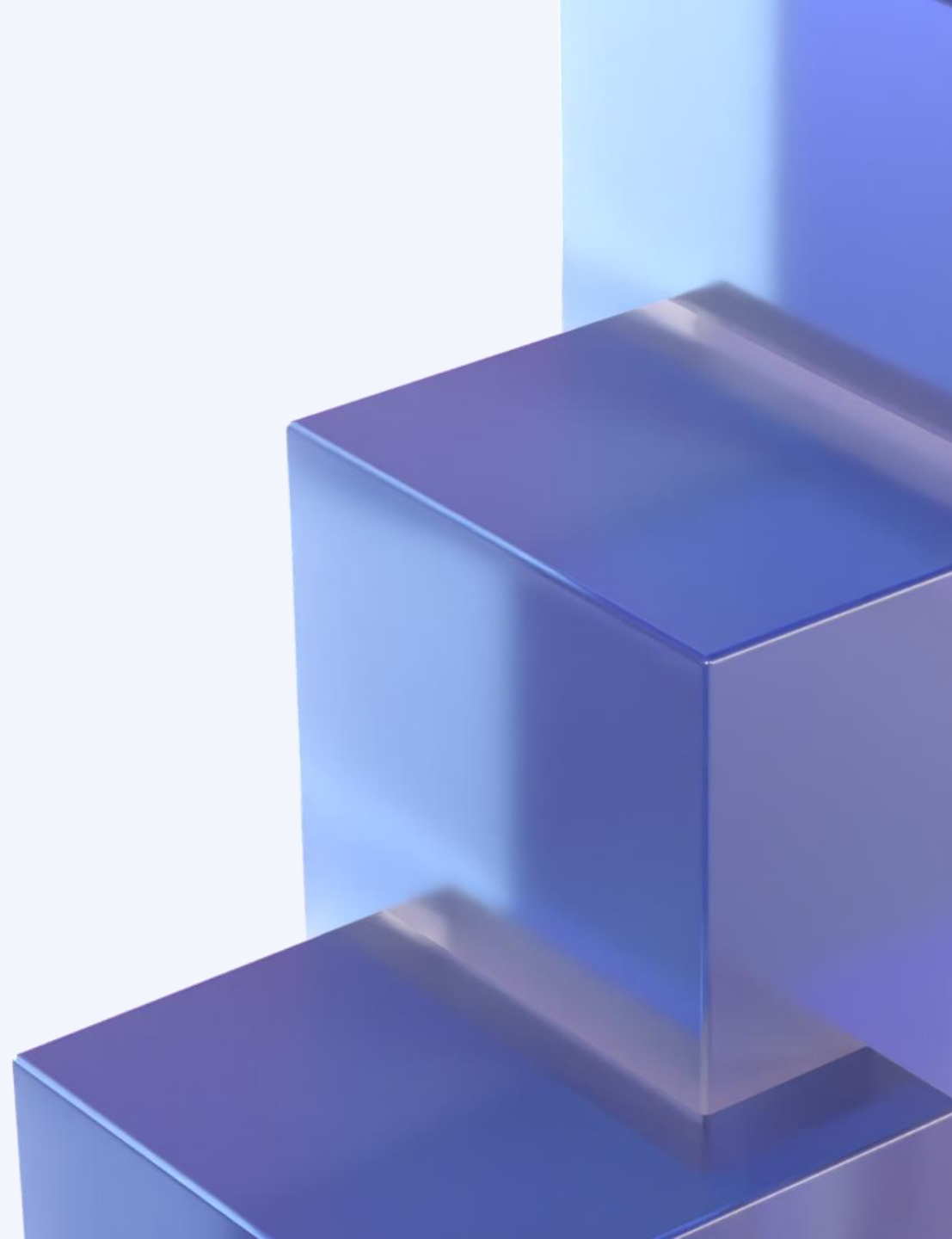




MPS Powers Humanoid Robots

Because without Motion, a Robot is just a Sculpture

September 2025



Agenda and Topics

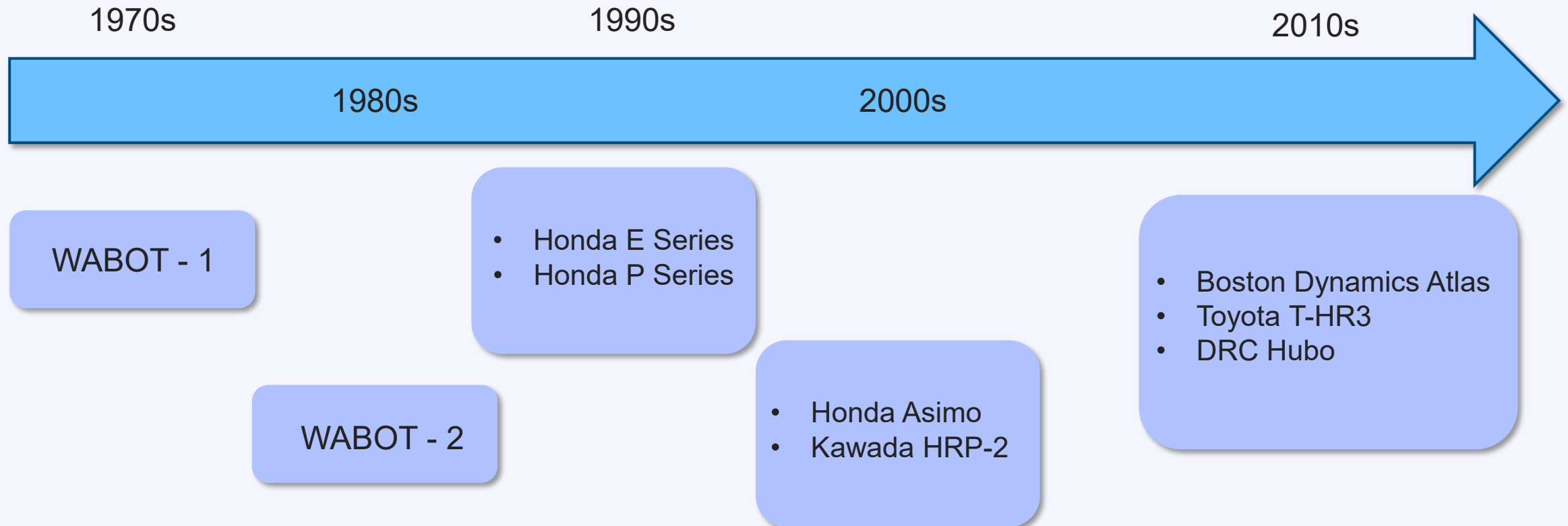
Introduction to Humanoid Robotics

Humanoid Robotics Blocks

Humanoid Robotic Motor Power Stages

Humanoid Robotic Motion Sensors

Humanoid Robotics Across the Decades



Humanoid Robots (2020s)



	Humanoid Robot #1	Humanoid Robot #2	Humanoid Robot #3	Humanoid Robot #4	Humanoid Robot #5
Height (cm)	173	168	175	172	170
Weight (kg)	56 to 73	60	65	72	70 to 75
Payload (Carry Capacity)	20kg	20kg	16kg to 18kg	25kg	25kg
Top Speed (km/hr)	8	2.7	3.3	3.4	2.7
Degrees of Freedom	50 to 55	40	20	30	55

Major Challenges



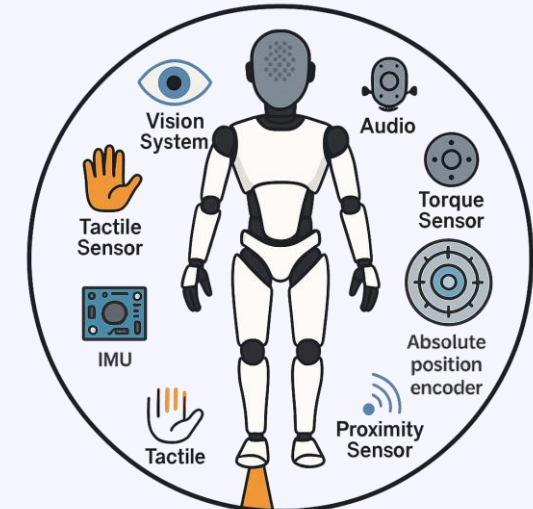
- Actuation and power density while obtaining human-like motion
- Large number of motor coordination in real time
- Balancing and locomotion



Human-to-Robot Interaction
Safety



Power Consumption and Battery
Life – Efficiency Is Key

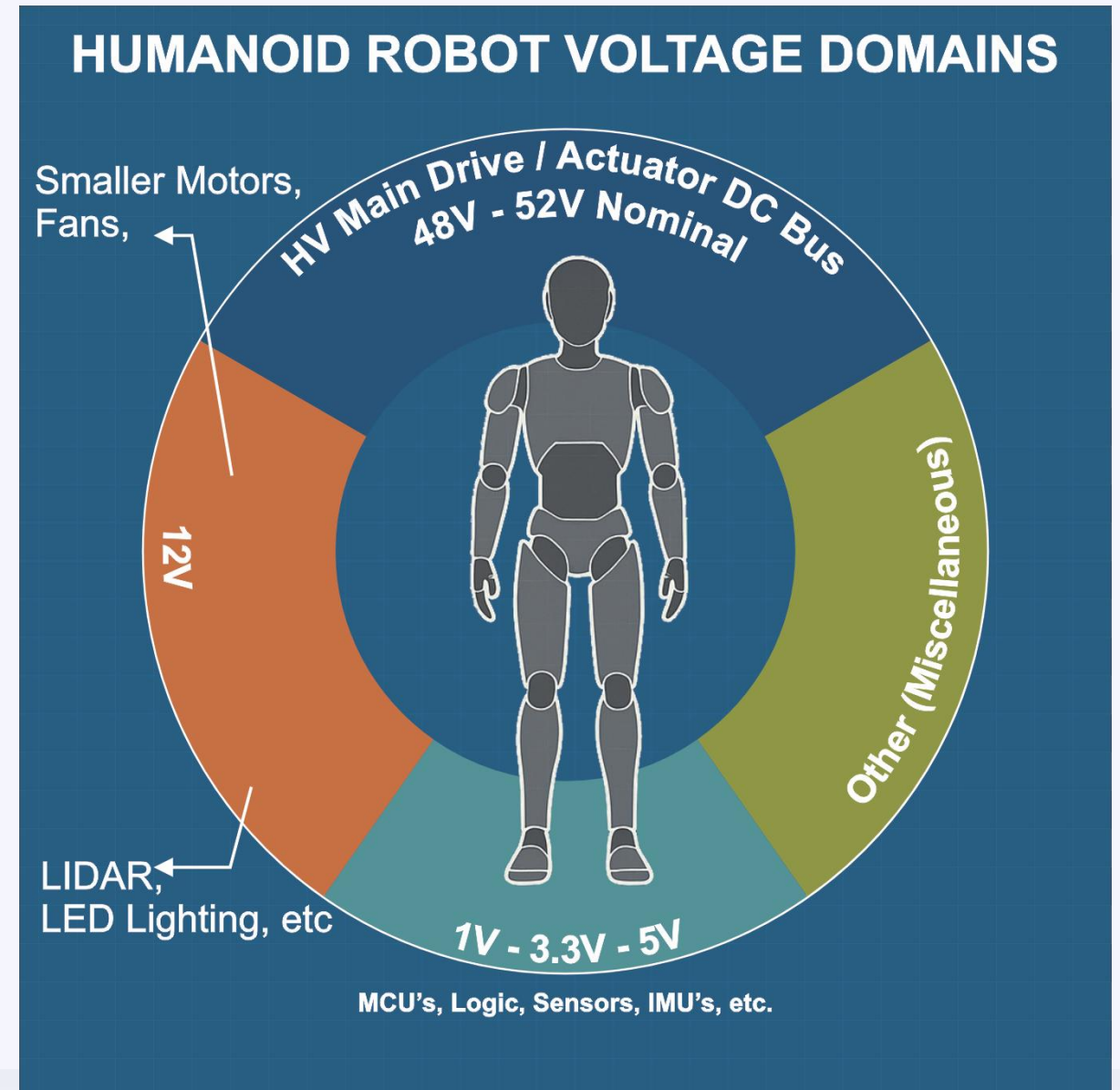


Sensor Integration and Feedback
Quality

	Humanoid Robot #1	Humanoid Robot #2	Humanoid Robot #3	Humanoid Robot #4	Humanoid Robot #5
Battery Voltage	48V	48V	48V	48V	48V
Battery Type	2.3kHw Li-Ion	2kHw to 2.5kHw Li-Ion	2kHw to 3kHw Li-Ion	Li-Ion (Swapable)	Li-Ion
Run Time (hrs)	8	5	4 to 6	4	4 to 5
Power Budget	2kW (Peak)	2kW (Peak)	2kW (Peak)	2kW (Peak)	2.5kW (Peak)
Cooling	Air-Cooled (Fans)	Air-Cooled (Fans)	Air-Cooled (Fans)	Air-Cooled (Fans)	Air-Cooled (Fans)
Number of Motors	50	40	20 to 24	30	30
Motor Type	PMSM	PMSM/BLDC	BLDC	PMSM/BLDC	PMSM/BLDC
Transmission	Harmonic	Harmonic + Custom	Custom Belt + Geared	Harmonic/Cycloidal	Harmonic/Cycloidal
Encoders	Abs. Magnetic Position Encoders	Abs. Magnetic Position Encoders	Abs. Magnetic Position Encoders	Abs. Magnetic Position Encoders	Abs. Magnetic Position Encoders
Sensors	Torque, IMU, Joint Angle, Vision	IMU, Joint Angle, Torque, Vision, Tactile	IMU, Foot Contact, Force, Stereo Vision	IMU, Vision, Force, End Effector Sensors	IMU, Vision, Force, End Effector Sensors

Nominal Voltage – 48V

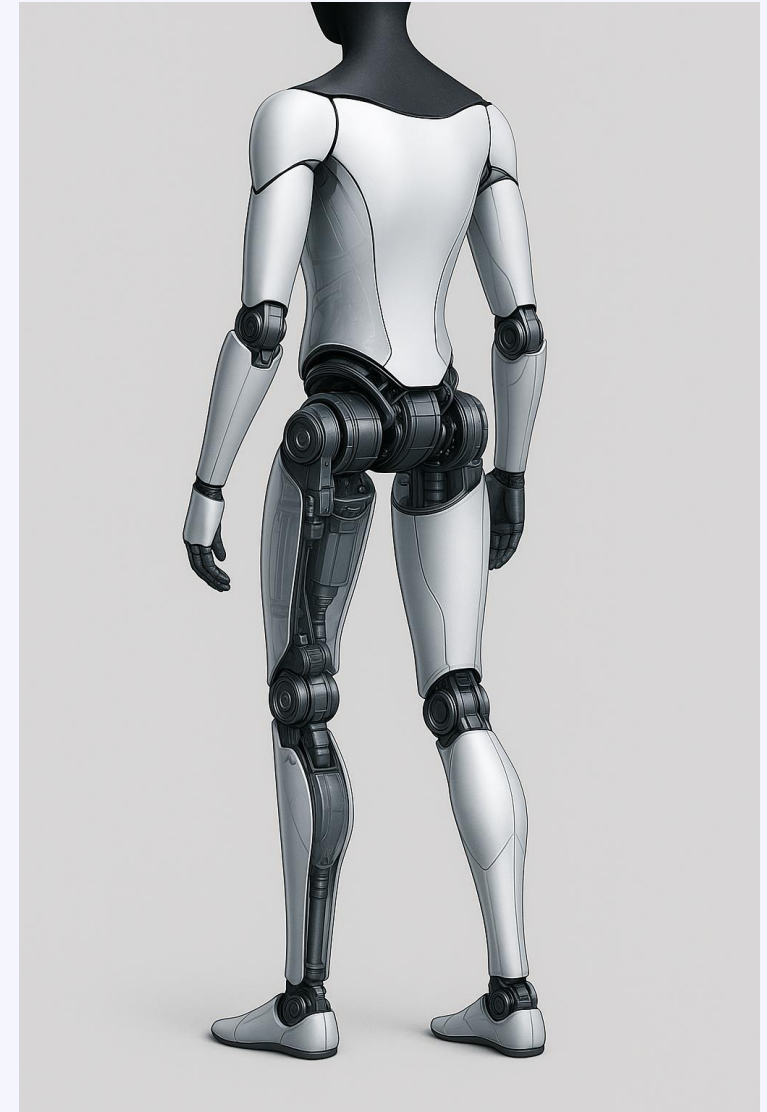
- 48V remains below the 60V safety margin.
- Step-down DC/DC converters can be used to reach lower voltage rails.
- Most motors will operate at a nominal 48V.
- Hand motors may operate at 12V.
- Cooling fans operate at 12V.



