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ESCON2 and it’s running smoothly

Technical White Paper

ESCON2 is the new generation of maxon servo controllers. The product line is based on the latest technology in semiconductor and PCB manufacturing and an innovative process for Hall sensor based speed control with FOC commutation of BLDC motors. This results in maximum power density and unparalleled smooth running thanks to optimized control performance for torque and speed.

ESCON2 - One product line for a wide range of applications

The ESCON2 product line consists of different derivatives that allow the use of a wide range of BLDC (= brushless) and brushed DC motors and can be easily integrated into a wide variety of applications.

- The "ESCON2 Modules", including miniaturized "Micro", "Nano" variants, are designed as intelligent plug-ins for customer-side electronic boards. This means that the ESCON2 fits directly into the customer design, space-saving, which is indispensable when developing small and hand-held devices in industrial and medical technology. ESCON2 covers the motion control functionalities such as speed, current and torque control. The actual device control (i.e. the electronic board developed by the customer) can be optimally adapted to the space available, the required connection technology and higher-level additional functions and only needs to provide slots for the necessary number of ESCON2 Modules, Micro or Nano.
- "ESCON2 Compact" controllers and product types in a housing are ready-to-connect solutions that can be placed in a control cabinet or close to the motor. This design is often favored in machine building or for fast prototyping.

The wide power range allows the technically and commercially optimal selection of an ESCON2 product variant that is ideally suited to maxon, Parvalux or third-party motors.

- The "ESCON2 Module 60/30" and the "ESCON2 Compact 60/30" allow the control of powerful BLDC and DC motors with a continuous power of 1.8 kW, as they are often found in mechanical engineering in rotating, milling or screwing applications, but also in the speed-controlled wheel drives of AGVs.
- The “ESCON2 Micro 60/5” and the “ESCON2 60/12” which is available as a Module, Compact, or in a housing, are best choice for motors in the medium power range of some hundred Watts, which are mainly used in device construction and power tools.
- At the lower end of the power spectrum, the “ESCON2 Nano 24/2” with 48 W continuous power is designed for ironless motors in hand-held devices, such as those used in medical technology, which require a high degree of precision, smooth running and energy efficiency.

The first number in the product name of all ESCON2 product variants represents the maximum supply voltage and the second number represents the continuous output current without additional cooling. For dynamic acceleration and deceleration, short-time peak currents with double to triple the nominal value are available for a few seconds.

High power density and compact design

Customers value the power density of the ESCON2. The key to this “minimum size with maximum power” approach is a sophisticated thermal design and the use of components specifically selected for their low power consumption at high output power. This solution is confirmed by the recurring feedback from the development teams of maxon’s customers:

> *“The high level of miniaturization of the ESCON2 derivatives greatly increases the possibilities for direct integration into single- and multi-axis systems – even in confined spaces such as handheld devices."*
>
> *“Despite their small size, the ESCON2 solutions are very powerful and achieve the specified motor currents, torques and speeds, even in continuous operation with high energy efficiency.”*

«ESCON2 Nano 24/2» (P/N 809635) 23 × 16 × 4.5 mm, 2.5 g
«ESCON2 Micro 60/5» (P/N 809631), 36.8 × 23.8 × 6.5 mm, 6 g
«ESCON2 Module 60/12» (P/N 854796), 49.5 × 31 × 12.4 mm, 12 g
«ESCON2 Module 60/30» (P/N 783722), 67 × 43 × 7.8 mm, 19 g

Dynamic control

One of the main features of maxon motors is the high motor dynamics and precision of movement that can be achieved. This also places high demands on the servo controller. The ESCON2 product line has been specifically designed to meet these requirements. The combination of highly responsive motors and the advanced ESCON2 control algorithms enables high accelerations with minimal control deviation. In practice, this means, for example, faster processing cycles and increased throughput of production machines, while maintaining high quality and dimensional accuracy of processed goods.

The sampling of the two analog inputs and the 10 kHz (100 µs) clock rate of the speed control loop ensure that the ESCON2 servo controllers meet the strict latency requirements and can therefore also handle applications with the most dynamic drives in the maxon catalog.

Figure 2 shows the increase in speed and motor current (also limited by the mechanical and electrical time constants of the motor) and the precise control in the millisecond range in case of a sudden setpoint step.

