Application Brief

Application of GaN FET in Humanoid Robots

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Introduction

Humanoid robots integrate many subsystems, including servo control systems, battery management system (BMS), sensor systems, AI system control, and many more. Size and heat dissipation requirements are challenging to meet when integrating these systems into the volume of a human while maintaining the smooth operation of this complex system. The most space constrained subsystem within the humanoid robot is the servo control system. To achieve range of motion similar to that of humans, about 40 servo motors (PMSM) and control systems are usually deployed throughout the robot. The motors are distributed through different parts of the body, such as the neck, torso, arms, legs, toes, and others. This number does not include the motors in the hands. To simulate the freedom of human hands, a single hand can integrate more than a dozen micro motors. The power requirements of these motors depend on the specific functions performed; for example, motors driving a robot's fingers possibly only require a few amps, while motors driving a hip or leg can require 100 amps or more.

Compared with traditional servo systems, servo systems for humanoid robots have higher control accuracy, size, and heat dissipation requirements. This article explains the various advantages of GaN (Gallium Nitride) technology in motor drives and shows how GaN can help solve the challenges faced by servo systems in humanoid robots.

More Precise Control

In servo motor-drive applications, motor control is typically separated into several control-loop layers: the current/torque loop, speed loop, position loop and a higher-level motion-control loop. These loops are typically arranged in a cascade, each with real-time processing requirements. The current/torque loop is the fastest control loop. Each upstream loop runs at a multiple of the loop before and provides input references to the downstream loops. Figure 1 shows a typical cascaded control topology.

