

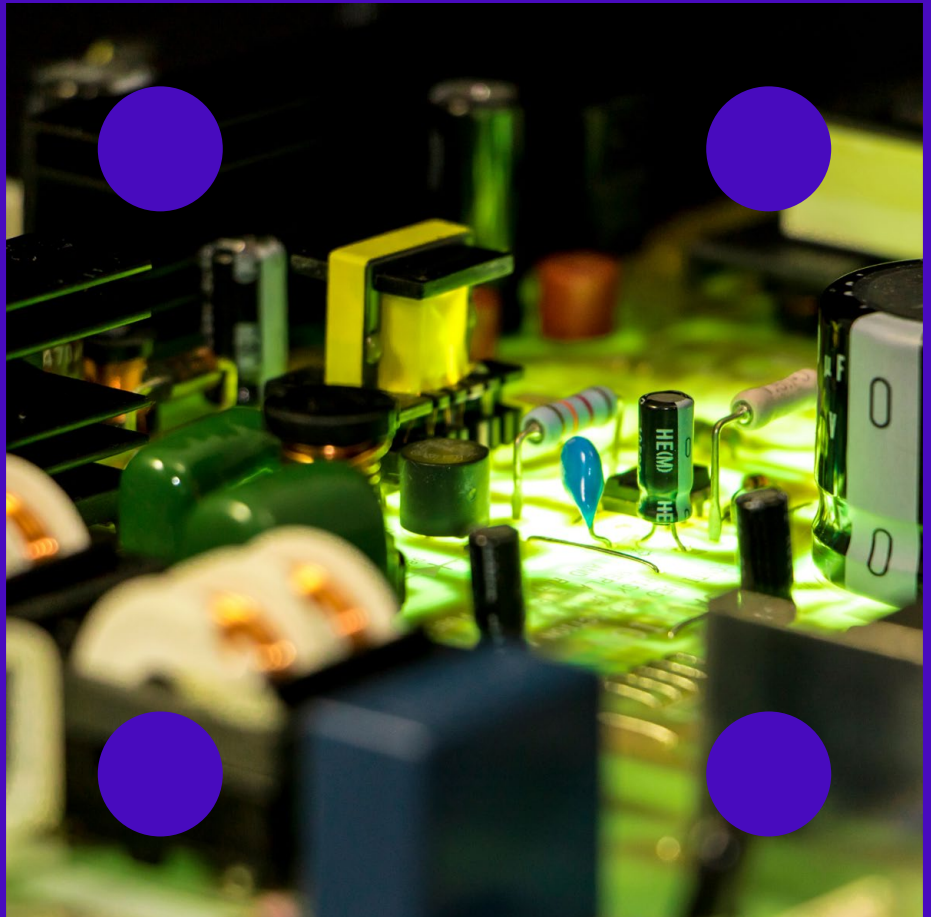
We get technical

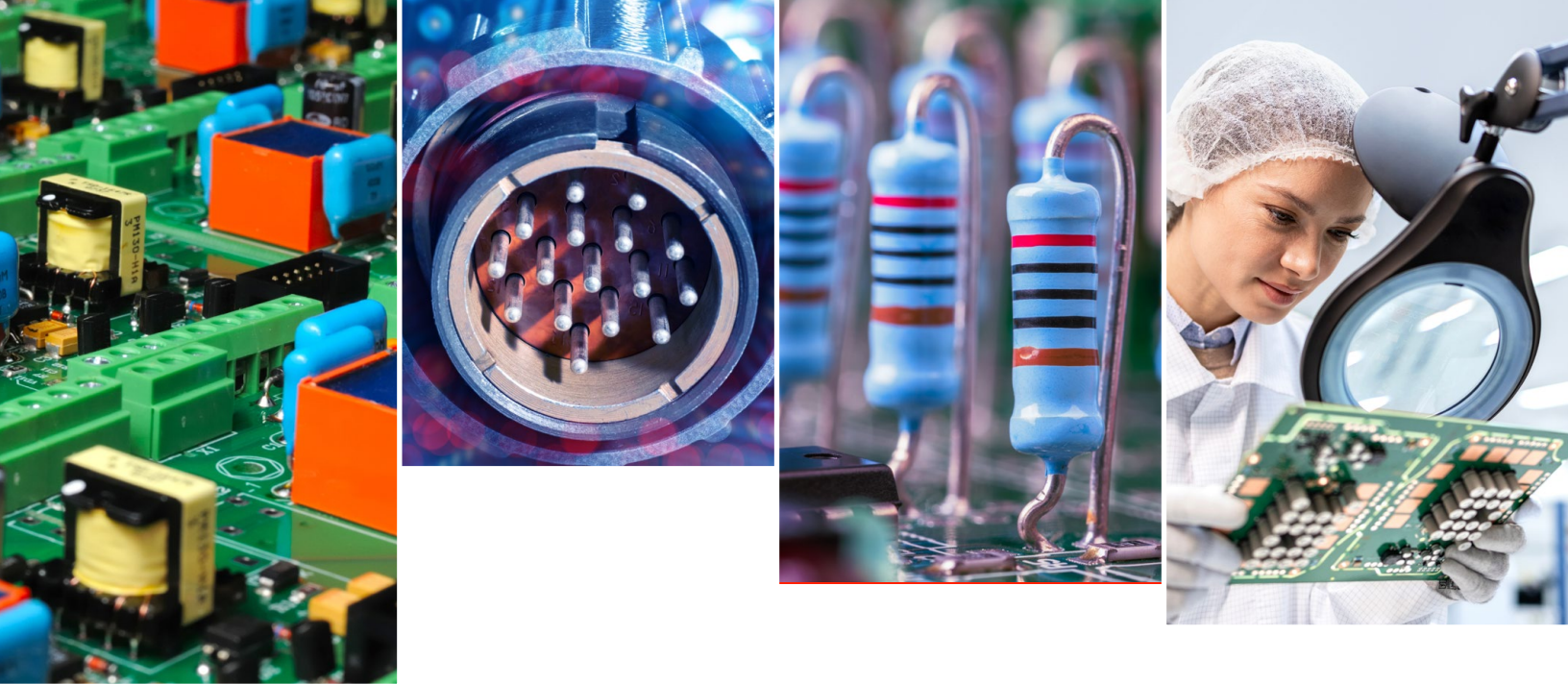
Designing reliable interconnects for space electronics

Selecting multilayer varistors for high-temperature circuit protection

Measuring laser diode temperature in optical transceivers

Capacitor deep dive: circuit protection, filtering, and energy storage





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Editor's note

Welcome to the DigiKey eMagazine Volume 37 – Passives and RF Design.

The continued evolution of wireless communications, power electronics, and aerospace systems is driving unprecedented demand for components that deliver greater efficiency, reliability, and performance. While processors and software often receive the spotlight, it is the passive components and RF technologies behind the scenes that enable today's most innovative electronic systems. From energy storage and circuit protection to signal integrity and high-frequency design, the right component choices can have a profound impact on overall system performance.

In this issue, we explore many of these critical technologies through a collection of articles from leading component manufacturers and industry experts.

Bourns examines its SM9127xAL Series Power Planar Transformers, demonstrating how advanced magnetic solutions help designers improve power density and efficiency in next-generation power conversion applications. Cinch Connectivity highlights its Space Mission Solutions, showcasing the rugged, high-reliability interconnect technologies that enable communications and control systems in some of the world's most demanding environments. Eaton's Electronics Division provides practical guidance on how to size and select supercapacitors for your design, offering engineers valuable insight into balancing power requirements, lifetime, and system reliability. Kyocera AVX Components Corporation introduces its VT Series Multilayer Varistors, explaining how these compact devices deliver effective overvoltage protection for increasingly sensitive electronics. Rounding out our featured supplier content, TDK Corporation explores its NTCWS Series AuWire Bond-Optional NTC Thermistors, designed to provide accurate temperature sensing for applications where precision and reliability are paramount.

Beyond these featured articles, this edition takes a deeper dive into several of the engineering fundamentals that influence successful electronic design. You'll gain a better understanding of the voltage coefficient of resistance (VCR) and why designers must understand its causes, performance implications, and mitigation techniques. We also present a comprehensive look at capacitor technologies through "Capacitor Deep Dive: Circuit Protection, Filtering, and Energy Storage," along with practical guidance in "Choosing the Right Capacitor Technology for an Application," helping designers navigate the growing range of dielectric materials and construction options available today.

Whether you're developing RF communications equipment, designing efficient power architectures, building aerospace systems, or selecting passive components for industrial electronics, we hope this issue provides both practical design guidance and fresh perspectives on the technologies shaping tomorrow's electronic systems.

Thank you for reading, and we hope you enjoy this edition of *Passives and RF Design*.

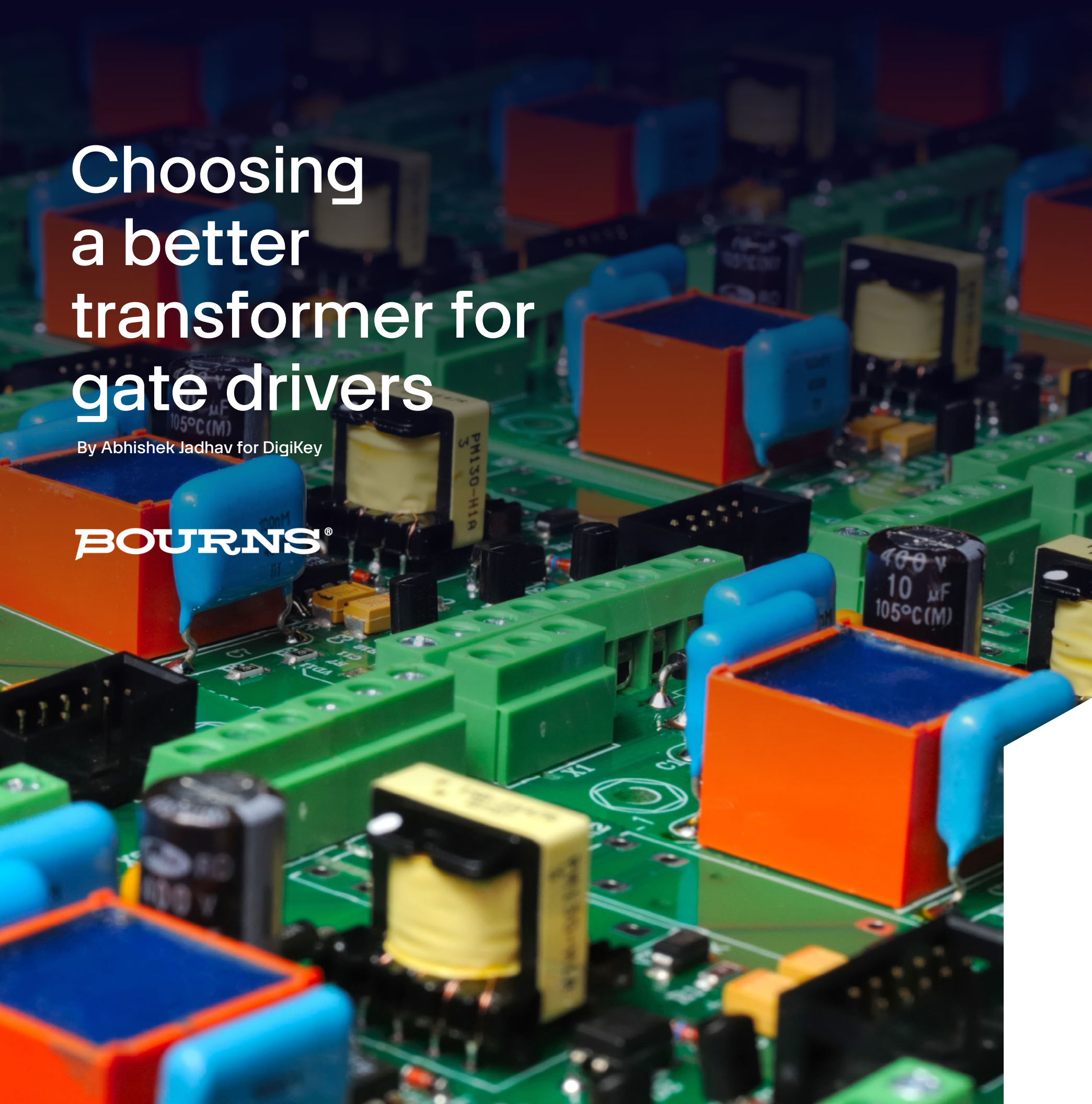
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Choosing a better transformer for gate drivers

By Abhishek Jadhav for DigiKey

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Applications like automotive traction inverters, on-board chargers, and solar inverters are expected to handle more power than ever before yet fit into an ever-decreasing footprint. As power density increases, every circuit on a PCB needs to be efficient.

One such circuit is the gate driver, which controls the ON/OFF switching of a high-power transistor. The gate driver requires its own power supply that utilizes an isolation transformer. Incorrectly designed, this transformer can cause a system to fail electromagnetic interference (EMI) tests.

Things become even more challenging as applications shift toward faster-switching transistors made from silicon carbide (SiC) or gallium nitride (GaN). More efficient than the silicon components they've replaced, these transistors switch at frequencies fast enough to generate electrical noise, which can adversely affect the transformer in the gate-driver supply.

In this article, we'll explore why LLC resonant converters have become the topology of choice for gate-driver supplies, and how planar transformers compare to conventional wirewound ones.

The complexities of LLC resonant converters

LLC resonant converters have become the most common circuit design for isolated gate-driver power supplies due to their efficiency. An LLC circuit is tuned to operate at a specific frequency, where each switching transition happens at or near zero volts. This reduces wasted energy from heat generation, resulting in a power supply that runs efficiently at high switching frequencies.

What makes LLC resonant converters unusual is the role the transformer plays in keeping the switching frequency stable. Every transformer is imperfect in two ways. For one, some magnetic energy put into the primary side doesn't get coupled to the secondary side. This "trapped" energy is called leakage inductance. Secondly, even though the two sides of a transformer are physically separated by an isolation barrier, a small amount of common-mode current can still leak across the barrier as interwinding capacitance.

In most power supply designs, leakage inductance is just a nuisance to be minimized. In an LLC circuit, the trapped energy is actually part of how the circuit resonates, so it needs to be a specific, predictable amount—not necessarily low, but consistent. Interwinding capacitance, by contrast, remains purely unwanted and needs to be kept low.

The problem with wirewound transformers

Most transformers in use today are wirewound, with copper wire wound around a ferrite core. They've worked well across power electronics for decades, and with careful design, they can achieve low interwinding capacitance and reasonable leakage inductance control.

The difficulty is that the winding process is difficult to control during volume production. Wire tension,

layer placement, and winding geometry all influence the final electrical characteristics, and these variables shift between production runs. A transformer that's perfectly in tune on the bench may come out slightly different at scale, impacting consistency in each LLC circuit. Wirewound transformers also tend to be tall, which causes problems in dense PCBs where real estate is at premium.

Where planar transformers come in

A planar transformer solves the wirewound problem by getting rid of the winding process entirely. Instead of copper wire wound around a core, the windings are copper traces printed onto a circuit board, the same way any other circuit on a PCB is made. The flat ferrite core is assembled around the planar conductors.

Because the transformer is now made the same way as the rest of the PCB, its characteristics are controlled by the same precise, automated processes and controls. This makes the leakage inductance and interwinding capacitance much more consistent from unit to unit; it's not dependent on how tightly a wire was wound on a given day. The tighter control also means planar transformers produce less conducted EMI than their wirewound equivalents.

Another other big benefit is height. A planar transformer sits very close to the board surface, helping to maintain creepage and clearance requirements in applications like traction inverters and on-board chargers where multiple high-voltage domains need to coexist within a compact enclosure.

Bourns SM9127xAL series

Bourns makes two versions of planar transformers: the [SM91270AL](#) and [SM91271AL](#) (Figure1). Built on the same platform and designed for low power consumption, both target the same isolated gate-driver supply applications.

The main difference between the two is their turns ratio—i.e., the ratio of windings on the primary side to the secondary side, which determines the relationship between input and output voltage. The SM91270AL has a 1:1 ratio, so the input and output voltage are equal. The SM91271AL has a 7:8 ratio, meaning the output is slightly stepped up relative to the input.

Both have been developed in conjunction with specific gate-driver ICs from [TI](#), [MPS](#) and [ADI/Maxim](#), so engineers working with those chips have a valid starting point rather than designing around the transformer from scratch.

The SM9127xAL series is automotive-grade, rated for a working voltage of up to 850 VDC with reinforced insulation and a Hi-Pot isolation voltage of 6,000 VDC. The operating temperature range of -40°C to +125°C covers the full automotive thermal envelope. Both

models carry AEC-Q200 and RoHS compliance, with a maximum output power reaching up to 5.4 W. The materials are also corrosion-resistant, contributing to a longer service life.

