Driving the future of robotics with Murata:

Lessons from Trends in Humanoid Robotics

Application guide

Humanoid Robotics

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Introduction

The field of humanoid robotics is experiencing a transformative evolution, marked by significant advancements in artificial intelligence, sensor technology, and mechatronic systems. Humanoid robots, designed to closely resemble human form and behavior, are being integrated into a wide array of industries such as manufacturing, healthcare, logistics, and customer service. As these robots increasingly mimic human motion and cognitive functions, the potential applications for bipedal, cooperative machines are expanding rapidly.

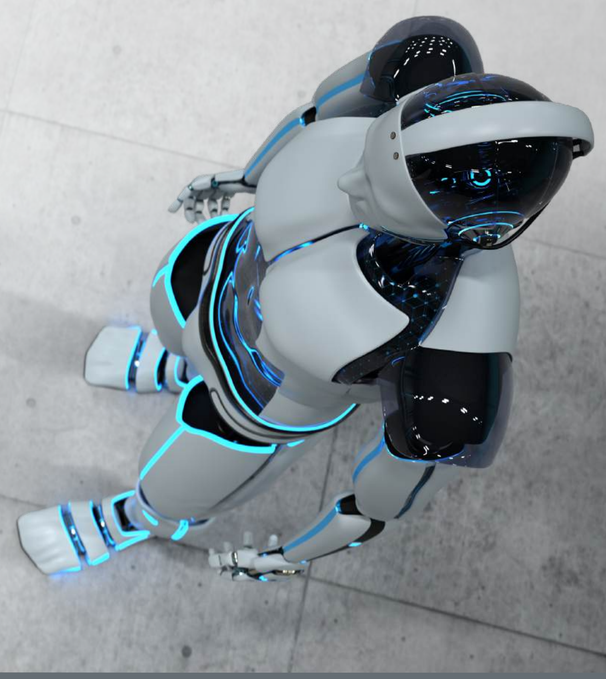
The global humanoid robotics market is poised for growth in the future, driven by factors including the escalating demand for automation, labor shortages across sectors, and the desire for more intuitive human-robot interactions. Key industry players, including leading research institutions and technology companies like Murata Manufacturing, are investing significantly in the development of advanced humanoid platforms. These platforms are not only capable of performing complex tasks but also exhibit adaptive learning and safe collaboration with human operators.

However, despite these promising advancements, the deployment and scaling of humanoid robots bring forth a unique set of technical challenges. Engineers are faced with issues related to real-time perception, dexterous manipulation, reliable locomotion, and effective human-robot communication. Additionally, considerations regarding safety, energy efficiency, and cost-effectiveness continue to pose significant obstacles in both research and commercial spheres.

As the industry transitions from experimental prototypes to practical real-world solutions, addressing these engineering challenges is crucial for unlocking the full potential of humanoid robots. This report offers a comprehensive overview of the humanoid robotics market, detailing the key technical issues that engineers encounter in this dynamic field, while also highlighting how innovative contributions—particularly those from Murata Manufacturing—are propelling the industry toward successful real-world integration.

Moreover, the total electricity consumption of data centers is expected to exceed the combined electricity usage of major industries such as aluminum, steel, cement, and chemicals. This fact strongly suggests the need for a reevaluation of energy distribution across entire industrial structures and improvements in efficiency.

The potential applications for bipedal, cooperative machines are expanding rapidly.



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Challenges

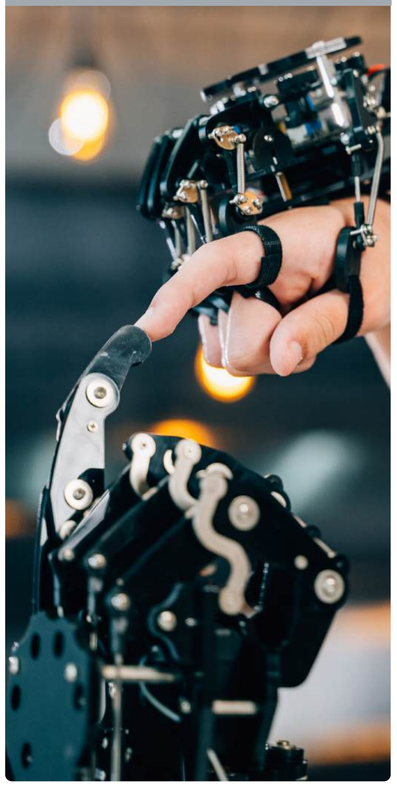
Engineering challenges in humanoid robotics development

The field of humanoid robotics has advanced significantly, yet engineers working in this domain confront a variety of formidable and interconnected challenges that must be navigated to ensure practical design and successful deployment.

These challenges highlight the need for innovations that incorporate intelligence, resilience, and efficiency—core components of effective humanoid robotics development.

The following pages examine the primary hurdles faced by engineers in this dynamic field.

Complex motion control



Safety & human interaction

Hardware constraints & cost reduction

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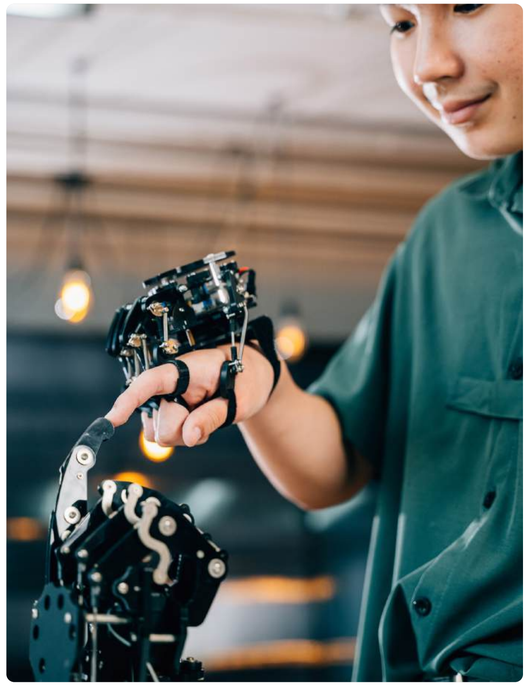
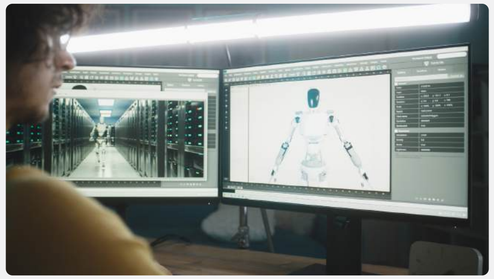
Challenges

Complex motion control

Replicating human-like motion with multiple degrees of freedom and intricate joint control is a highly demanding task. Engineers must develop high-speed, precise control algorithms that can maintain stability and prevent falls in dynamic environments.



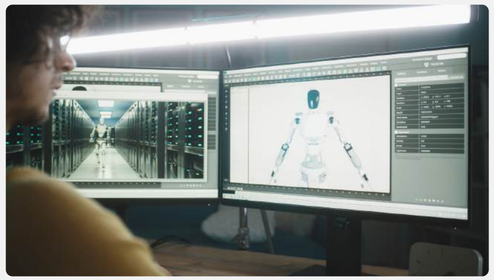


Modeling complexity:

Developing dynamic models to accurately represent the robot's physical behavior is inherently difficult, requiring advanced mathematical and computational techniques.

Real-time control:

Feedback loops must operate without delay to enable responsive adjustments, which is critical for safe operation.



Sensor fusion:

Engineers must integrate data from diverse sensors (e.g., accelerometers, gyroscopes, and cameras) to provide accurate self-localization and effective interaction with the environment.

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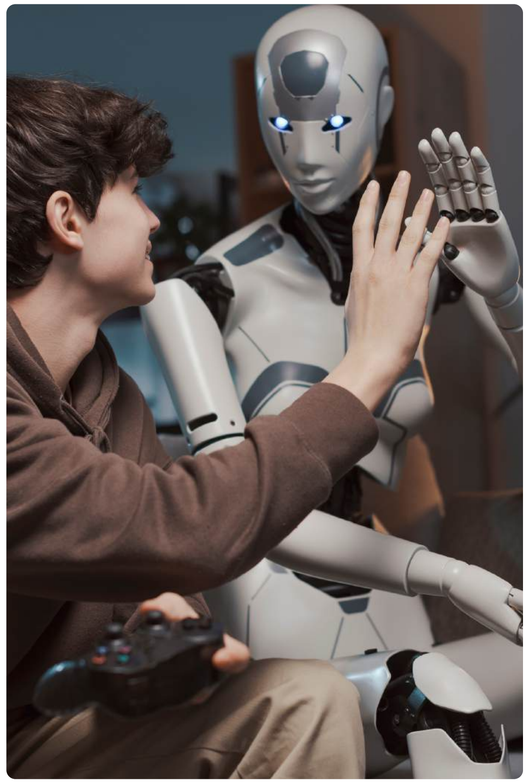
Challenges

Safety and human interaction

Given that humanoid robots are intended to operate in close proximity to humans, robust safety mechanisms and ethical considerations are paramount.



Collision detection:

High-level techniques for collision detection, force control, and emergency stop functions are essential to prevent accidents.

Unpredictable movements:

Engineers must account for unpredictable human movements to ensure the safe interaction of robots in various scenarios.

User-friendly interfaces:

Designing intuitive operational interfaces that are compliant with regulatory and ethical standards is crucial for user acceptance.

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Challenges

Hardware constraints and cost reduction

The components used in humanoid robotics - such as multi-joint mechanisms and high-performance sensors - are often expensive, thus constraining development budgets. Additionally, the selection of materials must balance weight reduction with durability.

Material optimization:

Engineers are tasked with optimizing materials and mechanical designs to enhance performance while minimizing weight.

Power management:

Effective power management and improvements in battery performance are ongoing demands for increased operational longevity.

Cost control:

Establishing techniques for mass production while controlling costs is necessary to make humanoid robots feasible for broader deployment.

