

We get technical

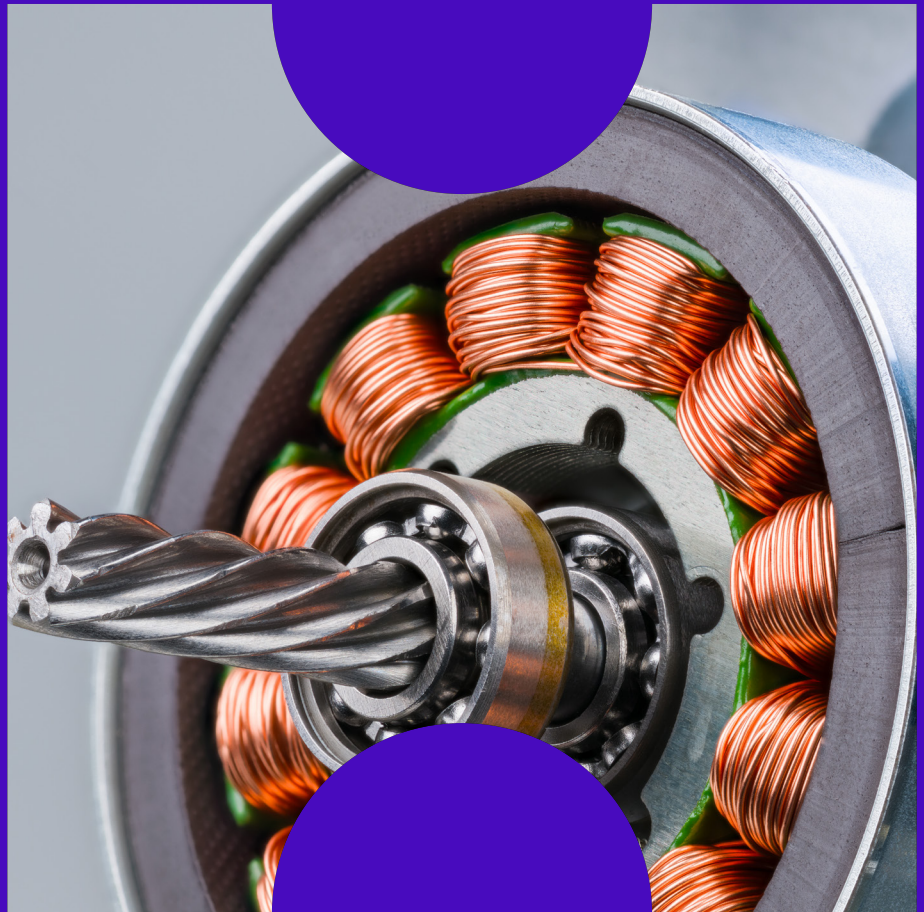
An introduction to relays

How to adapt solenoid and stepper motor drivers for industrial applications

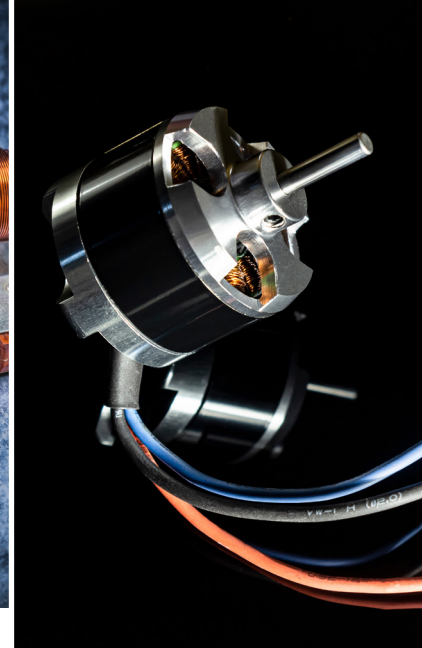
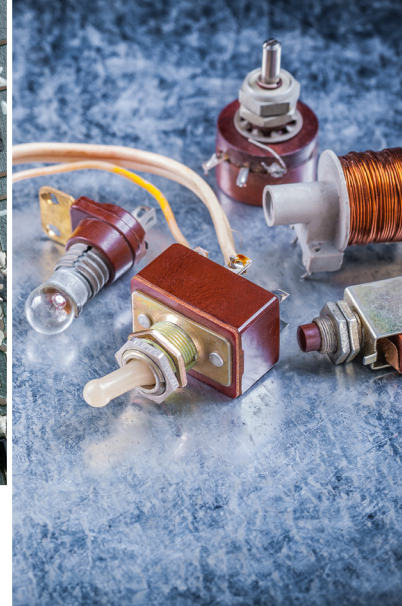
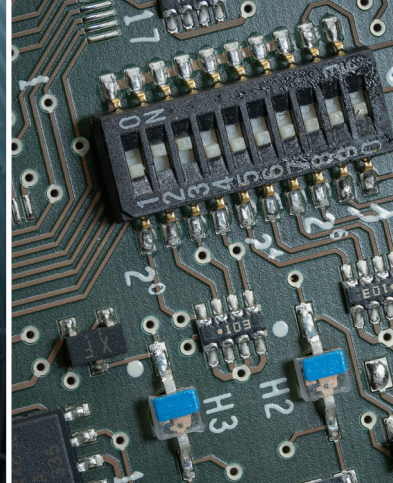
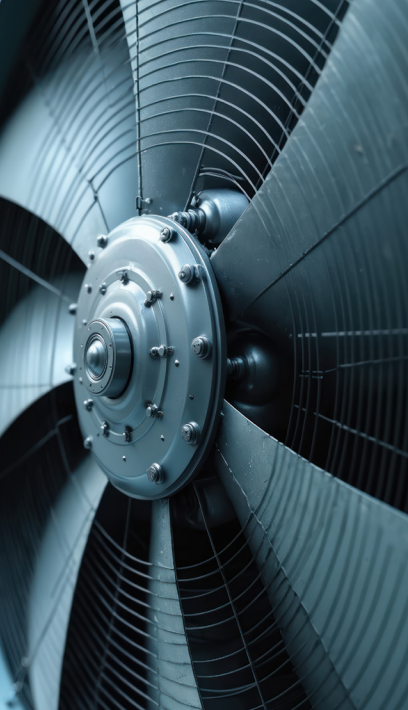
Comparing axial fans and centrifugal fans

Learn why sealed toggle switches are essential for many electronic applications

A better way to commutate BLDC motors



DigiKey



Editor's note

Welcome to the DigiKey eMagazine Volume 34 – Electromechanical.

Innovation in electronics continues to accelerate, driven by smarter control, greater efficiency, and increasingly demanding application environments. In this issue, we explore a range of technologies that are shaping modern design—from advanced motor control to ruggedized switching solutions.

We're pleased to feature insights from Infineon on their PSOC™ Control C3 family, highlighting how integrated control solutions are simplifying complex system design while improving performance and scalability. Complementing this, NKK Switches introduces its JWLW Series of 16 A rocker switches, engineered to deliver durability and reliability in demanding applications.

Beyond these featured contributions, this issue offers a deeper look into foundational and emerging topics alike. You'll find a practical introduction to relays, along with guidance on adapting solenoid and stepper motor drivers for industrial environments. We also examine airflow strategies by comparing axial and centrifugal fans, and explore why sealed toggle switches remain essential in many electronic applications.

Rounding out the issue, we dive into more advanced discussions, including improved methods for commutating BLDC motors and a comprehensive overview of switch technologies to support better component selection.

Whether you're refining existing designs or exploring new approaches, we hope this collection of articles provides both practical insights and fresh perspectives.

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Building smarter electromechanical systems with control, isolation, and protection



By Abhishek Jadhav

Industrial electromechanical systems are becoming more compact and software defined. The functions that were previously handled by mechanical contacts, optical isolation, thermal fuses, and discrete power stages, are increasingly being implemented using semiconductor-based control, switching, coreless transformer isolation, and protection devices.

This is changing how engineers design these subsystems. Motor control timing, power path switching, isolation, and wire protection cannot be addressed as separate design issues. A motor board may need synchronized current sensing and PWM generation, while the same system may also require bidirectional power switching, isolated relay outputs, and electronic I²t protection with diagnostic feedback.

Infineon Technologies' PSOC™ Control C3 microcontrollers, CoolGaN™ BDS 40 V G3 power devices, iSSl solid-state isolators, and BTG70008A-1ESW PROFET™ Wire Guard address different layers of the same design transition. Together, they show how electromechanical systems are moving from

passive components and isolated protection blocks towards active, software-visible semiconductor control of motion, power, isolation, and wiring protection.

Advanced real-time processing with PSOC™ Control C3

At the center of any modern integrated system is the control unit. It must manage high-speed peripherals with deterministic, low-latency execution. The Infineon **PSOC™ Control C3** microcontrollers (Figure 1) are designed for motor control and power conversion applications.



Figure 1. An Infineon PSOC™ Control C3 microcontroller with CORDIC math engine and sub-80 ps high-resolution PWM. (Image source: Infineon)

They are based on a 32-bit Arm® Cortex®-M33 core operating up to 180 MHz. The architecture supports the high performance required to manage WBG power stages and complex control algorithms like Field-Oriented Control (FOC).

The highlight of the product is its integrated Coordinate Rotation Digital Computer (CORDIC) accelerator, a dedicated math engine that offloads rotation and trigonometric calculations, such as the Park and inverse Park transforms. By executing these rotations in hardware, the CORDIC unit frees the main CPU to manage other tasks, such as state-machine logic, communication protocols, or diagnostics.

This is complemented by an integrated floating-point unit (FPU) and digital signal processor (DSP) instructions within the Cortex-M33 core. For example, a dual-motor FOC algorithm combined with an active power factor correction (PFC) stage can operate with a total CPU load of less than 50 percent in certain applications.

The bridge between the digital control algorithm and the gate drivers of the power stage is the Timer/Counter Pulse-Width Modulator (TCPWM) peripheral. In the PSOC™ Control C3 family, the TCPWM resource has sixteen 16-bit and four 32-bit timers capable

of generating complementary PWM outputs with programmable dead-time insertion. For advanced high-frequency topologies and systems using WBG (SiC and GaN) power devices, standard PWM resolution may be insufficient.

High-frequency switch-mode power converters and motor drives operating in the hundreds of kilohertz or megahertz range require control over the duty cycle to maintain voltage and current regulation. Standard PWM peripherals have a timing resolution limited by the clock period. At a switching frequency of 500 kHz, a 5.56 ns step size represents a relatively large percentage of the total switching period.

This leads to a limit cycle oscillation where the controller jumps between discrete duty cycles and generates low-frequency voltage ripple and output noise. The PSOC™ Control C3 Main Line addresses this limitation by incorporating a high-resolution PWM (HRPWM) peripheral capable of sub-80 ps timing resolution.

Infineon also provides the ModusToolbox™ Motor Suite with motor control code examples, configuration tools, and parameter-tuning support. It allows engineers to configure the synchronous ADC sampling, CORDIC math engine, and TCPWM peripherals through a GUI.

The Infineon PSOC™ Control C3 is PSA Certified Level 2, meaning the MCU contains a hardware-isolated Root of Trust and can defend against software-based attacks. The device incorporates a cryptographic accelerator that supports NIST P-256 elliptic-curve cryptography and a true random number generator (TRNG).

High-frequency power switching with CoolGaN™

In low-voltage electromechanical and embedded power paths where board area, switching loss, and reverse-current control matter, wide-bandgap devices can help reduce losses and increase power density. The Infineon [CoolGaN™ bidirectional switch \(BDS\) 40 V G3](#) family leverages these properties to address the common design challenge of creating a compact, efficient bidirectional switch.

A CoolGaN™ BDS (Figure 2) is a monolithic device that integrates two GaN switches in a common drain, dual-gate architecture to provide four-quadrant operation in a single component. The integration has a significant reduction in solution size, with Infineon reporting a footprint decrease up to 82 percent and a halving of the component count compared to equivalent back-to-back Si MOSFET solutions.



Figure 2. An Infineon CoolGaN™ bidirectional switch (BDS) 40 V G3 power device. (Image source: Infineon)

However, the adoption of GaN technology introduces design tradeoffs that engineers must manage. The extremely high switching speeds make these devices highly sensitive to PCB layout. Parasitic inductance in the power loop and gate-drive loop can cause voltage overshoot, ringing, and instability in a GaN circuit.

Minimizing this inductance requires careful layout practices, such as keeping the gate drive loop as short and wide as possible, minimizing common source inductance through optimized via placement, and using compact packages like the WLCSP in which the CoolGaN™ BDS devices are offered.

In addition, the gate of an e-mode GaN HEMT has a lower threshold voltage and tighter maximum voltage tolerance compared to Si MOSFETs. This requires a precise and clean gate drive signal to prevent damage or spurious turn-on. To ease this transition, the CoolGaN™ BDS family is designed to be compatible with standard 5V gate drivers to allow designers to leverage existing layouts and reduce redesign efforts.

Robust galvanic isolation with iSSI coreless transformer

In electromechanical systems where high-voltage power electronics coexist with low-

voltage digital control, robust galvanic isolation is required for operational integrity.

For years, optocouplers have been the default solution, comprising an LED and a photodetector to transmit signals across an insulation barrier. However, this technology has drawbacks in modern high-performance systems. The underlying GaAs technology suffers from aging effects where the current transfer ratio (CTR) degrades over time.

The Infineon [iSSI \(integrated solid-state isolator\)](#) family (Figure 3) addresses these challenges by replacing the optical methods with proprietary

coreless transformer technology. The architecture allows Infineon to create an isolation barrier with ratings up to 5.7 kV RMS and a maximum transient isolation voltage of 8000 V.

The iSSI family combines isolation, gate-drive energy transfer, and the features needed to build protected solid-state relay circuits. Its overcurrent protection (OCP) uses a current-sense input that compares a sensed voltage to a typical internal threshold of about 200 mV. When the threshold is exceeded, the device triggers a latched fault response with fast turn-off.

The [iSSI20R0xH](#) and [iSSI20BxxF](#) series are offered in compact 8-pin packages, while the [iSSI30RxxH](#)

devices use a 16-pin package to support additional functions such as separate current-sense and temperature-sense inputs and dynamic Miller clamp pins.

Intelligent protection and distribution with the PROFET™ eFuse

Traditional power systems with centralized fuse boxes and electromechanical relays are poorly suited for modern systems. Mechanical fuses are slow, imprecise, one-time-use devices that are incapable of providing the required diagnostic feedback. Relays are bulky, suffer from mechanical wear, and generate acoustic noise and EMI.

The [BTG70008A-1ESW](#) (Figure 4) from Infineon's PROFET™ (Protected High-Side Power Switch) Wire Guard series is designed to replace these legacy components with a highly integrated, intelligent electronic fuse (eFuse). This device can be integrated as a smart high-side power switch that combines control, diagnostics, and advanced protection in a single AEC-Q100 qualified package.

The most critical feature of the BTG70008A-1ESW is its hardware-based I²t wire protection. The PROFET™ Wire Guard emulates the thermal characteristics of a connected wire harness, offering six selectable curves that can be chosen to match its gauge and thermal tolerance.

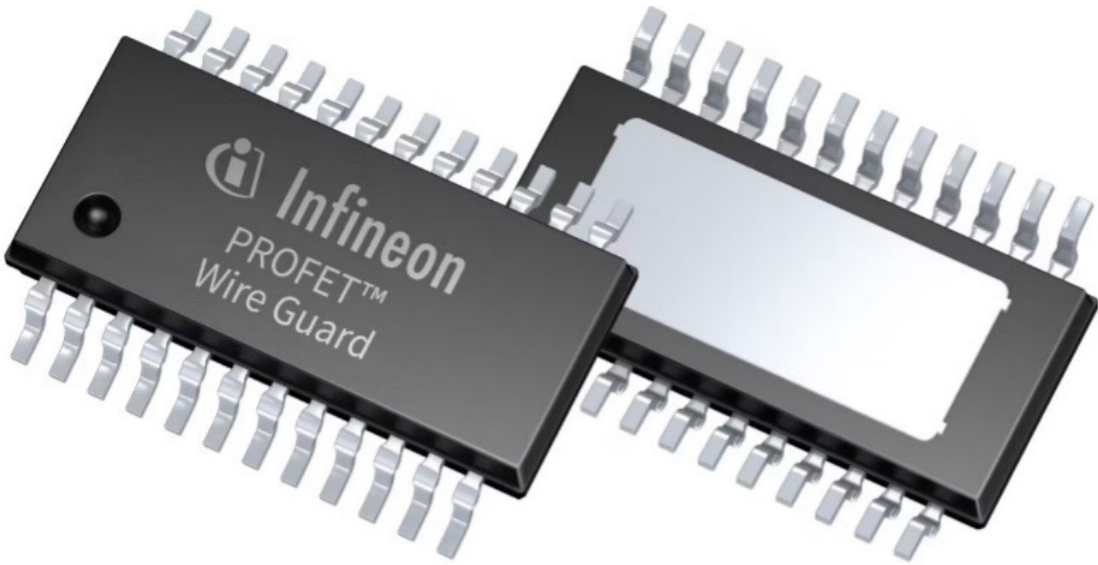


Figure 4. Infineon's BTG70008A-1ESW PROFET™ Wire Guard smart high-side switch with integrated I²t wire protection. (Image source: Infineon)

This protection remains active even if the main microcontroller is in a reset or standby state, providing a fail-safe mechanism. It allows for optimized wire harness design and potentially reduces copper weight, while ensuring that the wire is protected across a wide range of fault conditions, including transient inrush currents and sustained overloads.

The BTG70008A-1ESW provides an adjustable overcurrent threshold through an external resistor. When a hard short-circuit occurs, it can isolate the fault in microseconds. This rapid response prevents the fault from causing a voltage drop on the main power bus, which could otherwise lead to an undervoltage reset of critical ECUs.

It is documented as an ISO 26262 safety element out of context for safety requirements up to Automotive Safety Integrity Level (ASIL) D. The PROFET™'s predictable failure modes, integrated protection mechanisms, and diagnostic feedback capabilities are essential for creating a safety-critical system.

Conclusion

Electromechanical design now requires a more integrated approach. The motor, relay, fuse, isolator, power switch, and controller are part of a coordinated control and protection architecture.

As systems continue to become smaller and more power-dense,

engineers need semiconductor devices that can improve timing accuracy, switching efficiency, isolation reliability, and fault response. Infineon solves these challenges at different design layers through PSOC™ Control C3, CoolGaN™ BDS 40 V G3, iSSI solid-state isolators, and PROFET™ Wire Guard.



Figure 3. Infineon solid state isolators (SSIs) have a fast turn-off in response to faults. (Image source: Infineon)

Designing reliable power switching at the operator interface

By Abhishek Jadhav



A power switch looks like one of the simplest components on an industrial control panel. But it is often subjected to high electrical stress and extreme environmental conditions. When the switch is carrying high current rather than sending a low-voltage signal to a controller, failure can expose the equipment to downtime, unsafe operation, or loss of system availability.

For example, a power switch in an industrial, transportation, or telecom application may be exposed to dust, moisture, vibration, shock, frequent actuation, and high startup

currents. In these environments, engineers need a front-panel switch that can remain mechanically secure, electrically stable, and environmentally sealed while still providing an operator interface.

[NKK Switches](#) offers its [JWLW Series](#) 16 A rocker switches, designed for rugged operator interface equipment. They combine high-current AC switching capability, IP67-rated panel sealing, high inrush-current handling, and sealed mechanical construction in a snap-in rocker format.

This allows engineers to address the design problem of reliable load switching and environmental hardening at the human-machine interface. The first requirement is electrical where the switch must be rated for the system voltage and current profile of the load it is expected to carry.

Electrical rating for load current

The JWLW Series 16 A rocker switches (Figure 1) can control both AC and DC loads. They are nominally rated for a resistive load of 16 A at either the

standard North American (125 VAC) or international (250 VAC) mains voltage. This high current capacity allows the switches to serve as a main control across a wide range of resistive loads, including industrial machines and high-power appliances, without the need for an intermediate relay or contactor.

The rocker switches have a 5 A, 72 VDC rating for telecommunication applications. Switching DC loads is more challenging than switching AC due to the absence of a natural current zero-crossing to aid in arc extinction. A sustained DC arc can cause contact erosion and failure.



Figure 1. An NKK JWLW Series 16 A snap-in mount switch with an IP67 rating. (Image source: NKK)

Because DC switching does not benefit from the natural current zero-crossing of AC, engineers should verify the applicable DC rating and part number suffix for the exact JWLW configuration being specified. For an engineer designing power distribution units, this rating provides a high degree of confidence and simplifies regulatory compliance.

Another meaningful electrical characteristic is the contact resistance of 20 milliohms. At the full 16 A AC rating, a 20 milliohm resistance dissipates 5.12 watts of heat within the switch contacts. This low value is critical for preventing overheating and ensuring thermal stability over the component's lifetime.

The reliability of the insulation system is defined by its insulation resistance and dielectric strength. The JWLW Series 16 A rocker switches guarantee a minimum insulation resistance of 1000 megaohms at 500 VDC. This extremely high resistance ensures that leakage current between electrically isolated parts of the switch is negligible.

The dielectric strength measures the insulation's ability to withstand a high voltage without breaking down. The JWLW switch is rated for a minimum of 2,000 VAC for one minute between contacts,

and an even higher 4,000 VAC for one minute between contacts and the case. This high dielectric strength shows a robust internal construction with significant creepage and clearance distances, providing a wide safety margin against line voltage transients.

Managing high inrush current and contact stress

The capacity to switch high currents is a primary function of a rocker switch. The capability of the JWLW series with a TV-8

rating is a critical performance metric that separates industrial-grade components from standard commercial switches.

A transient surge can severely affect the switch contacts. As the mechanical contacts of a switch close, they can physically bounce several times in microseconds before settling. If a high inrush current flows during this bounce period, an electrical arc forms across the small contact gap each time the contact separates. Repeated

arcing can accelerate contact erosion, and in severe cases, contribute to contact welding.

The JWLW Series 16 A rocker switch's TV-8 rating indicates that they have been tested under defined high-inrush conditions. TV-8 involves two tests performed at 120V AC.

First is the overload test, in which the switches must withstand 50 operations while switching a steady-state current of 12 A, with a minimum peak inrush current of 163 A. After this, the switches undergo an endurance test, where they must complete 25000 operations, switching a steady-state current of 8 A with a minimum peak inrush current of 117 A.

A switch that passes these tests demonstrates that its contact systems and mechanical construction are designed to tolerate the extreme thermal and electrical stresses associated with high inrush switching over its rated operational life.

Maintaining the panel seal for repeated use

The JWLW series requires a rectangular cutout of 30.7 mm x 20.5 mm. Their snap-in design simplifies the assembly process, requiring no additional mounting hardware. However, the precision

of this cutout is critical for both mechanical stability and the integrity of the IP67 seal.

The switches accommodate a panel thickness from 1.0 mm to 4.0 mm, and are suitable for use with various panel materials, including sheet metal and molded plastics. The switch bodies feature flexible retaining tabs that compress upon insertion and expand behind the panel for secure locking.

Their rocker actuator has a defined angle of throw of 26°, providing a tactile and visual indication of the switch's state. The actuator has a nominal operating force of 10.00 N for the double-pole JWLW models. This force is enough to prevent accidental actuation while remaining comfortable for intentional operation.

