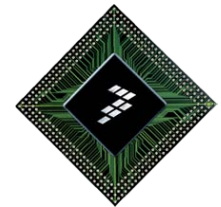![Freescale Technology Forum - Collaboration. Innovation. Inspiration.](image)

July 2009

Industrial Motor Control Part 2

Introduction to ACIM and PMSM Motor Control

**Jeff Wilson**

Industrial Segment Marketer, Americas

Agenda

► Introduction to ACIM and PMSM motors
- Asynchronous vs. synchronous
- AC induction motors and control techniques
- Permanent magnet motors and control techniques
  - PMSM
  - BLDC

► Control and drive system overview

► Field oriented control (FOC) principles and Freescale motor control libraries

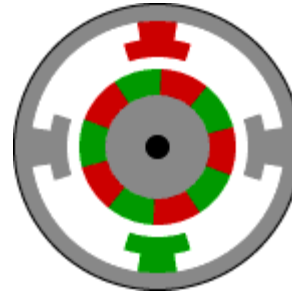► Sensorless FOC control of a PMSM demonstration and solution overview

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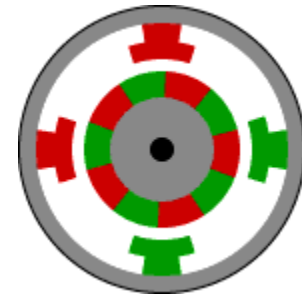*semiconductor*

Many Different Motor Types …
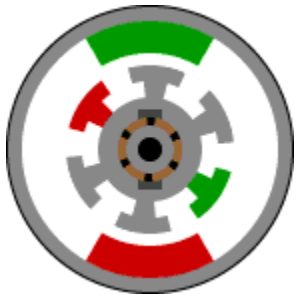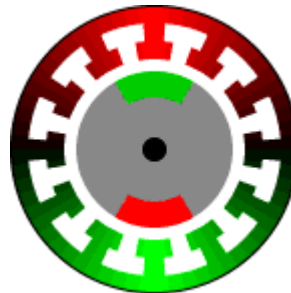
DC motor
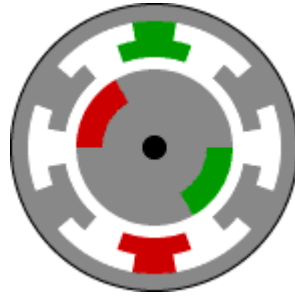
Brushless DC motor

Stepper motor (full step)
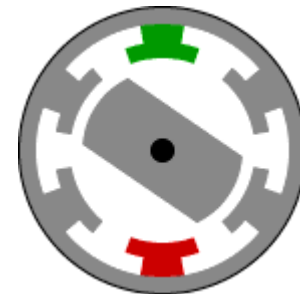
Stepper motor (half step)

AC induction motor

**Permanent magnet
synchronous motor (PMSM)**

Switched reluctance motor

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Asynchronous vs. Synchronous

▶ 3-phase winding on the stator

▶ Sinusoidal flux distribution in air gap

▶ Different rotor construction

- ACIM (Asynchronous)
  - Squirrel cage or windings
  - No permanent magnets
- Synchronous
  - Surface or interior permanent magnets
  - High efficiency (no rotor losses)

▶ Asynchronous means that the mechanical speed of the rotor is generally different from the speed of the revolving magnetic field

▶ Synchronous motors rotate at the same frequency as the revolving magnetic field
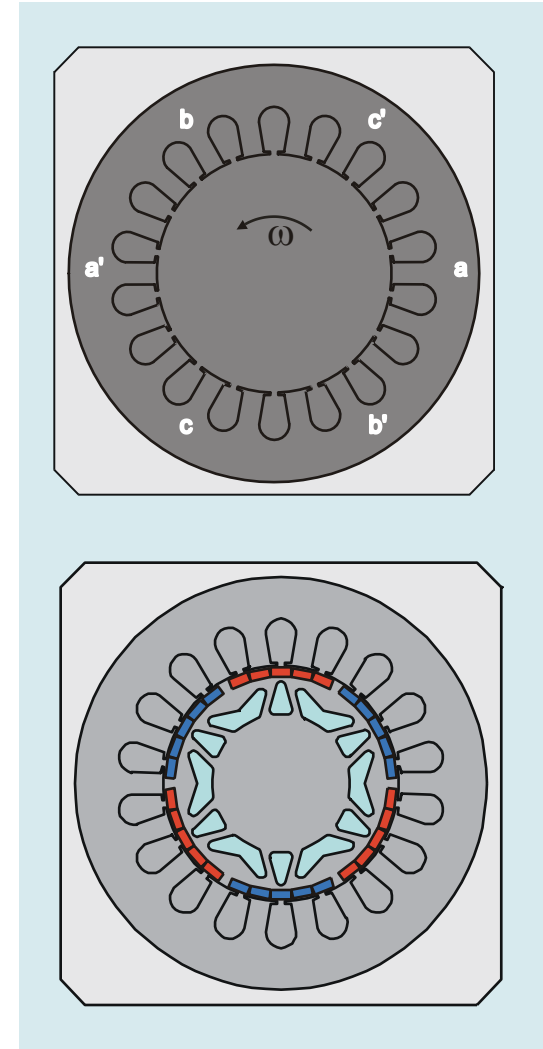
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► Invented over a century ago by Nikola Tesla

► No permanent magnets (the rotor most often consists of a squirrel cage structure)

► Think of it as a rotating transformer where the stator is the primary, and the rotor is the secondary