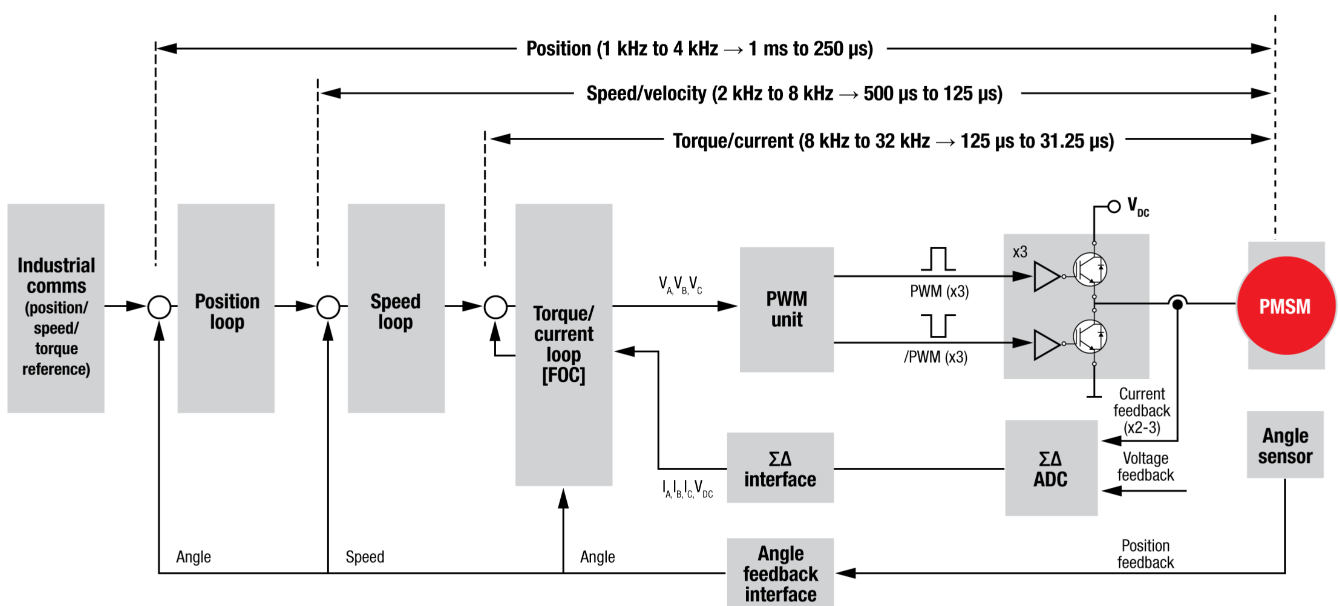

Figure 1. Typical Servo-Motor Control-Loop Technology

The most important part of the control loop is the current loop. Typically, the FET switching frequency is the same as current loop, around 8kHz to 32kHz. The speed of the current loop directly affects the accuracy and response speed of the motor control. A simple action of a humanoid robot involves the control of many servo motors. To coordinate nearly 40 motors in the robot body while maintaining the stability of the system, the control accuracy and response speed of each joint must meet very high requirements. These requirements can be met by increasing the speed of the motor control loop and the PWM frequency. For example, a switching frequency of 100kHz (Figure 2) can achieve a higher resolution motor current, corresponding to a smaller motor current ripple and more precise control. A high-resolution motor current waveform also means a better current sinusoidally, which improves the operating efficiency of the motor and reduces motor heating.

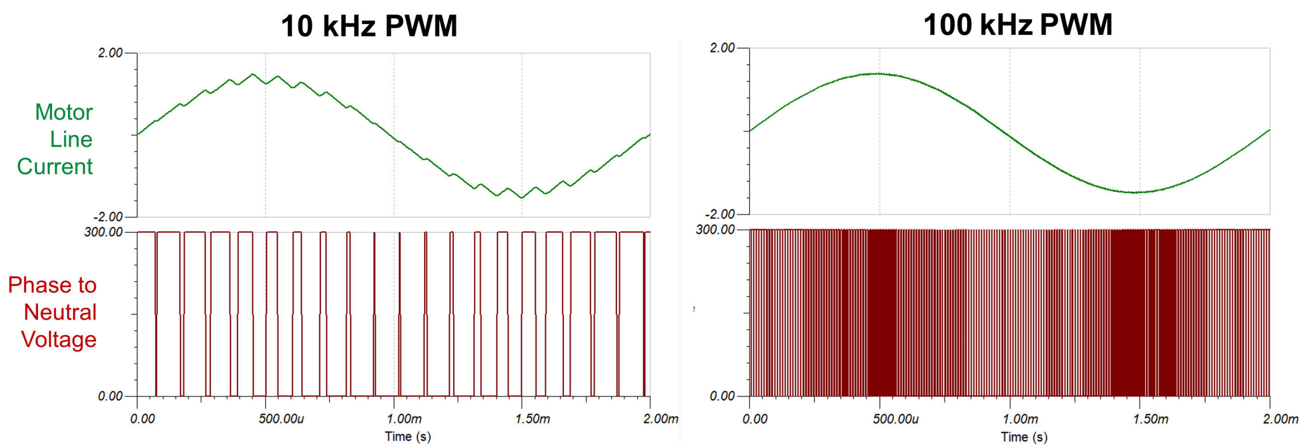

Figure 2. 100kHz and 10kHz PWM Motor Current

In addition, increasing the PWM switching frequency can reduce DC bus capacitor size and capacitance. The lower bus capacitance requirement for electrolytic capacitors to be replaced with ceramic capacitors. The servo power stage FETs periodically draw current from the bus capacitor with the PWM signal. When the PWM frequency is increased, the amount of charge drawn per unit time is smaller, meaning that the required bus capacitance is reduced. According to the test of TIDA-010936, after increasing the PWM frequency from 20kHz to 80kHz, the electrolytic capacitor can be replaced by a ceramic capacitor of equal capacitance to obtain a similar bus voltage ripple. Ceramic capacitors have obvious advantages over electrolytic capacitors: smaller size, longer life, improved high-frequency characteristics, and so on.