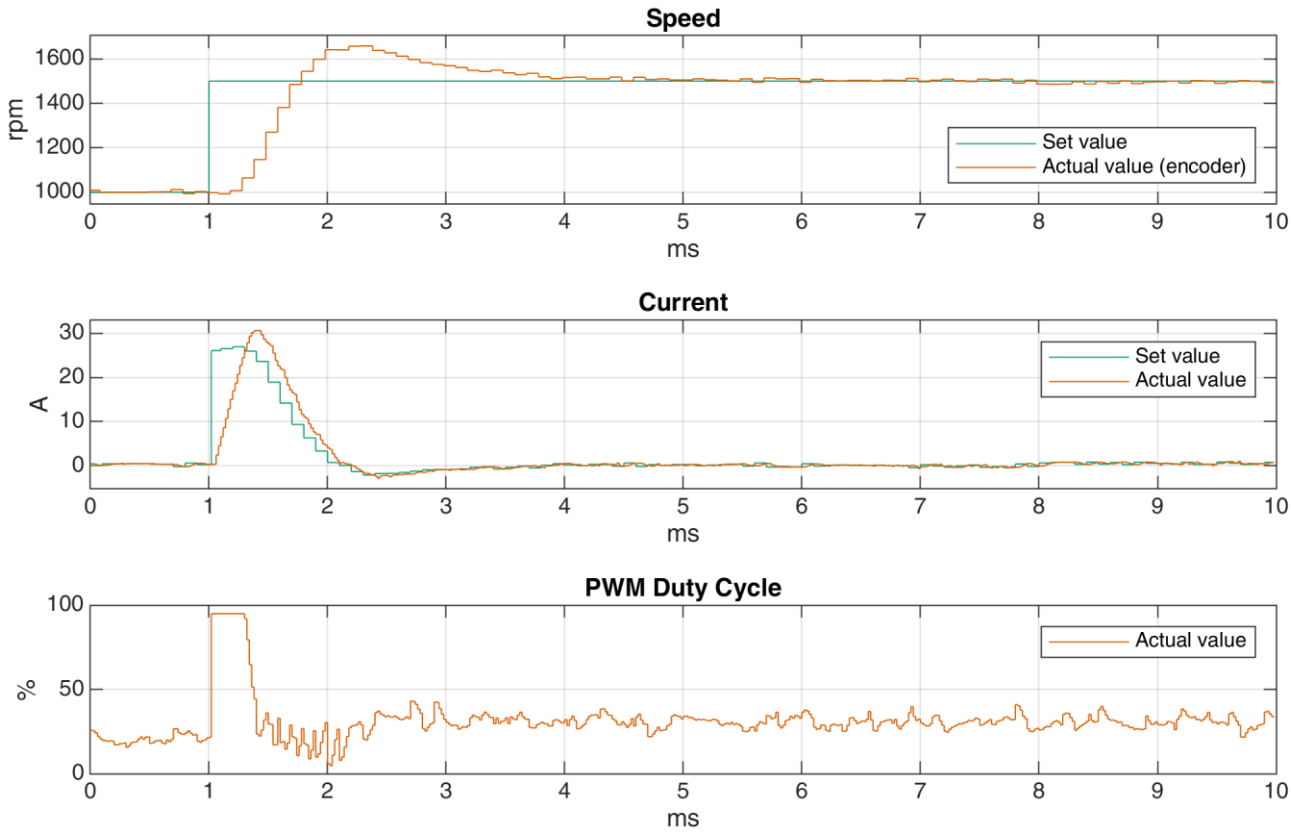

Figure 1: Step response of a speed control loop tuned for short settling time. The limiting factor is the available voltage and the electrical time constant of the winding. The PWM duty cycle is saturated for a short time.
"ESCON2 Micro 60/30" with "EC-i 52" (P/N 634043) and 4096 cpt incremental encoder.

High speed range up to 120,000 rpm

Dental applications, for example, often require high-speed drill drives. This requires the use of BLDC motors and a suitable control system that ensures precise electronic commutation (switching of the motor windings) even at the highest frequencies and with multi-pole motors. The ESCON2 servo controller can drive 1-pole-pair BLDC motors up to 120,000 rpm at the motor shaft. This limit is usually well above the mechanical speed limit of the motor and gearbox. The maximum PWM duty cycle of 95% also contributes to the optimal use of the available supply voltage.