► Rotor current is "induced" from stator current
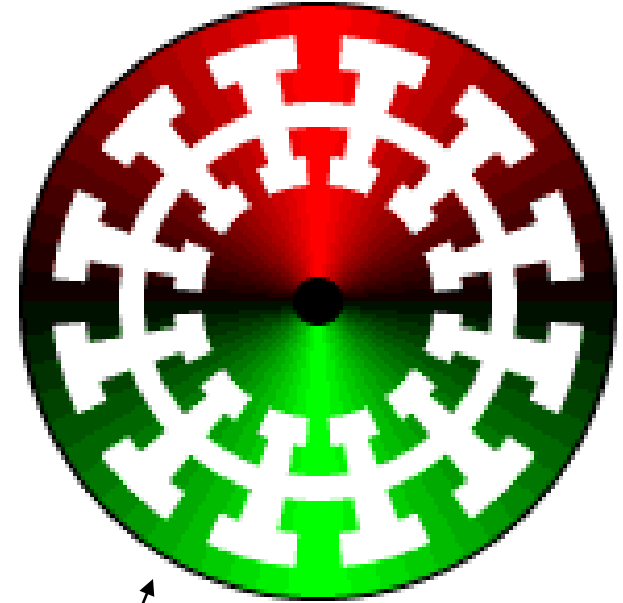
Notice the rotor slip

The **rotor** does not quite keep up with the **rotating magnetic field** of the stator.

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Speed-Torque Performance of Induction Motors
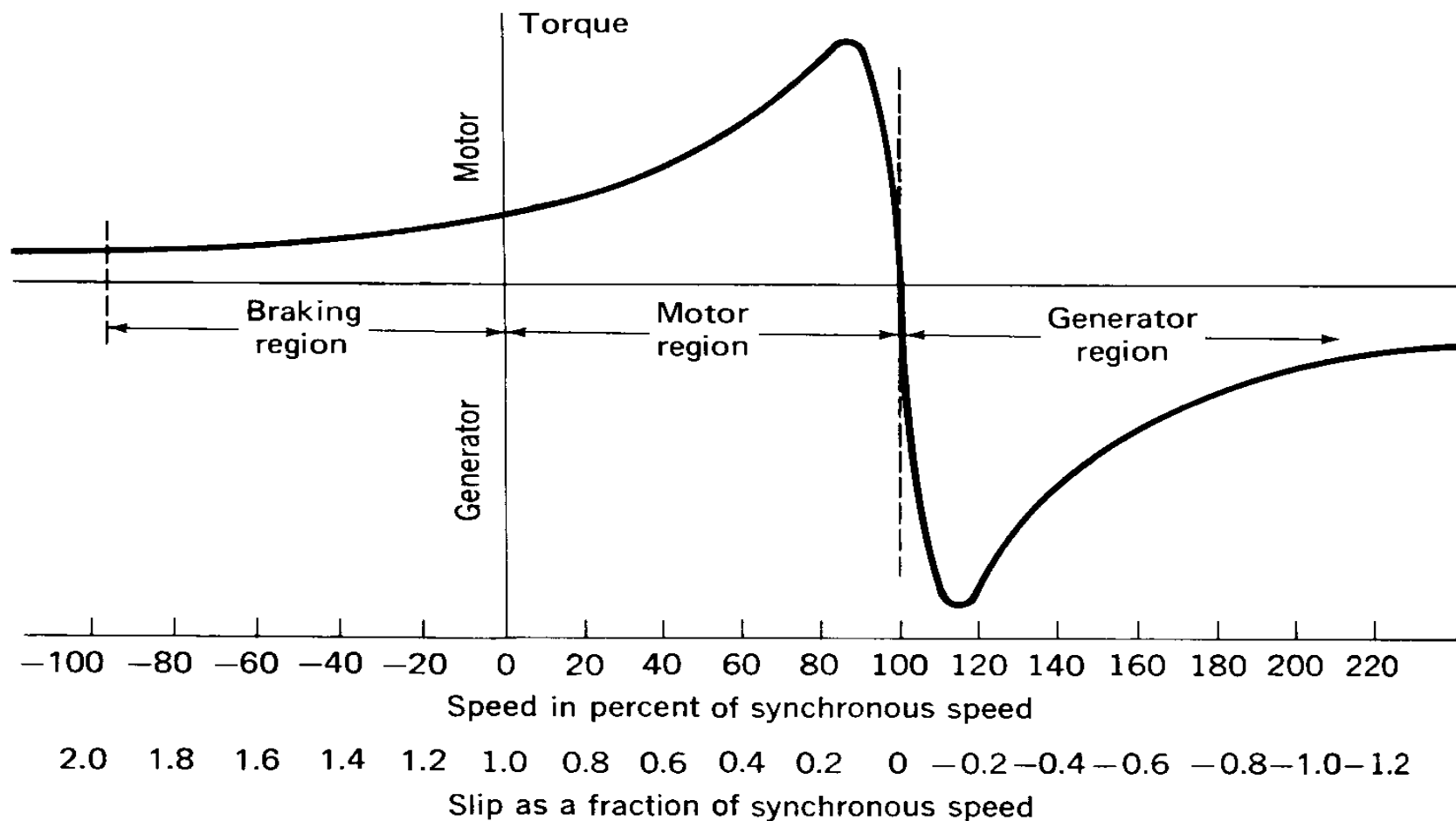
AC Induction Motor Control Methods

▶ V/Hz Drive: The control algorithm keeps a constant magnetizing current (flux) in the motor by varying the stator voltage with frequency. Often implemented with a "slip controller" (DRM 20 & 21)

▶ Field Oriented Control: Transforms voltage, current, and magnetizing flux values to space-vectors and controls the components of those vectors independently (DRM102)

