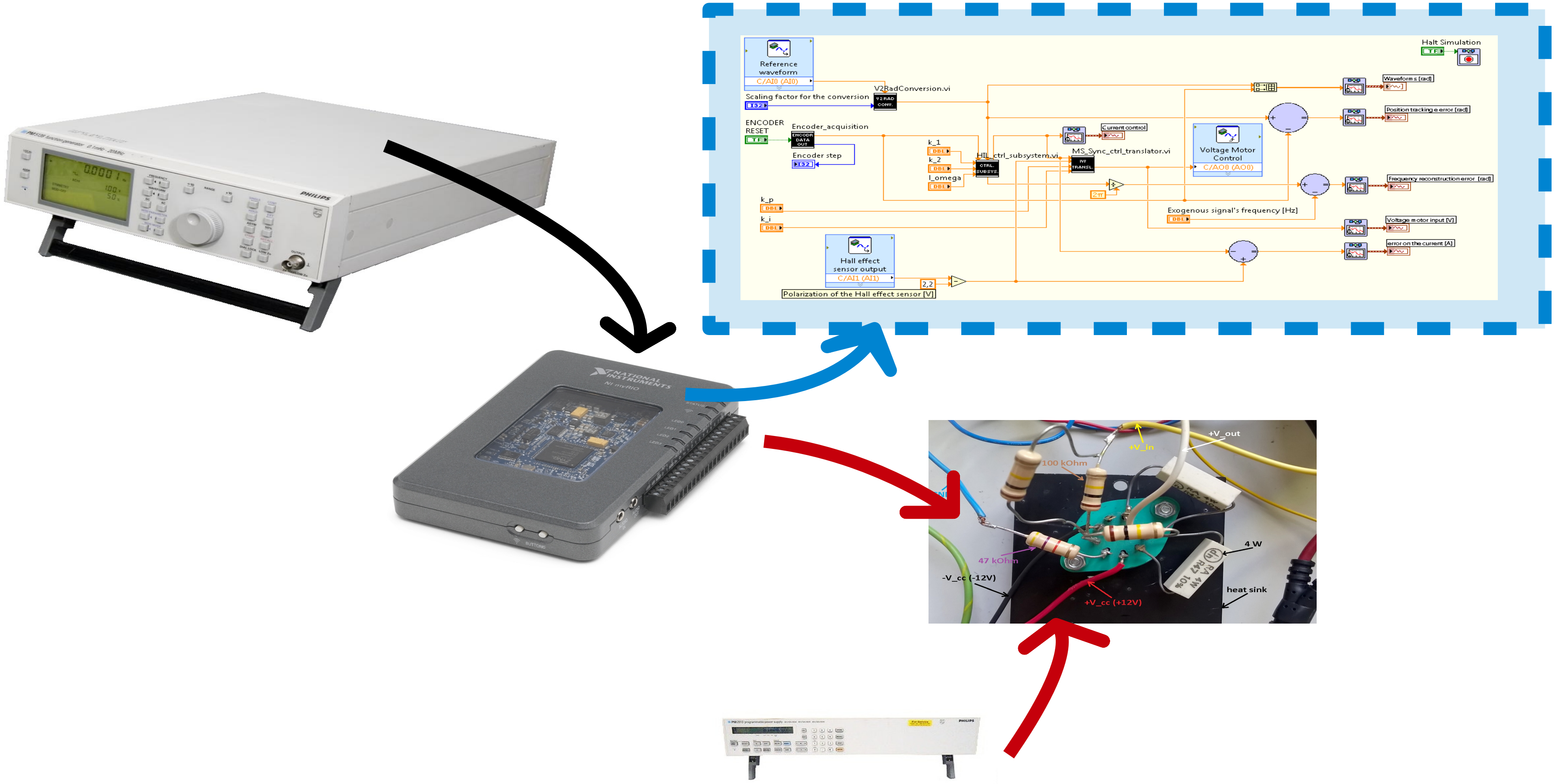

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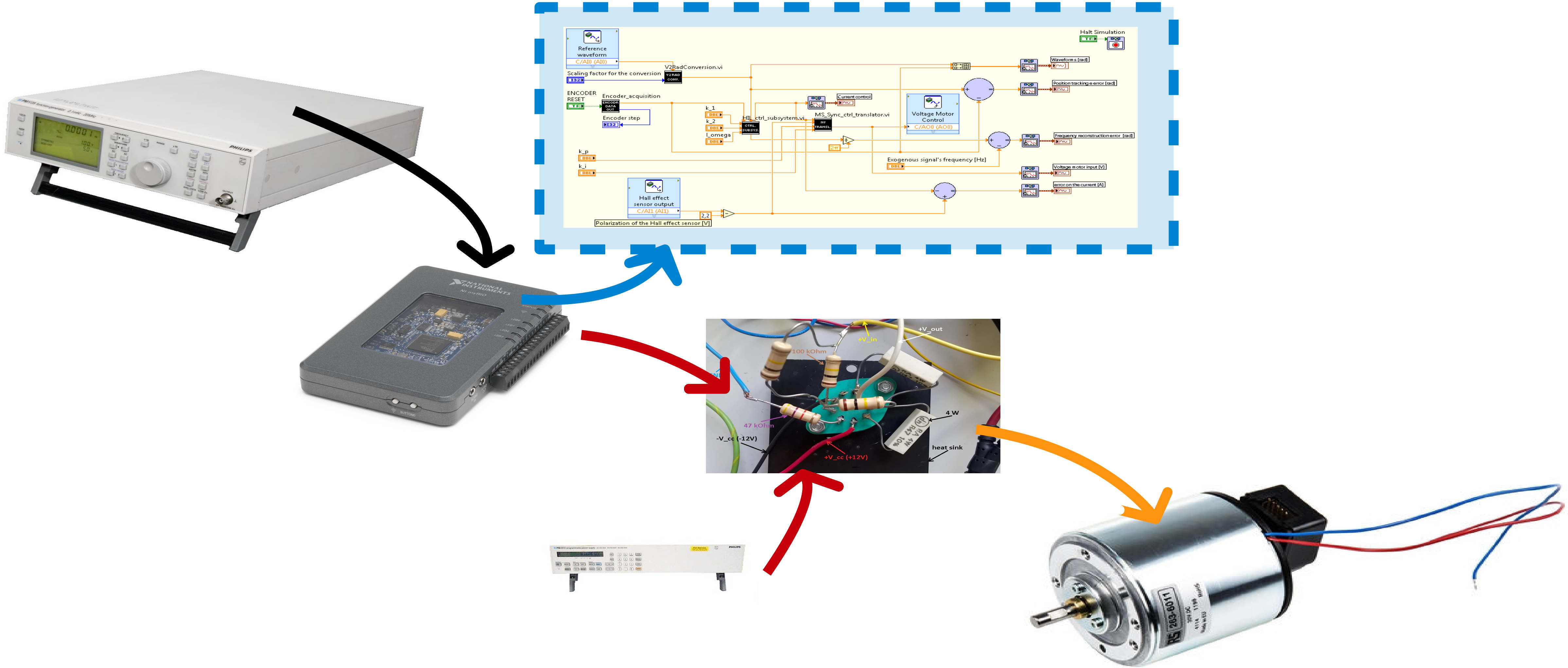