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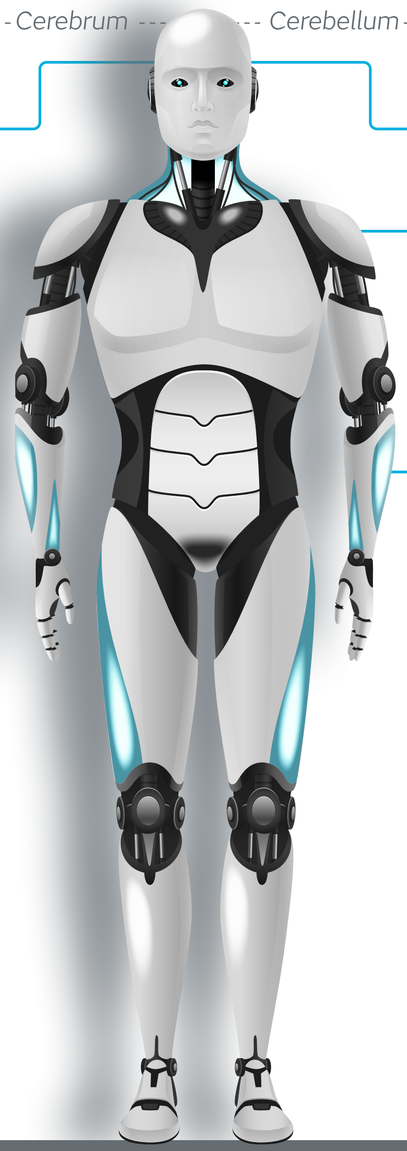
Murata solutions

Overview - Murata products

Overall humanoid robot system



Existing solutions
- Miniaturized MLCC & EMI

Decision making (IC)

Existing solutions
- Battery cell

Battery

Trunk skeleton

Existing solutions
- Communication model (GNSS, UWB+BLE)
- LCP (FPC & Antenna design)

Wire harness & cables

Operation system

Communication module

Existing solutions
- Force Tactile sensor (3D)
- Miniaturize MLCC & EMI
- Picoleaf (E-Skin)
- ~70V -> 12V/24V power module/IC

Dexterous hands

6-axis force sensor

Sensing

Existing solutions
- Smell sensing
- Radar/Lidar related components

Rotating joint module

Existing solutions
- Miniaturized MLCC & EMI
- PicBK/PoL PW-Mod 48v/24v PW-Mod/IC

Linear joint module

Existing solutions
- Miniaturized MLCC & EMI

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Overview - Humanoid system

Features of core parts								
Main power	Decision making	Joint & servo motor	Connectivity	Sensing				
Battery	GPU/GPU	Actuator Dexterous hand	Wireless for external communication	Vision: Camera	Vision: Radar/Lidar	Touching	Hearing	Smelling	IMU

Sensing

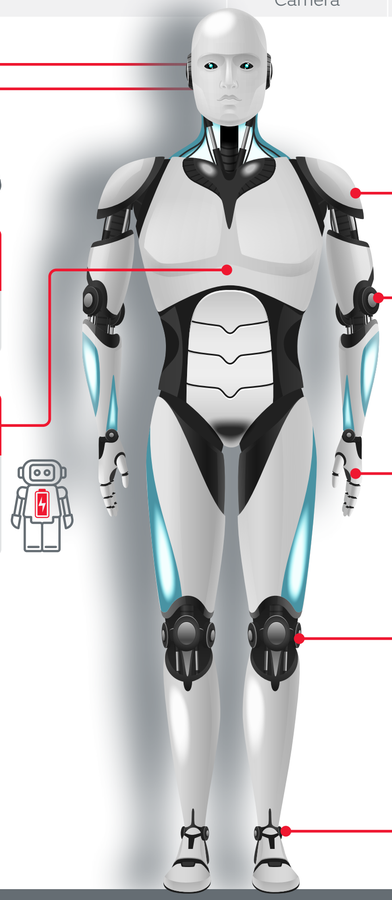
- (Cerebellum SoC)
- 3D camera
- Lidar
- Hearing
- Smelling (TBC)
- IMU

AI/CPU control system

- GPU/CPU (brain)

Battery & BMS system

- Battery cell
- BMS battery management



Motion system

- Servo motors for rotational & linear actuators

Motion system

Dexterous Hand

- Driver Motor
- Touching/Grabbing

Communications

- External
- Internal

Wi Fi 6 · Wi Fi 6E · Wi Fi 7 · 5G · LTE-M · EtherCAT

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Murata solutions

Overview - capacitor types

Small, thin & high-capacitance

Ultra-Small Size
(008004"/0.1µF, 01005"/1µF)

High-Capacitance
(~330µF)

Automotive-Grade Capacitors
(ISO9001, AEC-Q200, IATF16949)

Embedded capacitors for Class D

Low ESL
(~27µF)

Soft-terminal capacitors
(ISO9001, AEC-Q200, IATF16949)

Epoxy coating
(ISO9001, AEC-Q200, IATF16949)
(~1kV, ~47uF)

Polymer electrolytic
(~470µF, 2.5V~25V)

High-Q capacitors
(25V~500V, 1GHz~10GHz)

Wire bondable
(0303, ~0.47µF)

Anti-noise capacitor
(0603, ~47µF)

High voltage capacitor
(~3.15kV)

Safety capacitor

High reliability

Aerospace Specification

Metal terminal capacitors
(ISO9001, AEC-Q200, IATF16949)
(~1kV, ~47uF)

Application specific

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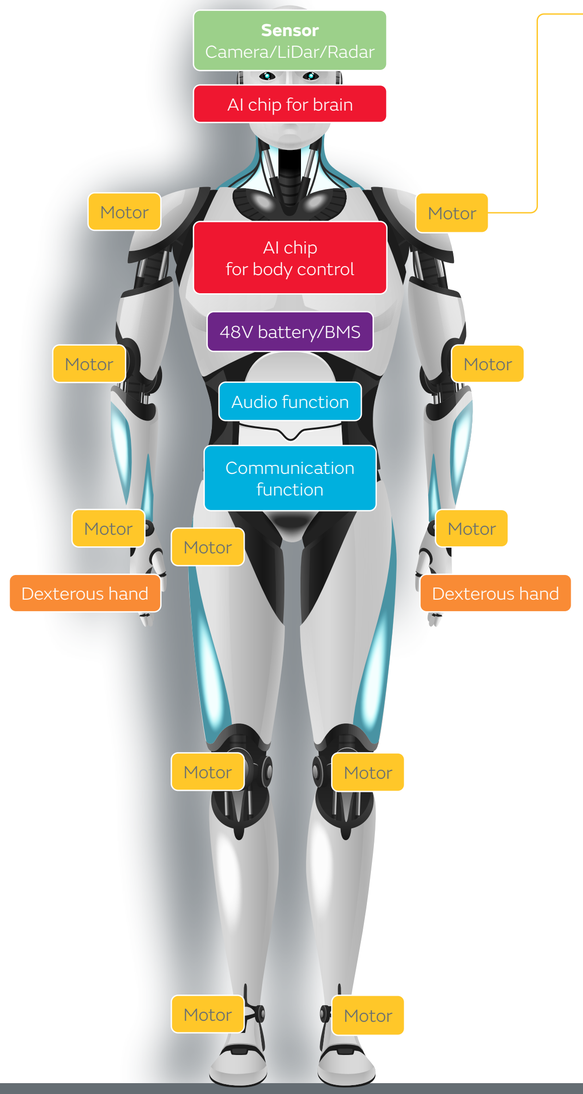
Murata solutions

Overview - ceramic capacitors

Humanoids integrate multiple applications and involve diverse technical requirements. Murata Ceramic Capacitors can comprehensively address all these needs, ensuring your specifications are met.

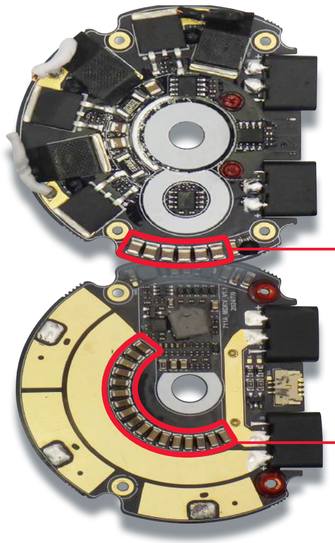
In addition, motors used in robotics represent a highly specialized application. To enhance robotic power or reduce motor size for increased installation count (e.g., improving degrees of freedom), components must be both compact and high-capacity.

With Murata's industry-leading lineup, we deliver cutting-edge solutions that strongly support your design requirements.



Motor controller board (inverter)

Top side



Back side

Murata MLCC solution for each function

- **Smaller size + high cap.** (01005 / 0201 / 0402)
- **Over 100uF cap.** And low ESL solution
- **Smaller size + high cap.** (01005 / 0201 / 0402)
- **High voltage and safety cap** (~3.15kV / Y1 – Y2 Class)
- **100V high cap + soft term.** (0603 – 1µF / 0805 – 2.2µF / 1206 – 4.7µF / 1210 – 10µF)
- **25V high cap + soft term.** (0603 – 10µF / 0805 – 22µF)
- **Lead type MLCC for motor noise**
- **Acoustic noise solution**
- **Wide line up coverage**

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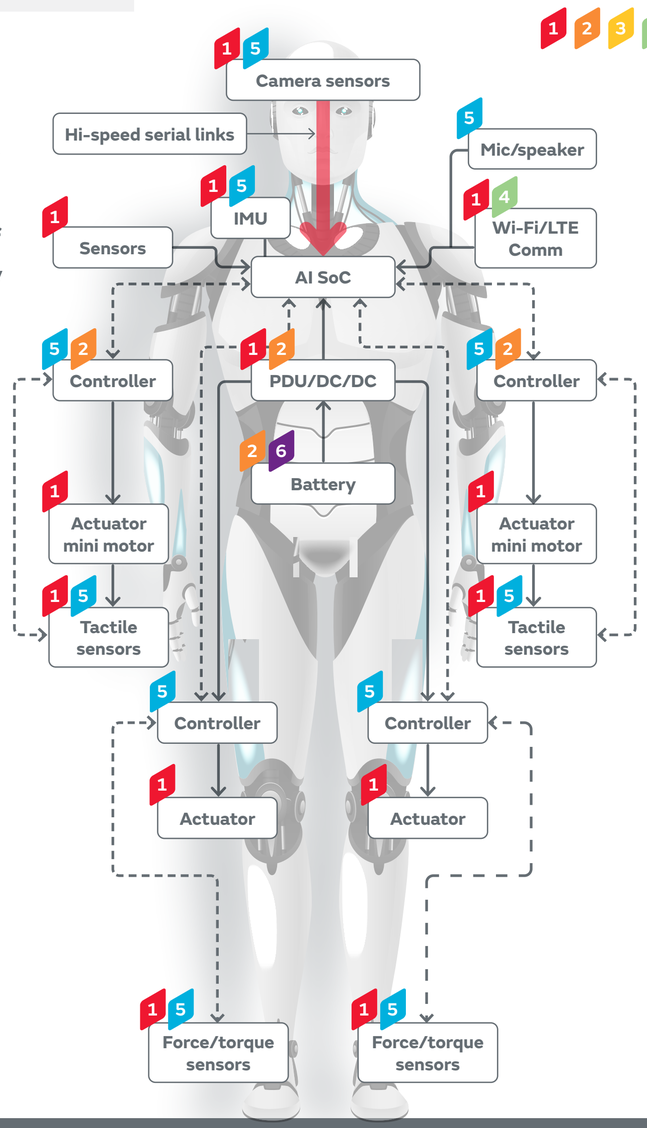
Overview - EMI products

Murata offers a diverse portfolio of EMI solutions capable of accommodating the wide range of interface and power requirements expected in the next generation of humanoid robots, while effectively addressing the various noise-related challenges these systems will face.

Leveraging the high quality and proven reliability cultivated through years of experience in the automotive market, Murata's products contribute significantly to ensuring functional stability, providing effective thermal management for humanoid robots as they advance toward higher performance and increased power consumption.