▶ Dave Wilson "Great Debate" Article: Slip Control vs. Field Oriented Control
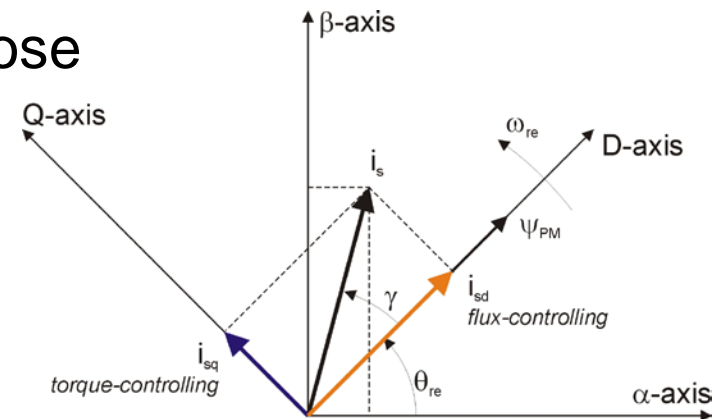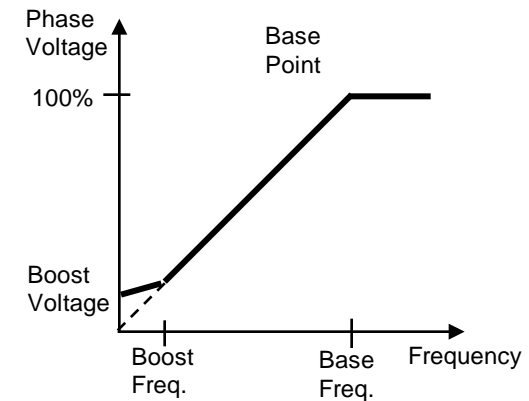
Permanent Magnet AC Motor

- ► A PMSM motor rotates because of the magnetic attraction between the rotor and stator poles.

- ► When the rotor poles are facing stator poles of the opposite polarity, a strong magnetic attraction is set up between them.

- ► The mutual attraction locks the rotor and stator poles together, and the rotor is literally yanked into step with the revolving stator magnetic field.

- ► At no-load conditions, rotor poles are directly opposite the stator poles and their axes coincide.

- ► At load conditions the rotor poles lag behind the stator poles, but the rotor continues to turn at synchronous speed; the mechanical angle (a) between the poles increases progressively as we increase the load.

Torque establishment (no-load condition)
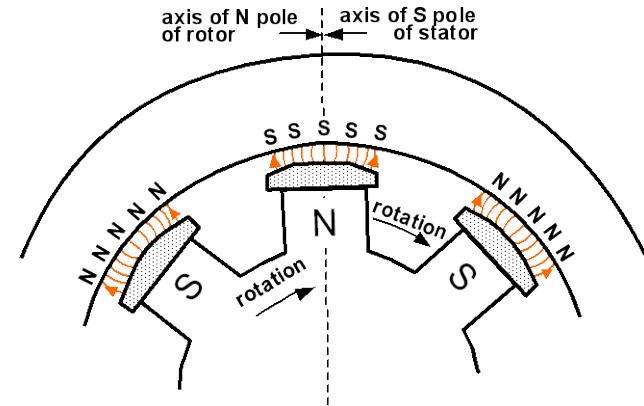
Torque establishment (load condition)

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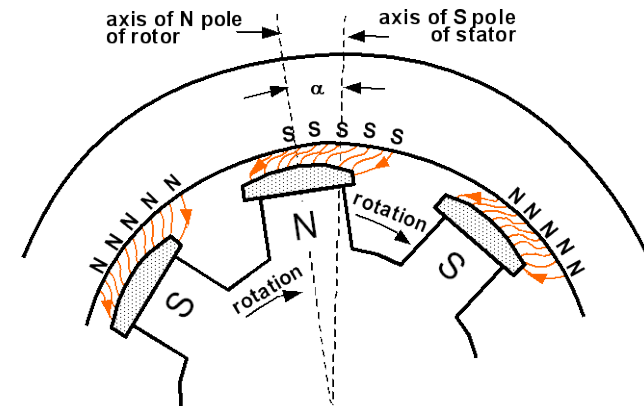
Trapezoidal vs. Sinusoidal PM Machine

► "Synchronous" in PMSM implies the motor is "sinusoidal"

► "Brushless DC" in BLDC implies the motor is "trapezoidal"

- Flux distribution characteristics have differing waveforms (sinusoidal vs. trapazoidal)
- Field-oriented control vs. "six-step" control
- Both methods require rotor position information
- BLDC motor control
  - At any instant, two of the three stator phases are excited
  - Unexcited phase used as sensor (back emf)
- Synchronous motor
  - All three phases persistently excited (continuous)
  - Sensorless algorithm becomes complicated

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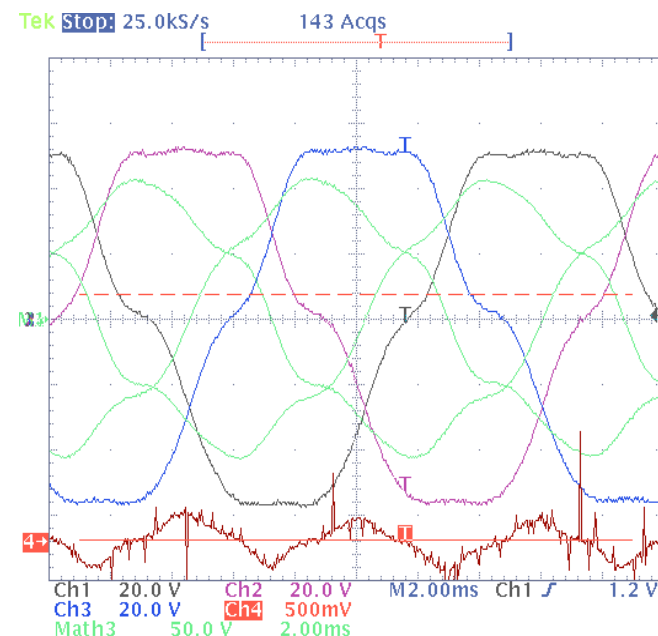
High Voltage Inverter-based ACIM and PMSM Drive System

Motor Drive

110V or 220V

230V or 460V

Converter

Filter Capacitor

Inverter

Fault Signals

Micro or DSP

Hot Ground!