Joint	Motor Topology	Average Power (W)	Peak Power (W)
Shoulder (3 DoF)	PMSM + Harmonic Drive	500-600	800-1200
Elbow (1 DoF)	PMSM + Harmonic Drive	200-300	400-600
Wrist (2 DoF)	PMSM + Compact Gearbox	100-200	200-400
Hand (10+ DoF per Hand)	Mini PMSM or DC Coreless Motors	50-100	120-200
Hip (3 DoF)	PMSM + Harmonic Drive	600-800	1500-2000
Knee (1 DoF)	PMSM + Harmonic Drive	300-400	800-1000
Ankle (2 DoF)	PMSM + Compact Harmonic/Cycloidal	200-300	500-800
Neck (2 to 3 DoF)	Miniature PMSM	50-100	150-250
Torso Twist/Bend (2 DoF)	PMSM + Cycloidal or Direct Drive	100-200	300-500

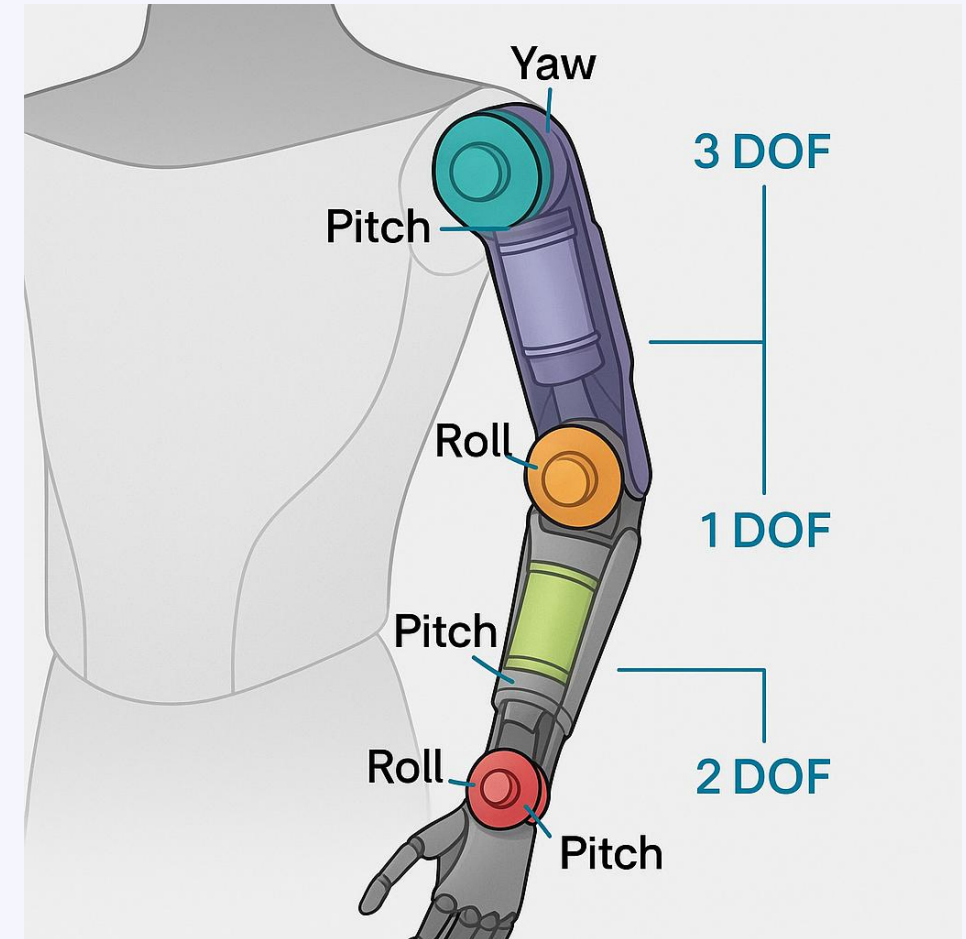
PMSM: Permanent Magnet Synchronous Machine
DoF: Degrees of Freedom

- Degrees of Freedom (DoF)
 - Hip: 3 DoF
 - Knee: 1 DoF
 - Ankle: 2 DoF
- Typical Motor Topology
 - PMSM with Magnetic Absolute Position Encoder
- Power Requirement (per Leg):
 - 48V Input Voltage
 - Peak Current: 40A to 60A
 - Continuous Current: 10A to 30A
 - Average Power: 400W to 800W
- Special Conditions:
 - 3kW to 4kW per Leg during burst (e.g. Jumping)

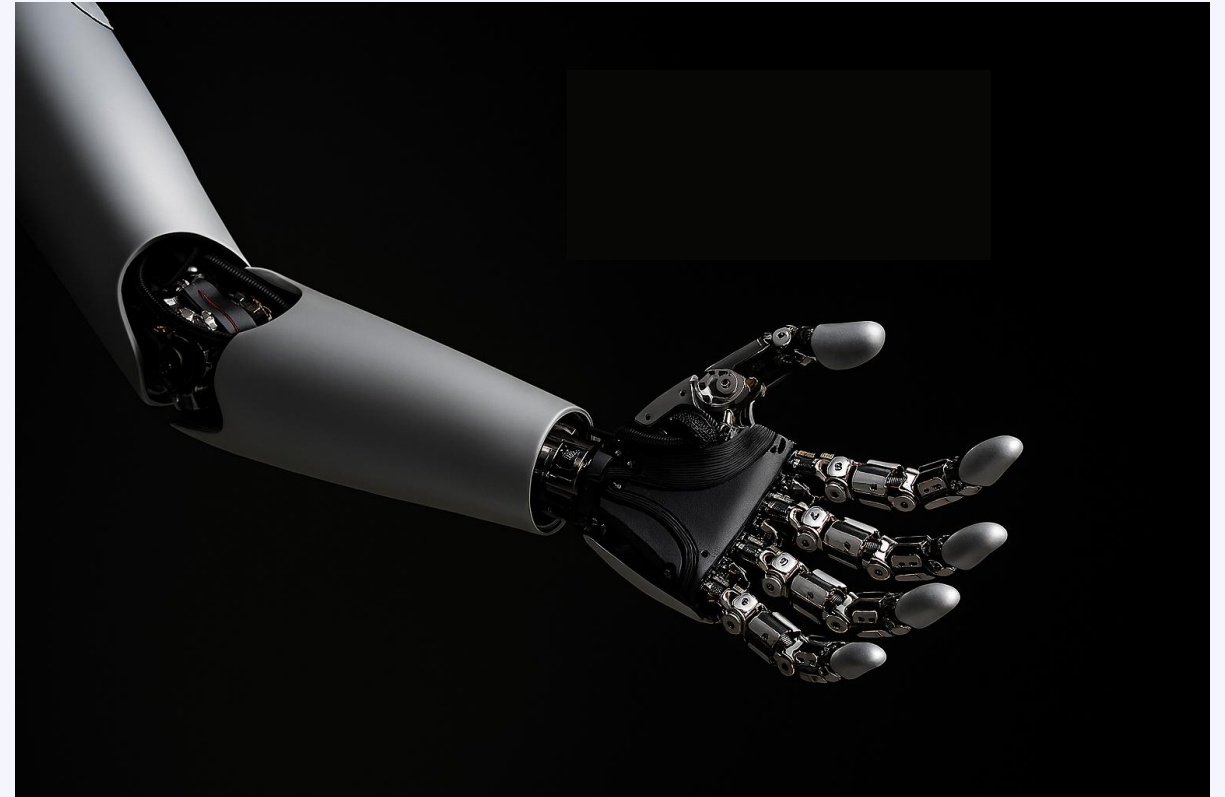


Arm Subsystem

- Degrees of Freedom (DoF)
 - Shoulder: 3 DoF
 - Elbow: 1 DoF
 - Wrist: 2 DoF
- Typical Motor Topology
 - PMSM with Magnetic Absolute Position Encoder
- Power Requirement:
 - 48V Input Voltage
 - Peak Current: 20A to 40A during bursts
 - Continuous Current: 5A to 15A
 - Average Power: 500W to 750W
- Special Conditions:
 - 1kW to 2kW per arm during lifts and dynamic motions.



- Degrees Of Freedom (DoF)
 - Fingers (Flexion/Extension): 3 DoF
 - Finger (Abduction): 1 DoF
 - Thumb: 4 to 5 DoF
 - Wrist*: 2 DoF
- Typical Motor Topology
 - Coreless BLDC with Magnetic Absolute Position Encoder
- Power Requirement:
 - 12V to 48V Input Voltage
 - Peak Current: 5A to 8A during Bursts
 - Continuous Current: 1A to 5A
 - Average Power: 50W to 100W



* If not on the arm subsystem

Motor Topology Distribution



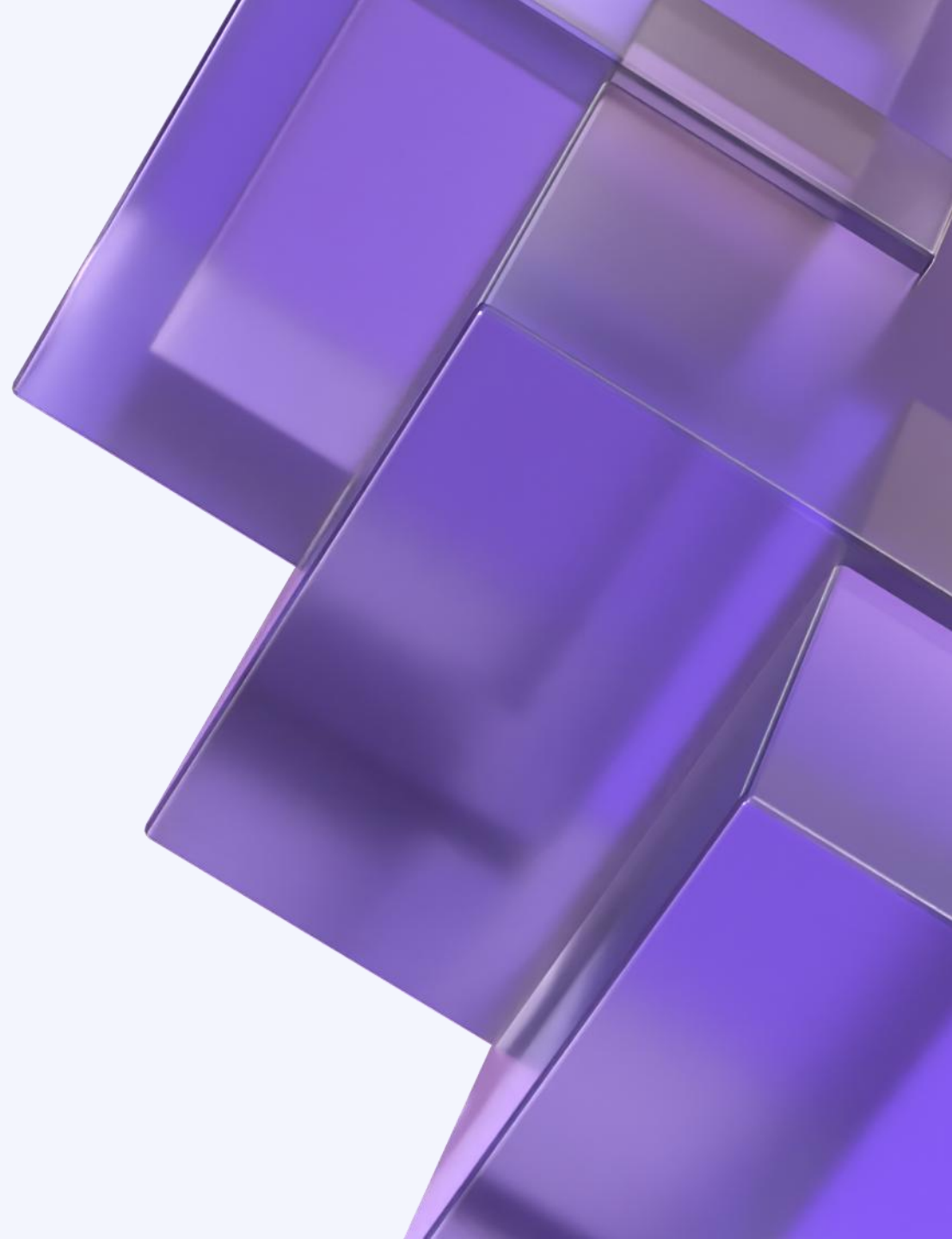
Joint / DoF	AC Induction Motor	Brushed DC Motor	Bipolar Stepper	Brushless DC (BLDC)	Coreless BLDC	PMSM
Shoulder (3 DoF)	Not used	Not used	Not used	Sometimes	Not used	Standard
Elbow (1 DoF)	Not used	Not used	Not used	Sometimes	Not used	Standard
Wrist (2 DoF)	Not used	Rare (grippers)	Rare (simple wrists)	Common	Rare	Preferred
Hand/Fingers (10+ DoF)	Not used	Rare (fingers, eyes)	Not used	Common	Preferred (fingers, eyes)	Less common
Hip (3 DoF)	Not used	Not used	Not used	Sometimes	Not used	Standard
Knee (1 DoF)	Not used	Not used	Not used	Sometimes	Not used	Standard
Ankle (2 DoF)	Not used	Not used	Not used	Common	Not used	Standard
Neck (2 to 3 DoF)	Not used	Rare (eyelids)	Rare (neck in research bots)	Sometimes	Sometimes (neck or eyelids)	Preferred
Torso (2 DoF)	Not used	Not used	Not used	Sometimes	Not used	Standard