These planar transformers sit less than 3.5 mm above the PCB with no base structure beneath them, and are supplied on 800-piece, 13-inch tape-and-reel packaging for automated assembly. Manufacturing is certified to ISO 14001, which requires facilities to minimize their environmental impact, including energy use. According to Bourns, the packaging is designed with eco-logistics in mind.

Conclusion

As gate-driver power supplies operate at higher frequencies and with space-constrained board layouts, the transformer in the resonant circuit becomes a critical design element. In an LLC converter, its leakage inductance helps define the resonant tank, while its interwinding capacitance can provide a path for high-frequency noise across the isolation barrier.

Planar transformers are well suited for power system designs due to their intrinsic advantages over traditional

wirewound transformers. PCB-based construction brings the same process precision to the transformer, producing more predictable electrical characteristics across production volumes.

The Bourns SM9127xAL series applies these advantages to automotive-grade isolated gate-driver bias supplies, delivering controlled leakage inductance and low interwinding capacitance in a low-profile, automotive-grade package.

To learn more about the SM9127xAL series, visit the [Switching Converter, SMPS Transformers page on DigiKey](#).

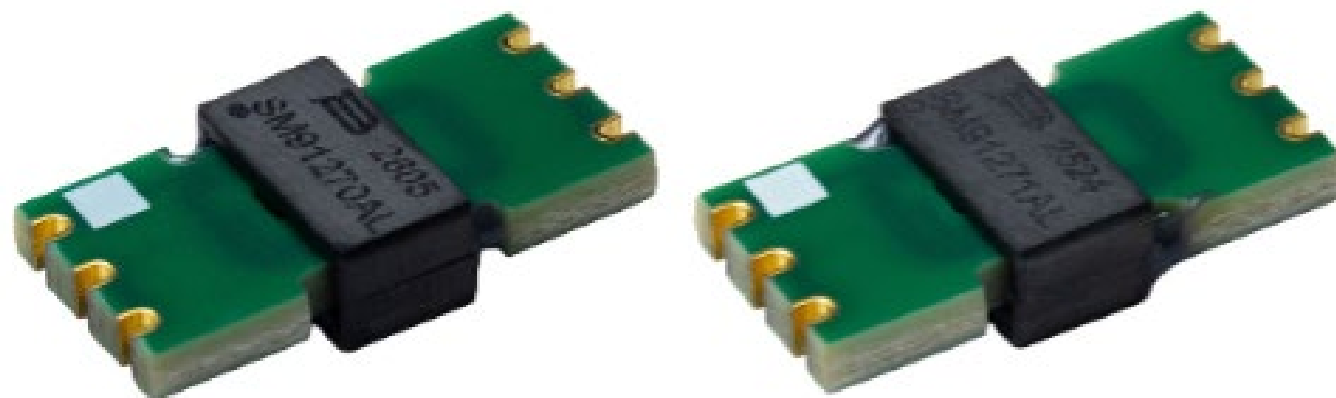


Figure 1: Bourns SM9127xAL series planar transformers. (Image source: Bourns)

Designing reliable interconnects for space electronics

By Abhishek Jadhav for DigiKey



Spacecraft depend on electrical interconnects to carry power, sensitive data, and RF signals between subsystems, while also needing to continue operating during launch vibration and shock, vacuum, thermal cycling, and extended periods without access for repair.

These conditions make it more challenging to maintain interconnect reliability. Vibration can disturb contact interfaces and stress cable terminations, vacuum can cause materials to outgas, and repeated temperature

changes can alter mechanical structures. The selection of spacecraft interconnects depends on contact mechanics, the materials used, shielding, and mechanical retention.

[Cinch Connectivity Solutions](#) addresses these requirements through its Space Mission Solutions portfolio of interconnect, cable, and RF technologies. The portfolio builds on more than six decades of spaceflight experience, with Cinch connectors used since the early days of NASA and

integrated into space telescopes, the International Space Station, and Mars rovers.

High-density connectivity

Space electronics often have many electrical connections within a limited volume and mass budget. Cinch's [Dura-Con Micro-D](#) connectors offer cable-to-equipment and board-level connections with contacts on a 0.050 inch (1.27 mm) pitch. Space-screened versions are available with up to 100 contacts to allow

multiple power, control, sensor, and other signal connections.

The key feature of Dura-Con is its twist-pin contact. The pin uses a compliant spring structure that creates seven points of contact against the socket. When the connector experiences small movements due to vibration or dimensional changes, the spring structure maintains contact pressure at these locations. This is important during spacecraft launch because any movement at the mating interface can produce changes in contact resistance,

causing temporary interface discontinuities.

These connectors combine the twist-pin contact system with an aluminum-alloy housing, gold-finished copper-alloy contacts, glass-reinforced insulating materials, and ETFE insulated wire.

The metal housing provides a structural path around the contact field and contributes to EMI shielding when properly bonded. The Dura-Con connectors also use low-outgassing materials with less than 1 percent total mass loss (TML)

and 0.1 percent collected volatile condensable material (CVCN).

Cinch's [CIN::APSE](#) stacking connectors solve a different packaging problem: connections within densely packed electronic assemblies. The connectors are a solderless Z-axis compression system that connects contact pads on opposing PCBs. The contact elements have a resilient wound-wire structure that compresses between the mating surfaces to create multiple electrical contact points.

The short contact paths offer low resistance and inductance, making them suitable for dense connections. Multiple contacts within a single array can be allocated to these functions, reducing the need for separate connector bodies in a board stack. Stacking jumpers can also connect coplanar, right-angle, folded, or intermediate board arrangements.

Preserving signal integrity

Spacecraft interfaces are defined by how a signal travels between subsystems. Signal paths carrying differential data or sensitive measurements need the connector and cable to preserve conductor geometry, impedance, and shielding.

Cinch's [Trompeter Twinaxial and Triaxial](#) connectors provide these controlled signal paths. Twinaxial connections use two inner conductors within a common outer shield, making it suitable for balanced or differential signaling. As the receiver responds to the voltage difference between the two conductors, noise coupled on both lines can be rejected as common-mode interference. The surrounding shield provides another barrier against electromagnetic fields.

Triaxial adds a concentric conductive layer that allows additional separation among the signal, guard, and outer shielding functions. It is important to maintain such an architecture because a discontinuity in conductor spacing can change the local impedance and reflect part of the signal.

Trompeter connectors use mechanically retained bayonet or threaded interfaces. Cinch also offers fixed-length cable assemblies to include 78Ω twinaxial configurations so the cable and connector can be treated as part of the same transmission path.

Where a signal has to cross a sealed barrier, Cinch offers [Dura-Con Hermetic Micro-D connectors](#). A hermetic connector limits gas leakage across the electrical feedthrough. Some configurations are qualified to specific leak-rate requirements, enabling signal transmission across pressure differentials or controlled-atmosphere boundaries.

These products are part of Cinch's MIL-STD-1553B physical layer offering. MIL-STD-1553B uses a 1 Mb/s, command/response, dual redundant data bus in which a bus controller coordinates communication with connected terminals. The

balanced transmission line, couplers, stubs, connectors, and terminations determine the electrical behavior of the bus.

Managing RF performance and cable reliability

Cinch Space Mission Solutions portfolio extends into the RF signal path through [Midwest Microwave](#) Qualified Parts for Space (QPS). These passive attenuators are for spacecraft RF and microwave systems where signal levels and impedance need to remain controlled across communications, telemetry, sensing, and other high-frequency circuits.

An RF attenuator reduces signal power by a specified amount (expressed in decibels). For example, a 3 dB attenuator reduces the output power to approximately half of the input, while 10 dB reduces it to one-tenth. This loss can be used to obtain specific drive levels, protect sensitive receiver inputs, manage gain across an RF chain, or improve the impedance match.

The QPS attenuators operate from DC to 18 GHz, with an operating temperature range of -55°C to +125°C. Their materials meet ASTM E595 low outgassing criteria of no more than 1 percent total mass loss

(TML) and 0.1 percent collected volatile condensable material (CVCN). These characteristics allow an attenuator to maintain predictable loss and impedance while also meeting the materials and screening requirements.

The connector is only one part of a reliable spacecraft interconnect. At the point where a flexible cable bundle enters a rigid [Dura-Con Micro-D connector](#), vibration can transfer bending and tensile loads on individual conductors and their terminations. Cinch's [Micro-D Backshells](#) provide relief by transferring more of this mechanical load onto the connector shell and mounting structure.

EMI backshells also provide a means to terminate the cable braid around the conductive backshell. This continues the cable shield toward the connector housing while the backshell also controls the cable entry and provides mechanical protection.

Conclusion

Spacecraft interconnect reliability depends on maintaining electrical continuity, preserving contact stability, signal integrity, shielding, and mechanical support. Cinch's Space Mission Solutions portfolio shows how spacecraft connectivity has to

be considered as a complete electrical and mechanical system, with each component selected for the specific signal, packaging, environmental, and reliability requirements.

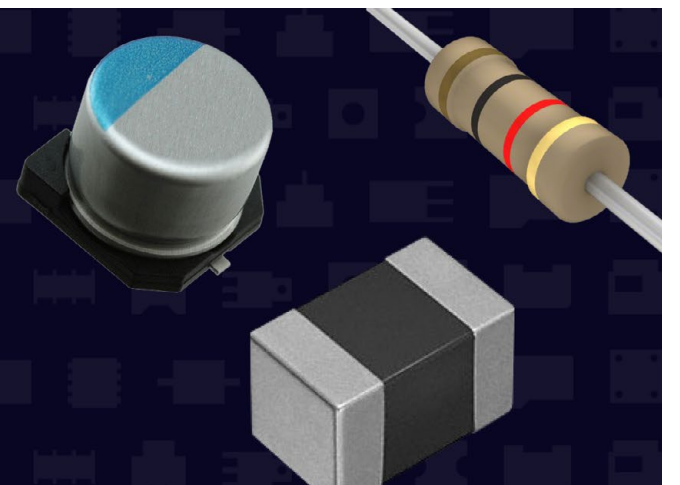
For more information, visit [Cinch's Space Mission Solutions](#).

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Getting supercapacitor selection right

By Abhishek Jadhav for DigiKey

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Batteries and supercapacitors store energy through fundamentally different mechanisms, and that difference determines where each technology belongs in a design.

In a battery, charges are transferred between electrodes and electrolyte through chemical reactions, producing an electrical current through an externally connected circuit. This chemistry is what gives batteries their high energy density—and why they're well-suited to applications requiring sustained current draw over long periods, such as electric vehicles and grid-scale storage.

Supercapacitors work differently. Like a conventional capacitor, they store charge electrostatically, but the double layer of stored charge (between each electrode and a wall of oppositely charged ions in the electrolyte) gives them far higher capacitance than a standard capacitor. The result is a device that can deliver power almost immediately, without the chemical overhead of a battery. Because charge storage in a supercapacitor doesn't involve chemical reactions, supercapacitors generally offer better thermal management, a longer cycle life, better performance across high and low temperatures, and higher efficiency than batteries.

The trade-off is energy density. Where batteries excel at storing energy for long-duration discharge, supercapacitors are optimized for rapid charge and discharge—making them the right choice for pulse power delivery or short-term hold-up power, but not a direct replacement for batteries in energy-intensive loads.

Selecting the right device means matching a capacitor's characteristics to specific application demands. [Eaton](#) addresses this through a broad portfolio spanning several distinct capacitor technologies, including a supercapacitor lineup that covers a wide range of requirements.

Eaton's capacitor portfolio

Eaton's electronic components division carries capacitors across four major families.

Aluminum polymer capacitors use a conductive polymer electrolyte in place of the liquid or gel found in standard aluminum electrolytics. The polymer construction yields lower equivalent series resistance (ESR) and improved high-frequency performance, making these capacitors a natural fit for power supply decoupling and filtering.

Aluminum electrolytic capacitors use a liquid electrolyte and an aluminum oxide dielectric formed on etched aluminum foil. The etching dramatically increases effective surface area, enabling high capacitance values in a compact package. These capacitors are widely used for bulk energy storage and filtering across industrial and consumer applications.

Metalized polypropylene film capacitors use a polypropylene dielectric with a thin layer of deposited metal, wound around a core. The dry, non-polarized construction gives these capacitors stable capacitance over temperature, with the ability to handle high ripple currents, high pulse and surge voltages, and high-frequency operation.

A key characteristic of the metalized construction is self-healing. If a dielectric fault occurs from overvoltage, overheating, or a transient event, the resulting discharge vaporizes the surrounding metal layer, isolating the fault and preventing a permanent short circuit. Eaton's film capacitor range includes DC link types for EV powertrains and solar inverters, as well as safety-rated Class X and Class Y types for AC line filtering. AEC-Q200 and THB Grade IIIB qualified versions are available for automotive and industrial use.

Electric double-layer capacitors (EDLCs)—also referred to as supercapacitors or ultracapacitors—store charge electrostatically between two carbon-based electrodes and a liquid electrolyte. Ions in the electrolyte are attracted to the electrode surface during charging and released during discharge, with no chemical transformation at the electrodes. This purely physical mechanism is what allows EDLCs to sustain millions of charge-discharge cycles with minimal degradation. Eaton's supercapacitor lineup includes individual cylindrical cells, hybrid variants, and complete modules.

How to size a supercapacitor

The starting point for sizing a supercapacitor is identifying which of two common use cases the application falls into.

Hold-up power applications require the supercapacitor to sustain load power for seconds or minutes. Common examples include parking a disk drive's read/write head when power is cut, or keeping a system running long enough for a safe shutdown. In these situations, capacitance is the specification to size for. The device needs enough stored energy to supply the load from its working voltage down to the minimum the system can tolerate.

Pulse power applications are characterized by a low continuous current with short, intense bursts. A GSM/GPRS modem, for instance, can draw up to 2 A during a transmit period measured in fractions of a millisecond. During a pulse, the voltage drop comes partly from ESR and partly from the depletion of stored charge. For very short pulses, the resistive contribution is larger, making ESR the more important specification to optimize.

When a circuit's working voltage exceeds the maximum rating of a single cell, supercapacitors can be placed in series. Series arrangements should be balanced to ensure equal voltage sharing across devices.

Eaton's [supercapacitor calculator](#) steps through the capacitance and ESR calculations for both application types.

Eaton's supercapacitor families

Eaton's supercapacitor products fall into six categories.

Coin cells

Coin-cell supercapacitors are compact devices for use cases like real-time clock and memory backup. An extended-temperature option covers -40°C to +85°C for industrial environments where standard coin

cells fall short. Applications include utility meters, medical devices, network equipment, computers, and industrial controls.

Small cylindrical cells

Eaton's small cylindrical cells offer capacitance from under 1 F up to 110 F, with variants spanning operating temperatures from -40°C to +85°C. An automotive-qualified version is available for safety applications such as emergency door locks and eCall. Across the range, typical use cases include smart utility meters, GPS and asset tracking, RF radios, and storage servers.

Cylindrical packs

Cylindrical packs combine two cells in a single assembly with integrated cell balancing, providing higher operating voltages than individual cells without external balancing circuitry. The use cases are similar to the small cylindrical range—smart meters, GPS tracking, storage servers, and automotive safety devices—where a higher system voltage is needed.

Large cells

Large cylindrical cells cover capacitance from 300 F to 3,400 F for applications requiring high energy storage or peak power in a single device. Applications range from engine starting and peak power shaving to energy regeneration, industrial backup power, and UPS.

Hybrid supercapacitors

Standard EDLCs have lower energy density than lithium-ion batteries and tend to self-discharge more quickly. Eaton's hybrid supercapacitor series addresses both constraints by combining EDLC and lithium-ion construction within a single device.

In a standard EDLC, both electrodes are carbon-based, and charge is stored electrostatically as ions are attracted to the electrode surface during charging and released during discharge. In a hybrid supercapacitor, one electrode is replaced with a lithium-doped carbon electrode, similar to the anode in a lithium-ion battery. Charge is stored electrochemically as a thin film that builds up on the surface during charging.

The lithium doping also lowers the electrode potential, which raises the maximum working voltage to 3.8 V, compared to approximately 2.7 V for a standard EDLC. A higher cell voltage means more energy per device and fewer cells needed to reach a target system voltage. Hybrid supercapacitors have up to 10 times the energy density of a standard EDLC.

Lithium-ion batteries use metal oxide cathode materials, which make them susceptible to thermal runaway when shorted or

punctured. Hybrid supercapacitors avoid metal oxide cathodes entirely, making them a safer option.

Eaton offers three series within the hybrid supercapacitor family:

- **HS series:** Capacitance from 5 F to 220 F at 3.8 V, with a cycle life up to 500,000 charge-discharge cycles. The high operating temperature capability makes the HS suitable for industrial backup power, IoT devices, and automotive subsystems that require frequent cycling.
- **HSL series:** Same capacitance and voltage range as the HS, optimized for low-temperature operation and lower ESR, with a cycle life up to 250,000 cycles. The HSL suits designs in cold environments where both energy delivery and pulse performance need to be maintained.
- **HSH series:** Capacitance from 3 F to 1400 F, with approximately 65% higher capacitance density than the HS and HSL, and a cycle life up to 250,000 cycles. The HSH is the highest energy-density option in Eaton's hybrid lineup, for applications that require substantial energy storage within a compact footprint.