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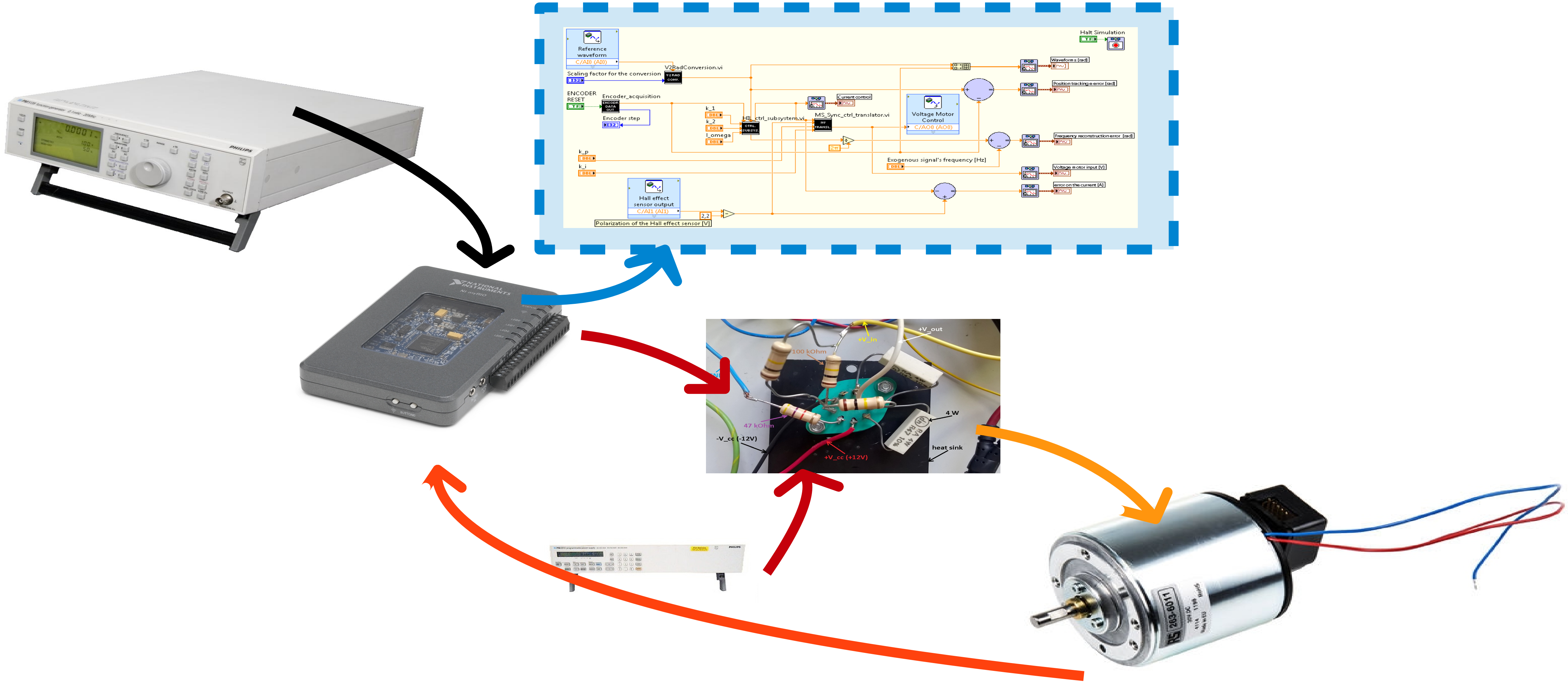

