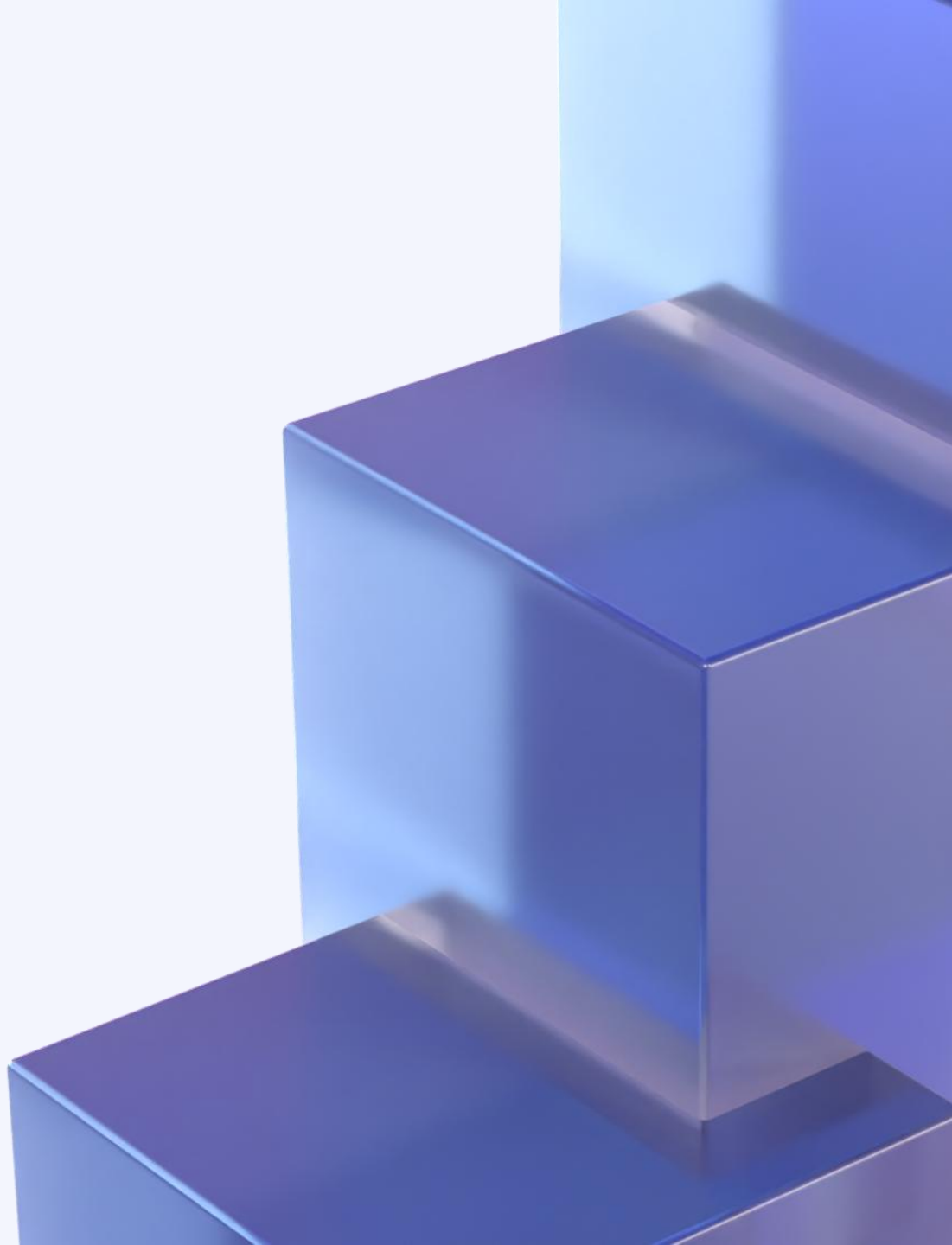
MPS Powers Humanoid Robots

Because Without Motion, a Robot Is Just A Sculpture

September 2025



Agenda & Topics

Introduction to Humanoid Robotics

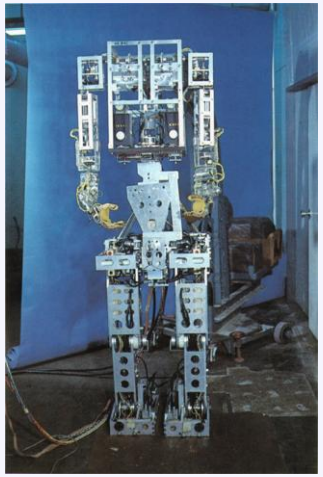
Humanoid Robotics Blocks

Humanoid Robotic Motor Power Stages

Humanoid Robotic Motion Sensors

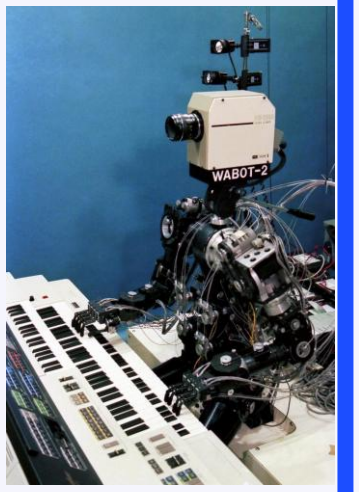
Humanoid Robotics Across The Decades

1970's



WABOT - 1

1980's



WABOT - 2

1990's

HONDA
E & P
Series

2000's

Honda
Asimo

Kawada
HRP-2

2010's

Boston
Dynamics
Atlas

DRC Hubo

Toyota
T-HR3

Humanoid Robots (2020's)

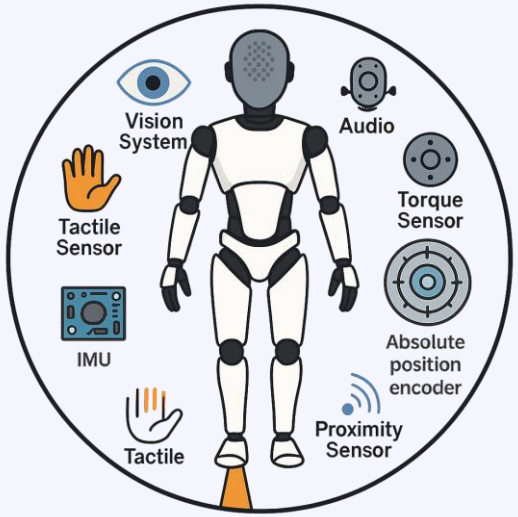
	Tesla	Figure AI	Agility Robotics	Apptronik	Sanctuary AI
Robot Name	Optimus	Figure 02	Digit	Apollo	Phoenix
Height (cm)	~173	~168	~175	~172	~170
Weight (Kg)	~56-73	~60	~65	~72	~70-75
Payload (carry capacity)	~20 Kg	~20 Kg	~16-18 Kg	~25 Kg	~25 Kg
Top Speed (Km/hr)	8	2.7	3.3	3.4	2.7
Degrees Of Freedom	~50-55	~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



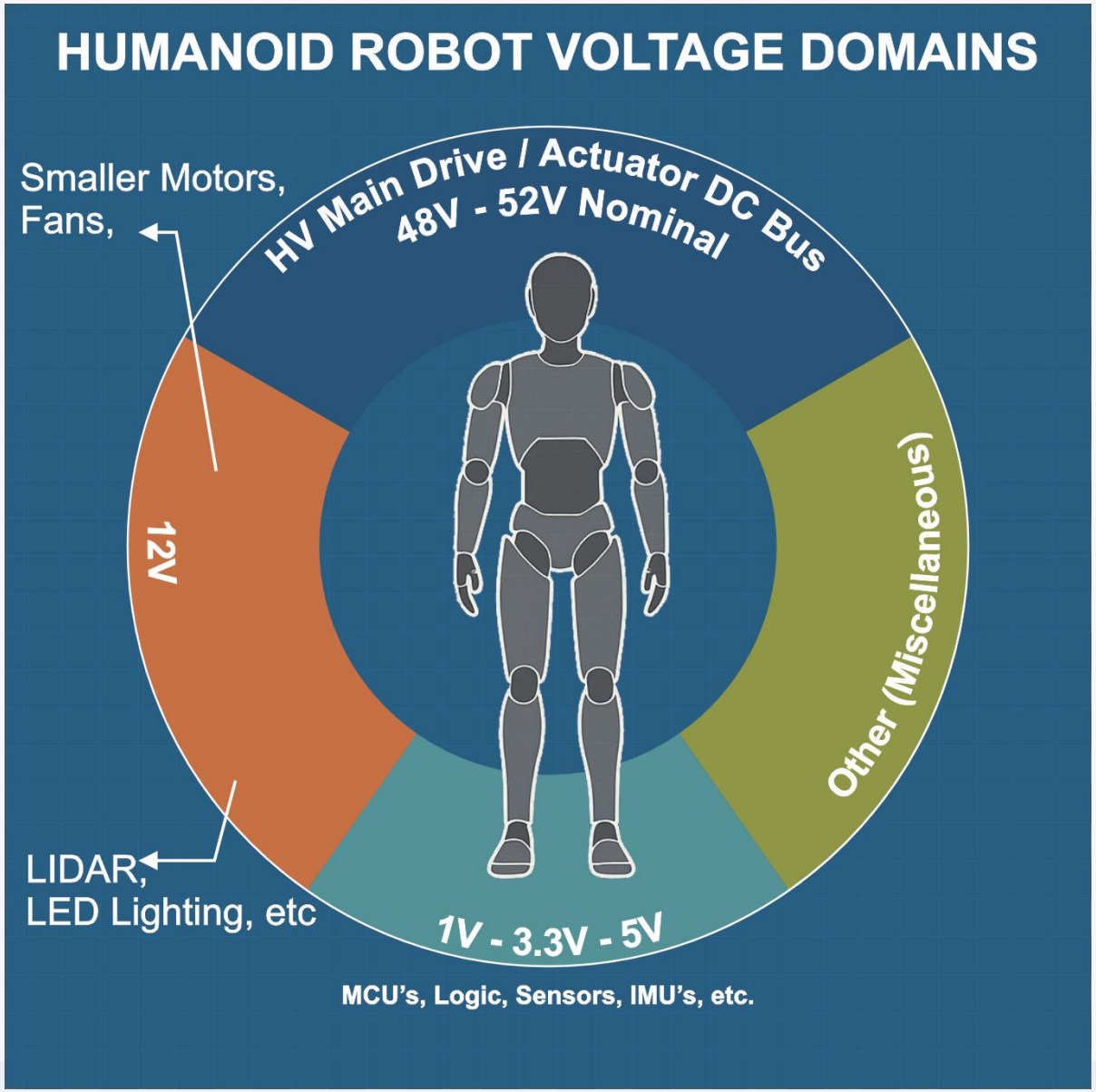
Sensor integration and feedback quality

Humanoid Robots

	Tesla	Figure AI	Agility Robotics	Apptronik	Sanctuary AI
Robot Name	Optimus	Figure 02	Digit	Apollo	Phoenix
Battery Voltage	48V	48V	48V	48V	48V
Battery Type	2.3 KHw Li-Ion	2-2.5 KHw Li-Ion	2-3 KHw Li-Ion	Li-Ion (swapable)	Li-Ion
Run Time (hrs)	~8	~5	~4-6	~4	~4-5
Power Budget	2 KW Peak	2 KW Peak	2 KW Peak	2 KW Peak	2.5 KW Peak
Cooling	Air Cooled (fans)	Air Cooled (fans)	Air Cooled (fans)	Air Cooled (fans)	Air Cooled (fans)
# Motors	~50	~40	~20-24	~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 used to reach lower voltage rails.
- Most motors will operate at nominal 48V.
- Hand motors may operate at 12V.
- Cooling fans will operate at 12V.