Component type	Series	Purpose
1 **Ferrite beads**	BLM, BLE, BLF, NFZ	Power & signal line filtering
2 **Power inductors, Power CMCC**	DFE, FCUL, LQH, MDH. PLT, DLW	Power conversion and line filtering
3 **PoC inductors**	LQW32FT, LQH	Bias-T filter
4 **RF inductors**	LQP, LQW, LQG	Impedance matching & RF choke
5 **Signal CMCC**	DLW, DLM, NFG	Common mode noise filter
6 **Block filter**	BNX	High power noise filtering

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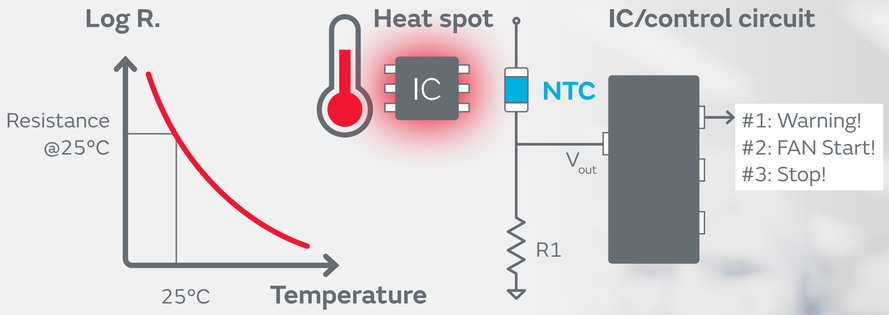
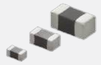
NTC thermistors

Temperature sensing and compensation



NCP series & NCU series



- Various size options
- High accuracy
- High reliability

NCP series 〉 NCU series 〉

Humanoid robotics applications

- Temperature control for SoC board
- Temperature monitoring of battery management system
- High reliability

Series	Notes	Size [mm]			
		0.4x0.2	0.6x0.3	1.0x0.5	1.6x0.8
NCP	Consumer applications	**NCP02**	**NCP03**		
NCU	High reliability applications		**NCU03** *(Automotive grade available)*	**NCU15** *(Automotive grade available)*	**NCU18** *(Automotive grade available)*
NCG	Conductive glue mounting				**NCG18** *(Automotive grade available)*

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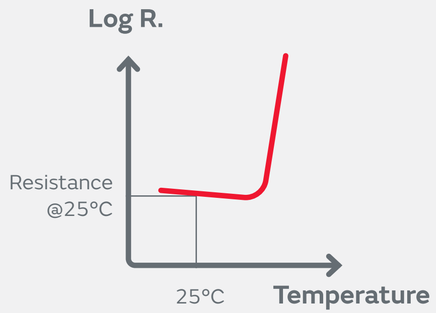
Overview - PTC thermistors

PTC thermistors

Overcurrent protection / Overheat detection



Overcurrent protection

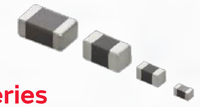
PRG series

- Resettable fuse
- Stable characteristics

PRG series

Maintenance-free resettable fuse

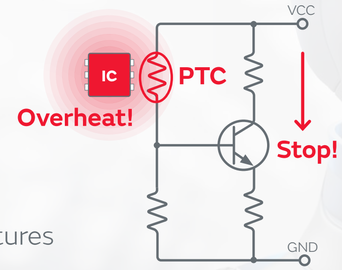
Overheat detection

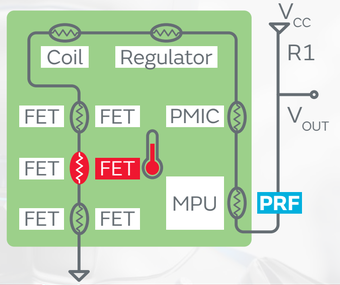


PRF series

- Simple detection circuit
- Wide range of detection temperatures

PRF series





Simple overheat detection without MCU

Multi-point detection

Humanoid robotics applications

- Overheat detection for motors and connectors
- Overcurrent protection as a resettable fuse

Series	Notes	Size [mm]			
		0.6x0.3	1.0x0.5	1.6x0.8	2.0x1.2
PRF	Overheat sensing	**PRF03**	**PRF05**	**PRF18** *(Automotive grade available)*	**PRF21**
PRG	Over-current protection	**PRG03**	**PRG05**	**PRG18** *(Automotive grade available)*	**PRG21** *(Automotive grade available)*

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24V Battery Module (LFP-type)

24V Battery Module (LFP-type) uses olivine type lithium iron phosphate (LiFePO4) for high safety and long life. It's widely used in AGV and robot, helping improve factory automation and logistics efficiency.

Features

- **High safety:** Resistant to ignition under high shock or pressure.
- **Long life:** The crystalline structure is solid and stable, so capacity deterioration is gradual even with repeated charging/discharging.
- **Fast charge:** Fully charges in about 1 hour.
- **Accurate SOC detection:** Detects remaining capacity to 1% accuracy.
- **Long-term cost efficiency:** Reduces maintenance efforts and operational costs.

System configuration	BMU function included
Chemical	LFP
Nominal voltage / capacity	25.6 VDC / 21 Ah / 537 Wh
Dimension (mm)	195 (L) x 132 (W) x 180 (H)
Weight	Approx. 6.5 kg
Max charge current	42A (2C)
Max. discharge current	100A / 80A / 60A (5sec / 25sec / Cont.)
Dust and waterproof	IP54

Lithium-ion Secondary Batteries (NCA-type)

Lithium-ion secondary batteries (NCA-type) have low resistance and large discharge current, making them ideal for powering compact actuators in robots.

Features

- Brings together technology behind the development of the world's first lithium-ion secondary battery products in 1991.
- Since the start of mass production, solid reliability has led to the adoption of these products in a variety of devices worldwide.
- A broad lineup of large-current-discharge models is available, covering a variety of capacities and sizes.

Example products:

Part number	Rated capacity	Nominal voltage	Weight	Continuous max. discharge current
US18650VTC6	3.0 Ah	3.6 VDC	46.5 g	30A
US21700VTC6A	4.0 Ah	3.6 VDC	68.0 g	40A

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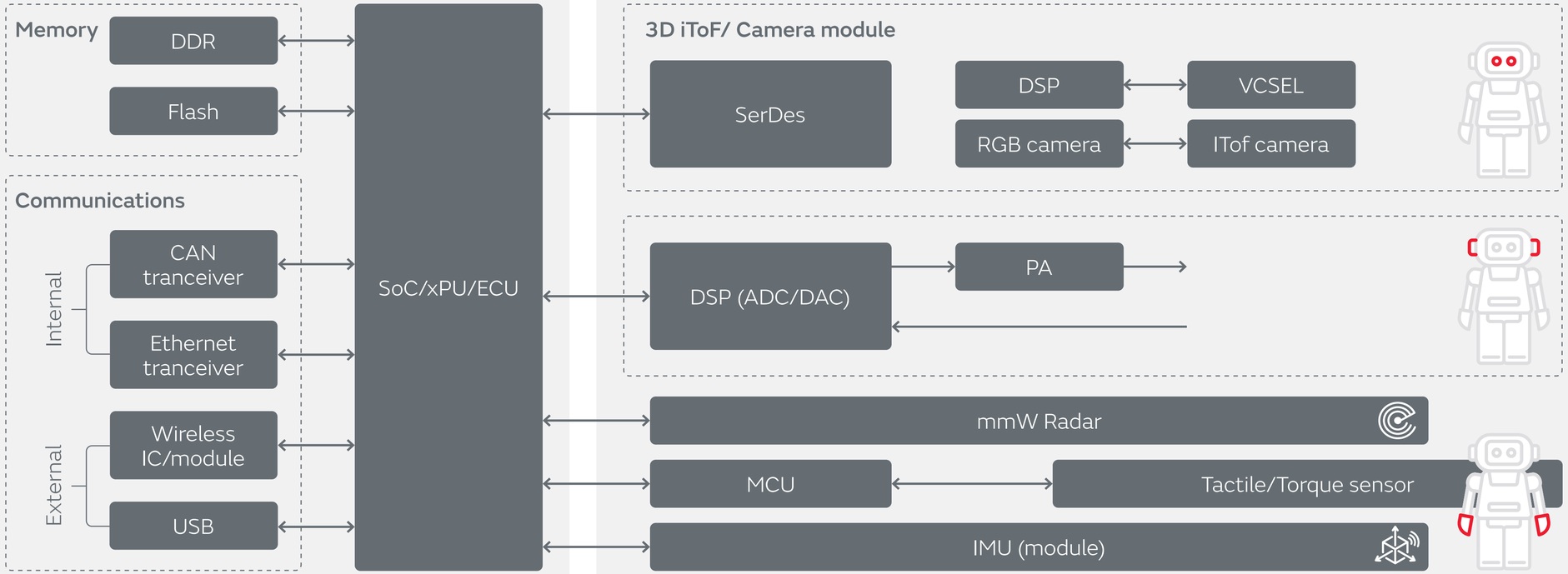
Murata solutions

Sensing system - block diagram

Features of core parts								
Main power	Decision making	Joint & servo motor	Connectivity	Sensing				
				Vision		Touching	Hearing	Smelling	IMU
Battery	GPU/GPU	Actuator	Wireless for external communication	Camera	Radar/Lidar				
		Dexterous hand							



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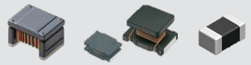
SoC core-board target items by circuit

Application	Circuit	Ref.D items	Appearance
Power supply	PMIC Power Management IC DrMOS (V Core 0.8v/1v/3.3v)	PI: DFE series	
		Decoupling Cap: NFM, Hi-Cap	
		Clock X'tal: XRCGB series	
Internal communication	CAN/EtherNet/EtherCat/USB	CMCC: DLW/DLM series	
		Bias-T L: LQW-FT/LQH/LQW/BLM	
	PoC, SerDes	Clock X'tal: XRCGB series	
External communication	WiFi/BT/UWB	Module types: UWB type 2AB	
	GPU/GPU	Thermistor: PRG, NTC	