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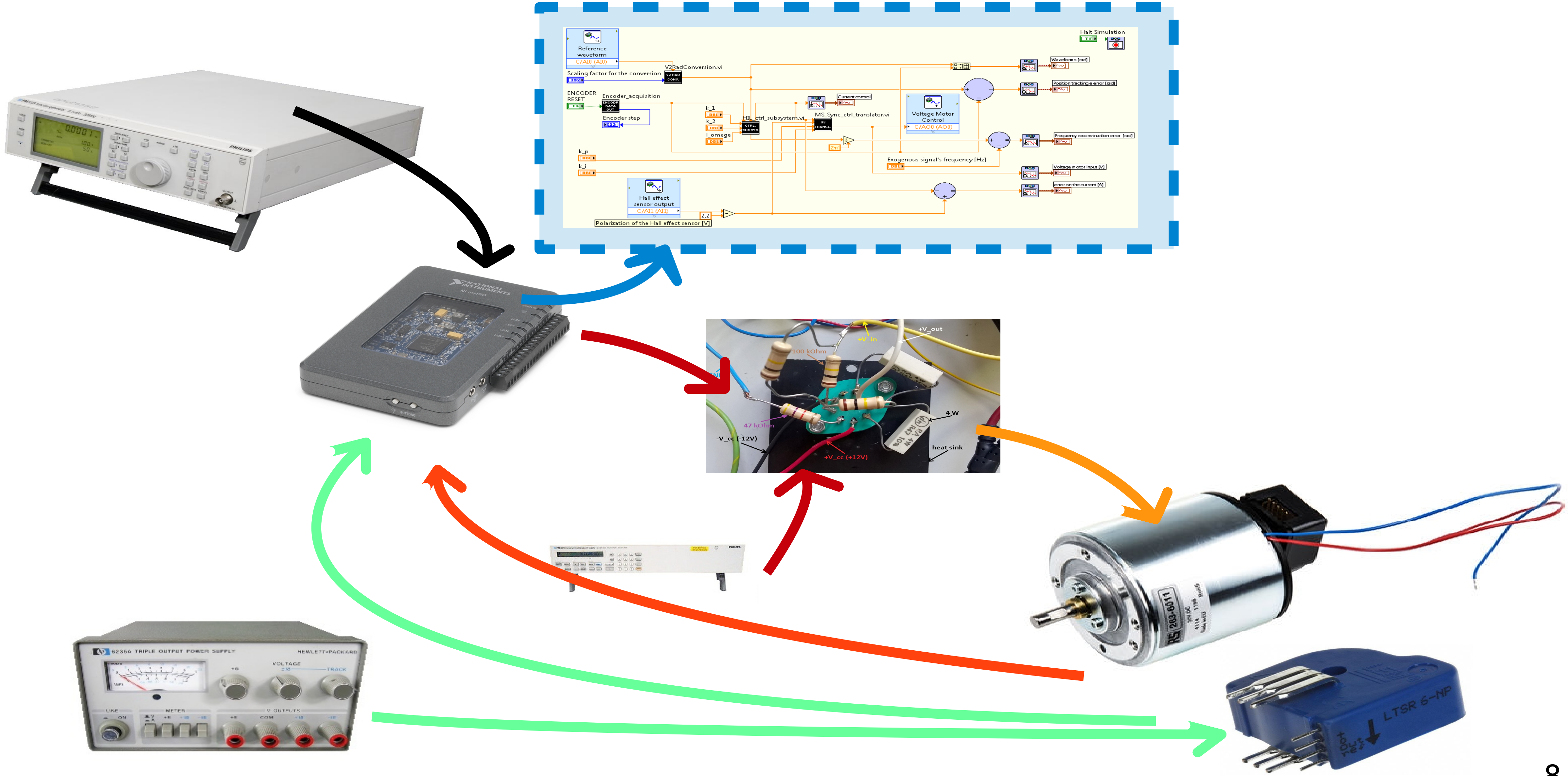
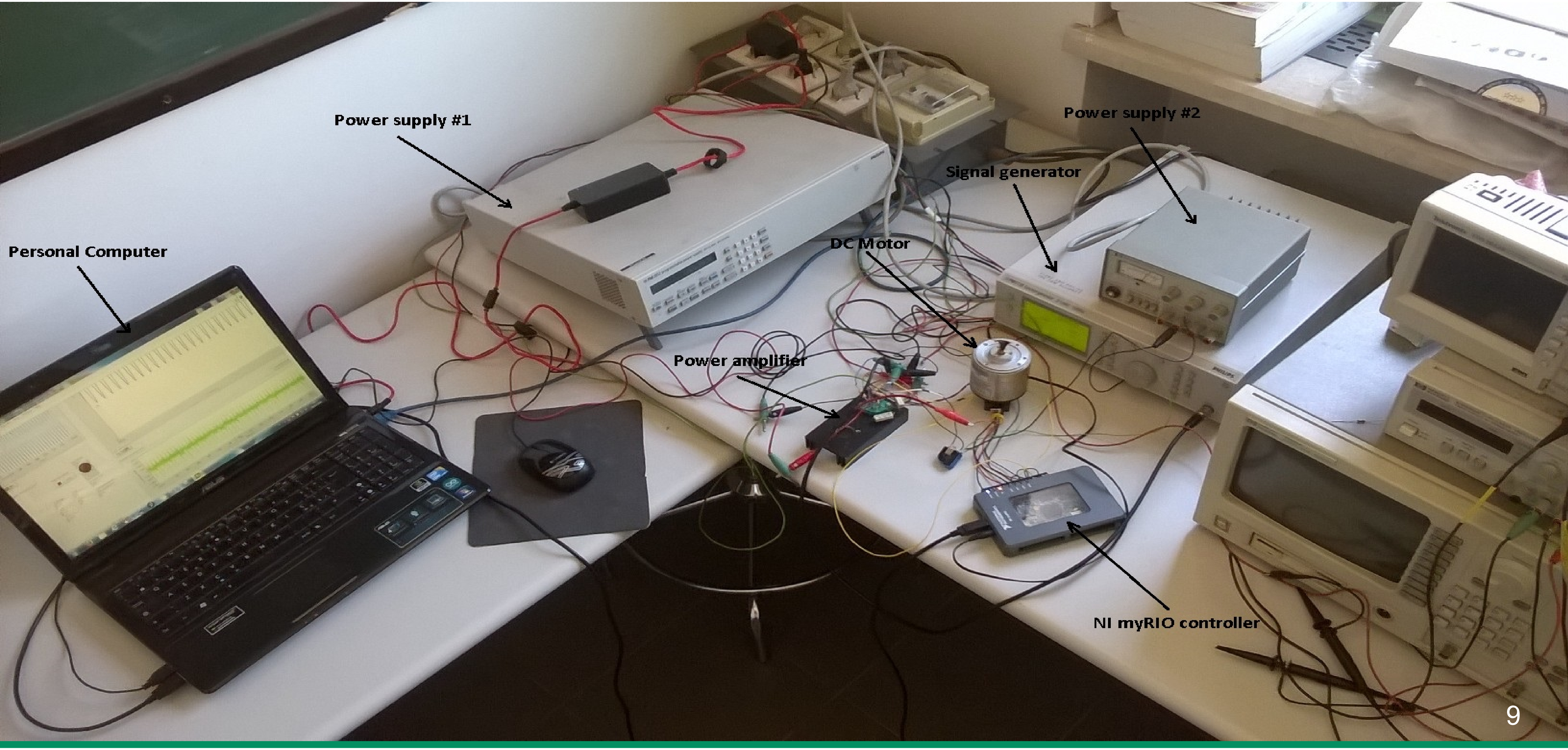
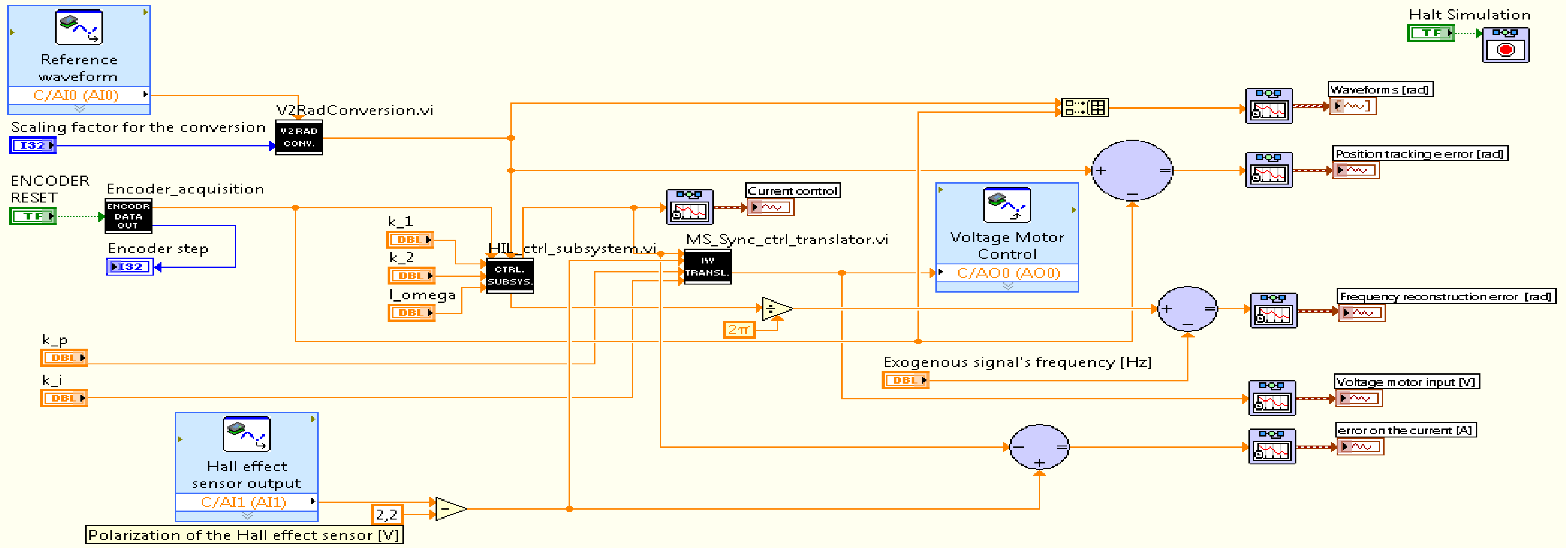