Logic Level PWMs

Communications

Isolation

Gate Drivers

Buffered PWMs

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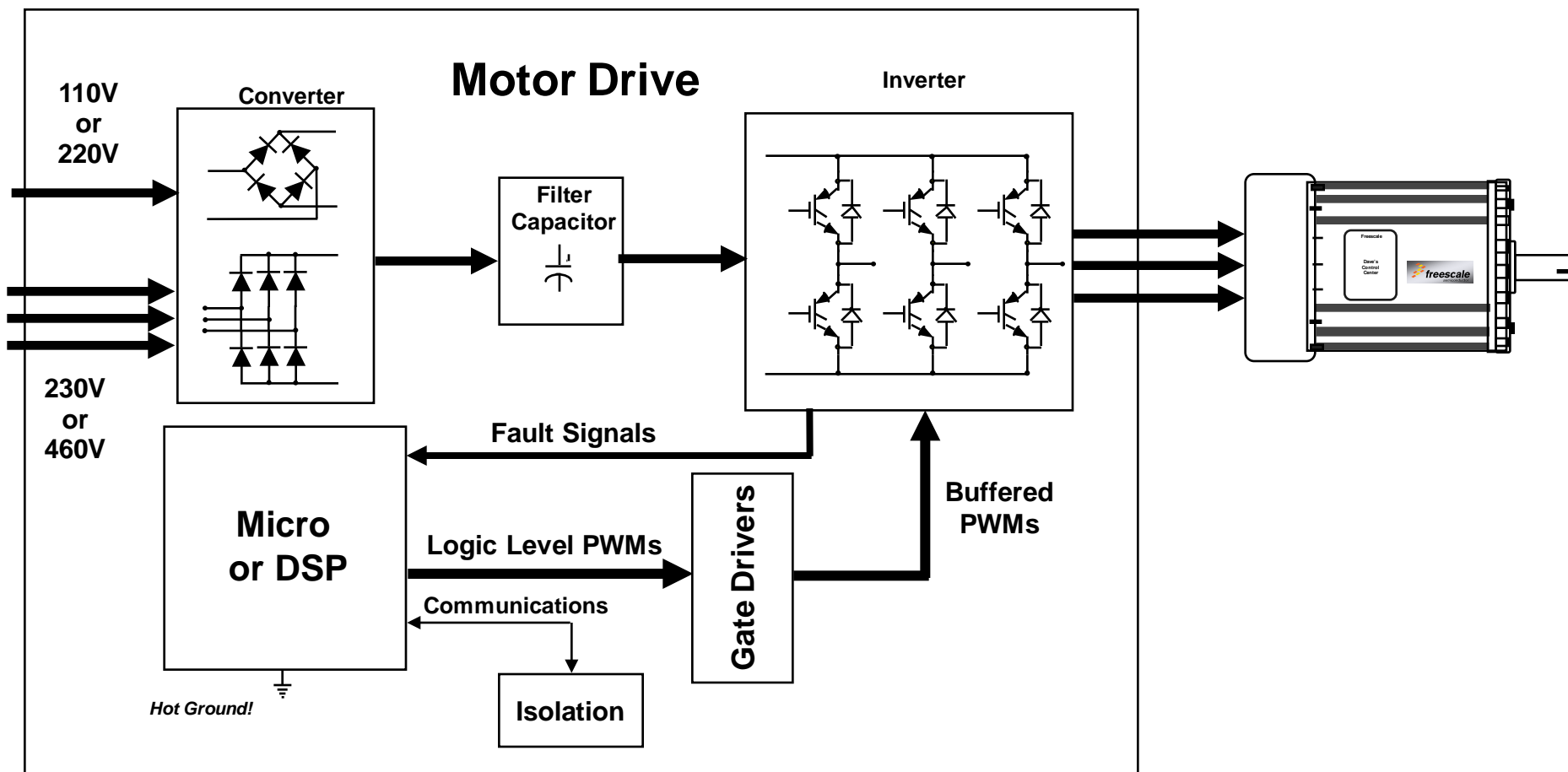
Freescale Motor Control Libraries

► Overview

- Over 35 functions available covering basic functions (including sin/cos processing), transformations, controllers, modulation techniques and resolver (position sensing) operations
- Theory and performance of software modules summarized in library documentation

► Specifics

- Written in assembly language with C-callable interface
- Intended for use in small data memory model projects
- Interfaces to algorithms combined into a single public interface include file (mclib.h)
- Matlab models available and used for functional testing

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Motor Variables in Vector Representation

The "q" axis is the axis of motor torque along which the stator field must be developed