Modules

Supercapacitor modules integrate multiple cells with built-in balancing and management into a ready-to-install unit. The integrated balancing prevents individual cells from being overstressed, and the absence of electrochemical degradation means the modules can be rated for as long as 20 years of maintenance-free service. Low ESR across the assembly supports high peak power delivery while minimizing internal heating.

Eaton's module range runs from 16 V to over 300 V as standalone units, scalable to 1,500 V through series and parallel combinations. Lower-voltage modules suit engine starting, material handling equipment, light rail, and traction systems, with IP65-sealed options for harsh environments. Higher-voltage modules are deployed in datacenter UPS, grid storage, renewable energy firming, and heavy industrial and transportation applications.

Taken together, Eaton's supercapacitor families provide designers with flexible options for addressing a broad range of application needs, making it easier to select the right solution for a given design.

To learn more, visit [Eaton's Capacitor Portfolio](#)



Selecting multilayer varistors for high-temperature circuit protection

By Abhishek Jadhav for DigiKey



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Transient protection has always been a problem in electric vehicle charging and industrial systems, especially because they produce overvoltages far above their nominal operating voltage, and the protecting component is already operating in an extreme environment. In such conditions, the electrical circuits are exposed to ESD, switching transients, and other voltage spikes.

Multilayer varistors (MLVs) provide compact surface-mount

protection by being highly resistive during normal operation and conducting when voltage rises into their nonlinear region. However, selecting one requires more than matching a maximum voltage. Engineers have to consider working and clamping voltage, transient current and energy, capacitance, signal speed, operating temperature, and package size.

[KYOCERA AVX](#) offers its MLV portfolio that addresses these electrical and environmental

requirements. This article explains how multilayer varistors provide transient protection and EMI filtering, and how they compare with transient voltage suppression diodes (TVS) and metal oxide varistors (MOV). We will also look at how to select the right device for a given circuit before going into the specifics of how the KYOCERA AVX VT Series extends its capabilities into high-temperature environments.

Multilayer varistors with transient protection and EMI filtering

A [multilayer varistor](#) is a surface-mount voltage-dependent resistor built from zinc-oxide ceramic layers and internal electrodes. During normal operation, the zinc-oxide boundary network delivers high resistance, allowing only a small leakage current to flow.

When the applied voltage enters the nonlinear region of the device, its resistance drops sharply and the MLV begins to conduct

transient current, clamping the voltage. KYOCERA AVX positions its MLVs for events such as ESD, load dump, jump-start, and other electrical transients.

The multilayer construction is important because alternating ceramic and electrode layers create a large active region within a compact SMT package. This structure distributes transient current through multiple internal layers, improving energy dissipation and thermal performance during surge events.

The same electrode structure also gives the device inherent capacitance. At higher frequencies, that capacitance gives a lower impedance, allowing high-frequency EMI/RFI to be attenuated even when the voltage is too low to trigger the varistor's nonlinear clamping behavior.

This shows how a single MLV can provide both transient suppression and useful high-frequency filtering, potentially reducing the need for a separate filtering component in some circuits.

MLVs and TVS diodes can both be connected across a protected line to divert transient current. However, they have different electrical characteristics. KYOCERA AVX MLVs provide bidirectional, nonlinear protection and can combine that function with capacitive EMI/RFI attenuation. TVS diodes may be preferable where very low capacitance or different clamping behavior is required, particularly on high-speed interfaces.

MLVs differ from traditional MOVs, even though both use nonlinear metal oxides. An MLV has thin ceramic layers and internal electrodes in a compact SMT package. On the other hand, bulk or disc MOVs provide much greater physical volume and are commonly used for higher-energy power line surges.

How to choose a multilayer varistor

Selecting an MLV starts with the circuit's highest operating voltage. The device's continuous working voltage rating must accommodate that voltage without entering significant conduction.

The varistor voltage identifies a reference point in the nonlinear V-I characteristic, while clamping voltage indicates the voltage remaining across the device at

a specified transient current. An MLV must operate normally without excessive leakage, yet clamp low enough for the residual voltage to remain within the tolerance of the protected circuit.

Peak current and transient energy ratings determine if the device can withstand the expected event. These values must be determined using specified waveforms. The VT Series specifies peak current using an 8/20 μ s pulse and transient energy using a 10/1000 μ s pulse. Larger devices can provide far greater energy capability, and capacitance also varies across the family.

It is important to note that a current rating alone does not establish protection because a longer pulse can dissipate considerably more energy. Other factors like package size, leakage current, and operating temperature range also have an influence on a suitable choice.

Capacitance adds another selection criterion when a shielded line carries data. The capacitance that enables an MLV to attenuate EMI can also load a fast signal, increasing rise and fall times and affecting insertion loss and impedance.

Higher capacitance may be useful on power rails, sensor

inputs and lower-speed control lines, while faster interfaces require closer attention to capacitance and the S21 behavior of the device. There is no single data rate limit because suitability depends on the bandwidth, impedance, and signal integrity requirements.

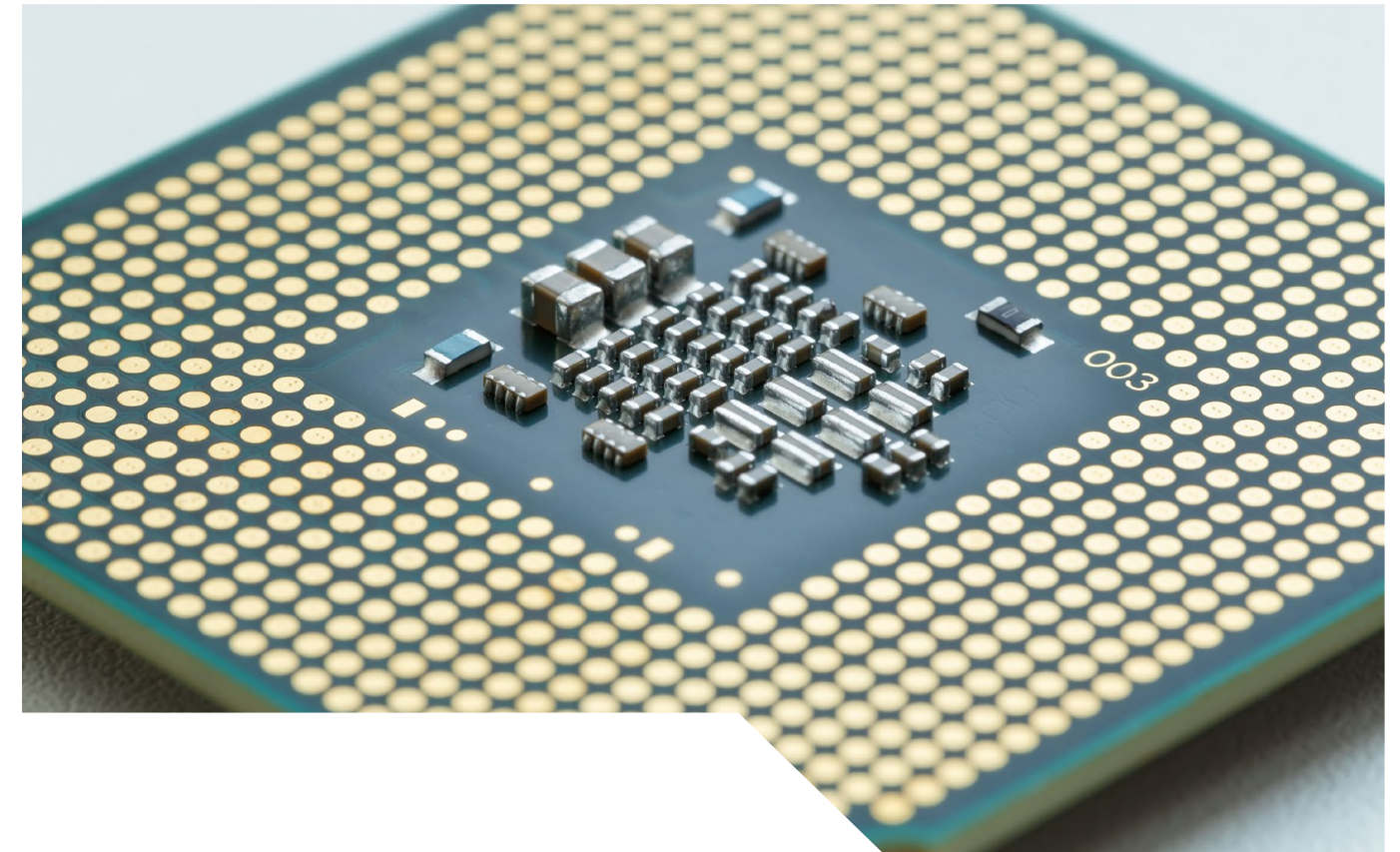
High temperature protection without derating

The [KYOCERA AVX VT Series](#) extends multilayer varistor protection across a range of electrical and thermal requirements.

The family includes VTA3 devices rated from -55°C to +150°C and VTA7 devices rated from -55°C to +175°C, with working voltage options extending to 56 VDC and SMT case sizes from 0603 through 2220. Both families are AEC-Q200 qualified for automotive component applications.

The selected 56 VDC VTA3 devices are designed and tested for 48 V vehicle power supplies in accordance with VDA 320 requirements, with available package and energy options extending to larger 2220 devices.

The temperature capability is more significant than having a high maximum operating temperature rating. The derating curves of the



KYOCERA AVX VT Series maintain 100 percent of the specified current, transient energy, and power ratings through +150°C for VTA3 and +175°C for VTA7.

A [protection device](#) selected solely by its room temperature surge rating offers less usable capability once installed in a variable operating environment.

Conclusion

The KYOCERA AVX VT Series highlights how multilayer varistor technology can provide both bidirectional transient protection and EMI/RFI

attenuation in a compact SMT package while maintaining reliable performance in automotive and industrial environments up to 150°C and 175°C. As part of the broader KYOCERA AVX varistor portfolio, the VT series gives designers the flexibility to select circuit protection solutions optimized for specific voltage ratings, transient energy requirements, capacitance characteristics, operating temperatures, and packaging constraints.

To learn more, visit the [KYOCERA AVX Varistors and MOVs](#) portfolio.

Measuring laser diode temperature in optical transceivers

By Abhishek Jadhav for DigiKey



Optical transceivers carry high-speed data over fiber between servers, switches, and other data center equipment. The core component on the transmit side is the laser diode that generates the optical signal. The thermal behavior of this laser affects its emission, wavelength, optical output, efficiency, and modulation behavior.

The main challenge in measuring the diode temperature is the placement of the sensing element. Sensors that measure ambient or module temperature may not show the local thermal conditions of the laser diode because heat flows through thermal resistances.

[TDK Corporation](#) addresses this with its [NTCWS Series](#) that combines submillimeter dimensions with Au electrodes and wire-bondable construction to allow the thermistor to be placed closer to the laser diode without occupying significant package area.

How NTCWS measures laser temperature

The TDK NTCWS Series is a negative temperature coefficient (NTC) thermistor with a ceramic sensing element whose resistance changes with temperature.

As with any other NTC, its resistance decreases with rising temperatures. The thermistor needs a measurement circuit that can read its resistance, and then convert that value into temperature.

Two specifications are important to understand this operation. TDK offers nominal resistances (B25) of 10 k Ω and 100 k Ω at 25 °C. The B value describes how sharply resistance changes with temperature. TDK specifies B25/85, which means the characteristic is defined by resistance at 25°C and 85°C.

Increasing the value from 10 k Ω to 100 k Ω also raises the impedance of the sensing circuit. A higher resistance reduces both the measurement current and the thermistor self-heating in a given circuit design. However, the higher impedance can also make ADC input leakage, parasitic leakage, and settling behavior more relevant.

For example, the nominal resistance of the 10 k Ω , 3930 K version drops to about 3.60 k Ω at 50°C and 1.10 k Ω at 85°C. The 100 k Ω , 4050 K version measures about 35.3 k Ω at 50°C and 10.27 k Ω at 85°C. The measurement circuitry uses these known resistance-temperature curves to determine the thermistor temperature.

A normal measurement circuit places the NTC thermistor in a voltage divider with a known resistor. When the thermistor resistance changes, the divider voltage also changes. An ADC converter measures that voltage, and the controller calculates the thermistor resistance.

The next step is converting that resistance into temperature. This relationship is nonlinear, so the controller cannot use a simple fixed number of ohms per degree. It can either use TDK's published resistance-temperature data with a lookup table and interpolation, or use a thermistor equation such as the Beta equation over an appropriate temperature range.

The TDK NTCWS devices have ± 1 percent tolerance for R25 and ± 1 percent tolerance for B value. These specifications control different errors. R25 tolerance limits part-to-part resistance variation at 25°C. The B-value tolerance limits the variation in the resistance curve deviation from that reference point.

Simplified assembly for laser temperature sensing

The sensor needs to fit and connect to a very small optoelectronic package for near-laser measurements. The NTCWS devices are roughly 0.31 to 0.48

mm square, depending on the variant, and around 0.25 mm thick (Figure 1). This allows the sensing element to be placed inside the laser diode package.

TDK also designed the electrodes for package-level assembly. The NTCWS supports Au wire bonding, in which a fine gold wire connects the thermistor electrode to another electrical connection in the package. The NTC ceramic still performs the temperature sensing, but the gold electrode and bond wire provide access to its resistance.

TDK identifies AuSn solder as a supported mounting method. These options give designers more flexibility to integrate the

thermistor into the same compact package environment as the laser diode. The exact attachment and bonding processes still have to be qualified for the specific package.

This placement also has an important thermal benefit. A sensor that is close to the laser has a shorter thermal path. Therefore, the measured temperature more accurately shows the laser's local thermal environment. It does not directly measure the laser junction temperature, since some thermal resistance still exists between the laser active region and the sensing element.

The surrounding electronics can then use local measurements for temperature control and

monitoring. For example, the system can compare measured temperature with an expected setpoint or operating profile and respond when the thermal behavior deviates from that expectation.

TDK describes close temperature measurements as enabling proactive temperature control and early abnormality detection. The NTCWS does not diagnose a fault, but it provides the system with local temperature information that can be compared with expected limits, rates of change, or operating conditions.

High reliability for harsh environments

A sensor placed inside a laser package needs to maintain a predictable resistance temperature characteristic over time.

When there is a resistance change in the thermistor, it could appear to the control system as a change in laser temperature. TDK pairs the NTCWS electrical specifications with environmental and reliability testing.

The Version 6 datasheet specifies several environmental stress tests. For the 10 k Ω NTCWS3U family, devices are tested for 1,000 hours at 125°C, 1,000 hours at -40°C, and 1,000 hours at 85°C and 85 percent relative humidity.

The thermal shock testing alternates between -40°C and 125°C for 1,000 cycles. After these tests, the change in resistance must remain within $\pm 1\%$. The 100 k Ω NTCWS4AF family is tested under the same conditions with a ± 2 percent resistance change limit.

TDK also reports a sulfurization test for the gold electrode thermistor. The device was exposed to hydrogen sulfide at 5 ppm, 40 $\pm 2^\circ\text{C}$, and 75 $\pm 3\%$ relative humidity for 240 hours. They reported that it passed the test.

These results show that the NTCWS resistance characteristic remains under control after defined thermal, humidity, and corrosive-gas stresses.

Conclusion

Measuring laser diode temperature in an optical transceiver is about selecting an accurate sensor that can be placed close enough to the laser to capture its local thermal condition. The TDK NTCWS Series has defined resistance temperature characteristics with R25 and B-value tolerances to provide a predictable electrical response. The submillimeter dimensions, Au electrodes, and support for wire bonding simplify integration into compact optical transceiver assemblies.

