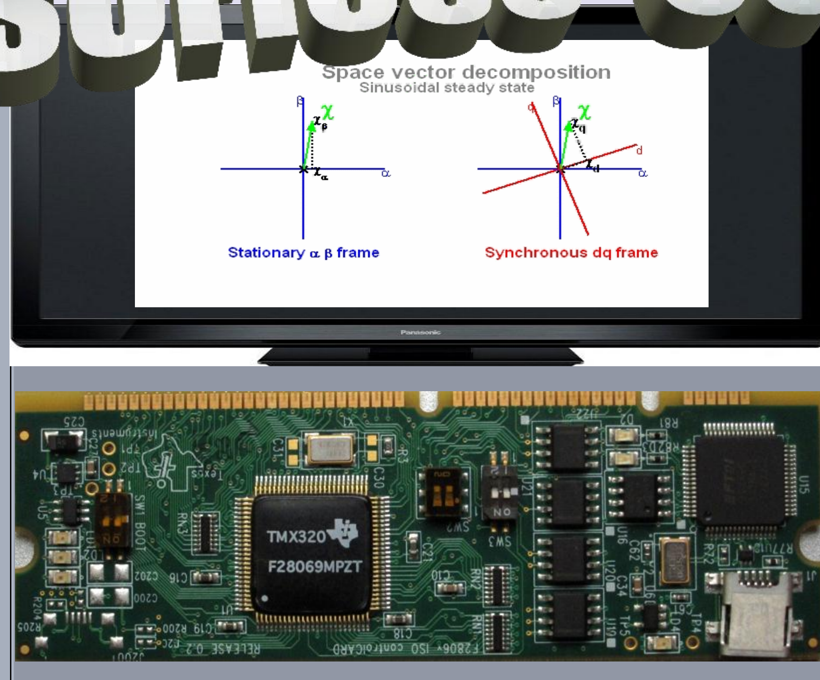
2014 Texas Instruments Motor Control Training Series