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Murata solutions

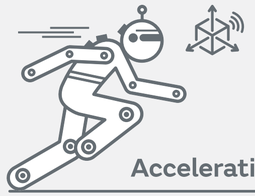
Sensing system - Murata sensor types

Motion: Inertial detection

Acceleration

MEMS

Acceleration sensor



Acceleration & gyro

MEMS

Gyroscope combo sensor

Horizontal level

MEMS

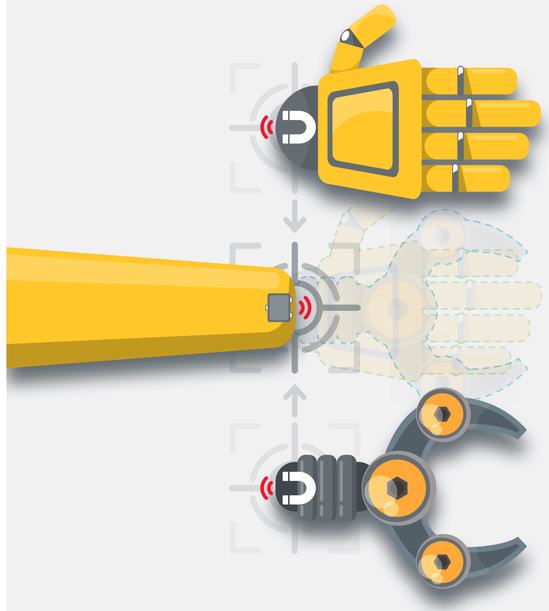
Inclinometer sensor

Object: Position detection

Magnetic detection

Magnetic

AMR sensors



Heat: Atmosphere detection

Temperature measurement
Over-current protection

Ceramic

NTC/PTC thermistors

Soil

Soil sensor

CO_2

CO_2 sensor

Air pressure

Barometric sensor

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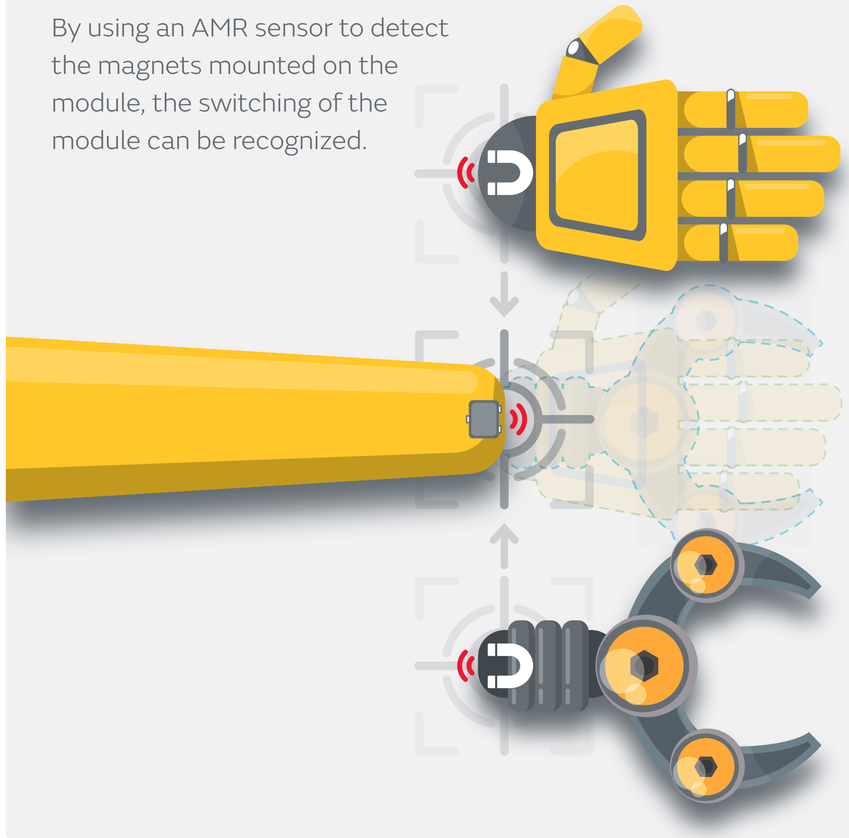
Murata solutions

Sensing system - AMR sensors

Use case 1: Module change detection

By using an AMR sensor to detect the magnets mounted on the module, the switching of the module can be recognized.



Use case 2: Charging detection

By using an AMR sensor to detect the magnets mounted on the charger, it is possible to determine whether the robot is in contact with the charger.

Part number	Appearance
MRMS501A-001 	Low current consumption (3uA @Vcc=1.8V) 
MRMS591P 	Wide range detection (360degree detection) 

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Sensing system - gyros and accelerometers

SCH16T Series combined gyro sensor and accelerometer

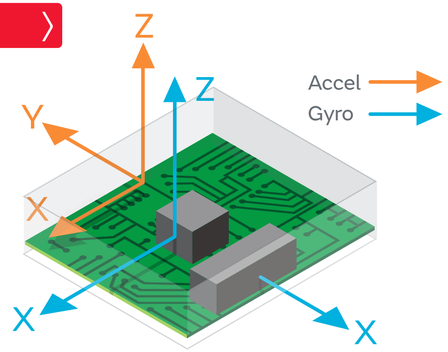
The SCH16T series delivers industry leading performance and safety in a single package 6DoF MEMS IMU, designed for demanding industrial environments. The series includes three variants:

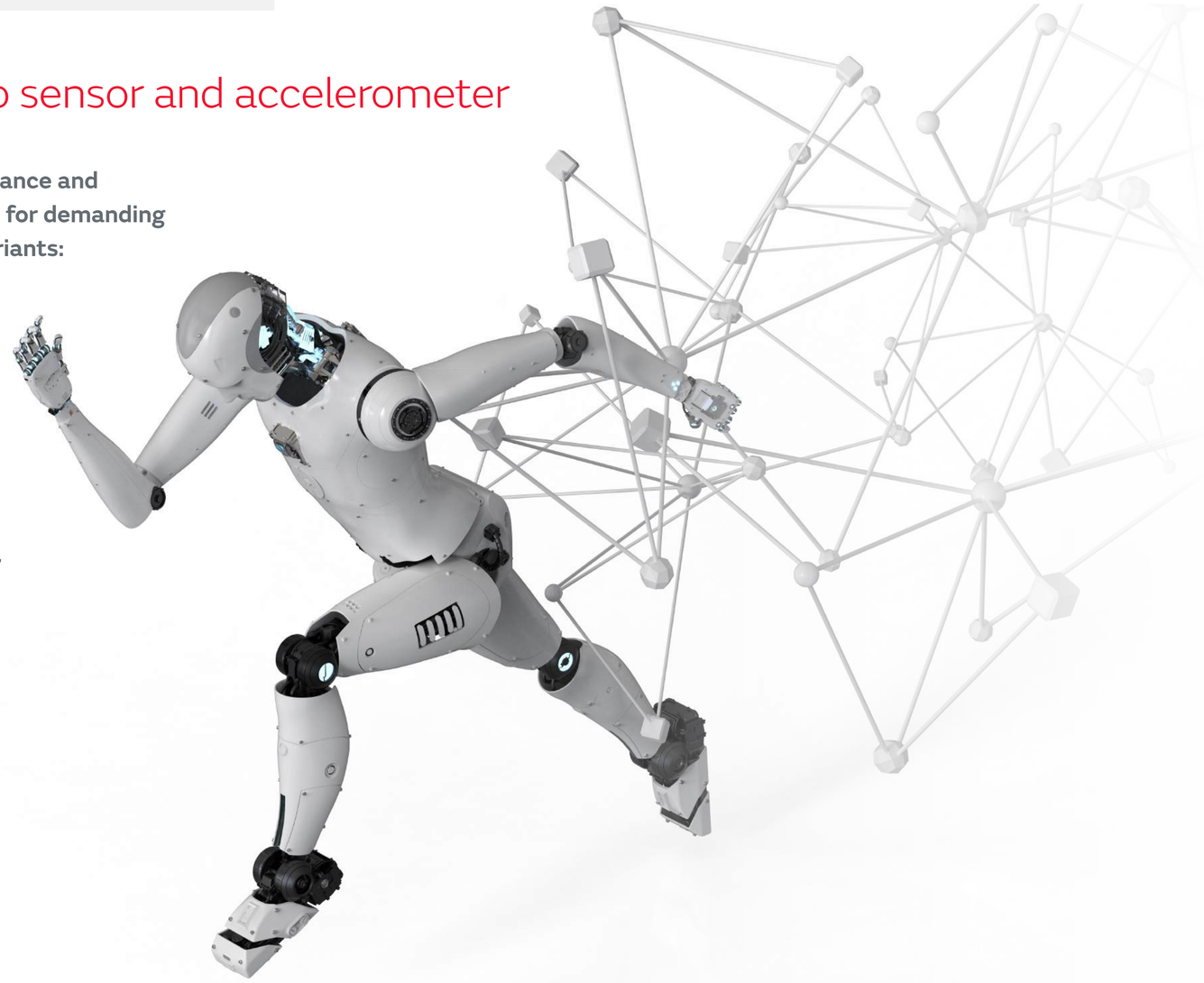
- SCH16T-K01
- SCH16T-K10
- SCH16T-K20

Features

- High performance (Good noise characteristics and temperature stability)
- High reliability (Robust against temperature changes, vibrations, and shocks, with minimal long-term drift)

Find out more 〉





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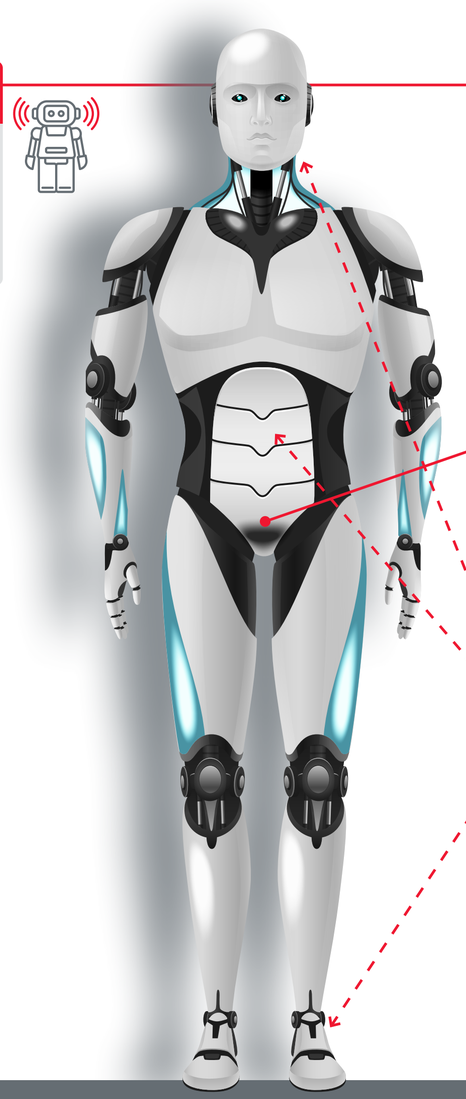
Murata solutions

Sensing system - IMU

Sensing

- 3D camera
- IMU



Perception fusion

The head IMU supports positioning and SLAM by integrating camera data, enabling high update rates, reducing image blur, and maintaining head stability during movement.

IMU

Posture estimation

The crotch IMU monitors posture and gait by detecting waist tilt angular velocity and adjusting lower limb joints in real time.

Posture estimation (optional)

SCH16T Series

- Low Noise
- High vibration robustness

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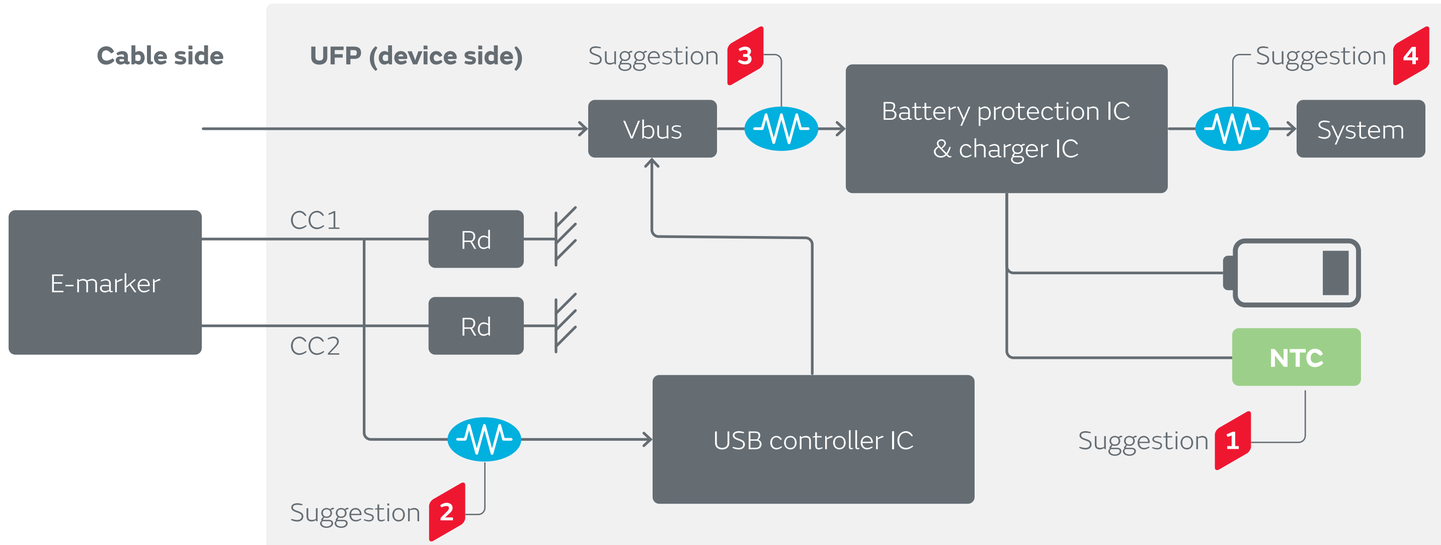
Murata solutions