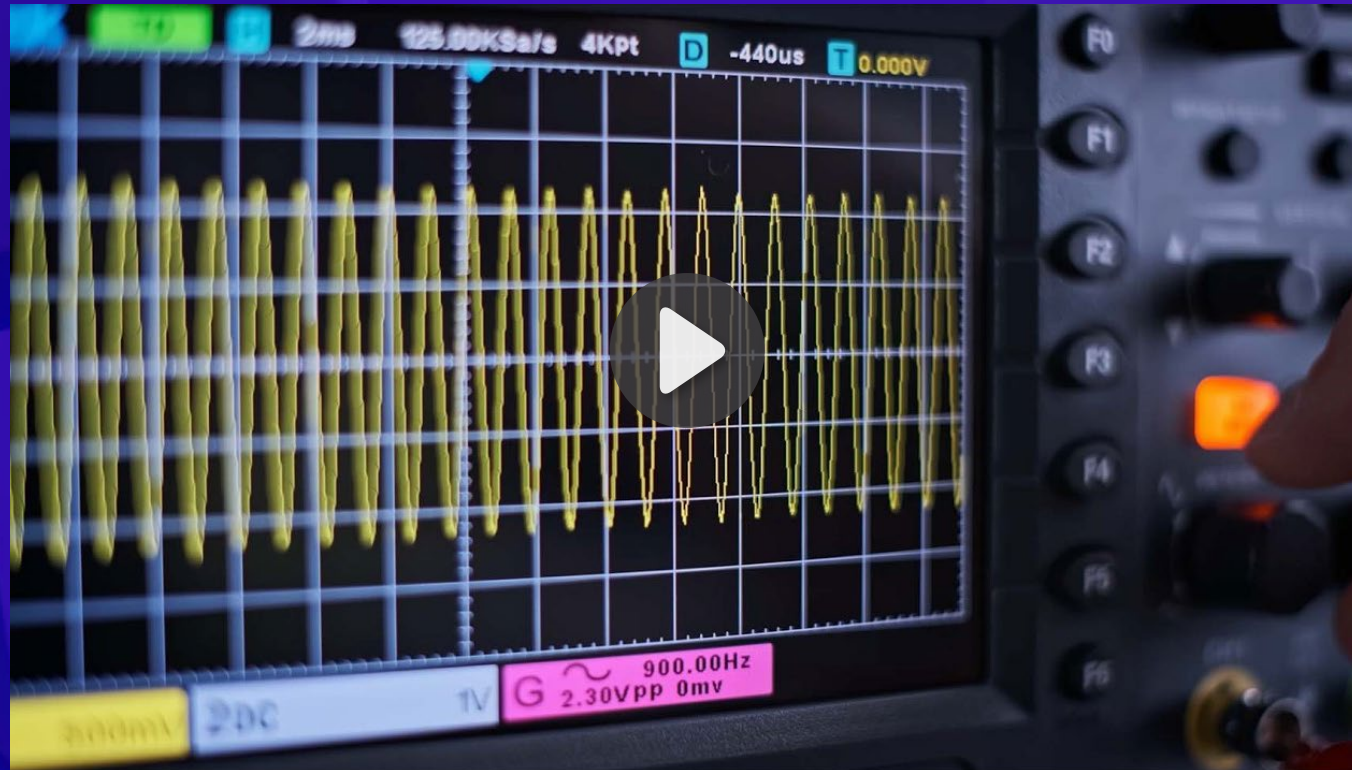
To learn more, visit [TDK's NTCWS Series Thermistors](#).



Figure 1: Representation of the NTCWS series device packaging.
(Image source: TKD)



Video spotlight



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Emile Berliner:

The loose-contact microphone and the first format war

By David Ray, Cyber City Circuits

Sound

How does someone turn fragile sound into something that can be transmitted, recorded, reproduced, manufactured, and distributed?

Emile Berliner spent much of his life solving different versions of that problem. His variable-contact microphone allowed the weak vibrations of a voice to control a stronger battery-powered electrical current,

making long-distance telephony practical. His gramophone used flat discs and a master-and-stamper manufacturing process that transformed recorded sound from an individual artifact into a mass-produced product. He later worked on acoustic building materials, lightweight rotary engines, and early helicopters with his son Henry. He repeatedly looked at an incomplete technology, identified

the underlying issues preventing it from becoming useful, and rebuilt it around a better idea.

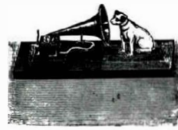
This article started as a story about the first practical microphone, but it turned into a story about what the inventor did with the money he made when he sold his invention to Bell Telephone, and how that culminated in technology's first format war.

Emile and his son, Henry, experimenting with helicopters and vertical flight.



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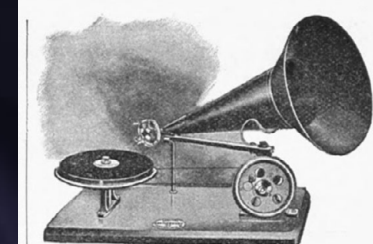
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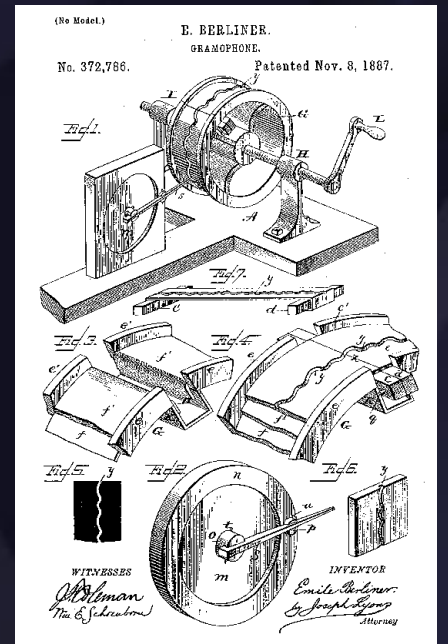
The Berliner
Gramophone

A Talking Machine That "Talks" \$15

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Our Offer: We shall be pleased to give the fullest information on request, and for a limited time offer to send this talking machine to any LADIES' HOME JOURNAL subscriber with privilege of returning within 3 days after its receipt, and refund money less express charges.

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FOR SALE by all MUSIC DEALERS



Writer's Note: There have been many tellings of Emile Berliner's story with some conflicting points. His grandson, Oliver Berliner, has given several speeches, talks, and interviews about his grandfather. The writer considers many sources when writing stories, but if a source conflicts with family stories, the writer will usually side with the family, unless the source is from conflicting patents, court records, or business documents. As the reader will soon read, it is a messy story.

Emile Berliner

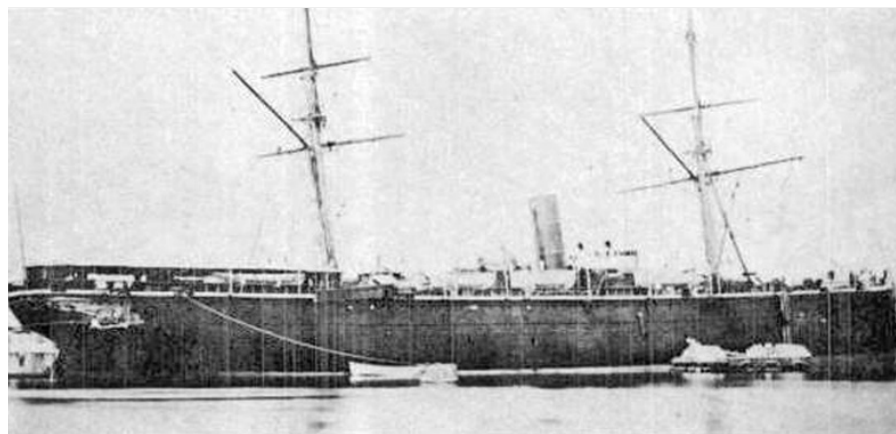
Emile Berliner was born Emil Berliner in Hanover on May 20, 1851 (adopted the moniker 'Emile' after immigrating to the United States). He was one of thirteen children born to Samuel and Sarah Friedman Berliner.

After attending school in Hanover, Berliner graduated in 1865 at fourteen, marking the end of his formal education. In 1870, a local business owner offered him a position at a dry-goods store in Washington, D.C. The offer gave Berliner a route out of Germany at a time when the Franco-Prussian War made military service an immediate possibility for young men his age. With his parents' permission, nineteen-year-old Berliner left Hanover in March and crossed the Atlantic aboard the

steamship Hammonia. He landed in New York before continuing to Washington, where he began working for Gotthelf, Behrend and Company as a store clerk.

For the next several years, Berliner worked at the store and also did a bunch of odd jobs. One job of note was as a general cleanup man in the laboratory of chemist Constantine

Fahlberg, who later became known for the development of saccharin. He washed the lab equipment and kept the laboratory in order. For the first time, he was surrounded by instruments, chemicals, experiments, and people who treated scientific questions as problems that could be solved with the brain and the hands. Fahlberg's laboratory



Berliner arrived in the US on the ship Hammonia in 1870. (Image from 1876)

gave Berliner something the sales counter could not. Daily evidence that an unanswered question could be attacked with instruments and experiments. Berliner decided that research and invention were what he wanted to do.

In 1876, his former employer persuaded him to return to Washington with better pay and more of a management role. By day, Berliner worked in the store, and at night, he built a small laboratory in his bedroom and began experimenting with electricity and the telephone. It was not unusual to have your lab in your bedroom at the time. Even Bell and Watson conducted their telephone experiments in a room in a boarding house.

Alexander Graham Bell's new telephone had recently captured public attention, but the instrument's transmitter remained weak. It was necessary for a user to yell into the transmitter for it to work. The user's voice had to generate the electrical signals with vibrations within the transmitter, leaving little energy available at the receiving end.

The loose contact microphone

While examining the weakest part of Bell's telephone in his bedroom laboratory, the twenty-five-year-

old store clerk discovered a way for the human voice to control a stronger current supplied by a battery. By 1877, Berliner had a working model of a new type of telephone transmitter. Berliner placed a movable diaphragm and an electrode in slight contact with each other as part of a battery-powered circuit. When someone spoke against the diaphragm, the sound vibrations changed the pressure between the contacts. The changing pressure varied the circuit's resistance, causing the battery current to rise and fall in step with the speaker's voice.

Suddenly, the voice alone didn't have to generate the energy needed to reach the other end of the line. It only had to control the current from the battery. Berliner's June 1877 application described this variable-pressure principle and allowed the contact surfaces to be made from metal or carbon. Berliner had identified the fundamental operating principle: sound could vary the resistance of an external electrical circuit rather than generate the transmitted current directly.

Strictly speaking, Berliner's first device was a loose-contact or variable-resistance transmitter, rather than the finished granular-carbon microphone that became the modern standard, but it pioneered all of the same principles.

Berliner prepared his own patent papers without the assistance of a patent attorney. When the newly formed Bell Telephone organization learned that an unknown Washington clerk claimed to have improved the telephone transmitter, its directors were skeptical enough to send Thomas Watson to investigate. Not everyone knows this about Thomas Watson, but he was the engineer who built all of Bell's telephone inventions and apparatus, including the original liquid transmitter that gave Bell his March 1876 breakthrough. Watson traveled to Washington to meet Berliner. After they spent some time together, no doubt sharing knowledge and answering each other's questions, Watson examined the device. When he returned to Bell Telephone, he brought an enthusiastic report about both the transmitter and its inventor. The company offered to acquire the invention for \$50,000 and bring Berliner into its research team.

The Bell company hired Berliner as a research assistant and kept him on a monthly salary. He worked first at Western Electric in New York and later in Boston, tackling problems associated with the rapidly expanding telephone system. He entered the company with only a modest understanding of electrical theory, but seven years among Bell's engineers transformed him into an experienced electrician.

Suddenly flush with investment cash, Bell could solve any problem he approached. Western Union, Bell's powerful rival, had acquired rights to Elisha Gray's work, Thomas Edison's improved transmitter, and was preparing to challenge Bell in the telephone market, but the timing could hardly have been better for Bell. Berliner's novel transmitter patent application was the thing that Bell needed to defend his new telephone business from Edison and Western Union.

In 1881, Berliner became an American citizen and married Cora Adler. The same year, Bell sent Berliner back to Germany to start the Hanover Telephone Factory under the management of his brother Joseph. The factory became an important early supplier of telephone equipment in Germany. This experience in Germany with his brother shaped his future entrepreneurial drive. When he returned in 1884, he wanted more than a place inside someone else's laboratory, and he formally resigned his position to work as an independent inventor and researcher.

The United States vs American Bell Telephone Company

Bell paid Berliner \$50,000 for the patent rights to the transmitter. What Bell purchased from Berliner

wasn't a patent though, because that patent would not exist for another fourteen years. The company purchased Berliner's invention and his interest in the pending June 4, 1877 patent application. When that application finally emerged from the Patent Office as Patent 463,569 in 1891, the patent was issued directly to the American Bell Telephone Company as Berliner's assignee. The patent took 14 years, while Bell's own telephone patent application only took a few weeks just the year before.

At this point, the story must jump ahead to follow Berliner's application to its conclusion, as it brought the wrath of the United States Federal Government down on Bell Telephone.

Bell could use the patent-pending material immediately. Bell had purchased Berliner's rights and was already incorporating his battery-powered transmitter into its telephone system by the end of the 1870s. The patent, once issued, would give Bell an additional legal weapon against competitors, but as long as it was eventually issued, he was protected from the beginning by the deal with Berliner.

According to court documents, the delay came largely from the Patent Office. Berliner's broad claims involving a variable-

pressure contact transmitter appeared likely to conflict with other pending applications, so examiners repeatedly suspended the case while waiting for possible patent-interference proceedings. In 1886, almost ten years into the application, an examiner explicitly told Bell's attorney that the office was waiting for no action from the applicant and that the delay was not Berliner's or Bell's fault.

The delay nevertheless looked remarkably convenient, adding fourteen years to the life of Bell's patent protection. Under the patent law then in effect, the patent's enforceable term began when it was issued. A patent granted in 1891 could therefore protect Bell's telephone business long after its original 1876 patent approached expiration. The United States government sued to cancel the Berliner patent, arguing that Bell had deliberately allowed the application to remain dormant so it could emerge later and prolong the company's monopoly.

The Supreme Court agreed that the delay had benefited Bell, but that wasn't proof of fraud. The record contained no evidence that Bell had bribed Patent Office officials, requested postponements, or improperly caused the application to be suspended. In fact, several examiners testified that Bell's representatives had persistently

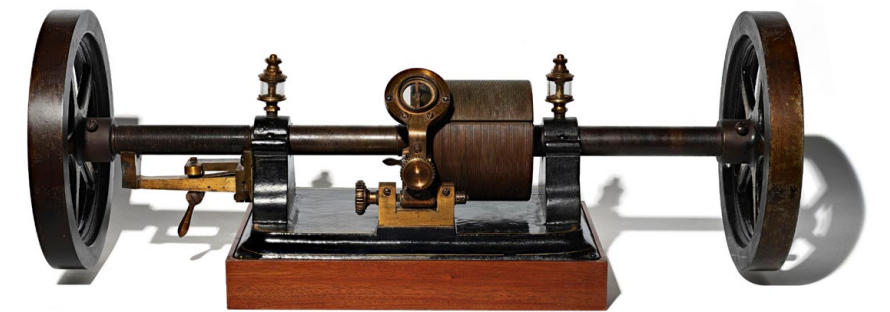
Retro Electro Fun Fact: This is not the first time that Bell was accused of shenanigans within the US Patent System. In 1886, the telephone patent examiner from 1876, Zenas Wilber, gave a sworn statement that Bell had bribed him with a hundred-dollar bill to give Bell preference over Elisha Gray's patent application. That story is included in the Retro Electro article "[Engineering Silence: The Telephone and the Negative Feedback Amplifier.](#)"

pressed them to act. In 1897, the Court ruled that the government had failed to provide the clear and convincing evidence required to cancel the patent. Bell kept Patent No. 463,569, and the fourteen-year delay was attributed to Patent Office procedure and bureaucracy rather than misconduct by the company.

The first format war

Edison's phonograph

Thomas Edison arrived at recorded sound indirectly. In 1877, while developing automatic telegraph equipment, he experimented with machines that embossed electrical messages onto moving paper tape so they could be transmitted again later. At the same time, his work on telephone transmitters led him to think of sound as a set of mechanical vibrations. Edison realized that if the motion of a



An example of Edison's tinfoil phonograph. The stylus would follow the grooves in the cylinder and punch indentations into the cylinder, through the foil, recording the sound.²¹²³

telegraph signal could be stored as physical marks, perhaps the vibrations of speech could be stored the same way and then used to reproduce the original sound.

Edison's first successful phonograph used a sheet of tinfoil wrapped around a grooved metal cylinder. A hand crank rotated the cylinder while its threaded shaft carried it steadily past a diaphragm and stylus. When someone

yelled into the mouthpiece, the diaphragm vibrated, driving the stylus up and down and pressing a succession of indentations into the foil. Because the groove varied in depth rather than moving from side to side, this technique later became known as hill-and-dale recording. To reproduce the sound, the operator returned the cylinder to its starting position and turned the crank again. A playback stylus followed the indentations, moving

the diaphragm in approximately the same pattern and sending the recorded voice back into the air. Edison reportedly tested the machine by reciting “Mary Had a Little Lamb.” When it repeated the words, even he was astonished that the apparatus had worked.

The public reaction was immediate. A machine that could speak after the speaker had stopped talking seemed to violate the rules of the world, and some scientists initially doubted reports that it worked at all. Yet the tinfoil phonograph was far more convincing as a demonstration than as a product. The foil wrinkled, tore easily, and survived only a few playbacks. Recordings were faint and difficult to understand, and the hand crank made pitch and timing dependent on the operator maintaining a steady speed, which is a lot harder than it sounds if the reader has never tried such a thing. Preparing the foil, positioning the stylus, and replaying a recording all required care. Edison and his associates demonstrated the machine widely, but they didn’t know how to turn it into a reliable consumer product. History shows that the tinfoil phonograph was really only an impressive tech demo that Edison had oversold, but most importantly, he had the patent on the technology. Edison soon redirected much of his attention back toward electric lighting.