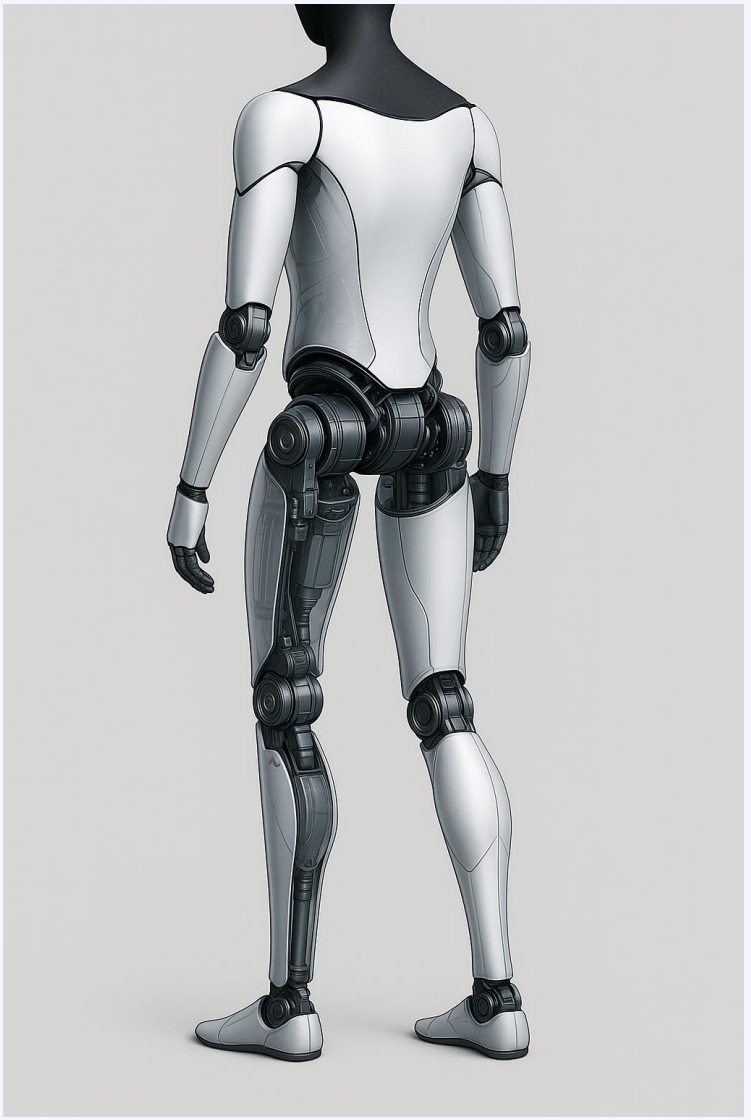
Power Distribution

Joint	Motor Topology	Average Power (W)	Peak Power (W)
Shoulder (3 DOF)	PMSM + Harmonic Drive	300	700
Elbow (1 DOF)	PMSM + Harmonic Drive	200	400
Wrist (2 DOF)	PMSM + Compact Gearbox	100	200
Hand (10+ DOF per hand)	Mini PMSM or DC Coreless Motors	30	80
Hip (3 DOF)	PMSM + Harmonic Drive	400	1000
Knee (1 DOF)	PMSM + Harmonic Drive	250	600
Ankle (2 DOF)	PMSM + Compact Harmonic/Cycloidal	150	300
Neck (2–3 DOF)	Miniature PMSM	50	120
Torso Twist/Bend (2 DOF)	PMSM + Cycloidal or Direct Drive	75	200

PMSM: Permanent Magnet Synchronous Machine
DOF: Degrees Of Freedom

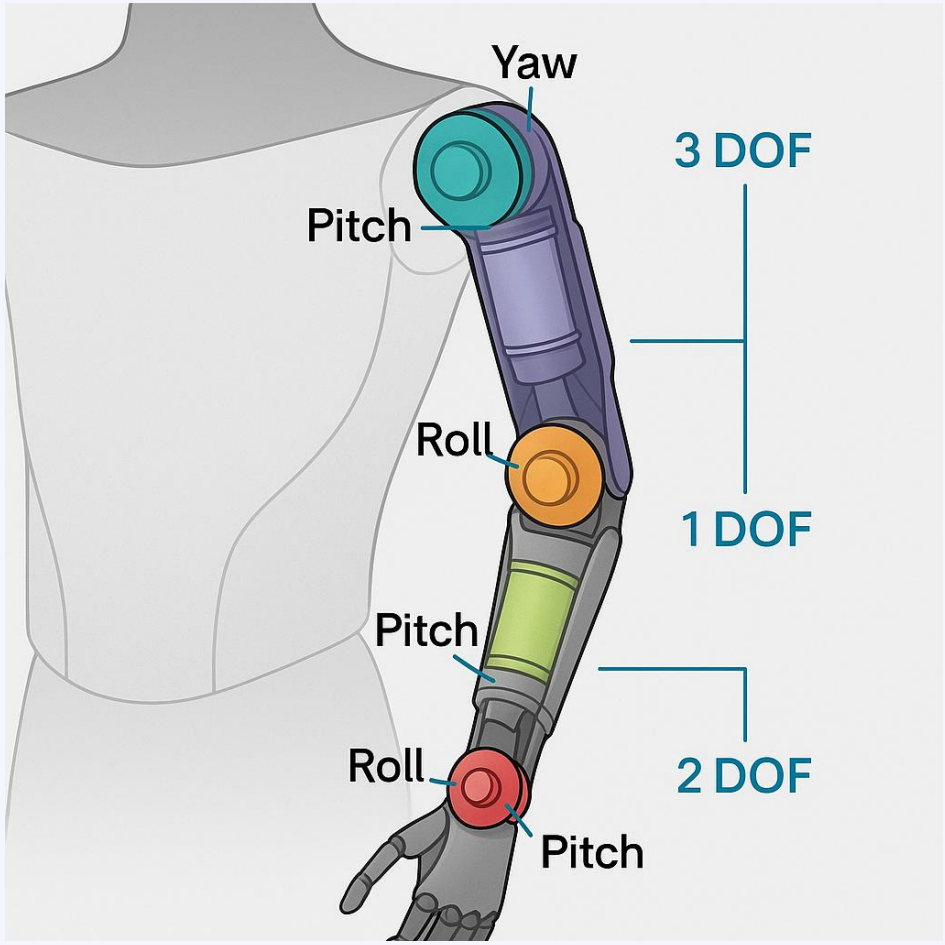
Leg Subsystem

- 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: 40-60A
  - Continuous current: 10-30A
  - Average Power: 400-800W
- Special Conditions:
  - 3-4 KW per leg during burst (i.e. jumping)



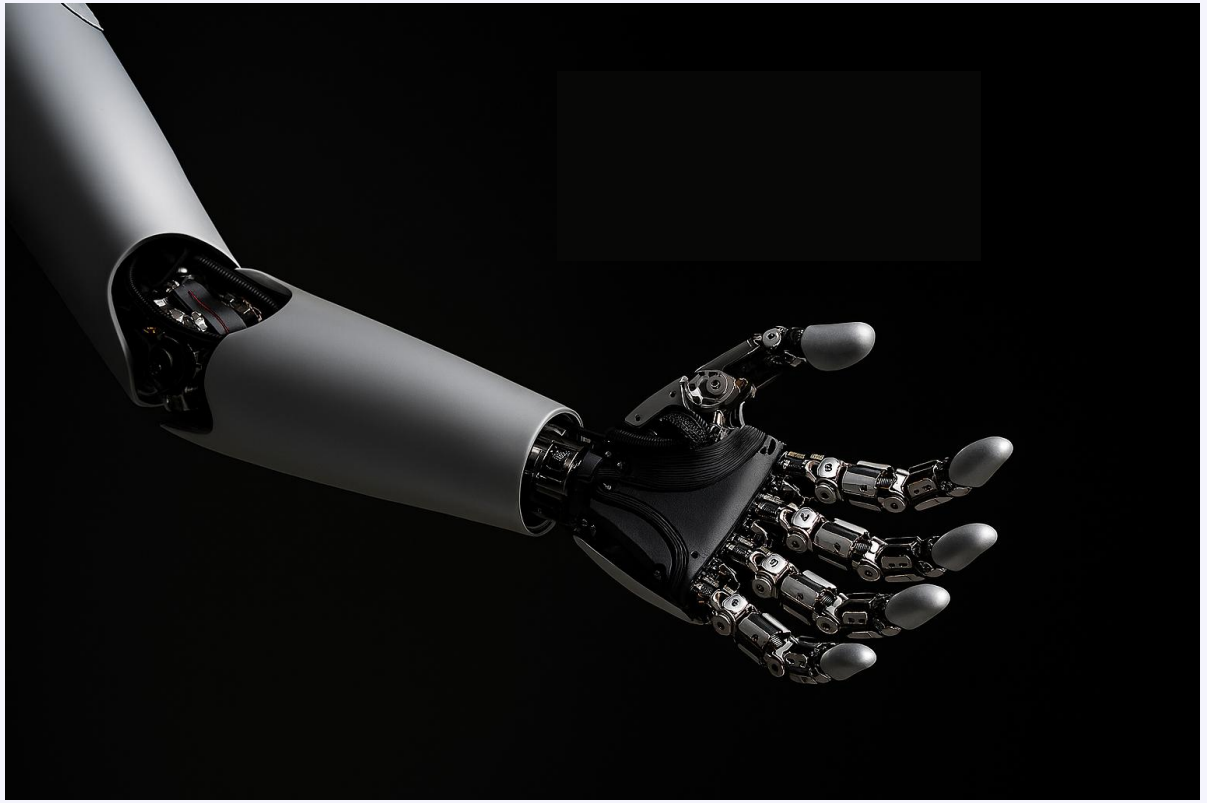
Arm Subsystem

- 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: 20-40A during bursts
  - Continuous current: 5-15A
  - Average Power: 500-750W



Hand Subsystem

- Degrees Of Freedom (DOF)
  - Fingers (flexion/extension): 3 DOF
  - Finger (abduction): 1 DOF
  - Thumb: 4-5 DOF
  - Wrist: 2 DOF
- Typical Motor Topology
  - Coreless BLDC with magnetic absolute position encoder
- Power Requirement:
  - 12V to 48V input voltage
  - Peak Current: 5-8A during bursts
  - Continuous current: 1-5A
  - Average Power: 50-100W

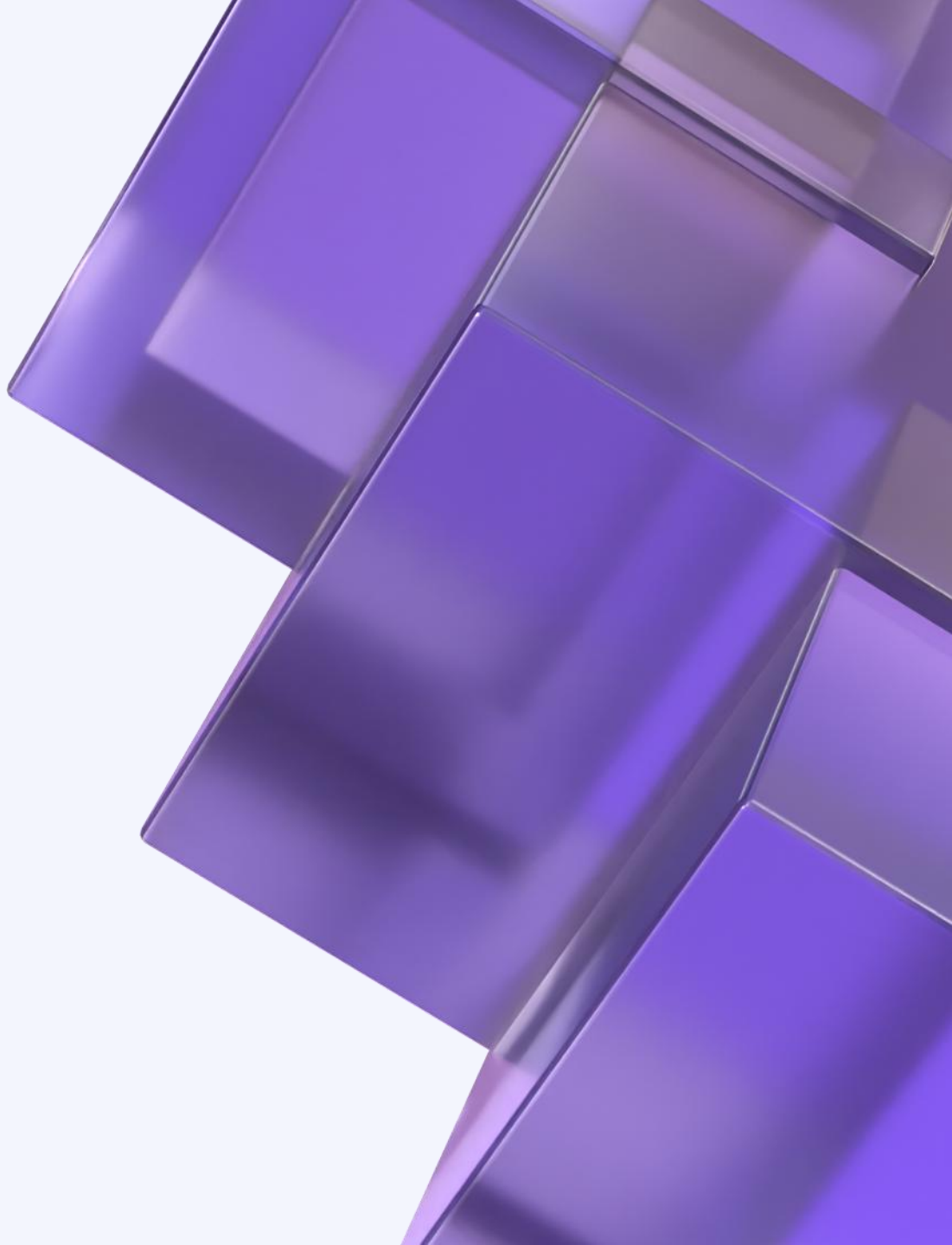


Motor Topology Distribution

Joint / DOF	AC Induction Motor	Brushed DC Motor	Bipolar Stepper	Brushless DC (BLDC)	Coreless Brushless DC	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 (2-3 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