Perfect commutation and smooth operation even without an encoder

Important features that differentiate ESCON2 from modern "state of the art" servo controllers are commutation performance and control quality.

- ESCON2 uses field-oriented control (FOC) to generate sinusoidal motor currents over the entire speed range, regardless of whether an encoder or only Hall sensors are available.
- A new method, for which maxon has applied for a patent, enables commutation and speed control of previously unattainable quality and smoothness based purely on Hall signals.

In case of BLDC motors without encoders, the challenge is that Hall sensors offer only a low resolution per rotor revolution, and the switching edges are not evenly distributed symmetrically with 100% identical spacing over a motor shaft revolution due to the usual manufacturing tolerances. Ultimately, this leads to sub-optimal commutation and a deviation between measured and effective speed in almost all known servo controllers. The method developed by maxon and used for the first time in the ESCON2 analyses the switching edge distribution of the Hall sensors within a few seconds during the first commanded movement and generates a virtual, precise sensor from this, in which the inaccuracies of the switching points are compensated. This "perfect" sensor is used for commutation and speed control over the entire speed range. The intermediate steps required for FOC commutation within two switching edges are determined by extrapolation. As a result, the speed stability and smoothness of the drive are so good that an encoder is often considered to be the sensor system.

A recording of the relevant control variables best illustrates the effectiveness of this innovation in practice: Figure 3 compares the speed response of a conventional modern speed controller (left, blue curve) with that of an ESCON2 (right, orange curve).

- For both speed controllers, a fixed setpoint of 1000 rpm was commanded, and an iron-core maxon "EC-i 40" motor (P/N 449470) with Hall sensors as feedback sensors was operated under speed control.
- The speed measurement for the evaluation of the motor shaft movement was carried out independently via a high-resolution encoder (16384 cpt), which was not used for either control or commutation.
- The actual speed of the ESCON2 (right, orange curve) shows a significantly lower fluctuation and thus a better smoothness along the setpoint than the compared “State-of-the-art” controller (left, blue curve).

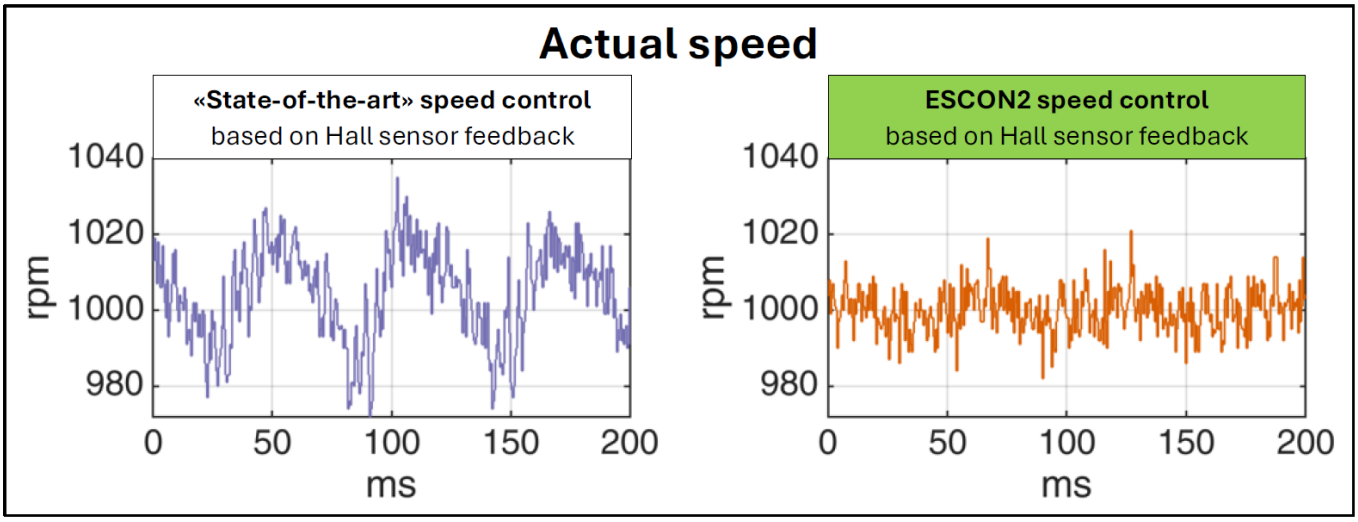

Figure 3: Comparison of the speed stability between a modern (= “state-of-the-art”) servo controller and the ESCON2 in the speed-controlled operation of a BLDC motor “EC-i 40” with Hall sensor feedback.