Therefore, a higher speed current loop and PWM frequency must be considered when designing a humanoid robot. For MOSFET-based servo drivers, the increase in PWM switching frequency brings large additional losses, causing serious heating of the driver. When the switching frequency increases from 10kHz to 20kHz, the MOSFET-based driver increases the overall loss by 20% to 30%, which is unacceptable for humanoid robots. Alternatively, GaN FETs offer low switching losses at high frequencies. In the TIDA-010936 test, the board losses are almost identical at 40kHz and 80kHz, so GaN is particularly good for high switching frequency scenarios.

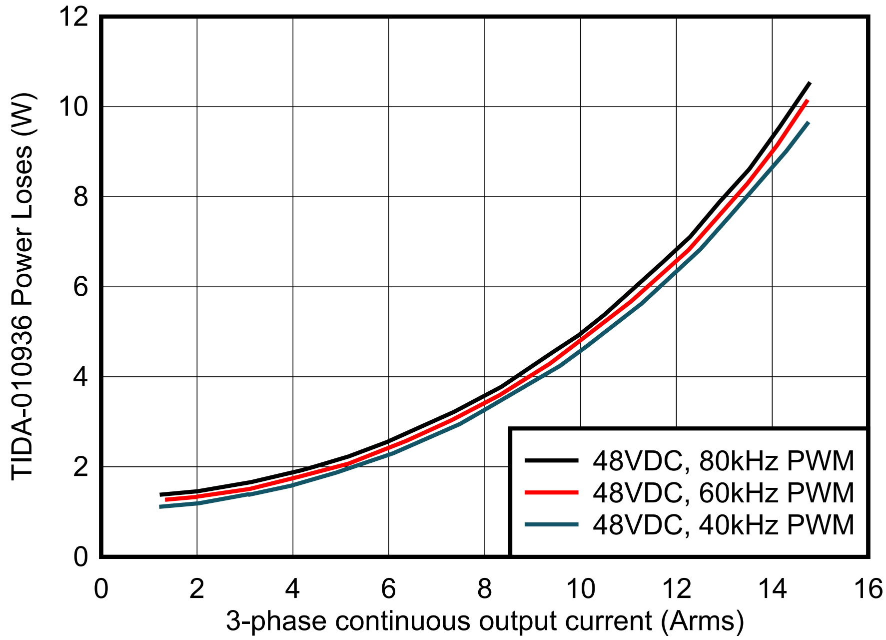

Figure 3. TIDA-010936 Board Losses at 48V Input Versus 3-Phase Output Current

Lower switching loss

The reason why GaN can achieve such low switching losses is due to the characteristics of the GaN device. GaN devices have smaller gate capacitance (Cg) and smaller output capacitance (Coss), which can achieve switching speed 100 times faster than Si-MOSFET. As the turn-off and turn-on time is shortened, the dead time can be controlled within a shorter range, such as 10-20ns, while MOSFETs usually require dead time of about 1us. The reduction of dead time results in lower switching losses. Additionally, GaN FETs do not have a body diode, but the freewheeling functionality is realized through the third quadrant operation. In high-frequency PWM scenarios, the body diode of a MOSFET causes a large reverse recovery loss (Qrr loss). The third quadrant operation also avoids the risk of switch node ringing and EMI caused by the body diode, which can reduce interference with other devices in humanoid robots with high power density.

Smaller size

The joint space of humanoid robots is limited. The power board is usually a ring PCB with a diameter of 5-10 cm. In addition, a joint must integrate a motor, reducer, encoder, and even a sensor. Crucially, designers must achieve higher power and more stable motor control in a limited space. Compared to MOSFET, GaN has smaller Rsp (specific resistance, area to die size comparison) meaning GaN has a smaller die area compared to a MOSFET of the same Rdson. Texas Instruments further reduces footprint area by integrating the FET and gate driver. This allows for a 4.4mΩ half-bridge + gate driver in a package of just 4.5 x 5.5mm.