An Edison Home Phonograph

The Volta Prize of 50,000 francs or \$9,500 has been awarded to Mr. Graham Bell, by the committee appointed by the French minister of public instructions. A most fatal disease is raging to an alarming extent in Havana. Among

Newspaper listing announcing Bell's award of the Volta Prize.

Bell and Tainter's graphophone

In 1880, the French Government awarded the Volta Prize to Bell for his innovations in communication. Bell used the 50,000 francs to establish a Washington, DC laboratory devoted to acoustics and communications that he named 'The Volta Laboratory.' He, along with his cousin, Chichester Bell, and machinist Charles Sumner Tainter, started the lab in 1881. It was here that the two invented the Bell and Tainter Graphophone to compete with Edison's phonograph.

The Volta Lab experimented with all sorts of mediums, including jets of air and even methods of recording sound with light. Eventually, they returned to Edison's basic mechanical arrangement of a spinning cylinder with a diaphragm that moved a stylus. Their breakthrough was to replace the parts of the phonograph that made it so terrible to use.



A nameplate to a graphophone.

Instead of wrapping a metal cylinder in fragile tinfoil, they used a paper or pasteboard recording surface coated with a mixture of wax and paraffin. They used a sharp, chisel-like stylus to cut away tiny shavings and engraved the sound into the wax. The resulting groove was sharper and better defined than Edison's phonograph, allowing for much higher fidelity, tighter grooves, and more recording time.

Bell and Tainter also developed what became known as the floating stylus. Edison's original reproducer was rigidly held in position. The Volta Laboratory design loosely mounted

the reproducing head so that its own weight held the stylus against the record while allowing it to adjust itself to the groove. A foot pedal and a weighted flywheel provided a steadier speed than Edison's hand crank, reducing the strange rises and falls in pitch caused by an inconsistent operator. The machine was still recognizably descended from Edison's phonograph, but it was much closer to something an office could use repeatedly.

The inventors named their improved machine the Graphophone, partly to distinguish it from Edison's Phonograph. Before introducing

it commercially, representatives of the Volta group approached Edison and proposed cooperation.



Early graphophone that was used for dictation.

Writer's Note: Because currencies and economies varied widely across the countries involved in nineteenth-century technological development, direct modern conversions are often misleading. When no reliable comparison is available, the writer estimates a historical sum by calculating the amount of gold it represented at the time and then converting that quantity into present-day U.S. dollars. The 50,000 francs were equivalent to 2500 20-franc 90% gold coins. The sum of the gold would be 14.5 kg (467 troy ounces) or around 32 pounds. In 1880, gold was \$20.67 per troy ounce, and 32 pounds of gold would have had the value of approximately \$9,600 USD in 1880. As writing this article, the value of gold is \$4,000 per troy ounce. This makes the 50,000 francs in 1880 worth about \$1.87M today.



A Bell and Tainter Graphophone

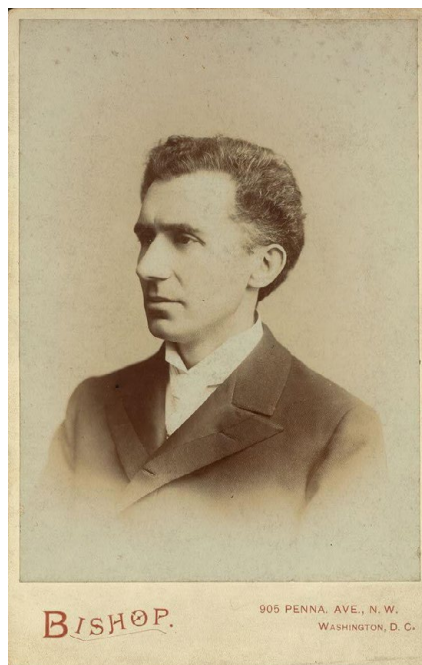
According to Edison's secretary, they openly described their work as an extension and refinement of Edison's original invention and reportedly offered to abandon the Graphophone name if Edison joined them. Edison refused. He viewed Bell and Tainter as trespassers who had entered a field that belonged to him. Over time, Edison developed contempt for anything that had the name 'Bell' on it.

The Graphophone also provoked Edison into returning to recorded sound. His later improved phonograph used a solid wax cylinder and a loosely mounted reproducer, features uncomfortably similar to those developed at the Volta Laboratory. Edison maintained that Bell and Tainter had merely dressed up his invention, while the Graphophone interests argued that Edison's improved machine infringed their patents for engraving wax and

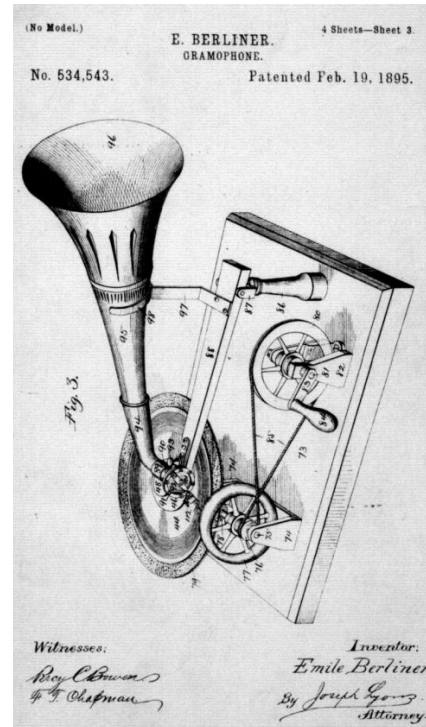
allowing the stylus to float. Lawyers on both sides prepared for a patent fight, but no clean courtroom decision settled the argument.

Berliner's gramophone

After leaving the Bell Telephone Company, Berliner returned to Washington, D.C., determined to work as an independent inventor. Berliner saw that the larger commercial problem remained unsolved: cylinder recordings were difficult to duplicate and mass-produce. Every additional copy required another recording or a complicated copying process. In any case, it really wasn't commercially viable, but nobody had the solution.



Berliner in 1881



Drawing from a gramophone patent.

Berliner began experimenting with a flat disc and a stylus that moved from side to side rather than vertically. His first records were traced into lampblack on glass and transferred into metal through photoengraving. The process worked, but it was slow and unreliable. He then developed a better method using a zinc disc covered with a thin, acid-resistant coating. The recording stylus scratched through the coating, exposing the metal underneath. When the disc was placed in acid, the exposed lines were etched into a permanent groove.

On November 8, 1887, Berliner received U.S. Patent No. 372,786.

He also got related patent protection in Britain and Germany. He called the invention the Gramophone, combining Greek-derived roots suggesting "written sound" while distinguishing it from Edison's Phonograph and Bell and Tainter's Graphophone.

Unlike his competitors, he didn't think of his invention as a business dictation machine. He saw it as home-entertainment built around commercially manufactured recordings. Over the next several years, he developed a method of electroplating an original recording to create a reversed metal matrix. That matrix could then stamp copies of his records

into a moldable material. This was mass production at a scale impossible for Edison or American Graphophone with wax cylinders.

A business built in pieces

Berliner still needed performers, recording studios, stampers, pressing facilities, motors, advertising, dealers, and overseas partners. Rather than consolidating those functions under one company, he distributed them across several. That decision allowed the Gramophone to grow quickly. It also left the business vulnerable to anyone who controlled an indispensable piece of the operation.



Prototype gramophone used for early demos in 1888.

American Gramophone Company (New York)

Berliner's first attempt to commercialize the Gramophone in the United States was the American Gramophone Company, formed with financial backers in New York. Very little documentation about the company survives, and it does not appear to have produced records or machines in meaningful quantities.

United States Gramophone Company (Washington, D.C.)

In 1893, Berliner formed the United States Gramophone Company with friends and relatives in Washington. Its principal assets were his Gramophone patents, and it became the legal foundation for his American business. The company began selling locally in 1894, offering hand-driven machines and small hard-rubber discs.



Fun Fact: The Grammy Award is named after the gramophone, and the award itself resembles an early gramophone.

Berliner Gramophone Company (Philadelphia)

In 1895, Philadelphia investors supplied the capital needed for a larger operation. The Berliner Gramophone Company was incorporated there and licensed the patents held by the United States Gramophone Company. The Washington organization controlled the invention, while the Philadelphia company concentrated on producing records and machines.

Berliner now had patents in Washington and manufacturing in Philadelphia. Berliner could record the disc. He could press copies. He could not manage to put them in stores. What he knew he needed was a national sales organization capable of advertising the Gramophone and

placing it in front of customers and store owners across the country. That missing part would soon be supplied by Frank Seaman and the National Gramophone Company with consequences Berliner did not foresee.



Berliner examining a disc

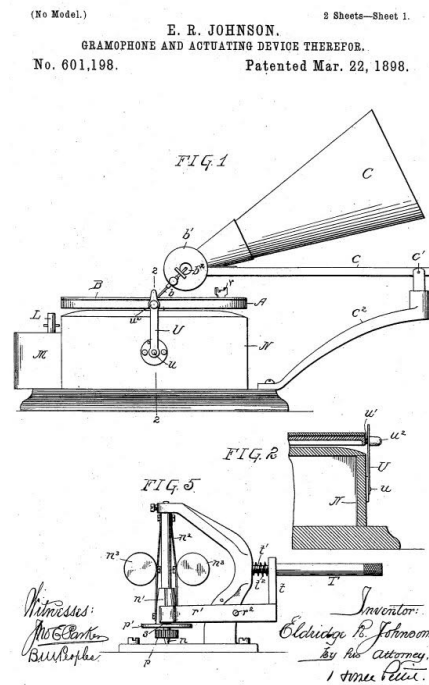
National Gramophone Company

In 1896, the Berliner Gramophone Company signed a fifteen-year agreement with Frank Seaman, an energetic New York advertising man who promised to promote the Gramophone at no direct cost to Berliner. In exchange, Seaman received the exclusive right to sell Gramophones in the United States and formed the National Gramophone Company at 874 Broadway in New York. He flooded newspapers and magazines with bold advertisements.

The arrangement split the American business among three independent companies: the United States Gramophone Company owned the patents, the Berliner Gramophone Company manufactured the records and machines, and Seaman's National Gramophone Company controlled advertising and sales. It worked remarkably well, but it also placed Berliner's access to his own customers in Seaman's hands.



A National Gramophone nameplate.



Patent by Eldridge Johnson for essential improvements to the gramophone.

Eldridge Johnson

At about the same time, Eldridge R. Johnson, a machinist operating a small shop in Camden, New Jersey, solved one of the Gramophone's largest mechanical problems. Johnson founded the Eldridge

R. Johnson Manufacturing Company in 1894 and, after examining the clockwork design of a gramophone, developed a reliable spring-driven motor that maintained a steadier speed and allowed the machine to play without being continuously turned by hand or pedaled by foot.



Johnson's Improved Gramophone used a spring-driven motor that mounted to the back of the chassis.

Berliner's company ordered its first two hundred spring motors in the summer of 1896, and by Christmas, Seaman was selling the spring-driven model faster than the company could manufacture it. Johnson later helped develop the "Improved Gramophone" that became the foundation of the growing business.

The Gramophone Company Ltd (London)

In July 1897, William Barry Owen, a salesman working for Seaman, left the National Gramophone Company in the United States and headed for Britain. He was sent to establish a British operation, secure financial backing, and introduce the new machine to the overseas market.

It is said that Owen had the gift for persuasion. He also had a taste for risk. New ventures offered the possibility of both large profits and the affluent lifestyle he enjoyed, and Berliner's gramophone seemed to promise both.

Writer's Note: The company's name is sometimes written as the British Gramophone Company. The writer is pretty sure there was no company under that name, and that it always refers to Owen and William's The Gramophone Company.



Owen left for London to start The Gramophone Company.

Soon after arriving in Britain, Owen met Trevor Lloyd Williams, a young Welsh lawyer who became his most important business partner. Together, they established The Gramophone Company LTD, formally incorporated in 1899.

At first, Owen devoted himself to the new business. The machines sold reasonably well, but London's financial establishment proved harder to win over. Investors remained cautious, and Owen struggled to raise the capital needed to expand manufacturing and distribution.

By 1904, having already made a few bad deals, Owen left operations to just participate on the board, and in 1906, he left the company

altogether. Owen then returned to the United States, where he pursued several agricultural ventures. None succeeded. By 1910, he had exhausted his fortune and accumulated substantial debts. He spent the remainder of his life supported in part by a pension provided by the Victor Talking Machine Company and the Gramophone Company.

The company continued on for many years.

American Graphophone vs Berliner (1898-1901)

The American Graphophone Company held the rights to the Bell-Tainter patent (1886 US Patent 341,214), which had a floating stylus, similar to Berliner's gramophone. Fundamentally, everything about the two floating styluses was different, but the wording of the patent was so vague that American Graphophone was hopeful it would kill Berliner's patent.

The Graphophone used a worm screw gear that slowly and mechanically moved the floating stylus from one end of a wax cylinder to the other, while the cylinder was turned by hand at a constant pace. Very different than a record player, which uses the physical groove in the record



Offices of The Gramophone Company

to move a free-floating stylus. Ultimately, after an appeal, American Graphophone lost this lawsuit, and its patent expired a few years later.

Berliner vs Frank Seaman (1899-1900)

Frank Seaman had done exactly what Berliner hired him to do. He taught America to want the Gramophone. His National Gramophone Company advertised aggressively, established branch offices, and transformed Berliner's little disc machine into a strong consumer business. By 1899, however, Seaman believed that his company was receiving too little of the profit. He controlled advertising and sales, but he remained dependent



The Board of The Gramophone Company in 1919.

on the Berliner Gramophone Company for every machine and record he sold. Berliner's group regarded the arrangement as a contract that Seaman had signed in good faith. Seaman regarded it as an obstacle between himself and control of the business.

Universal Talking Machine Company

Seaman established the Universal Talking Machine Company as a manufacturing subsidiary, to produce his own product, while still holding an exclusive sales license within the US. Universal began building a competing disc machine while Seaman continued to advertise and sell Berliner Gramophones. Then, in October 1899, his orders from the Berliner company abruptly stopped.

Seaman called his new machine the Zonophone. It was somewhat heavier and more ornate than Eldridge Johnson's Improved Gramophone, and its spring motor was enclosed inside the cabinet rather than mounted at the rear. Beyond those differences, it was fundamentally the same as the Gramophone. Seaman's Zonophone was very popular. This was likely because he regularly gave them away for free. Seaman knew that the real money was in selling the recordings and not the player, giving people an expensive player, which they otherwise maybe couldn't afford, locked them into the format.

Seaman had gone from defending Berliner against the world to leading the end of Berliner's business in the US.

Berliner's original agreement with Seaman

National Gramophone still possessed the exclusive right to sell Gramophones in the United States. Seaman had stopped buying Berliner's products and was selling his own competing machine, but the Berliner Gramophone Company could not simply bypass him and sell directly. On June 25, 1900, Seaman persuaded the court to issue an injunction restraining the Berliner's company from selling any Gramophone merchandise. Berliner still owned his American patents through the United States Gramophone Company, but those patents were commercially useless while he was legally prevented from selling the products they protected.



National Gramophone developed the Zonophone with Berliner's patents.

His Master's Voice

The story of what happened to Berliner and the rights to the gramophone following the loss to Seaman is best told by tracing the story of the trademark “His Master’s Voice.” The story is a cautionary tale of licenses and trademarks in markets outside of your own.

For over 50 years, “His Master’s Voice” and Nipper the Dog were quite literally the world’s most recognizable commercial trademark. Painted by Francis Barraud in 1898, the painting depicts the artist’s dog, Nipper, listening to his master’s voice play from an Edison phonograph. The dog had belonged to his older brother, who had died some time earlier, and the dog himself died in 1895. The painting and the copyright were purchased by The Gramophone Company in 1899 for £100, but only after Barraud painted over the phonograph with a Berliner gramophone. The Gramophone Company registered it as a trademark in Britain and let Berliner register it in the US and Canada.

The trademark rights for this painting have been split half a dozen times, and it is a fun trip through international business in the twentieth-century music industry.

The American side:

Victor Talking Machine Company

Following the legal loss against Seaman in 1900, Berliner’s business had to stop immediately. Eldridge Johnson, whose new Camden factory depended on the disc-machine business, was left to reorganize what remained. Berliner assigned the US patent rights to Johnson, and in 1901, Johnson founded Victor Talking Machine Company, combining his own gramophone patents for manufacturing, the stylus, and the motor drive with his perpetual patent license from Berliner. Berliner was a founding shareholder of the company, and Victor decided to use the memorable dog branding.



The original ‘His Master’s Voice’ painting featured a graphophone.



The artist, Francis Barraud, with his painting.



His Master's Voice US Trademark

Victor would become most remembered for both their advertising and their series of Victor Victrolas.