Sensing system - thermistors for USB protection

USB type-C

Risks of short circuit

- Dust
- Liquid



PRG series

- Robustness because of the simple circuit
- Space saving by small component size

USB type-C (24 pins)

GND	RX2+	RX2-	VBUS	SBU1	D-	D+	CC	VBUS	TX1-	TX1+	GND	—	—
GND	TX2+	TX2-	VBUS	VCON	—	—	—	—	SBU2	VBUS	RX1-	RX1+	GND

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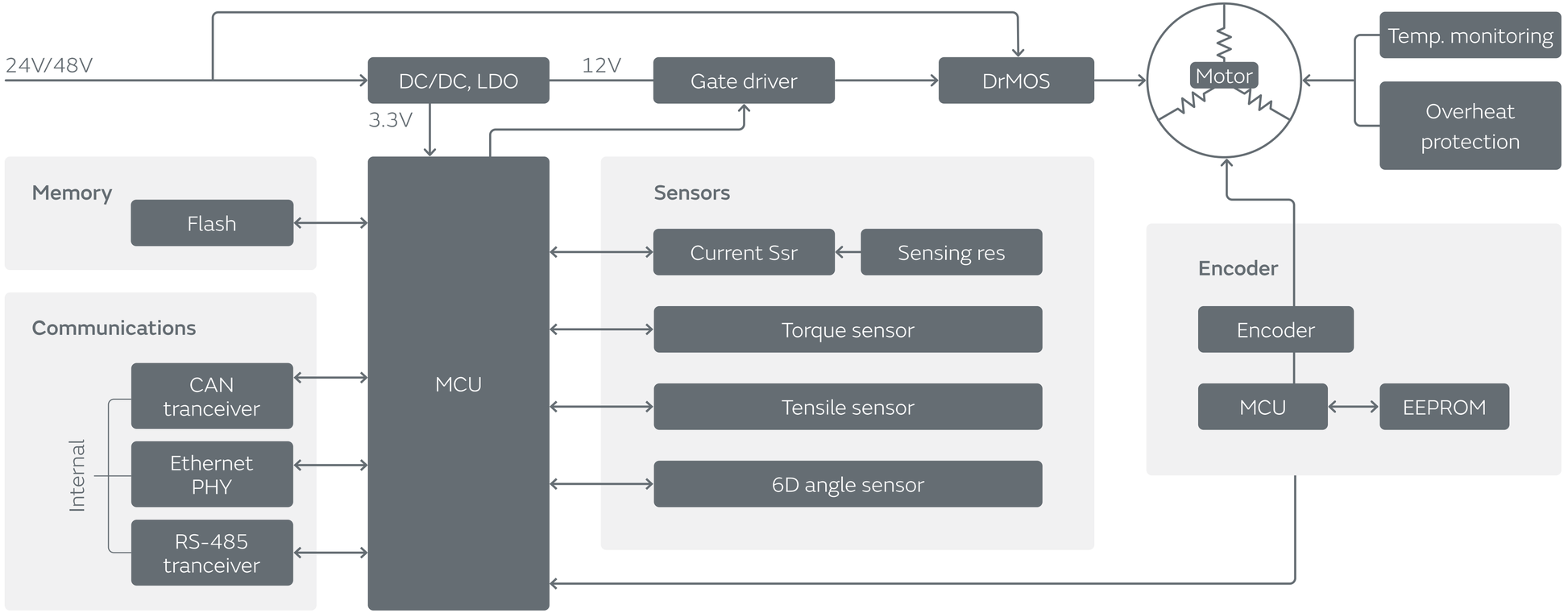
Motion system - actuators

Features of core parts								
Main power	Decision making	Joint & servo motor	Connectivity	Sensing				
				Vision		Touching	Hearing	Smelling	IMU
Battery	GPU/GPU	Actuator Dexterous hand	Wireless for external communication	Camera	Radar/Lidar				



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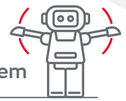

Motion system - high-effective-capacitance MLCCs

Capacitor Type	Package/ Rated capacitance	Part number	L (mm)	W (mm)	T max. (mm)	Effective capacitance @ 0.8/25°C	Capacitance density @ 0.8/25°C
MLCC	1210/330µF	GRM32EC80E337ME05	3.2±0.3	2.5±0.3	2.8	289µF	**36µF/mm²**
MLCC	1206/ 330µF	†GRM31CC80E337m***	3.2±0.3	1.6±0.3	1.9	285µF	**56µF/mm²**
MLCC	1206/220µF	GRM31CC80E227ME11	3.2±0.3	1.6±0.3	1.9	185µF	**36µF/mm²**
MLCC	0805/100µF	GRM21BC80E107ME15	2.0±0.2	1.25±0.2	1.45	83µF	**33µF/mm²**
MLCC	0603/100µF	GRM188C80E107ME01	1.6±0.2	0.8±0.2	1.0	60µF	47µF/mm²
Polymer	7343/470µF	ECASD40E477M4R5KA0	7.3±0.3	4.3±0.2	2.0	470µF	15µF/mm²

†*Under Development. Specifications and appearance are subject to change without notice*

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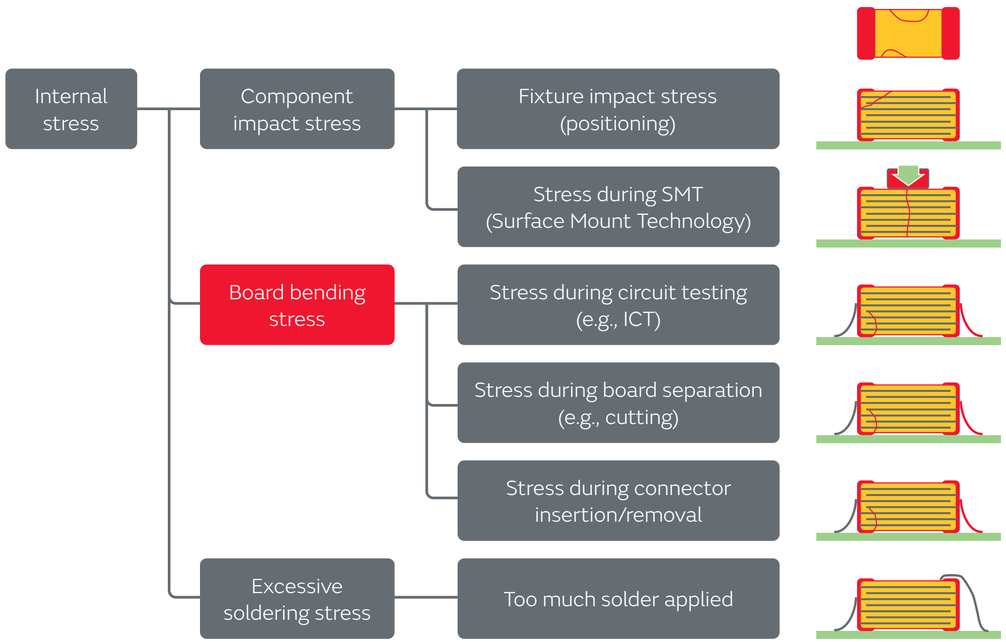
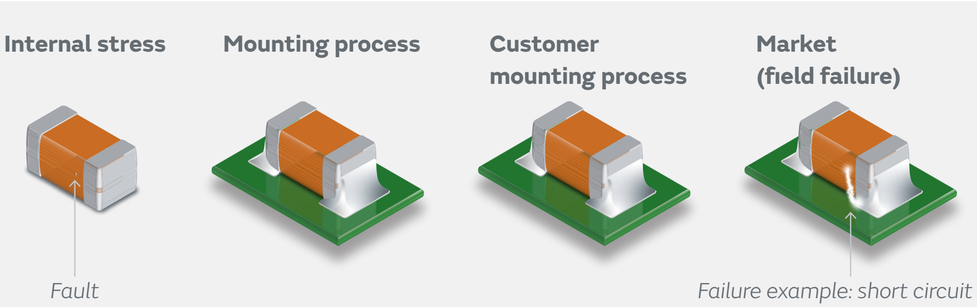
Murata solutions

Motion system - PCB-bend-stress-resistant MLCCs





Product countermeasures

- **GRM** series standard products
- **GRJ** series wide terminal products
- **KRM** series metal terminal products

Type	Structure comparison	Bending spec.
 Standard (**GRM** series)	 Cu Electrode Layer Ni/Sn Plated Layer	1mm
 Soft termination (**GRJ** series)	 Cu Electrode Layer Resin Electrode Layer Ni/Sn Plated Layer	General: 3mm
 Metal termination (**KRM** series)	 Ferric Alloy LF High-Temp Solder	5mm

Service countermeasures

- Murata engineers assist customers with on-site mounting process checks and identify bending stress during assembly.
- By improving the mounting process, we can help reduce bending stress and prevent internal cracks.
- KRM series metal terminal products

Notes

- Verify actual stress and correct environmental conditions.
- Identify root cause by providing mounting process information.
- If the failure is due to internal cracks, it is difficult to determine the original cause.