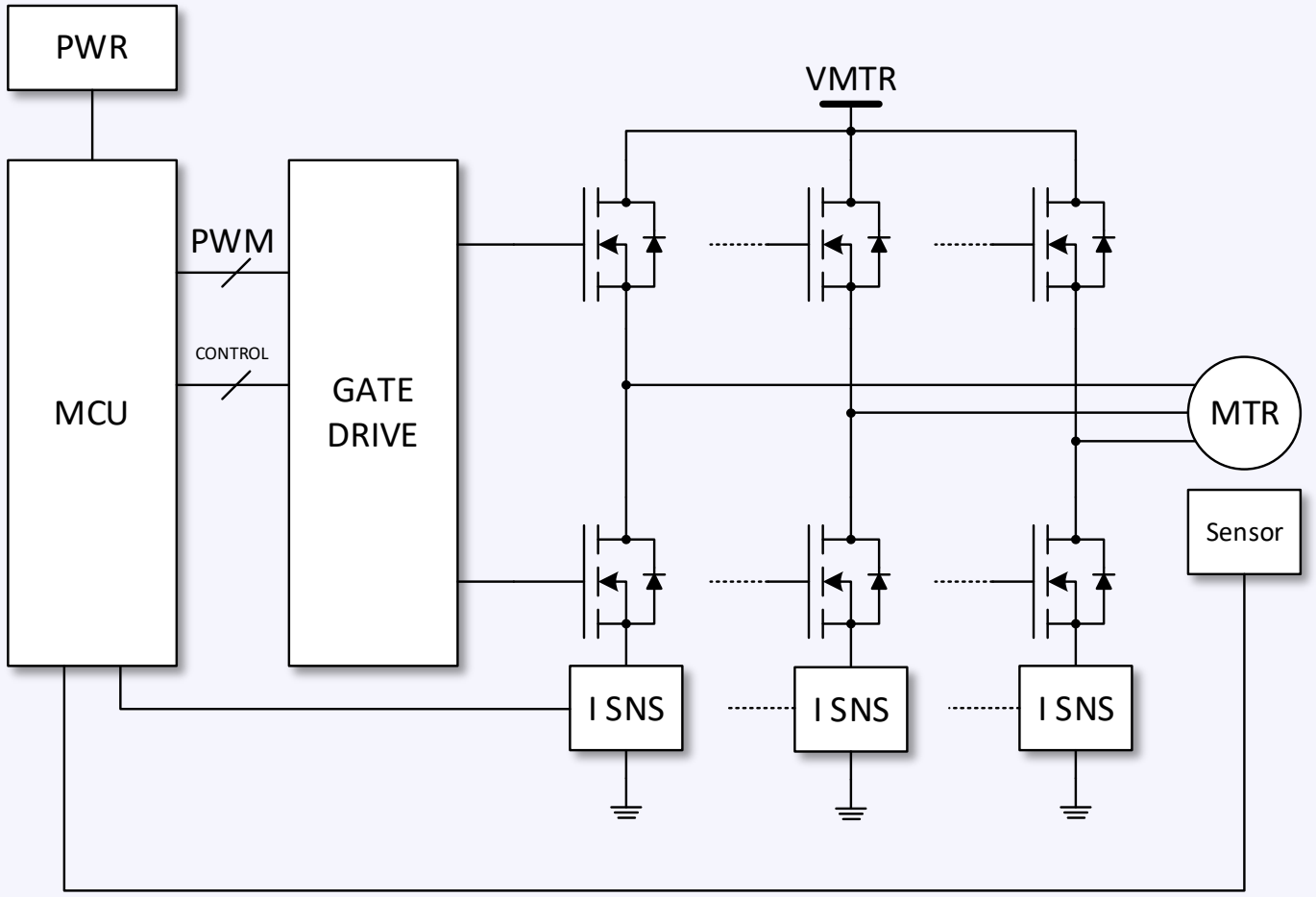
FOC Driven

Power Stages

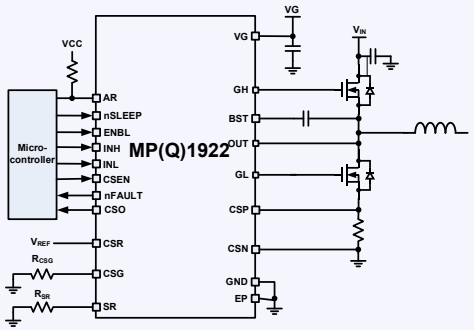


Typical Tri Phase Inverter

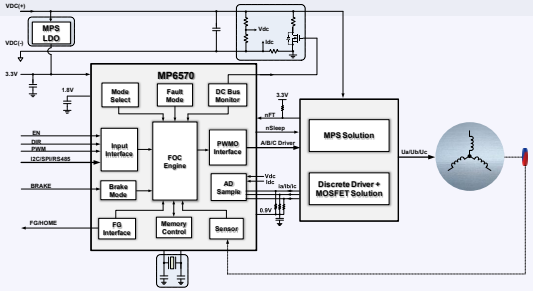
- Power Stage: 6 N Channel MOSFET
- High Current Gate Drivers
- Current Sensing
- Micro Controller / DSP (FOC)
- Power Management
- Absolute Position Encoder
- Protection Blocks



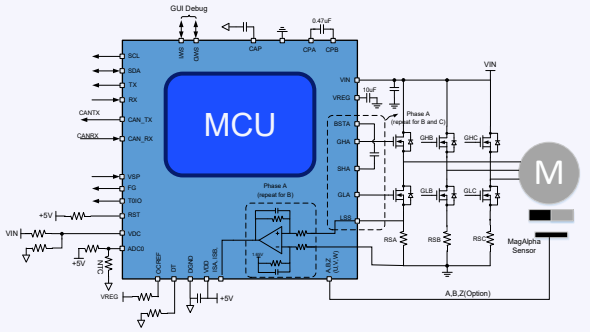
Three Phase Inverter Power Stage Topologies



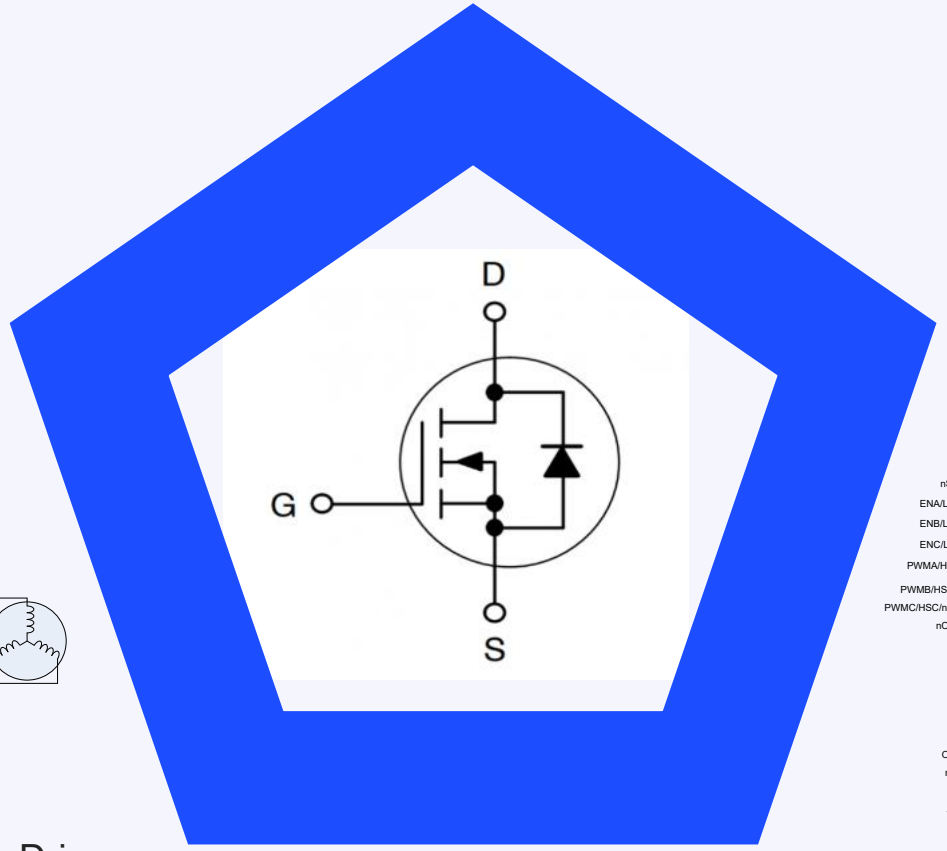
Half H Bridge Gate Drivers

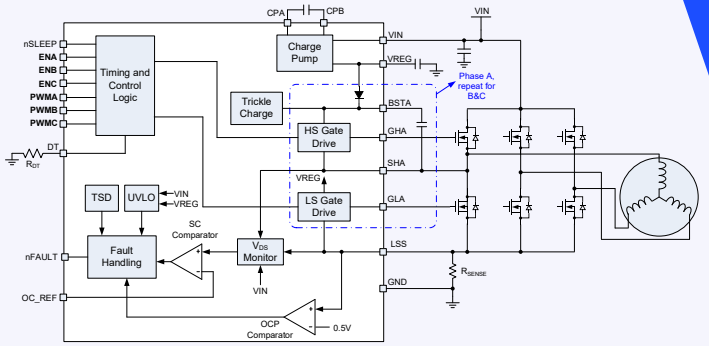


FOC Controller

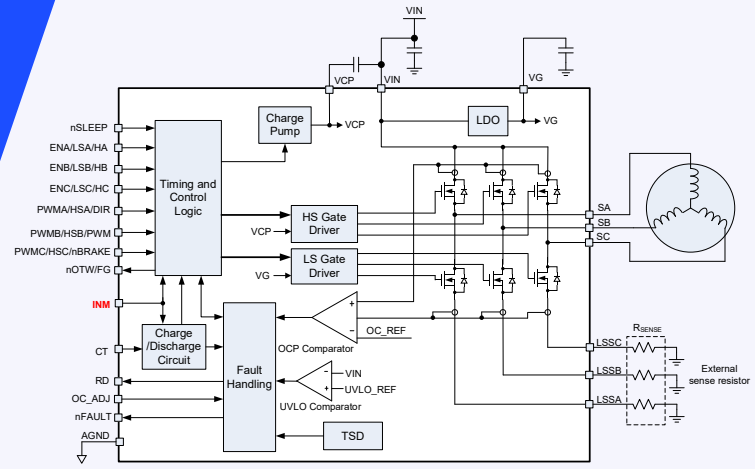


Intelligent Three Phase Inverter





Integrated Three Phase Inverter Gate Drivers



Fully Integrated Three Phase Inverter

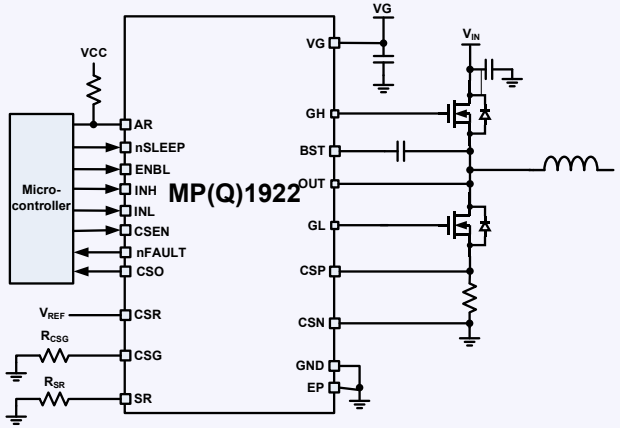
Three Phase Inverter With Half Bridge Gate Drivers

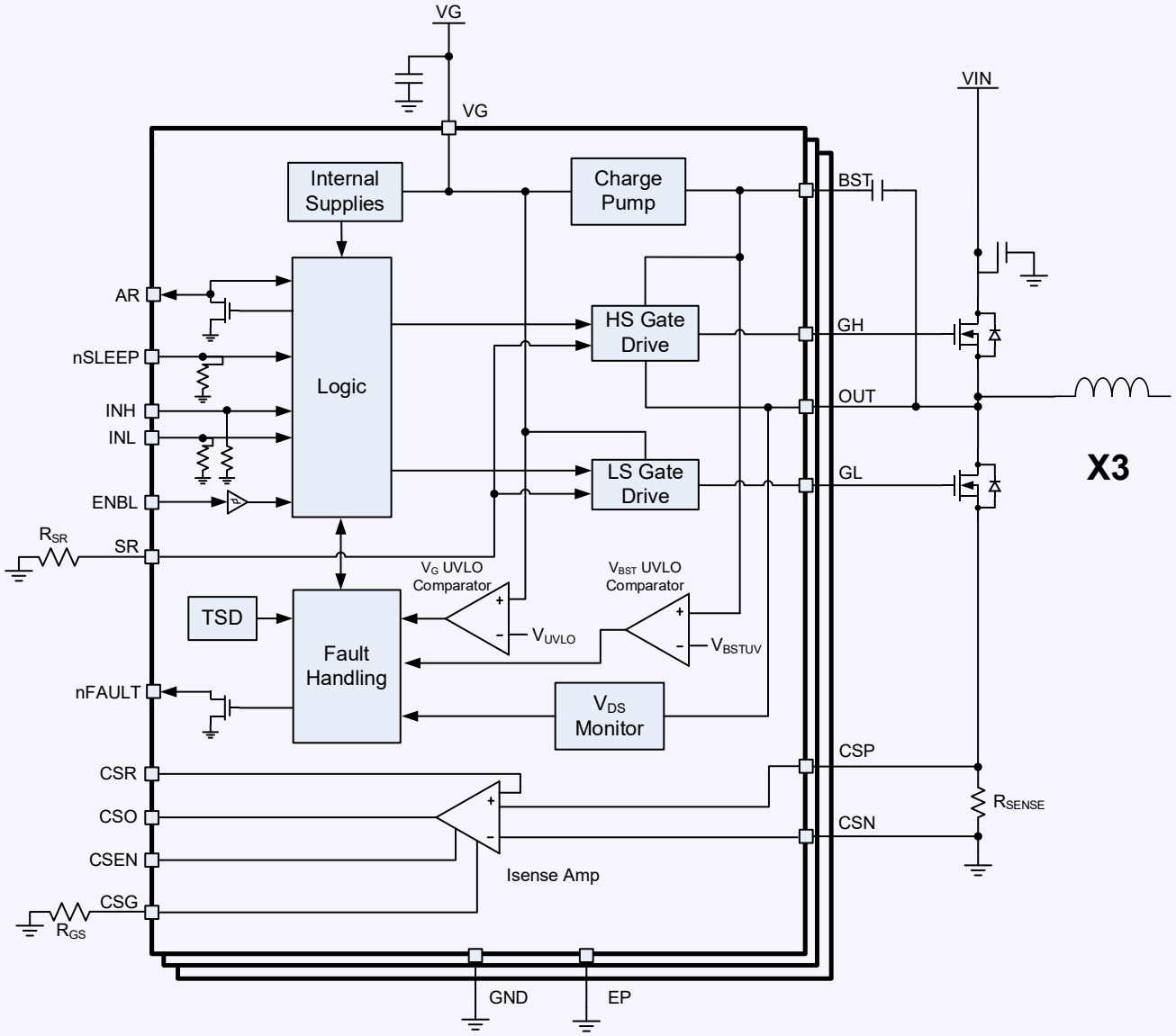
Features

- **5V-15V** Input Voltage, Supports 100V Supply Operation
- 3A Source, 4A Sink Gate Drive Current
- Internal Charge Pump and Auto-Refresh for HS Gate Drive
- Programmable Controlled Slew Rate
- Low-power Sleep Mode (0.1μA)
- **Integrated Current-Sense Amplifier**