Experimental *set-up*



Main ***LabVIEW program*** loaded on the controller



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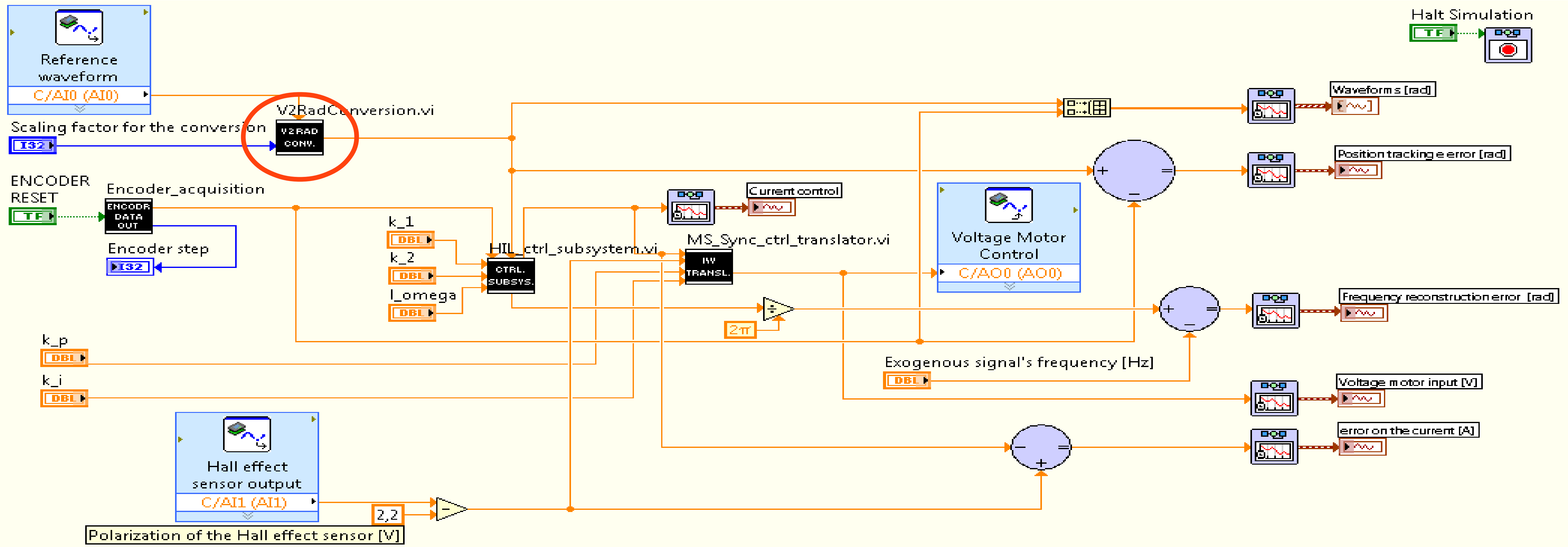
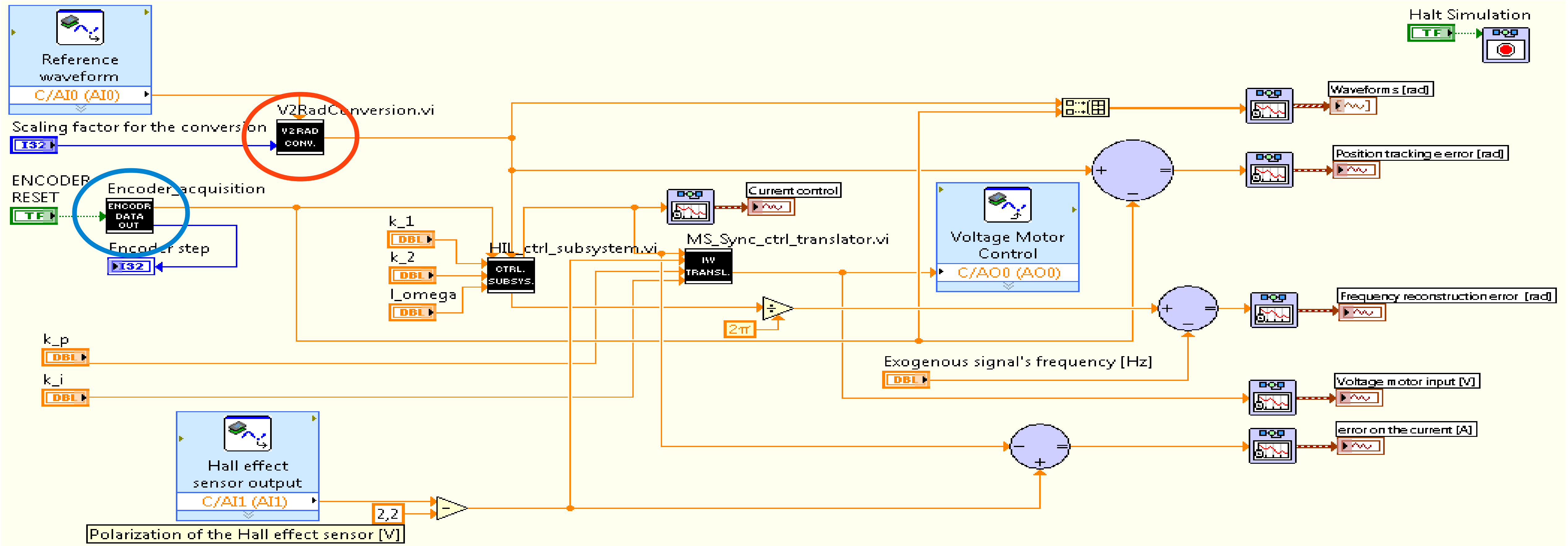


Control subsystems:

- Subsystem for the conversion of the reference signal, from Volts to radiants

Main *LabVIEW program* loaded on the controller



Control subsystems:

- Subsystem for the conversion of the reference signal, from Volts to radiants
- Subsystem for the acquisition of the encoder steps and their conversion to an angle (in radiants)