RCA-Victor

RCA purchased the Victor Talking Machine Company in 1929, rebranding to RCA-Victor, continuing to feature Nipper on its products. RCA would later take the music portion of the business to form RCA Records, which later merged with BMG, then Sony in 2008, forming Sony Music. It is thought that Sony Music is the current holder of the “His Master’s Voice” trademark in most countries.

The Canadian side:

Berliner Gram-O-Phone Company of Canada (Montreal)

Berliner had already established a Canadian operation in Montreal in 1899, while the disputes with Frank Seaman and American Graphophone were still unfolding. Berliner himself remained based in Washington, D.C. The operation began selling records and gramophones in 1900. Once Victor was operational in America, the company started distributing records and equipment made by Victor in the United States.



Eldridge Johnson, founder of Victor Talking Machine Company



Johnson's Camden machine shop became the first Victor Talking Machines location.

Retro Electro
Fun Fact: RCA played a huge part in the development of modern electronics and communications. Part of their story can be found in the Retro Electro article "[The Rise of Designators.](#)" Check it out.



A classic Victor Victrola

This setup allowed Victor to enter the Canadian market without taking over the family business right away, while the Berliners benefited from Victor's growing catalog and enhanced talking machines. The Montreal firm became Canada's first significant record producer, releasing material for both English and French-speaking listeners.

In 1904, the business received its charter as the Berliner Gram-O-Phone Company of Canada. Emile remained its president, but much of the day-to-day work fell to his sons. Herbert Berliner became a director, vice-president, and general manager, as his younger brother Edgar joined the company in 1906

and later became secretary-treasurer. Early Canadian records were pressed from masters recorded elsewhere, but the Berliners gradually built a complete recording and manufacturing system in Montreal. In 1906, the company began constructing a factory and studio in the Saint-Henri district, giving it the ability to record performers, prepare masters, press discs, assemble machines, and distribute the finished products from one Canadian operation.

Victor Talking Machine Company of Canada (Montreal)

The family's control began to loosen before Victor formally purchased the company. The sons started to slowly lose grip of the business.

In 1924, Berliner relinquished the family's controlling interest to the Victor Talking Machine Company, which acquired the Montreal business and renamed it the Victor Talking Machine Company of Canada. Emile had remained president until the sale, while his son, Edgar, continued with the reorganized company and remained through Victor's acquisition by RCA in 1929, leaving the recording industry in 1930.



The Berliner Gram-O-Phone of Canada building, after being converted to RCA Victor many years later.

The British side:

hmv

In 1899, The Gramophone Company in London purchased the original painting from Barraud. They filed for the rights within Britain themselves and never lost ownership. In 1921, The Gramophone Company started a retail chain that sold gramophones, radios, and other retail items. It named the stores after the painting, "His Master's Voice," and later changed it to simply "hmv." The retail chain is still in operation today, with locations in several markets, including Britain, Canada, Ireland, and the Netherlands. The HMV store brand



His Master's Voice after the artist painted over the graphophone with a gramophone.

was split off for Japan, where it is branded “HMV & Books.” Even though there are HMV stores all around the globe, they only hold the rights to the “His Master’s Voice” trademark in Britain.

The German side:

Deutsche Grammophon

Deutsche Grammophon (Sometimes called Deutsche Grammophon Gesellschaft or DGG) was founded in 1898 by Berliner and his brother (sometimes listed as nephew) Joseph Berliner (sometimes listed as Joseph Sanders, but that is a different person). They went to Hanover, Germany, to start the

company in Berliner’s hometown. In 1900, Deutsche Grammophon reorganized in order to sell stock in the company. The Gramophone Company in London bought a controlling stake in the company. Berliner’s American company kept 40% ownership, but it does seem that the company primarily worked with its British stakeholders.

The German company is especially noteworthy because Berliner used it as a jumping-off point in developing mass-production methods for both the discs and the players themselves.

Electrola

During the First World War, the Gramophone Company and

Berliner’s company had to sever ties with the German company altogether. After the war, in 1925, The Gramophone Company in Britain created a new company named “Electrola” to compete with Deutsche Grammophon within Germany. Electrola did not have the right to “His Master’s Voice” in Germany at first, but in 1949, Deutsche Grammophon split into a couple of record labels and sold Electrola a perpetual exclusive license, as the new management no longer wanted it.

Electrola was later absorbed into the EMI sell-off to Universal Music Group, which owns the rights to “His Master’s Voice” in Germany.

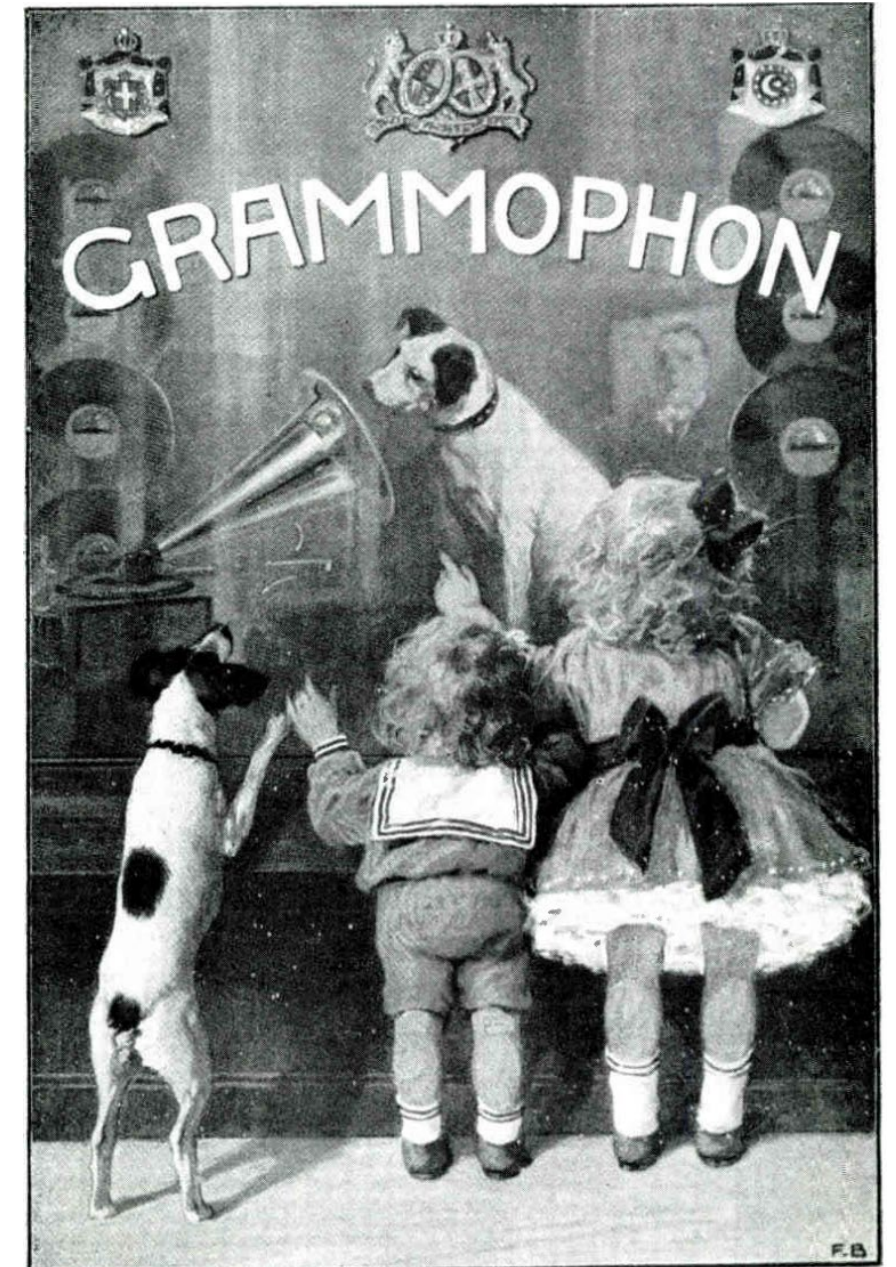
The Japanese side:

Victor Talking Machine Company of Japan, Ltd.

In 1927, to break into the Japanese market, the Victor Talking Machine Company established the Victor Talking Machine Company of Japan, Ltd., as a subsidiary of the American-owned company. In 1938, ahead of the beginning of World War II, RCA-Victor sold the Japanese business due to strained business relations between Japan and the US. When this happened, the business was rebranded to The Victor Company of Japan, Ltd. This company was able to retain the trademark rights from RCA-Victor, but only within Japan. The company was able to keep licenses and manufacturing rights within Japan while paying royalties to RCA.

Japan Victor Company (JVC)

After a couple of decades, the company started producing its own products, but it couldn’t export using the Victor brand because they only had the rights to the name within Japan. So, in the 1950s, the company started exporting radios and televisions all around the world under the brand “JVC”, short for “Japan Victor Company.” JVC was destined for greatness as they later developed the VHS tape and the VCR, competing with and defeating Sony’s inferior Betamax system. Today it has merged with Kenwood and is known as JVCKenwood.



A 1919 ad for Deutsche Grammophon



The first HMV store in 1921.

The HMV & Books stores in Japan are owned by a separate company, Lawson Entertainment. Even though the store is named after the painting, it does not hold any trademark rights to the painting itself, just the stylized letters.

The original painting

The original painting became part of the EMI Archive Trust’s collection, an organization established in 1996 to maintain EMI’s archival holdings. In



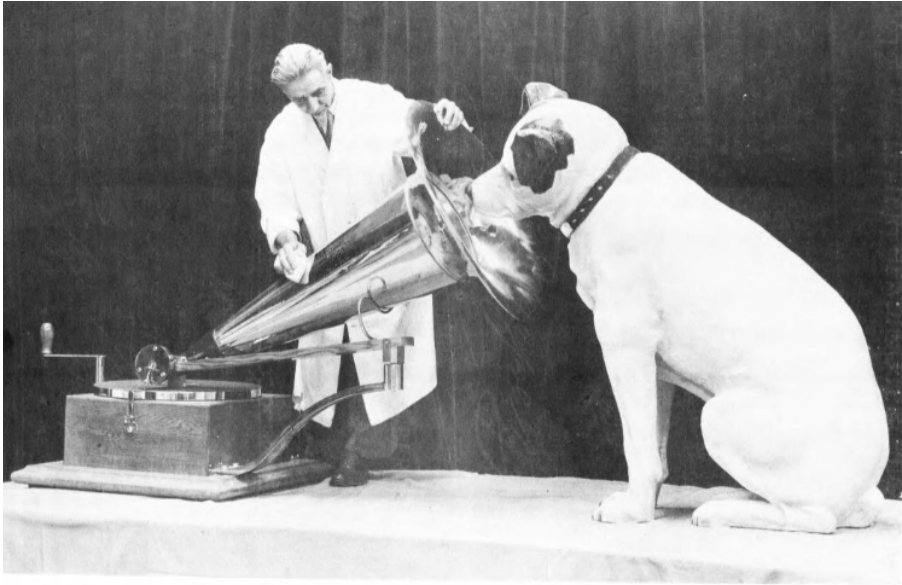
The later ‘oversized’ painting now on display at The Huguenot Museum in England.

November 2025, the Huguenot Museum in Rochester, Kent, England, purchased a “supersized” copy commissioned in 1937 from the EMI Archive Trust. Many news articles report that as being the original painting, but it is not. It seems the original is still in the EMI Archives.

When it was on display in EMI’s headquarters, it is said that the overpainted cylinder phonograph could still be seen beneath the gramophone image in the right light.

Gyro Motor Company (Washington DC)

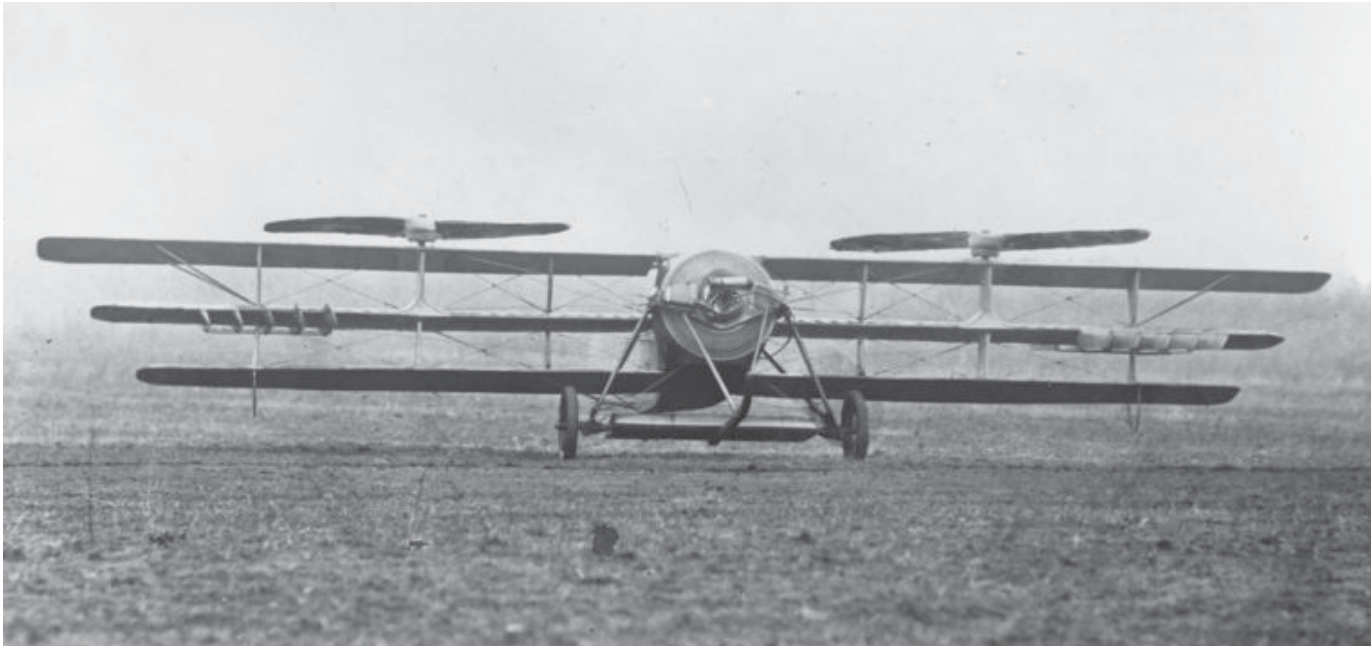
When Berliner exited his Canadian enterprise in 1924, he had



Thousands, if not more, paintings and models of Nipper the dog were made in all shapes and sizes.

already spent nearly two decades investigating lightweight engines and vertical flight. Beginning

around 1907, he began developing rotary aircraft engines, established the Gyro Motor Company in 1909,



Henry Berliner spent much of his life developing aircraft, and many were considered the best of their time.

and experimented with helicopters. His son Henry eventually joined the work, helping transform his father’s tethered lifting machines into increasingly controllable aircraft. Their 1924 helicopter represented some of the best progress made by an American vertical-flight project before Igor Sikorsky’s experiments fifteen years later. The building that Berliner used as his ‘Helicopter Factory’ is now being used as residential “luxury” condos.

Legacy and lessons

By the final years of his life, Emile Berliner had largely stepped away from the recording industry, but he never stopped working. He continued to support public health

education, architectural acoustics, and the aircraft experiments carried forward by his son Henry. In a 1928 letter describing the funeral he wanted, Berliner asked for simplicity, music, assistance for poor mothers with babies, and burial near sunset. He died in Washington, D.C., on August 3, 1929, at the age of seventy-eight.

The microphone and the gramophone grew from the same way of thinking of sound as a mechanical trait of air. In the transmitter, the weak movement of a voice through the air controlled a stronger current supplied from elsewhere. In the gramophone, one recording of a performance was capable of producing

thousands of copies. Berliner repeatedly moved the burden away from the original event and placed it in the home of the user.

The next time a design needs a microphone, DigiKey carries a broad selection of modern [microphone elements](#), including electret-condenser and MEMS devices, with options for different sensitivities, frequency ranges, output formats, directional patterns, and package sizes. The carbon granules and large diaphragms have disappeared from most new designs, but the engineering problem Berliner helped solve, turning a fragile sound into a useful electrical signal, remains.