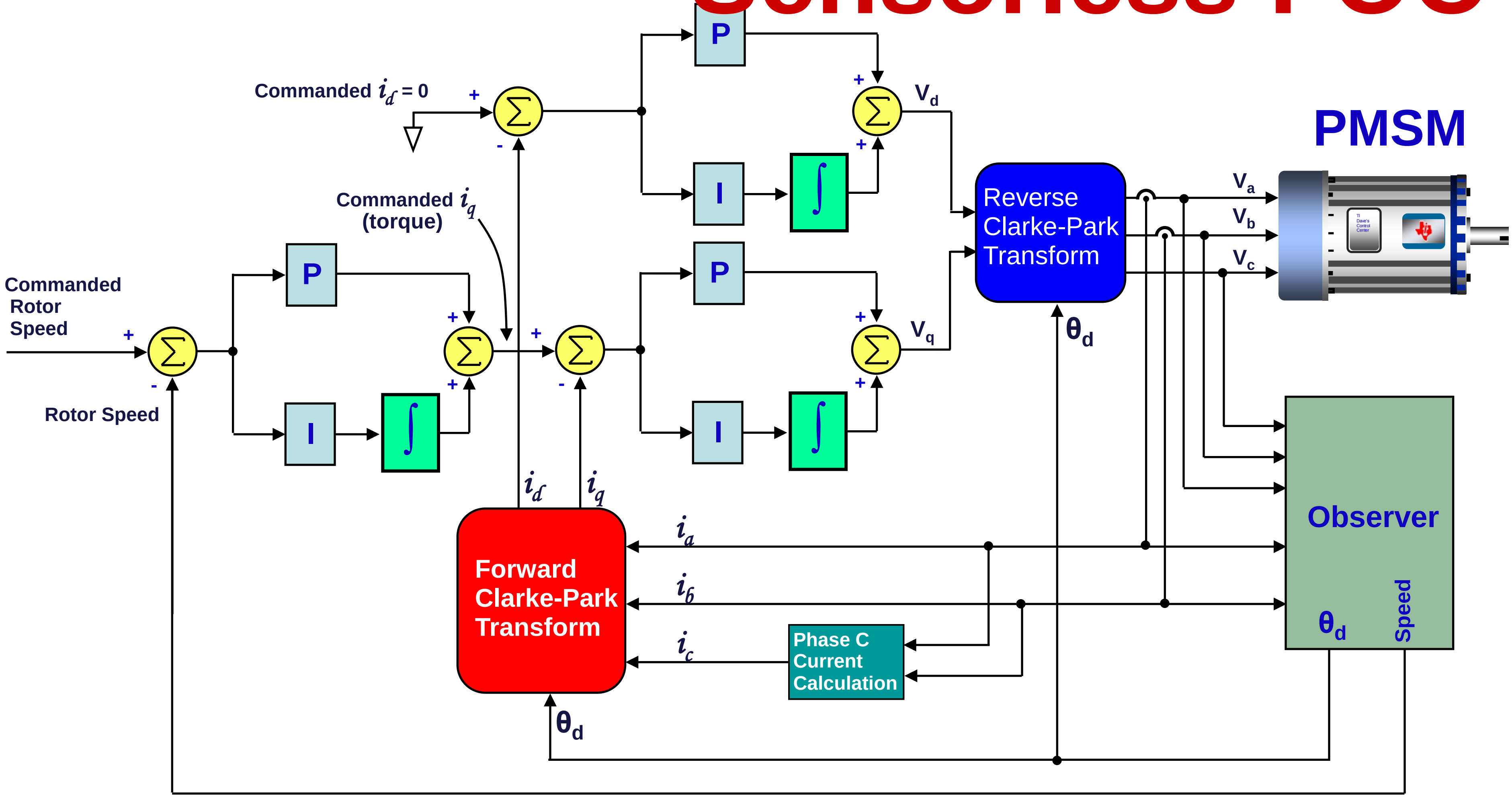
Intro to Sensorless Control



Dave Wilson

Texas Instruments

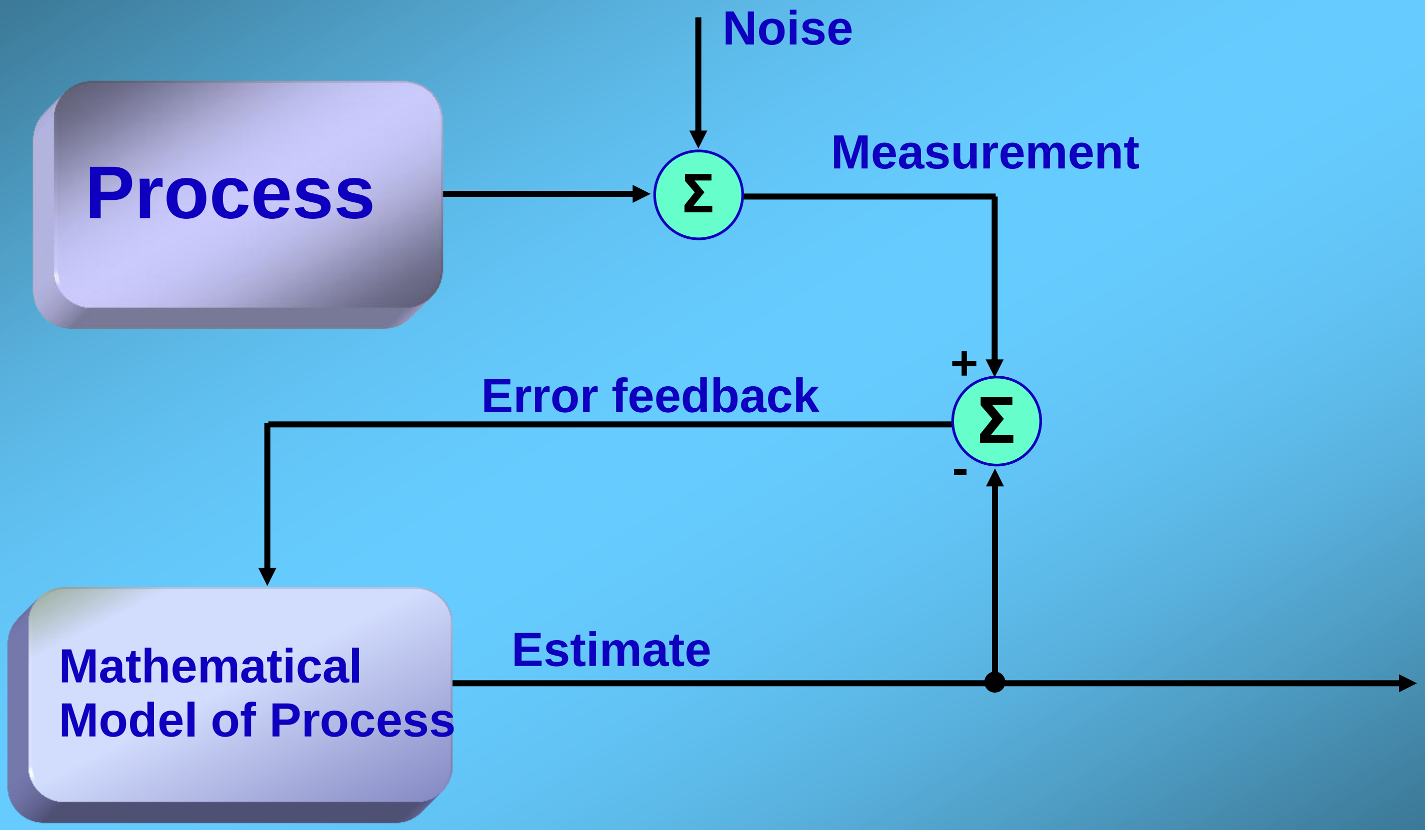
Sensorless FOC



Shaft position sensors are VERY expensive ($1,500 in some cases).

Many applications cannot afford the cost of a shaft sensor.

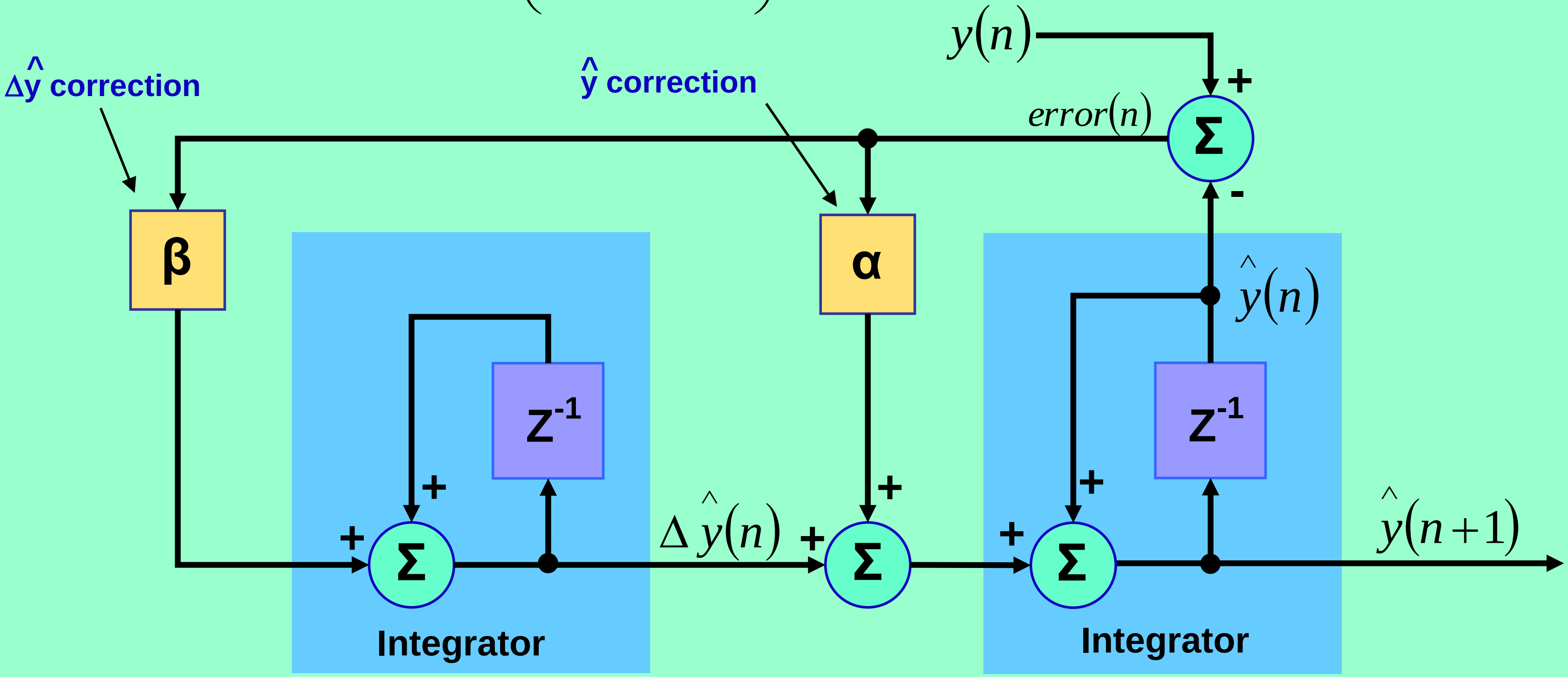
Model Based Filtering



Tracking Filters

$$\hat{y}(n+1) = \hat{y}(n) + \Delta\hat{y}(n) + \alpha\left(y(n) - \hat{y}(n)\right)$$