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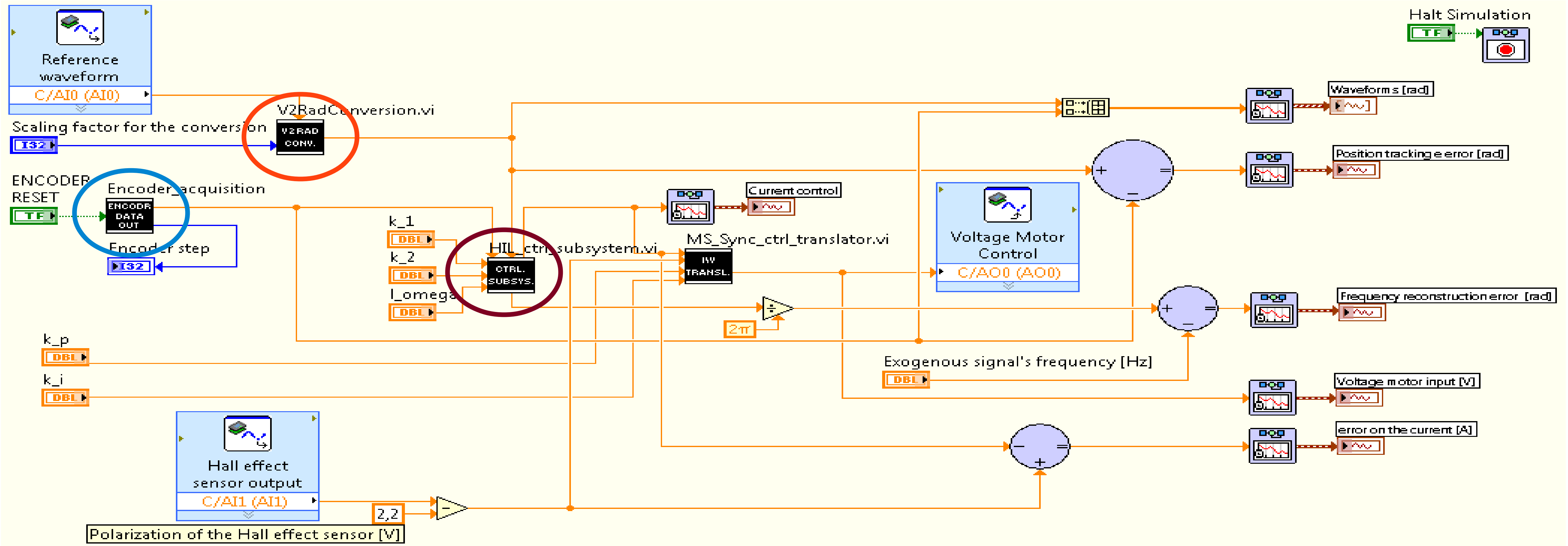
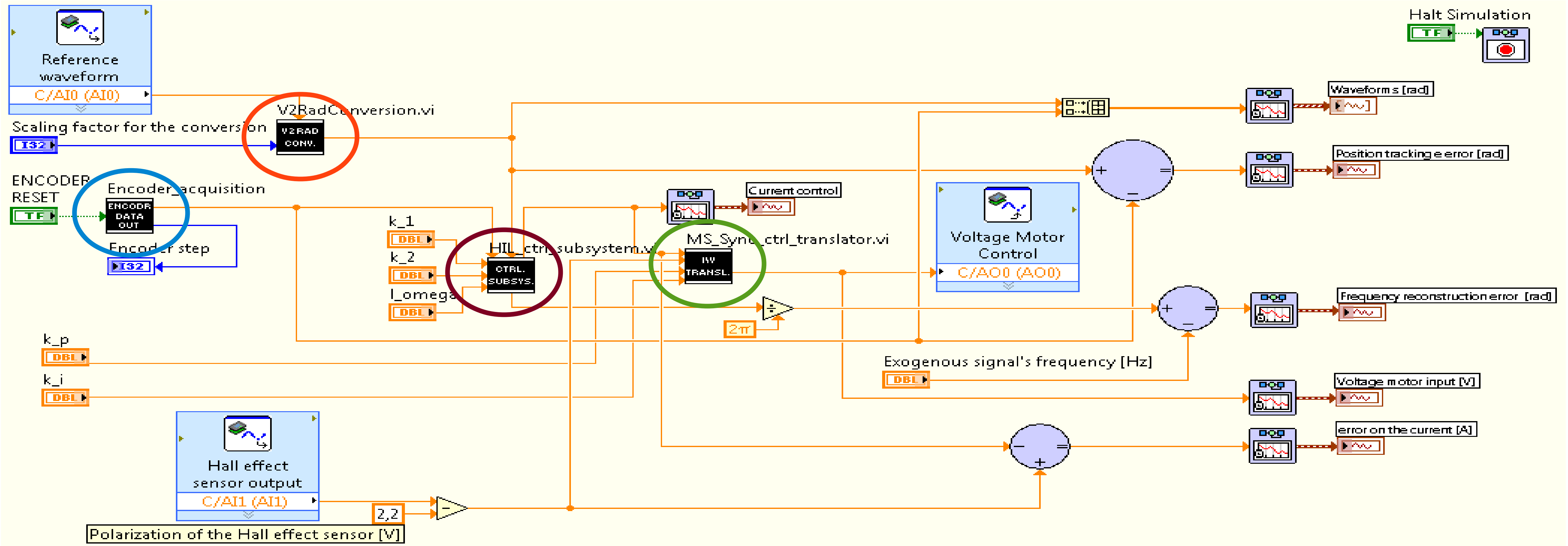


Control subsystems:

- Subsystem for the conversion of the reference signal, from Volts to radiants
- Subsystem for the acquisition of the encoder steps and their conversion to an angle (in radiants)
- Subsystem implementing the whole controller

Main *LabVIEW program* loaded on the controller



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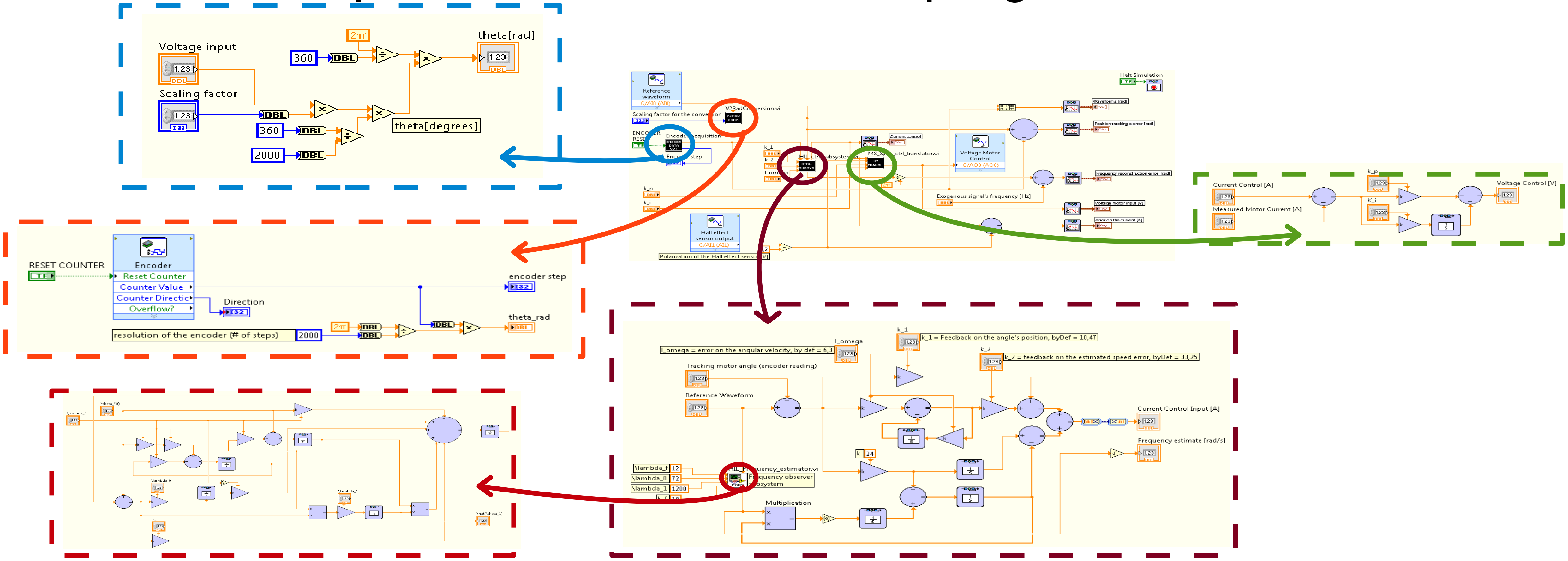
- Subsystem implementing the whole controller
- Subsystem containing the PI control block generating the voltage input for the power amplifier