The "d" axis refers to the "direct" axis of the **rotor flux**

Axis of phase b

Axis of phase a

+a

-c

-b

N

Rotation

S

+b

+c

-a

Rotor made from permanent magnets

Stator windings

Axis of phase c

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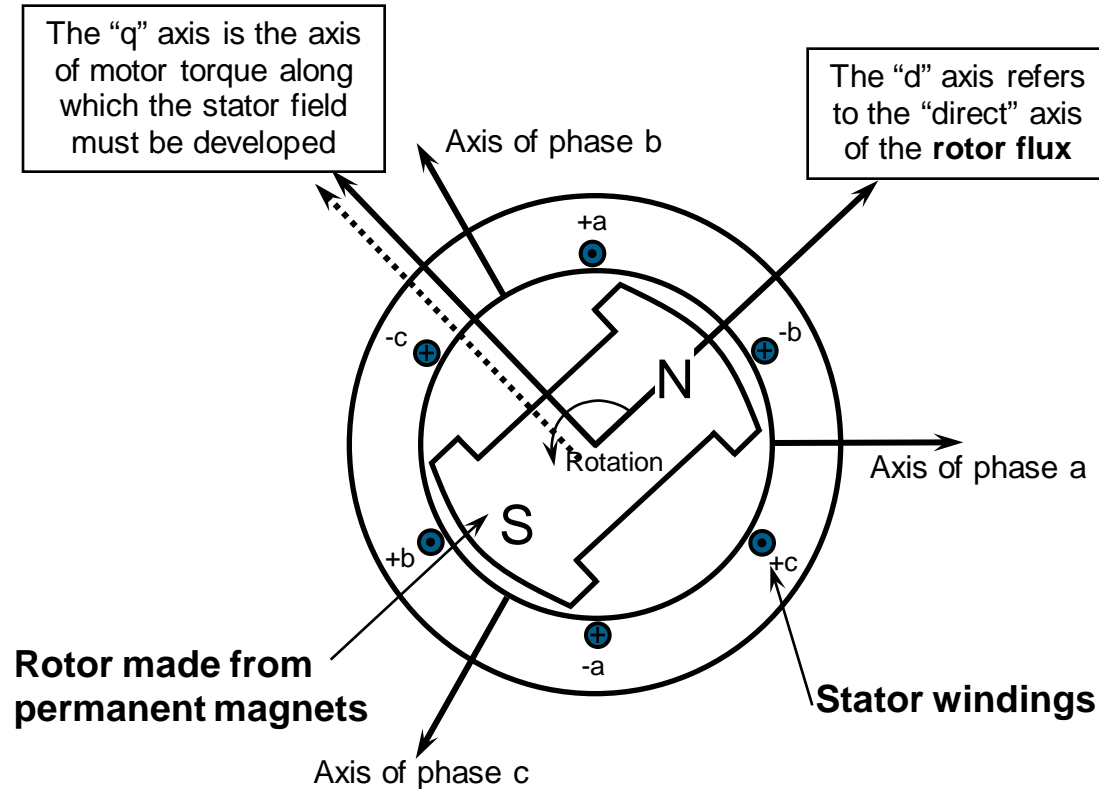
Transformation Functions - MCLIB

► Features

- Written using CodeWarrior intrinsic functions.
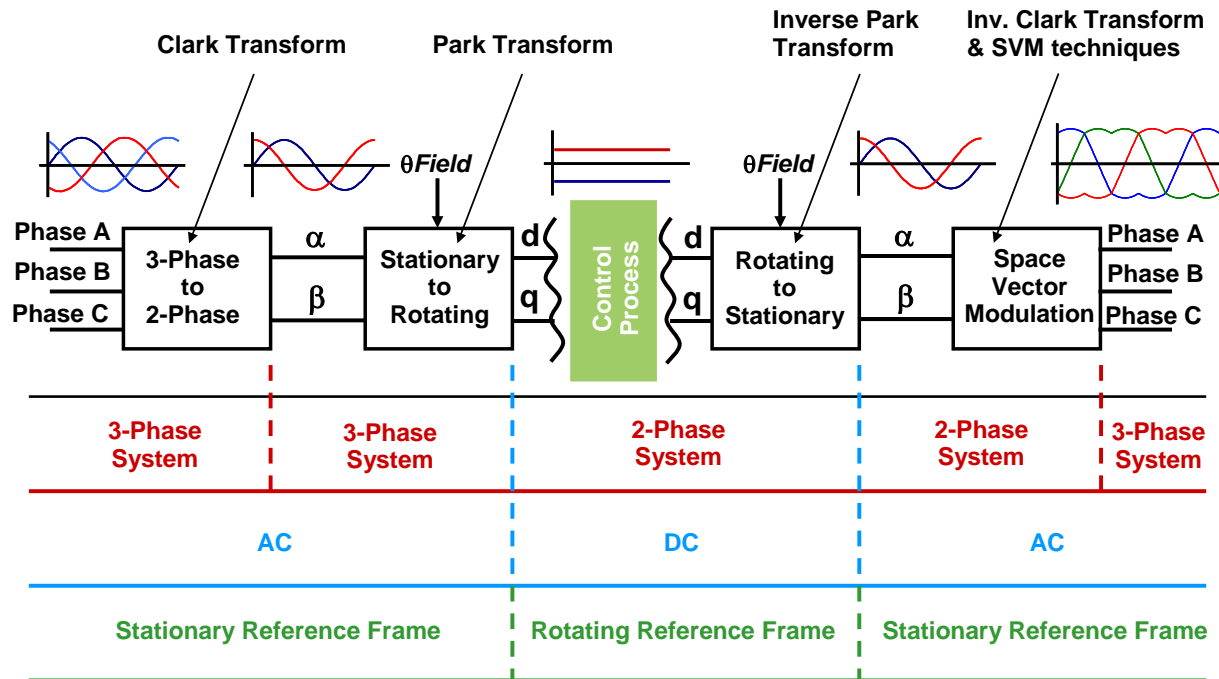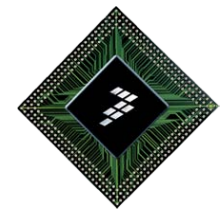- Documentation describes transformation theory and implemented equations.
- Correct evaluation is guaranteed when saturation flag is set prior to these function calls.