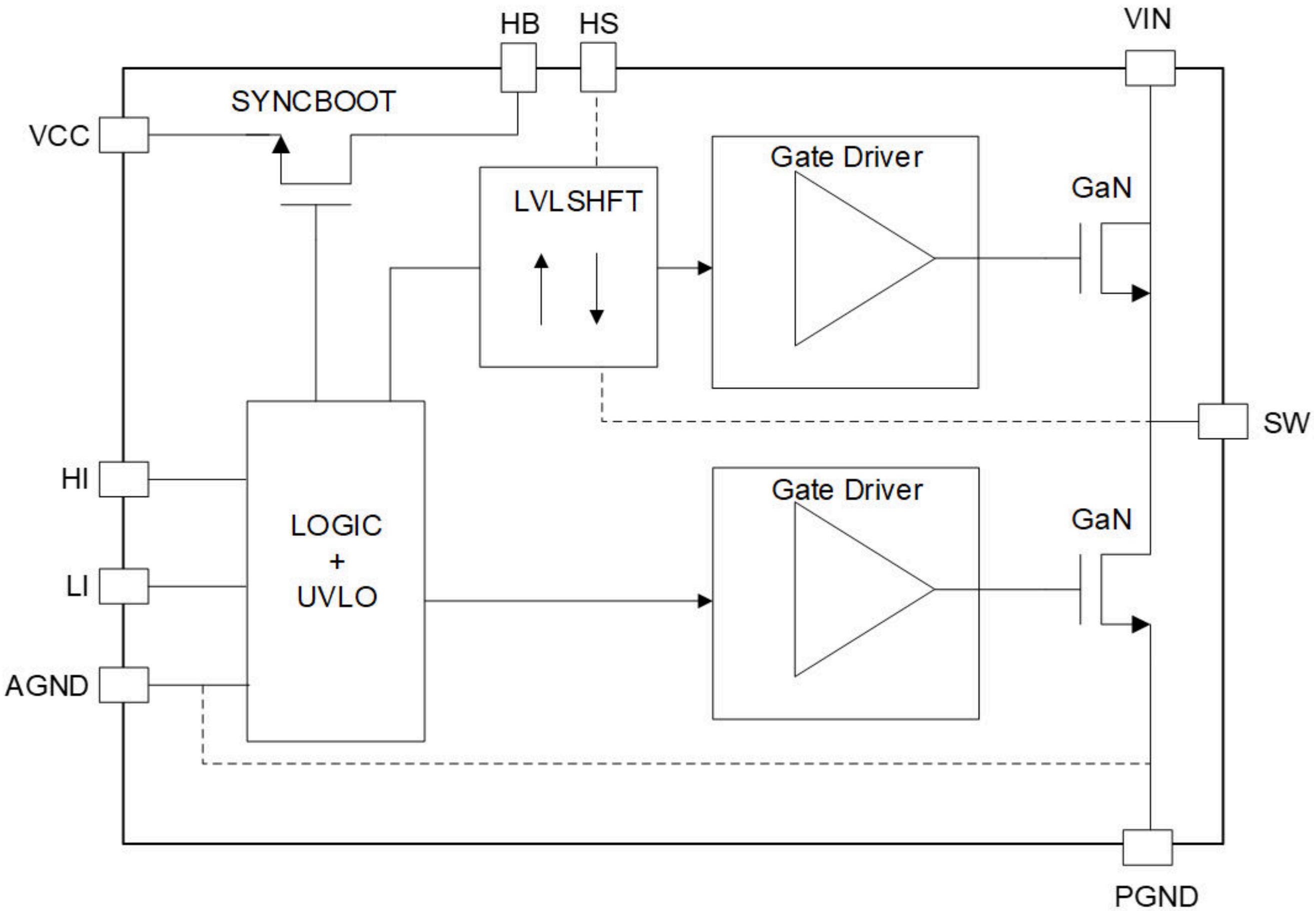

Figure 4. LMG2100 Block Diagram

Take LMG2100R026 as an example. This device integrates the FET of the half-bridge and the half-bridge driver, and can withstand a continuous current of 55A. There are many advantages to integrating the driver with FET including:

- Reduced gate ringing for more reliable operation
- Reduced power loop inductance with an optimized package footprint
- Reduced the size by integrating the gate driver
- Protect the device with integrated protection

To compare GaN with MOSFET in design we can look at TIDA-010936 and TIDA-01629 designs offering similar power levels. As Figure 5 shows, the chip area of the entire power device is reduced by more than 50% due to the integrated gate driver and lower Rsp of GaN.

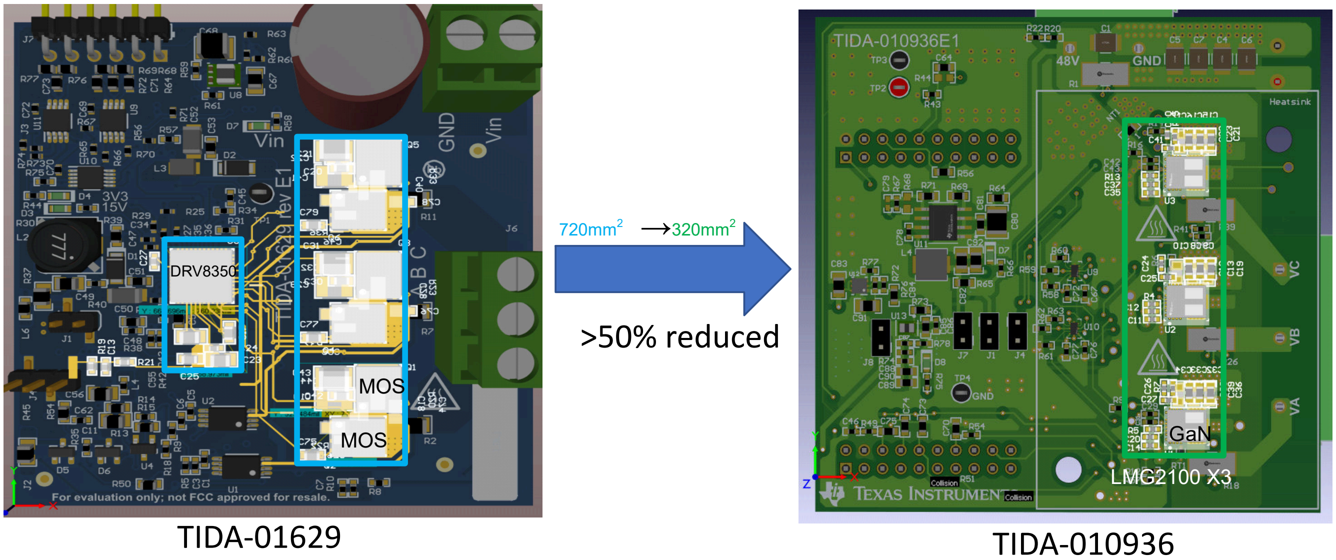

Figure 5. GaN Vs. MOSFET Power Stage Comparison

Summary

Humanoid robots have higher requirements for control accuracy and power density. GaN can easily achieve higher-precision motor control with low loss at high PWM frequencies. The high-power density nature of GaN combined with the characteristics of an integrated driver from Texas Instruments can further reduce the size. Due to these benefits, the GaN based motor drive likely becomes the preferred design in humanoid robots offering a more efficient, stable, and intelligent robot design.

In addition to humanoid robots, GaN technology is also an excellent choice for other types of robots (collaborative robot, surgical robot, AGV), industrial servos, home appliances and other applications that require high power density.

References

1. TIDA-010936
2. LMG2100R026
3. LMG2100R044
4. TIDA-01629
5. Does GaN Have a Body Diode? - Understanding the Third Quadrant Operation of GaN

Trademarks

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