- **Inherent Protection Features:**
- Desaturation Protection of External MOSFETs
- OTP, UVLO
- Fault Indication output
- QFN-22 (4mmx5mm)

- **Available in AEC-Q100 Grade 1**

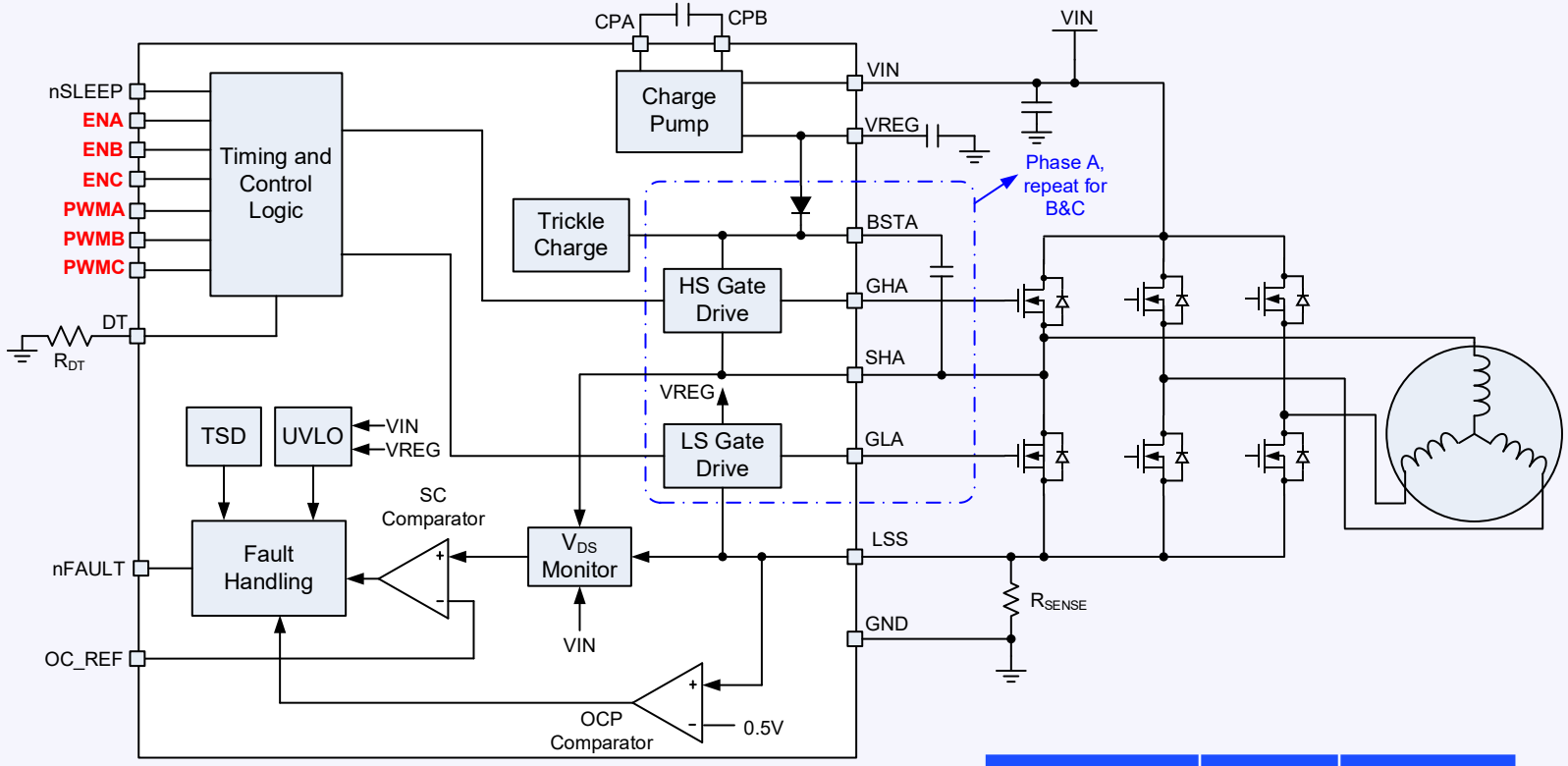




Three Phase Inverter Gate Drivers

For Medium power Loads:

- N Channel MOSFET Drivers
- Charge Pump Support
- Over Current Protection
- Integrated Boot Strap Diode
- Multiple Control interfaces
  - Lx/Hx PWM
  - EN/PWM
  - DIR/PWM/BRK
  - SPI
- Protection and Fault reporting



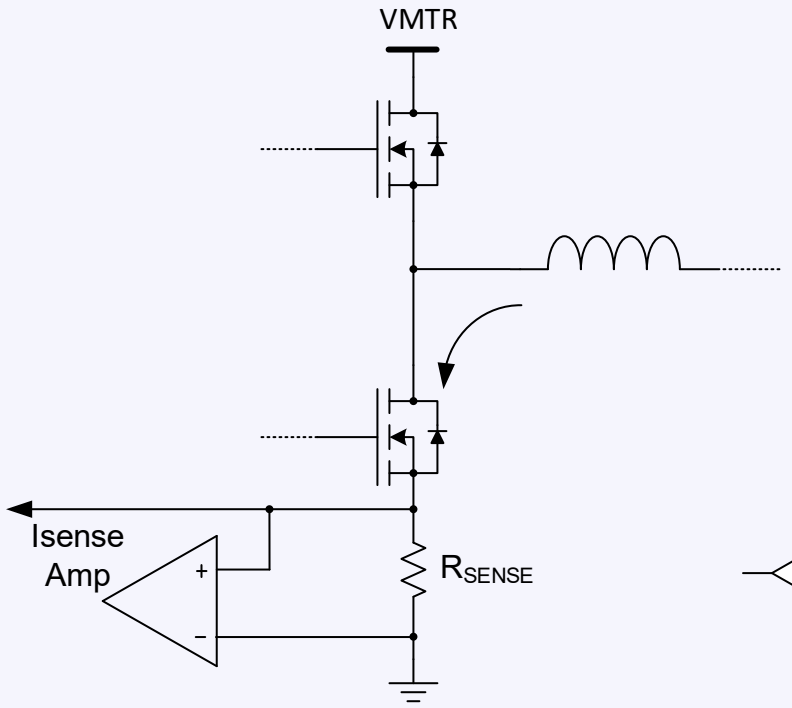
MP6534

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

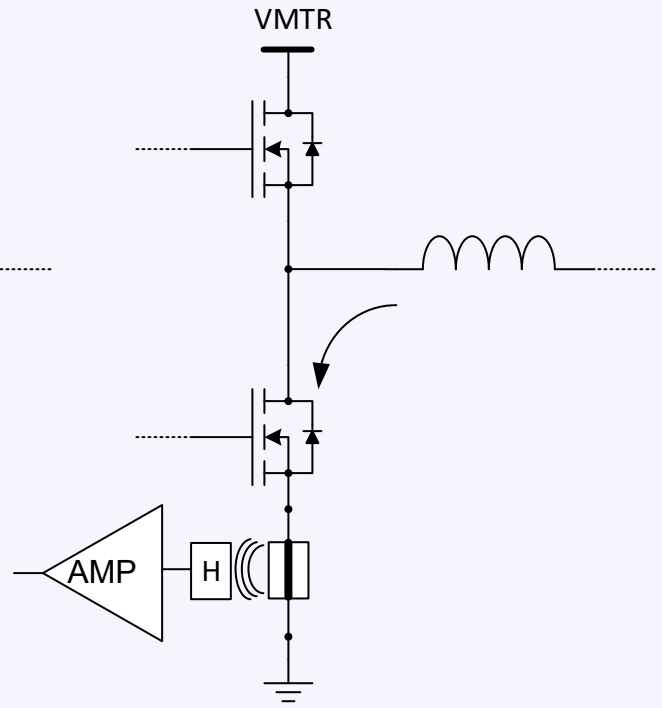
Current Sense Techniques

Pro's:
1. Lower Cost
2. MHz Bandwidth

Con's:
- Higher power dissipation.
- Low side sensing preferred
- Limited current range
- No isolation
- Amplifier required



Resistive Shunt Current Sense



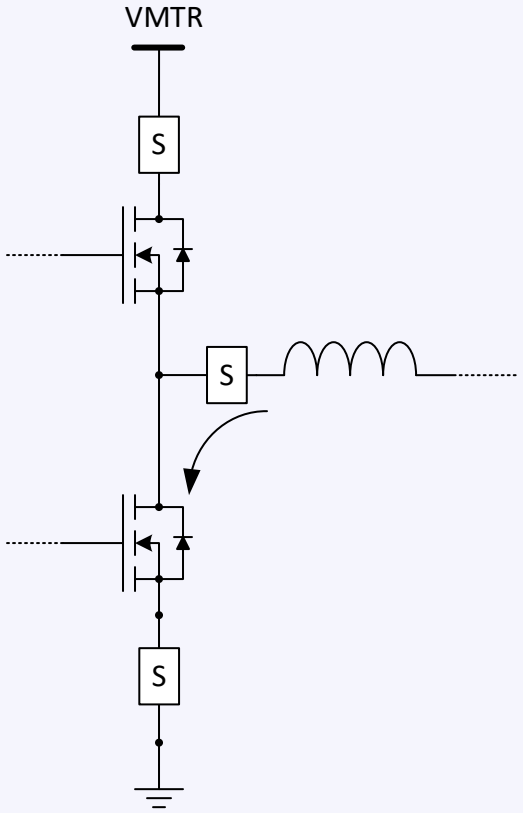
Magnetic Hall Sensor Based Current Sense

Pro's:
1. Isolation
2. High, Phase, Low side placing
3. Lower power dissipation
4. Noise immunity

Con's:
- 100KHz Bandwidth

Current Sensor Placement

- Keeps GND clean
- Detects/protects shorts to GND
- Detects/protect shoot through
- Requires High Voltage analog (resistive only)

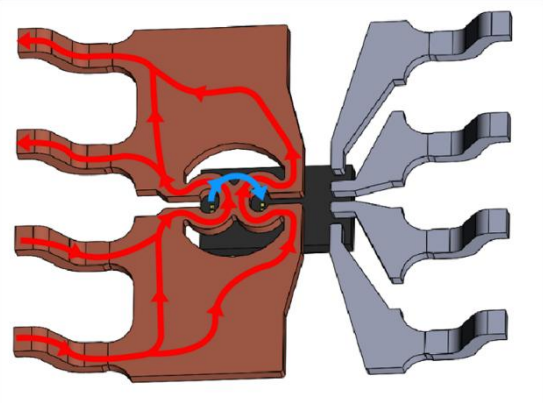


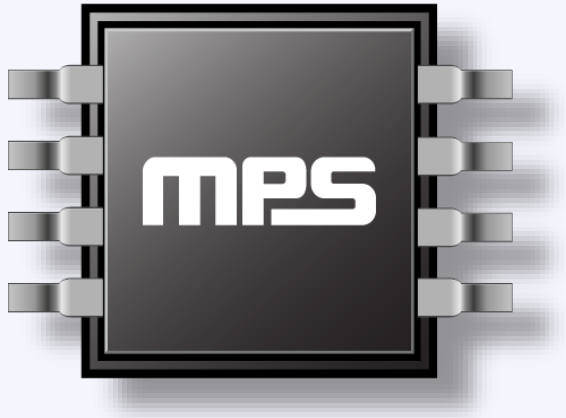
- Current measurable at all times
- Best for FOC Algorithms
- Re
- Can’t protect from shorts