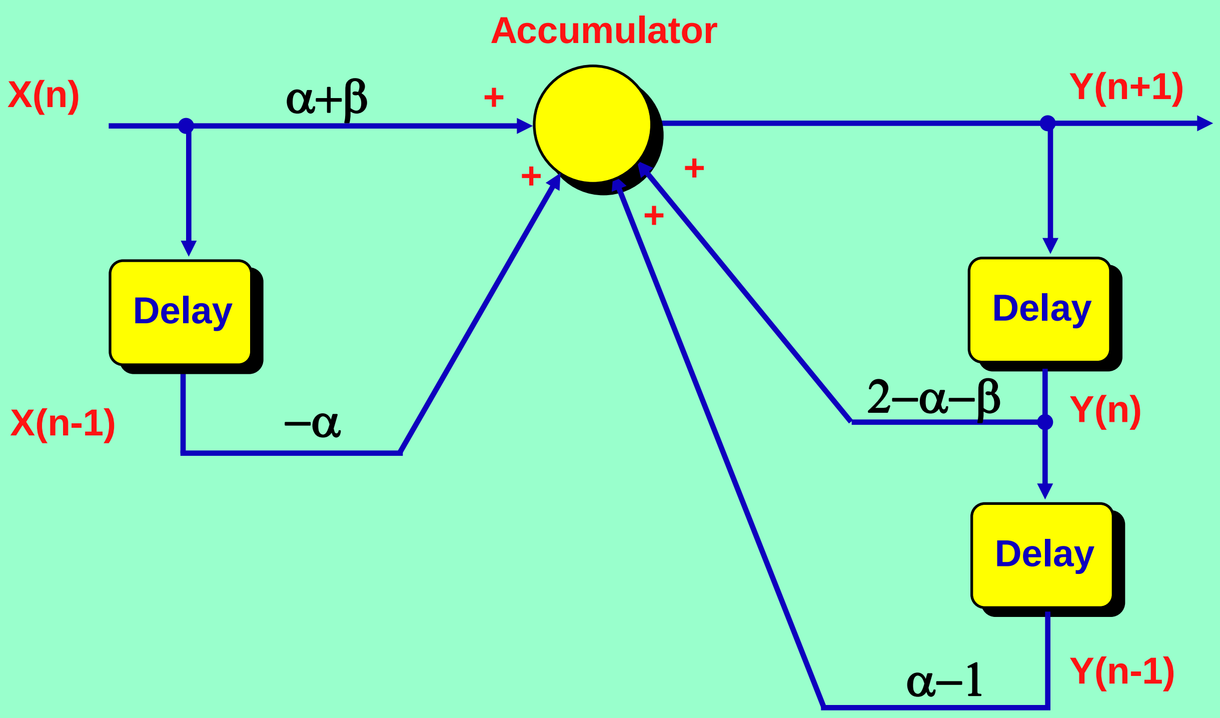
$$\Delta\hat{y}(n) = \Delta\hat{y}(n-1) + \beta\left(y(n) - \hat{y}(n)\right)$$



Better tracking is obtained when α and β are high
Better filtering is obtained when α and β are low

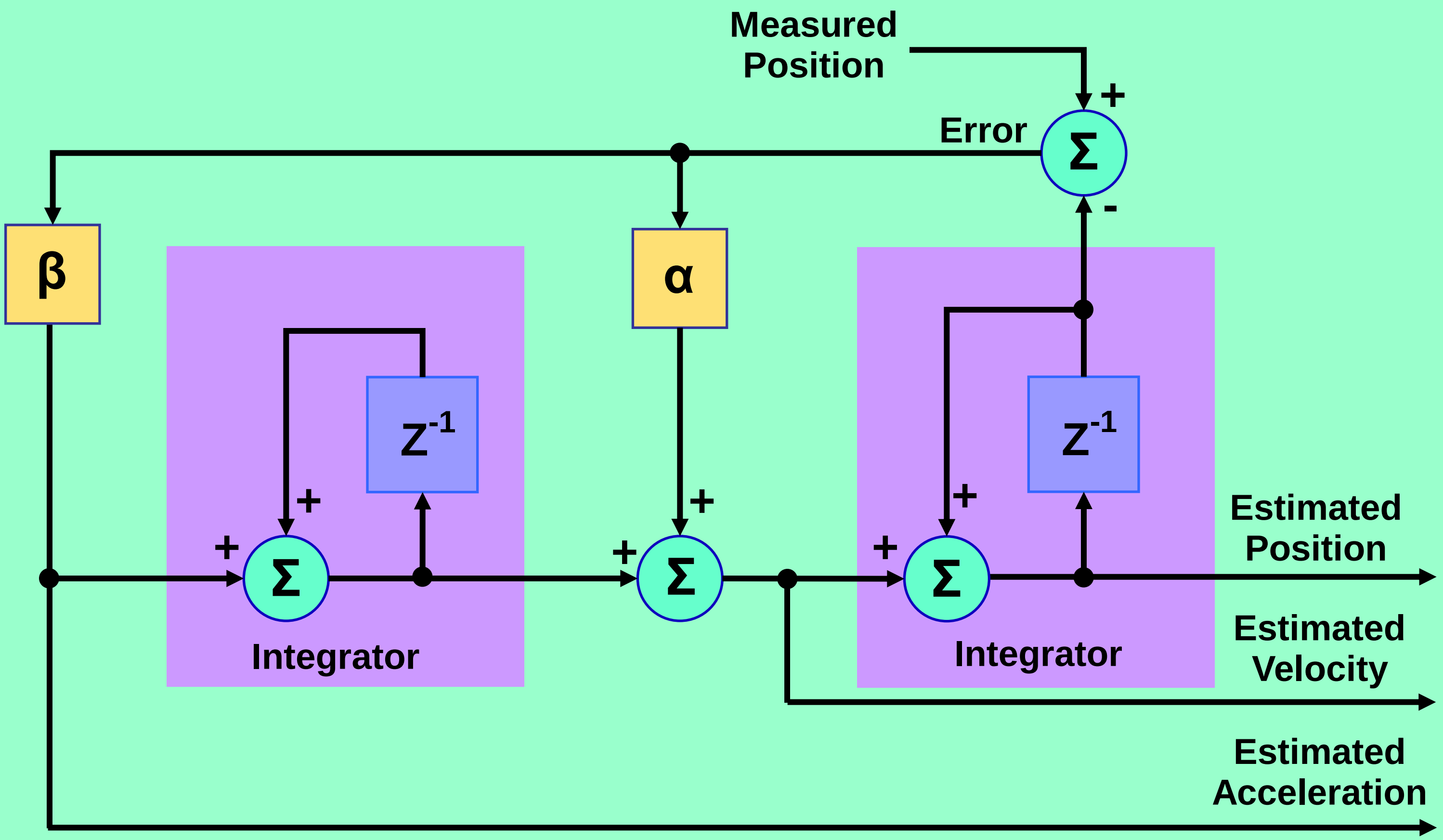
The Tracking Filter…Unmasked!

The tracking filter is revealed to be a simple 2nd order IIR filter as shown below.



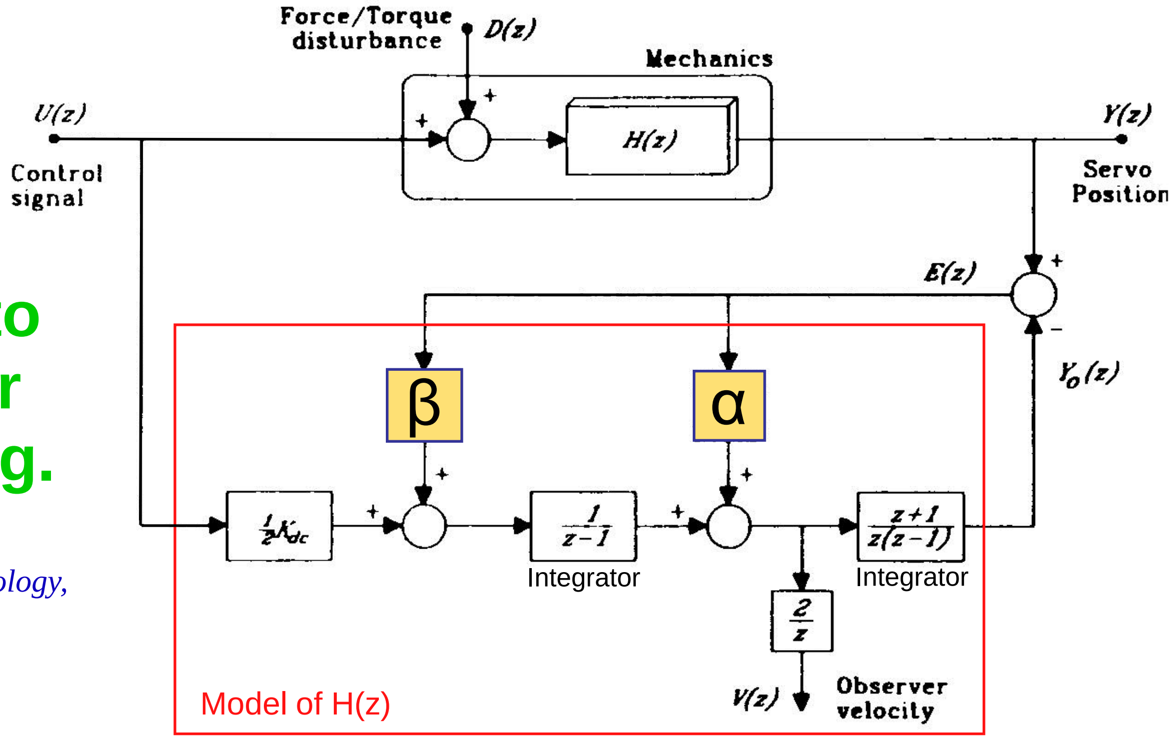
Cascaded Representation

This form of the filter reveals the derivatives of the tracked variable.