Figure 4 shows a comparison of the smooth running in terms of the motor current.

- Both servo controllers were operated identically as speed controllers as before and the motor current was compared. The "EC-i 40" (P/N 449470) with Hall sensor feedback (without encoder) was again used for control and commutation.
- Under identical load conditions, an averaged motor current of approximately 100 mA was measured.
- The actual motor current of the “normal” servo controller (left, blue curve) shows significantly larger current fluctuations than the motor current of the ESCON2 (right, orange curve), which is very smooth and free of cyclic oscillations.

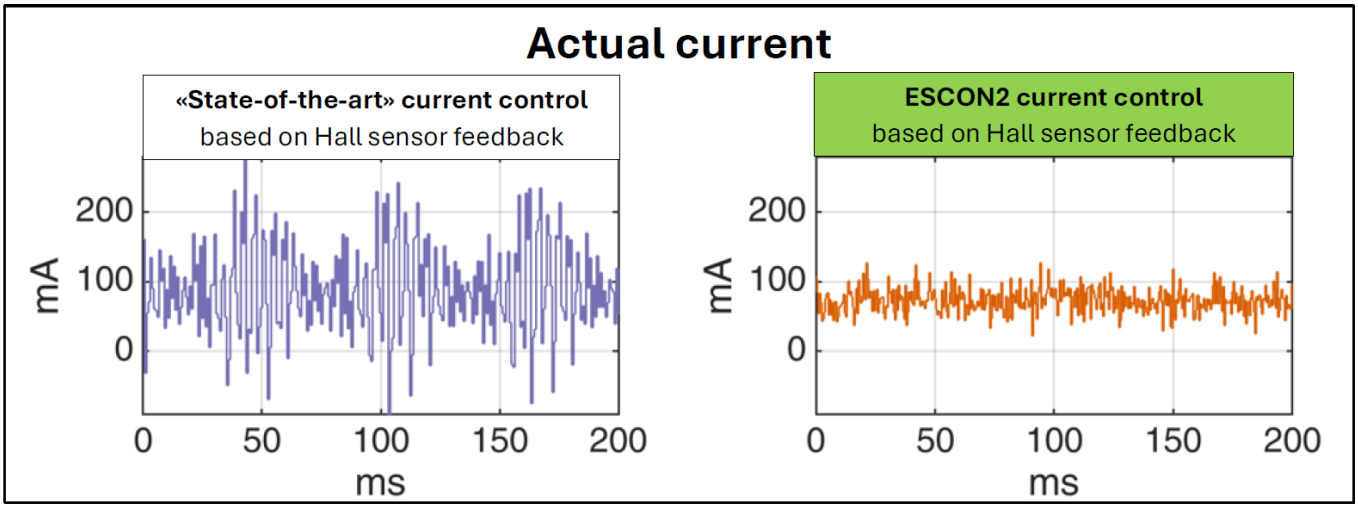

Figure 4: Comparison of the motor current between a modern (= “state-of-the-art”) servo controller and the ESCON2 in the speed-controlled operation of a BLDC motor “EC-i 40” with Hall sensor feedback.

This results in the following advantages of an ESCON2 control:

- First, the speed control of the ESCON2 with Hall sensor feedback is much smoother than that of other servo controllers. This difference, which is also audible, results in higher energy efficiency.
- Secondly, there is almost no difference between the speed control of the ESCON2 with Hall sensor feedback compared to drives with encoders.
- Last but not least, not using an encoder when using ESCON2 offers the possibility to reduce costs and wiring.