FOC-Driven

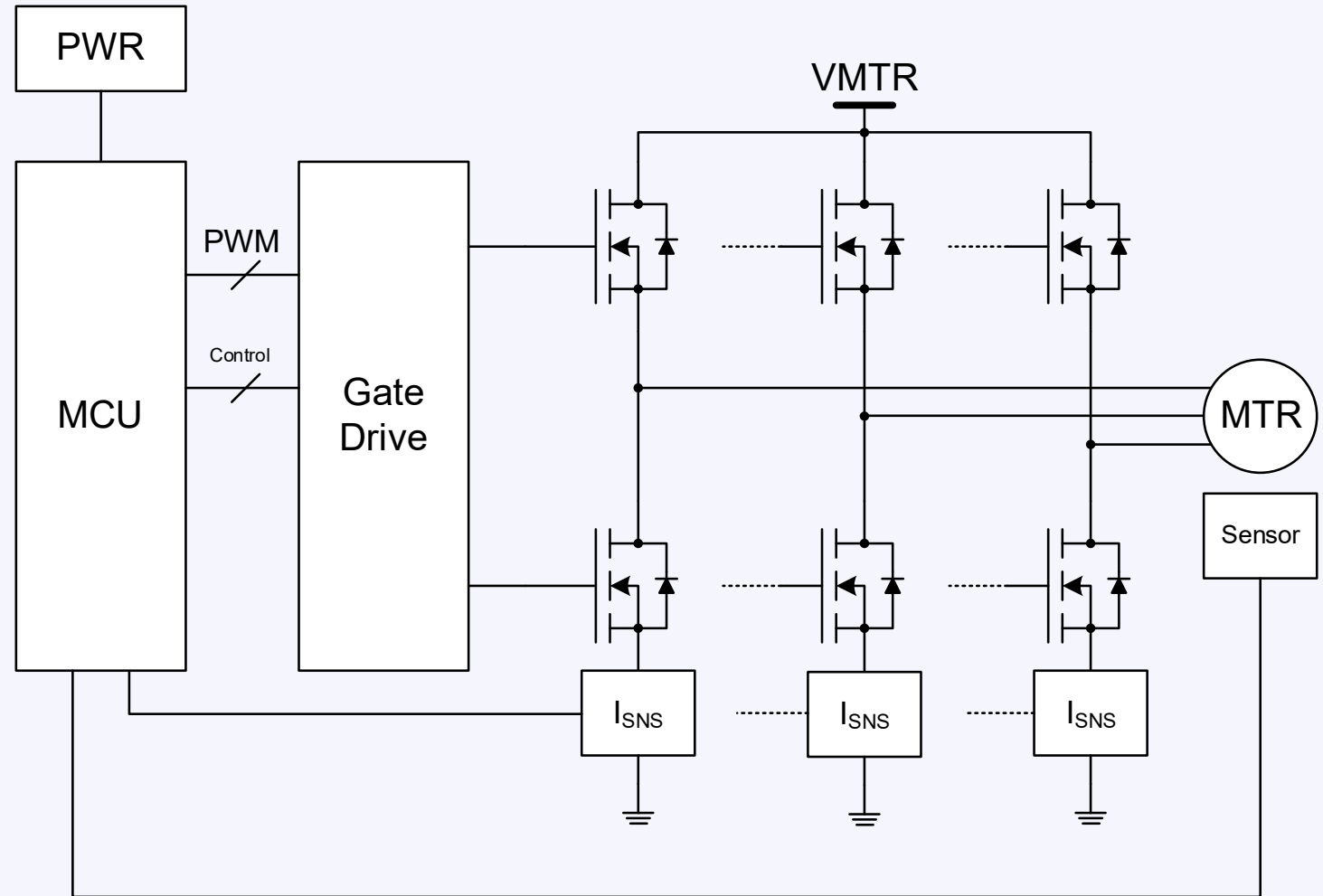


Power Stages

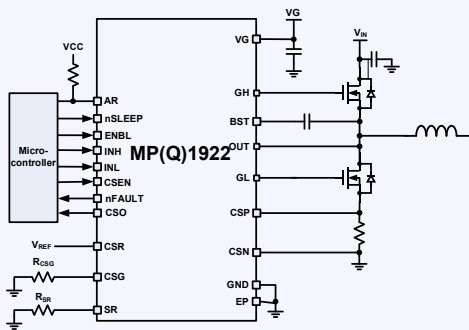


Typical Three-Phase Inverter

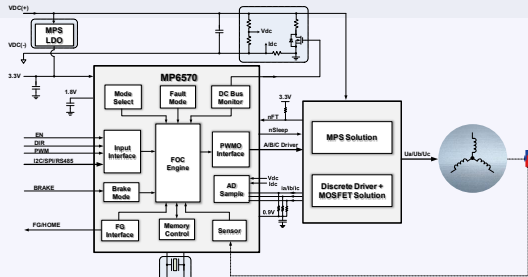
- Power Stage: 6 N-Channel MOSFETs
- High-Current Gate Drivers
- Current-Sensing
- Microcontroller / DSP (FOC)
- Power Management
- Absolute Position Encoder
- Protection Blocks



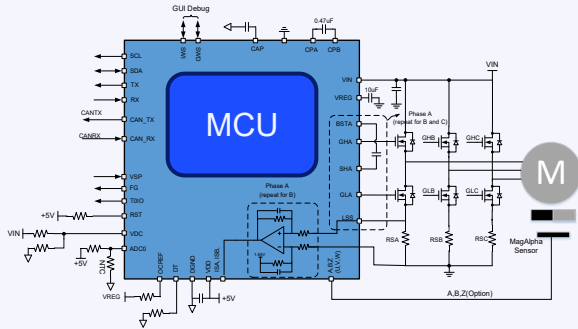
Three-Phase Inverter Power Stage Topologies



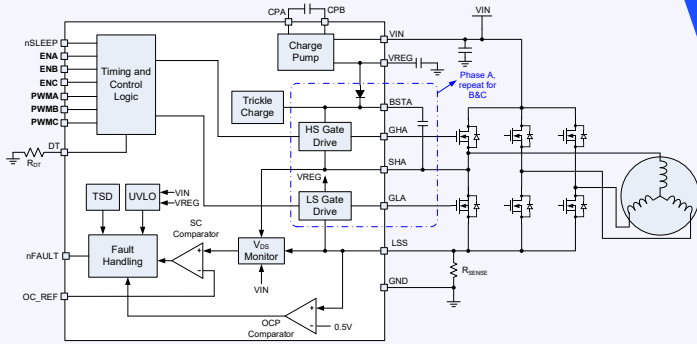
Half H-Bridge Gate Drivers



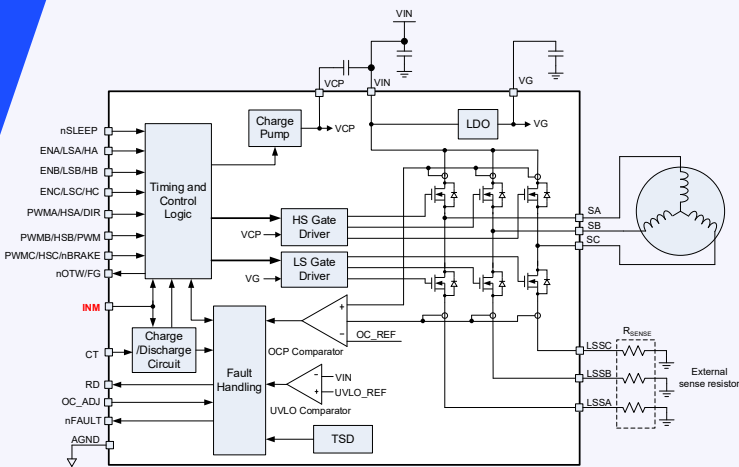
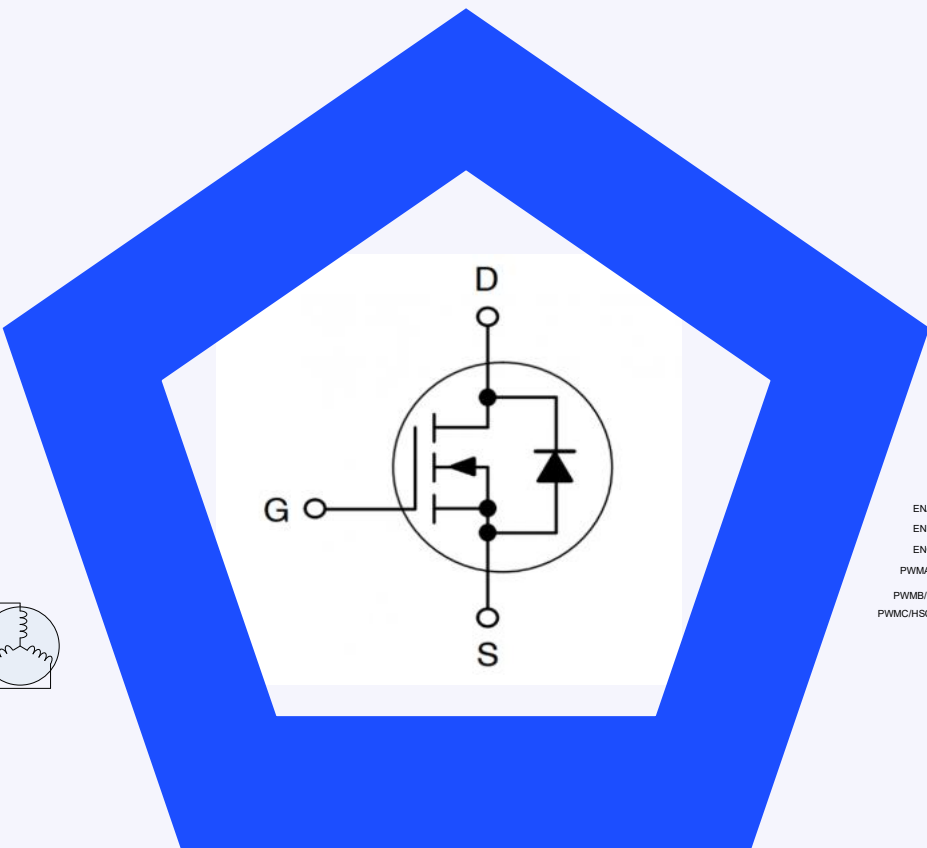
FOC Controller



Intelligent Three-Phase Inverter



Integrated Three-Phase Inverter Gate Drivers

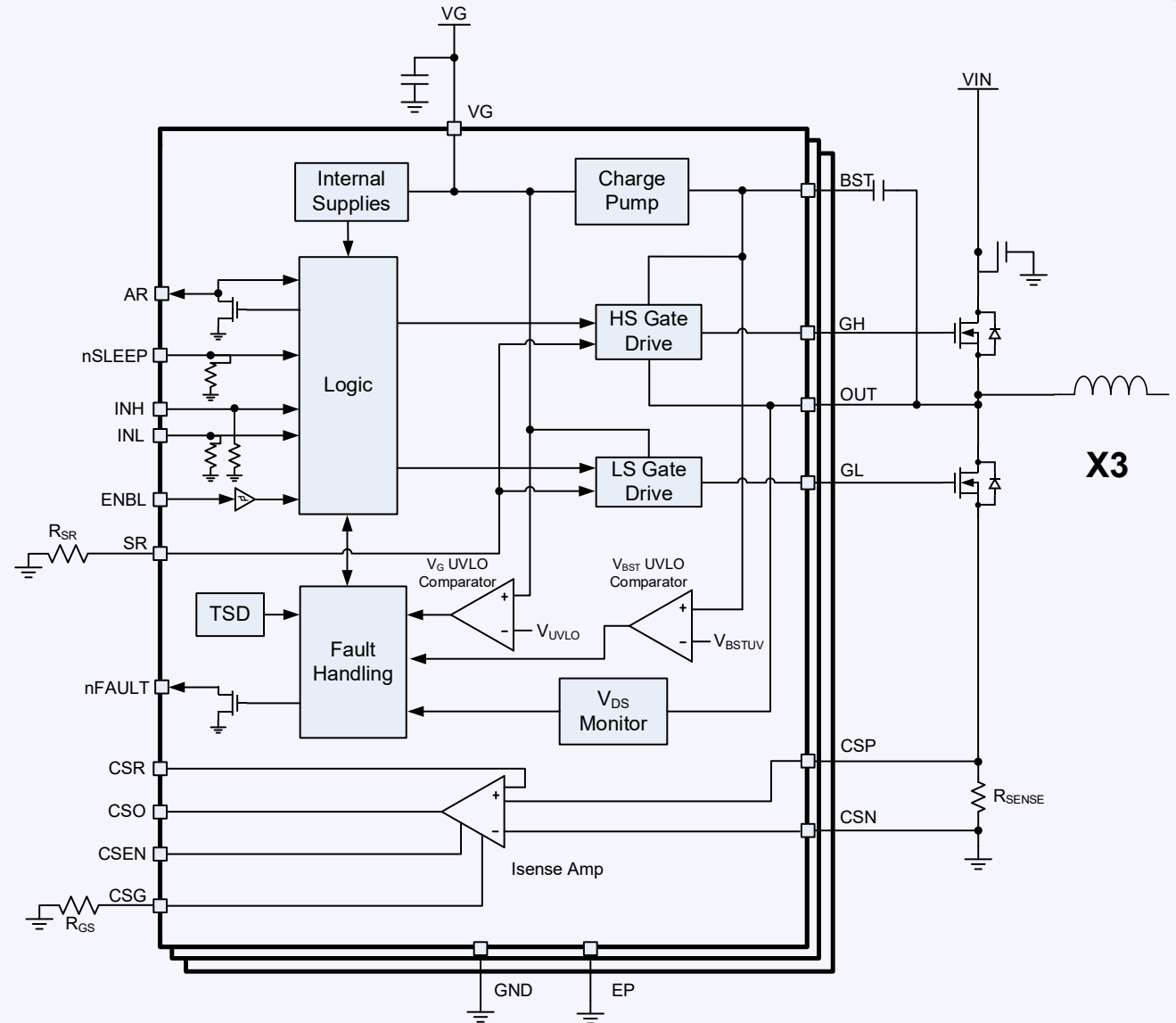
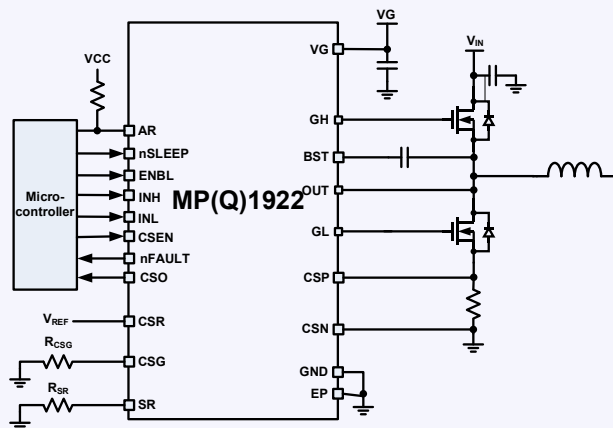