Parameter Estimation with Observers

By providing an additional feedforward input, the tracking filter can make better output estimates. It then takes the form of an OBSERVER.



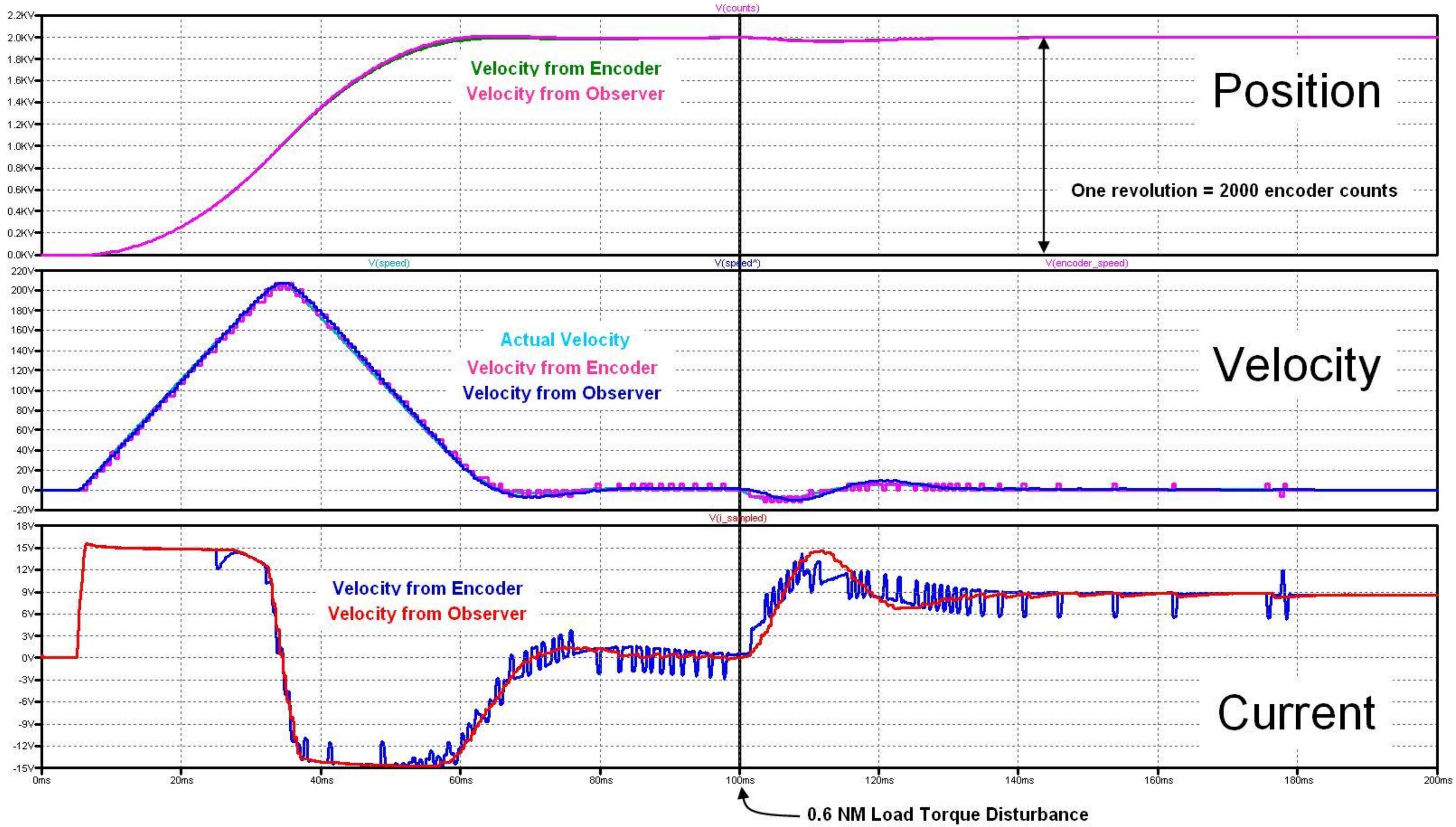
Can be designed to have zero (or near zero) estimation lag.

Source: Motion Controller Employs DSP Technology, Robert van der Kruk and John Scannell, Phillips Centre for Manufacturing Technology, PCIM – September, 1988

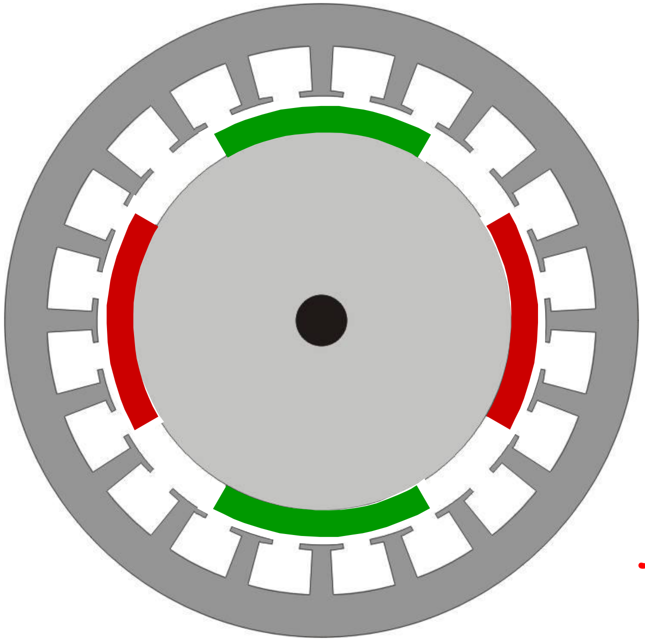
Observers are used to "observe" a quantity which is difficult to measure by mathematically modeling the system.