The housing and frame are made of polyamide, the rocker of polyphenylene ether, and the case of melamine. NKK lists these switch materials as meeting UL94V-0 flammability requirements. This certification is an important safety metric for components used in mains-powered equipment.

Conclusion

The selection of a human-machine interface component, such as a power switch for high-reliability systems, is a complex decision that goes beyond current and voltage ratings.

The NKK JWLW series 16 A rocker switches offer direct switching of rated AC loads, provide a defined DC rating for telecom applications, handle transient inrush currents through their TV-8 rating, and help preserve functional integrity in harsh environments. For engineers designing a rugged operator interface, this combination reduces the number of tradeoffs between power switching, mechanical integration, and environmental protection.

To learn more, visit [JWLW Series 16A Rocker Switches](#).



Video spotlight



Rocker Switches for Tough Environments

The NKK's dual seal waterproof toggles include the M series and the S series. Both have an IP68 rating, protecting against immersion of 5 cm up to 1.5 m, and is salt spray tested per MIL-STD-810G section 509.5. The M series toggle is miniature, designed for use in high-density boards. The S series dual seal waterproof toggle is available in ten configurations.

[Learn more](#)

High-Efficiency Power for Robotics

Robots play a growing role across industries—from agriculture and warehouses to campus and consumer delivery. Battery power makes efficiency, size, and weight critical as performance demands increase. This video shows how Vicor power modules enable high-density, high-efficiency power delivery for motor drives and advanced CPUs.

[Learn more](#)

Video spotlight



T-Global Technology's TG-AD series

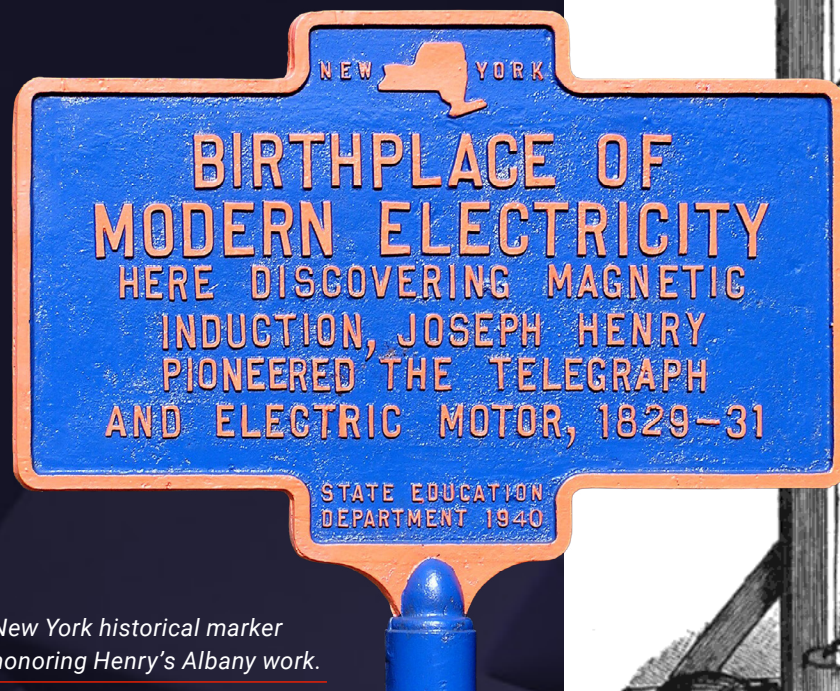
The TG-AD series ultra-soft thermal pads offer long-term, reliable performance. The TG-AD series is formulated to provide the ideal combination of low hardness and high thermal conductivity alongside good electrical isolation, making them ideal for use across many applications. They offer exceptional void filling between components and heat sinks and requires only light pressure to fill gaps.

[Learn more](#)

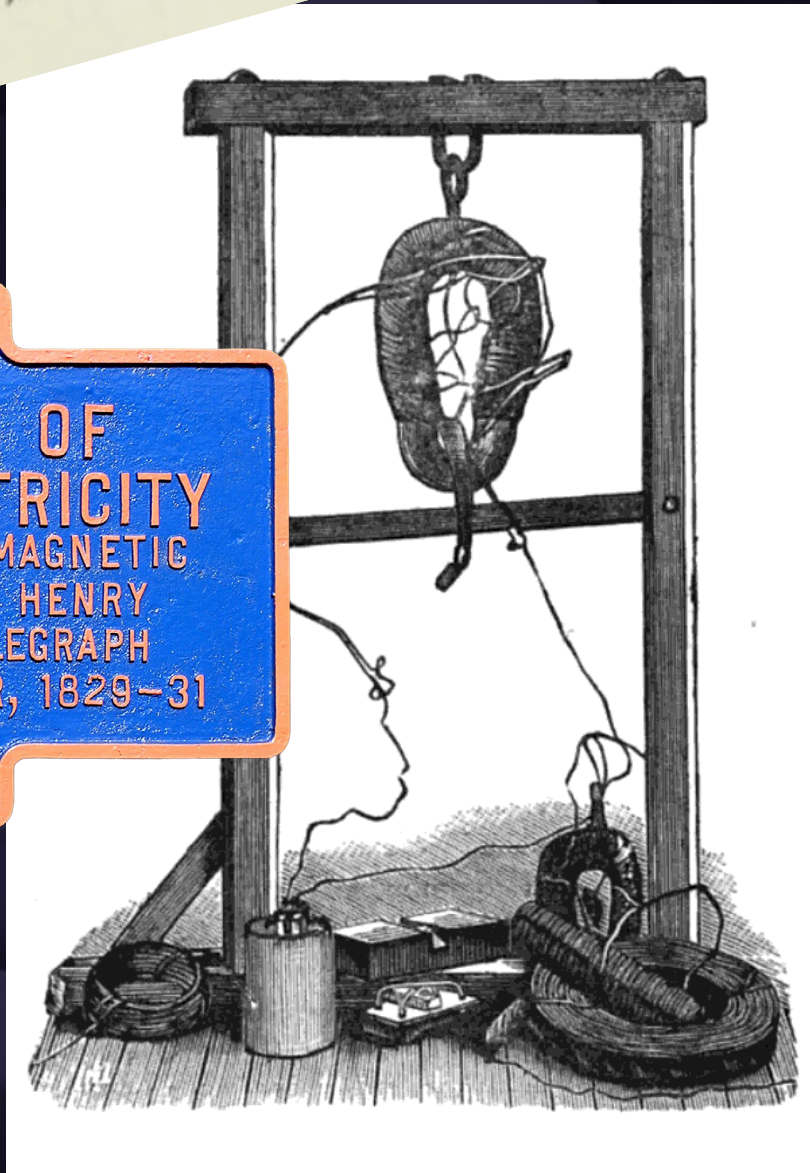
Miniature SMT or THT Slide Switch

The EGJ1210 Series slide switch features a compact footprint and variety of terminal options, including surface mount and through hole PC board design with the potential for right angle implementation. The EGJ1210 has a SPDT contact arrangement, only 1.60mm of travel, a contact rating of 300mA @ 24VDC and operates in temperatures ranging from -40°C to +85°C.

[Learn more](#)

Joseph Henry

New York historical marker honoring Henry's Albany work.



How Joseph Henry made electricity work at a distance:

The story of the first electrical relay

By David Ray, Cyber City Circuits

When electricity was still a spectacle

Before Joseph Henry began winding wire, electricity had already spent a century making itself loosely known. It popped from glass globes, leaped from Leyden jars, crawled through wires, twitched dead frogs, deflected compass needles, and occasionally convinced a physician that he had discovered the missing key to human health.

Electricity could astonish a crowd. It could injure someone. It could entertain a lecture hall or terrify a patient. It could be stored briefly, discharged violently, and coaxed out of a wet pile of metal discs, but people didn't know how to make it behave like an obedient tool.

This was the world Henry inherited, where our story starts.

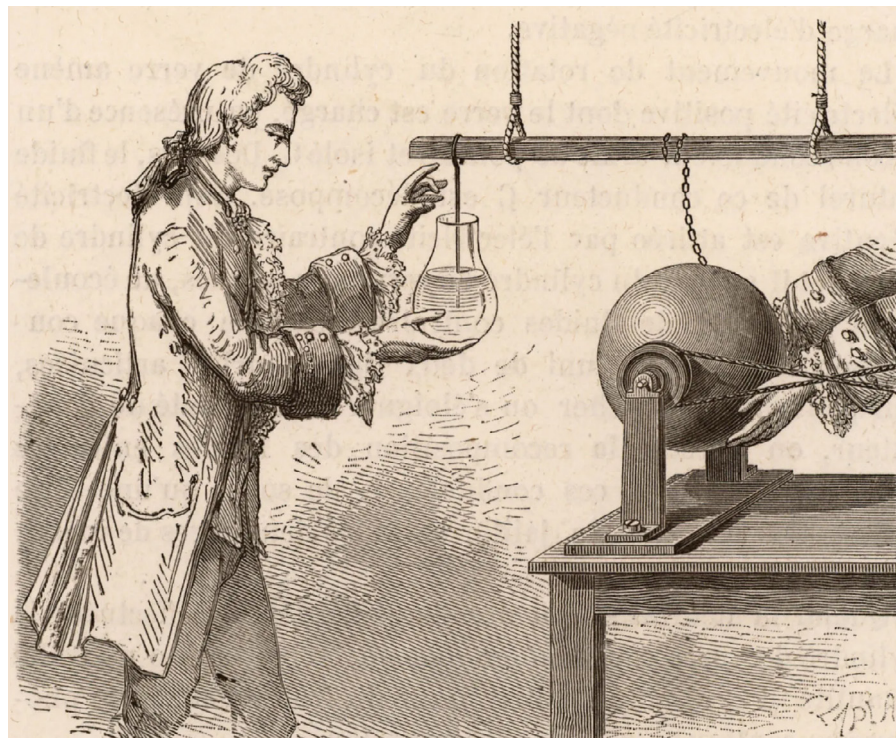
For much of the eighteenth century, electricity was a science of sudden events. The best-known tools were friction machines and Leyden jars. A Leyden jar could store an electrical charge long enough for a quick demonstration, an experiment, or a medical shock. It was progress, but not the kind of progress that could build infrastructure. A Leyden jar was less like a battery and more like a crude capacitor.

Retro Electro fun fact: Around this time, in 1802, an unknown New York doctor named T. Gale wrote the first medical technology book in the New World. Named “Electricity or Ethereal Fire Considered,” it describes the ways you can build an electroshock generator in order to cure or treat many different ailments like asthma, dysentery, and madness. Read more about that in the Retro Electro article [“Electricity or Ethereal Fire Considered.”](#)

The Leyden jar helped researchers store electricity, but it did not solve the larger problem. It made electricity more accessible for study, but it still delivered its energy in short bursts. The world was waiting for something more reliable and longer-lasting.

That change came in 1800, when Alessandro Volta introduced the voltaic pile.

The pile wasn’t spectacular in the same way as a Leyden jar. It didn’t need a spinning glass machine or have the theatrical spark. It was almost disappointingly plain. Alternating discs of metal, separated by paper soaked in saltwater or acid. While it didn’t provide the same theatrics required for the Leyden Jar, it did something entirely new. It produced a relatively steady current.



Leyden jar electrical demonstration.

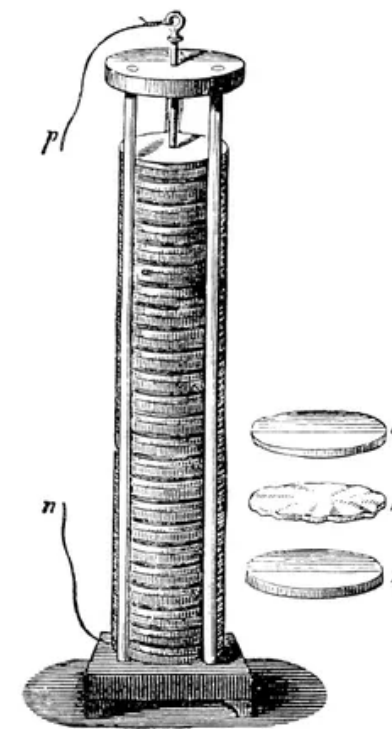
Steady current changed everything in the experimental world. With friction machines and Leyden jars, electricity required a

lot of regular effort, but with the voltaic pile, it could be built and studied. The reliability of these new batteries made a new world

of innovation possible. Current could now be sent through wires for enough time that researchers could ask better questions.

What does current do near a compass? What does it do in a coil? What does it do to iron? What does it do to another current-carrying wire?

By the late 1820s, the study of electricity had advanced to include batteries, needles, coils, and a handful of mathematical laws. The pieces were coming together, but nobody had figured out how to make it useful.



Voltaic pile battery diagram.

Retro Electro fun fact: The galvanometer originated in central Europe during this time. Within only a few months of Hans Christian Ørsted’s 1820 discovery that electric current could deflect a compass needle, experimenters across Europe began pulling the idea apart and rebuilding it into useful instruments and mathematical formulas. Read that story in the Retro Electro article [“Experiments on the Effect of a Current of Electricity on the Magnetic Needle.”](#)

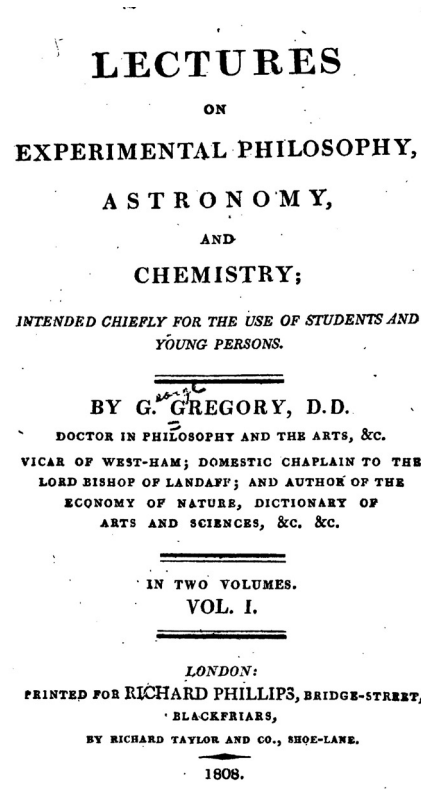
Joseph Henry

Joseph Henry did not begin as the inevitable founder of American electromagnetism. Nothing in his childhood announced that a future Secretary of the Smithsonian was quietly assembling himself from borrowed books, failed ambitions, and whatever education could be found around the edges of work. There was nothing in Henry’s youth that could foretell the life that followed.

Joseph Henry was born in Albany, New York, to Scottish immigrants on December 17, 1799. (Writer’s note: The year Henry was born is

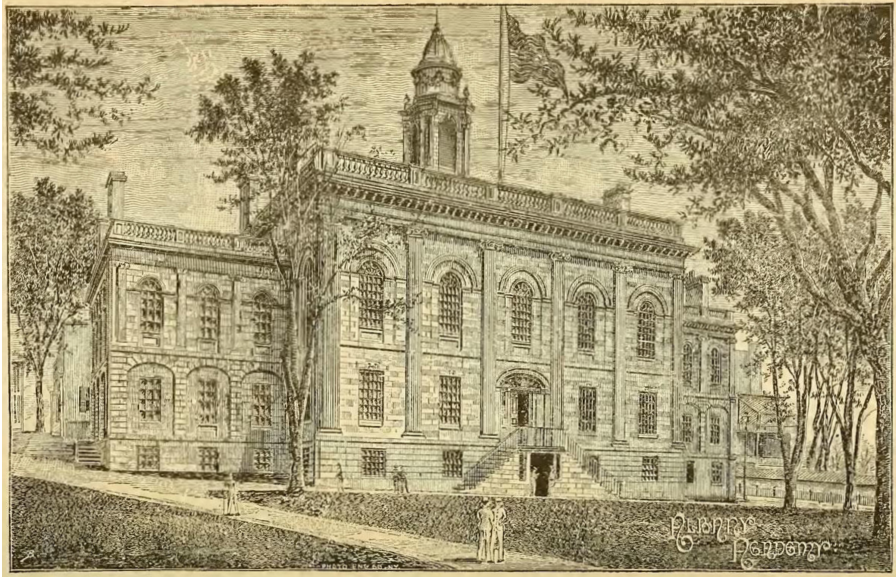
often written as 1797, but many official memorials from the time following his death say it was 1799.) Joseph lost his father early and spent much of his youth under the care of his maternal grandmother in Galway, Saratoga County, New York. There, he attended the local district school until he was about ten years old.

At age ten, Henry took a job working in a store, where he worked hard and was allowed to attend some of the afternoon school sessions. Through this schoolwork, he eventually earned a scholarship to Albany Academy and moved back to Albany to attend.



George Gregory's book that helped turn Henry toward science.

At about fifteen years old, Henry returned to Albany and entered a watchmaker's shop as an apprentice. Here, he learned to perform precise work with his hands. He did not want to remain



Albany Academy in 1815.

a watchmaker, but the training was not wasted. The skills he gained working on watches and clocks were invaluable later in life.

During a brief illness where Henry was stuck in bed at home, he read a book by Dr. George Gregory, "Lectures on Experimental Philosophy, Astronomy, and Chemistry." Later in life, Henry says that finding this book led him to science and

that he cherished the volume until the end of his life. He completed his education at a night school, then with an itinerant teacher, and finally at the Albany Academy. He impressed the faculty so much that the school's principal recommended that the president of the academy, Stephen Van Rensselaer III, hire Henry as a private tutor to the Van Rensselaer family after he graduated.

Retro Electro fun fact: Many of the nineteenth century's innovators and instrument makers started out working for clockmakers. This includes the French inventor of the fuse, Louis Breguet. Read his story in the Retro Electro article "[The Blade That Breaks the Circuit: A Milestone History of the Blade Fuse.](#)"

Stephen Van Rensselaer III

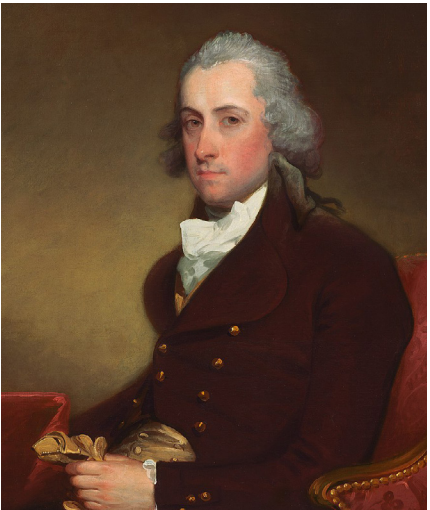
The Van Rensselaer family goes back to the 1600s as a line of very wealthy Dutch landowners. At the time Henry was tutoring, the patriarch of the family would have been Stephen Van Rensselaer III.

Van Rensselaer was one of the most powerful men in early nineteenth-century New York.



Major General Stephen Van Rensselaer III at the Battle of Queenston Heights.

Heir to the vast Dutch patroon estate of Rensselaerswyck, a major landowner, businessman, civic patron, and political figure whose influence reached far beyond Albany. He served in both houses of the New York legislature, became lieutenant governor of New York under John Jay, and later represented New York in the U.S. House of Representatives. He was also tied by marriage to the highest Federalist circles as Alexander Hamilton's brother-in-law, placing him near the political elite of early America. During the War of 1812, Van Rensselaer held the rank of major general in the New York militia and commanded American forces on the New York border with Canada. Following the war, in 1813, Van Rensselaer founded the Albany Academy.



Stephen Van Rensselaer III, founder of Albany Academy. This was made around the time he met Joseph Henry.

The position within the Van Rensselaer home was important to Henry's development. Henry was able to meet many influential people. The work paid well and required only a few hours of his day, leaving Henry time for mathematics, chemistry, and the self-directed study that would soon define his career.

Amos Eaton and road surveying

In 1824, Van Rensselaer, along with a friend and colleague, Amos Eaton, founded the Rensselaer School, now named Rensselaer Polytechnic Institute in Troy, New York. Being involved in the Van Rensselaer household and the Albany Academy, Henry would have been associated with setting up the school and here he worked with the senior lead instructor, Amos Eaton.

Amos Eaton was born on May 17, 1776, in New Concord parish, now Chatham, New York, and built one of the most unusual scientific careers in early America. He graduated from Williams College in 1799 and worked as a lawyer, land agent, and land surveyor. In 1818, after a rocky professional surveying career, Eaton had moved into the Troy-Albany world of canals, agriculture, surveying, and industrial growth, where Stephen Van Rensselaer III became his patron. Eaton spent the next several years lecturing, writing

textbooks, and conducting geological and agricultural surveys across New York, including work connected to the proposed Erie Canal route. His educational philosophy was unusually practical for the time. ***Science should be learned by doing and applied to the common purposes of life.*** That concept became the underlying principle of his career as Academic Head at the Rensselaer School until his death in 1842.

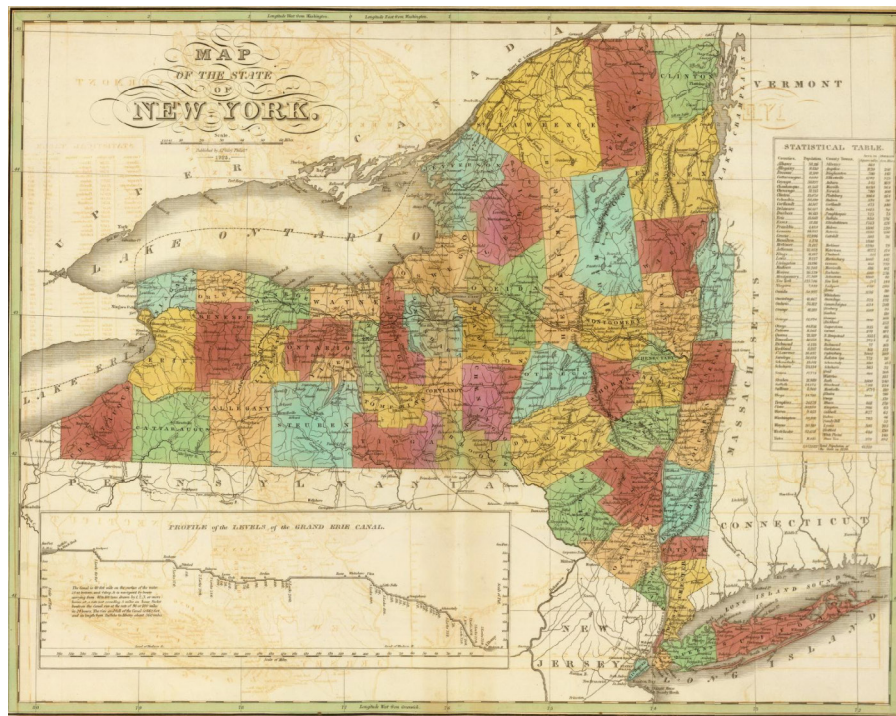
In 1825, Henry was pulled into a survey job with Amos Eaton for a new road across New York State. The route was planned for 300 miles across New York's lower counties, from West Point to Lake Erie. The work was very hard and went into the winter, surveying the wilderness of New York in the deep snow. Henry looks back at this time as difficult work, but he clearly enjoyed it, because after the survey's completion, he was ready to accept the director position of the construction of a canal in Ohio.

Before he accepted the Ohio canal position, he learned that the Chair of Mathematics at Albany Academy would soon become vacant and that his name had already been put forward before he returned from the survey work. This is widely regarded in every history of Joseph Henry as a major turning point for him. Henry was the kind of man who would have been successful and at the top of his field no matter what career path he took.