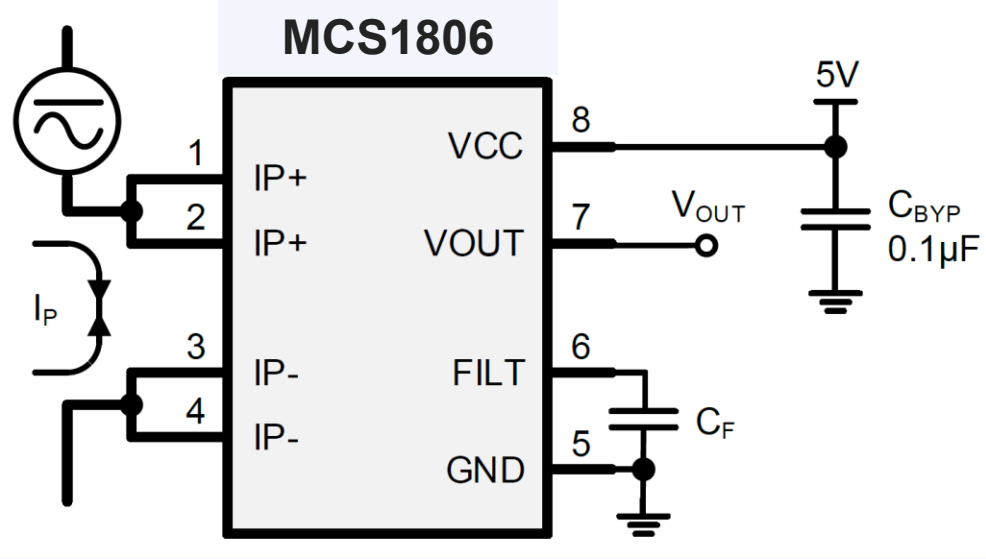
- Detects/protects shorts to VMTR
- Detects/protect shoot through
- May affect GND due to voltage drops

Cost Effective Isolated Current Sensing

- Integrated Solution in SOIC-8
- Smallest **Isolated** Solution Footprint
- 3kV$_{RMS}$ Isolation
- 580V$_{RMS}$ Working Voltage
- Immune to External Stray Fields
- Coreless, No Magnetic Hysteresis
- Senses up to ±100A
- 0.3 - 1mΩ Primary – Power Efficient







MCS(Q)1823 – Current Sensor w/ OCD in 3x3mm² QFN

Key Specifications

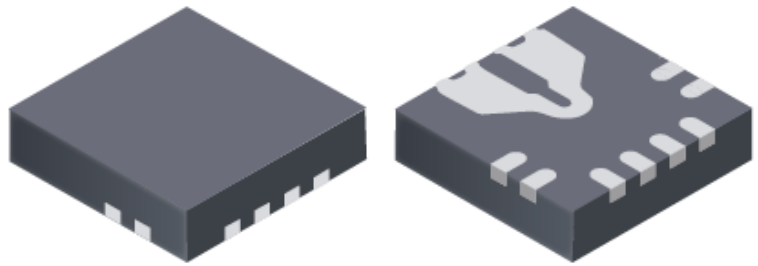
- **Tiny Footprint: 9mm² QFN-12 Footprint**
- **Immune to All Gradient Stray Fields**
- **±2.5% Total Accuracy**
- **0.6mΩ Internal Conductor Resistance**
- **Fast Overcurrent Detection (OCD)**
  1µs response time
- **UL Certified**

CB Certificate Number:
CA-11398-UL

- 3.3V or 5V single supply options
- 5A to 50A range
- 120kHz Bandwidth
- Ratiometric or absolute output from supply voltage optional

Applications

- Automotive amplifier current limit
- ATM bank machines – bill dispensing
- Load detection & management
- Switched-mode power supplies
- Over-current fault protection



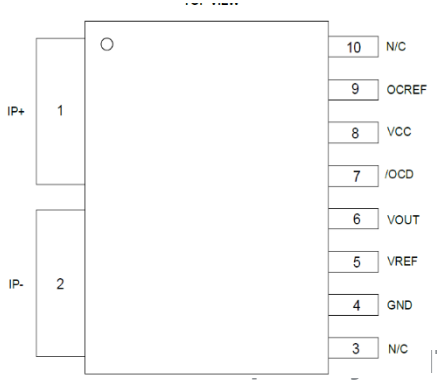
3mm x 3mm QFN-12 package

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

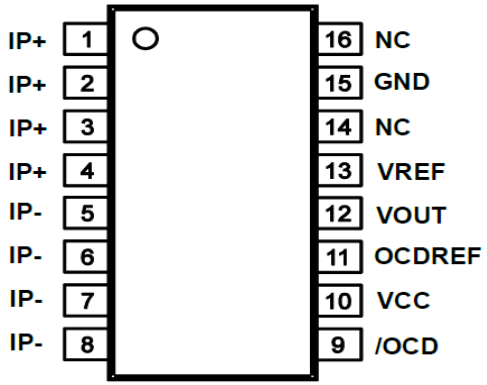
Key Specifications

- Package & Current Range Options:
  - MCS/Q1810 in WSOIC-10: 5A to 100A_{RMS} (0.3mΩ)
  - MCS/Q1812 in WSOIC-16: 5A to 80A_{RMS} (1mΩ)
- Same Package Footprint: 10.3mm x 10.3mm
- 400kHz BW
- Supports Reinforced Isolation
- Bidirectional & Unidirectional, Absolute Out
- p2p to ACS37002, ACS724/5

MCS1810



MCS1812



Applications

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

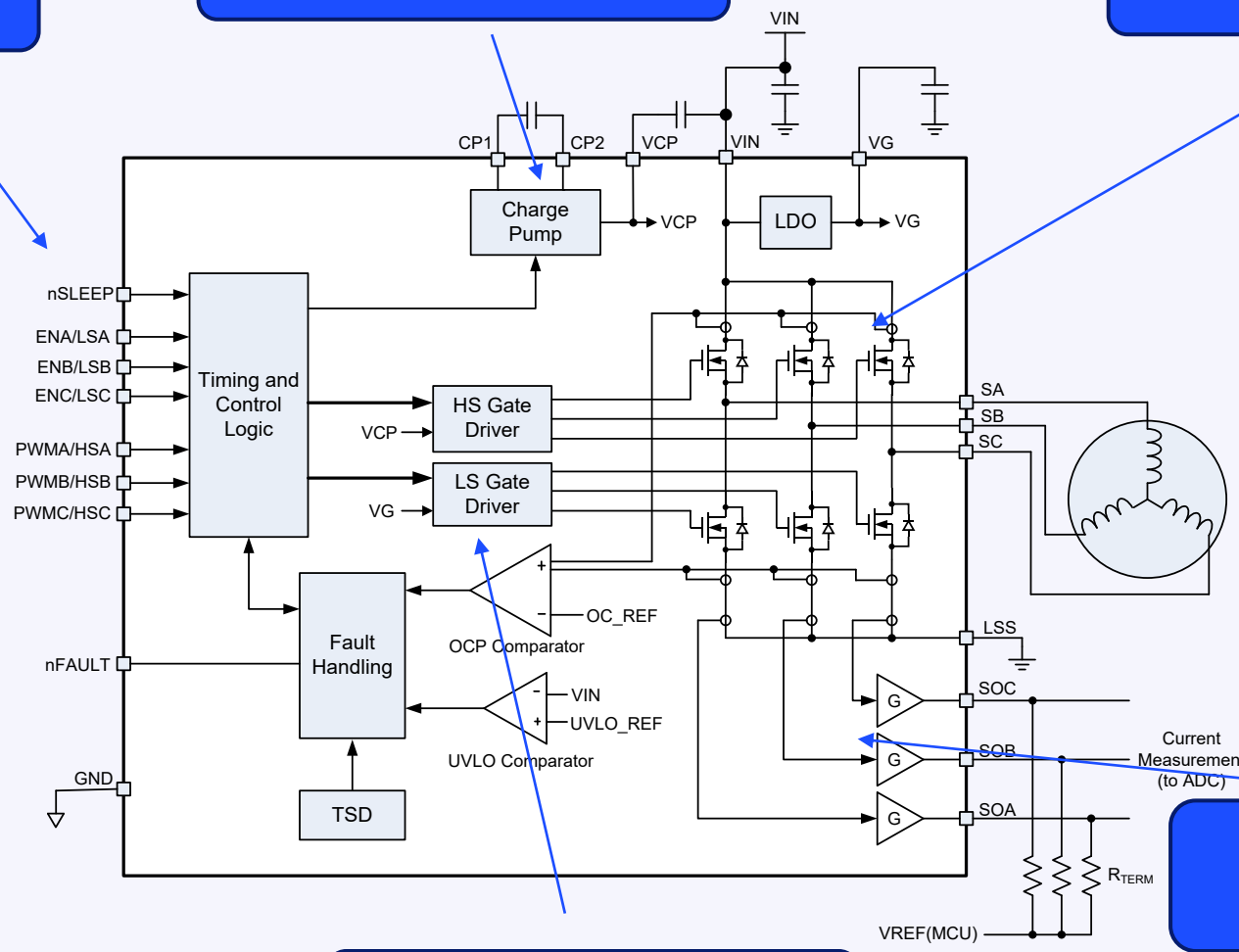
Key Specifications	MCS1810/12
Accuracy	1.5%
V_{ISO} (RMS)	6000V
V_{IOWM} (RMS)	1100V
OCD Response	500ns

Fully Integrated Three Phase Inverters

Control Signal Interface

Charge Pump

N Channel MOSFET



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

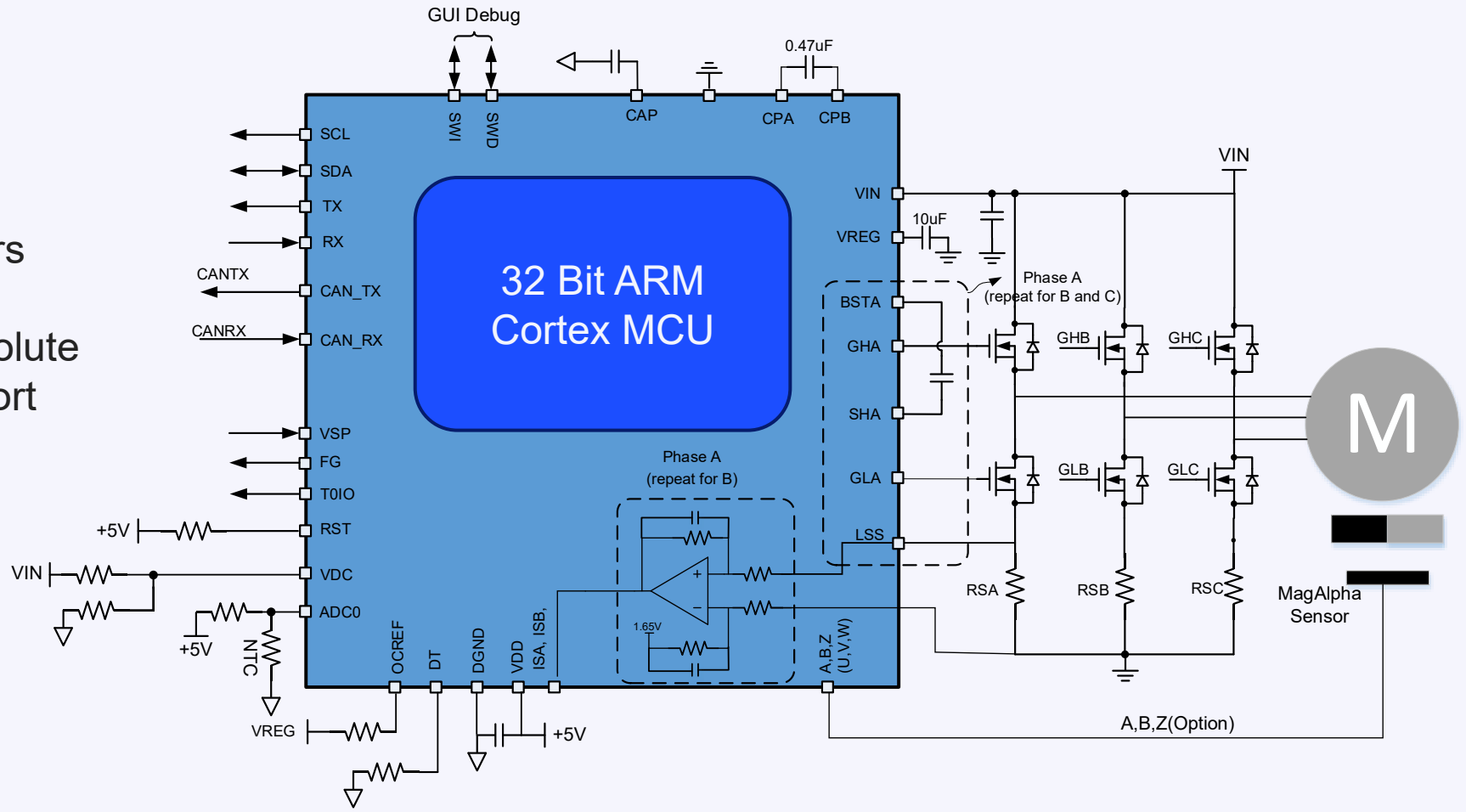
Device	Voltage	Current
MP6540	50V	5A
MP6540H	50V	5A
MP6541	40V	8A
MP6543	22V	2A
MP6545	45V	2.5A
MP6549	18V	10A