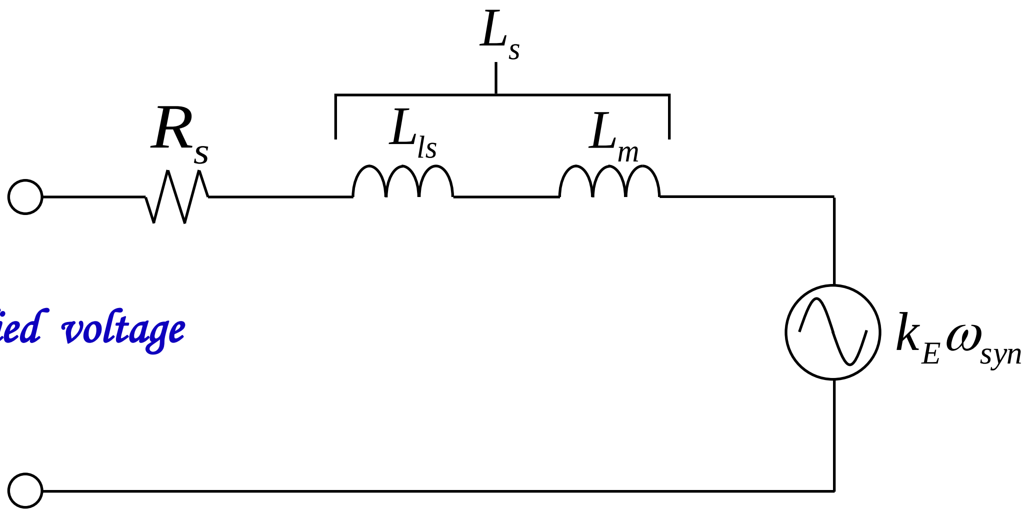
Observers literally recreate the desired signal mathematically (great noise decoupling). The "guess" is corrected by comparison with an observable signal.

Servo Performance with Velocity Directly from Encoder vs. Observer



Sensorless Sinusoidal PMSM Control





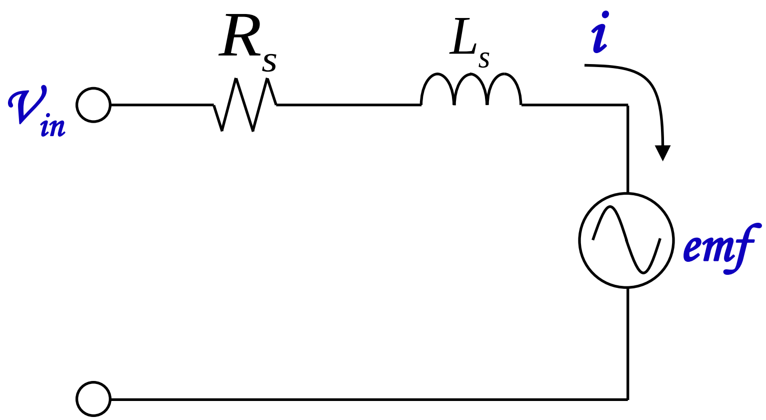
Assuming no saliency, stationary frame equations are:

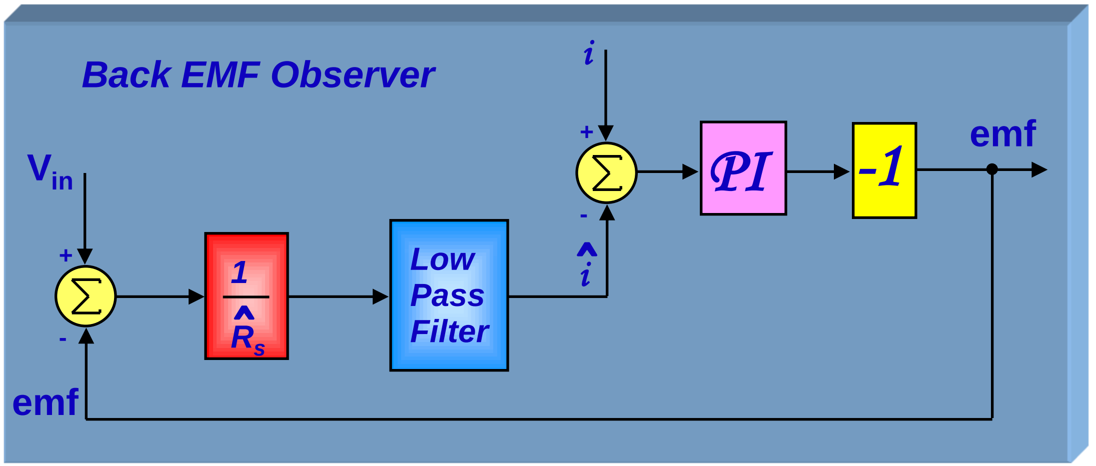
$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = R_s \cdot \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} + L_s \frac{d}{dt} \cdot \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} + k_E \omega_{syn} \cdot \begin{bmatrix} -\sin(\theta_e) \\ \cos(\theta_e) \end{bmatrix}$$

Rotor with surface-mount magnets
Non-salient design (magnetically round))

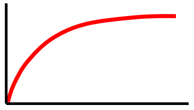
Back EMF component

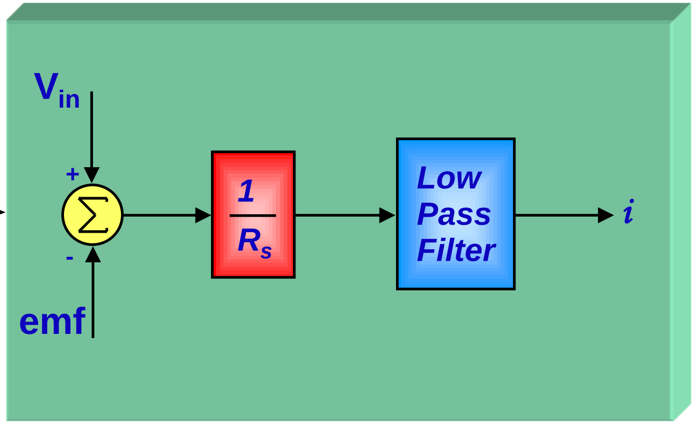
Stationary Frame Back EMF Observer



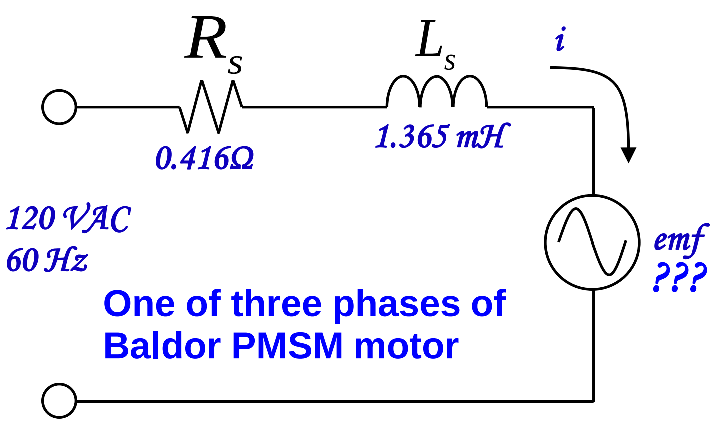


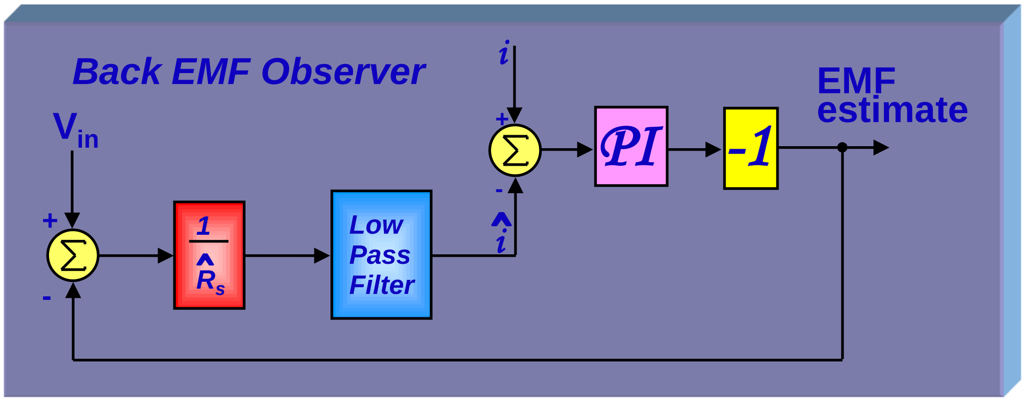
$$i(t)=\left(\frac{V_{in}(t)-emf(t)}{R_s}\right)\left(1-e^{-\frac{t}{\tau}}\right)$$