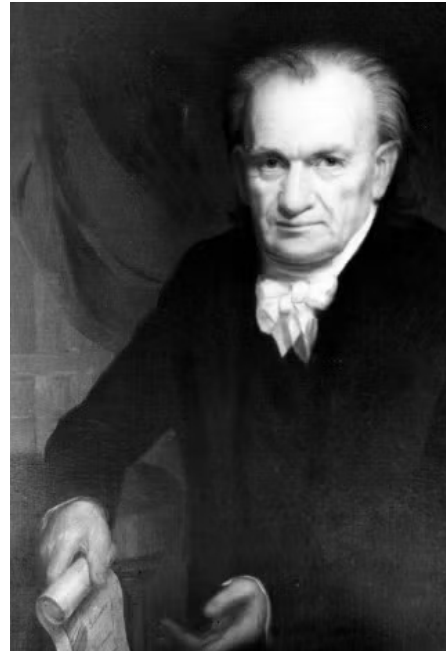
Thankfully, he chose the pursuit of science over civil engineering.

That spring, he accepted the position at Albany Academy, starting in September of 1826. Frequent Retro Electro readers will know that 1826 is right in the middle of technological innovation on the other side of the ocean in Europe. Henry, on the other hand, had to wait for these writings to be translated and republished in the New World before he could read them.

This new position as Chair of Mathematics at Albany Academy allowed him a budget, a state-of-the-art laboratory, the latest European journals and magazines, and almost anything else he wanted for his research.



Map of 1826 New York State.



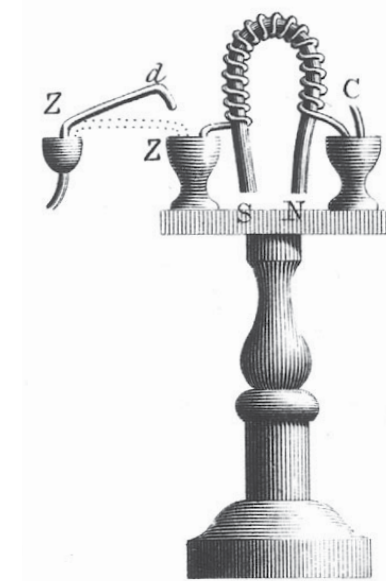
Amos Eaton, educator, scientist, and co-founder of the Rensselaer School.

William Sturgeon and the Electromagnet

In 1825, a British natural philosopher named William Sturgeon bent soft iron into a horseshoe shape, coated it with a nonconducting varnish, and wound it with some bare copper wire. When current flowed through it, the iron became magnetic. When the current stopped, the magnetism ceased. A battery could now command a piece of iron to become a temporary magnet. Sturgeon converted electrical energy into useful and controllable mechanical work.

Sturgeon's electromagnet was not the electromagnet that would build the oncoming electrical age. The wire was loosely wound to avoid shorting the wire. This new tool could lift small objects from a tabletop, but it could do very little to be useful. No matter how small the effect was, it was huge news to researchers. Men all around the United States and Europe were trying to recreate Sturgeon's experiments and somehow improve them.

When Henry entered electromagnetism, he wasn't a polished European physicist, a bored wealthy gentleman-investigator, or a professional inventor seeking a patent. He entered as a teacher with long hours, mechanical hands, a confident education, and a mind



William Sturgeon's early electromagnet.

trained to see possibilities. When Henry finally looked at Sturgeon's electromagnet, he did not see a finished invention.

He saw an incomplete machine.

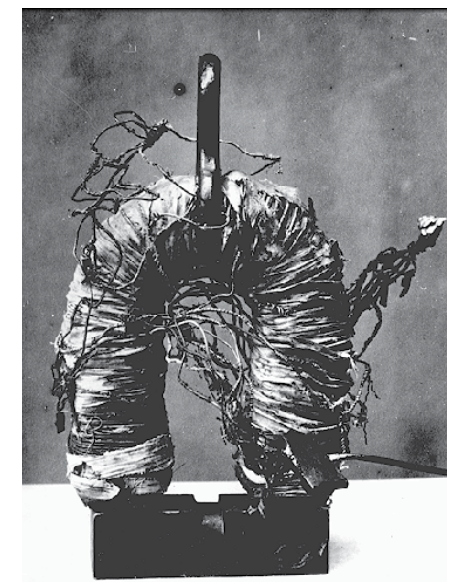
The Insulated Coil

The grand innovation that changed everything was silk wrapped around copper wire.

That is easy to miss because modern engineers are surrounded by insulated conductors. Every transformer, motor winding, relay coil, solenoid, speaker, telephone receiver, inductor, and power supply quietly depends on the conductors being electrically isolated from their neighbors. In Sturgeon's electromagnet, the iron was insulated. The wire was not.

That makes sense for a first attempt. Sturgeon's electromagnet used bare wire, and if one turn touched the next, the current could take a shorter path rather than traveling through the full winding. The turns had to be kept apart, which limited the number of turns.

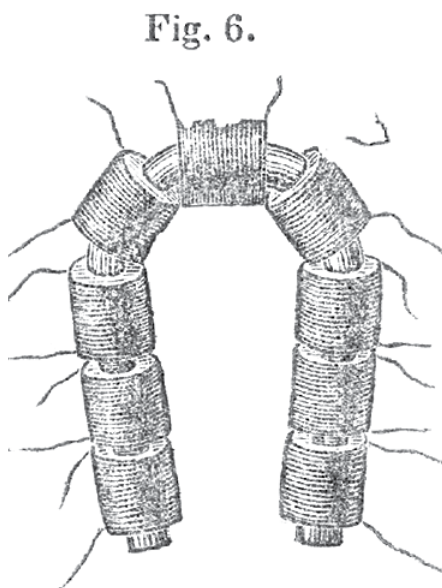
It seems that most researchers working on the electromagnet at the time, thought the limitation was the battery's strength. Henry immediately recognized that the real limitation was the winding. Henry saw the problem differently. If the conductor itself could be insulated, the turns could lie close together, even on top of each other. They could be wound tightly around the iron. This moved electromagnets from a few loops of wire to a dense coil of wire.



Henry's Albany electromagnet.

When Henry published his work in October 1827, the wire used was described as “fine copper or brass wire, wound with silk, to prevent contact, and the whole bound together so as to have the appearance of a single wire.”

Henry’s Albany experiments pushed the electromagnet out of the novelty category. At this time in history, Georg Ohm’s mathematical revelations of the galvanic circuit had only just appeared in Europe and was not yet the common language of American experimenters. Henry was not plugging values into Ohm’s Law. He was discovering the behavior of circuits with pen, paper, wire, acid, zinc, copper, silk, iron, and patience.



Henry's multi-coil electromagnet design.

Soon, Henry was running lengths of wire to “remotely” control the electromagnet by putting the battery in a different room. An electromagnet that worked only beside its battery was useful, but limited. A magnet that could respond over a distance suggested something far more powerful. Bells. Signals. Recording instruments. Mechanical motion at a distance.



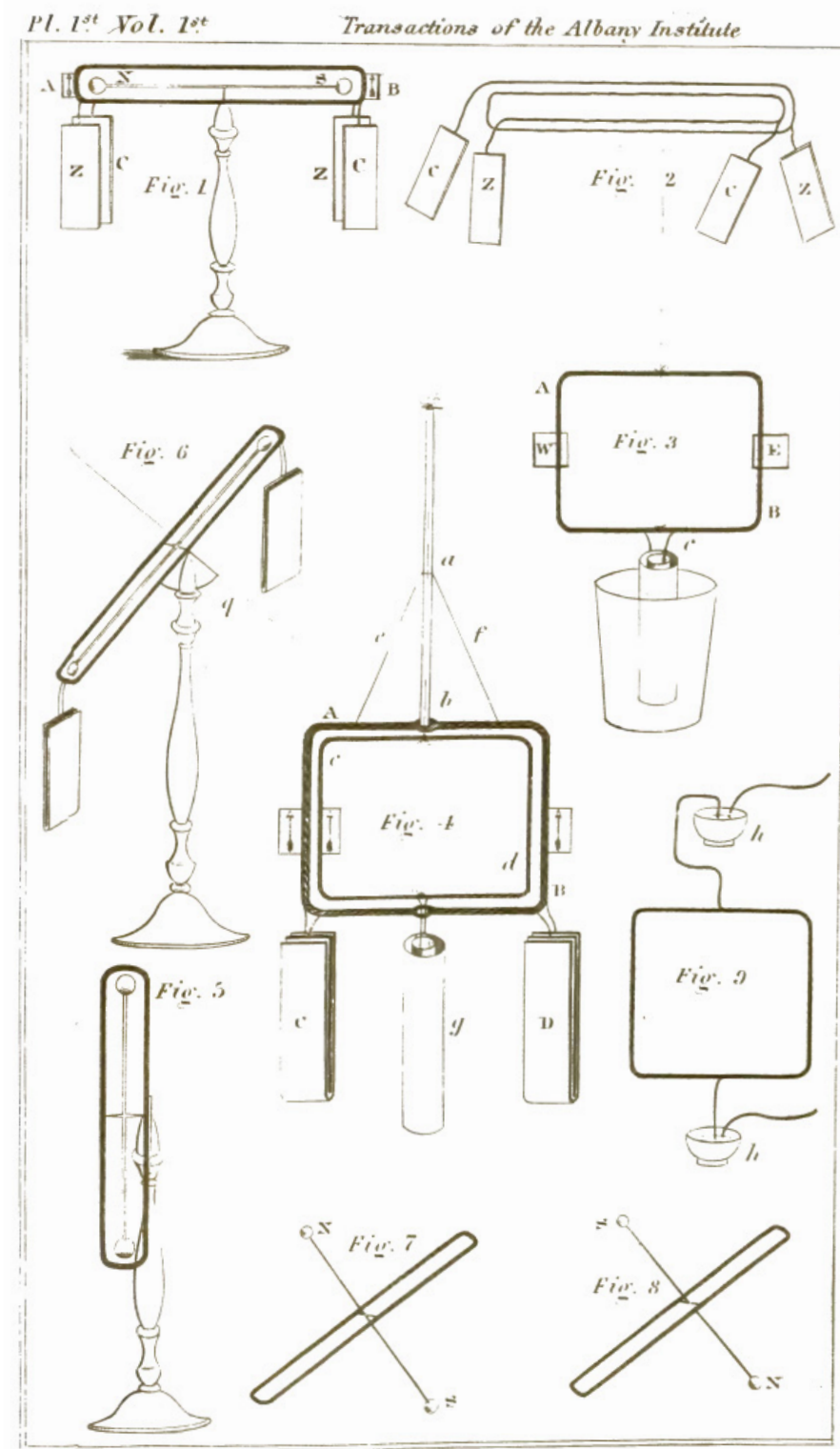
Electromagnetic bell apparatus showing current converted into motion.

Retro Electro fun fact: Georg Ohm was very influential in discovering the foundations of the electrical sciences, but have you ever wondered about the origin of the Ohm (Ω)? This crucial unit of electrical resistance has a fascinating history that connects science and innovation. Read the story of the Ohm (Ω) in the Retro Electro article “[Ohm’s Day](#)”.

Henry did not come up with the electromagnet, but he certainly developed the design rules.

Barlow’s Law

By the late 1820s, the concept of electrical signaling was not new. People had imagined sending messages by electricity for decades. The hard part was making it work outside the room. In 1825, English Mathematician Peter Barlow gave the puzzle a discouraging solution. In his experiments with electromagnetic signaling, he concluded that the effect diminished so severely with wire length that long-distance electromagnetic telegraphy was impractical. In other words, electricity could perform tricks nearby, but distance seemed to drain the possibility out of it.



Various apparatus used in Henry’s Albany experiments.

Barlow’s experiments were recreated and confirmed. It looked bleak that electricity could be truly useful. For a few years, this was accepted by many in the field, until Georg Ohm’s book “The Galvanic Circuit Investigated Mathematically” was published internationally, and it was proven that Barlow’s Law was incorrect and the premise was misunderstood, but that would still be some time away.

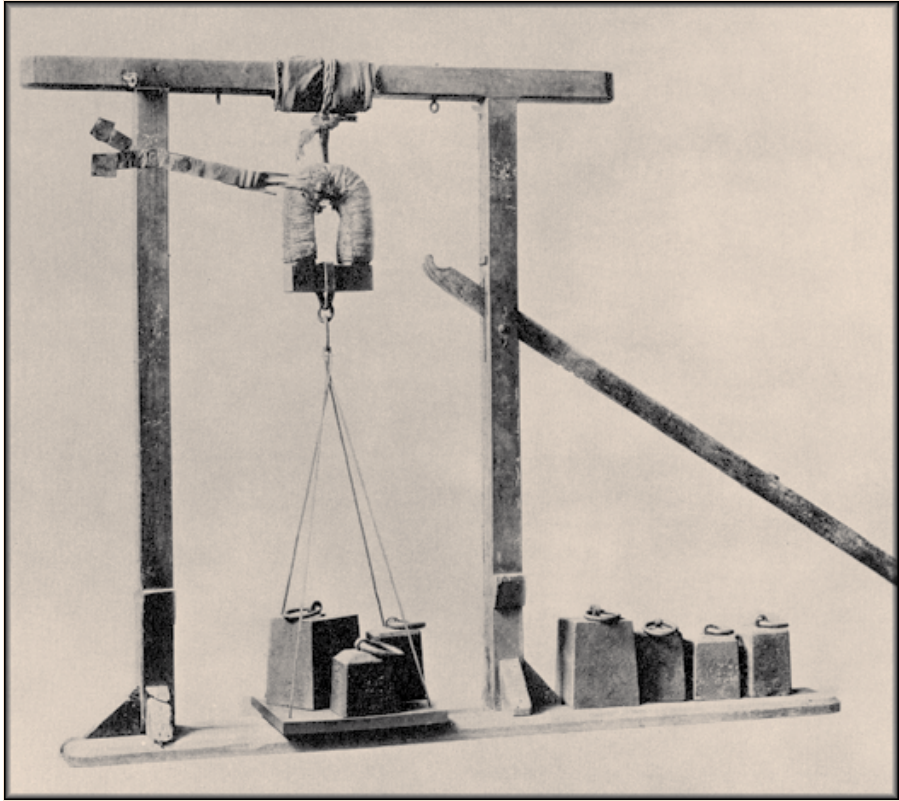
If Barlow was right, then electromagnetism could remain a lecture-room marvel and it could not become a communication system. It could not cross a city, much less a state or a continent.

Convinced he could solve the distance problem, he began spending much of his time developing remote signaling devices. In one demonstration, Henry ran a long length of wire around a room and used the current from a battery to ring a bell at the far end. Some accounts say the wire was over a mile long, pretty much disproving Barlow’s Law. Henry even remarked that the method could give signals by ringing a bell many miles away. In this way, Henry is said to have invented the telegraph a decade before Samuel Morse.

Henry understood the significance. He did not rush to patent it. He did not turn immediately into an entrepreneur. He was an academic. A properly designed electromagnet could work in a long circuit, and this innovation was not patented.

The College of New Jersey

In 1831, Henry’s work had become too important to remain merely local. His results were published in The American Journal of Science, the most important American scientific journal of its day. The article titled “An Account of a Large Electro-Magnet” garnered a whole lot of attention.



Picture of Henry’s Albany-era electromagnet experiment.



Joseph Henry’s large electromagnet built for Yale College.

Retro Electro fun fact: The distance problem would show up again a couple of decades later with submarine telegraph cables, culminating with the failure of the first Trans-Atlantic Cable. You can read that story in the Retro Electro article [“Wildman Whitehouse and the Twenty Five Hundred Mile Long Capacitor.”](#)

Previous journal articles on electromagnet attempts were uneventful and didn’t really push the subject forward, but Henry not only pushed it forward, he showed that it works better than anyone thought.

The numbers were surely jarring. With one battery arrangement, the magnet sustained 1,600 pounds. With larger batteries, it readily supported 2,000 pounds, and in one trial reached 2,063 pounds. Even days after the battery had been started, the electromagnet held enough magnetism that additional weight could be added before it fell.

Albany Academy had given Henry the room, apparatus, students, and civic stage to develop his experiments, but this Journal gave the work a national scientific audience, and now people saw him.



Joseph Henry’s house at Princeton.

Then, the College of New Jersey called.

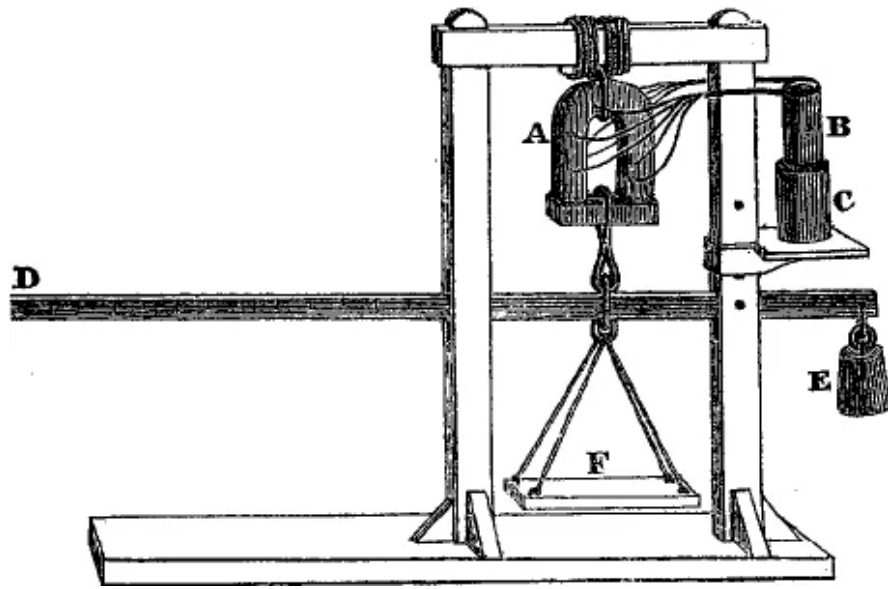
The call came from men who understood the value of scientific reputation. Among them was Dr.

Jacob Green, a former professor at the College of New Jersey, and John Torrey of New York. In 1832, Henry left Albany Academy for the College of New Jersey, the institution later known as Princeton. *(Writer’s Note: For simplicity’s sake, it will be referred to as Princeton.)*

At Princeton, he continued his experiments, now with essentially unlimited resources.

The Invention of the Electric Relay

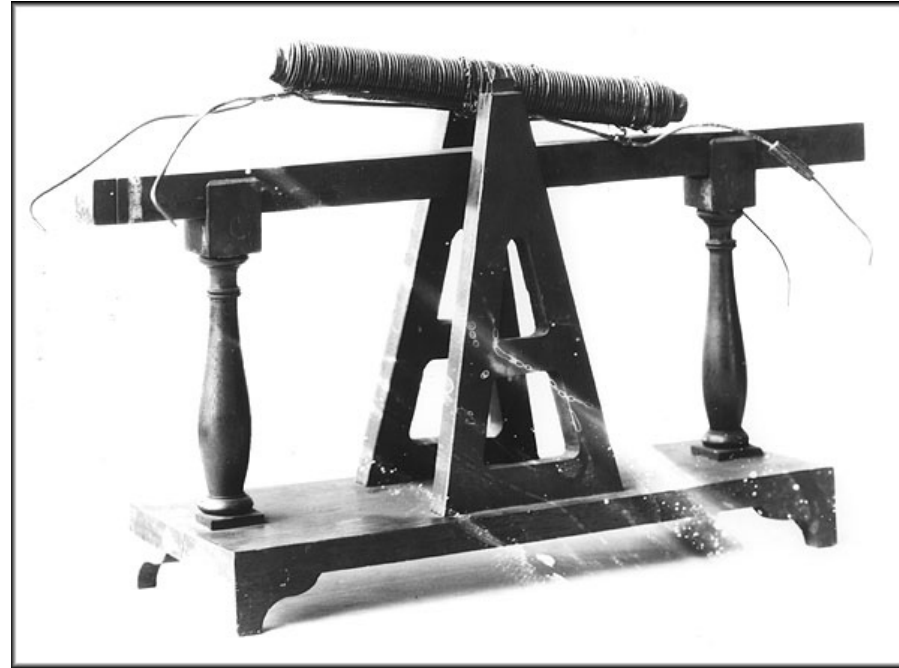
A relay is defined as an electromechanical switch that allows one circuit to control another circuit while keeping the two circuits isolated. While this concept is very fundamental today, it somehow took Henry nearly



Electromagnetic lifting experiment.

ten years to develop the relay. In Albany, Henry had shown that a current could travel through a long wire and still make an electromagnet respond at the far end. That was direct action. The distant current still had to do the work itself. At Princeton, Henry separated the problem into two parts. A weak current arriving through a long wire could energize a sensitive electromagnet. That electromagnet did not need to ring a bell, mark paper, or lift a load. It only needed to move a contact and close a second local circuit. That local circuit, powered by its own nearby battery, could then energize an even stronger electromagnet and do the real work.

In 1835, Henry demonstrated the first electric relay, but again, he decided not to patent any of his work. Historically, academics have struggled to commercialize their groundbreaking concepts and discoveries. This is when the story introduces an artist named Samuel F.B. Morse.



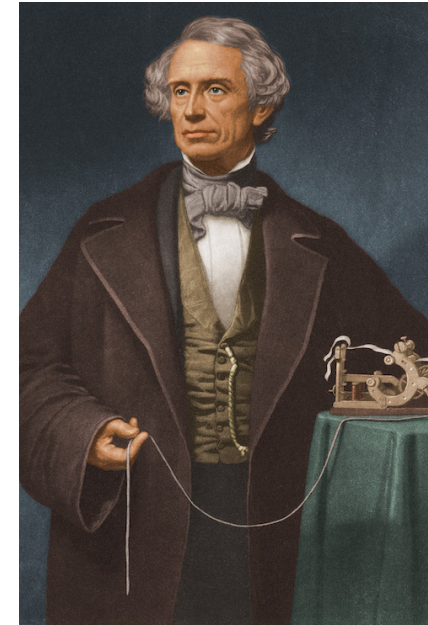
Joseph Henry's early electromagnetic motor.

Samuel F.B. Morse

Samuel Finley Breese Morse did not arrive at the telegraph by the usual engineering road. He was born in Charlestown, Massachusetts, in 1791, trained at Andover and Yale, sailed to Europe to study painting,

exhibited at the Royal Academy, helped organize the National Academy of Design, and spent decades trying to become the kind of American artist whose canvases could carry a young republic's dignity. Morse spent the first half of his life as an artist and the last half as an electrician.

Retro Electro fun fact: The house the Henry family lived in while at Princeton is a registered historic landmark. Currently owned by the university, the house has been moved a number of times and is now the school's Andlinger Center for the Humanities.



Samuel F. B. Morse and his telegraph.

The telegraph entered Morse's life almost as a second career, and not a tidy one. In 1832, returning from Europe aboard the packet ship Sully, Morse claims he first conceived the idea of an electric telegraph.