Integrated Current Sensing

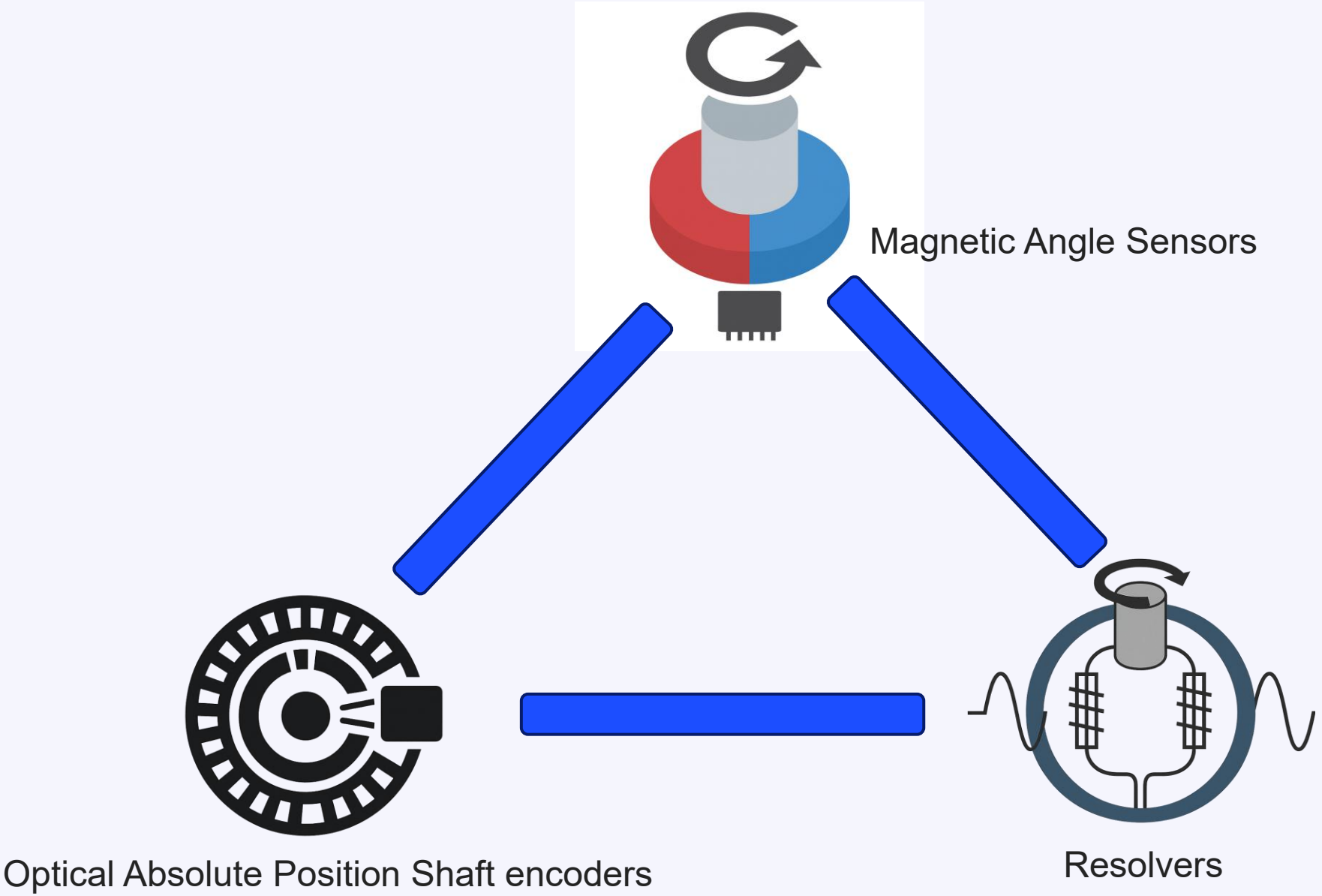
Gate Drivers

Intelligent Three Phase Inverters

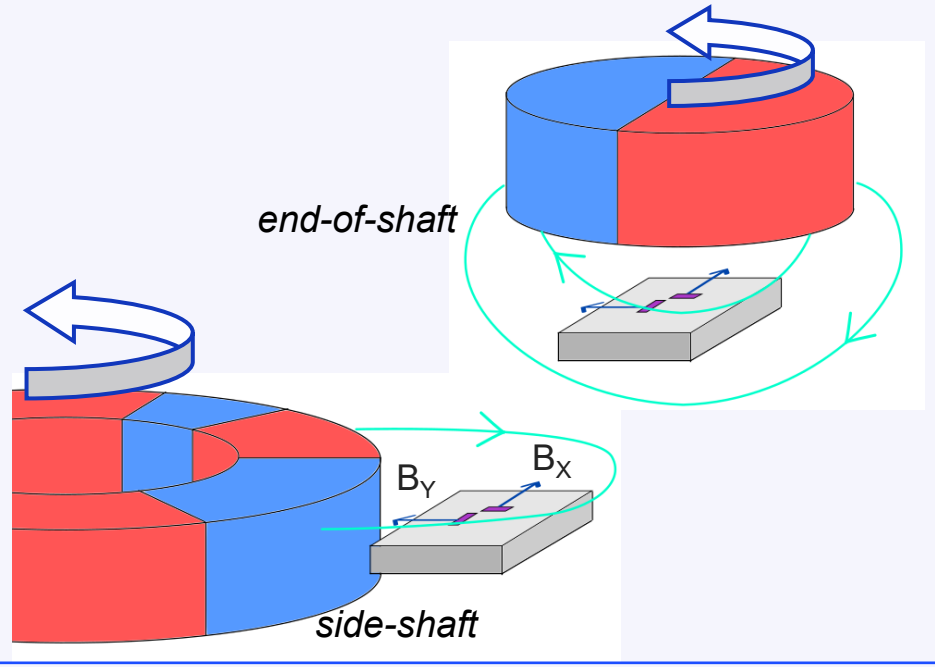
- 32 bit Cortex M4F MCU
- Integrated Gate Driver
- Current Sense Amplifiers
- FOC Algorithm Support
- Hall Sensor Based Absolute Position Encoder Support



Absolute Position Encoders



Position Sensor Overview

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

Magnetic field lines

Sensitivity direction

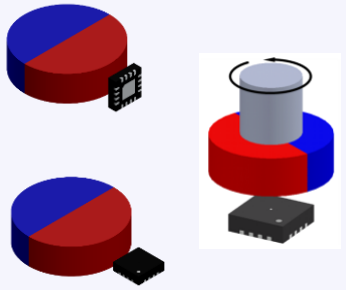
Direction of motion

MA732, 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 is adjustable to optimize control loop performance when used in servo applications. MAQ473-AEC1 is automotive grade based on MA732.

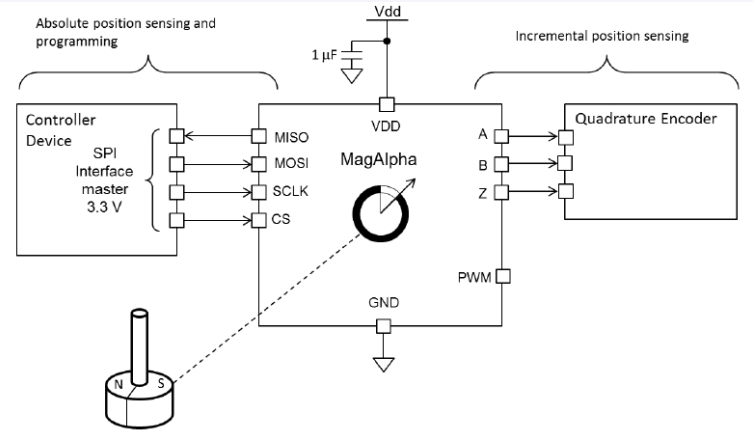


Features

Noise Free Resolution	9-bit to 14.5-bit (±3σ deviation of the noise distribution)
Supply Voltage	3.0V to 3.6V
Interfaces	ABZ, PWM, SPI, SSI
Field Range	30mT to >100mT
Technology	Hall-Based

Applications

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

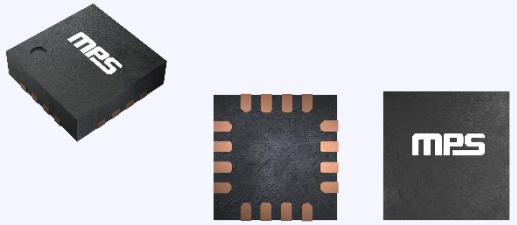


Highlights

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

Packaging

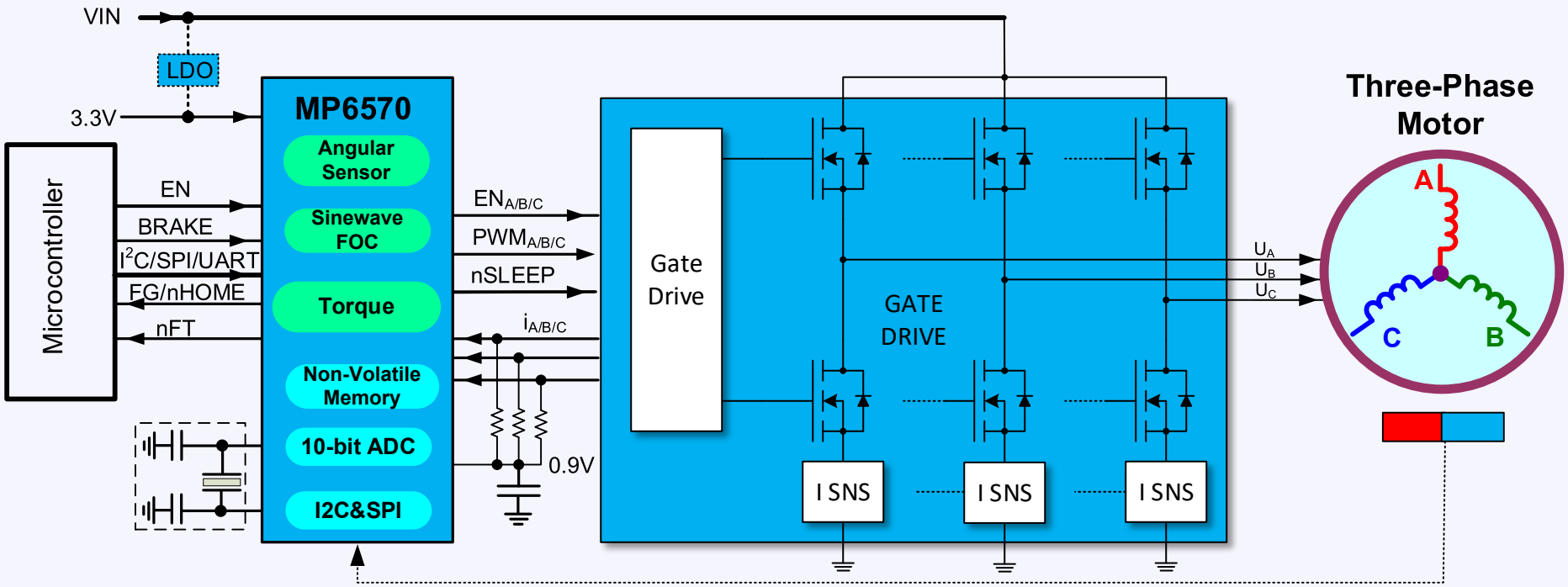
- QFN-16 (3x3mm²)