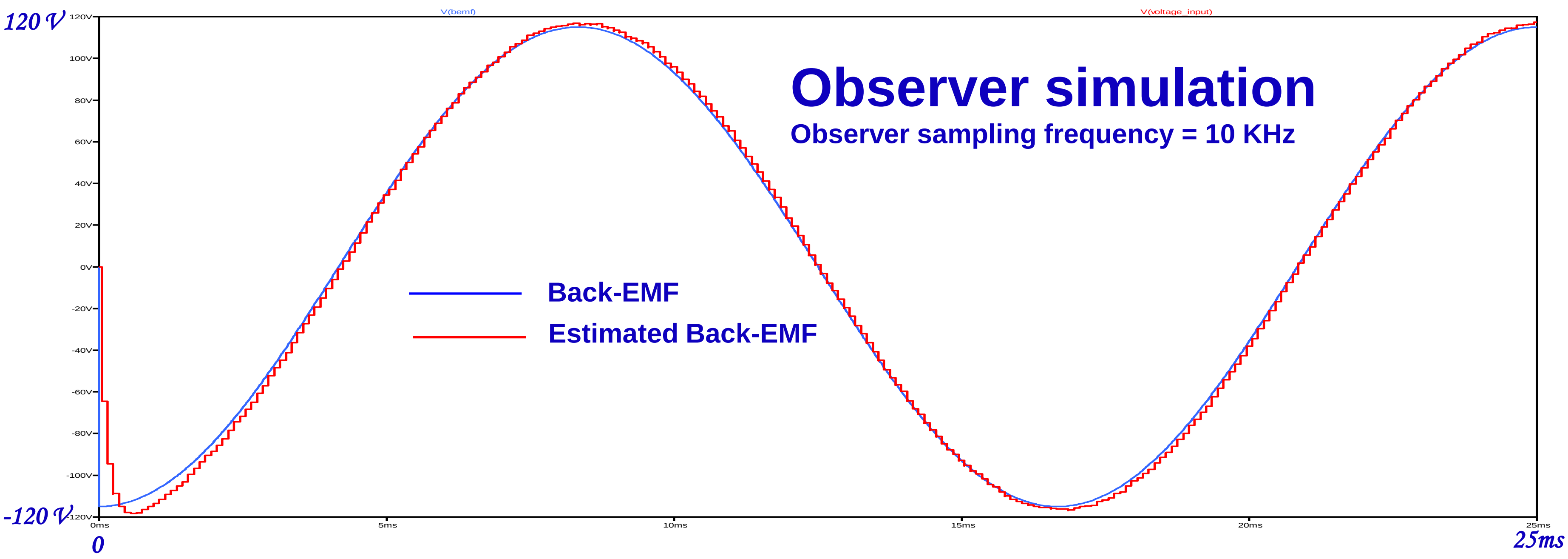




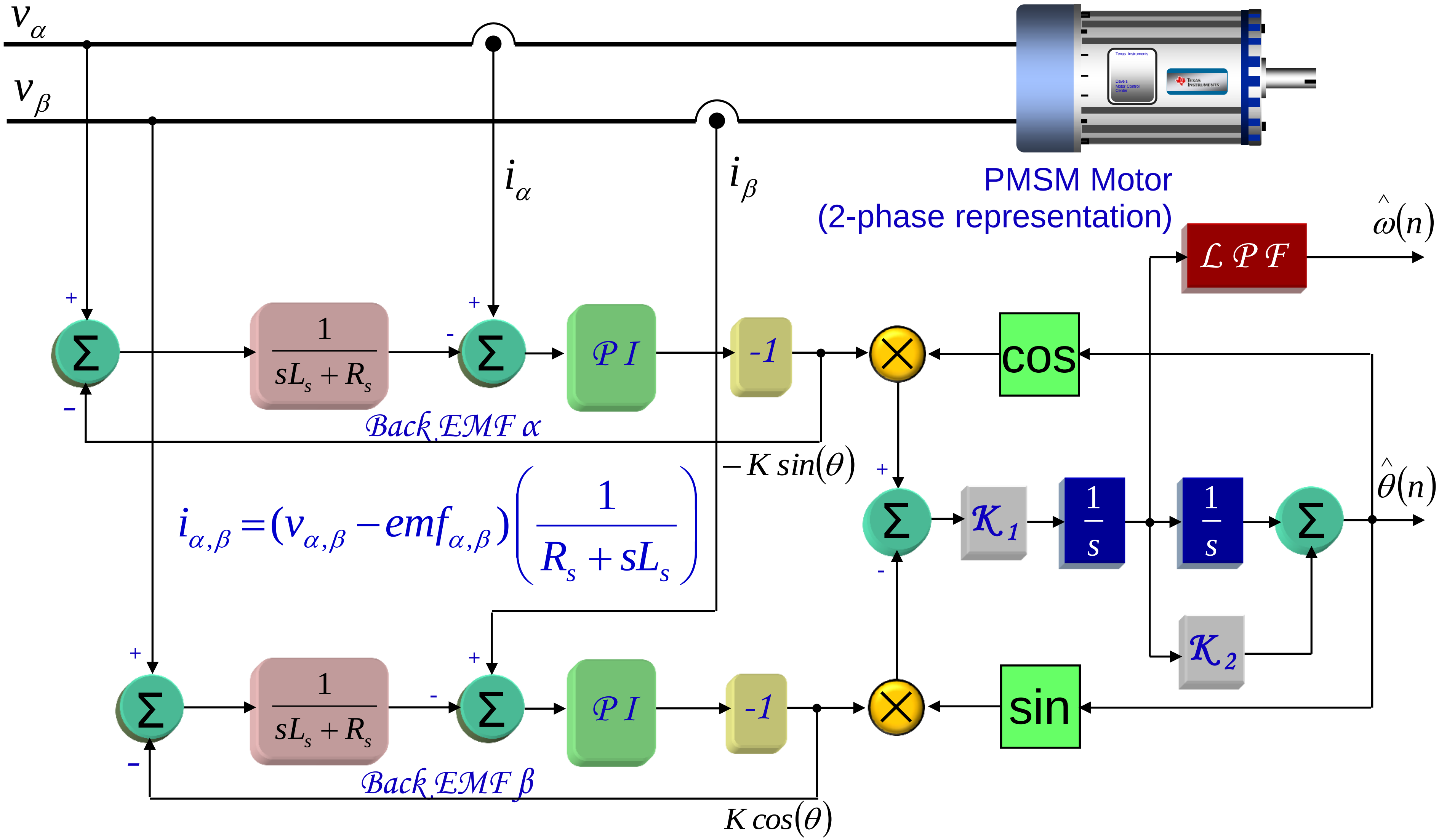
Back-EMF Observer Performance



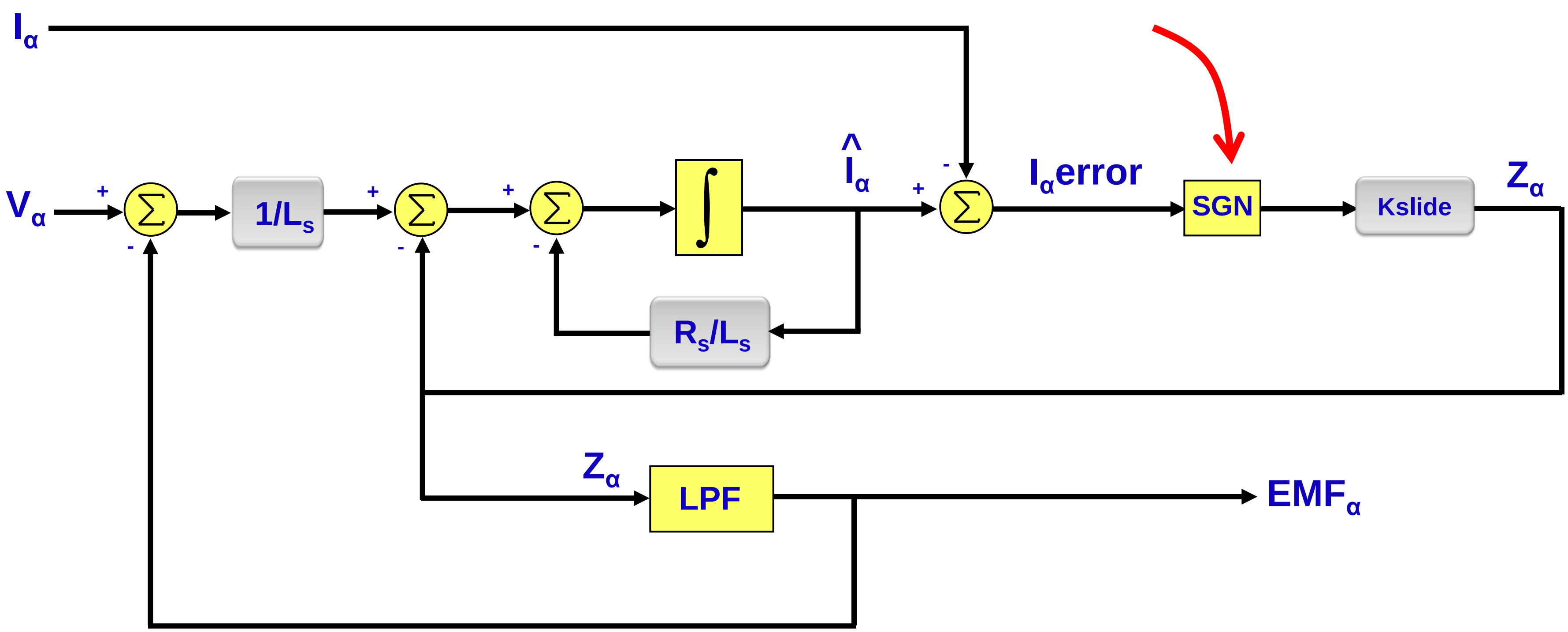




Stationary Frame State Observer for a Non-Salient Machine

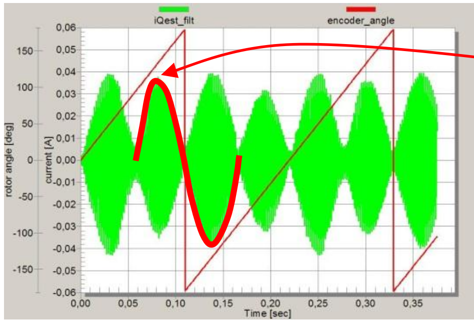


Sliding Mode EMF Observer