An “exploded” overview of the program modules



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Computation of the parameters through ***trial and error*** method

$$l_\omega = 1.14$$
$$k_1 = 1.5$$
$$k_2 = 10.25$$

"PD-like" control block (the position tracking)

Computation of the parameters through ***trial and error*** method

$l_\omega = 1.14$ $k_1 = 1.5$ $k_2 = 10.25$	“PD-like” control block (the position tracking)
$k_p = 1$ $k_i = 0$	PI control block (the current feedback)

Computation of the parameters through ***trial and error*** method

$l_\omega = 1.14$ $k_1 = 1.5$ $k_2 = 10.25$	"PD-like" control block (the position tracking)
$k_p = 1$ $k_i = 0$	PI control block (the current feedback)
$\lambda_f = 12$ $\lambda_0 = 72$ $\lambda_1 = 1200$ $k_f = 18$	Frequency observer

Computation of the parameters through ***trial and error*** method

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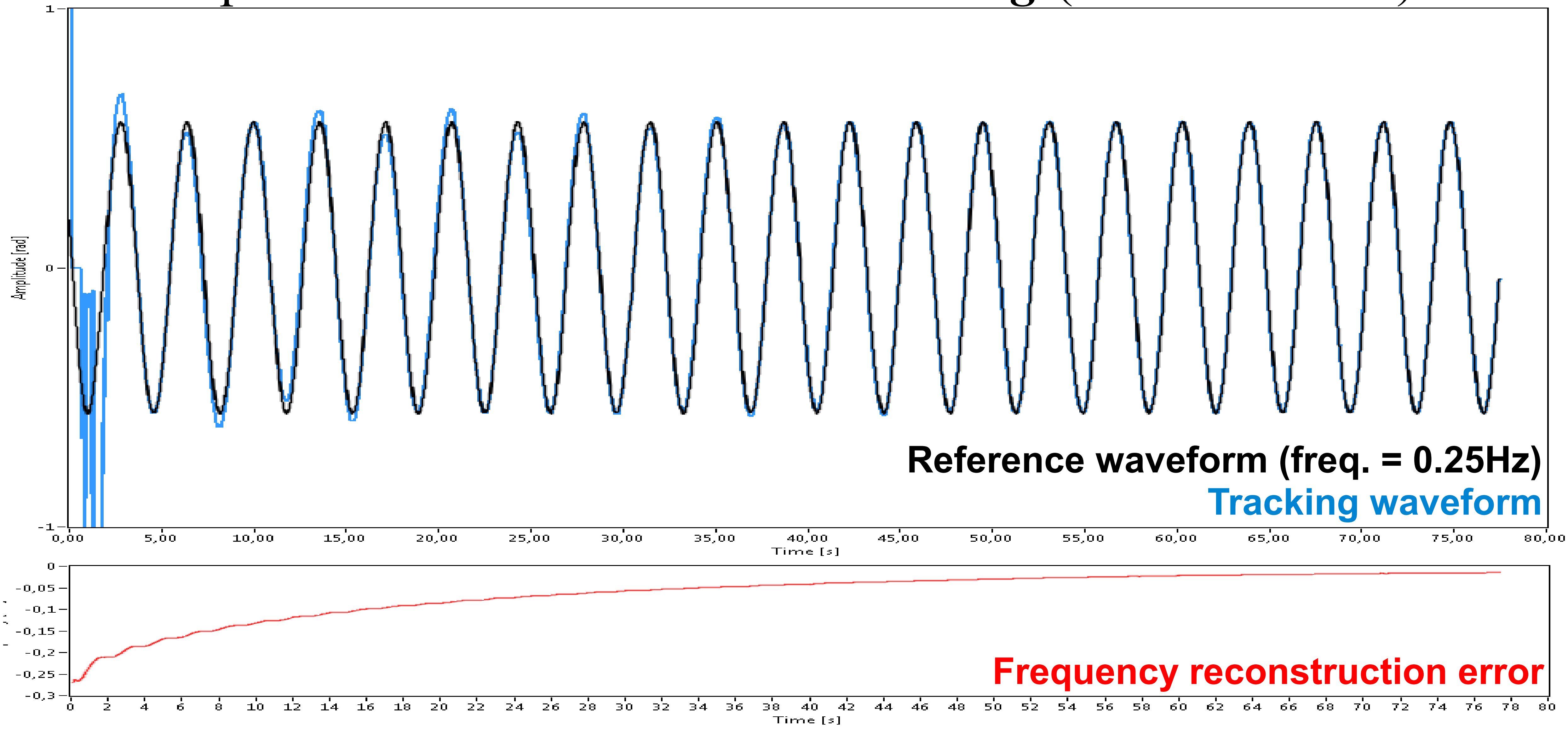
$k_p = 1$ $k_i = 0$	PI control block (the current feedback)
$\lambda_f = 12$ $\lambda_0 = 72$ $\lambda_1 = 1200$ $k_f = 18$	Frequency observer
$k = 24$	Gain of the internal model

Experimental results – ***Position tracking*** (initial transient)