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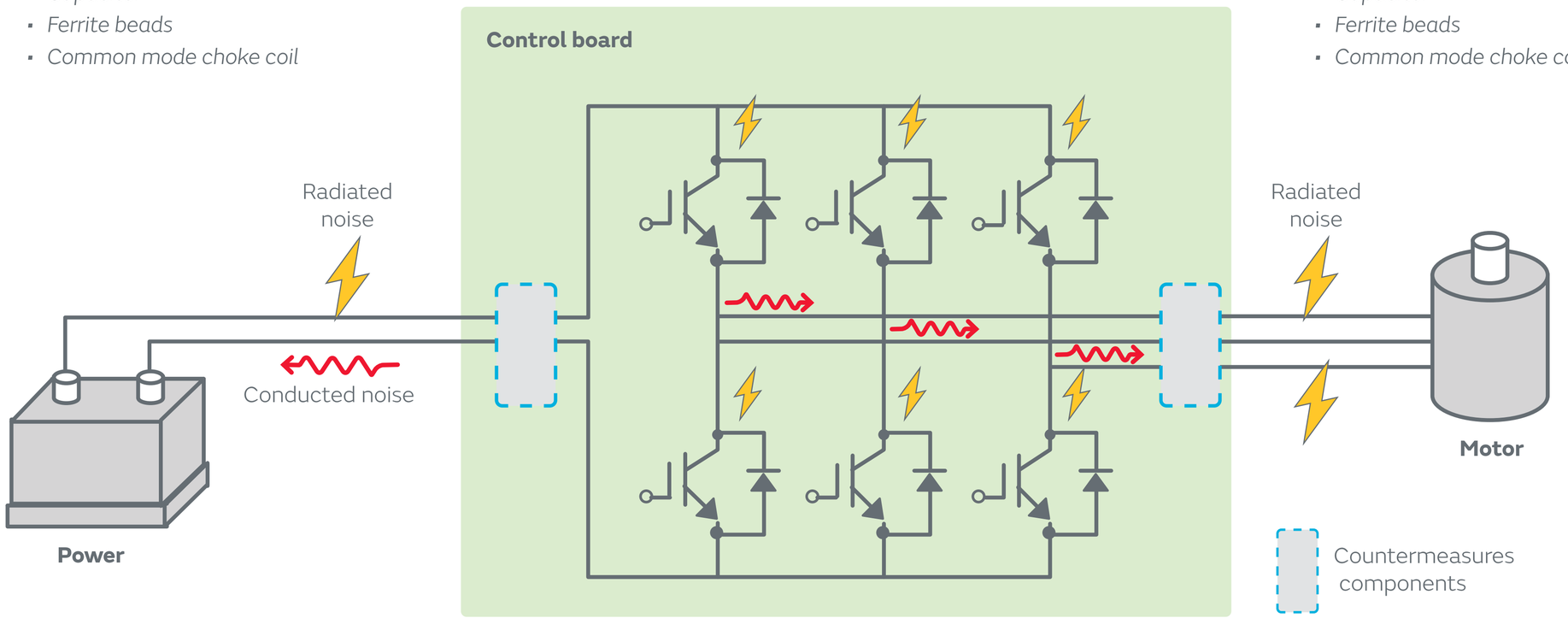
Motion system - three-phase brushless motor noise (partial)

Input side (power supply line)

- Common-mode noise is dominant
- Countermeasure components:
  - *Capacitor*
  - *Ferrite beads*
  - *Common mode choke coil*

Output side (three-phase lines)

- Common-mode noise is dominant
- Countermeasure components:
  - *Capacitor*
  - *Ferrite beads*
  - *Common mode choke coil*



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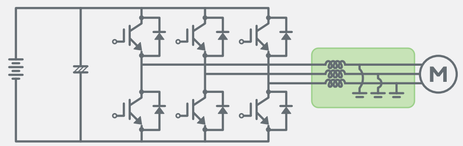
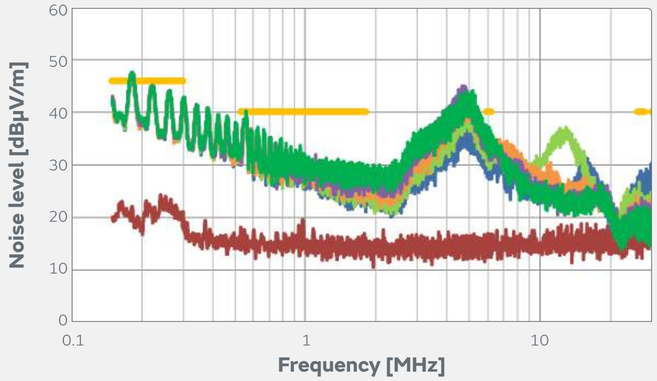
Motion system - three-phase brushless motor noise

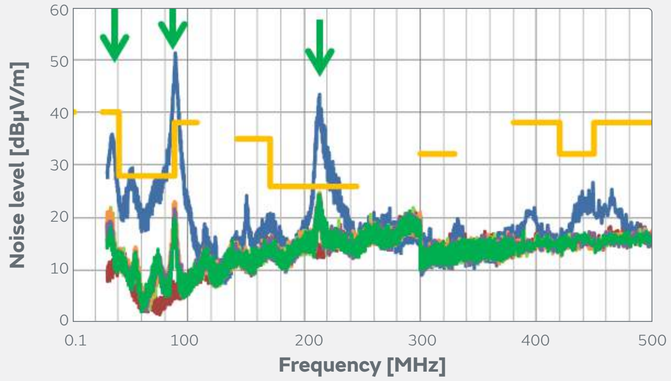
Noise countermeasures

Output side



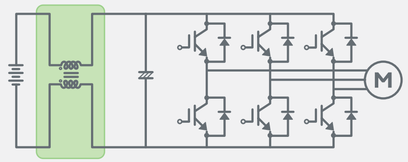
- Initial noise level
- Cap 1nF + ferrite beads 30Ω/10A
- Cap 1nF + ferrite beads 30Ω/10A
- Cap 1nF + ferrite beads 30Ω/10A
- Cap 1nF + ferrite beads 30Ω/10A
- Floor



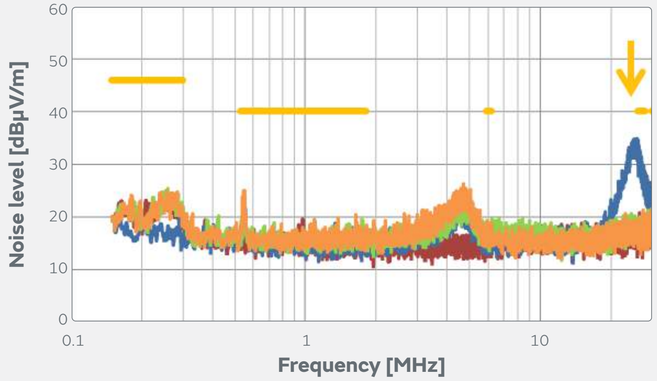


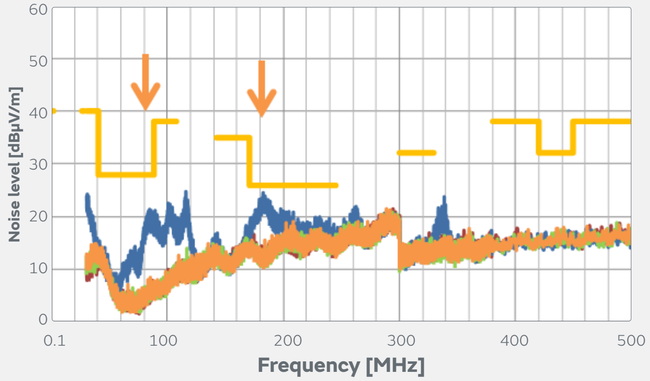
Noise countermeasures

Input side



- Initial noise level
- 500Ω/2A(PLT5BPH501)
- 1000Ω/6A(PLT10HH102)
- Floor





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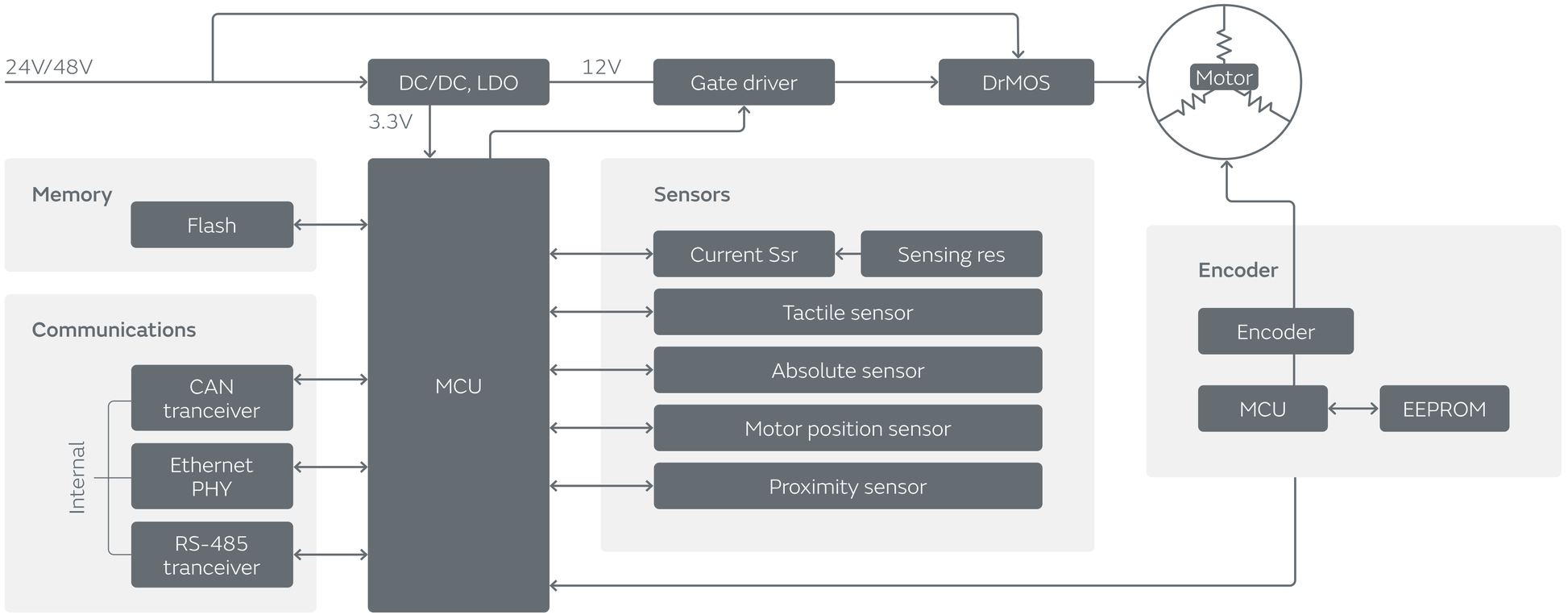
Murata solutions

Motion system - dexterous hand

Features of core parts								
Main power	Decision making	Joint & servo motor	Connectivity	Sensing				
				Vision		Touching	Hearing	Smelling	IMU
Battery	GPU/GPU	Actuator	Wireless for external communication	Camera	Radar/Lidar				
		Dexterous hand							



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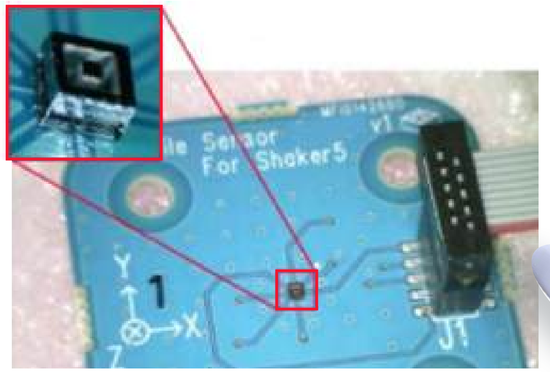
Motion system - dexterous hand

Tactile sensor

Specification comparison

Company	A	B	muRata INNOVATOR IN ELECTRONICS
Sixe mm	1.5x0.85	2.0x2.0	**1.0x1.0**
Detection axis	Z 1-axis	XYZ 3-axis	**XYZ** **3-axis**
Minimum force	10mN	1N	**1mN**
Max force	8N	7N	TBD

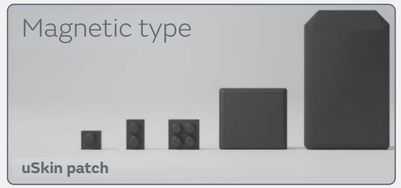


Murata product advantages

- **Ultra-small**
  Can be integrated into fingertips
- **Three-axis detection**
  Slip detection is available
- **Small-force detection**
  Contributes to delicate fingertip control

Sensor

Finger rubber



Peripheral circuit design

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Flexible PCB (Murata LCP)

Liquid Crystal Polymer (LCP)