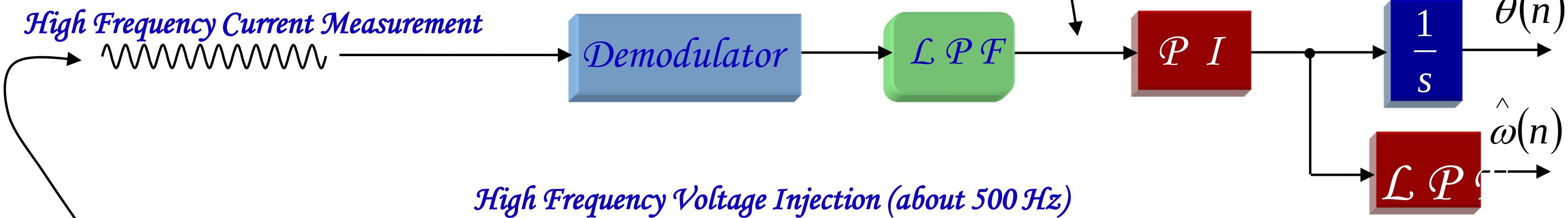
"A Position and Velocity Sensorless Control of Brushless DC Motors Using an Adaptive Sliding Observer", Takeshi Furuashi, Somboon Sangwongwanich, Shigeru Okuma, 1990 IEEE Proceedings, 087942-600-4/90/1100-1188, pp. 1188-1192.