Tools & 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

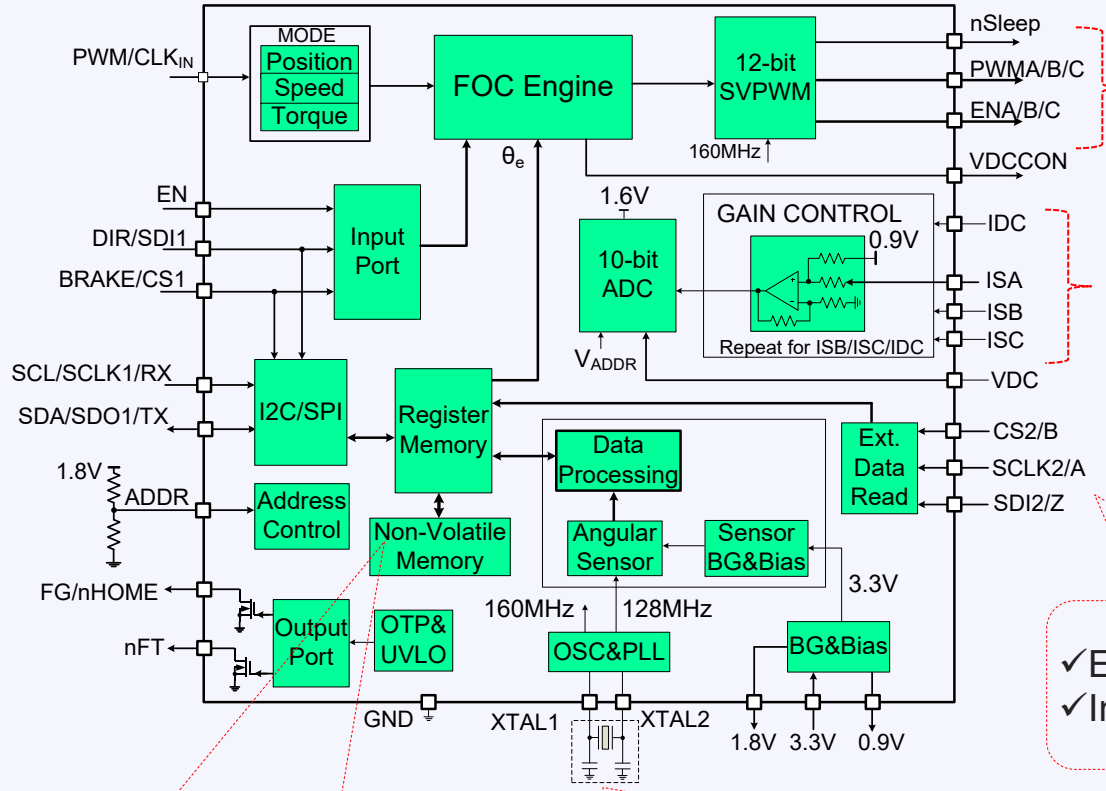
FOC Controller



MP6570 FOC Motor Controller

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

✓ FOC control
✓ Position/speed/torque mode



✓ MP6540 family compatible
✓ Separate MOS gate signal interface

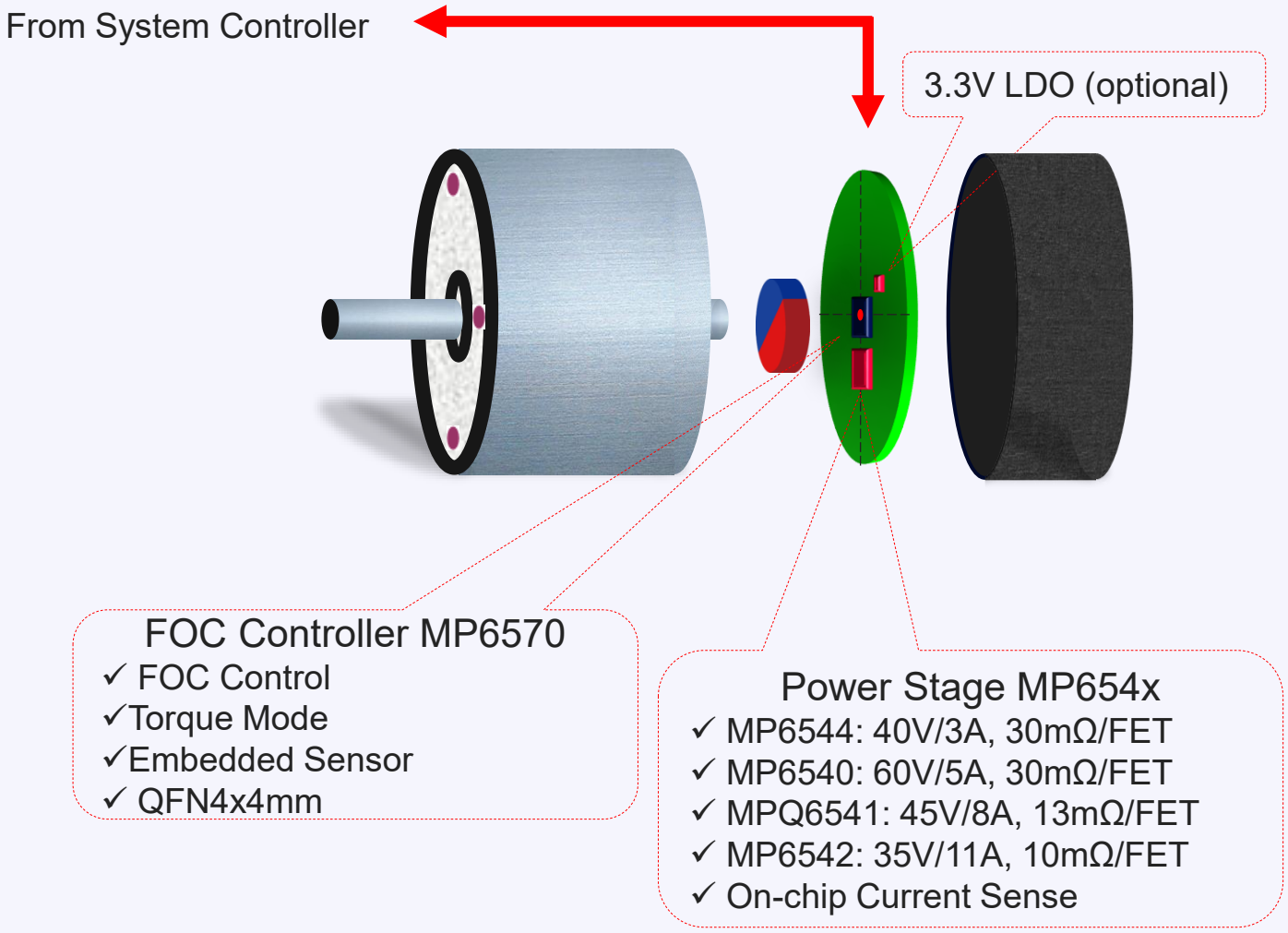
✓ 1/2/3 phase current sensing
✓ DC bus protection
✓ 10-bit ADC, 1% ref.

✓Ext. sensor interface
✓Internal sensor A/B/Z output

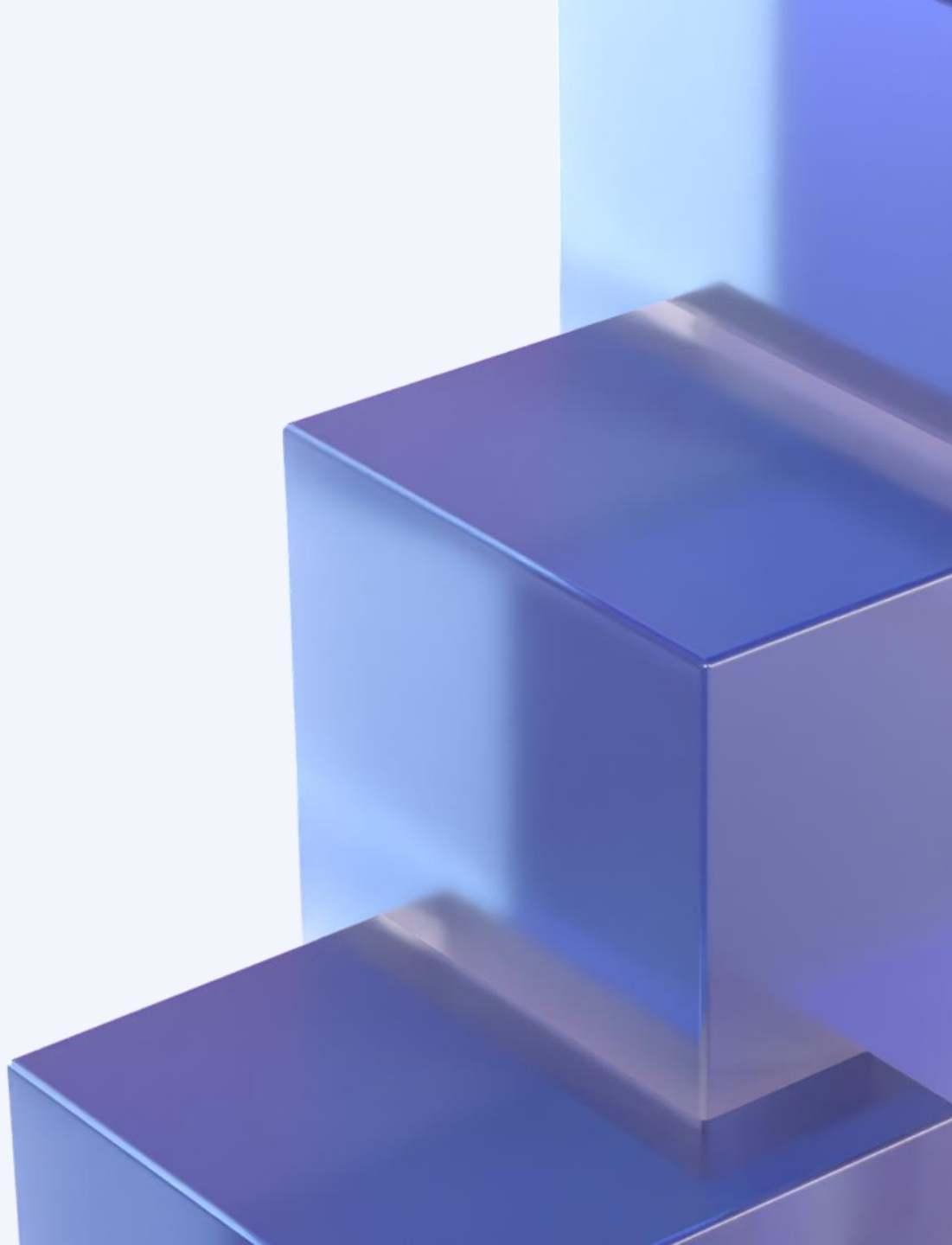
✓ All spec/parameter supports non-volatile memory program

✓ External oscillator input or
✓ Internal on-chip oscillator

MP6570 FOC Motor Controller



Dexterous Hand Solution



Robot dexterous hand solution

- **FOC Control**
- **Embedded Angle Sensor**
- **Very Small Size: Diameter 9mm, Thickness about 6.5mm**
- 5V to 18V Input Voltage
- Maximum 2A Phase Current
- Support maximum 60000rpm motor speed
- RS485 interface with MODBUS protocol
- Configurable Protection
  - UVLO
  - OCP
- Up to 80kHz programmable switching frequency
- Angular sensor resolution up to 14 bits
- Rigid-Flex-Rigid PCB structure