Function	Code Size	Execution Clocks
ClarkTrfm	14	61
ClarkTrfmInv	16	73
ParkTrfm	17	91
ParkTrfmInv	17	92

Clark Transform   Park Transform   Inverse Park Transform   Inv. Clark Transform & SVM techniques

θField   θField

Phase A						
Phase B	3-Phase to 2-Phase	α / β	Stationary to Rotating	d / q	Control Process	d / q
Phase C						

Rotating to Stationary   α / β   Space Vector Modulation   Phase A / Phase B / Phase C

3-Phase System   **3-Phase System**   **2-Phase System**   **2-Phase System**   **3-Phase System**

AC   **DC**   **AC**

Stationary Reference Frame   **Rotating Reference Frame**   **Stationary Reference Frame**

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Sensorless FOC of PMSM Demonstration

Sensorless FOC System Block Diagram

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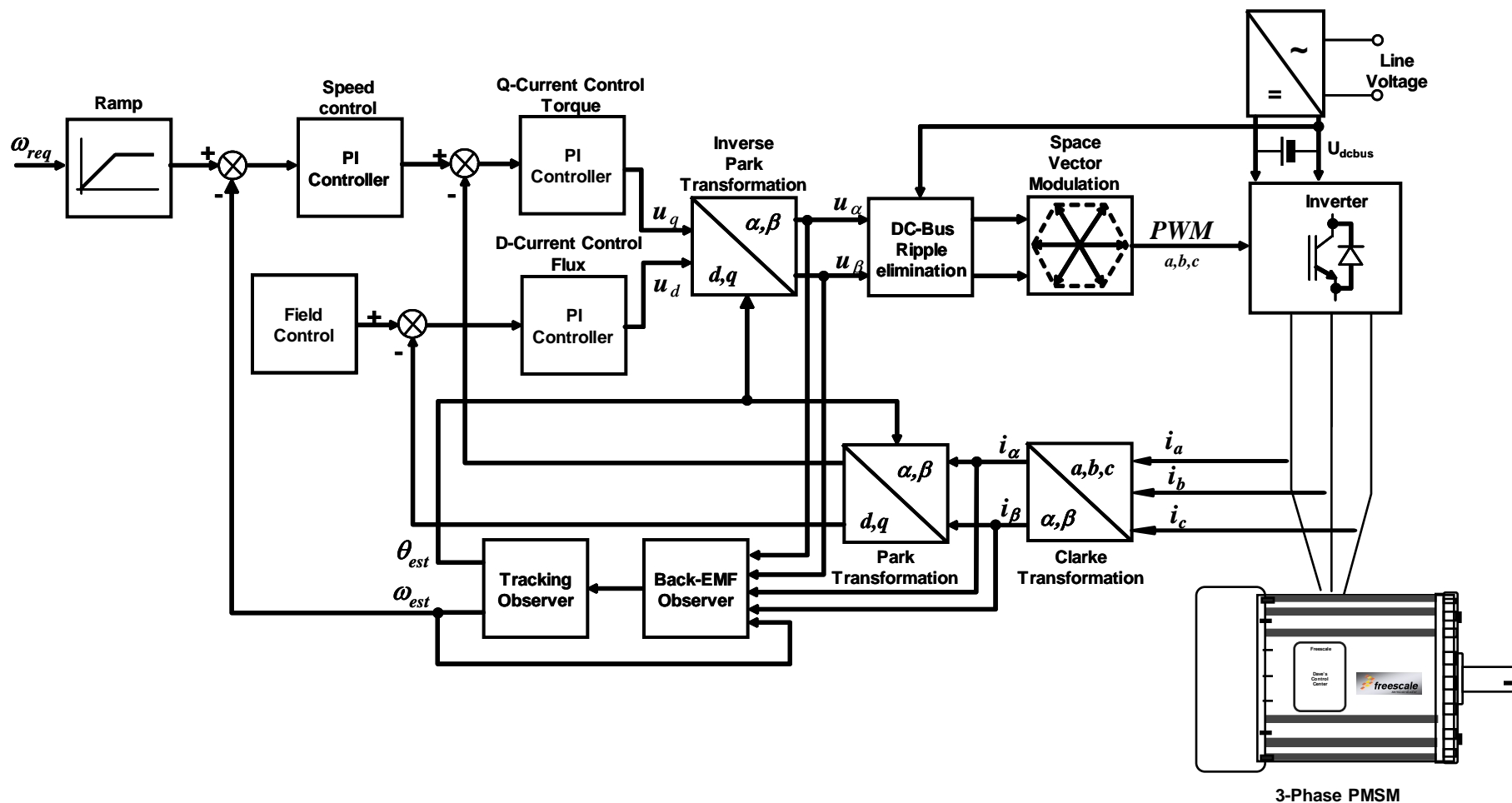
► Application based on **MC56F8025**

► Pulse width modulation running at 20 kHz with dead-time insertion

► FOC current loop running at 10 kHz (100 μsec)

► Speed control loop running at 1 kHz (1 msec)

► Field weakening implemented

► Freescale DSC software library
  - GFLIB (general functions)
  - GDFLIB (digital filtering)
  - MCLIB (motor control)
  - ACLIB (advanced control - sensorless)


Algorithm Performance

FOC current loop takes .55 usec to execute (loop running at 100 usec)

Speed control loop takes 17 usec (loop running at 1 msec)