By 1836, Morse was showing rough models of an electric telegraph. In 1837, Alfred Vail entered the story, bringing money, mechanical skill, and the Speedwell Iron Works behind Morse's idea. That partnership turned Morse's apparatus from a fragile demonstration into a more practical instrument. Soon, he was able to demonstrate his invention and applied for a patent with the patent office. In 1844, the Washington-to-Baltimore line finally gave the invention its public sentence: "*What hath God wrought.*"

The Smithsonian Institution

James Smithson was one of history's stranger benefactors: a British scientist, born illegitimately into aristocratic circles, who never visited the United States but left his fortune to it anyway. Smithson never married and had no children. In his will, he left his estate to his nephew, but Smithson directed that if his nephew died without heirs, his estate should go to the United States to found, in Washington, an institution for the "increase and diffusion of knowledge." Smithson died in 1829, the nephew died in 1835, and by 1838, the bequest had arrived in Philadelphia as more than 100,000 gold sovereigns, recoined into more than \$500,000.



James Smithson, founder by bequest of the Smithsonian Institution.

Then the money sat inside an American political argument. Congress had accepted the gift in 1836, but for nearly a decade no one could quite agree what Smithson's vague, magnificent phrase was supposed to mean in practice. Was this to be a museum? A national library? A university? A research bureau? A public lecture hall? A cabinet of curiosities?

That deadlock finally broke under President James K. Polk. On August 10, 1846, Polk signed the act establishing the Smithsonian Institution as a trust administered by a Board of Regents and a Secretary. The act created more than a simple museum. It called for a building with space for natural-history collections, a chemical laboratory, a library, an art gallery, and lecture rooms, while preserving the original Smithson fund as a trust whose income would support the Institution.

In 1846, the Board of Regents of the Smithsonian Institution came to Henry with a once-in-a-lifetime job offer. As a leading advocate for science education, they saw it fit to offer Henry the position of Director and first Secretary of the Institution, to study the will of James Smithson, and to plan the future of the generous gift from Smithson. The appointment transformed him from a leading experimental physicist into one of the central organizers of American science.

He served for more than thirty years until his death, and the memorial notice after his death explicitly states that he devoted those years to making the Institution an efficient instrument for the “increase and diffusion of knowledge among men.” Henry pushed the Smithsonian toward original research, publication, and scientific communication rather than letting it become merely a library, museum, or lecture venue. The Smithsonian was to be an “active organization” meant to promote original research and disseminate knowledge more widely, while also acknowledging that collections and publications could coexist if funds were carefully balanced.



Joseph Henry in the 1840s.

Telegraph from Henry?

Some historians say he certainly did. Other biographies of Henry tell it differently. Early on, Henry does not seem bitter toward Morse for the telegraph. In fact, he taught him how to do it. Between 1839 and 1842, Morse corresponded with Henry for scientific advice and public support, and Henry willingly provided both. Henry’s 1842 letter even helped Morse’s push for Congressional support. At that stage, Henry’s position was basically: Morse’s machine is a good practical invention, but it rests on scientific principles discovered by Henry and others. There wasn’t hostility between the two, because Henry understood the difference between scientific discovery and commercial invention.

The real bitterness comes later, after money, patents, assistants, books, and lawsuits entered the story. The first serious break appears around 1845, when Alfred Vail’s (Morse’s business partner) book acknowledged that the electromagnet was central to Morse’s telegraph but gave Henry only slight credit. Henry was upset, but even then he left room for the possibility that Morse had not approved the omission.

The deeper rupture came during the patent litigation from roughly 1845–1854, when Henry’s testimony threatened Morse’s

broad patent claims. Morse was being sued by his competitors, trying to invalidate his patents. Henry was sent to testify on his knowledge of Morse’s work, and he stated simply that he did not know of any original discovery in electricity, magnetism, or electromagnetism applicable to the telegraph that is attributable to Morse, explaining that it was an aggregation of other people’s work and discoveries, like many other inventions.

Henry didn’t want to destroy Morse. Morse had made a practical telegraph, and Henry would not deny him that. Morse was trying to claim a patent on the general use of electromagnetism for signaling at a distance, regardless of the specific machinery used. In his testimony, Henry’s point was that Morse had not discovered the electromagnetic principles that made long-distance telegraphy possible. Those principles came from earlier work by Henry and others. This alone probably should have rendered Morse’s patent void, but it did not.

That is where the drama truly detonated. Morse answered Henry’s deposition in 1855 with a published attack titled “A Defence Against the Injurious Deductions Drawn from the Deposition of Prof. Joseph Henry.” Morse tried to argue that he owed Henry nothing

in science and even attacked Henry’s competence and integrity by picking apart Henry’s 1831 paper. The book Morse published is just that, a book. Not an article or pamphlet. 138 pages of rhetoric from a spited man. Henry then asked the Smithsonian Regents to exonerate him because Morse’s attack questioned his character and fitness for the position of Secretary.

Later life

Later in life, Henry continued to apply the same habits to other public systems. He never officially retired. On the Light-House Board, he investigated fuels, lamps, fog signals, and the practical reliability of aids to navigation. With the fledgling national weather service, he supported coordinated weather observations and the use of the telegraph to gather meteorological information across distances. At the Smithsonian, he promoted original research across every corner of science, from helping Alexander Graham Bell with his telephone to sponsoring archeological digs in the Grand Canyon and surveying the American West.

In front of the Smithsonian Castle stands a bronze statue of Henry. In 1883, five thousand people gathered to honor him.

THE ELECTRO-MAGNETIC TELEGRAPH.

A DEFENCE

AGAINST THE INJURIOUS DEDUCTIONS DRAWN FROM THE

DEPOSITION OF PROF. JOSEPH HENRY,

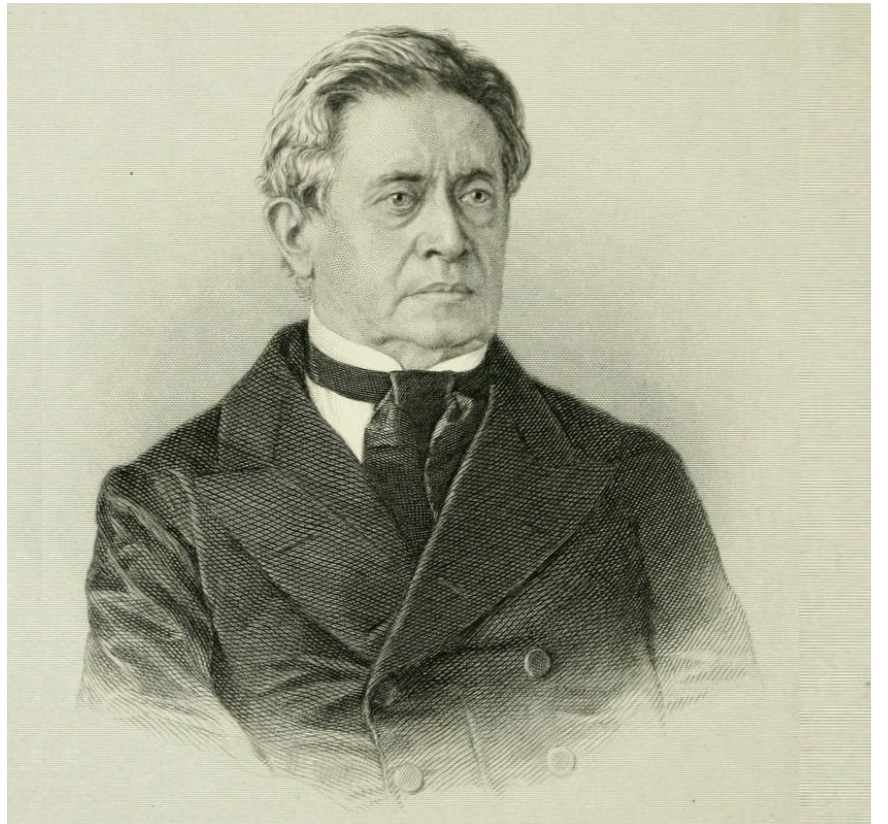
(IN THE SEVERAL TELEGRAPH SUITS.)

WITH A CRITICAL REVIEW OF SAID DEPOSITION, AND AN EXAMINATION OF PROF. HENRY’S ALLEGED DISCOVERIES, BEARING UPON THE ELECTRO-MAGNETIC TELEGRAPH.

BY SAMUEL F. B. MORSE, LL.D.,

PROFESSOR IN THE NEW-YORK CITY UNIVERSITY, &c., &c., &c.

Morse’s published attack on Henry’s telegraph testimony.



Joseph Henry in later life.

The government closed early, John Philip Sousa conducted a march written for the occasion, the “Transit of Venus” March, and Congress spent \$15,000 to build the statue and place it there. Today, Joseph Henry’s statue is often mistaken for somebody else, which is poetic because much of Henry’s career consisted of him being humble.



Joseph Henry statue outside the Smithsonian Institution.

In 1893, at the Chicago World’s Columbian Exposition, Henry’s name was attached to the unit of inductance. Making Henry the only standard unit of measure named after an American. It was a fitting memorial. The henry measures the tendency of a circuit to resist changes in current, a property of coils. Henry had spent his life showing what coils could become.

Suggested Reading

[Memorial of Joseph Henry](#) by the Smithsonian Institution 1881

[Unit of Inductance Named the “Henry”](#) by the Smithsonian Institution

[“A Memoir of Joseph Henry”](#) by William B Taylor

[Joseph Henry Letters, 1838-1878](#)

[“The Papers of Joseph Henry Vol 4 \(The Princeton Years\)”](#) edited by Nathan Reingold

[“The Papers of Joseph Henry Vol 6”](#) edited by Marc Rothenberg

[“Transit of Venus” March](#) by John Phillip Sousa

[“Lectures on Electricity”](#) by William Sturgeon

[“Amos Eaton”](#) by The RPI Institute Archives and Special Collections

[“On Some Modifications of the Electro-Magnetic Apparatus”](#) by Joseph Henry

[“Joseph Henry’s Contributions to the Electromagnet and the Electric Motor”](#) by Roger Sherman of the National Museum of American History

[“An Account of a Large Electro-Magnet”](#) by Joseph Henry

[Joseph Henry House](#) from The Historical Marker Database

[“The Electrical Discoveries of Joseph Henry”](#) by H. S. Osborne and A.M. Downling

[“Joseph Henry: The Rise of an American Scientist”](#) by Albert E. Moyer

[“A Defence Against the Injurious Deductions Drawn From the Deposition of Prof. Joseph Henry”](#) by Samuel F.B. Morse

[“The Henry”](#) by Atlantic Magazine – May 1894

[“Who Invented the Telegraph? Joseph Henry, A Bored Math Teacher!”](#) by Kathy Loves Physics

1745

The Leyden jar gives experimenters a practical way to store electrical charge, turning electricity from a fleeting spark into something that could be held briefly, discharged, and studied.

December 17, 1799

Joseph Henry is born in Albany, New York, to a family of recent Scottish immigrants.

1814

Henry returns to Albany and apprentices in a watchmaker’s shop, gaining the mechanical precision and hand skills needed.

1825

William Sturgeon demonstrates an early practical electromagnet by winding bare copper wire around a varnished soft-iron horseshoe.

October 1827

Henry publishes work describing his improved electromagnet using insulated wires.

1831 – 1832

Henry demonstrates long-distance signaling at Albany, running wire around a room, and showing that electricity can actuate an electromagnet at a distance.

1835

At Princeton, Henry demonstrates the relay principle: a weak long-distance circuit can control a separate local circuit with its own battery and stronger electromagnet.

1844

Morse’s Washington-to-Baltimore telegraph line sends the famous message, “What hath God wrought.”

1846

Henry becomes the first Secretary of the Smithsonian Institution, beginning more than thirty years of work shaping American science.

1854

The Supreme Court preserves Morse’s narrower telegraph claims but rejects his broadest claim to the general use of electromagnetism for marking intelligible signs at a distance.

1878

Joseph Henry dies while still serving as Secretary of the Smithsonian Institution.

1893

At the Chicago World’s Columbian Exposition, Joseph Henry is honored by having the unit of inductance named the henry, making him the only American commemorated in a standard electrical unit.

1752

Benjamin Franklin’s lightning experiments helped popularize electricity in America and encouraged a generation of natural philosophers, physicians, and hobbyists to experiment with electrical machines, Leyden jars, and lightning rods.

1809

Henry, still a child, works in a store and attends some afternoon school sessions while living in Galway, New York, under the care of his grandmother.

1810s

During an illness, Henry reads George Gregory’s Lectures on Experimental Philosophy, Astronomy, and Chemistry, the book he later credits with turning him toward science.

Spring 1826

Henry is elected Professor of Mathematics and Natural Philosophy at Albany Academy.

1831

Henry’s large electromagnet work appears in The American Journal of Science, giving his Albany experiments a national scientific audience.

1832

Henry leaves Albany Academy for the College of New Jersey, later known as Princeton University.

1839 – 1842

Morse corresponds with Henry for scientific advice and public support. Henry encourages the telegraph project while maintaining that its electrical principles rest on earlier discoveries.

1845

Alfred Vail’s book on Morse’s telegraph gives Henry only slight credit, helping start the serious rupture between Henry and Morse.

1849 – 1854

Morse’s telegraph patents become the subject of major litigation, and Henry’s testimony threatens Morse’s broadest claims.

1855

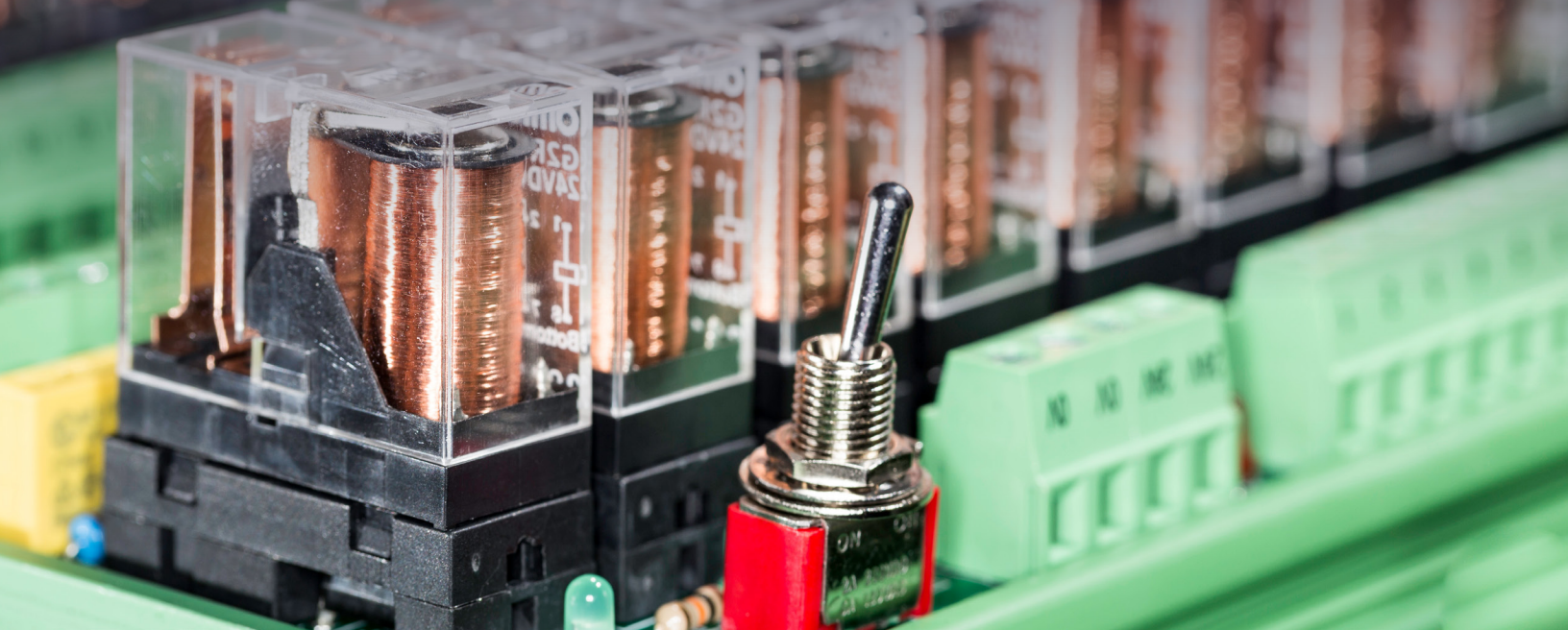
Morse publishes A Defence Against the Injurious Deductions Drawn from the Deposition of Prof. Joseph Henry, escalating the dispute into a public attack on Henry’s competence and integrity.

1883

A bronze statue of Henry is dedicated in front of the Smithsonian Castle, with thousands attending the memorial ceremony.

An introduction to relays

By Jeff Smoot,
VP of Apps Engineering and Motion Control at Same Sky



Relays play a vital role in countless consumer, commercial, and industrial applications and systems. They are often employed in everyday systems without notice. For example, relays are used when adjusting a household furnace, clicking a TV remote, or operating an elevator. Originally conceived in 1835 for the establishment of extended-distance telegraph connections, relays were subsequently adapted for use in telephone exchanges

and continue to operate dependably, inconspicuously, and with high efficiency.

From a pragmatic perspective, relays function as electrical switches. They utilize a low-power signal to govern a high-power circuit whether in proximity or situated at a distance. Their inherent design facilitates effective isolation between the low-power signal and the high-power circuit, often referred to as galvanic isolation.

This isolation ensures the safe and robust operation of electrical systems for users. Relays exhibit versatility, as they can be employed to regulate a single circuit or multiple circuits, and they can serve as amplifiers or circuit breakers.

The ability to control device power remotely also translates into enhanced safety measures, especially in industrial processes that might present physical hazards to operators. These

versatile devices are available in a wide array of packages, offering diverse current capacities, mounting options, and physical footprints, making them as prevalent as the everyday, ubiquitous switch.

Relays – how they function

For a better understanding of the subject, relays can be categorized into two fundamental types: electromechanical (EMR) and solid-state (SSR). The key distinction lies in the presence or absence of moving components.

The oldest of the two types is electromechanical, which comprises contacts, an armature, a spring, and an electromagnet. In its most basic operation, a spring maintains the armature's position. Upon the application of current, the electromagnet exerts an attractive force on the armature, causing it to move and close a set of contacts, thus enabling the flow of current through the circuit.

Conversely, solid-state relays, which emerged in the late 1950s, serve the same fundamental purpose as electromechanical relays but are entirely electronic without moving parts. They encompass an input circuit, a control circuit, and an output circuit to regulate current. When a voltage surpassing

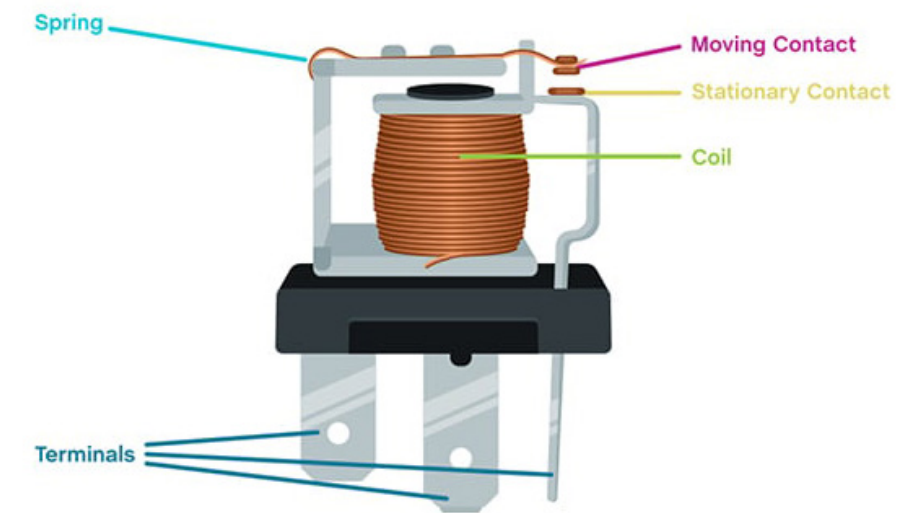


Figure 1: The basic internal structure of an electromechanical relay. (Image source: [Same Sky](#))

the specified pickup voltage is applied, the control circuit triggers the relay. Once the voltage falls below the dropout voltage, the relay deactivates.

Electromechanical vs solid-state relays continued

As with any electronic component technology, electromechanical and solid-state relays each come with distinct advantages and disadvantages that need to be considered.

Due to their two-century-old design, electromechanical relays are robust devices with straightforward operation, demonstrating reliability in a range of applications, including those involving high current

and hazardous environments. They offer complete electrical isolation, can withstand high current and voltage surges, and are impervious to electrical noise, such as electromagnetic interference and radio-frequency interference (EMI/RFI).

Nevertheless, because electromechanical relays have moving parts, physical degradation does occur over time, and contacts can deteriorate due to corrosion and oxidation. They may be susceptible to contact arcing, resulting in pitting and short circuits. Their mechanical nature makes them vulnerable to contact bounce from shock and vibration, and they can generate their own EMI/RFI noise. Additionally, external magnetic fields may affect their operation.

In contrast, solid-state relays offer a longer operational life and function with significantly lower control power thanks to their design without moving parts. They provide faster on/off cycling, eliminate arcing and contact bounce, and remain unaffected by external mechanical shock, vibration, or magnetic fields. Solid-state relays operate within a lower voltage range than electromechanical relays, making them suitable for electronic devices but less suited for high-power applications.

However, due to their unique design, solid-state relays may be susceptible to voltage or current transients and EMI/RFI noise. They tend to generate more heat than their mechanical counterparts and may be sensitive to ambient temperatures. Notably, achieving complete electrical isolation between the control signal and the load is not inherently possible with standard semiconductor switches, but it can be accomplished using optoelectronic components in photo-coupled devices, which isolate the input and output signals.

Common relay types

A diverse array of relay types is available, each tailored to address specific application requirements. It is worth noting that manufacturers may employ

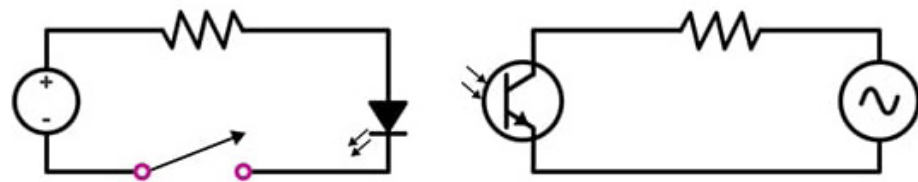


Figure 2: The basic internal schematic of solid-state relays. (Image source: Same Sky)

slightly different terminology for their product offerings, but here is a generalized summary of the major relay types:

- **General Purpose:** These are common electromechanical relays that operate with AC or DC current in the range of 12 to 230 volts and can control currents from 2 to 30 amps.
- **Signal:** Signal relays are used to control low-power loads, typically less than 2 amperes. For more information, you can refer to Same Sky ["Signal Relays – Understanding the Basics"](#) article.
- **Power:** Power relays are specifically designed to manage high-power loads, minimizing heat generation and reducing arcing. For more information, you can refer to Same Sky ["An Introduction to Power Relays"](#) article.
- **Machine Control:** These are heavy-duty and rugged relays intended for use in large industrial applications.
- **Latching:** Latching relays maintain their set or reset condition (either ON or OFF) until they receive an inverting voltage signal.
- **Reed:** Reed relays are compact and operate swiftly. They use an electromagnet to control one or more hermetically sealed reed switches, allowing for immunity to external contaminants or moisture.
- **Zero Switching:** These relays activate the load when the control voltage is applied, and the load voltage is close to zero. They deactivate the load when the control voltage is removed.
- **Peak Switching:** Peak switching relays activate the load when a control voltage is applied, and the load voltage is at its peak. They deactivate the load when the control voltage is removed and the current load approaches zero.
- **Instant ON:** Instant ON relays promptly activate the load when the pickup voltage is applied.