Suggested reading

[“The Talking Machine: The Advertising History of the Berliner Gramophone and Victor Talking Machine”](#) by James N Weber

[“The Story of Nipper and the His Master’s Voice Picture Painted by Francis Barraud”](#) by Leonard Petts

[“Thomas Edison at Menlo Park”](#) by ETHW

[Playlist of Speeches and Interviews given by Oliver Berliner \(Grandson\)](#) by Phonoguy

[The Talking Machine Review #23](#)

[“Graphophone at the London Museum”](#)

[“Graphophone, Type C”](#) at The Smithsonian

[“Museum 'delighted' to get iconic Nipper painting”](#) by the BBC

[Nipper and His Master’s Voice](#) at the Huguenot Museum

[“Nipper and His Master’s Voice – A Little History”](#) by EMI Archive Trust

[“Recording Pioneers- Part 7, William Barry Owen”](#) by Sound of the Hound

[“Meet Edison’s Tinfoil Phonograph from 1877”](#) by The National Museum of American History

[“Edison’s Impression: Laying Sound into a Groove”](#) by Technology Connections

[“Emile Berliner's Fix: Flatten the Cylinder to a Disc”](#) by Technology Connections

[“United States v. American Bell Telephone Company, US Supreme Court 167 US 224”](#) on Justia

[“The Birth of Disc Recording”](#) by Oliver Berliner for MIX Magazine, August 1987 (Pages 29, 30)

[“Father of the Gramophone”](#) by Audrey Fischer for the Library of Congress



Understanding the cause and impact of VCR and how to mitigate it

By Art Pini

Many designers are unaware that resistors have a voltage coefficient of resistance (VCR) as well as a temperature coefficient of resistance (TCR). That is understandable because in low-voltage and low-resistance applications, the voltage effects are minor and well masked by the temperature effects. However, in circuits that use high resistances and/or high voltages (HVs), resistance variability with voltage can be a big concern. These circuits are used in applications such as HV power supplies, transimpedance amplifiers (TIAs), HV LED lighting, and pulsed communications systems.

Designers of such circuits need to understand the cause and impact of VCR and how to mitigate it.

This article provides an overview of VCR and its impact on circuit designs. It then uses examples of low-VCR resistors from [Stackpole](#) to illustrate how to select and apply such devices to minimize the effects of VCR in support of accurate and reliable operation of critical circuits.

What is VCR?

The VCR of a resistor can be defined as the change in resistance value proportional to an applied voltage. It is generally measured

in units of parts per million per volt (ppm/V) and can be calculated using the equation:

$$VCR = 106 \times (R_2 - R_1) / (R_1 \times (V_2 - V_1))$$

Where:

R_1 is the resistance value, in ohms (Ω), at a reference voltage (V_1)

R_2 is the resistance value, in Ω , at the test voltage (V_2)

V_1 is the reference voltage

V_2 is the test voltage

The VCR can be positive or negative. A positive VCR indicates that the resistance will increase with increasing voltage

across the resistor, while a negative VCR indicates that the resistance will decrease.

Typical HV chip resistors with a VCR of 200 ppm/V to 300 ppm/V will show a 20% to 30% change in resistance for a change in applied voltage of 1,000 V. Choosing a resistor with a VCR of 25 ppm/V to 50 ppm/V reduces the change in resistance to 2.5 to 5% for the same 1,000 V change.

The standard testing method for measuring VCR follows MIL-STD-202G Method 309. This standard establishes uniform methods for testing electronic components, specifying the standard test voltage equal to the maximum specified working voltage, and the reference voltage level of 10% of the maximum working voltage.

How to minimize VCR

VCR can be minimized by appropriate design and material selection. There is an engineering tradeoff required in the choice of resistive materials here because low-VCR resistive materials can improve VCR but can also increase TCR, reducing temperature stability. The selection of lower resistance inks will also improve VCR but limit the maximum resistance achievable. Careful selection of the type of resistive ink and the application method can optimize VCR.

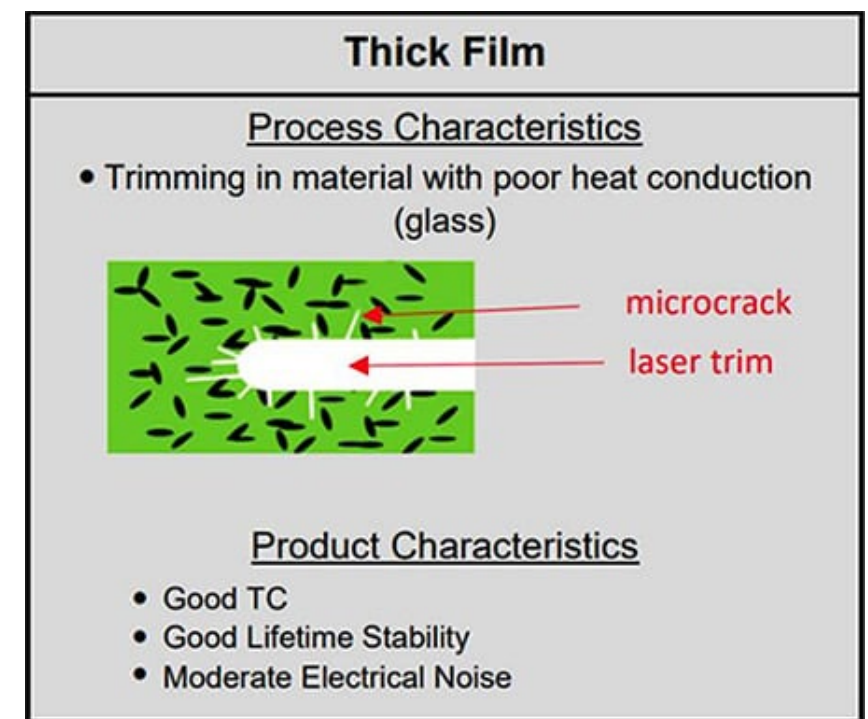


Figure 1: The physical effects of laser trimming thick-film chip resistors can degrade VCR. (Image source: Stackpole Electronics Inc.)

Laser trimming can also have an impact on VCR. Untrimmed resistors typically yield resistance values within 5 to 20% of the intended value. Laser trimming is used to adjust resistance values to within a smaller tolerance, for instance, within 1%. The laser trimming process can degrade VCR by generating microcracks that result in local, unintended impedance changes, which increase VCR (Figure 1).

Minimizing the use of laser trimming reduces these effects, as does the selection of the laser trimming geometry and the size of the package. In general, larger packages offer reduced VCR.

Applications for low-VCR resistors

Low-VCR chip resistors find applications in LED lighting, medical devices, audio-visual equipment, and communications systems that require HVs and/or high resistance values. A good circuit example is a TIA (Figure 2). This amplifier takes a current input and outputs a proportional voltage.

The output voltage of a TIA is equal to the product of the input current and the feedback resistor, R_f .

A common usage of the TIA is to interface with photodiodes, accelerometers, photomultiplier

tubes, and similar sensors where the sensor current response is more linear than its voltage response. Generally, these applications require high gain, which in turn means a high-value feedback resistor. Since the input end of the resistor is held at ground, the resistor sees the full output swing. In a great many cases, the input signal may be pulsed, as in electromagnetic interference (EMI) or mechanical shock testing, resulting in large voltage swings across the resistor.

A change in the resistor value related to the voltage across the resistor will result in the amplifier gain being modulated. This modulation adds a squared term to the voltage output. The squared term increases the second and other even harmonic terms in the output, causing linearity and harmonic distortion issues. The amount of resistance variation does not have to be great to produce significant distortion levels.

Another application where low-VCR resistors are used is in voltage dividers (Figure 3), which are used to reduce a voltage level.

The voltage divider is used for applications such as sensing the output of an HV power supply and feeding that back to the power controller. It might also be used as an attenuator to reduce an HV signal, such as an EMI pulse or a

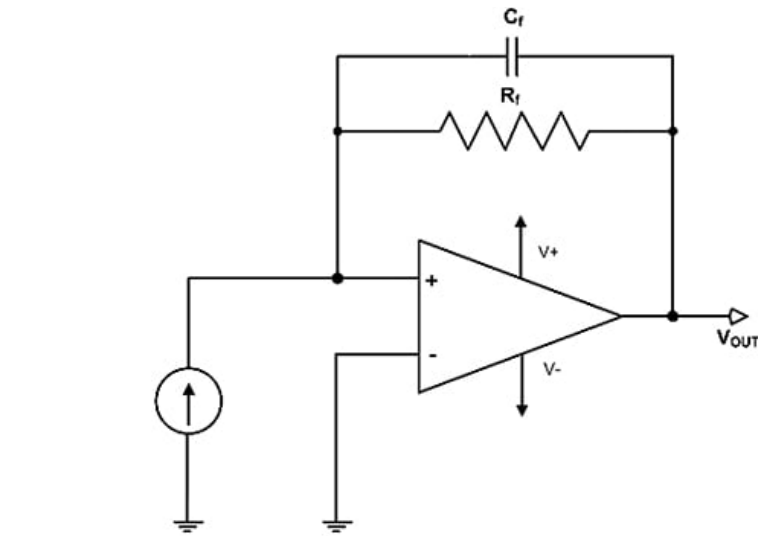


Figure 2: A TIA converts a current input into a voltage output proportional to the feedback resistor value. (Image source: Art Pini)

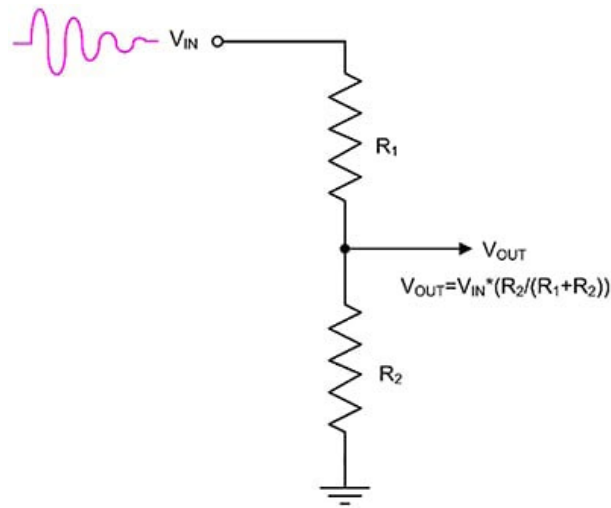


Figure 3: Low-VCR resistors are used in voltage divider circuits; these reduce the voltage level of a signal and are typically used for feeding back a high voltage to a device with a lower voltage-input rating. (Image source: Art Pini)

lightning strike, to a safe level for a measuring instrument.

In almost all applications, the upper resistor, R_1 , has a much higher value than that of the

lower resistor, R_2 , and has the higher voltage across it. A low-VCR resistor is required for applications where the input signal varies, as in measuring an EMI pulse. The VCR causes the divider

output attenuation to vary with the input voltage level, causing an error in the attenuation.

Assuming the input is a 1,000 V peak damped sine EMI pulse, if R_2 is 1000 Ω , R_1 is 1 megaohm (M Ω), and they are ideal resistors, the output is a damped sine with a peak amplitude of 0.999 V. If, however, R_1 has a VCR of -200 ppm/V, then with an input voltage of 1,000 V, the resistance will decrease by 200 kilohms (k Ω). The attenuation of the voltage divider will be reduced, and the peak amplitude of the output will be 1.25 V. As the input voltage varies, the varying attenuation will distort the output waveform.

When dealing with high resistor values and HVs, it is essential to consider the VCR.

Examples of HV, low-VCR chip resistors

The Stackpole [RVCU](#) series of HV, low-VCR chip resistors provides exceptional voltage stability over voltage ranges of 800 V to 3,000 V, depending on the package size. The series offers resistors with resistance tolerances of 0.5% to 5% over a range of 75 k Ω to 30 M Ω . They all have a VCR of ± 25 ppm/V for resistor values below 3 M Ω and 50 ppm/V for values greater than 3 M Ω to 30 M Ω . The TCR is common across all packages at 100 ppm/ $^{\circ}$ C.

They are AEC-Q200 compliant for automotive applications, as well as anti-sulfur ASTM-B-809 tested.

The RVCU family contains resistors in 1206 (3216 metric), 2010 (5025 metric), and 2512 (6332 metric) surface-mount packages (Figure 4).

The package model number encodes the length and width dimensions. The first two numbers represent the package length, the last two represent the width. The US dimensions are in hundredths of an inch (in.), to the nearest integer value. The metric dimensions are tenths of a millimeter (mm). All three packages have a standard height of 0.022 in. (0.55 mm). The maximum working voltage specification varies with the package size.

The Stackpole [RVCU1206FT1M00](#), for example, is a 0.33 watt, 1 M Ω , 1% thick-film resistor in a 1206 surface-mount package. It has a maximum working voltage rating of 800 V with a maximum overload voltage limit of 1,000 V.

For slightly higher power levels, the [RVCU2010FT1M00](#) is a 0.5 W, 1 M Ω thick-film resistor in a 2010 surface-mount package. This resistor has a tolerance of 1%, a maximum working voltage of 2,000 V, and a maximum overload rating of 3,000 V.

The Stackpole [RVCU2512FT1M00](#) is a 1 M Ω , $\pm 1\%$ thick-film chip resistor with a power rating of 1 W.

It comes in a 2512 surface-mount package. The working voltage of this device is higher than the RVCU2010FT1M00 at 3,000 V, with an overload-voltage rating of 4,000 V.

Conclusion

HV and high-resistance circuits need resistors with a low VCR for accuracy and stability. The Stackpole RVCU series chip resistors provide a low VCR of 25 ppm/V to 50 ppm/V and are designed to offer exceptional stability at voltages from 800 V to 3000 V.

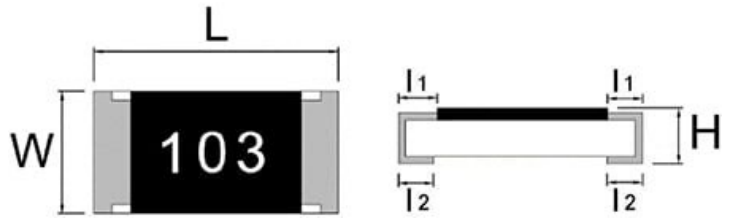


Figure 4: Shown are the mechanical dimension callouts of the RVCU series of surface-mount chip resistors. (Image source: Stackpole Electronics Inc.)

Capacitor deep dive: circuit protection, filtering, and energy storage

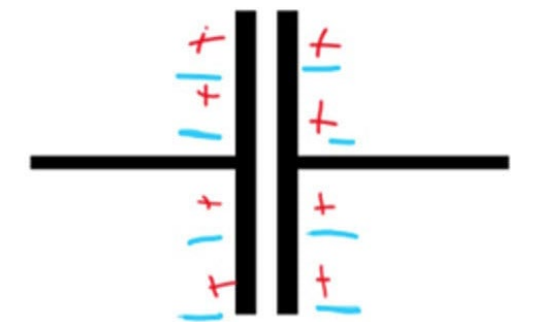
By Will Siffer

When it comes to circuit design, it's easy to forget to add capacitors when you are just trying to build a simple circuit. The truth is, until just a few years ago, I never really added capacitors to my projects because I wasn't sure I even needed them. Eventually, I took some classes in school, and I was given some real examples of when to use capacitors and how they worked. From circuit protection to filtering and from energy storage to sensing, I'm diving into the simply complex world of capacitors.

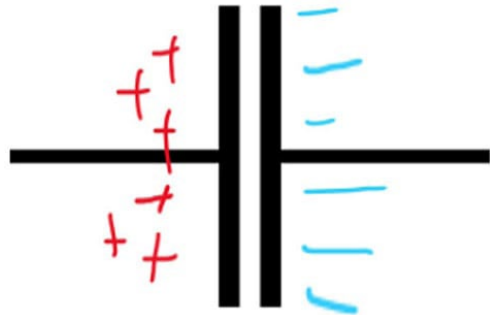
How do these things even work?

The truth is, that all that makes up a capacitor is two conductors separated by an insulator. You can actually even make one yourself, setting two wires next to each other in parallel with an insulator in between will even make a (pretty weak) capacitor. But how does it work? If the two sides are separated by an insulator, then how come current can flow through it?

The answer lies in what is called the "electric field." Imagine a capacitor at rest with no power going to either end. Each conductor would have the same charges in balance, and there would be no flow between or away from the plates.



This capacitor is at rest and has no effective energy storage. The magic happens when you connect it to a battery. Imagine now we take the same capacitor and connect the left side to positive and the right side to ground. Now there's a **voltage potential** across the plates, and since the plates are so close together, they actually have an effect on each other.



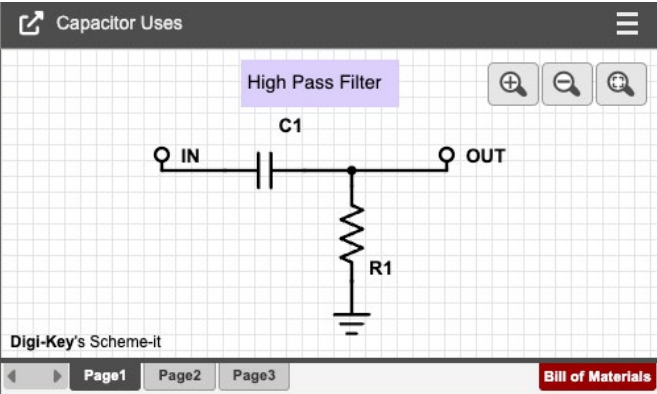
Notice now what has happened? The battery acted as a pump and pushed all of the electrons from one side of the capacitor to the other. For a short while, this happened quickly at first as there were more electrons to move but then slowed down as the capacitor “charged” and the plates each were carrying their own unique charge. When using a DC battery this can only happen one time until the capacitor is given a chance to return to equilibrium, a very important fact to remember when I talk about applications later in this blog.