Fully Integrated Three-Phase Inverter

Three-Phase Inverter with Half-Bridge Gate Drivers

Features

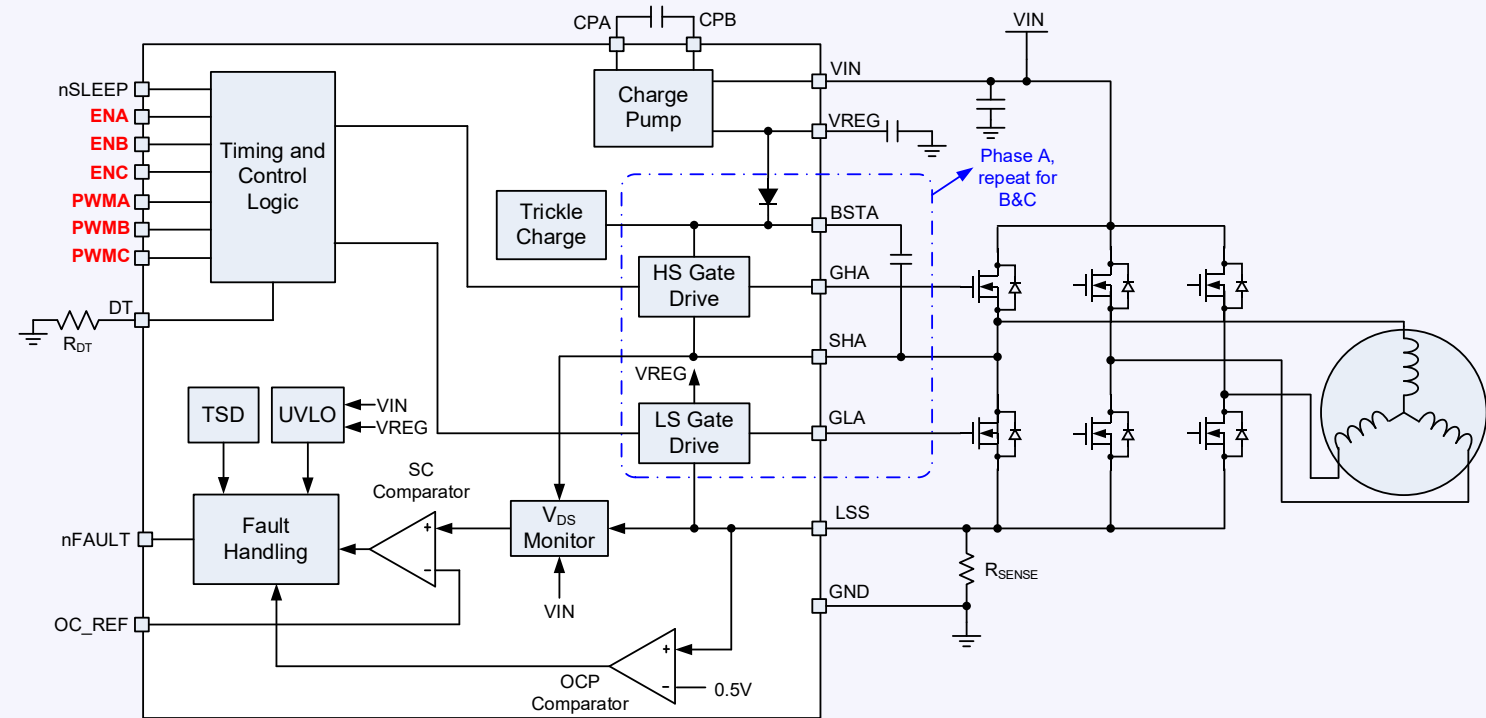
- **5V to 15V** Input Voltage (V_{IN}), Supports 100V Supply Operation
- 3A Source, 4A Sink Gate Drive Current
- Internal Charge Pump and Auto-Refresh for HS Gate Drive
- Configurable, Controlled Slew Rate
- Low-Power Sleep Mode ($0.1\mu A$)
- **Integrated Current-Sense Amplifier**
- **Inherent Protection Features:**
 - Desaturation Protection of External MOSFETs
 - Over-Temperature Protection (OTP), Under-Voltage Lockout (UVLO)
 - Fault Indication Output
- Available in a QFN-22 (4mmx5mm) Package
- **Available in AEC-Q100 Grade 1**



Three Phase Inverter Gate Drivers

For Medium-Power Loads:

- N-Channel MOSFET Drivers
- Charge Pump Support
- Over-Current Protection (OCP)
- Integrated Bootstrap Diode
- Multiple Control Interfaces:
 - Lx/Hx PWM
 - EN/PWM
 - DIR/PWM/BRK
 - Serial Peripheral Interface (SPI)
- Protection and Fault Reporting



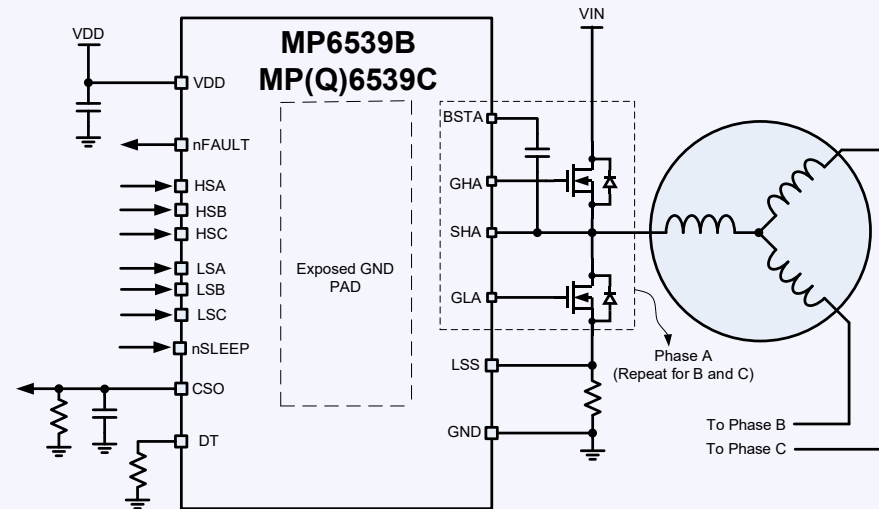
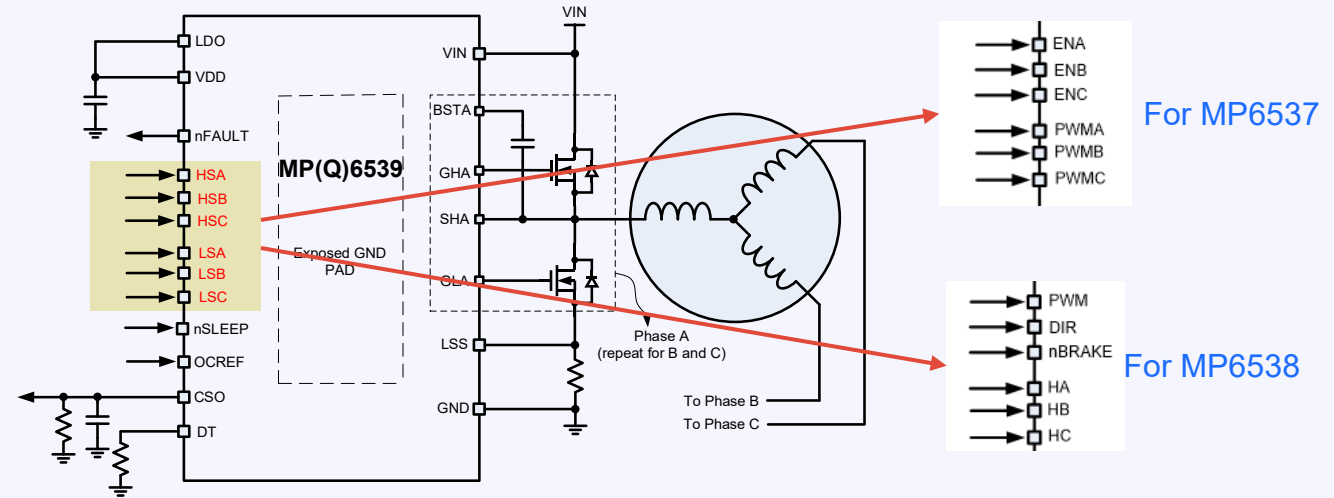
MP6534

Device	Voltage	Gate Drive Strength
MP6530/31	60V	1.0A/0.8A
MP6534/35	55V	1.0A/0.8A
MP6537/38/39	100V	1.0A/0.8A

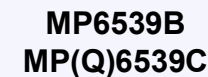
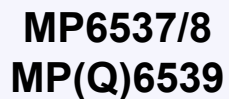
MP(Q)6539 family: 100V/80V, 3-phase Gate Driver

Features

- **8V-100V** V_{IN} (MP6537/8/MP6539), **8V - 80V (MP6539C)** V_{IN}
- **8.5V -14V** Input Voltage (MP6539B/MP(Q)6539C)
- **0.8A/1A Source/Sink Gate Drive Current**
- Supports 100V Operation, 120V V_{BST} Max. Voltage
- **Supports 80V Operation, 100V V_{BST} Max. (MP6539C)**
- **Internal LDO Supports External NPN for High-Current Drive (only MP6537/8, MP(Q)6539)**
- Low-Power Sleep Mode ($I_{SLEEP} \leq 1\mu A$)
- **Integrated Current-Sense Amplifier**
- **Input Logic Interface:**
 - **MP6537: PWMx&ENx Inputs**
 - **MP6538: PWM/DIR Inputs, 3x Hall sensor inputs**
 - **MP(Q)6539/MP6539B/MP(Q)6539C: HSx&LSx Inputs**
- **Inherent Protection Features:**
 - Adjustable Dead Time Control
 - **Programmable OCP** (Only for MP6537/8/MP(Q)6539)
 - OTP, UVLO
 - Fault Indication output
- QFN-28 (4mmx5mm)
- TSSOP-28 EP (Only for MP6539B)
- **Available in AEC-Q100 Grade 1**



MPS



Compared with MP6537/8/MP(Q)6539, MP6539B/MP(Q)6539C does not implement auto bootstrap charging, does not include over-current protection, and is powered only from the VDD pin (VIN and LDO have been removed).

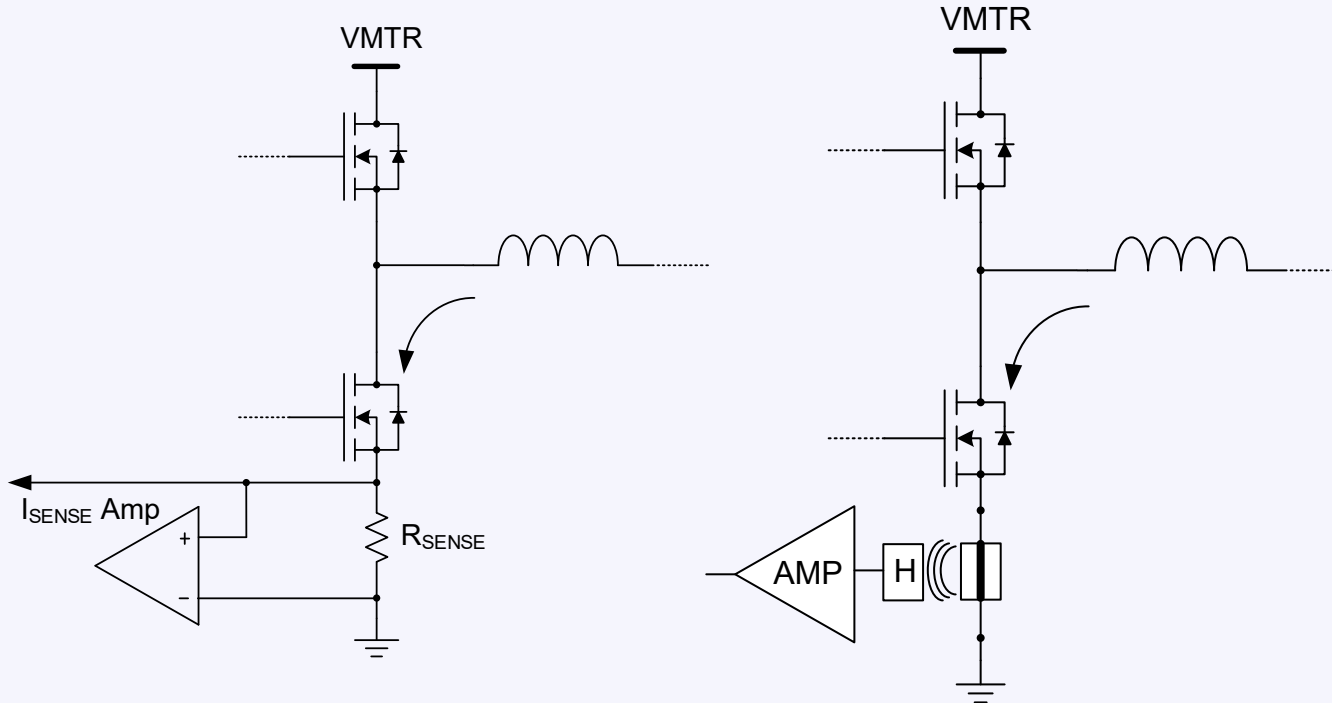
Current-Sense Techniques

Pros:

- Cost-Effective
- MHz Bandwidth

Cons:

- Higher Power Dissipation
- Low-Side Sensing Preferred
- Limited Current Range
- No Isolation
- Amplifier Required



Resistive Shunt Current-Sensing

Magnetic Hall Sensor
Based Current-Sensing

Pros:

- Isolation
- High, Phase, Low-Side Placing
- Lower Power Dissipation
- Noise Immunity

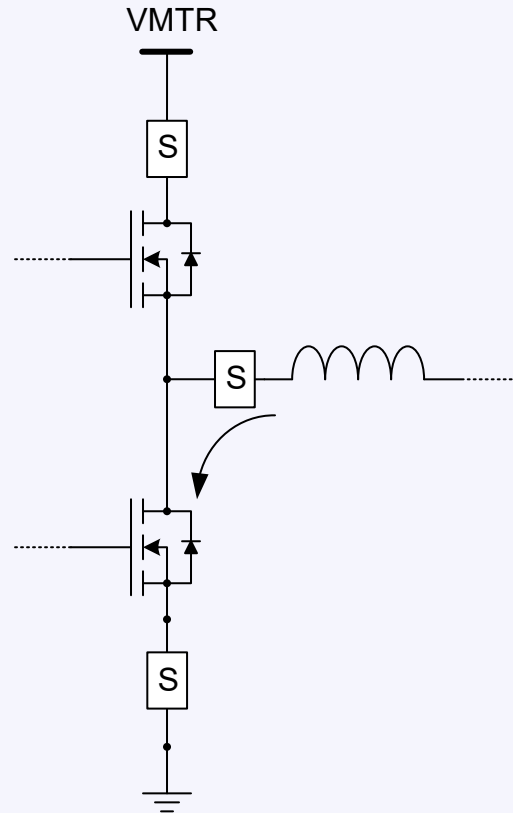
Cons:

- 100kHz Bandwidth

Current Sensor Placement

- Keeps GND Clean
- Detects/Protects Shorts to GND
- Detects/Protect Shoot-Through
- Requires High-Voltage Analog (Resistive Only)

- Detects/Protects Shorts to VMTR
- Detects/Protect Shoot Through
- May Affect GND due to Voltage Drops



- Current measurable at all times
- Best for FOC algorithms
- Cannot reliably protect from shorts