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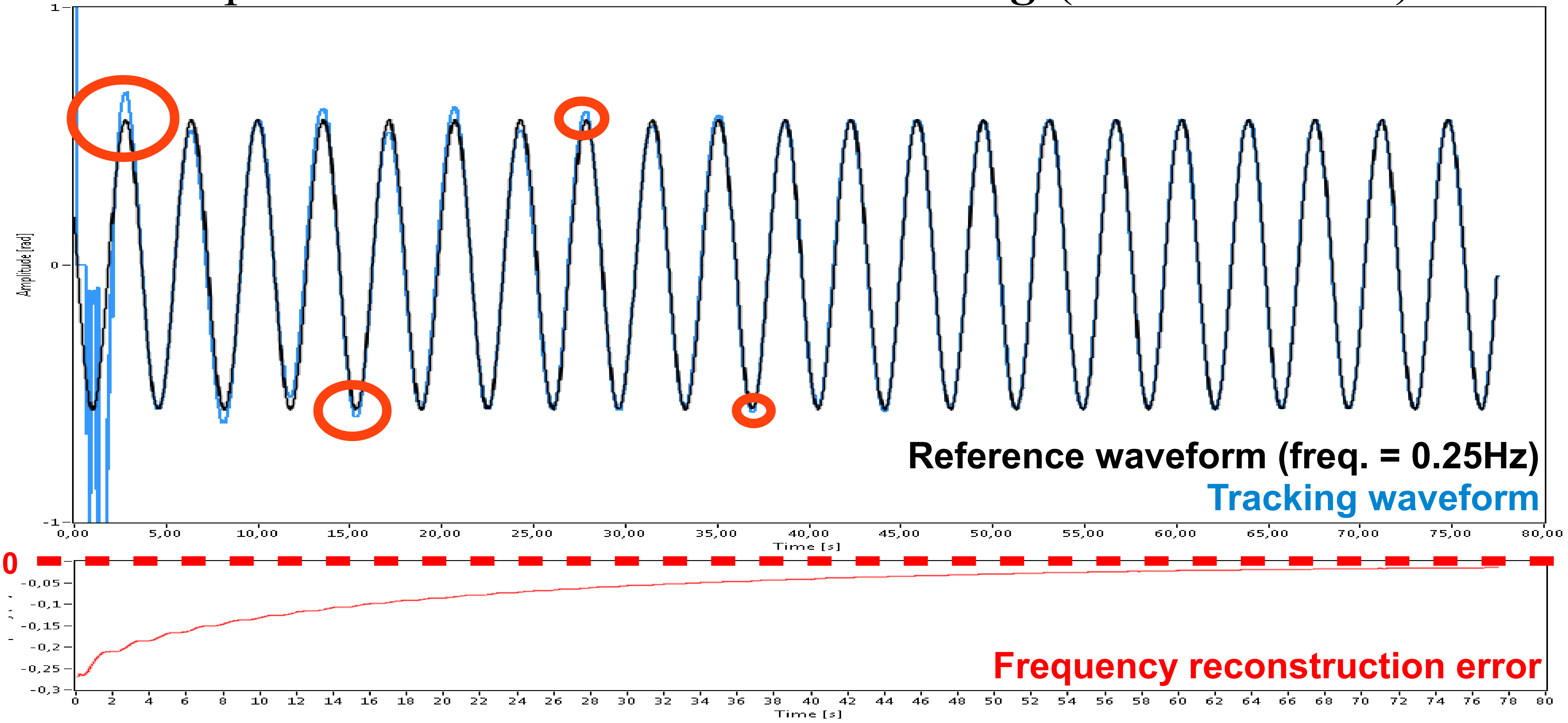

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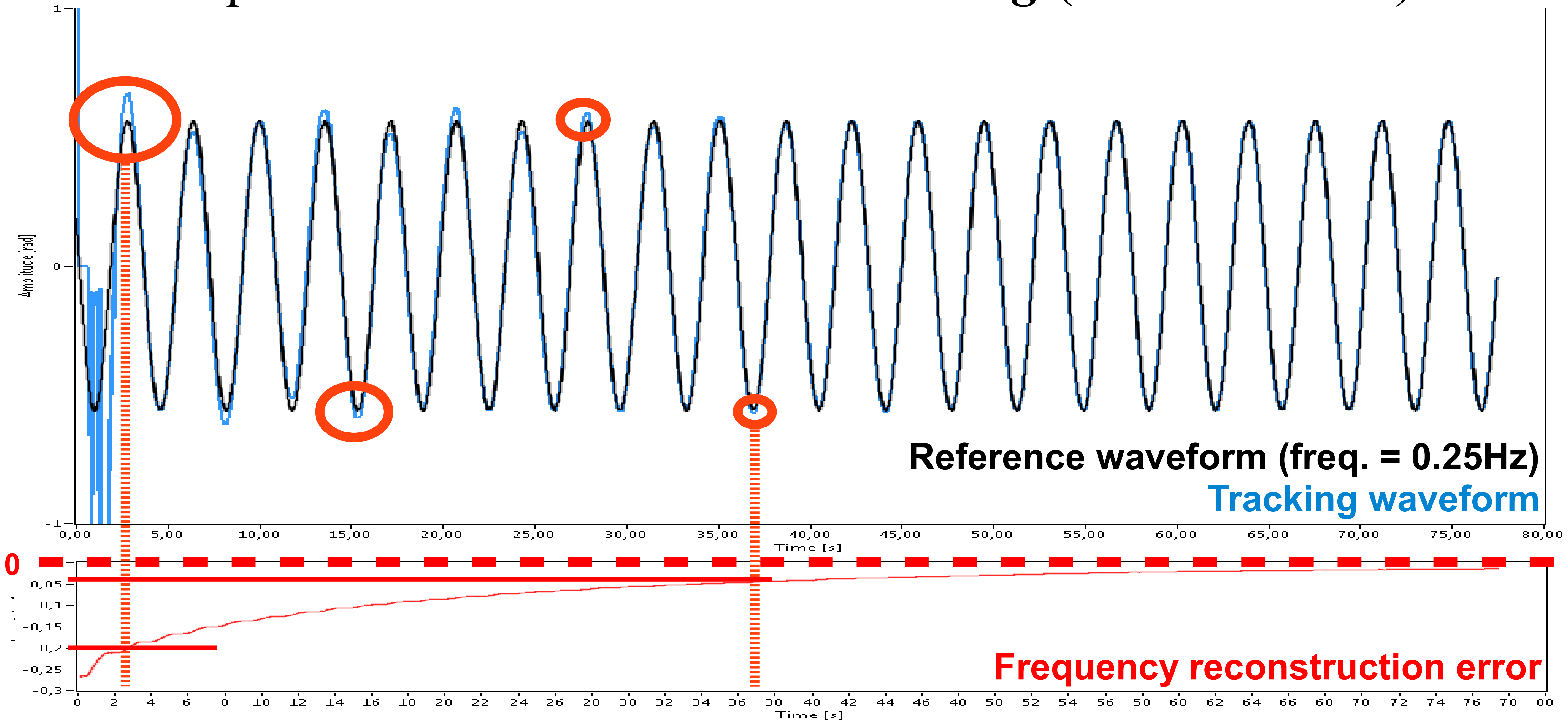
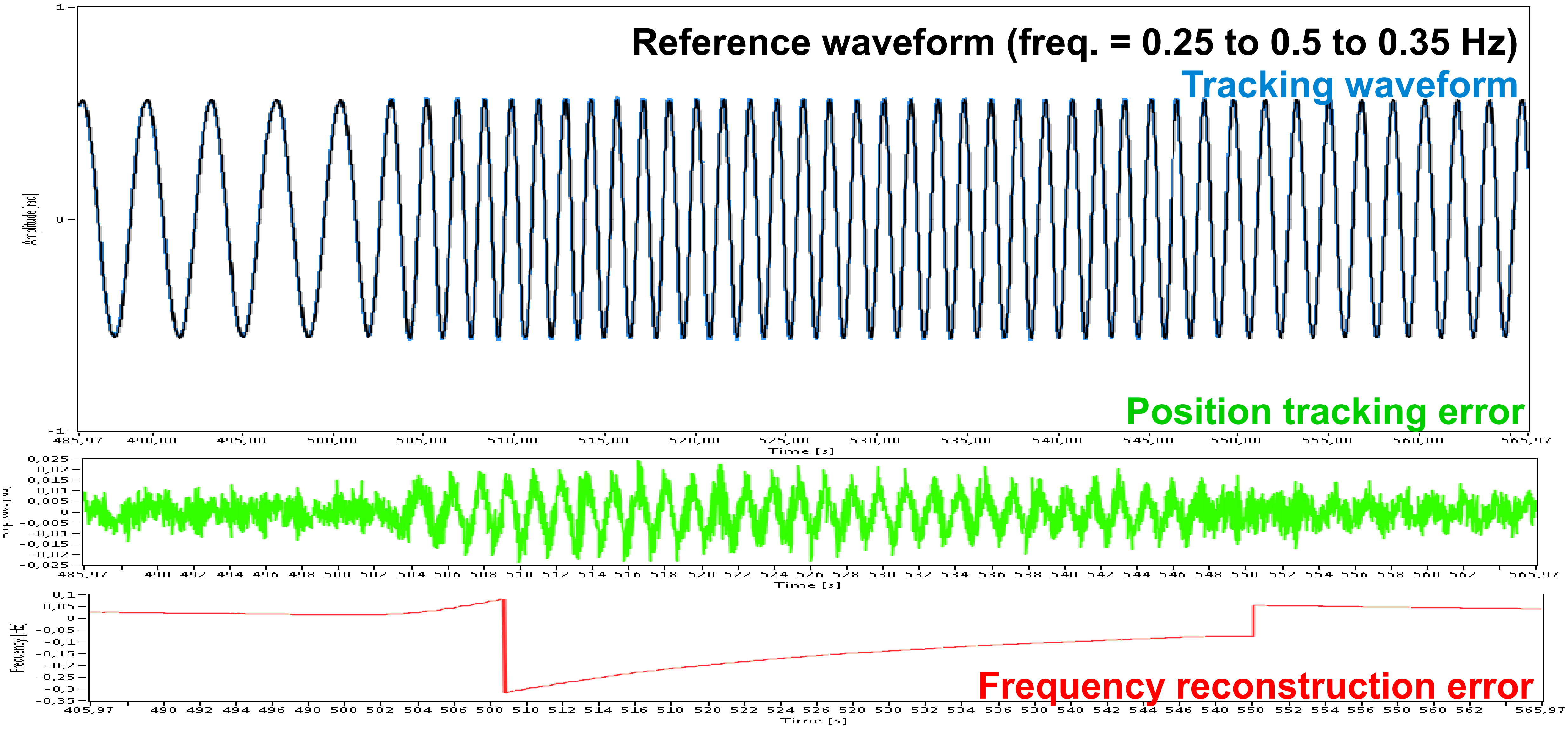