- **Time Delay:** Time delay relays incorporate a built-in timer to control events based on time.

- **Analog Switching:** Analog switching relays manage the output voltage as a function of the input voltage, allowing for infinite output voltages within the relay's rating.

- **Optically Coupled:** These are solid-state relays that provide isolation between the control and power circuits by switching in response to an internal light source.

- **Military/Hi-Rel:** These relays are specially engineered to operate in demanding and harsh environments.

Relays can further be categorized as normally open (NO), where the contacts are open and the circuit is not energized, or normally closed (NC), where the contacts are closed when the circuit is not energized. In summary, relays are typically specified as either NO or NC when no power is applied.

Ratings and configurations

Relays are rated based on their capacity to safely switch electrical power through the device. These ratings are categorized as either AC or DC and are typically expressed in amperes. It is crucial that

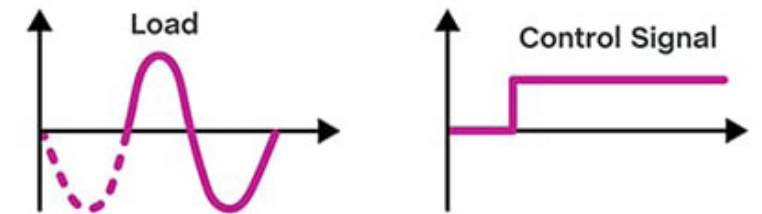


Figure 3: Basic principle of zero switching with relays. (Image source: Same Sky)

the relay's rating is equal to or greater than the device it will be controlling.

Relays have the capability to control multiple circuits simultaneously and are designated to indicate their specific characteristics. If familiar with poles and throws, these designations include SPST, DPDT, 3PDT, and SP3T.

In addition to the number of poles and throws, relays can describe important characteristics using the term "forms." Phrases like "1 Form A" or "2 Form C" highlight two key pieces of information. The form type indicates whether the switch is normally open or normally closed, and in the case of SPDT switches, whether they are "break-before-make" or "make-before-break." The number (1 or 2) before the form signifies how many contacts of that style are available within the relay. Some common styles include:

- Form A - Normally Open
- Form B - Normally Closed

- Form C - Break-Before-Make SPDT switches

- Form D - Make-Before-Break SPDT switches

Conclusion

Given their simplicity of design and reliable operation, relays are used in devices and systems across a wide range of industries and markets. Originating as basic components in telegraph systems, and even contributing to the early development of computers, relays maintain their essential role in the present day, ensuring the safe and efficient control of electrically powered devices from a remote location.

To fulfill an engineer's requirements for low-level or high-level current switching, Same Sky offers a comprehensive selection of [power and signal relays](#) with a variety of ratings and configurations.

How to adapt solenoid and stepper motor drivers for industrial applications

By Bill Schweber
Contributed By DigiKey's North American Editors

Edge device applications, such as factory floor control systems, automotive, and lab equipment, increasingly utilize Internet of Things (IoT) and artificial intelligence (AI) capabilities for low-latency decision making, higher performance, lower cost, and greater safety and productivity. Drivers for solenoids and stepper motors need to evolve to incorporate more onboard sensing and intelligence to facilitate their integration into this rapidly evolving environment, and to further improve precision, reliability, closed-loop control, cost, footprint, and ease of use.

This article summarizes the basic operation of solenoids and stepper motors and outlines the benefits of driver ICs designed for the intelligent edge. It then introduces and explains how to start designing with sample drivers from [Analog Devices](#).

Solenoids and steppers: similar yet different

Solenoids and stepper motors convert electrical current to physical motion via a wound coil acting as an electromagnet. Despite the differences in appearance and function, the coil commonality allows the same

driver IC to be used for both actuators in some circumstances.

Solenoids are relatively simple components that develop linear mechanical motion with applied current. They comprise an electrical coil wound around a cylindrical tube with a ferromagnetic actuator (also called the plunger or armature) in the hollow core that is free to move within the body of the coil (Figure 1, left).

In contrast, stepper motors use multiple stator coils arranged around the circumference of the motor body (Figure 1, right). The motor also has a set of permanent magnets attached to its rotor.

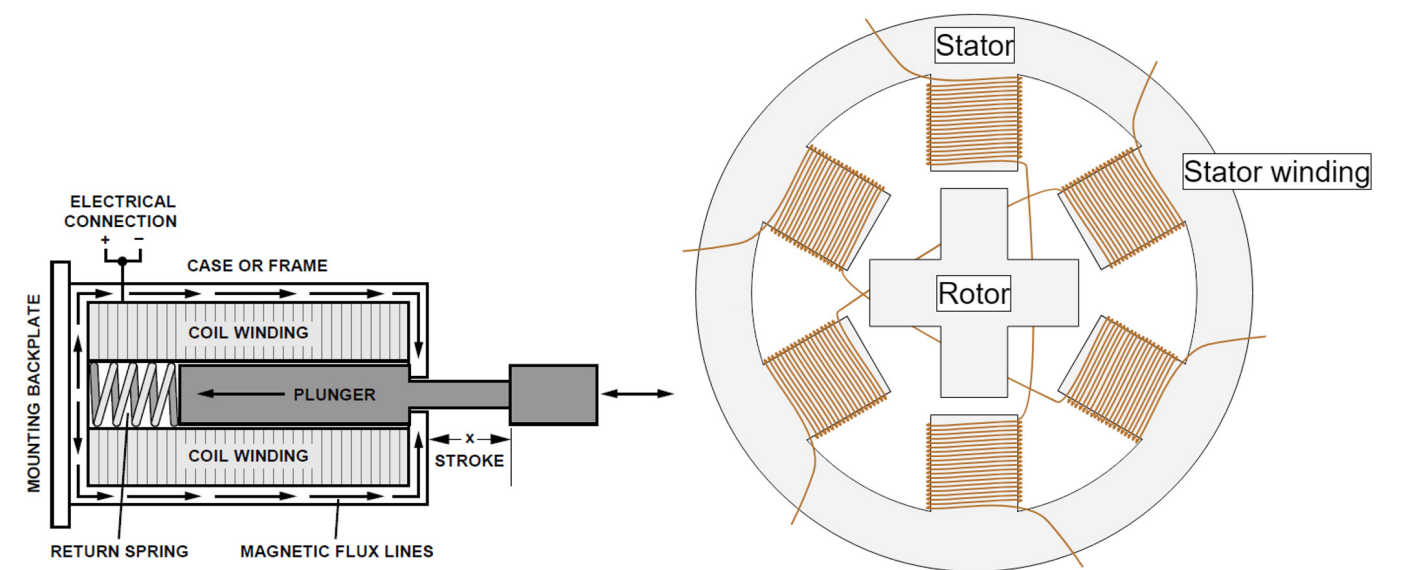
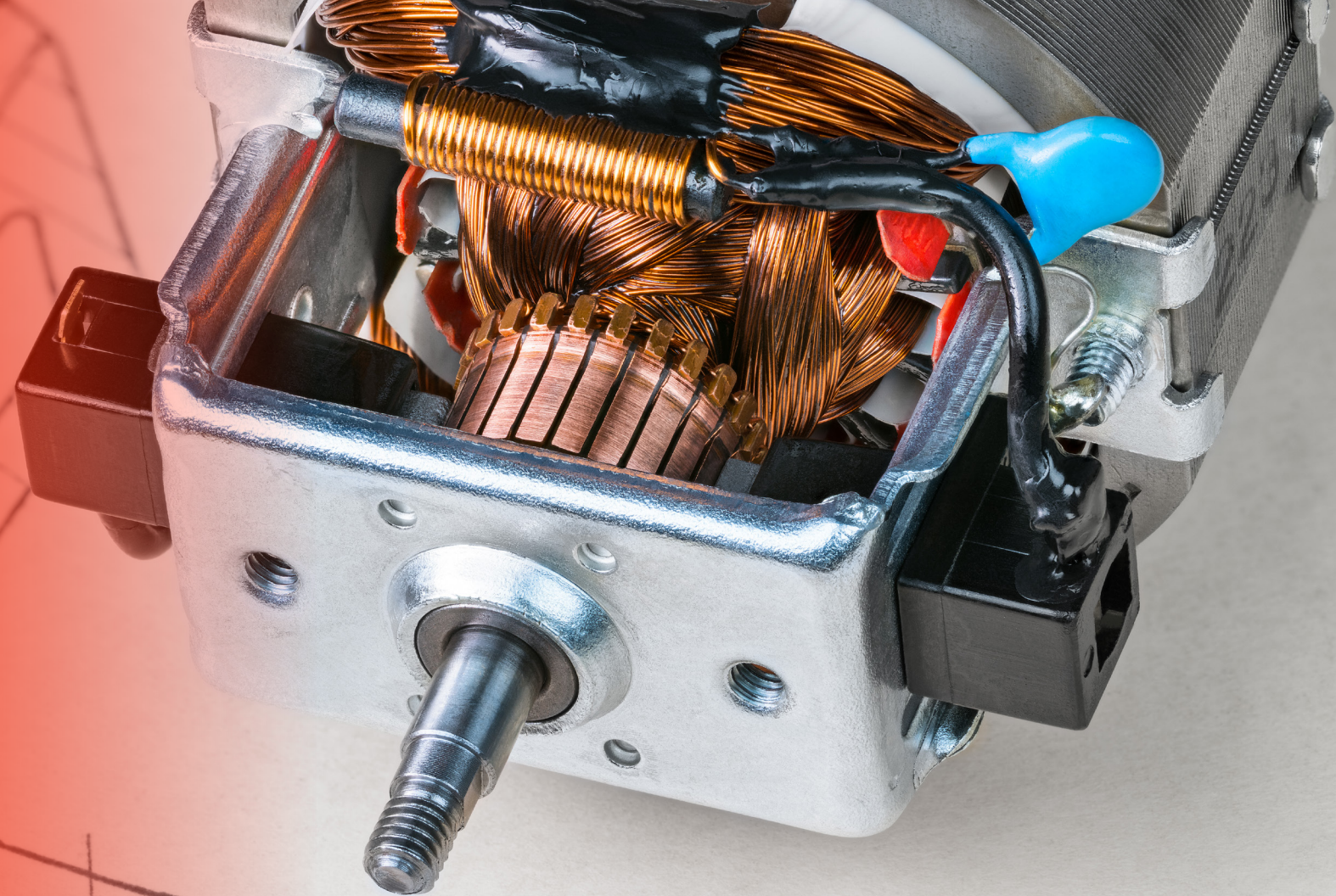


Figure 1: Solenoid construction comprises a wound coil with an internal sliding plunger (left); stepper motors are more complicated, with permanent magnets on the rotor and electromagnetic coils arranged on the stator (right). (Image sources: Analog Devices, Monolithic Power Systems)

For solenoids, the motion of the plunger is a single “punch” impact that occurs when a current is applied, slamming the plunger to its extreme position. When the power is removed, most solenoids use a spring to return the plunger to its nominal rest position.

In the most basic drive scheme, the solenoid is controlled by a crisp on/off current pulse. While this is simple and direct, its drawbacks include high impact force, vibration, audible and electrical noise, electrical inefficiency, and little control over the plunger action or its return.

The rotational action is activated for the stepper motor when the stator coils are energized in sequence, and the resultant rotating magnetic field pulls on the armature magnets. By controlling the sequencing, the stepper’s rotor can be made to rotate continuously, stop, or reverse direction.

Unlike the solenoid, which has no timing considerations, the stator coils must be energized sequentially and with the correct pulse width among other attributes.

Smart drivers overcome limitations, enhance performance

By carefully controlling the current driving the coils of solenoids and stepper motors, including waveform



profile shape, up and down ramp rate, and other parameters, an intelligent driver can provide many benefits, including:

- Enhanced smoothness of motion and rotation with minimal chattering
- Reduced vibration and impact, especially for solenoids
- More precise positioning for the stepper motor start/stop/reverse motion
- Consistent performance and accommodation of transient or varying load conditions

- Improved efficiency
- Less physical wear
- Generation of less audible and electrical noise
- Ease of interfacing with a supervisory processor, essential for IoT installations

The Analog Devices [MAX22200](#), an integrated, serial-controlled solenoid and motor driver, shows what a sophisticated driver can do for solenoids (Figure 2). The eight, 1 ampere (A) half-bridge drivers in this 36 volt IC can be paralleled to double the drive current, or configured as full bridges to drive

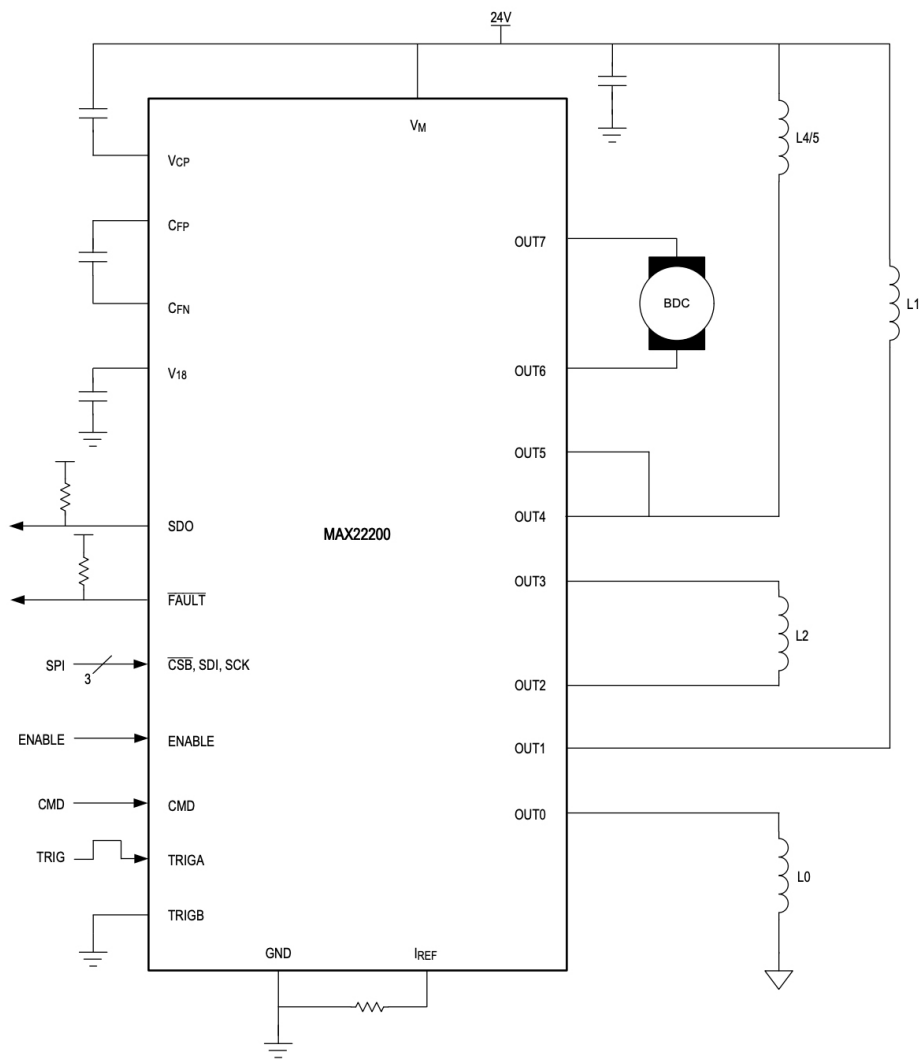


Figure 2: The Analog Devices MAX22200 is an integrated, serial-controlled solenoid and motor driver with eight half-bridge drivers that can be arranged in different configurations. (Image source: Analog Devices)

up to four latched valves (also called bi-stable valves).

This driver supports two control methods: voltage drive regulation (VDR) and current drive regulation (CDR). With VDR, the device outputs a pulse width modulated (PWM) voltage in which the duty cycle is programmed using its SPI interface.

The output current is proportional to the programmed duty cycle for a given supply voltage and solenoid resistor. CDR is a form of closed-loop control where an integrated, lossless current-sensing circuit senses the output current and compares it with an internal programmable reference current.

Unlike a simplistic current-source driver, the MAX22200 offers tailoring of the current-drive profile. To optimize power management in solenoid drive applications, the excitation drive level (I_{HIT}), the hold drive level (I_{HOLD}), and the excitation drive time (t_{HIT}) can be individually configured for each channel. It also offers multiple protection and fault-related features, including:

- Overcurrent protection (OCP)
- Open-load (OL) detection
- Thermal shutdown (TSD)
- Undervoltage lockout (UVLO)
- Detection of plunger movement (DPM) verification

The first four features are standard and well understood. DPM requires further explanation. For instance, if the valve works correctly when the solenoid is activated in a solenoid-controlled valve, the current profile is not monotonic (Figure 3, black curve). Instead, it shows a drop due to the back electromotive force (BEMF) generated by the movement of the plunger (Figure 3, blue curve).

When set up and used for solenoids, the DPM function of the MAX22200 detects the presence of the BEMF drop during the excitation phase. If the drop is undetected, an indication is set on the FAULT pin and in the internal fault register.

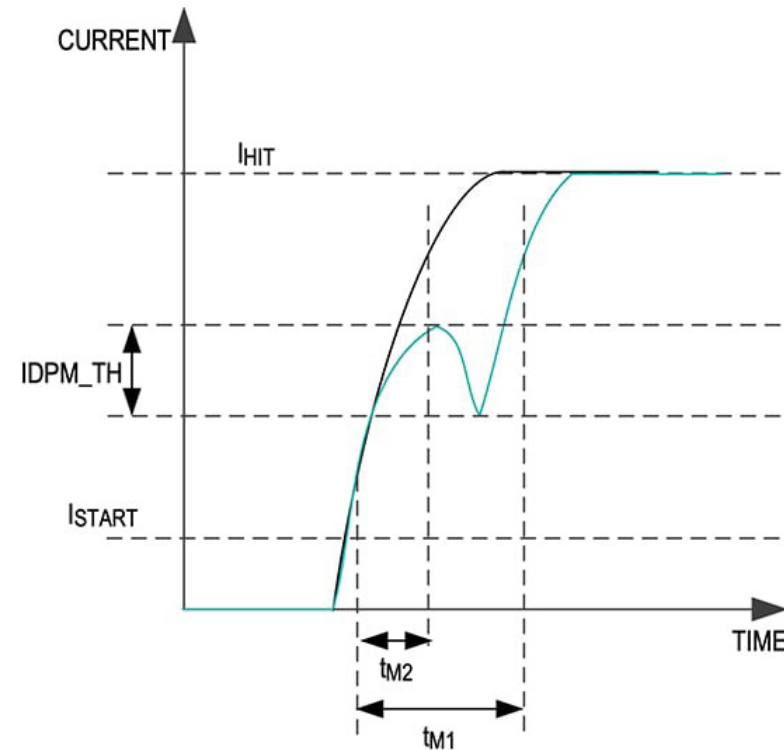


Figure 3: When driving a solenoid, the MAX22200 can detect a stuck solenoid or valve by looking for the expected BEMF-driven current drop versus the threshold value ($IDPM_TH$) as the solenoid is driven from the start current (I_{START}) to the final excitation drive level (I_{HIT}). (Image source: Analog Devices)

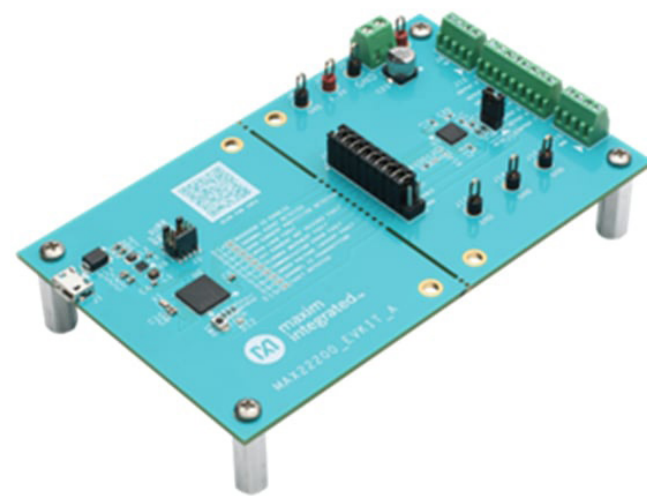


Figure 4: The MAX22200EVKIT# Solenoid Control Power Management Evaluation Board for the MAX22200 facilitates full exercise of the IC and its load using a Windows-based GUI. (Image source: Analog Devices)

Evaluation kits ease the process

To resolve issues related to the system's performance under different static and dynamic demands and load conditions, Analog Devices offers the [MAX22200EVKIT#](#) Solenoid Control Power Management Evaluation Board for the MAX22200 (Figure 4). This evaluation kit (EVK) enables serial control of the MAX22200 and fault monitoring through an onboard USB-to-SPI interface via a [MAX32625](#) microcontroller. It includes a Windows-compatible graphical user interface (GUI) for exercising the features of the MAX22200 IC, making it a complete PC-based evaluation system.

This fully assembled and tested board is configurable as a high-side/low-side solenoid, and for latched valves (often driven by solenoids) or brushed DC motors.

Stepper motors: more degrees of freedom to control

Stepper motors are more complicated than solenoids and have more control requirements. This is seen in the features of the Analog Devices [TMC5240](#) (Figure 5), an integrated, high-performance stepper motor controller and driver IC with serial communication interfaces

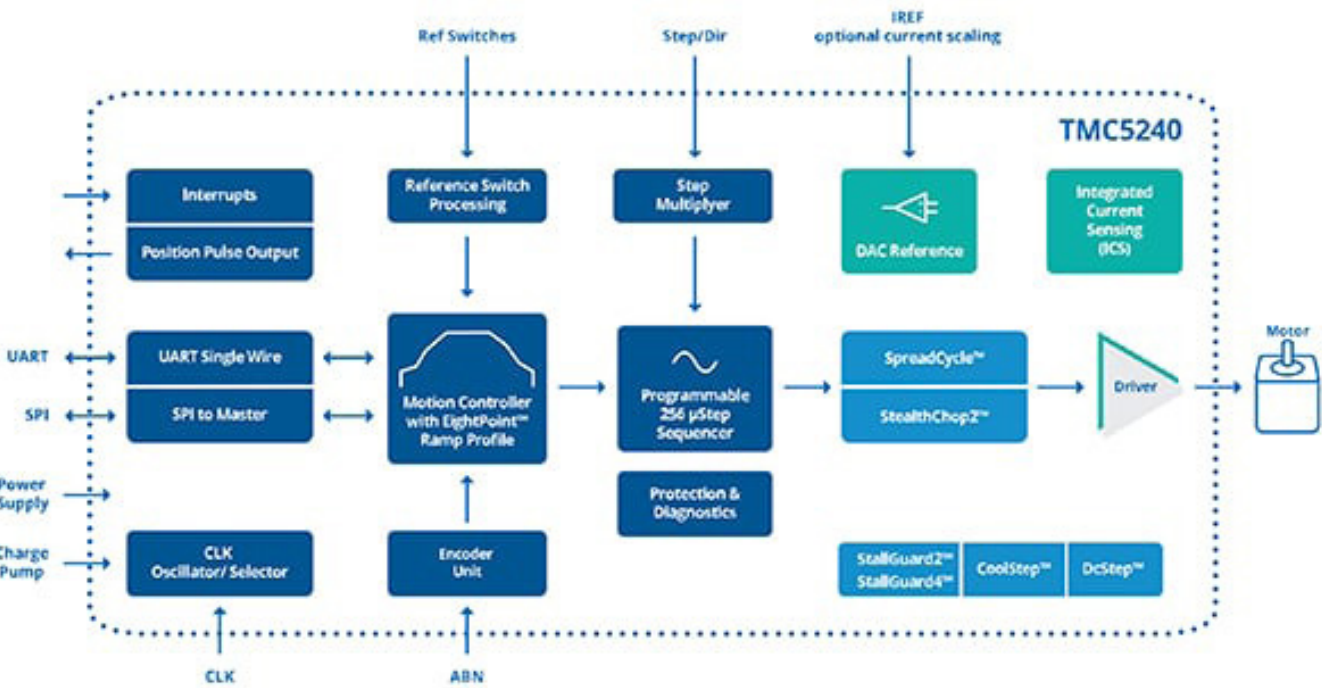


Figure 5: The TMC5240 high-performance stepper-motor controller and driver IC embeds sophisticated algorithms to deliver optimum performance with solenoids and stepper motors. (Image source: Analog Devices)

(SPI, UART), extensive diagnostic capabilities, and embedded algorithms.