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DC Bus Voltage Measurement

- Feedback signals are proportional to bus voltage.
- Bus voltage is scaled down by a voltage divider.
- Values are chosen such that a 400-volt maximum bus voltage corresponds to 3.24 volts at output V_sense_DCB.
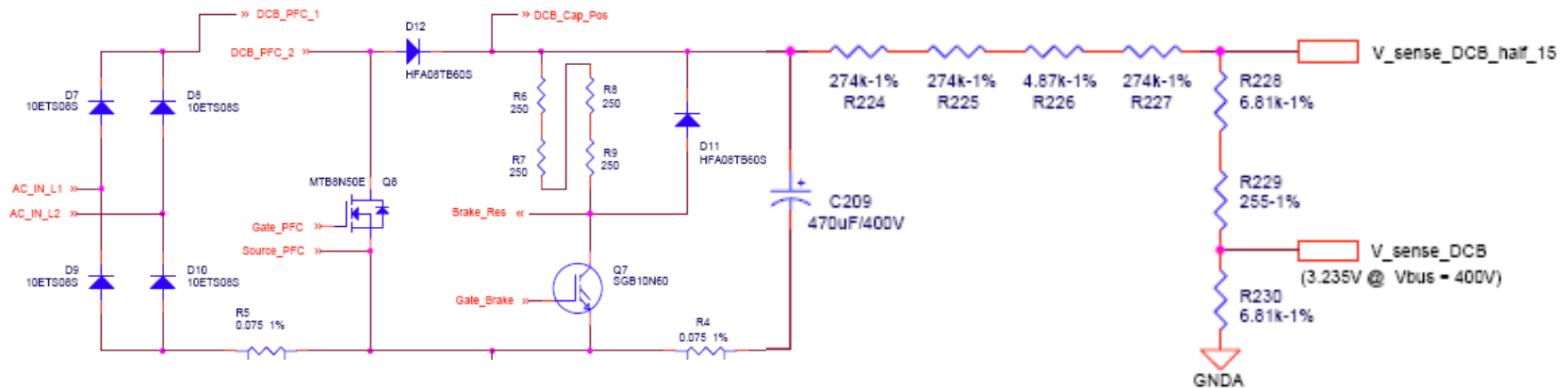
Phase Current Measurements

- Shunt resistors measure voltage drop
- Two channels sampled simultaneously with 12-bit resolution
- Software calculation to obtain values for all 3 phase currents (Kirchhoff's current law)
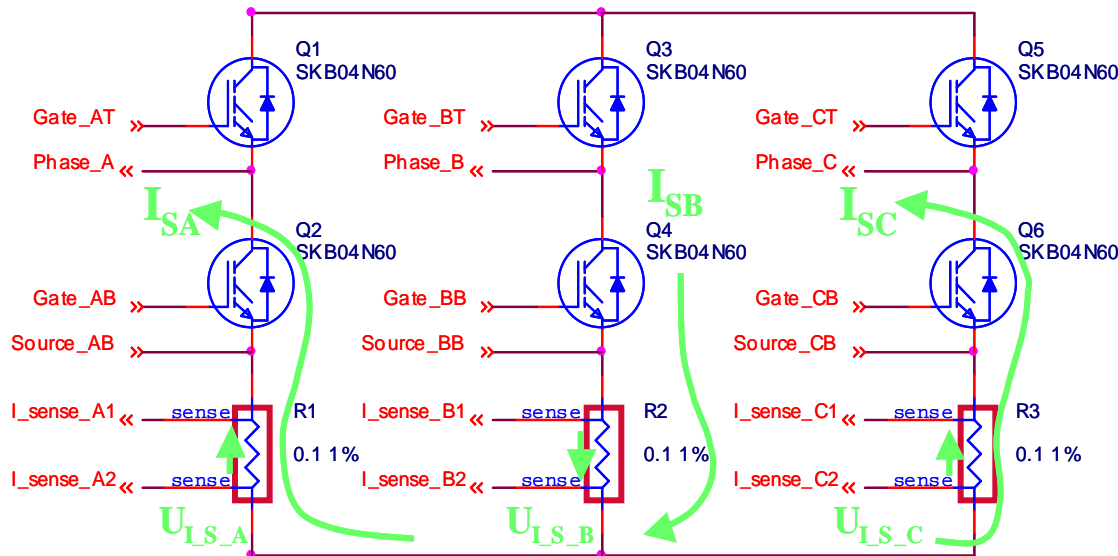
# Classifications of Sensorless Methods for PM Motors

► Back EMF observer
  ▪ Proper motor parameters, voltage and current required
  ▪ Challenges at zero and low speed estimation
    – Measured current low, distortion caused by inverter irregularities
    – Parameter deviation becomes significant with lowering speed

► Utilization of magnetic saliency
  ▪ Difference in Ld-Lq
  ▪ Rotor position detected by tracking magnetic saliency
  ▪ Carrier signal superimposed to main voltage excitation

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Open Loop Start Up

- Starting procedure differs from V-axis washer
  - No need to operate at low speed (>300[rpm])
  - High start-up torque required to speed up a loaded drum

- Motor accelerated in "open loop" means there is no measured position feedback

- **FG-I** and **FG-W** carefully chosen in order to assure a safe starting with minimum oscillation up to the maximum torque

- **FG-I –** Current function generator
- **FG-W** – Velocity function generator
- **MTPA** – Maximum torque per amp