Experimental results – ***Reaction to frequency changes***



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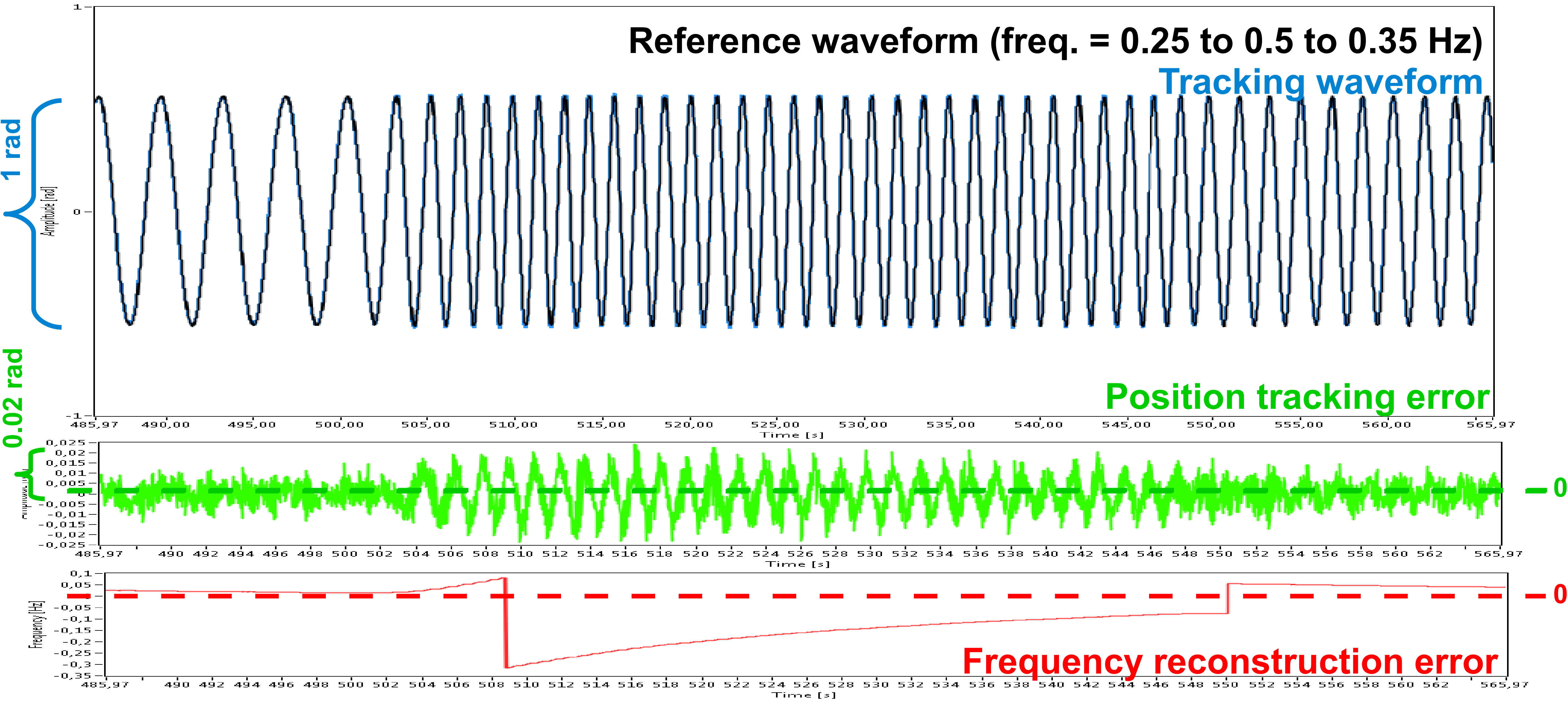

Practical demonstration *– Control of an actual DC motor*

Conclusions

The algorithm is ***easily implementable***

- The algorithm structure is ***flexible*** and it can be adapted to the control of any DC motor (with a relatively easy tuning of the parameters)
- The controller performance in terms of velocity of the reference signal frequency reconstruction action is satisfactory
- The combined action of the frequency reconstruction and the "PD-like" position control is an extremely efficient strategy for the removal of a sinusoidal disturbance characterized by a single frequency

Thank you for your attention!