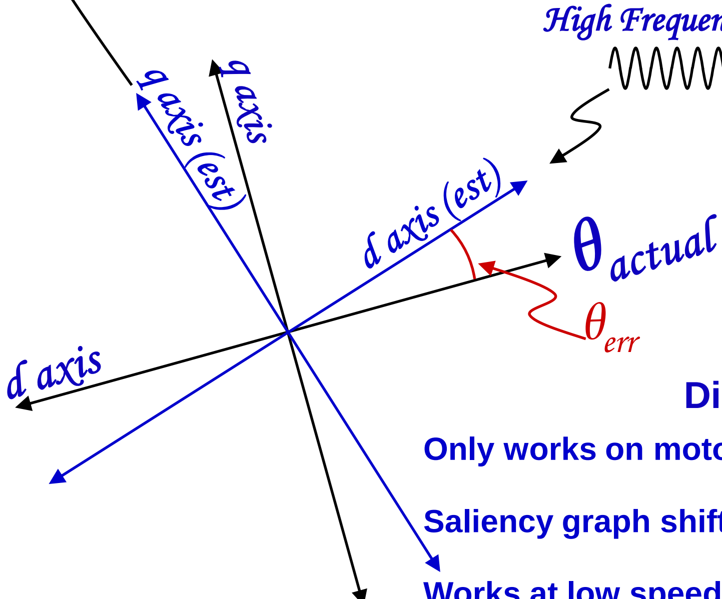
Low Speed Saliency Tracking Observer

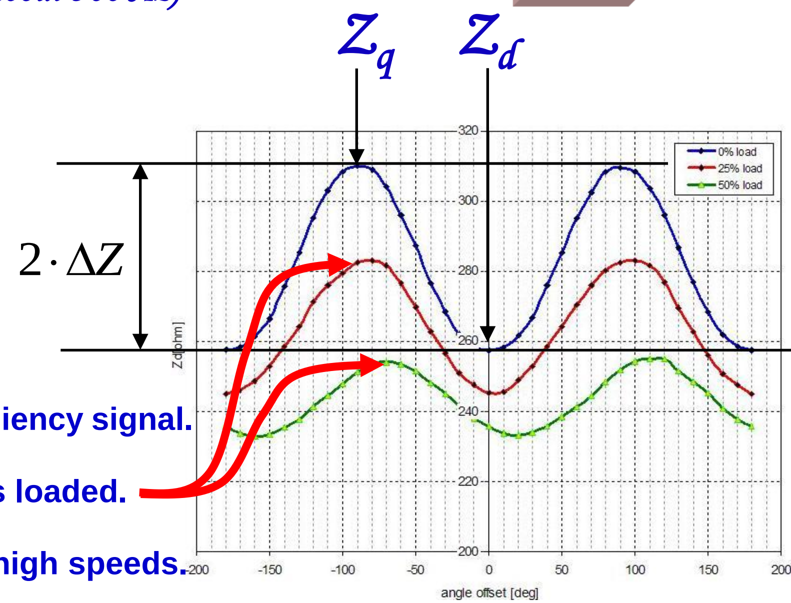


$$\hat{i}_q = -\frac{V_m \Delta Z}{2\omega_{hf} Z_d Z_q} \sin(2\theta_{err})$$

P I regulator results in steady state value servoing to zero







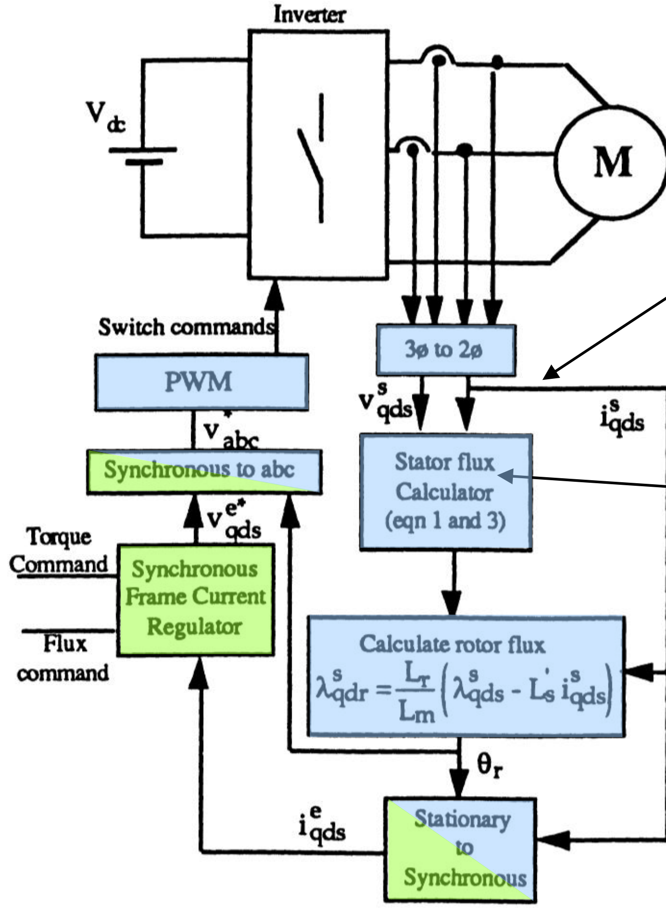
Disadvantages:

Only works on motors with a strong saliency signal.

Saliency graph shifts when the motor is loaded.

Works at low speeds, but falls apart at high speeds.

ACIM Sensorless Control



Block diagram of a sensorless induction machine drive based only on stator voltage integration.

Note: Still in stationary frame

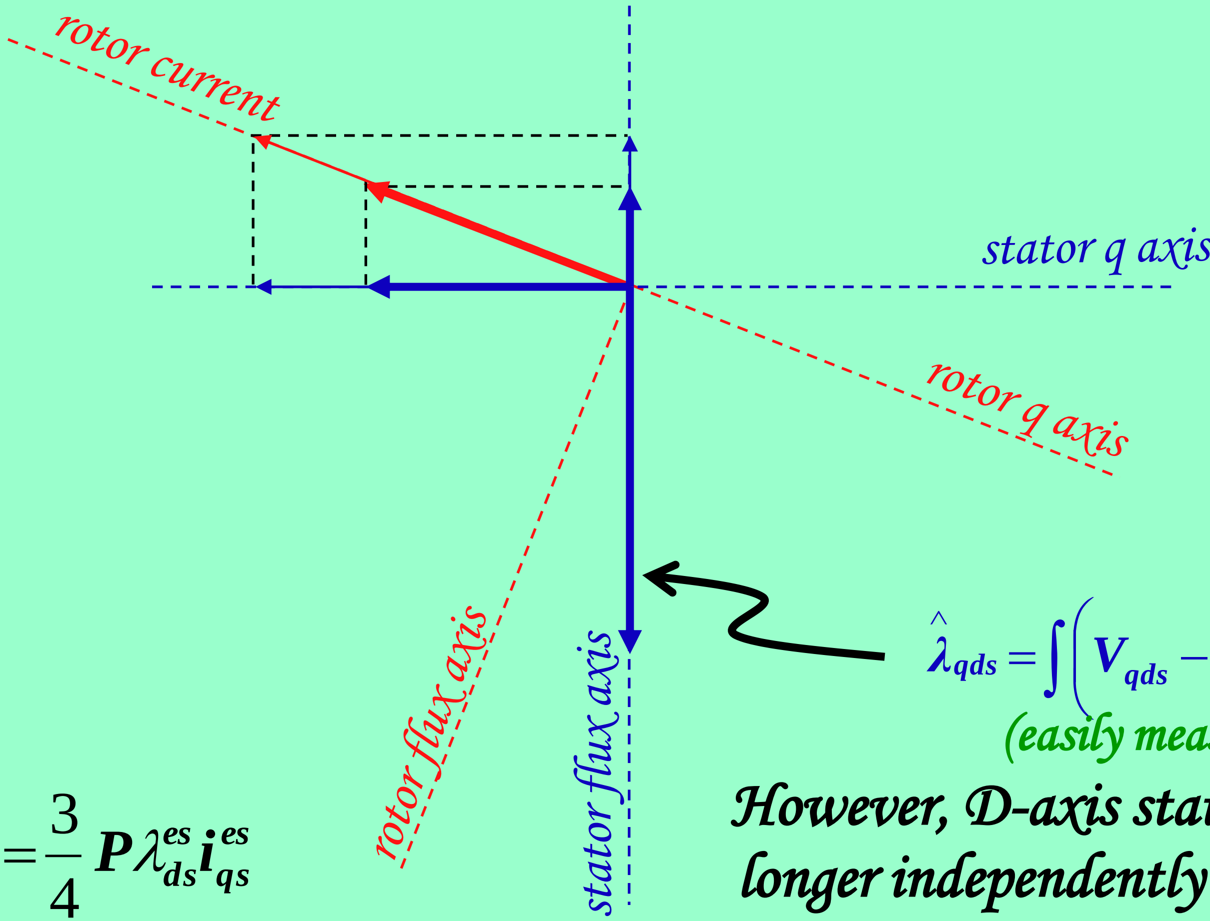
$$\hat{\lambda}_{qds} = \int \left(V_{qds} - \hat{R}_s \, I_{qds} \right) dt$$

Stationary Frame

Synchronous Frame

Source: Zero-Speed Tacho-less I.M. Torque Control: Simply a Matter of Stator Voltage Integration, by K.D.Hurst, T.G.Habetler, G. Griva F. Profumo, IEEE paper, 1997

ACIM Stator Flux Referenced FOC



$$\hat{\lambda}_{qds} = \int \left(\mathbf{V}_{qds} - \hat{\mathbf{R}}_s \, \mathbf{I}_{qds} \right) dt$$

(easily measured)!

However, D-axis stator current no longer independently controls flux (i.e., the axes are now COUPLED).

$$\mathbf{Torque} = \frac{3}{4} P \lambda_{ds}^{es} \mathbf{i}_{qs}^{es}$$

DTC: A Peek under the Hood