MCS(Q)1810/12 ±100A_{RMS} with 6kV Isolation



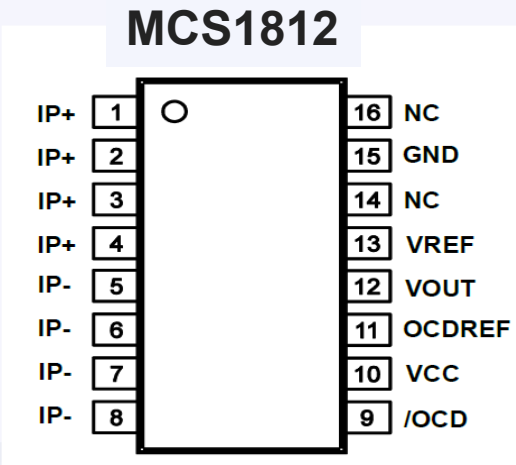
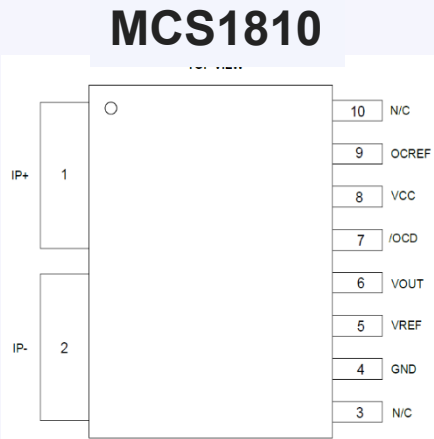
Key Specifications

- Package and Current Range Options:
 - MCS/Q1810 in SOICW-10 Package: 5A to 100A_{RMS} (0.3mΩ)
 - MCS/Q1812 in SOICW-16 Package: 5A to 80A_{RMS} (1mΩ)
- Same Package Footprint: 10.3mmx10.3mm
- 400kHz Bandwidth (BW)
- Supports Reinforced Isolation
- Bidirectional and Unidirectional, Absolute Out
- P2P to ACS37002, ACS724/5

Applications

- On-Board Chargers (OBC)
- Charging Stations
- Motor Control
- Inverter Load Detection Mgt for UPS and PVC

Key Specifications	MCS1810/12
Accuracy	1.5%
V _{ISO} (RMS)	6000V
V _{IOWM} (RMS)	1100V
OCD Response	500ns



Fully Integrated Three-Phase Inverters

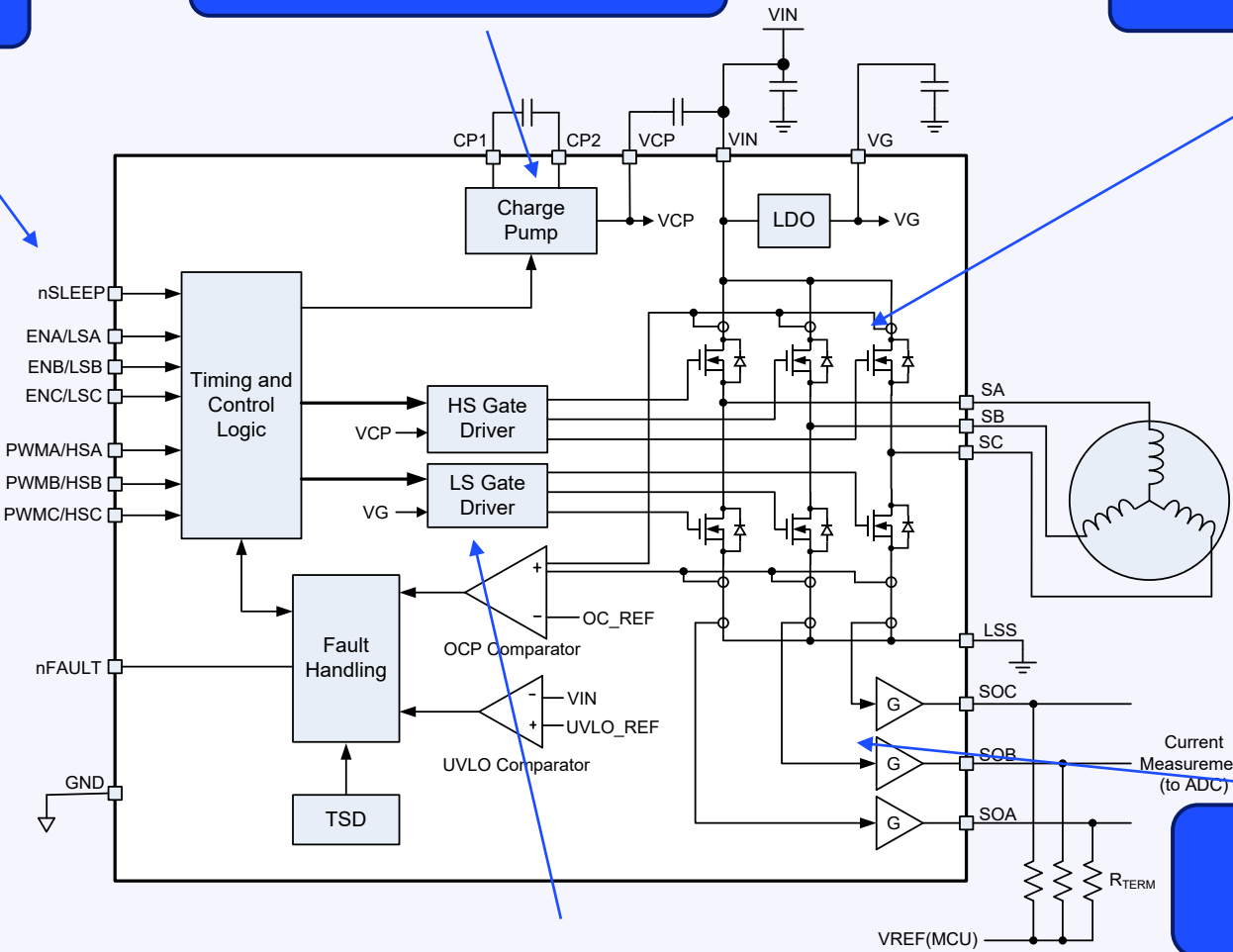


Control Signal Interface

Charge Pump

N-Channel MOSFET

- Power Stage
- Gate Driver
- Current-Sensing
- Fault Handling
- Over-Current Protection



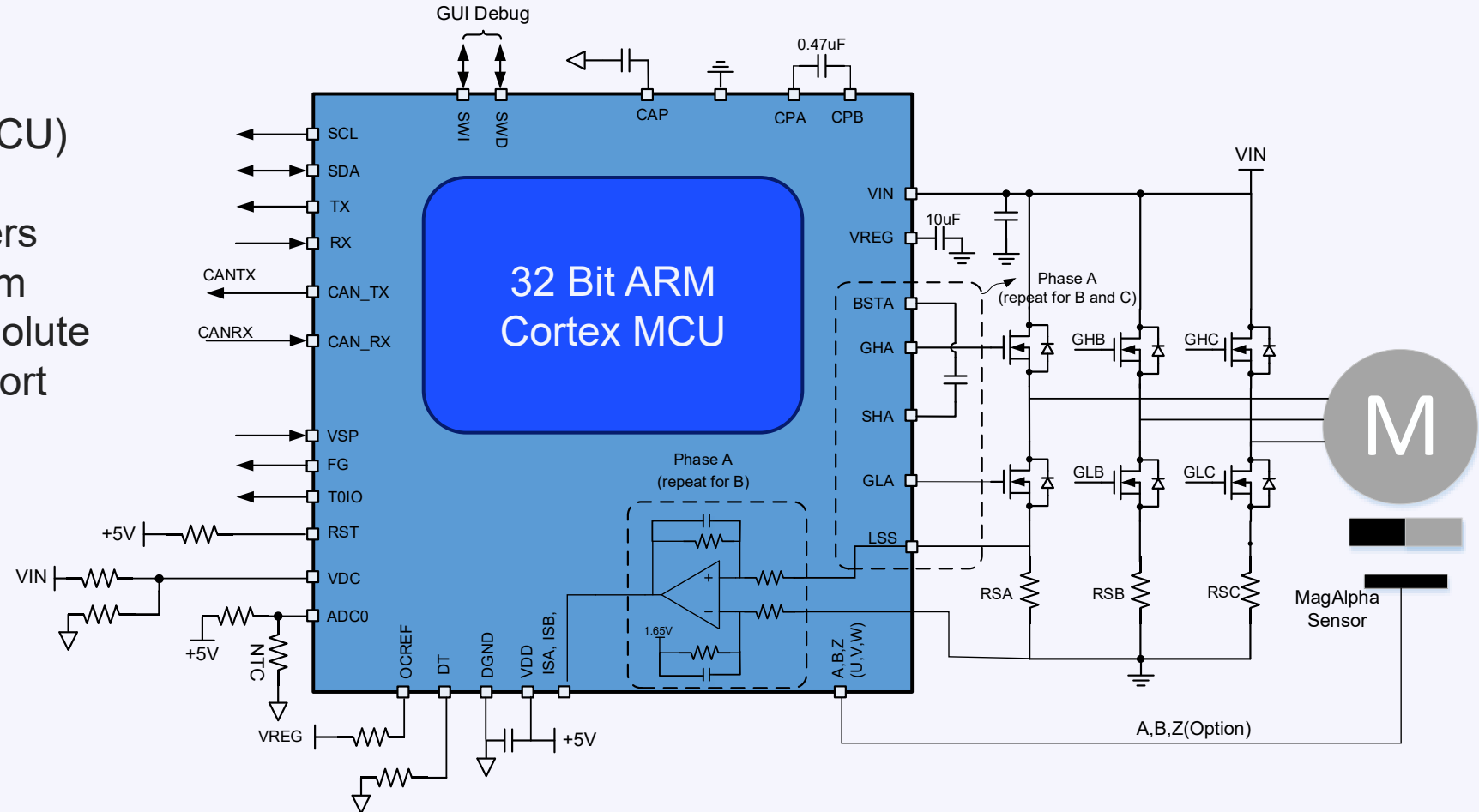
Device	Voltage	Current
MP6540	50V	5A
MP6540H	50V	5A
MP6541	40V	8A
MP6543	22V	2A
MP6545	45V	2.5A
MP6549	18V	10A

Integrated Current-Sensing

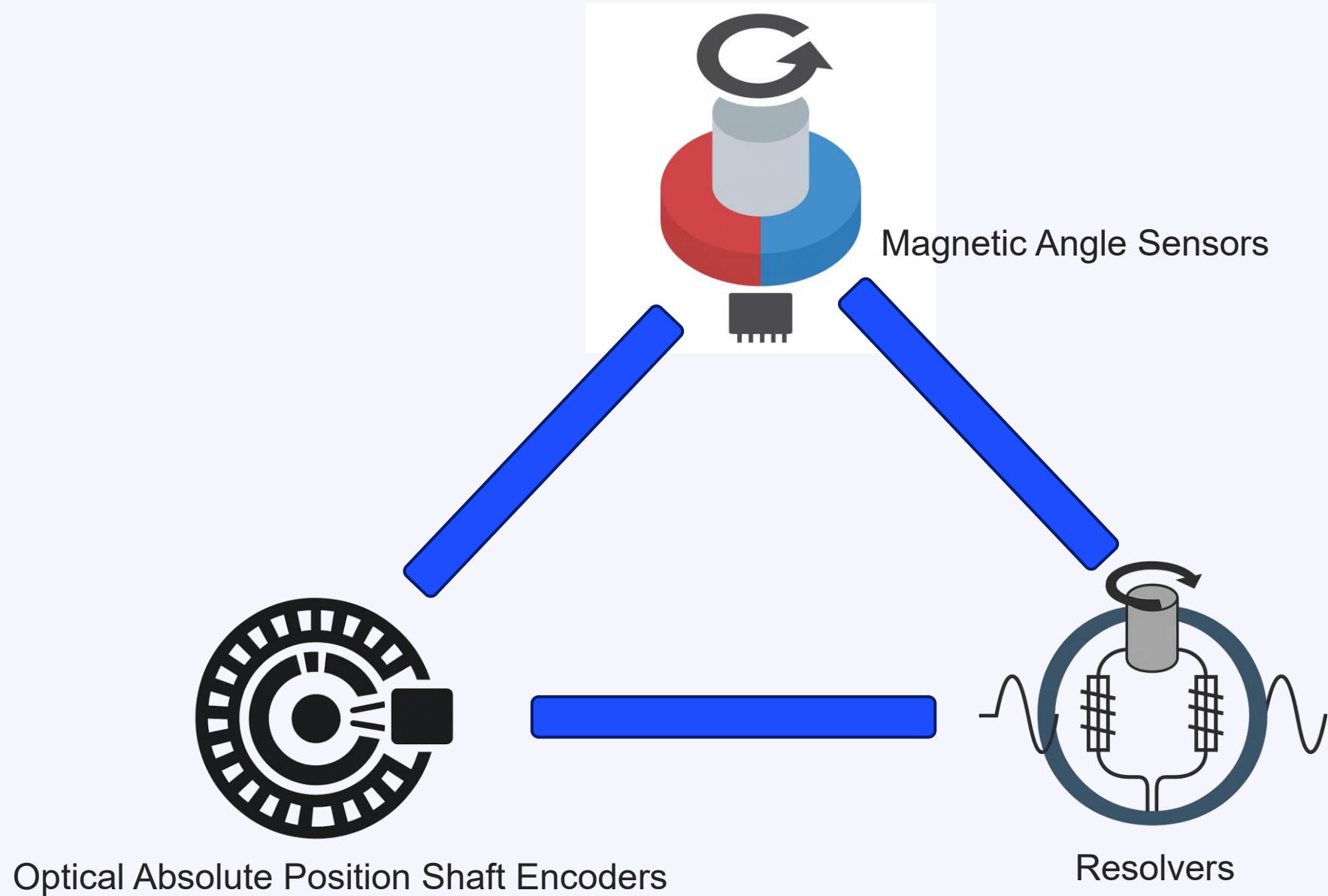
Gate Drivers

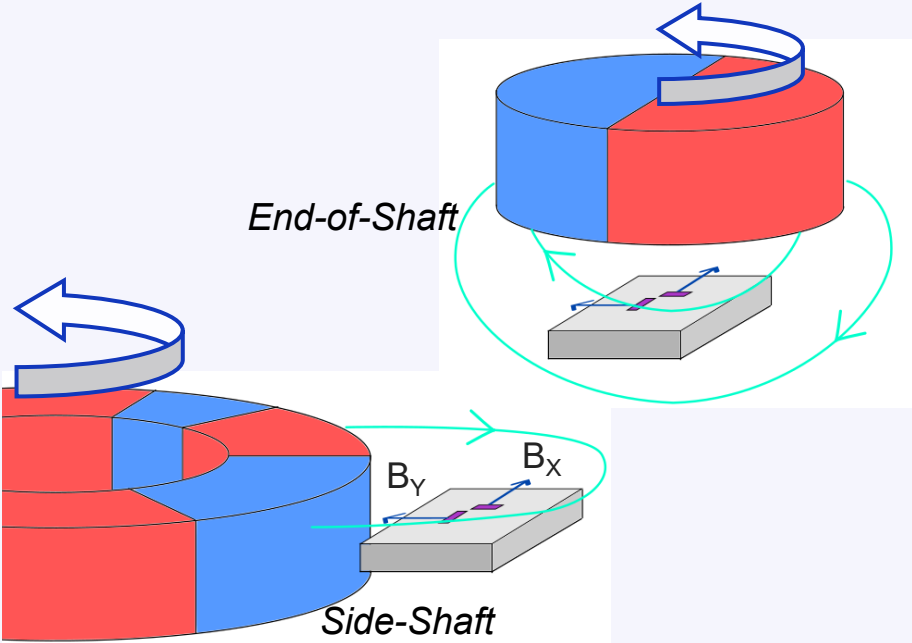
Intelligent Three-Phase Inverters

- 32-Bit Cortex M4F Microcontroller Unit (MCU)
- Integrated Gate Driver
- Current-Sense Amplifiers
- Supports FOC Algorithm
- Hall Sensor Based Absolute Position Encoder Support



Absolute Position Encoders



MagAlpha™	
Part Numbers	MA732, MA735/6, MA702, MA302, MA782, MA600A, MAQ600A, MAQ430, MAQ470/3
Magnetic Configuration	
Qty Measured	B_x, B_y
Sensor Output	$angle = \text{atan} \frac{B_y}{B_x}$

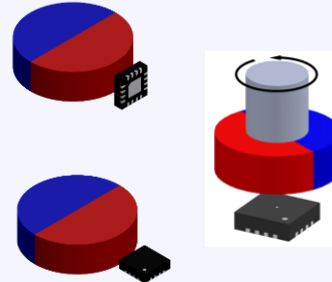


The MA732 and MAQ473-AEC1 (Released)



Overview

The MA732 detects the absolute angular position of a permanent magnet, typically a diametrically magnetized cylinder on a rotating shaft. Fast data acquisition and processing provide accurate angle measurements at speeds from 0rpm to 60,000rpm. The digital filtering can be adjusted to optimize control loop performance when used in servo applications. The MAQ473-AEC1 is the automotive-grade sensor based on the MA732.