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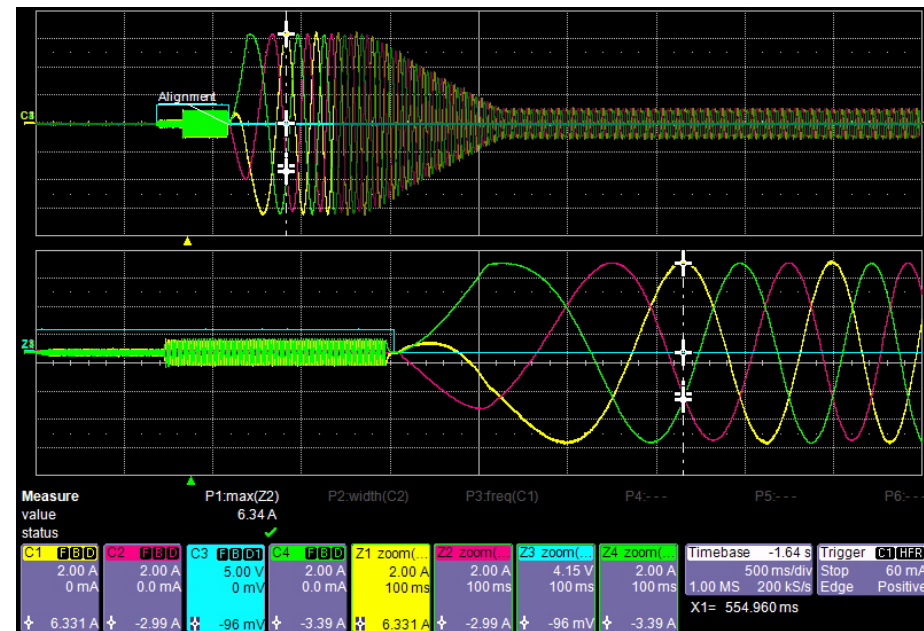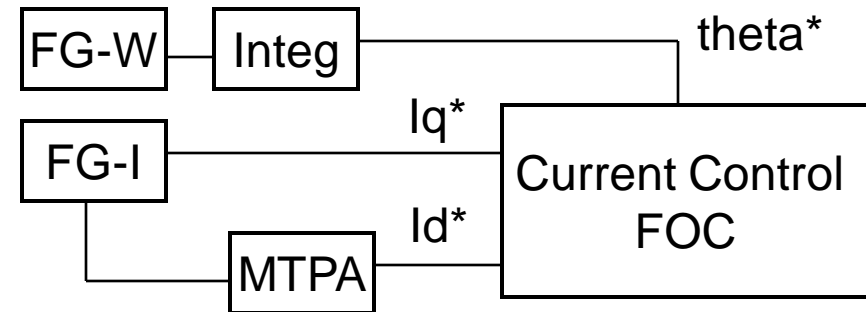
Model-based Estimator - Extended BEMF Observer

-Model-based algorithm

- Based on extended BEMF observer

- Position and speed extraction by angle tracking observer

- Algorithm used over wash cycle operation

- Operation speed range starts reliably from ~300 [rpm]

Summary
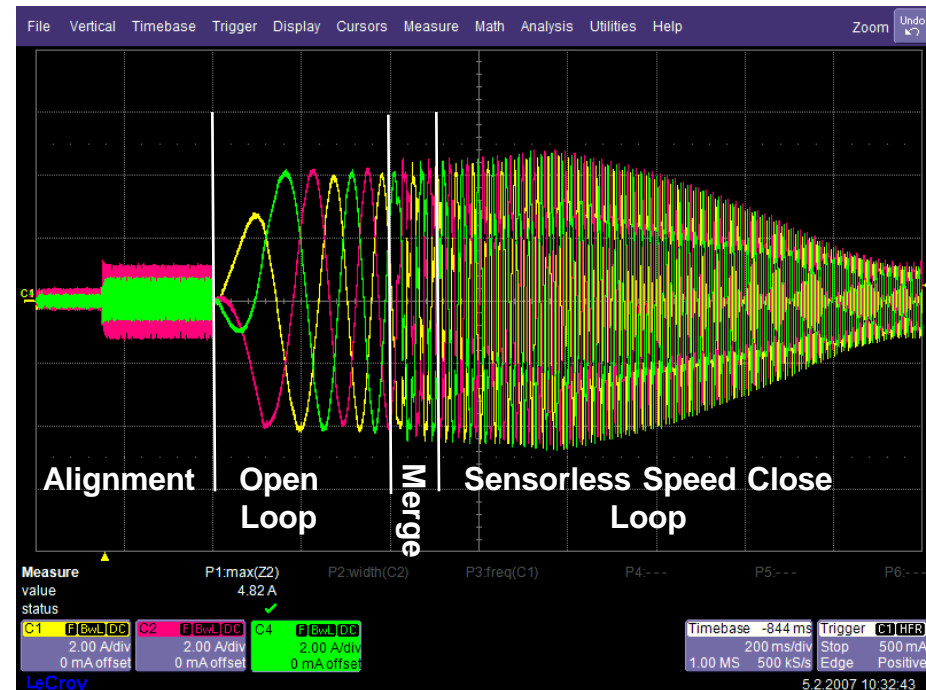
► Introduced ACIM and PMSM motors
  - Asynchronous vs. synchronous differentiators
  - AC induction motors and control techniques
  - Permanent magnet motors and control techniques

► Outlined motor control and drive system architecture

► Discussed field oriented control (FOC) principles and Freescale's motor control libraries

► Demonstrated and reviewed a Freescale DSC-based sensorless FOC control PMSM for a washer application

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►Thank you for attending this presentation. We'll now take a few moments for the audience's questions, and then we'll begin the question and answer session.

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Related Session Resources

Sessions

Session ID	Title
AZ116	Industrial Motor Control Roadmap (Part 1)
AZ141	FreeMASTER and Quick Start Overview

Demos

Pedestal ID	Demo Title
	PMSM Sensorless FOC Demo
	PMSM Dishwasher Pump Demo
	PMSM for a Top Loading Washer

Meet the FSL Experts

Title	Time	Location

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For Further Reference

- ▶ DRM020: 3-Phase AC Induction Motor Drive with Tachogenerator Using MC68HC908MR32

- ▶ DRM021: 3-Phase ACIM Volt per Hertz Control Using 56F80x

- ▶ DRM092: 3-Phase AC Induction Vector Control Drive with Single Shunt Current Sensing

- ▶ DRM102: PMSM Vector Control with Single Shunt Current Sensing Using MC56F8013/23

- ▶ Dave Wilson "Great Debate" Article: http://www.industrial-embedded.com/

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