This almost automatically raises the question of whether high-resolution encoders are needed at all with ESCON2, or when they are recommended. The use of an encoder is particularly advantageous in applications where the motor is operated exclusively or predominantly in the very low speed range of a few hundred rpm. However, such low speed limits are rather rare with direct drives. In general, it should be noted that the Hall sensor-based method of balancing requires several seconds for adjustment after each power-on cycle of the supply voltage. In addition, at low speeds, extrapolation between switching edges is no longer sufficient to respond to sudden setpoint jumps or load variations. This means that the use of an encoder can be still indicated in specific applications with low speeds and high dynamics.

Open interfaces for commanding and data exchange

Size and control performance are important factors for system integrators when deciding to use ESCON2. However, another aspect is the question of control by a higher-level device controller or microcontroller. Here ESCON2 scores with the possibility of control and feedback via analog and digital signals. However, even for "simple" systems, the ability to exchange data via a bus interface is becoming increasingly important, for example for commanding of precise speed or motor current, or for monitoring actual values as part of IoT data acquisition or "predictive maintenance". ESCON2 offers cost-effective and established interfaces for this purpose, including USB, SCI (RS232) and CAN. User feedback is already available:

> *"Thanks to the CAN interface, mixed systems with low-cost speed or torque controlled axes (ESCON2) and position controlled axes (EPOS4) can be networked on a common bus, eliminating the effort and complexity of different interfaces."*
>
> *"The standardized 'CiA402 - CANopen Device Profile for Drives and Motion Control' of ESCON2 (as well as EPOS4) reduces the integration and development effort as well as the general risk of incompatibility in mixed system solutions - even when using additional CANopen slaves or masters from third party suppliers."*

Updates and application-specific add-ons

All functions are identical across the entire ESCON2 product line. This is the basis for a free choice of the optimal power rating and product type, without having to accept functional compromises. User feedback and requests for functional enhancements are consistently collected, evaluated and implemented using agile methods. Firmware and software releases are made available free of charge, typically on a six-month cycle. These updates provide new features, additional modes of operation, and further performance enhancements. This means that ESCON2 does not age, but is constantly rejuvenated, while at the same time always ensuring backward compatibility.

In project discussions, however, there are also very specific application requirements that give an individual customer a real market advantage, but do not have a sufficiently broad base as a general extension. maxon offers the development of customer-specific firmware and hardware for this purpose. This is based on the proven ESCON2 development platform, or as one ESCON2 developer puts it:

> *"The ESCON2 platform is a solid foundation for custom development. It has sufficient computing power reserves to integrate even complex additional functionalities and requirements."*

The required development effort can be clearly estimated and provided by maxon as a binding offer. The customer benefits from clear cost transparency, an established system basis and low development risk right from the start. In addition, they have the advantage of exclusive additional functions that are not available to their competitors in the catalog product. For series customers, customer-specific firmware extensions offer additional IP protection with regard to the special functionality and specific use of the ESCON2 with its own maxon article number.

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Easy commissioning with maxon's «Motion Studio»

For the configuration of a drive system with ESCON2, maxon provides the PC Windows application "Motion Studio" free of charge. "Motion Studio" intuitively guides the user through the most important steps and allows him to quickly achieve an operational system with optimal parameters and to move the motor for testing. The created system configuration can be saved in a project structure and transferred to other ESCON2 controllers.

The initial starting point for every commissioning of a new drive unit or an entire system is the "Startup" wizard, which is used to define the drive data, but also the system limits (such as speed or current limits) and the mapping of functions to inputs and outputs step by step.

Once the configuration is complete, the "Regulation Tuning" Wizard can be used to automatically determine all control parameters. During this process, the motor is moved briefly in rapid succession and advanced data from the drive and load are measured to find optimized values for the controller setting. The optimization methods are not only based on theory and simulation, but also on the extensive practical experience of maxon engineers from hundreds of drive systems. This concentrated know-how for control loop optimization is available to the user of "Regulation Tuning" at the click of a mouse button. Application-specific optimizations, such as softer or harder control reaction, can be set at any time using sliders or by directly entering parameters. The wizard has a verification function to assess the effects of automatic or manual controller tuning. The step response of the current or speed controller to a short, adjustable test signal is recorded and graphically displayed. This makes tuning a breeze with just a few keystrokes, and the data is transferred to the ESCON2.