Material:	All LCP, adhesive-free lamination, low water absorption
Base Material Electrical Properties:	Dk 3.0, Df 0.002
Chemical Resistance:	Acid-resistant, alkali-resistant, low water absorption
Lamination Process:	Single lamination molding, supports multi-layer product manufacturing
Layer Limit:	Up to 22 layers
Thinnest Base Material:	13 µm LCP
Minimum Line/Space:	L/S = 40 µm / 40 µm
Bending Capability:	Good bending capability; electrical performance remains stable and does not degrade with repeated bending

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Murata solutions

Motion system - power modules

PDU (Power Distribution Unit)

Isolated DC/DC

UWE series
48Vin-12Vout
120~240W

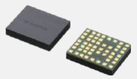
DSE series
48Vin-12Vout
400W

MPQ600
48Vin-24Vout
600W

MPQ700
48Vin-48Vout
700W

Intermediate converter

Non-isolated DC/DC



MYC0409
48Vin-12Vout
72W

MYC0409*4para
48Vin-24Vout
200W

Interface/BMS system

Low power isolated DC/DC

NXJ1T series
1W

NXE1S series
1W

NME1 series
1W

NCM3C series
3W

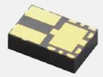
NXJ2S series
2W

Sensors

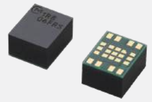
IMU, vision camera, LiDAR, ultrasonic, infrared

DAQ

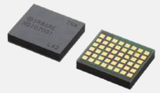
(Data Acquisition Module)



MYRGM series
1.5~2A



MYM series
2.5~40A



MYTN series
6~8A

UWS series
50W

ULS series
60-100W

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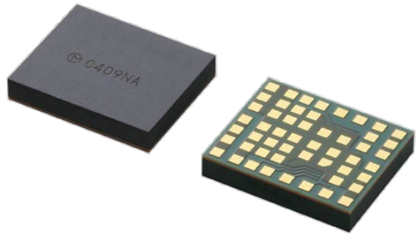
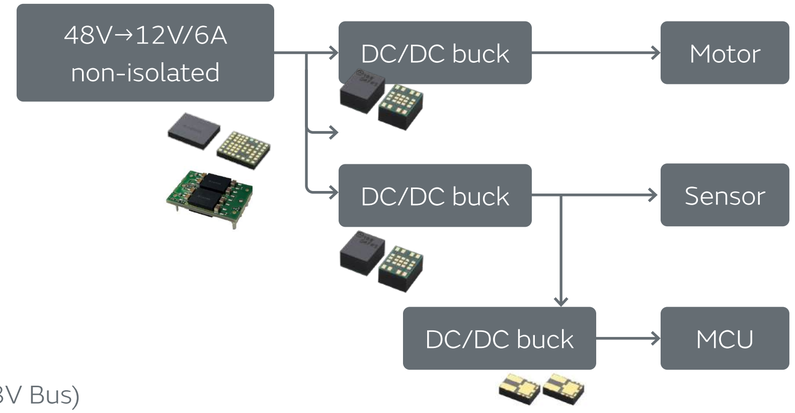
Low-profile power supply (Murata MYC0409)

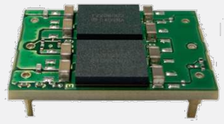
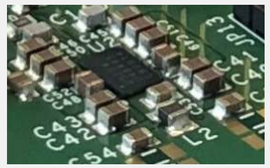




Features

- Input voltage:
  Output voltage = 4:1 Fixed Ratio
- Input voltage range: 20 to 60 V (48V Bus)
- Output voltage: Vin/4
- Output current: Up to 6A
- Output efficiency: Up to 96.5%
- Ultra-low profile
- Up to 4 modules can be connected in parallel

Simultaneously

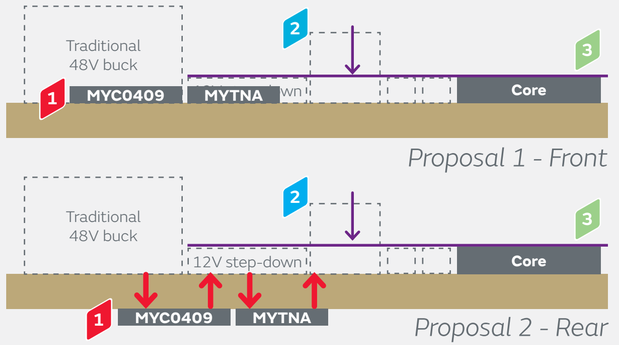
16th Brick (2 or 4 in parallel)	Discrete IC
	
MYBSN	PE25204

Proposal & advantages

1 **Ultra-low profile**
(suitable for surface-mount backplane)
→ Reduces space and losses

2 **Stepped small voltage drop + high frequency**
→ Fewer filters in the buck stage

3 **Thinner modules**
→ Shared heat sink



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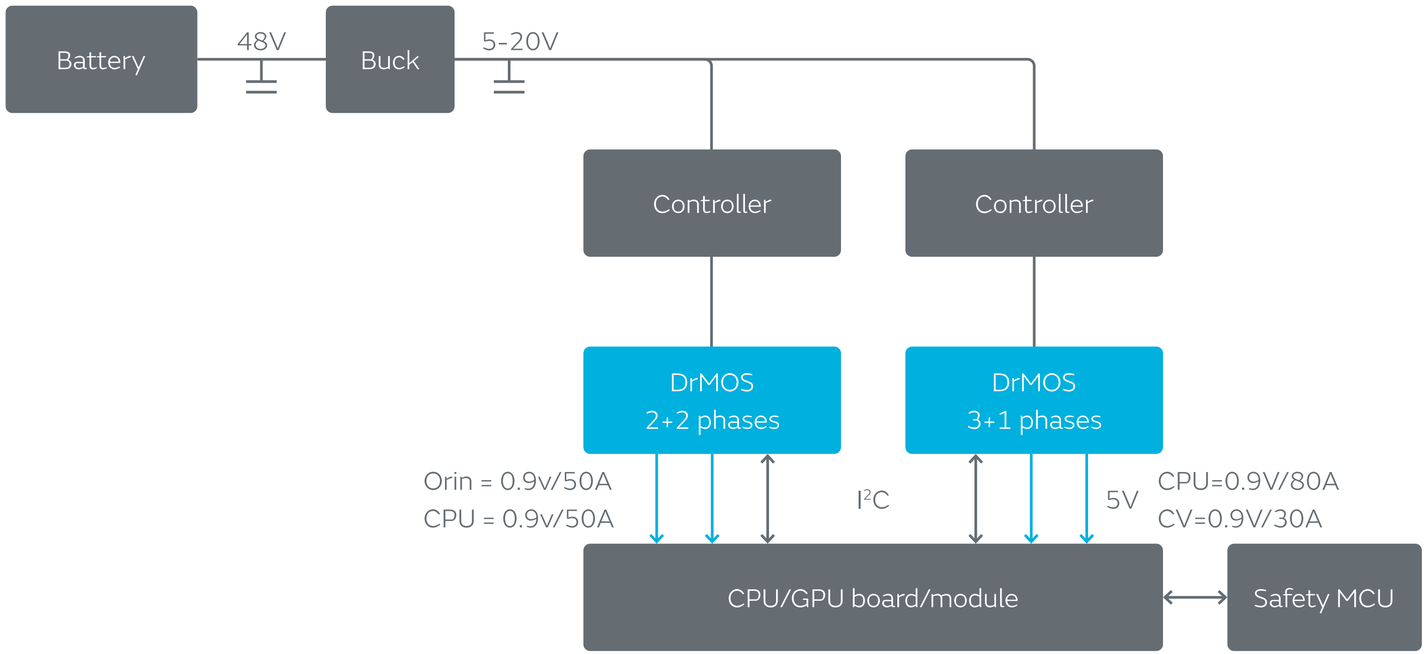
Control system

Features of core parts								
Main power	Decision making	Joint & servo motor	Connectivity	Sensing				
Battery	GPU/GPU	Actuator	Wireless for external communication	Vision		Touching	Hearing	Smelling	IMU
		Dexterous hand		Camera	Radar/Lidar				

GPU/CPU power structure



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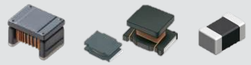
Control system - power modules

SoC core-board target items by circuit

Application	Circuit	Ref.D items	Appearance
Power supply	PMIC Power Management IC DrMOS (V Core 0.8v/1v/3.3v)	PI: DFE series	
		Decoupling Cap: NFM, Hi-Cap	
		Clock X'tal: XRCGB series	
Internal communication	CAN/EtherNet/EtherCat/USB	CMCC: DLW/DLM series	
		Bias-T L: LQW-FT/LQH/LQW/BLM	
	PoC, SerDes	Clock X'tal: XRCGB series	
External communication	WiFi/BT/UWB	Module types: Please consult with Murata PE team) UWB Type 2AB (for example)	
	USB (type C)	Thermistor: PRG, NTC	

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Murata solutions

Battery & BMS

Features of core parts								
Main power	**Decision making**	**Joint & servo motor**	**Connectivity**	**Sensing**				
Battery	GPU/GPU	Actuator	Wireless for external communication	Vision		Touching	Hearing	Smelling	IMU
		Dexterous hand		Camera	Radar/Lidar				

Pack core parts

- Battery cell string
- Harness board & bus bar
- Module housing

↕ Data collection / protection

BMS

- Data acquisition
- Protection mechanism: over-charge/over-discharge/temp. etc.
- Cell balancing
- Comms interface, CAN

↕ Data collection / protection

External interaction & connection

- Charger
- Robot main controller

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Battery & BMS - Why choose Murata?

Murata VX Battery – Why choose Murata?

A: Higher reliability with less imbalance for end users

- **Imbalance suppression method**
  - Muata's unique formation process condition (common to all models)
- **Less contamination due to unique forming method**
  - Murata's Unique ORIGAMI* process (specific to tabless models)

*art of folding paper

B: Higher productivity for end users

- **Fast charging performance**
  - Murata's unique design of the electrolyte + optimal formation condition (common to all models)

C: Stable performance for end users

- **Less deterioration on 1. impedance and 2. thermal stability during product life**
  - Muata’s electrode design specialized for resistance increase suppression (common to all models)
  - Murata's unique design of the electrolyte + optimal formation condition (common to all models)