Features

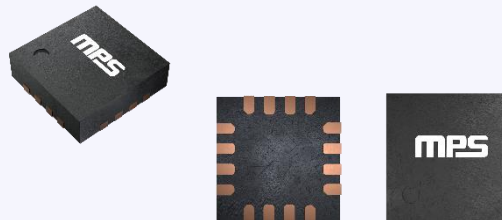
Noise Free Resolution	9-bit to 14.5-bit ($\pm 3\sigma$ deviation of the noise distribution)
Supply Voltage	3V to 3.6V
Interfaces	ABZ, PWM, SPI, and SSI
Field Range	30mT to >100mT
Technology	Hall-Based

Highlights

- 9-Bit to 14-Bit Resolution Absolute Angle Encoder
- ABZ Incremental and PWM Outputs
- Serial Peripheral Interface (SPI) for Digital Angle Readout and Chip Configuration
- Configurable Magnetic Field Strength Detection for Diagnostic Checks

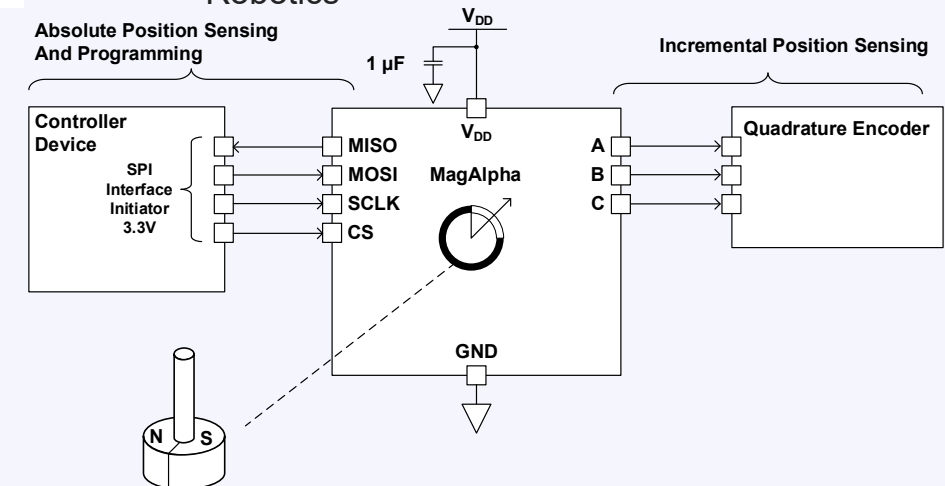
Packaging

- QFN-16 (3mmx3mm)



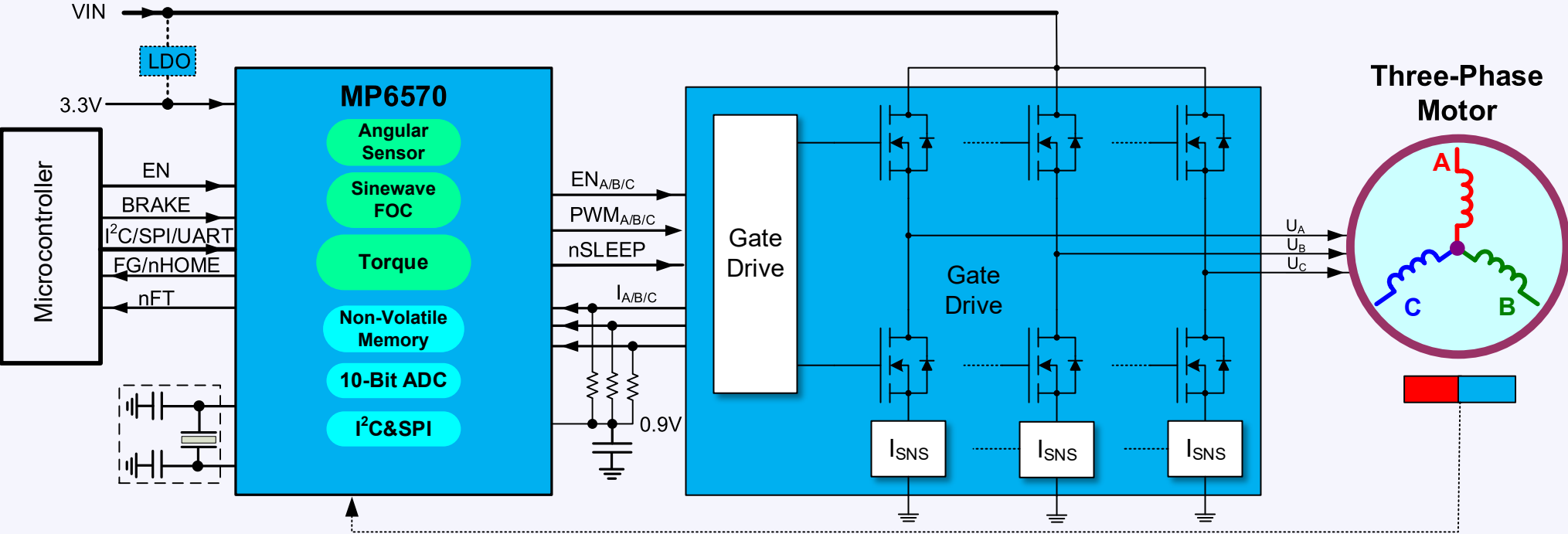
Applications

- General-Purpose/Automotive Angle Measurements
- High-Resolution Angle Encoders
- Automotive Angle or Speed Sensors
- Robotics



Tools and Resources

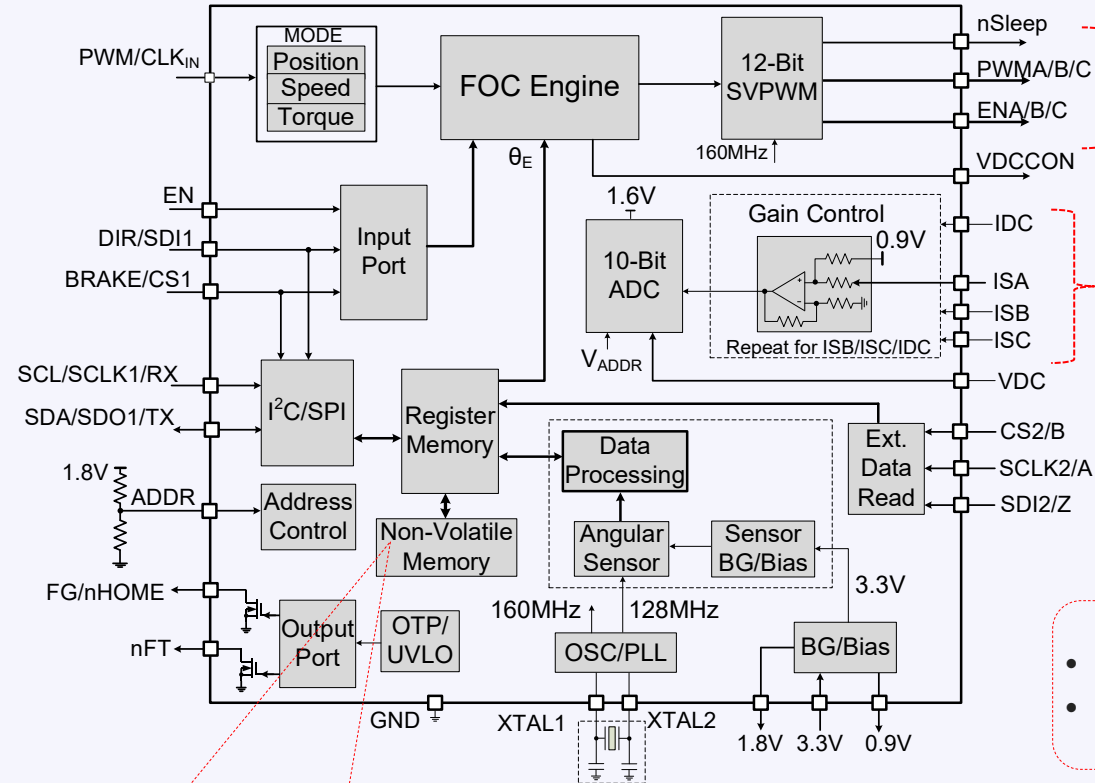
- Evaluation System: [EVKT-MagAlpha-MagDiff](#)
- Test Board:
 - TBMA732-Q-LT-01A
 - TBMAQ473-Q-LT-01A
- [MagAlpha Evaluation App](#)
- [Magnetic Sensor Simulation Tool](#)
- [MPS Technical Forum](#)



MP6570 – FOC Motor Controller

- PWM/BRAKE/DIR Input Or
- I²C/SPI/UART Input

- Field-Oriented Control (FOC)
- Position/Speed/Torque Mode



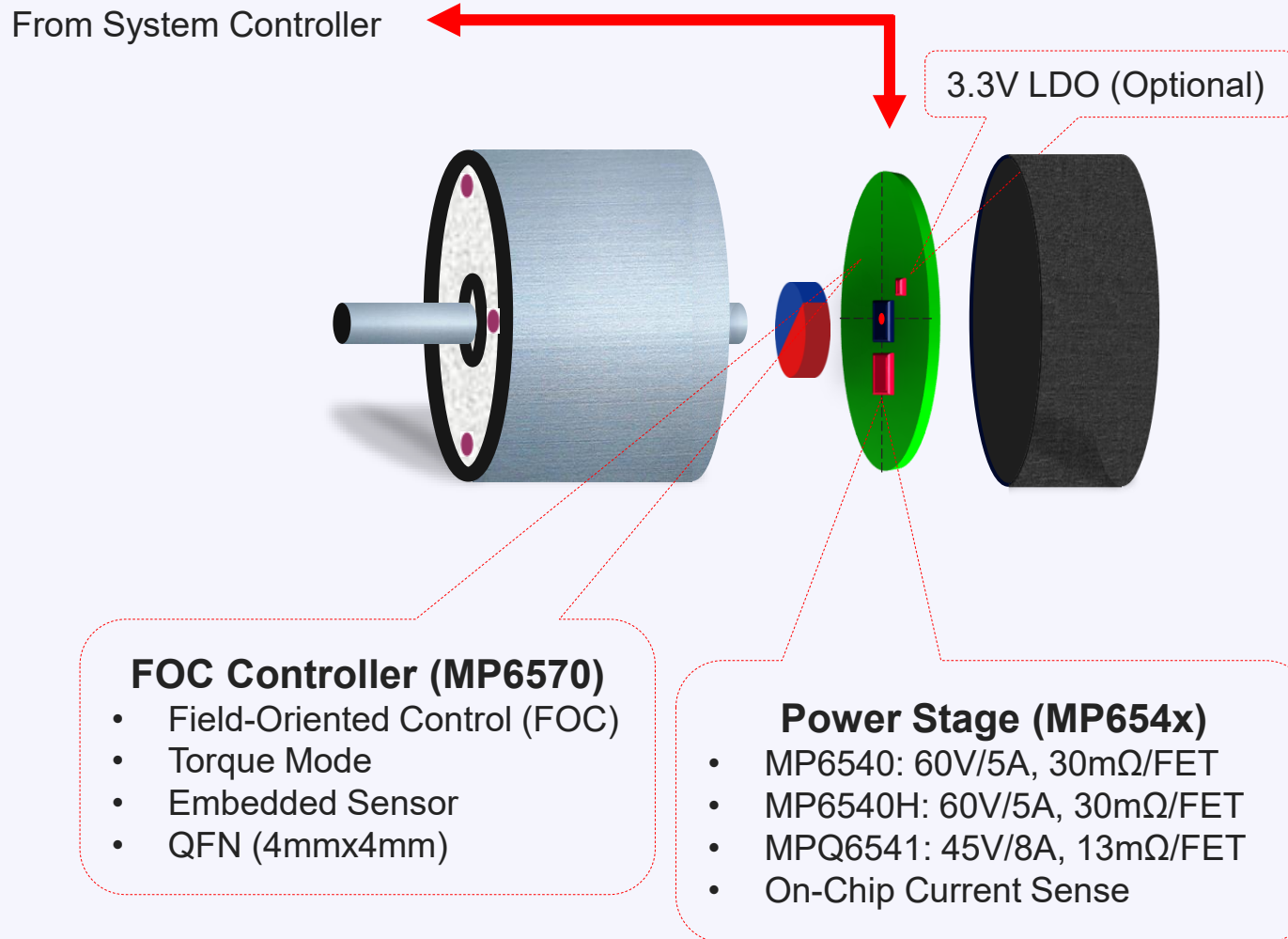
- MP6540 Family Compatible
- Separate MOS Gate Signal Interface

- 1/2/3 Phase Current Sensing
- DC Bus Protection
- 10-Bit ADC, 1% Ref.