This IC combines a flexible eight-point ramp generator for minimum jerk in automatic target positioning. Jerk is the rate of change of acceleration, and excessive jerk can cause many system problems and performance issues. This stepper-motor driver integrates 36 volt, 3 A H-bridges with 0.23 ohms (Ω) on-resistance and non-dissipative integrated current sensing (ICS). The TMC5240 is available in a small, 5 × 5 millimeter (mm)

TQFN32 package and a thermally optimized 9.7 × 4.4 mm TSSOP38 package with an exposed pad.

The TMC5240 implements unique and advanced features that enable enhanced precision, high energy efficiency, high reliability, smooth motion, and cool operation. These features include:

- StealthChop2: A no-noise, high-precision chopper algorithm for inaudible motion and standstill of the motor, allowing for faster motor acceleration and deceleration than the simpler StealthChop

- SpreadCycle: High-precision, cycle-by-cycle current control for the highest dynamic movements
- StallGuard2: Provides sensorless stall detection and mechanical load measurement for SpreadCycle
- StallGuard4: Offers sensorless stall detection and mechanical load measurement for StealthChop
- CoolStep: Uses StallGuard measurement to adapt the motor current for the best efficiency and lowest heat-up of the motor and driver

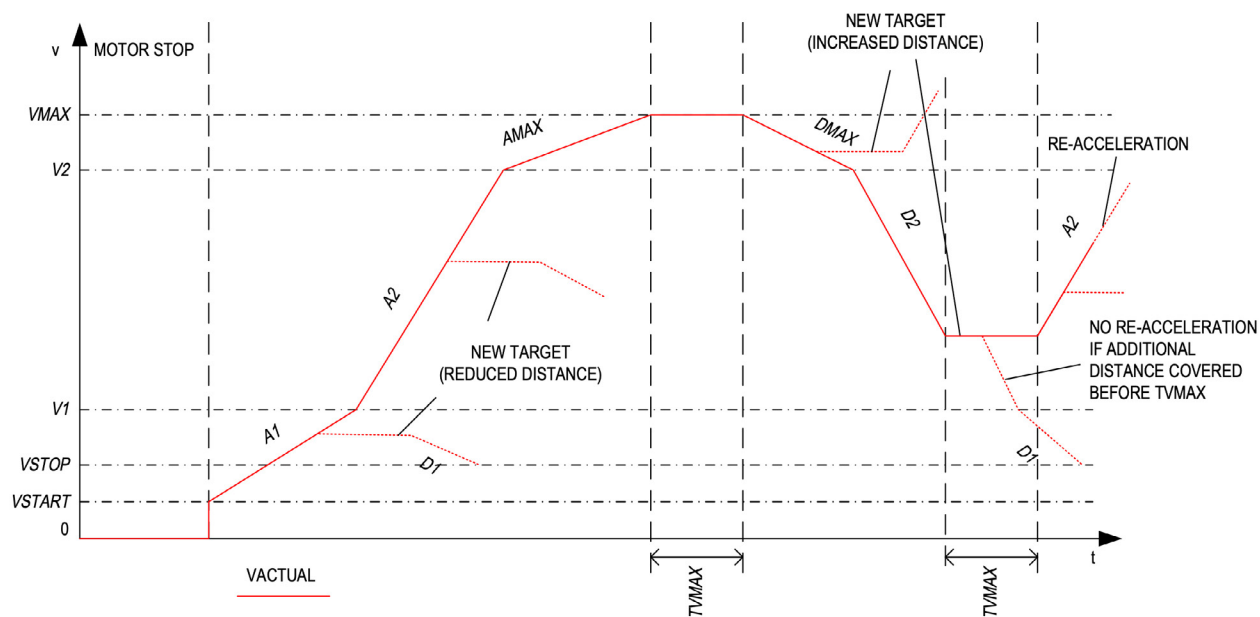


Figure 6: The TMC5240 offers an eight-point ramp supporting on-the-fly target position change, resulting in bumpless mode transfers. (Image source: Analog Devices)

These features can be pre-set and invoked during the motor's operating cycle. In addition, torque can be controlled in conjunction with acceleration to develop the desired value while providing efficient and smooth acceleration and deceleration.

For example, a set of three acceleration and deceleration segments can be used in two ways: for adaptation to the motor torque curve by using higher acceleration values at a lower velocity, or to reduce the jerk when transitioning from one acceleration segment to the next. To address both, the TMC5240's eight-point motion-profile generator allows the controller

to maintain a constant-velocity segment while the desired target position changes in real time, resulting in bumpless mode transfers (Figure 6).

Given the flexibility, versatility, and complexity of this driver IC, the [TMC5240-EVAL](#) evaluation board is a welcome adjunct (Figure 7). It uses the standard schematic diagram for the IC and offers several options in its software, allowing designers to test different modes of operation.

For designers with less complex evaluation and design requirements, Analog Devices also offers the [TMC5240-BOB](#). This basic IC breakout

board brings the physical pin connections of the TMC5240 out to user-accessible header rows.

Conclusion

Adding intelligence to solenoid and stepper motor drivers provides better control and fault detection, enables real-time decision making, and allows communication with higher-level control or AI-based productivity systems. Highly integrated drivers, such as the Analog Devices MAX22200 and TMC5240, allow users to quickly get up and running with advanced algorithms to optimize solenoid and stepper motor performance for their application.

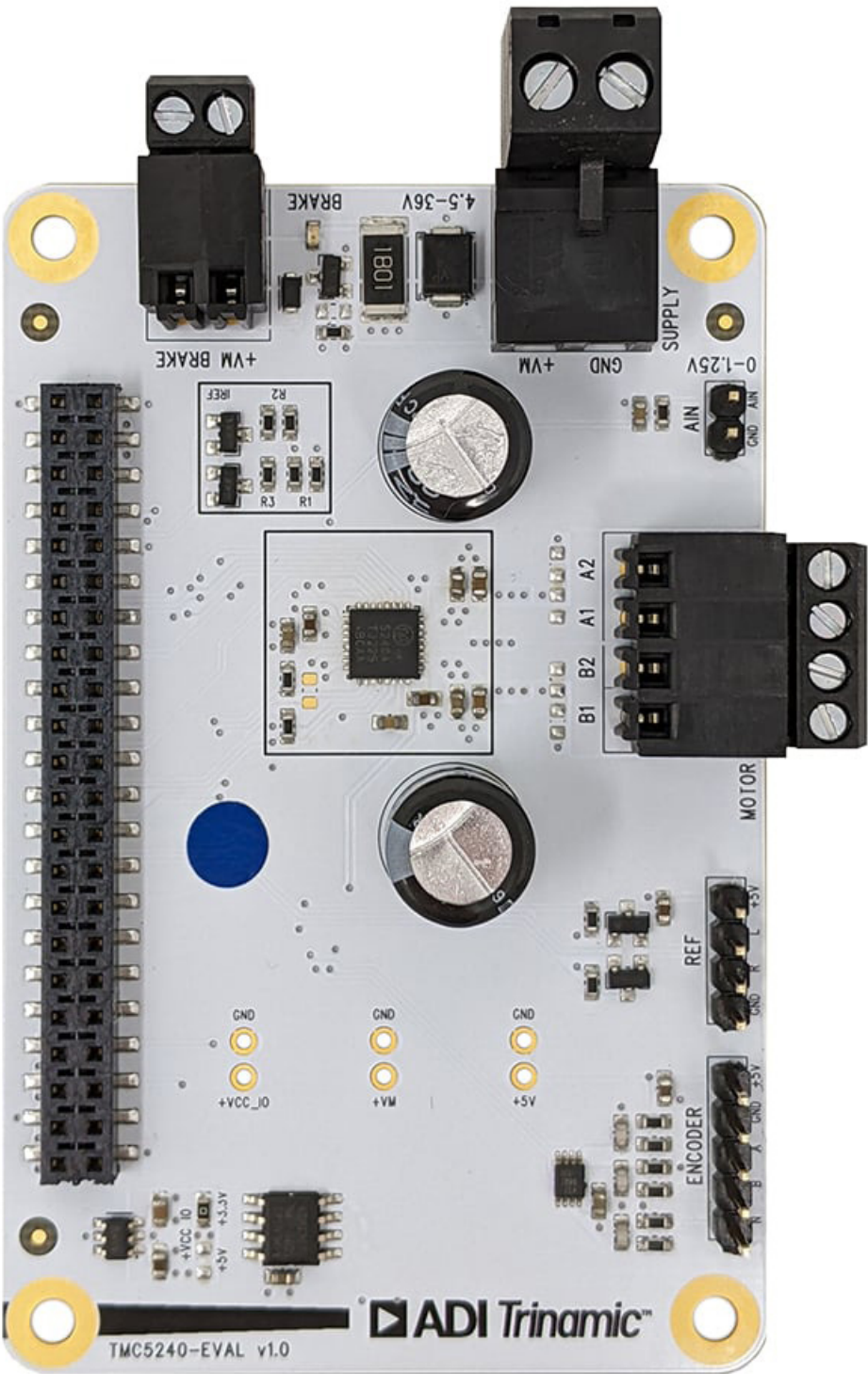


Figure 7: Using the TMC5240-EVAL evaluation board and associated GUI, designers can investigate and tune the performance of the TMC5240 to their specific actuator and load combination. (Image source: Analog Devices)

Comparing axial fans and centrifugal fans

By Ryan Smoot, Technical Support Engineer, Same Sky



When it comes to dealing with excess heat in a system, fans are a go-to thermal management solution for removing unwanted heat and providing cooler air across critical components. Outside of throttling system power, adding heat sinks, or utilizing pipes or cold plates, there often remains a need to generate forced air to further cool things down.

This presents an engineer with the choice between an axial fan design or a centrifugal fan design. While not an overly complex decision, this article aims to outline the basic operating principles of each type, discuss their common applications and uses, and summarize their advantages and disadvantages.

Axial fan basics and applications

Sometimes referred to as propeller fans, axial fans feature skewed blades mounted on a rotating axis (or shaft) which is driven by a motor. [Axial fans](#) operate by pulling air in one end and forcing it out the other in a parallel direction to the axis (Figure 1). Tubeaxial or vaneaxial fans are other common terms, which are simply axial fans intended to fit in a duct.

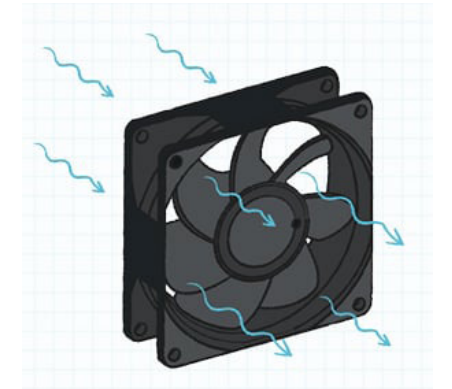


Figure 1: Basic airflow direction of an axial fan. (Image source: [Same Sky](#))

Axial fans are available in virtually any size from board level to room size, and while dependent on size, typically do not require much power to operate. Offered in both AC and DC versions, AC fans utilize line current and are generally rated over 100 V, while DC fans carry much lower voltages in the 3 to 48 Vdc range and are usually driven by batteries or a power supply.

The airflow that axial fans produce is high volume, but low pressure. This high-volume, low-pressure output makes them well-suited for cooling equipment and spaces both small and large due to airflow being evenly distributed in a defined area. Axial fans can often be found cooling computers or datacenter equipment, utilized in HVAC, AC condensers, or heat exchange units, and used for spot cooling in industrial systems. They can also serve as exhaust fans.

Centrifugal fan basics and applications

Also known as radial fans or [centrifugal blowers](#), centrifugal fans feature impellers contained within a motor-driven hub that intakes air into the housing and then expels the air from an outlet at a 90-degree angle (perpendicular) to the intake (Figure 2).

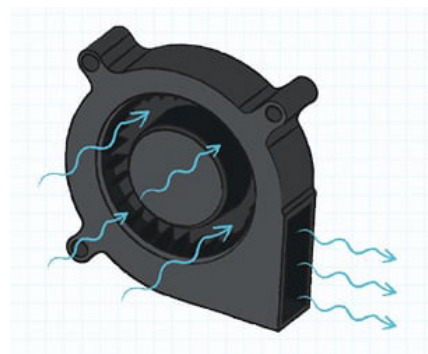


Figure 2: Basic airflow direction of a centrifugal fan. (Image source: Same Sky)

As high-pressure, low-volume output devices, centrifugal fans essentially pressurize air within the fan housing, which works to produce a steady, high-pressure stream of air, but at more limited volumes compared to axial versions. Because they expel air from an outlet, they are ideal for targeting airflow in a specific area to cool a particular part of the system that generates more heat like a power FET, DSP, or FPGA. Similar to their axial counterparts, they are also available in AC and DC versions with a range of sizes, speeds, and footprints, but typically consume more power. Their enclosed design

does offer some additional protection to the various moving parts, making them a reliable, durable, and damage resistant option.

Both centrifugal and axial fans produce audible and electromagnetic noise, but centrifugal designs tend to be louder than axial models. Since both fan designs use motors, EMI effects can impact system performance in sensitive applications.

A centrifugal fan’s high-pressure, low-volume output ultimately makes it ideal for airflow in concentrated areas like pipes or ductwork (Figure 3), or for ventilation and exhaust. This means they work well in air conditioning or drying systems, while their added durability mentioned earlier can allow for operation in harsh environments that deal with particulates, hot air, and gasses. In terms of electronic applications, centrifugal fans are commonly utilized in laptops due

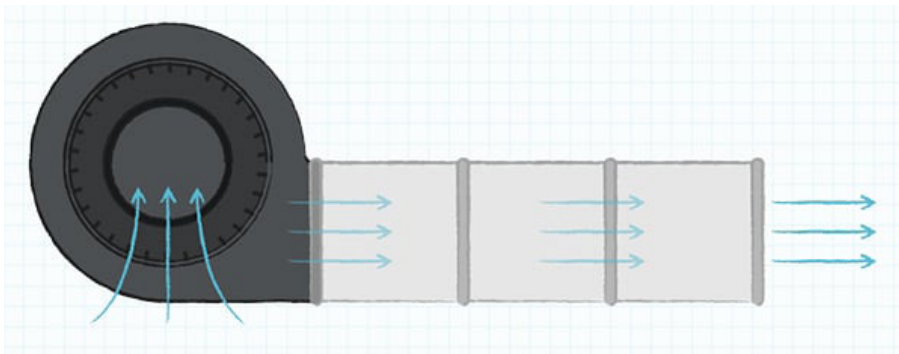


Figure 3: Centrifugal fan used in ductwork. (Image source: Same Sky)

to their low profile and higher directionality (airflow expelled at 90 degrees from the intake).

Fan EMI and noise considerations

Electromagnetic interference (EMI) generated by fans is an important design consideration to take into account early on. All fans can generate either radiated EMI from the fan itself or conducted EMI from the power leads. Uncontained magnetic fields (UMF) arising from the motor magnets and stator windings can also result in interference. While application specific, careful consideration in the early stages of design will save time and money down the road. In general, DC fans create less EMI than their AC fan counterparts.

Another application-specific design consideration is the audible noise generated by fans. Noise varies by application, density of

the components, placement in a system, size of the fan, amount of air moved, bearing types used, etc. [Bearings in a fan](#) not only affect acoustics but can impact the lifespan and potential applications. Audible noise can often be mitigated by better fan placement, mechanical isolation, or the use of air inlet grills or outlet diffusers. A good rule of thumb is, the higher the CFM or airflow, the higher the audible noise. With that being said, if a larger fan and a smaller fan both have similar CFM ratings, the larger fan will typically result in a quieter overall solution. As mentioned earlier, axial fan designs are usually quieter than centrifugal options.

Final comparison

To help wrap things up, here is a quick comparison of the various advantages, disadvantages, and characteristics of axial and centrifugal fans. Deciding on the best option will truly depend on

the intended application, space available, and overall thermal requirements of the end system.

Conclusion

Keeping electronic components that produce unwanted heat cool can be effectively managed with

either axial fans or centrifugal fans. Both have been proven in the field through many years of use and continuous improvement. Same Sky offers a wide range of [dc axial fans and centrifugal blowers](#) with a variety of frame sizes and airflow ratings to help match an engineer’s specific thermal requirements.

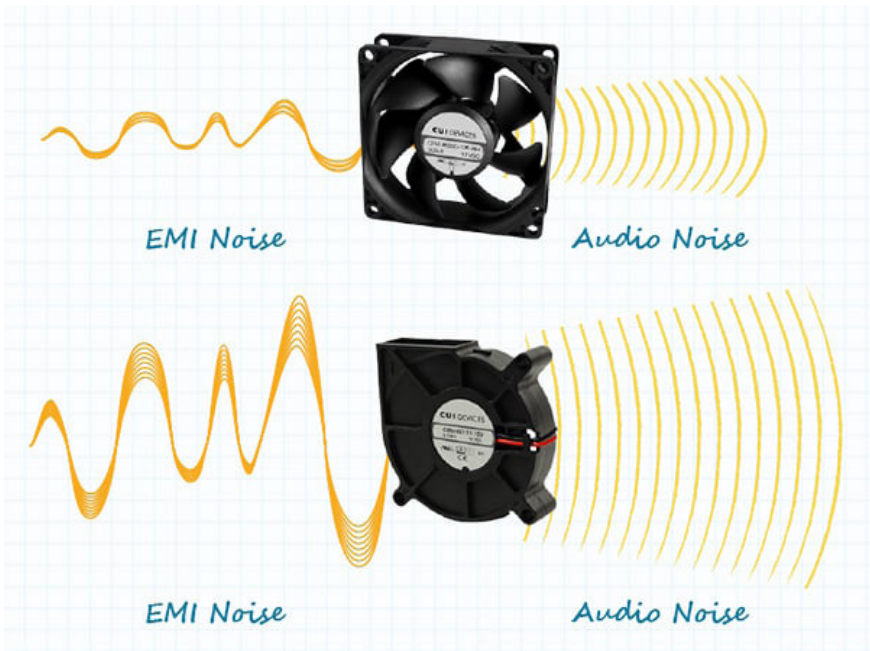


Figure 4: Axial fans tend to produce less noise than centrifugal blowers. (Image source: Same Sky)

AXIAL FANS	CENTRIFUGAL FANS
• High volume / low pressure • Airflow parallel to axis • Higher operating speed than centrifugal • Compact designs • Lower power usage than centrifugal • Less audible noise than centrifugal • Typically less expensive than centrifugal	• High pressure / low volume • Airflow perpendicular to axis • Lower operating speed than axial • Better for specific directed cooling • Typically uses more power than axial • More audible noise than axial • Durable and resistant to harsh environments

Figure 5: Comparing basic characteristics of axial and centrifugal fans. (Image source: Same Sky)

Learn why sealed toggle switches are essential for many electronic applications

By Pete Bartolik

Toggle switches are essential for many electronic applications in the digital era. They provide tactile feedback, reliability, and intuitive operation where precision and instant control matter.

In demanding environments where equipment is exposed to dust, water, solar radiation, or mechanical stress, failure is not an option for mission-critical and safety-sensitive aerospace applications, industrial machinery, marine equipment, and medical devices. Product designers might want to consider a line of sealed switches from [APEM](#) that are designed to ensure functionality even in the harshest settings.

Unlike touchscreens or digital interfaces, toggle switches provide immediate mechanical actuation, ensuring functionality even in high vibration, extreme temperature, or moisture-prone settings. Durability, simplicity, and the ability to operate without power or software dependencies make them indispensable in both traditional and modern electronic systems.

When failure is not an option

Harsh environments present a variety of failure risks for toggle switches that aren't up to the task.

Moisture ingress can result in short circuits and corrosion; dust and debris contamination can obstruct actuation; extreme temperatures can cause material degradation or freezing; and repeated use can create mechanical wear.

Vibration and shock can loosen connections or cause unintended activation, while exposure to chemicals and saltwater can corrode contacts and housings. Additionally, high inrush currents from inductive loads may cause contact pitting or welding.

IP-rated sealed switches, durable materials, and proper electrical ratings can mitigate risks and ensure long-term performance and reliability. APEM's [CT Series](#) of IP67-sealed toggle switches are designed to withstand extreme conditions while delivering precise performance. The IP67 rating signifies complete protection against dust ingress and immersion in water up to 1 meter for 30 minutes.

APEM CT Series toggle switches provide consistent actuation force, preventing accidental switching while ensuring deliberate engagement. This physical feedback creates a muscle-memory advantage, enabling professionals to operate equipment more intuitively. The

future of product design likely will rely heavily on hybrid interfaces with physical toggles alongside digital controls to create seamless user experiences.

The robust internal mechanism of the CT Series prevents accidental switch toggling due to environmental stressors. These toggle switches are capable of functioning in sub-zero conditions and high-heat environments without performance degradation, providing consistent actuation force even in fluctuating thermal conditions. The completely sealed

switching chamber ensures resistance to chemical exposure in industrial and marine applications.

With a focus on reliability, APEM CT Series toggle switches reduce the risk of failure, minimize maintenance, and enhance operational efficiency. These switches can be configured with three main types of terminals, depending on the application and mounting requirements:

- Solder lug terminals, for providing secure electrical connections when wires

are soldered directly to the terminals, as well as for manual wiring and prototyping

- Printed circuit board (PCB) terminals, ensuring a clean and reliable connection with direct mounting onto PCBs, reducing the need for additional wiring
- Quick-connect (FASTON) terminals, which enable tool-free installation and removal using crimped connectors to speed up assembly and maintenance

The APEM CT Series provides a range of switch options with varied electrical functions, including ON-OFF, ON-ON, ON-OFF-ON, momentary (MOM)-OFF-MOM, and ON-OFF-MOM. For example, single pole switches control a single circuit, making them ideal for simple ON-OFF functions in low-power applications, while double pole switches can control two independent circuits simultaneously, offering enhanced electrical isolation and functionality.