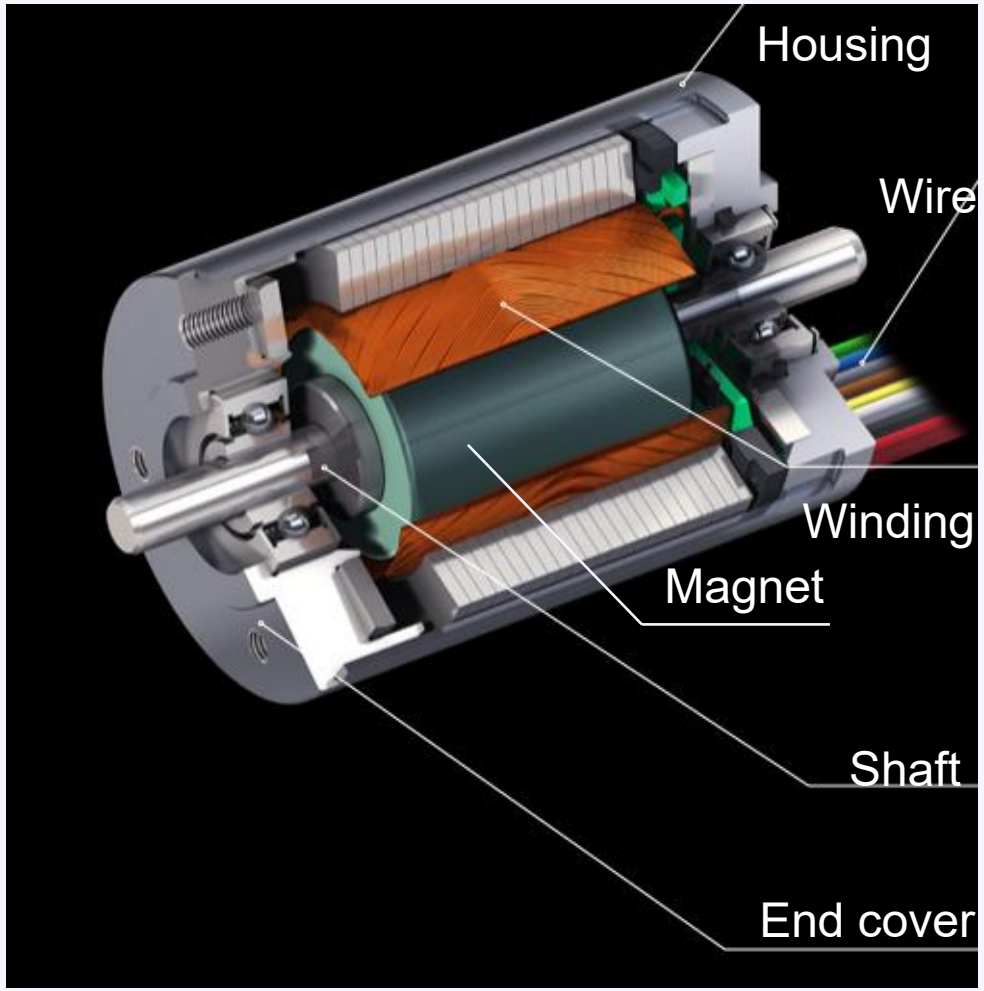
MP6570
MP6543H
MP6710
MP2015A

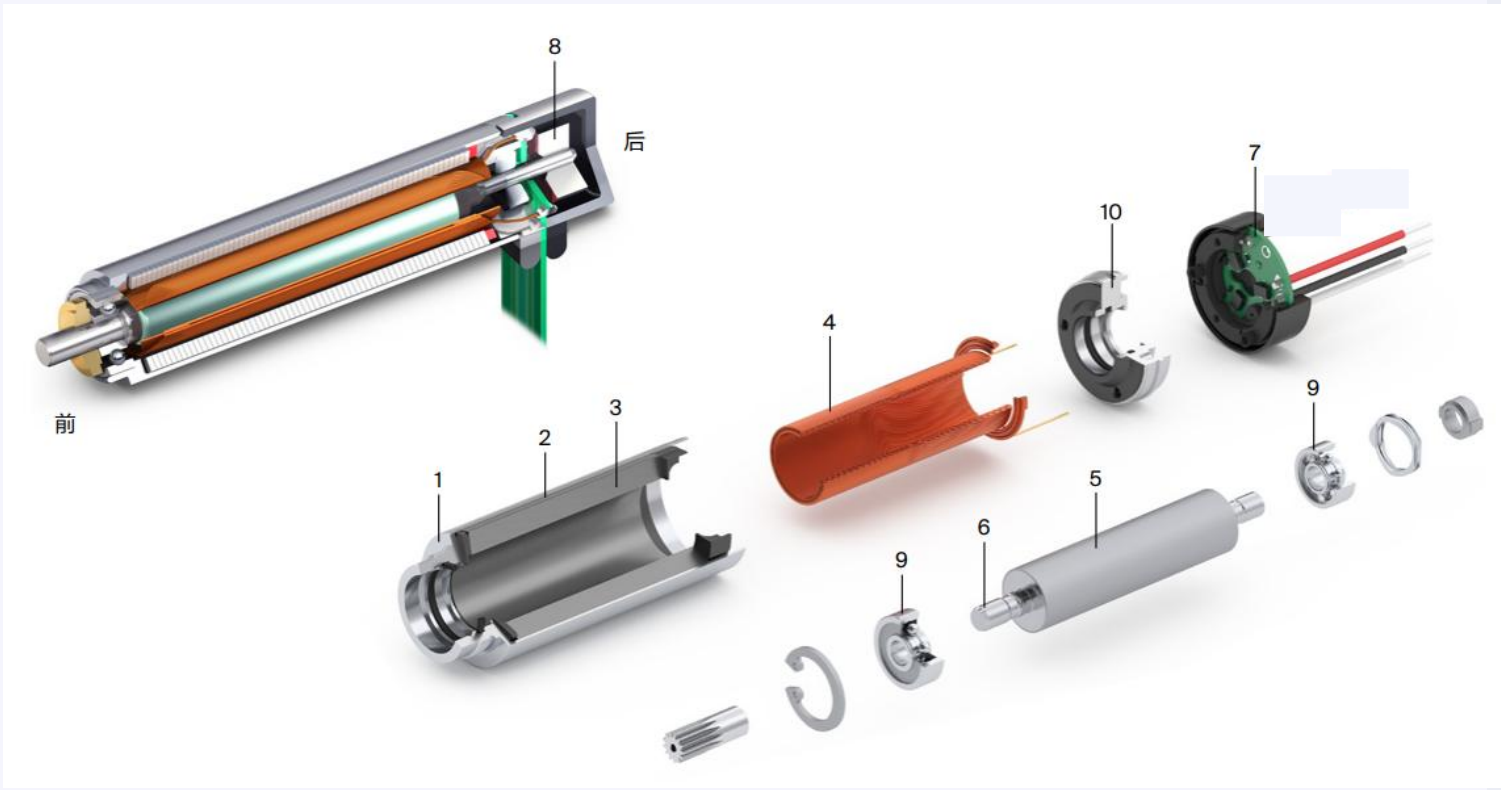
D=9mm

Connector Definition

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

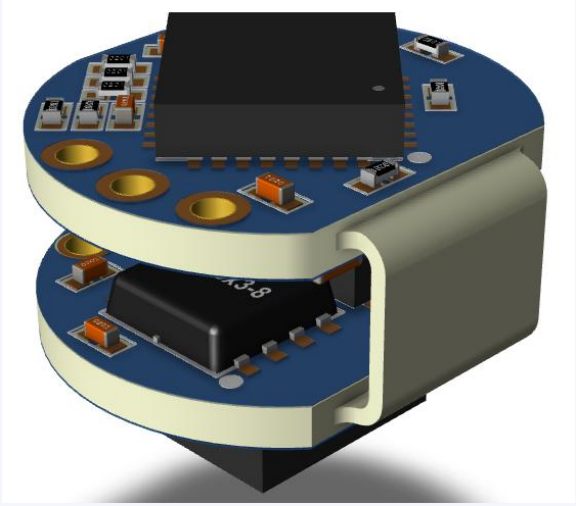
Coreless Motor Structure



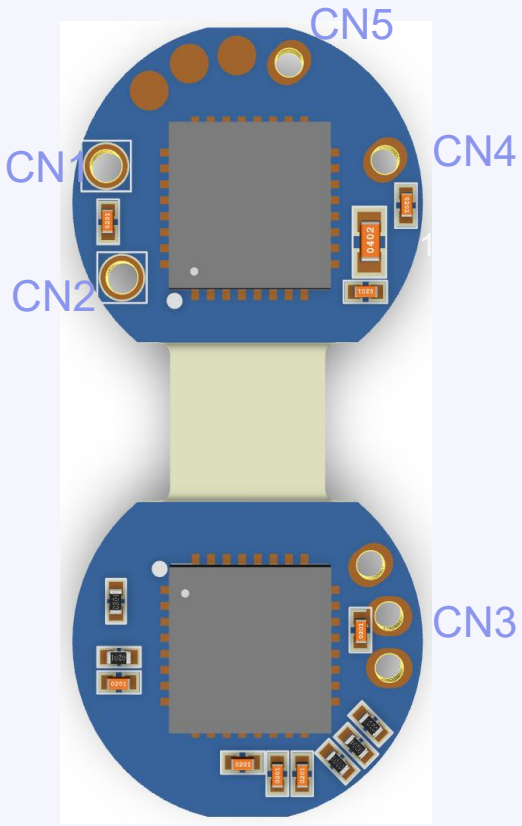


MMP1RH

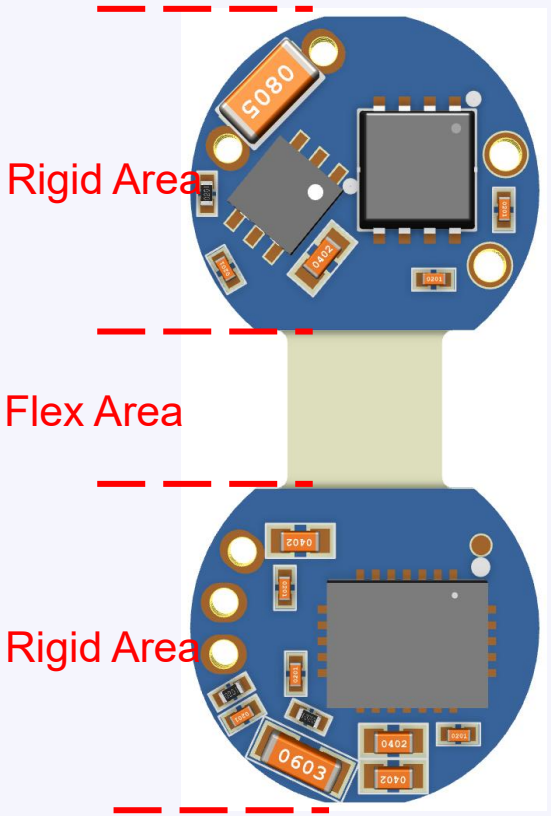
- **FOC Control**
- **Embedded Angle Sensor**
- **Very Small Size: Diameter 9mm, Thickness about 6.5mm**
- 5V to 18V Input Voltage
- Maximum 2A Phase Current
- Support maximum 60000rpm motor speed
- RS485/CAN communication interface
- Configurable Protection
  - UVLO
  - OCP
- Up to 80kHz programmable switching frequency
- Angular sensor resolution up to 14 bits
- Rigid-Flex-Rigid PCB structure



MMP1RH-R9A2-0000 (RS485) / MMP1RH-C9A2-0000 (CAN)



Top View



Bottom View

Connector Definition

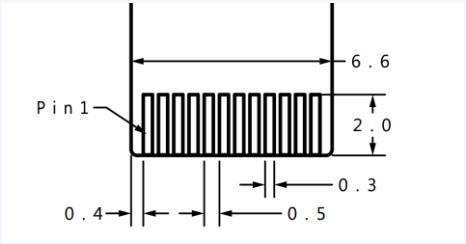
CN #	Pin Name	Function
1	RS485_B	RS485 B port
2	RS485_A	RS485 A port
3	Output	Connect to motor's UVW winding
4	GND	DC power input ground
5	VIN	DC power supply input, 5V to 18V

Connector Definition

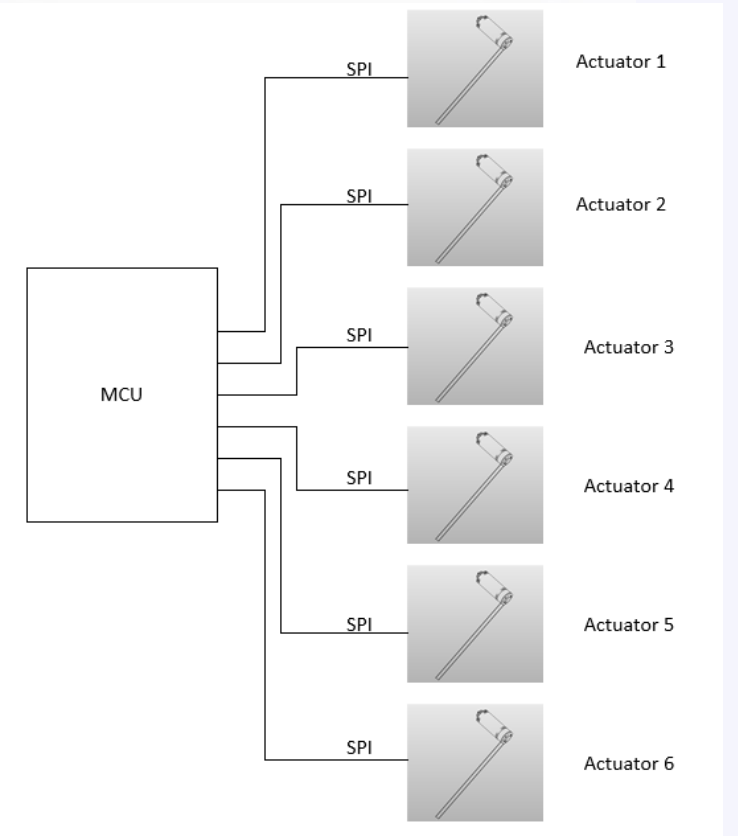
CN #	Pin Name	Function
1	CAN_H	CAN_H port
2	CAN_L	CAN_L port
3	Output	Connect to motor's UVW winding
4	VIN	DC power supply input, 5V to 18V
5	GND	DC power input ground
6	5V	5V power supply

MMS1RH With SPI Interface

- **High Integration Actuator**
  - **Very Small Size (8mm/10mm/12mm/13mm Diameter)**
  - **Motor Spec**
    - **10mm:** 1.7mNm Rated torque, 35000rpm Max Speed, 25000rpm Rated Speed @12V
    - **13mm**: 6.1mNm, 18000rpm Max Speed, 14000rpm Rated Speed @12V
- 4V to 18V Wide Input Voltage Range, 12V Nominal Input
- **Torque Control** with FOC Technology
- Embedded 14bit Angle Sensor for **Accurate Position Control**
- **Function Extendable** with MCU C Code Library
- Rigid-Flex PCB Structure for Power and SPI Interface
- SPI Interface with over 8MHz clock frequency



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



EasyFOC Library

01

Real Time Feedback

Read position, current and voltage feedback via SPI

02

Close Loop Control

Position and Speed Close Loop 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

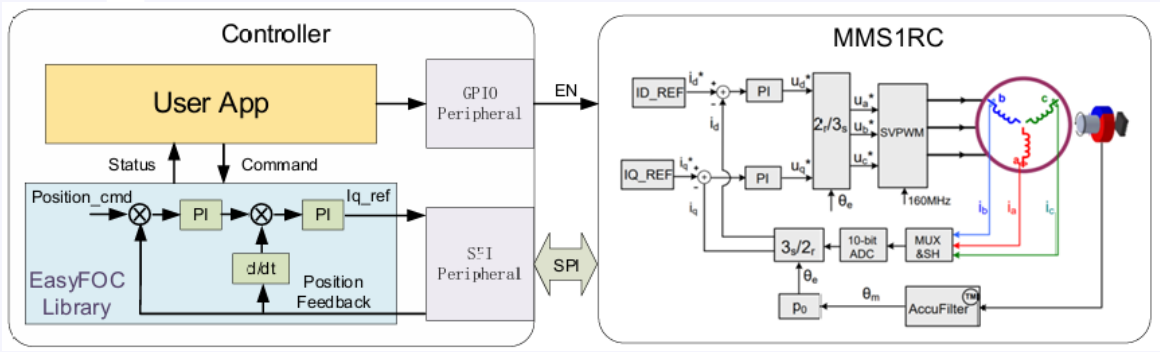
Up to 80KHz switching frequency, reduce the motor power loss which means less power consumption, less heat and more efficiency

06

Protection

EasyFOC Library Provide Variables for System Diagnose

System Block Diagram



Summary

- Support to all humanoid robotic three phase BLDC/PMSM motors under FOC Algorithms.
- Multiple current sense topologies supported for current sampling as well as protection.
- Close Loop support through magnetic Hall Sensor based absolute position encoders.
- Support three phase inverter discrete implementations, highly integrated power stages, as well as off the shelf motor solutions.
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Questions?