- External Sensor Interface
- Internal Sensor A/B/Z Output

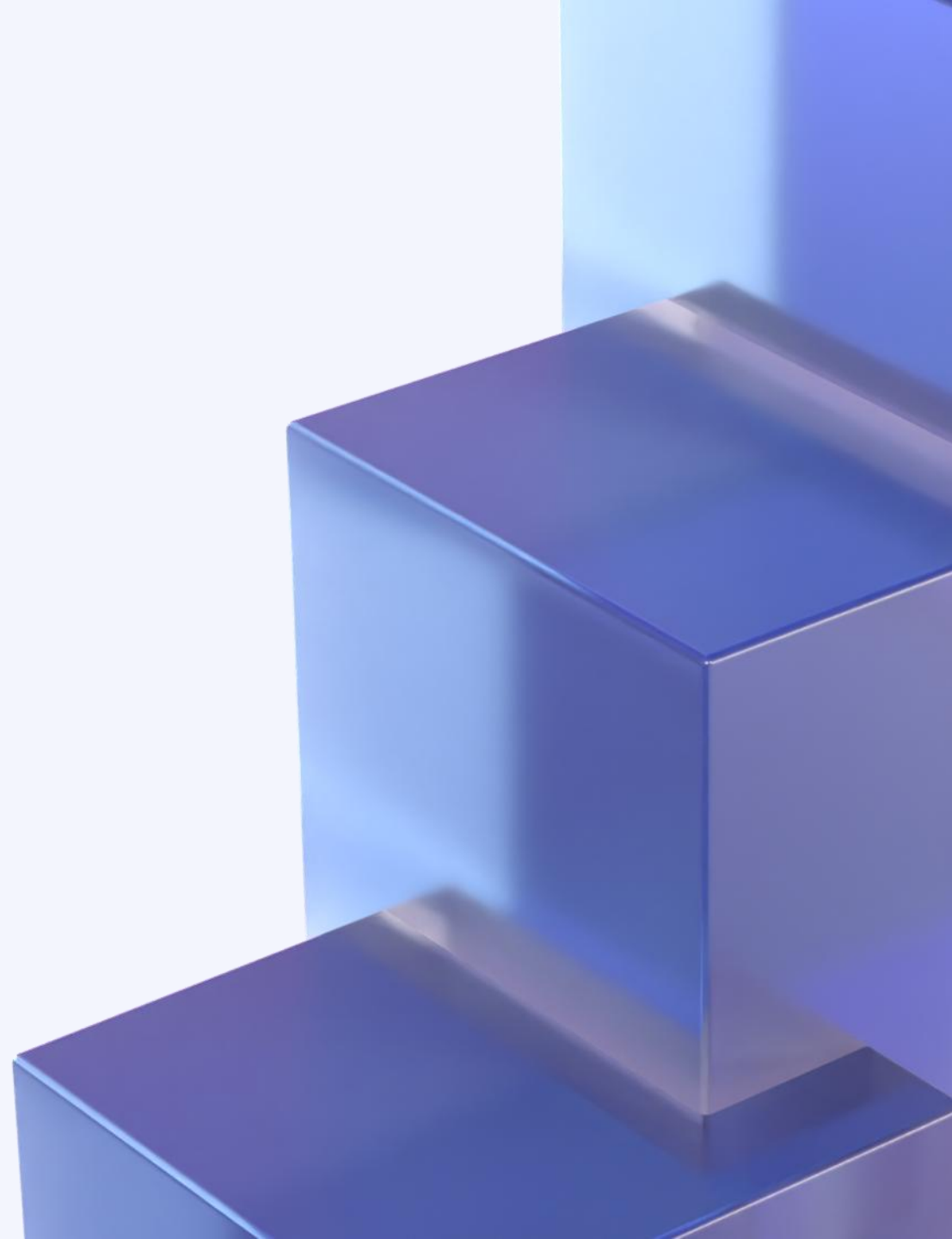
- All Specifications/Parameters Support Non-Volatile Memory (NVM) Configurations

- External Oscillator Input Or
- Internal, On-Chip Oscillator





Dexterous Hand Solution



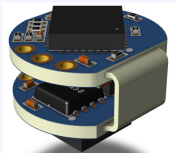
Robot Dexterous Hand Solution



- **Field-Oriented Control (FOC)**
- **Embedded Angle Sensor**
- **Very Small Size: Diameter 9mm, Thickness about 6.5mm**
- 5V to 18V Input Voltage (V_{IN})
- Maximum 2A Phase Current
- Support Maximum 60000rpm Motor Speed
- RS485 Interface with Modbus Protocol
- Configurable Protections:
 - Under-Voltage Lockout (UVLO)
 - Over-Current Protection (OCP)
- Up to 80kHz Configurable Switching Frequency (f_{SW})
- Angular Sensor Resolution up to 14 Bits
- Rigid-Flex-Rigid PCB Structure

MP6570,
MP6543H,
MP6710,
MP2015A

D = 9mm

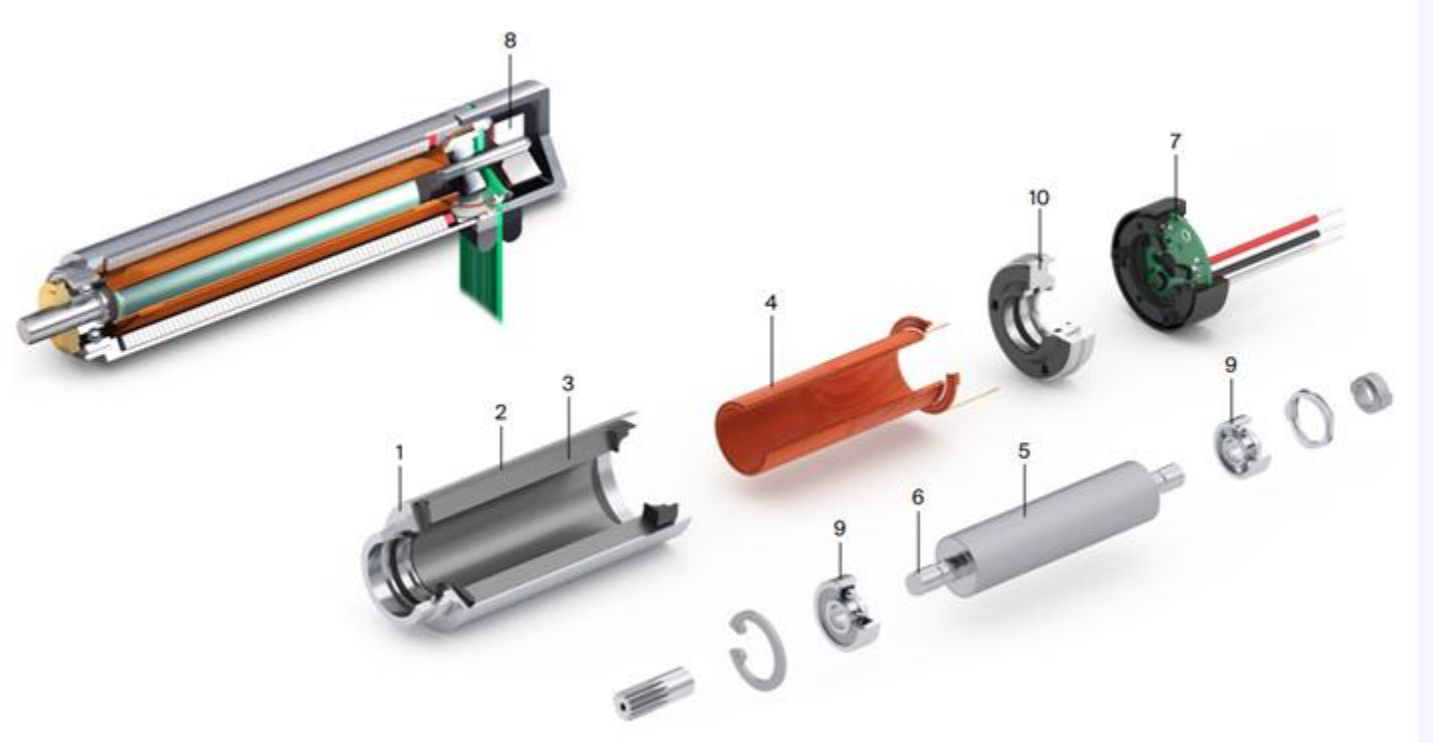
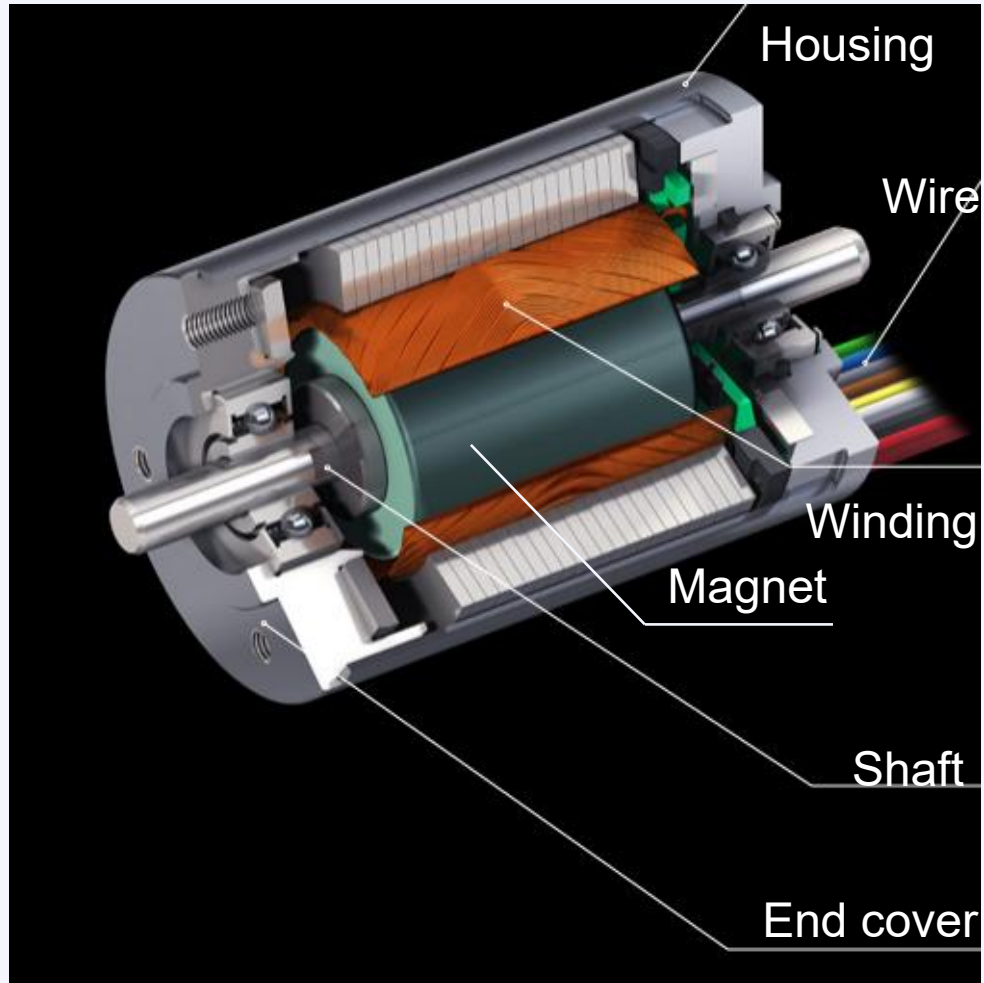


Connector Definitions

CN #	Pin Name	Function
1	RS485_B	RS485 B port
2	RS485_A	RS485 A port
3	UVW	Connect to motor's UVW winding
4	GND	DC power input ground
5	VIN	DC power supply input, 5V to 18V

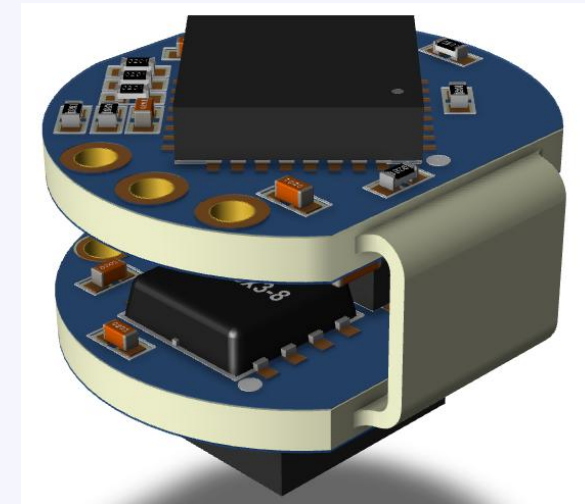


Coreless Motor Structure

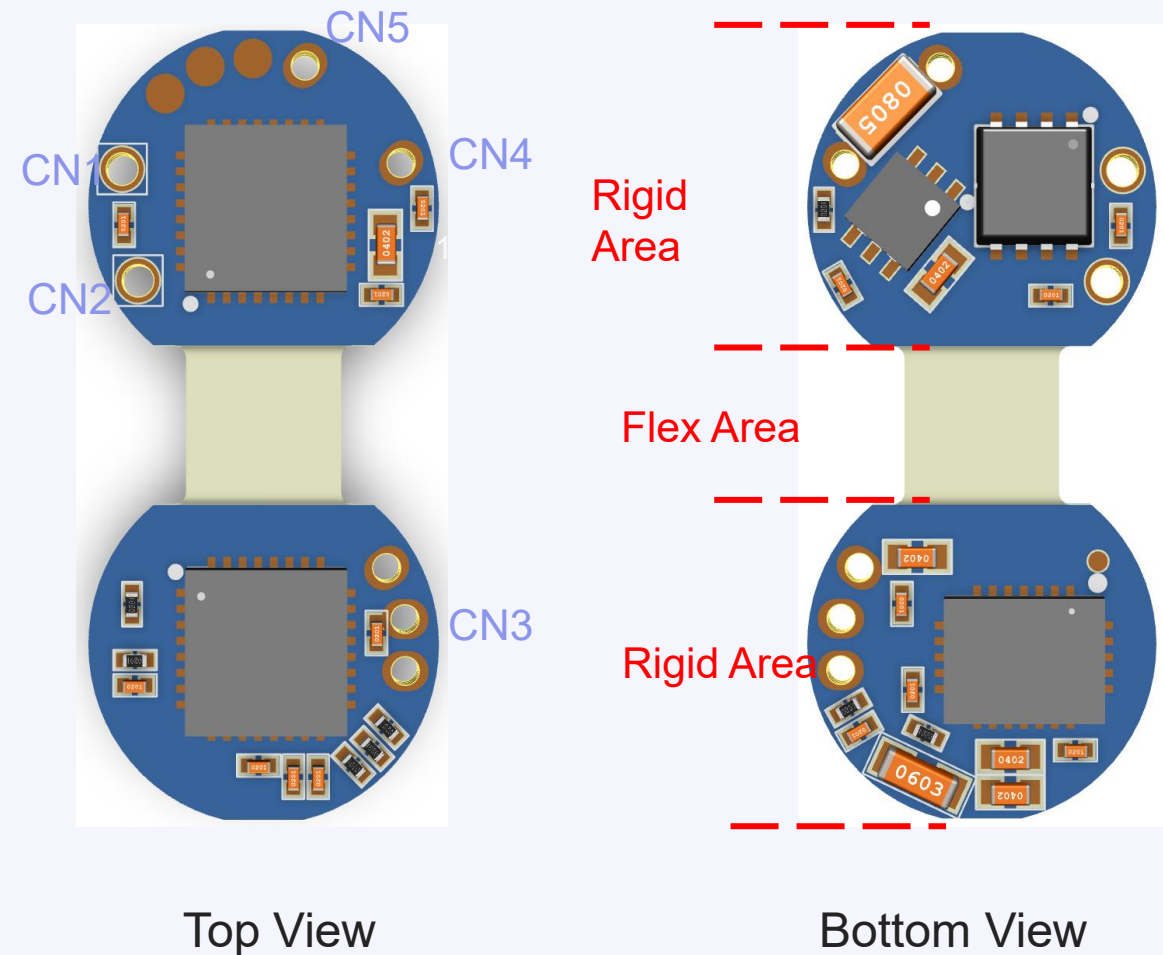


9mm Coreless Intelligent Motor

- **Field-Oriented Control (FOC)**
- **Embedded Angle Sensor**
- **Very Small Size: Diameter 9mm, Thickness about 6.5mm**
- 5V to 18V Input Voltage (V_{IN})
- Maximum 2A Phase Current
- Support Maximum 60000rpm Motor Speed
- RS485/CAN Communication Interface
- Configurable Protections:
 - Under-Voltage Lockout (UVLO)
 - Over-Current Protection (OCP)
- Up to 80kHz Configurable Switching Frequency (f_{sw})
- Angular Sensor Resolution up to 14 Bits
- Rigid-Flex-Rigid PCB Structure