The [CT31-001N022](#) (Figure 1) is a single pole, ON-OFF toggle switch, making it ideal for applications requiring a simple, straightforward power control mechanism. With screw terminals, it is suited for applications in industrial control panels, vehicle systems, and general electrical circuits.

The [CT41-021N022](#) (Figure 2) is a double pole, ON-OFF switch, allowing it to control two independent circuits simultaneously. It is suitable for applications that require dual-circuit control, such as marine equipment, avionics, and high-power industrial machines. This switch is equipped with solder lug quick-connect terminals for a secure and efficient connection.

Conclusion

Toggle switches are here to stay as a physical interface for electronic applications. In demanding environments where reliability is non-negotiable, the APEM CT Series provides designers with a range of IP67 sealed toggle switches designed to withstand extreme conditions while ensuring functionality and performance.

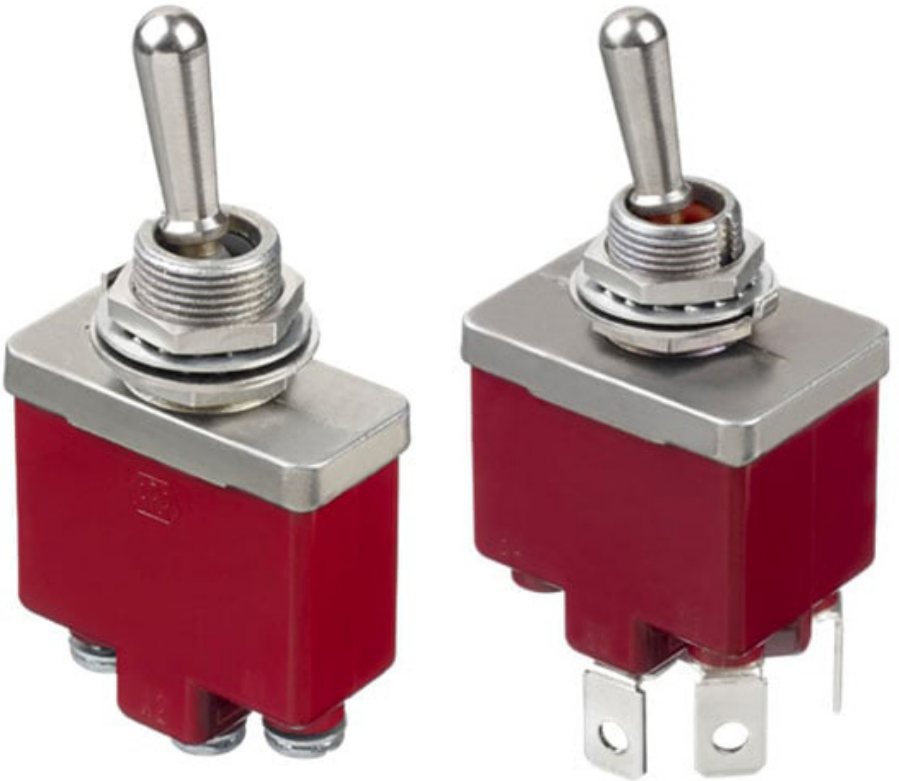
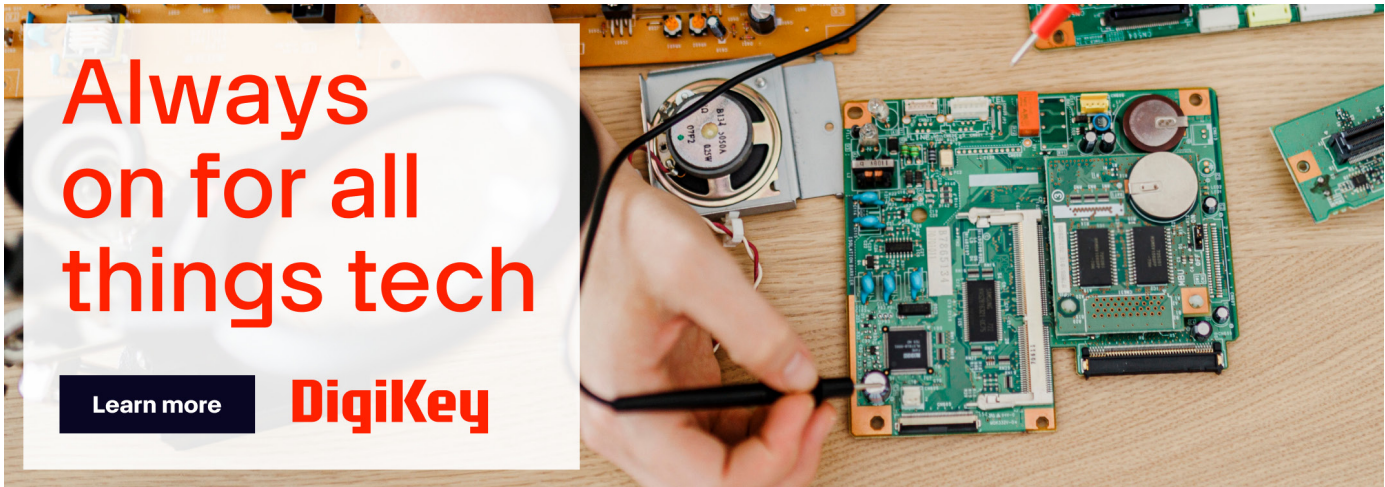
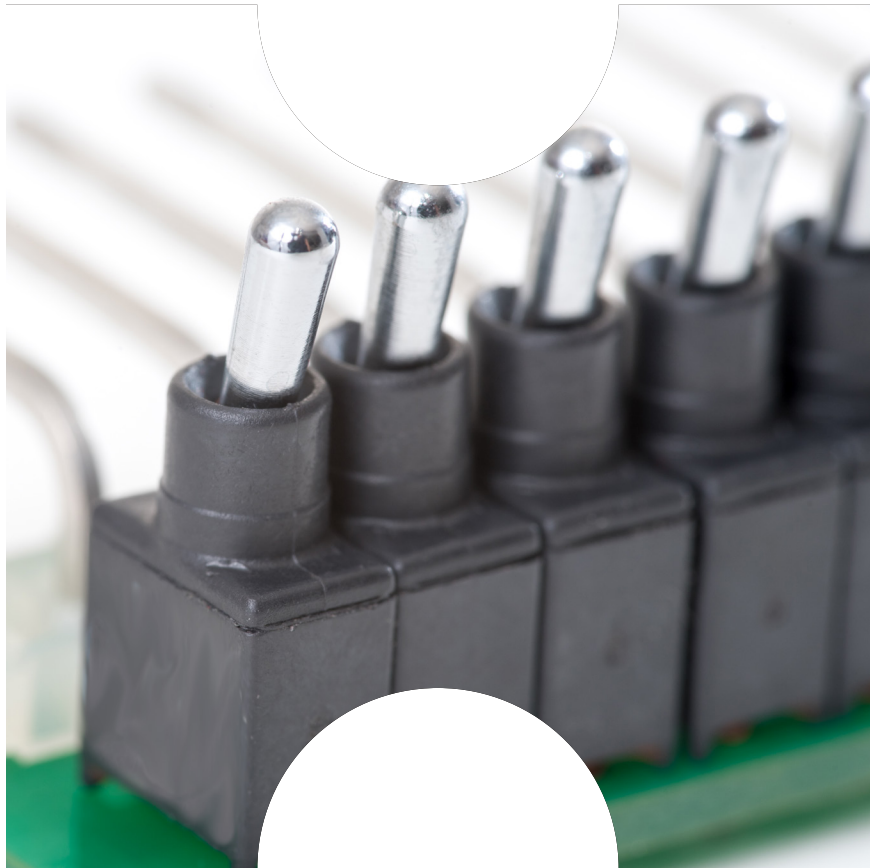


Figure 1: APEM's CT31-001N022 single pole toggle switch with screw terminals. (Image source: APEM)

Figure 2: The CT41-021N022 double pole switch has solder lug quick-connect terminals. (Image source: APEM)



A better way to commute BLDC motors

By Jeff Smoot,
VP of Apps Engineering and Motion Control at Same Sky



Brushless direct current electric motors, or BLDC motors, are electronically commutated motors powered by a dc electric source via an external motor controller. Unlike their brushed relatives, BLDC motors rely on an external controller to achieve commutation, which is the process of switching current in the motor phases to generate motion. Brushed motors have physical brushes to achieve this process twice per rotation, while BLDC motors do not, and due to the nature of their design, they can have any number of pole pairs for commutation. This article will review BLDC motor basics, look at common methods of commutating BLDC motors, and introduce a new solution for gathering position feedback.

BLDC motor commutation basics

The most common configuration of BLDC motors is 3-phase. The number of phases match the number of windings on the stator, while the rotor poles can be any number of pairs depending on the application. Because the rotor of a BLDC motor is influenced by the revolving stator poles, the stator pole position must be tracked to effectively drive the three motor phases. Therefore, a motor controller is used to generate a 6-step commutation pattern on the three motor phases. These six steps, or commutation phases, move an electromagnetic field which causes the permanent magnets of the rotor to move the motor shaft (Figure 1).

For the controller to commute the motor effectively, it must always have accurate information on the position of the rotor. Hall effect sensors have been the popular choice for commutation feedback since the inception of the brushless motor. In a typical scenario, three sensors are required for 3-phase control. The Hall effect sensors are embedded into the stator of the motor to detect rotor position, which is used to switch the transistors in the 3-phase bridge to drive the motor. The three sensor outputs are commonly noted as U, V, and W channels. Unfortunately, there are some drawbacks to this method of position feedback. While the BOM cost of the Hall effect sensors is low, the cost of integrating these sensors into the BLDC can double the total cost of the motor. Additionally, the controller only gets a partial picture of the motor's position from the Hall effect sensors, which can cause problems in systems where precise position feedback is required to operate properly.

Encoders deliver greater precision

In today's world, systems that require BLDC motors need far more precision in position measurement than ever before. To accomplish this, incremental encoders can be paired to the BLDC motor in addition to Hall effect sensors. This presents

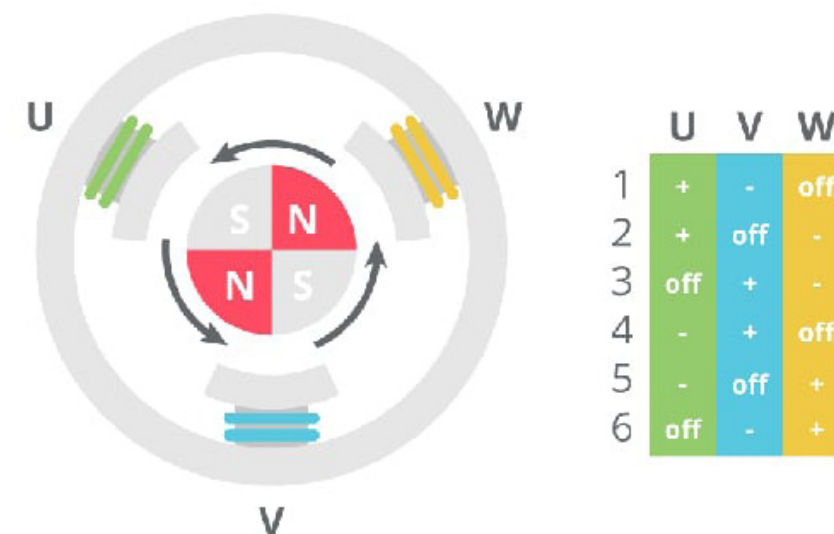


Figure 1: 6-step pattern for BLDC motor commutation. (Image source: [Same Sky](#))

a system that provides improved position feedback, but now requires the motor manufacturer to add both Hall sensors in the motor, along with an incremental encoder after assembly. A better option skips the Hall effect sensors altogether and replaces the incremental encoder with a commutation encoder. These commutation encoders, such as Same Sky AMT31 series or AMT33 series, have incremental outputs for precise position tracking, along with commutation outputs that match the motor's specific pole configuration. [Same Sky commutation encoders](#), being digital, allow for these parameters, including pole count, resolution, and direction, to be programmed. This provides the engineer flexibility during prototyping and testing as well as a reduced encoder SKU count across multiple designs.

Aligning a commutation motor

When current is applied to a motor it spins, and conversely when you spin a motor, it generates current. If you were to spin a BLDC motor, you would see outputs on the 3 phases similar to Figure 2. To properly align a commutation encoder or even Hall effect sensors to a BLDC motor, the resulting commutation waveform should be aligned to the back EMF. Traditionally, this results in an iterative process requiring

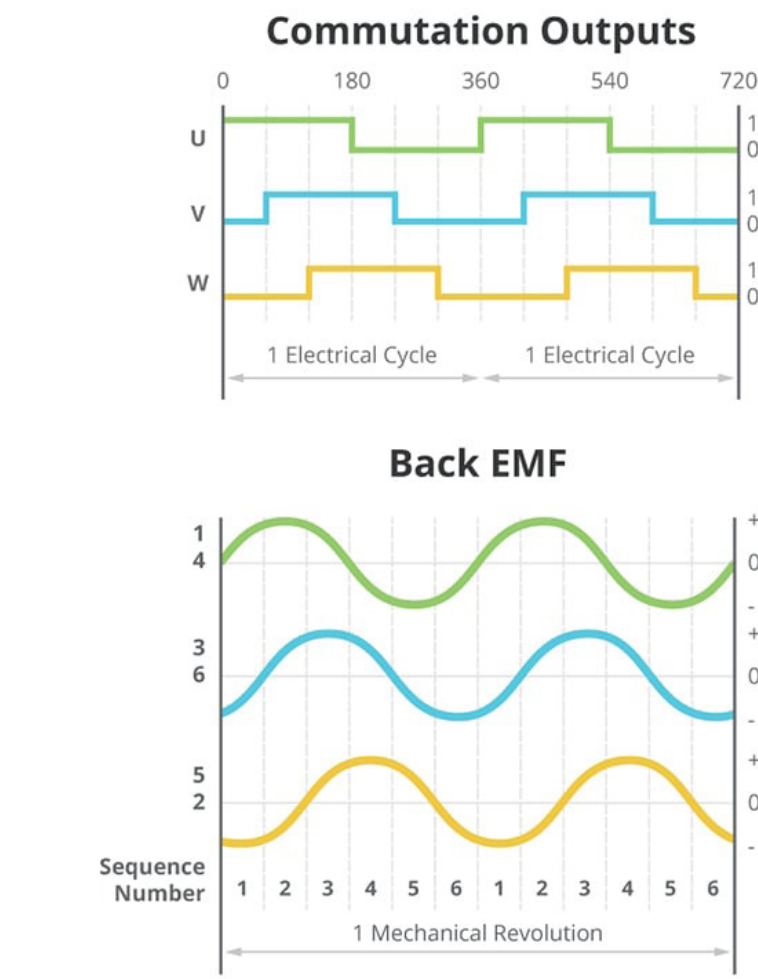


Figure 2: Commutation outputs and motor phases (Image source: Same Sky)

a second motor to drive the first, and an oscilloscope to observe the waveforms. This can be time consuming and add significant costs during the manufacturing process.

With an AMT capacitive encoder, the alignment process is nearly instant and only requires a power supply. Once the encoder is mounted, the user needs only to apply power to the two phases that correspond to the

desired starting position of the AMT encoder and send the alignment command. In doing so, the user has essentially set the starting position of the encoder's commutation waveform and the motor's back EMF waveform.

In addition to the ease of alignment, the AMT encoder's commutation signals are much more precisely aligned to the motor poles. Aligning a commutation encoder to a motor

just sets the start position (i.e., where the commutation waveform begins). If done properly, the commutation waveform should perfectly match the motor's back EMF waveform. However, this is not always achievable. A typical alignment with hall sensors or an optical encoder is on the order of ± 1 electrical degrees. AMT encoders, on the other hand, can achieve much greater precision, typically within ± 0.1 electrical degrees. The AMT encoder's waveform begins when U and W are both high (third state in the above waveform); consult your motor manufacturer for the appropriate back EMF diagram to determine which phases should be energized during alignment.

Direction settings for AMT commutation encoders

Along with the programmable pole count and resolution features, the AMT series offers a direction setting for commutation applications – a unique option not provided by most other commutation encoder manufacturers. Put simply, the direction tells you which way the encoder's shaft should rotate for the commutation signals to advance. Typically, commutation encoders are placed on the back shaft of the motor. In this scenario, the commutation signals advance through their states when the motor is turning counter-clockwise (as viewed from the back

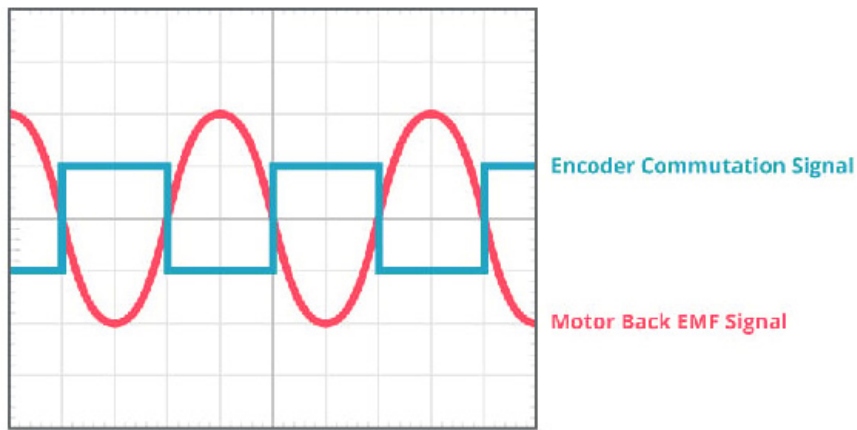


Figure 3: Commutation waveform going opposite of back EMF (Image source: Same Sky)

of the motor). However, if you put the encoder on the *front* shaft, you have essentially flipped the encoder upside down and now when you rotate the *motor* counter-clockwise (viewed from the back), the *encoder's* shaft is actually rotating clockwise (viewed from top down on the encoder). This means the motor's poles are rotating the opposite direction as the encoder's poles, as shown in Figure 3 below. Other technologies that do not include this programable option require the physical swapping of the encoder disk or the U, V, W channels to accomplish the same task. For applications utilizing multiple BLDC motors with varying directional requirements, this programable feature can be particularly useful.

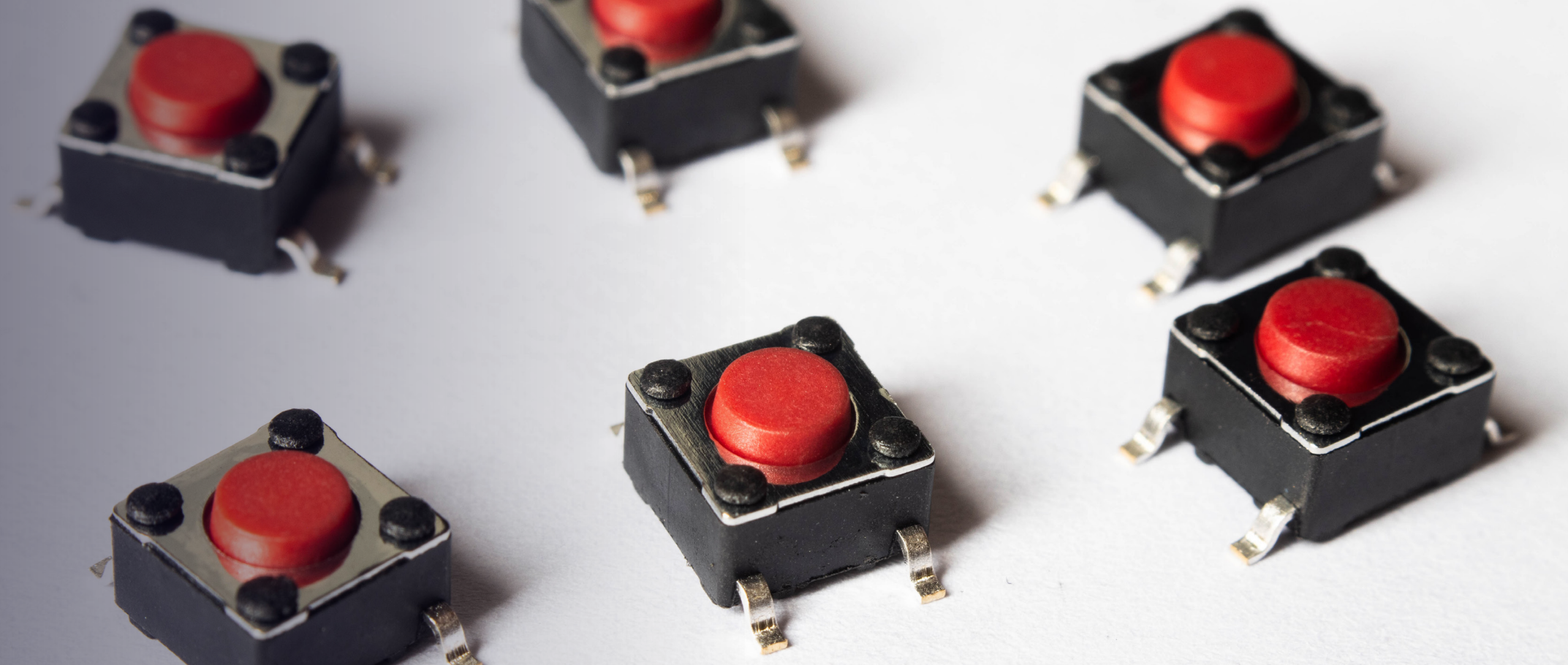
Conclusion

BLDC motors continue to grow in use and can excel in many applications when afforded a tight

control loop and high accuracy position sensing feedback. Hall effect sensors have been the go-to solution for many years due to their low BOM cost, but they often fall short in providing a complete picture of a motor's position unless paired with an incremental encoder. However, Same Sky AMT commutation encoders provide an all-in-one solution that eliminates the need for Hall effect sensors and incremental encoders altogether. Same Sky AMT31 or AMT33 commutation encoders are the most versatile options on the market due to their flexible programmability and simple installation. A basic understanding of commutation encoder principles as outlined in this article can make them a compelling option for an upcoming BLDC motor project.

What you need to know about switches

By Ryan Smoot, Technical Support Engineer, Same Sky



Switches are an integral part of our daily lives, offering both variety and ubiquity. They come in countless forms, from tiny buttons to massive controls, and encompass a spectrum of functions. This diversity, influenced by factors such as mechanical or electrical operation and manual or electronic control, can often boil down to personal preferences in aesthetics and user interfaces.

While electronic switches, rooted in technologies like BJTs, MOSFETs, IGBTs, and other semiconductor designs, are garnering increased attention due to declining costs and expanding features, mechanically operated switches are still the go-to switch solution. This article will delve into switch basics, with a

particular focus on physically operated and actuated models, to understand how they bridge the realms of form and function.

Switch basics

The starting point for selecting any switch necessitates a grasp of the concepts of poles and throws. Simply put, poles denote the number of circuits that a single switch can govern, while throws denote how many contacts the

switch can select from. This notion is most effectively comprehended through straightforward visual representations.

In the case of a switch featuring just a single pole and single throw, aptly referred to as SPST, it offers control over a solitary circuit, with the switch being capable of simply opening and closing a single contact. Now, let's contrast this with a switch possessing a single pole but a double throw configuration, known as SPDT.