Like a Swiss army knife, "Motion Studio" provides additional wizards and tools that can be used for initial drive testing or troubleshooting after commissioning. The "Data Recorder" integrated into "Motion Studio" is particularly useful for system designers or service personnel. Its oscilloscope-style interface allows users to record four channels, trigger on system or motion states, and export or reimport the recorded data.

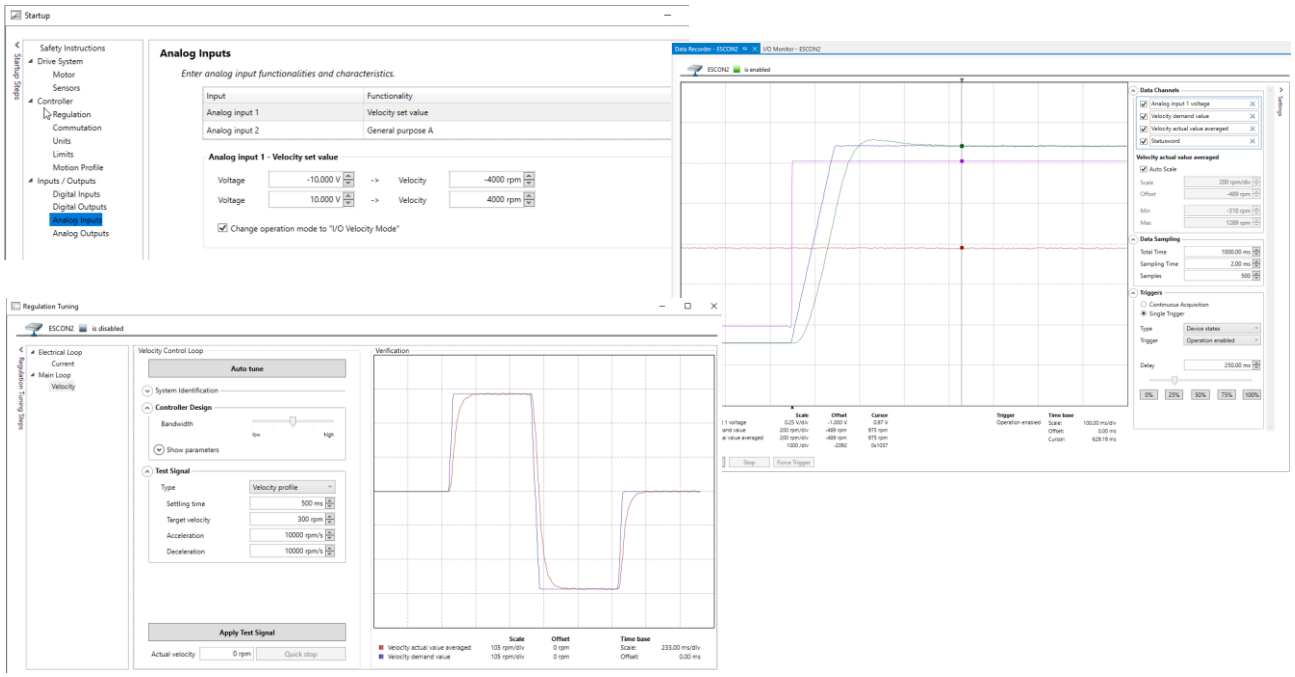

Figure 5: Motion Studio:"Startup", "Regulation Tuning", "Data Recorder" tools

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Summary – In a nutshell

- ESCON2 is a high performance speed and current/torque servo controller.
- ESCON2 offers FOC commutation up to 120,000 rpm with one pole pair.
- Speed control and FOC commutation are based on a new maxon method (patent pending) for unprecedented speed stability and smooth operation of brushless motors with Hall sensors, even without an encoder.
- The command and feedback is possible via I/O, USB, SCI (RS232) or CANopen (CiA402).
- A wide range of designs and power outputs are available:
  - For motors from a few watts up to 1.8 kW continuous power
  - Ready-to-connect “ESCON2 Compact” or in a housing
  - Miniaturized ESCON2 Module, Micro and Nano, for plugging into the electronic circuit boards of customer’s small and hand-held devices or multi-axis systems.
- Easy commissioning through intuitive GUI with automatic "Regulation Tuning”.
- Future-proof thanks to functional, free updates.
- Customer-specific function extensions and hardware designs are easily possible.

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