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Battery & BMS - Thermistors

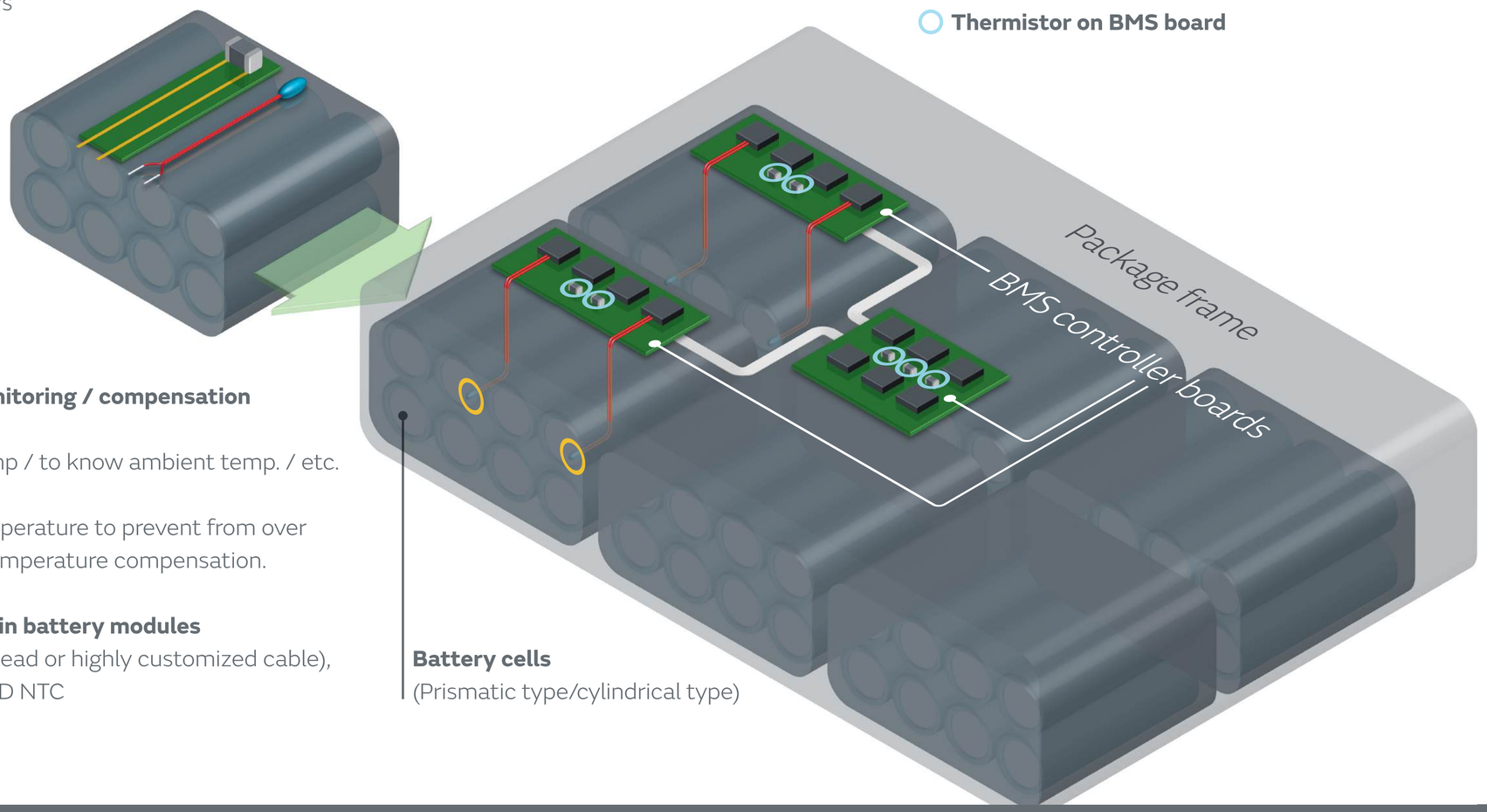
NTC/PTC thermistors

Control board, battery cell, shunt resistor...

All will incorporate thermistors, with a requirement for high-reliability thermistors

Typical positioning of thermistors in a BMS battery pack

- **Thermistor attached at battery cells**
- **Thermistor on BMS board**



NTC function

- **Temperature monitoring / compensation**
  - BMS board:
    Detect ECU temp / to know ambient temp. / etc.
  - Battery cell:
    Detect Cell temperature to prevent from over heating or do temperature compensation.

Typical NTC usage in battery modules

- Lead type (bead head or highly customized cable), or FPC(FDC) + SMD NTC

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The future of humanoid robots

Predictions

1 Rapid market expansion

The ongoing advancements in artificial intelligence and sensor technologies are driving a significant increase in demand for humanoid robots equipped with sophisticated autonomous functions and human-like interfaces.

The adoption of these robots is expected to accelerate in key sectors, including manufacturing, logistics, healthcare, and service industries. This surge in demand will necessitate a robust supply chain capable of supporting the complexities associated with design, production, and deployment.

2 Transition to mass production

Currently, many humanoid robots are confined to prototyping and limited-implementation phases. However, a pivotal shift toward large-scale mass production and commercialization is projected to occur in the late 2020s.

This transition is essential for achieving cost reductions and enhancing quality stability through economies of scale. The evolution from small-scale production to mass production will demand a re-examination of supply chains, ensuring that they can accommodate increased volume while maintaining high standards of quality and efficiency

3 Diversification of applications & needs

The demand for humanoid robots is expanding beyond simple task execution, incorporating intricate movements and interactions that address emotional intelligence and human-centric designs.

Consequently, there is an increasing requirement for the development of more advanced, multifunctional models that can serve diverse industries and applications. The supply chain must adapt to facilitate the integration of innovative components and technologies that enhance the capabilities of humanoid robots.

4 Modular architecture & enhanced integration

As the industry evolves, the real-world applications of humanoid robots are also shifting toward modular architecture, broader cloud and AI integration, and the development of bio-inspired sensing and actuation systems.

This trend will play a crucial role in how humanoid robots are designed, produced, and operated. Startups and established players alike face the challenge of adapting to emerging safety frameworks and reliability standards, making it imperative to scrutinize component choices throughout the design process.

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The future of humanoid robots

Murata's vision and conclusion

Murata is proactively updating its product roadmap in response to these new realities. We are accelerating the development of certified, high-reliability sensor modules, multilayer capacitors with industry-leading lifespans, and fully tested communications platforms for autonomous, human-centric environments.

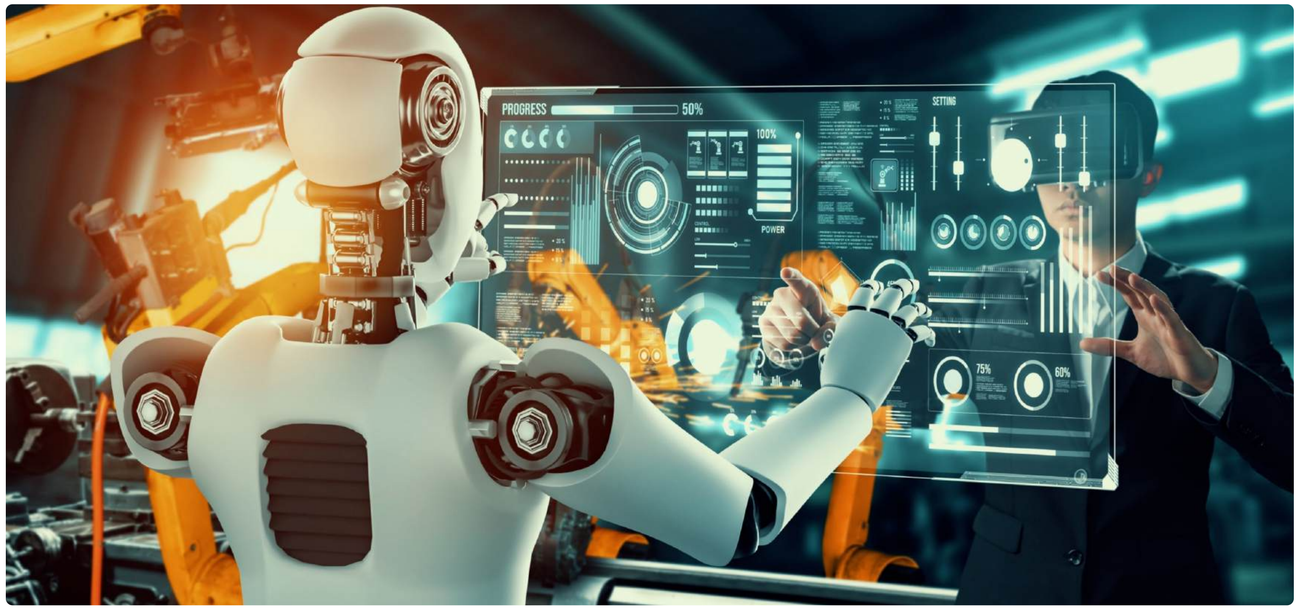
> A collaborative approach across the supply chain will be critical

Murata's close partnerships with robotic manufactures, ongoing investment in research and development, and legacy of reliability position it as a key player in the advancing field of humanoid robotics.

Companies that anticipate these convergences and invest in certified, high-reliability systems will be at the forefront of defining the next era of humanoid robotics. As the market expands and diversifies, a collaborative approach across the supply chain will be critical in ensuring that humanoid robots meet the increasing expectations of functionality, safety, and adaptability.

The future of humanoid robotics is promising, marked by rapid market expansion, a transition towards mass production, and an evolution of applications that require sophisticated interactions.

Supply chains must adapt to these changes, embracing modular approaches and integrating advanced technologies to remain competitive. Murata Manufacturing is poised to lead the charge, leveraging their expertise and resources to shape the landscape of humanoid robotics and ensure its successful integration into society.



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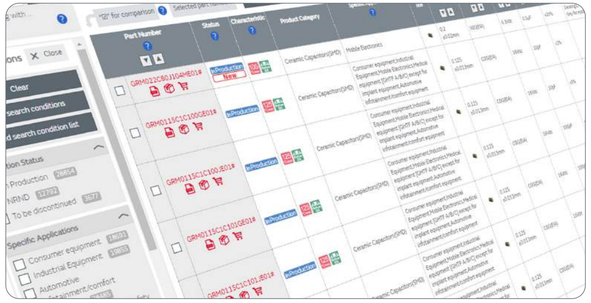
Corporate support

Online support & services

As part of our commitment to customer support, Murata aims to...

Foster innovation with a user-friendly website offering comprehensive search functionality



Product search and data

- Search for products by product number and specifications.
- Download data files.

View product search 〉

Product FAQs

- Questions and answers on various topics, such as "What are some board design precautions when using MLCCs to reduce size?"

View FAQs 〉

Accelerate design with simulation tools for efficient development

SimSurfing

- Search effective components in our solutions (example case : "capacitance of 5 uF or greater at a DC voltage of 1 V and a temperature of 50°C").
- Compare multiple products with electrical characteristics overlaid on a graph.

View SimSurfing 〉

Offer enhanced, personalised experience for valued customers

myMurata

- Free samples may be requested.
- You can contribute or refer to any questions on Bulletin board.
- Member-only detailed information such as “EDA Library“, “S-PARA“ and “crack formation mechanism".

View myMurata 〉

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Murata is committed to meeting market demand and driving sustainable value creation

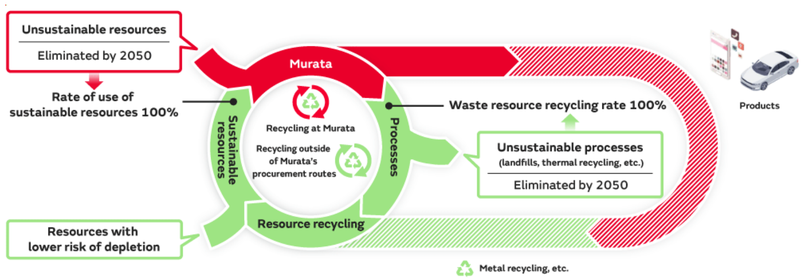
Establishing stable supply to meet market demand

We prioritize building a robust infrastructure to ensure stable supply, aligned with market requirements.

- **Murata locations**
  Administration offices
  Research centers
  Sales offices
  Manufacturing plants

Embracing sustainability for long-term value

We actively reduce environmental impact across our operations and focus on developing environmentally conscious products to achieve long-term value creation.



Find out more 〉

Contact us 〉

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