9mm Coreless Intelligent Motor (RS485/CAN)



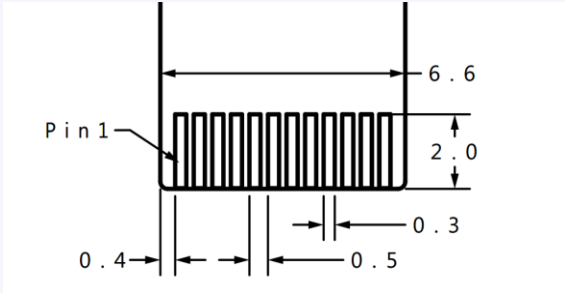
Connector Definitions		
CN #	Pin Name	Function
1	RS485_B	RS485 B port
2	RS485_A	RS485 A port
3	Output	Connect to motor's UVW winding
4	GND	DC power input ground
5	VIN	DC power supply input, 5V to 18V

Connector Definitions		
CN #	Pin Name	Function
1	CAN_H	CAN_H port
2	CAN_L	CAN_L port
3	Output	Connect to motor's UVW winding
4	VIN	DC power supply input, 5V to 18V
5	GND	DC power input ground
6	5V	5V power supply

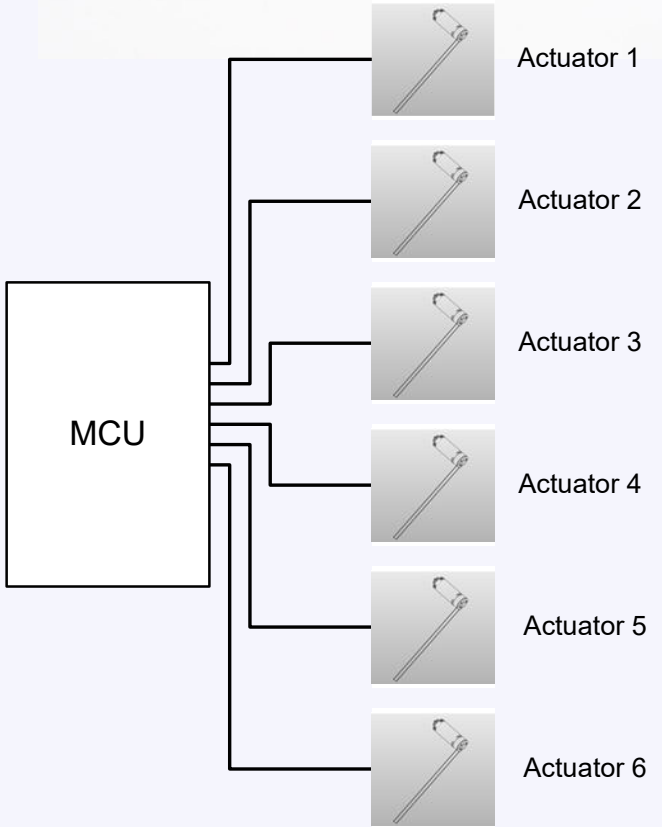
Coreless Motor with SPI



- **High-Integration Actuator**
- **Very Small Size (8mm/10mm/12mm/13mm Diameter)**
- **Motor Specifications:**
 - **10mm:** 1.7mNm Rated torque, 35000rpm Max Speed, 25000rpm Rated Speed at 12V
 - **13mm:** 6.1mNm, 18000rpm Max Speed, 14000rpm Rated Speed at 12V
- 4V to 18V Wide Input Voltage (V_{IN}) Range, 12V Nominal Input
- **Torque Control** with Field-Oriented Control (FOC) Technology
- Embedded 14-Bit Angle Sensor for **Accurate Position Control**
- **Function Extendable** with MCU C Code Library
- Rigid-Flex PCB Structure for Power and Serial Peripheral Interface (SPI)
- SPI with over 8MHz Clock Frequency



Connector Definitions	
Pin #	Pin Name
1, 2, 3	VIN
4	EN
5	CS
6	MOSI
7	SCLK
8	MISO
9	3V3
10, 11, 12	GND



01



Real Time Feedback

Read Position, Current, and Voltage Feedback via SPI

02



Close Loop Control

Position and Closed-Loop Speed Control

03



Minimize MCU Resource

FOC Current Loop Control is Done by Hardware

04



Flexible Control

Can Achieve Flexible Control Logic in MCU Code Using APIs

05



Improve Efficiency

Up to 80KHz Switching Frequency, Reduce the Motor Power Loss which Means Less Power Consumption, Less Heat, and More Efficiency

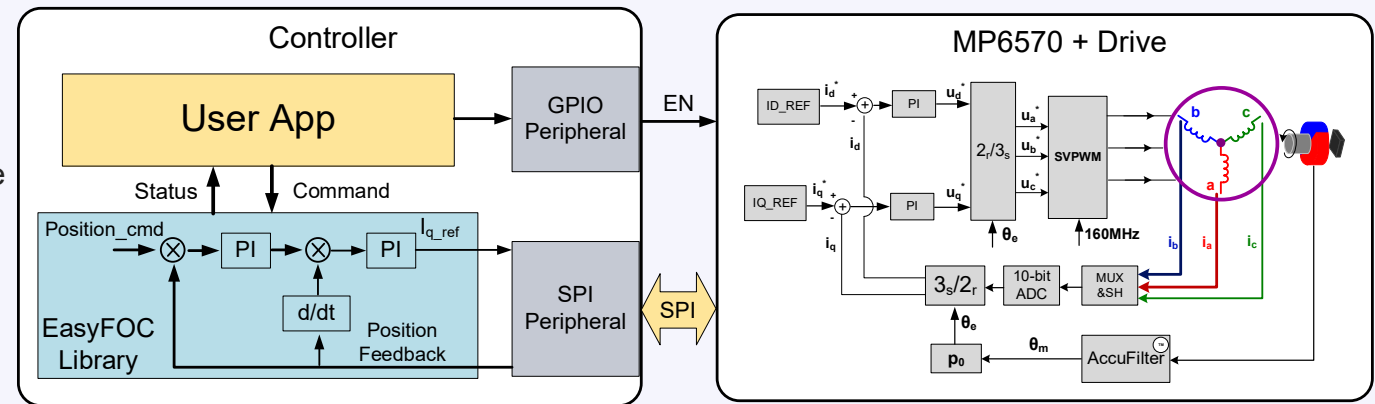
06



Protection

EasyFOC Library Provide Variables for System Diagnostics

System Block Diagram

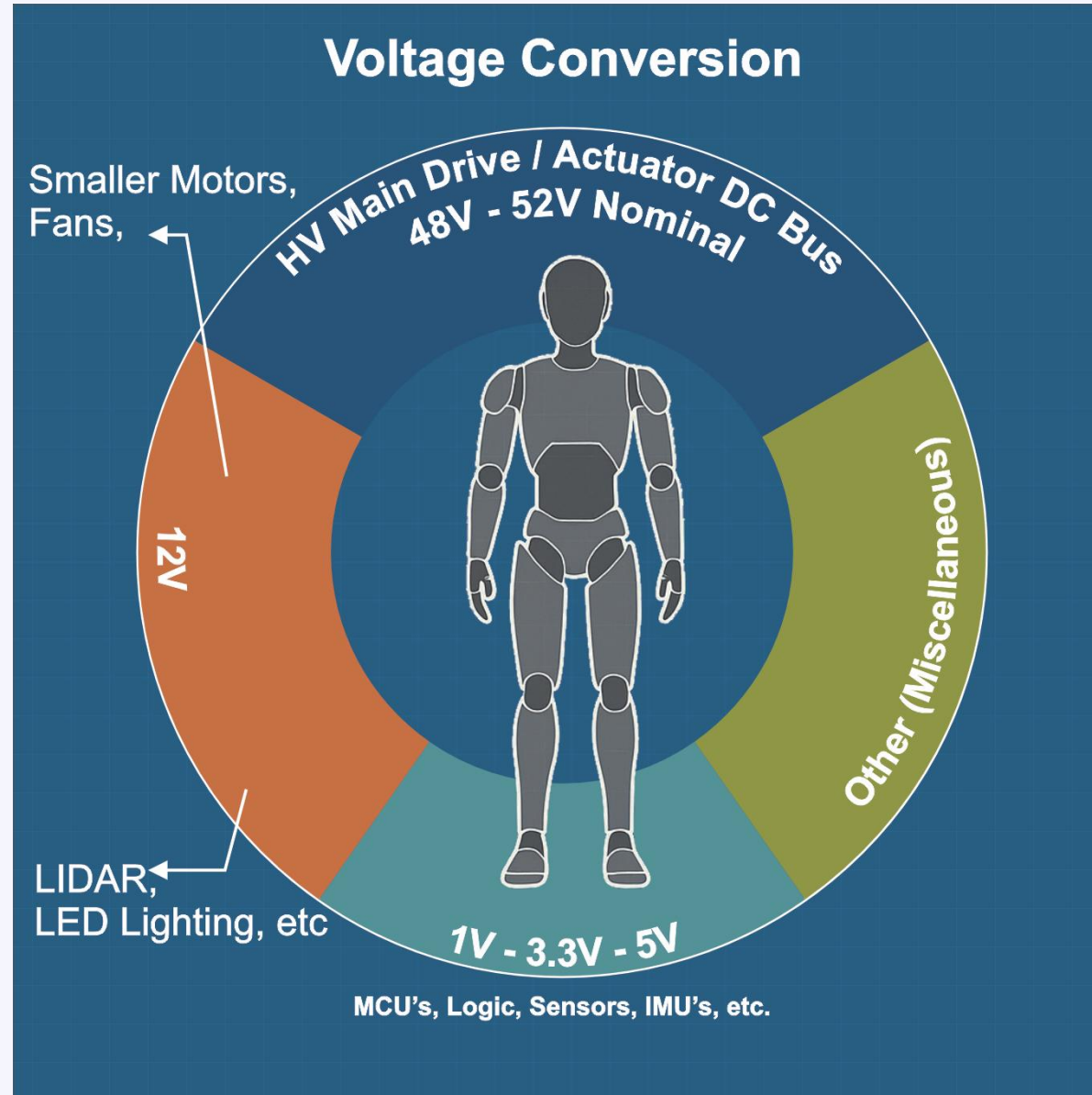


DC/DC Power Conversion

- Step-Up (Boost)
- Step-Down (Buck)
- Buck-Boost
- PMICs

AI & Computing Power

- CPU & GPU Core Power
- High-Current DrMOS
 - 90A DrMOS 4mmx6mm Package
- 60A POL Module 6mmx6mm Package
- 60V Intermediate Bus Converter Modules
- Z-Axis Power Delivery Multiphase Modules



Power Modules

- 6V, 600mA to 100A
- 16V, 600mA to 1000A+
- 36V, 600mA to 24A
- 55V, 1A to 3A
- 80V, 600mA

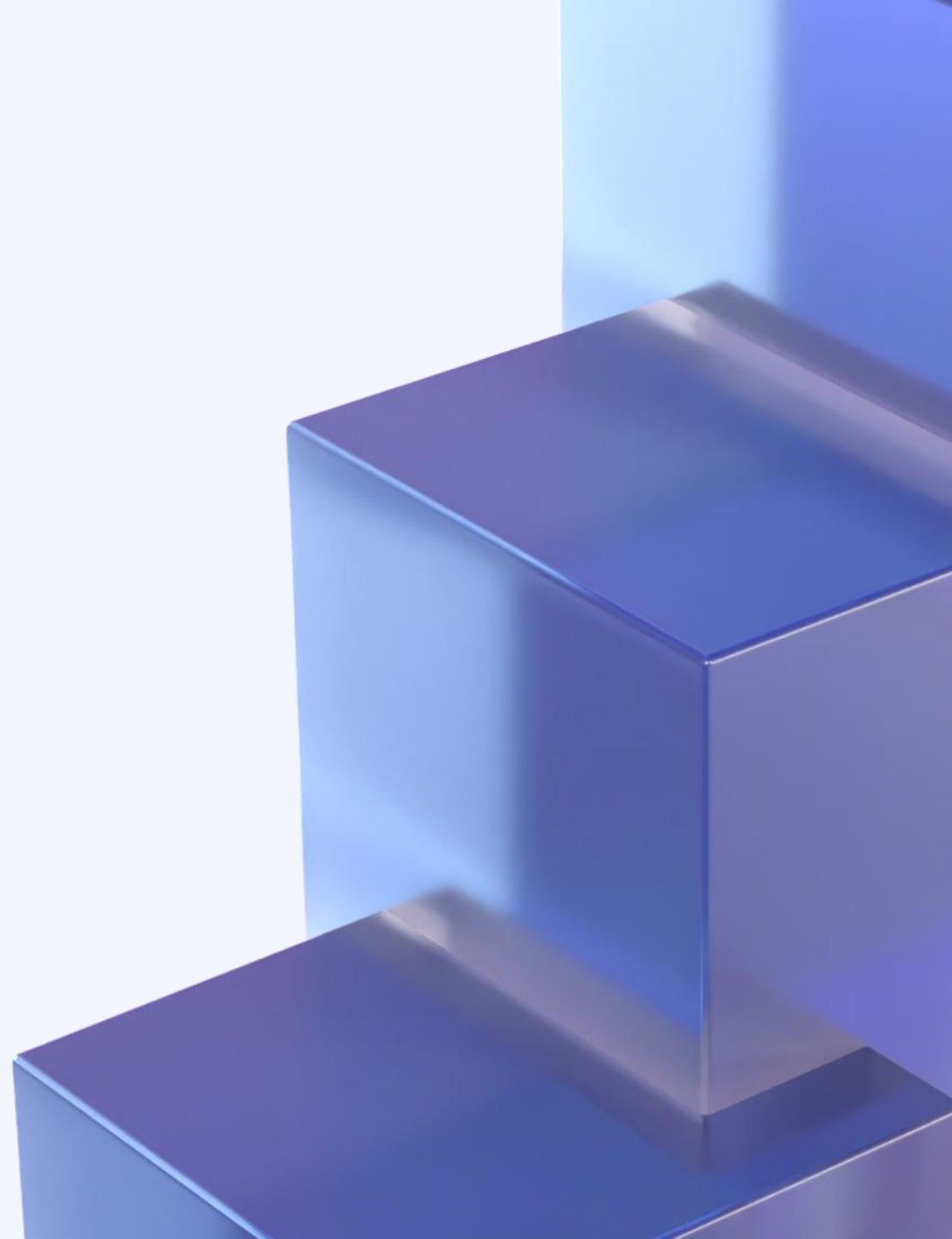
Battery Management

- Battery Monitors & Protectors
- Fuel Gauges
- Active Balancers
- Switching Chargers: Buck, Boost, Buck-Boost
- Linear Chargers

- MPS Motor Drive solutions provide comprehensive motor control solutions for humanoid robotics, supporting all three-phase BLDC and PMSM motors under advanced Field-Oriented Control (FOC) algorithms.
- Our portfolio delivers robust current measurement and protection, with multiple current-sensing topologies that ensure precision, reliability, and safety in every joint.
- Designers gain high-resolution closed-loop feedback through magnetic Hall-based absolute position encoders, delivering the accuracy and responsiveness humanoid robots demand
- You can count on flexible power stage options — from discrete three-phase inverter designs to fully integrated intelligent drivers and turnkey motor modules — empowering faster time-to-market.



Questions?





Thanks!