Figure 1: SPST switch diagram. (Image source: [Same Sky](#))

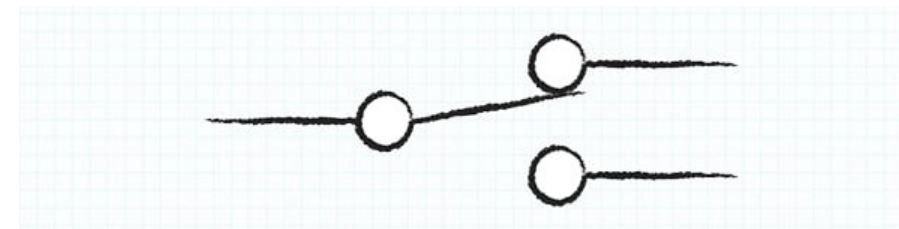


Figure 2: SPDT switch diagram. (Image source: [Same Sky](#))

Within the SPDT switch, there remains a solitary circuit under control, yet the switch can transition between two distinct contacts. In the realm of SPDT, the switch isn't confined to the mere act of opening and closing a circuit but, rather, to the redirection of the circuit itself.

When it comes to a double pole, double throw (DPDT) switch, a single switch assumes control over two circuits, and each switch within it navigates between two contacts.

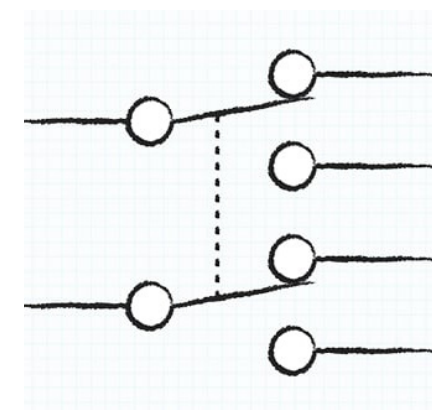


Figure 3: DPDT switch diagram. (Image source: [Same Sky](#))

Although SPST, SPDT, DPST, and DPDT represent the most prevalent switch configurations, there's no theoretical constraint on the number of poles and throws a switch may possess. When there are more than two poles or throws, numerical labels replace the 'S' or 'D'. For instance, a switch offering four poles and five throws might be labeled as a 4P5T switch by its manufacturer. Similarly, a double pole with six throws could be represented as DP6T.

Switch selection considerations

Outside of poles and throws, there are several other switch specifications to consider during the selection process. The below

list includes some of the more common features but is by no means exhaustive.

- **Size:** As alluded to earlier, switches come in many shapes and sizes. From switches that are smaller than a grain of rice to those that are too large to move by hand, size will typically come down to the intended application. Industrial settings often implement larger switches where gloves come into play or fine motion is difficult, while compact, embedded devices usually seek out the smallest switch possible.

- **Default State:** The majority of switches lack a predefined state, but there are momentary switches, which usually exhibit a pre-set condition, either normally open (NO) or normally closed (NC).

- **Positions:** This parameter dictates the quantity of switches incorporated within a solitary unit. There may be instances where this concept is mistakenly interchanged with "throws", but it's crucial to recognize that positions signify discrete switches within the same unit, each capable of independent actuation.

- **Mounting:** Like any electronic component, switches offer a variety of mounting

configurations. Surface mount and through styles are usually associated with smaller switches on PCBs, whereas panel mount and DIN rail mount switches tend to be larger. A pivotal consideration in both surface mount and through hole setups is the parameter known as "pitch", signifying the separation distance of the leads. In the context of through hole switches, pitch is of particular significance, as the appropriate pitch allows for use with breadboards.

- **Actuation:** In addition to distinguishing between manual and electronic actuation, switches offer various actuation methods. This could include actuation by hand or utilizing small screwdrivers or tools.

However, the most common option will be choosing between a raised or flat actuator level.

- **Current and Voltage Rating:** Switches exhibit a broad spectrum of voltage and current ratings from a few volts and amps up to hundreds or even thousands. It is imperative to always verify that a switch can accommodate both the expected current and voltage ratings of the intended application.
- **Environmental Factors:** This typically refers to ingress protection or IP ratings used to indicate a switches' level of protection from dust and liquid. However, some switches may have increased vibration sensitivity or vandal-proof features.

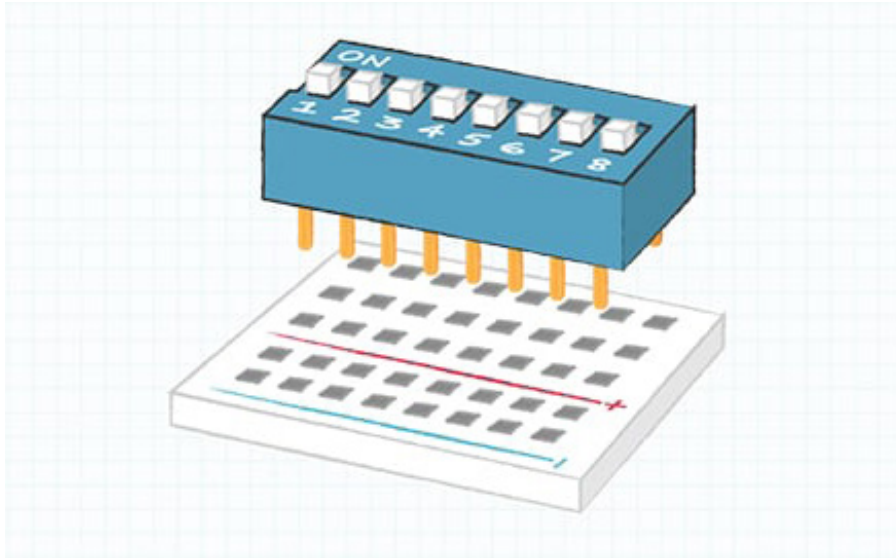


Figure 4: Through hole switch use on a breadboard. (Image source: Same Sky)

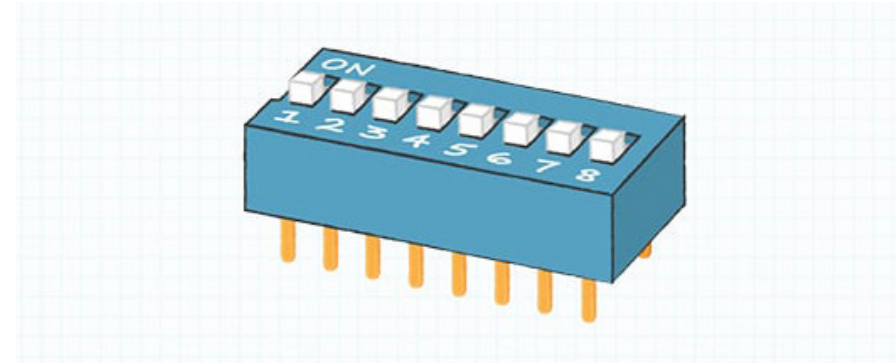


Figure 5: DIP switch example. (Image source: Same Sky)

Types of mechanical switches

The switch types provided below are mechanically operated and actuated, and they are commonly encountered, though not exclusively, in smaller, portable, or embedded systems.

- **DIP Switches:** Available in through hole or surface mount packages, [DIP switches](#) are most commonly an array of SPST switches. They fit well on breadboards and in finished products, enabling semi-permanent selections. They come in piano, slide, and rotary forms used for option settings in devices, especially in industrial applications and development kits. DIP switches offer more options than jumpers and are user-friendly, but not for frequent adjustments.

- **Rotary DIP Switches:** As a subset of DIP switches, these have a [rotary format](#) for selecting discrete options (usually 4 to 16 positions) and feature either a flat or raised knob. Like linear DIP switches, they're available in through hole or surface mount options. However, unlike linear DIP switches, they can output in BCD or hex. While compact and user-friendly, they offer a single output and aren't meant for continuous use.

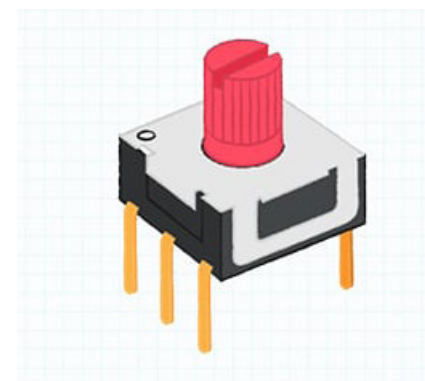


Figure 6: Rotary DIP switch example. (Image source: Same Sky)

- **Slide Switches:** Commonly recognized as power switches, [slide switches](#) are operated by sliding an actuator. They are typically SPST and can handle frequent use. While some have multiple poles or throws, this can make precise positioning challenging. Although they have higher capacity than DIP switches, they remain low power and are commonly surface or through hole mounted on PCBs. Occasionally, they serve as more accessible DIP switches in consumer electronics, although balancing ease of use with avoiding accidental actuation can be a challenge.

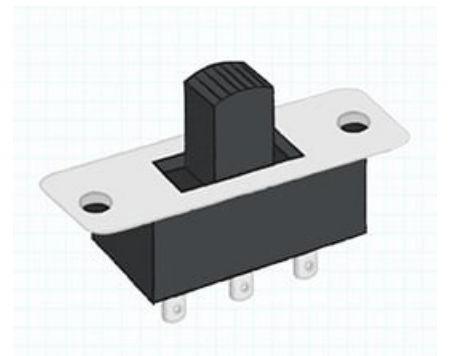


Figure 7: Slide switch example. (Image source: Same Sky)

- **Tactile Switches:** Known for their noticeable click, [tactile switches](#) are small, momentary buttons designed for low voltage, low current signals. They compensate for their modest electronic capabilities with robustness, offering long

lifecycles in the hundreds of thousands or even tens of millions. While typically single pole, they can also feature multiple throws and high IP ratings. Their widespread use in consumer electronics, such as game controllers, remote controls, garage doors, and various industrial applications, underscores their popularity due to their small size and durability.

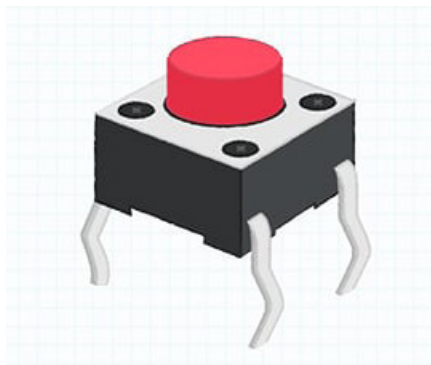


Figure 8: Tactile switch example.
(Image source: Same Sky)

- **Rocker Switches:** Rocker switches pivot in the middle to toggle between two options, usually not momentary. They commonly serve as power switches for high-voltage circuits with some carrying LED or incandescent bulb illumination for switch status. They can be IP rated for harsh environments. Their straightforward interface and actuation make them popular in consumer electronics, despite a slightly higher cost

due to size and features. In industrial settings, they complement toggle switches and may have covers to prevent accidental actuation.

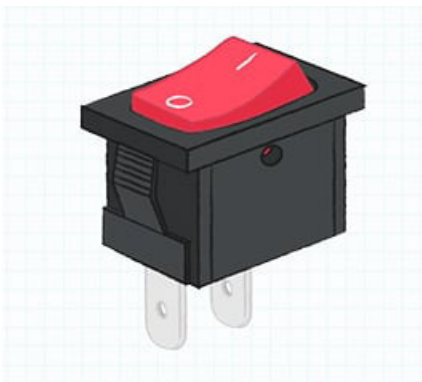


Figure 9: Rocker switch example.
(Image source: Same Sky)

- **Pushbutton Switches:** [Pushbutton switches](#), often called buttons or pushbuttons, feature simple in-and-out actuation. They can be momentary, come in various shapes, and LEDs are often integrated for illumination or indicating the switch's state. They handle a wide range of voltages and currents, typically mounting on PCBs or panels. Their user-friendliness suits public areas with constant users. Pushbuttons can be made rugged, with anti-vandal series and high IP ratings, ideal for harsh environments like elevators or subways. However, their size, LED options, and materials

can lead to higher costs compared to simpler, smaller pushbutton switch models.



Figure 10: Pushbutton switch example.
(Image source: Same Sky)

- **Toggle Switches:** Toggle switches are recognized for their extended lever, making them suitable for glove-wearing or situations with limited fine motor control. The prominent lever offers clear visual feedback, eliminating the need for extra LEDs, and their large movements ensure unmistakable toggling. They come in various poles and throws, though they are less commonly configured as momentary switches. Toggle switches are prized for their easy actuation, quick feedback, and safety integration, making them well-suited for industrial or scientific applications. Due to their mission-critical use in aircraft, control instrumentation, and medical equipment, they tend to be more costly.

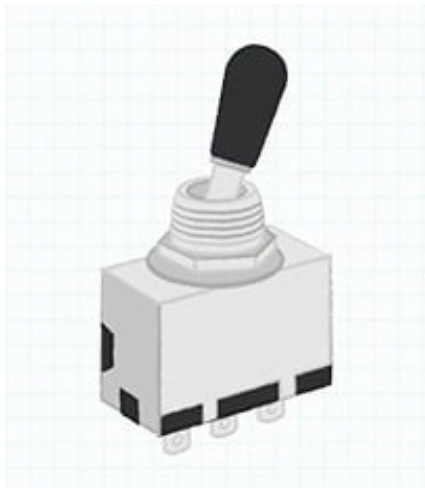
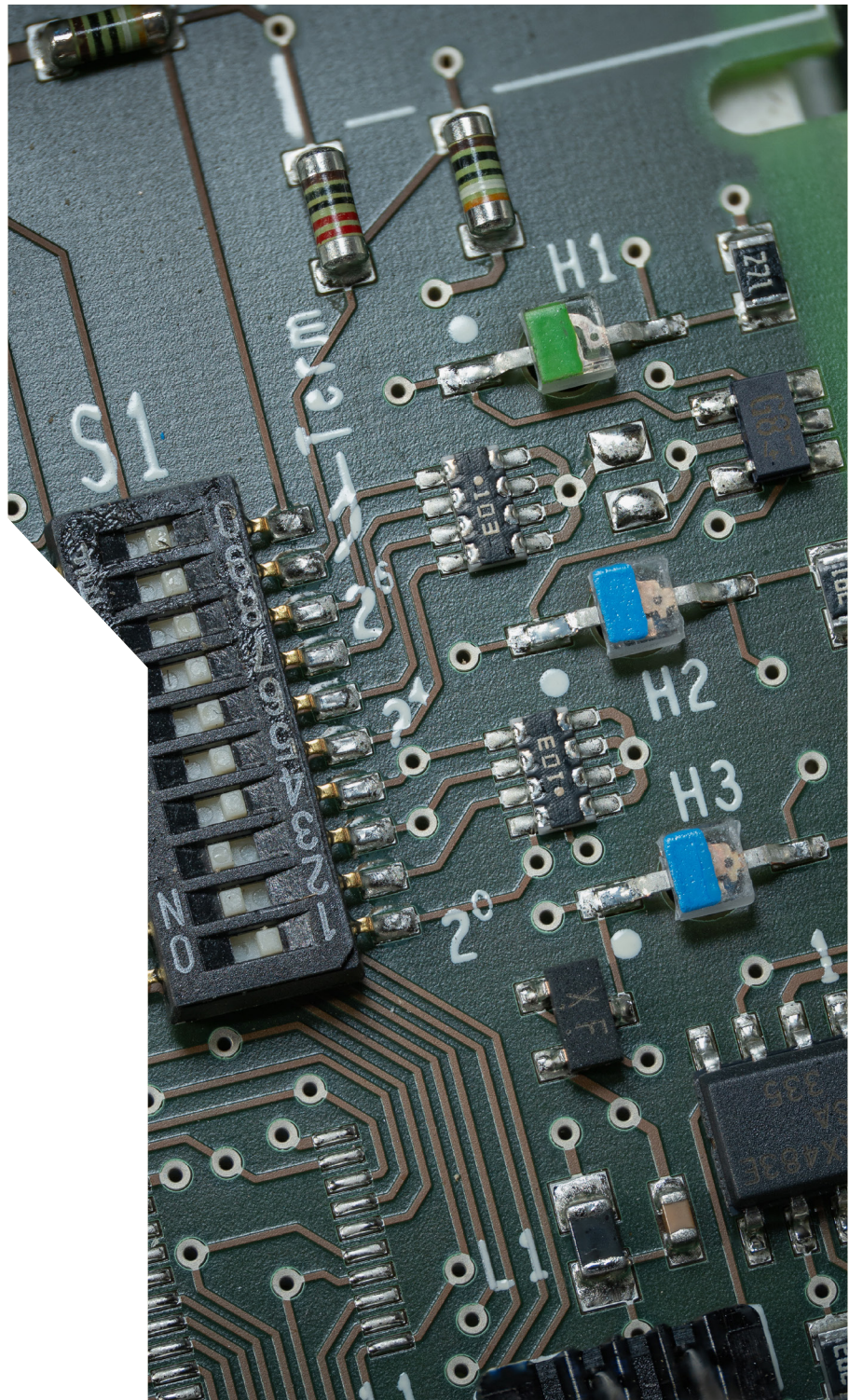


Figure 11: Toggle switch example.
(Image source: Same Sky)

Summary

Switches are fundamental components that play a pivotal role in electronics and electrical systems. This article has provided a comprehensive overview of the key aspects of switches, including their types, operation, applications, and considerations. Whether designing a consumer electronic device or working on a complex industrial project, choosing the appropriate switch can greatly impact the functionality and reliability of a system. Same Sky has a range of [switch solutions](#) standing and ready to meet a variety of switching needs.



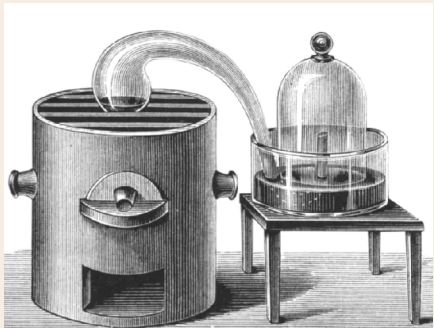
This month in history

1774

August 1

Priestley isolates oxygen

Joseph Priestley isolated a gas he called “dephlogisticated air” while heating mercuric oxide with sunlight focused through a lens. While he didn’t know it at the time, he had isolated elemental oxygen for the first time. The experiment became a key moment in the chemical understanding of oxygen.



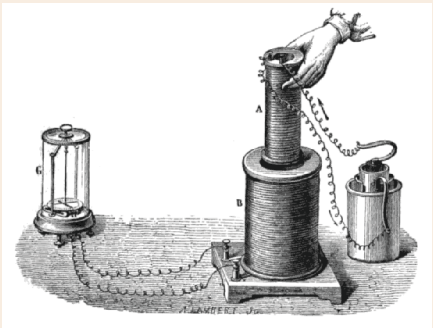
Drawing of the apparatus Priestley used in his experiments.

1831

August 29

Faraday discovers electromagnetic induction

Michael Faraday demonstrated electromagnetic induction. The principle showed that changing magnetic fields could produce an electric current. It became the basis for generators, transformers, motors, and much of modern electric power.



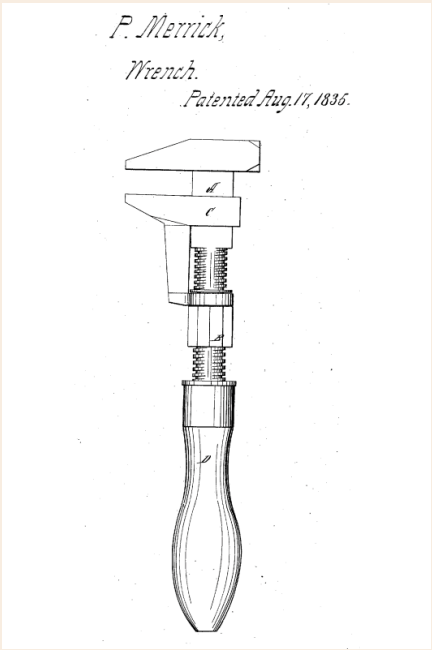
Drawing of the apparatus Faraday used to demonstrate electromagnetic induction.

1835

August 17

First wrench patent is issued

Solymon Merrick received an early U.S. patent for a wrench. Adjustable and specialized hand tools became important to machine shops, railroads, and industrial maintenance. The patent reflects the growing importance of standardized mechanical work in the nineteenth century.



Drawing from an early Merrick wrench patent.

1846

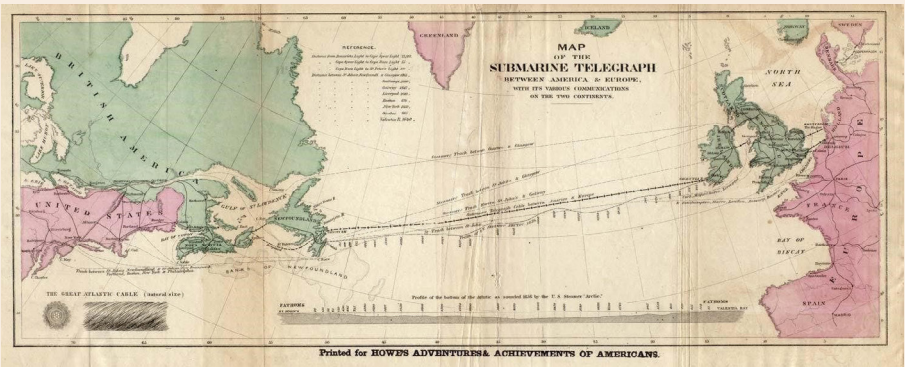
August 10

Smithsonian Institution established

The Smithsonian Institution was established in Washington, D.C. Its museums, archives, and research centers later became major repositories for scientific and technological history. The institution helped preserve instruments, machines, and records that document technical change.



The original Smithsonian Castle.



Map of the route of the first Transatlantic Telegraph Cable.

1858

August 5

First Transatlantic Telegraph Cable is completed

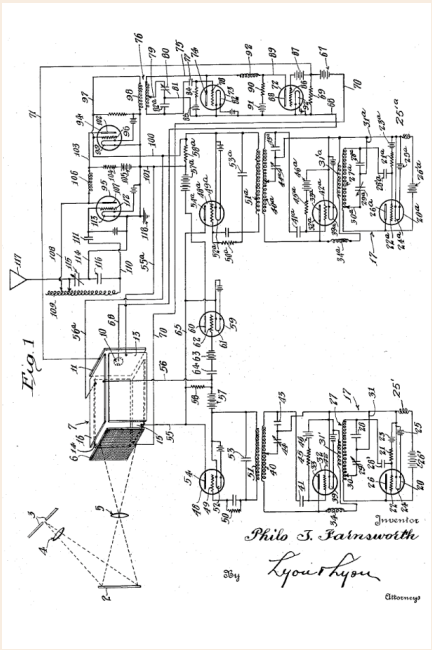
The first Transatlantic Telegraph Cable was completed between Ireland and Newfoundland. Although it failed after a short period of service, it proved that electrical messages could cross the ocean. Later cables made rapid intercontinental communication routine.

1930

August 26

Farnsworth electronic television patent is issued

Philo T. Farnsworth received a patent for an electronic television system. His work helped move television away from mechanical scanning systems and toward wireless electronic image transmission. Television became the dominant medium for broadcasting in the twentieth century.



Patent drawing for Farnsworth's electronic television.



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