When you remove the battery from the capacitor each plate will still carry the charge from before, waiting to be discharged and returned to a more stable equilibrium state. If you shorted the two leads together the capacitor would act the same way as it did when it charged but in reverse, quickly returning to a steady state and slowing as fewer charges had to make their way to their respective sides.

This is cool and all, but basically, all we did is show how a capacitor acts sort of like a battery that can be charged and discharged very quickly. This is pretty much only useful in applications where short bursts of high energy are required, such as disposable camera flashes and electric firework ignitors. What about some of their other less obvious applications?

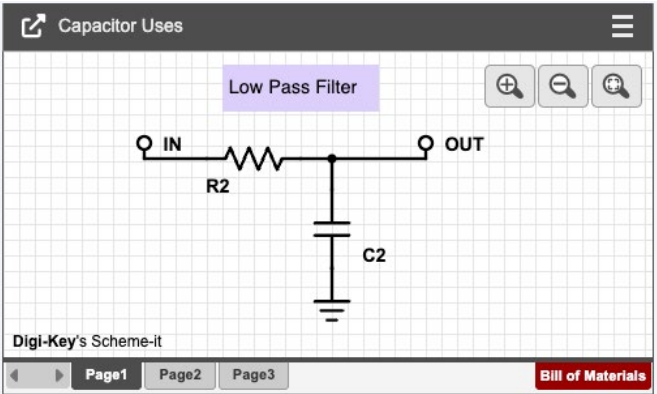
AC applications: filtering

The same principles I just mentioned above can be applied to the rest of these applications, but in this case, we are going to talk about filtering frequencies. Consider a low frequency signal; as the frequency gets lower and lower the signal eventually appears to be a simple DC source. As we discovered above, the capacitor will not let DC sources through so if we want to block a low frequency, we can simply add a capacitor to the input of our device and the capacitor will only allow the high frequency parts of the signal through. This is called a High Pass Filter



High Pass Filter Example

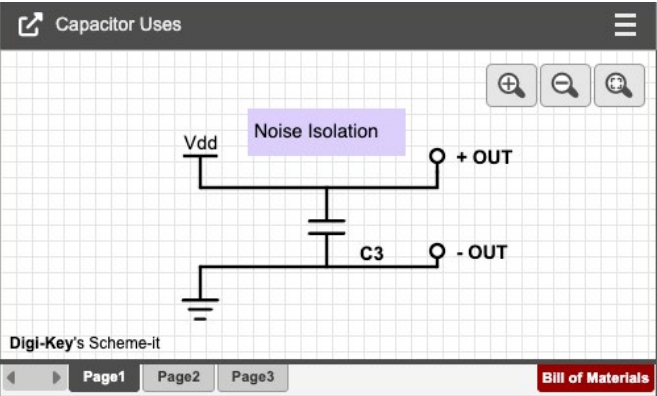
What if, instead we only wanted to let low frequencies through? Well, all we would have to do is switch the order of the capacitor and resistor and the high-frequency part of the signal would be shorted to ground while the low frequencies could “float” across the capacitor to the output. This is called a Low Pass Filter.



Low Pass Filter Example

AC application 2: noise filtering

Now imagine you took the same idea as the low pass filter but simply connected your power supply and ground together with a capacitor. At first, the capacitor would act like a short circuit, but quickly it would charge, and it would only allow the DC aspect of your supply to continue while shorting to ground any high-frequency noise. This is why in many circuits with integrated circuits (IC's) it is recommended to put a capacitor across the power and ground pins somewhere physically close to the chip. This allows for the least amount of noise to make it to the IC and affect its function.



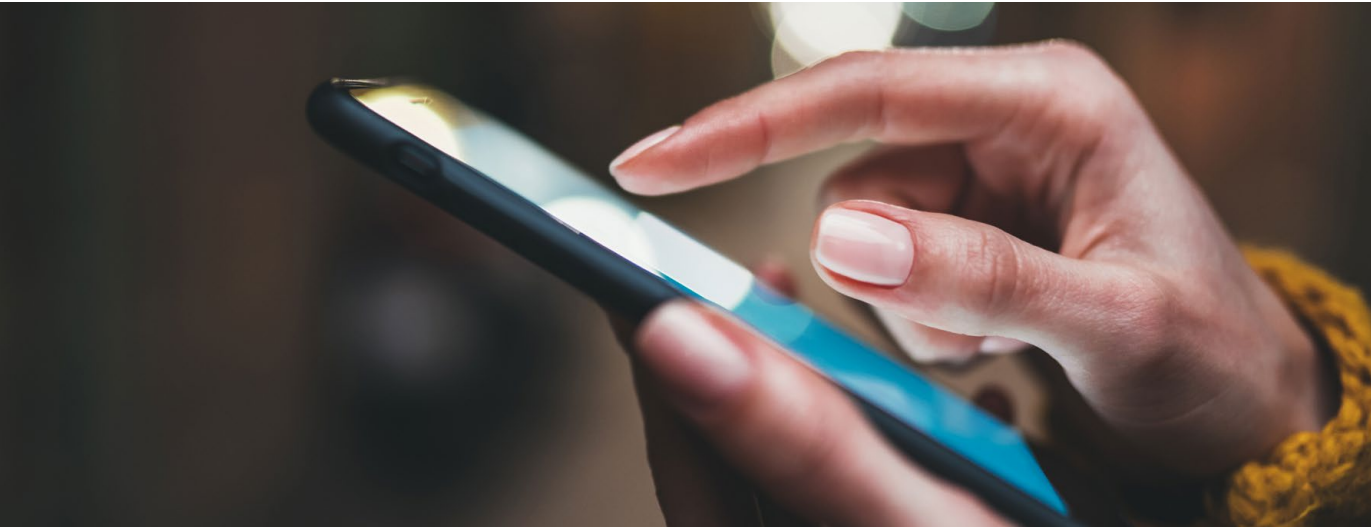
Bonus application: sensing

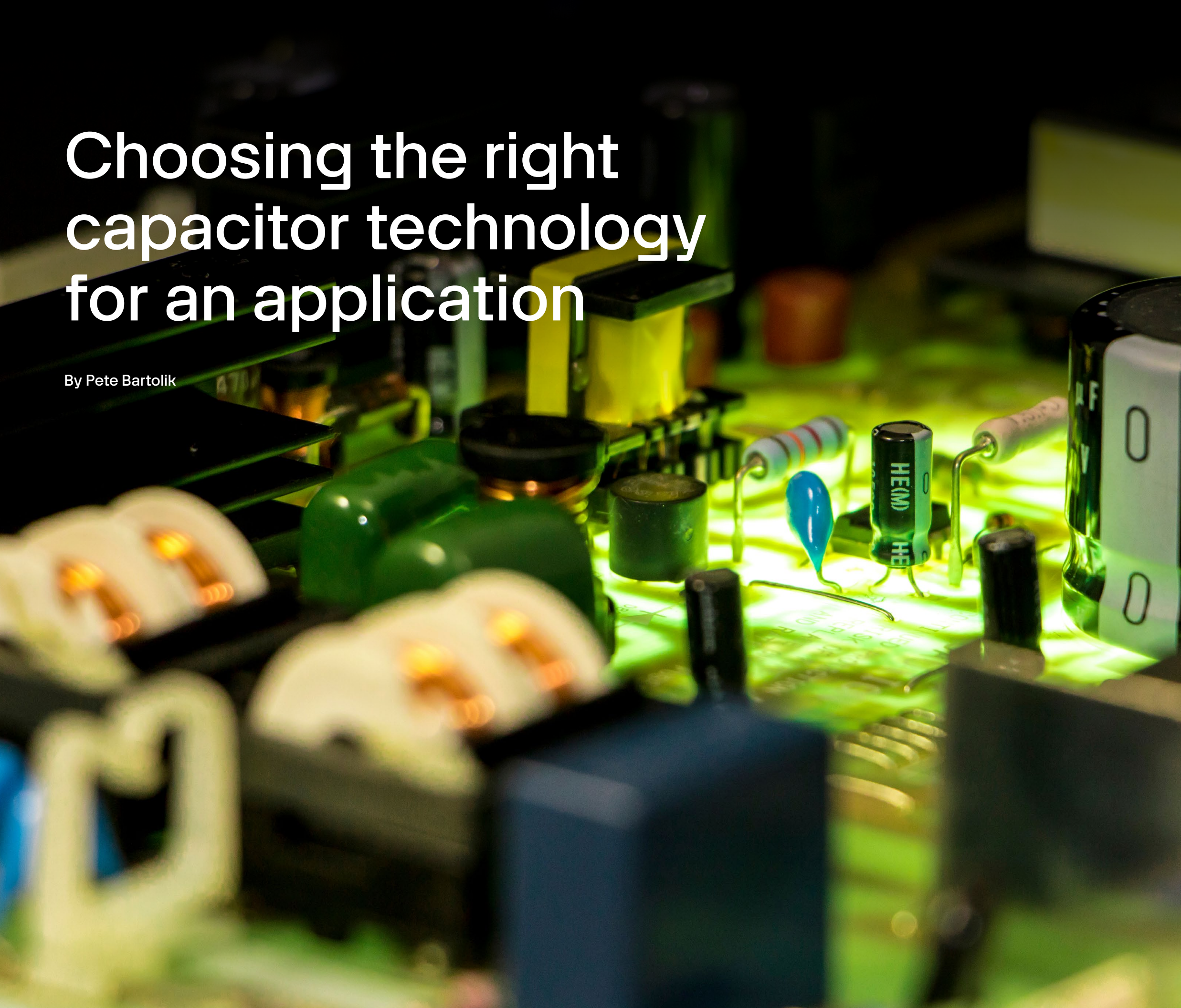
The final application I want to discuss here is the ability of a device to use capacitance as a sensor. Imagine your phone screen, or just take a moment to look at it now, maybe you are reading this blog and scrolling with the touch screen. Built inside of your phone screen there is a large conductor that is connected at each corner with resistors to a sensing circuit. On top of that layer is the LCD and eventually the glass surface. Your finger is conductive, and your body makes up a path to ground. When you touch the screen, the sensing circuit senses a change in capacitance of the large conducting area, and the circuit can use the four connection points to the layer to determine where on the screen your finger must be based on how current flows through each location.

Wrap up

This is by no means a complete list or education on how a capacitor works, but I hope this guide offered some insight into the “why” of this component for when you build your next project. I find that sometimes the why can be just as important, if not more important, than the technical aspects of how to use something.

Until next time, my name is Will, and I hope you learned something new today.





Choosing the right capacitor technology for an application

By Pete Bartolik

Choosing the right capacitor for an application can make a significant difference in the performance, reliability, and efficiency of products such as power supplies for defense, aerospace, medical technology, critical energy infrastructure, or fast EV chargers.

Capacitors are essential components in many electronic circuits as they store and release electrical energy, filter out unwanted signals, and perform other functions. However, not all capacitors are created equal, and different types of capacitors have varying characteristics, advantages, and limitations.

Selecting the right capacitor type is crucial in product design. Three common options—multilayer ceramic capacitors (MLCCs), film, or aluminum electrolytic—offer advantages and disadvantages, and there are myriad variations within each category. Choosing the right type ensures the final product has enough energy storage, fits in the available space, and functions reliably for its intended use.

The case for MLCCs

MLCCs consist of alternating layers of ceramic dielectric and metal electrodes stacked and sintered together to form a compact package. Widely used in many electronic devices, MLCCs provide high capacitance values in small sizes, low equivalent series resistance (ESR), low leakage current, high frequency response, and good temperature stability.

MLCCs are suitable for applications that require high power density, high efficiency, low noise, and high reliability. However, there are variations among this category that can make a difference in developing successful products:

- **High Reliability MLCCs:** Offer high reliability, low failure rate, long life, and high performance under harsh conditions. These characteristics are important in meeting stringent requirements of industries such as aerospace and defense, including specifications under MIL-PRF-55681, MIL-PRF-123, MIL-PRF-49470, and MIL-PRF-39014, as well as medical applications.
- **High Voltage MLCCs:** Operate at voltages above 500 V and up to 12 kV. They are designed for applications that require high voltage isolation, such as power supplies, pulse generators, and X-ray equipment. They feature high capacitance, low ESR, low dissipation factor, and high breakdown voltage.
- **High Temperature MLCCs:** Operate at temperatures above +125°C, up to +250°C. They are designed for applications that require high temperature stability, such as down-hole drilling, automotive, and

industrial. They provide high capacitance, low ESR, low temperature coefficient, and high thermal shock resistance.

Advantages of film capacitors

Film capacitors are suitable for applications that require high power, high current, high voltage, and high frequency, such as power conversion, filtering, snubbing, and coupling. These capacitors consist of a thin film of dielectric material—such as polyester, polypropylene, polycarbonate, or polyphenylene sulfide—sandwiched between two metal electrodes, either wound into a cylindrical shape or stacked into a flat shape.

Film capacitors are often larger and more expensive than MLCCs, but they provide high capacitance values, high voltage ratings, low ESR, low dissipation factor, high frequency response, and long life. Advantages of this technology include higher voltage ratings, linear capacitance change with voltage and temperature, no piezoelectric noise, self-healing capability, and long life.

There are several categories of film capacitors that can impact which is right for an application:

- **Metallized polyester film capacitors** use a thin layer of metal, such as aluminum or

zinc, deposited on the polyester film as the electrodes. They offer high capacitance, low ESR, low cost, and good self-healing properties. They meet the needs of general-purpose applications such as bypass, coupling, and decoupling.

- **Metallized polypropylene film capacitors** utilize polypropylene film as the electrodes with a thin layer of metal, such as aluminum or zinc. They are characterized by high capacitance, low ESR, low dissipation factor, high frequency response, and high stability. They are suitable for high performance applications, such as power factor correction, filtering, and snubbing.
- **Polycarbonate film capacitors** use a polycarbonate film as the dielectric material. They offer high capacitance, high voltage rating, low temperature coefficient, and high reliability. These are appropriate for applications that require high temperature stability, such as timing, sensing, and precision circuits.

- **Polyphenylene sulfide film capacitors** use polyphenylene sulfide film as the dielectric material. They offer high capacitance, high temperature rating, low ESR, low dissipation factor, and

high frequency response. Suitable applications include those that require high temperature performance, such as automotive, industrial, and telecom.

- **Metallized paper film capacitors** rely on metallized paper film as the dielectric material. They offer high capacitance, high voltage rating, low ESR, low dissipation factor, and high self-healing properties. They are suitable for applications that require high voltage isolation, such as power supplies, pulse generators, and X-ray equipment.

Aluminum electrolytic capacitors

Aluminum electrolytic capacitors are suitable for applications that require high capacitance, high voltage, and low frequency, such as smoothing, filtering, and energy storage.

With the ability to store large amounts of electrical energy for its size, an aluminum electrolytic capacitor is applicable for smoothing power supplies in electronic devices. They may have a shorter lifespan than MLCCs and film alternatives, and because they are polarized with a positive and a negative

terminal, can be damaged if installed backwards. They also may continuously leak a small amount of current and are not as stable at high frequencies compared to alternatives.

Aluminum electrolytic capacitors are available in various electrolyte types, such as liquid, solid, or hybrid, which have different performance, stability, and reliability characteristics:

- **Liquid aluminum electrolytic capacitors** use a liquid electrolyte solution as the cathode. They offer high capacitance, high voltage rating, and low cost. However, they also have high ESR, high leakage current, high dissipation factor, and limited life. They are suitable for general purpose applications, such as smoothing, filtering, and energy storage.
- **Solid aluminum electrolyte capacitors** have a solid electrolyte material — such as manganese dioxide or conductive polymer — for the cathode. They offer low ESR, low leakage current, low dissipation factor, and long life. However, they also have lower capacitance, lower voltage rating, and higher cost than liquid electrolyte capacitors. They are suitable for high performance

applications, such as switching power supplies, LED drivers, and audio amplifiers.

- **Hybrid aluminum electrolytic capacitors** use a combination of liquid and solid electrolytes as the cathode. They offer a balance of capacitance, voltage rating, ESR, leakage current, dissipation factor, and life. They are suitable for applications that require high power density, high reliability, and high temperature performance, such as automotive, industrial, and telecom.

Supplier acquisition broadens capacitor portfolio

[Knowles](#) and [Cornell Dubilier Electronics](#) (CDE) are two leading manufacturers of capacitors, offering a wide range of capacitor technologies and products. Knowles acquired CDE in 2023, combining complementary strengths of both companies, including CDE's film capacitors and aluminum electrolytic capacitors, and Knowles Precision Devices' film and MLCCs.

Knowles offers a comprehensive portfolio of MLCCs in standard surface mount packages and ribbon or radial lead packages, ranging from under a picofarad to hundreds of microfarads,

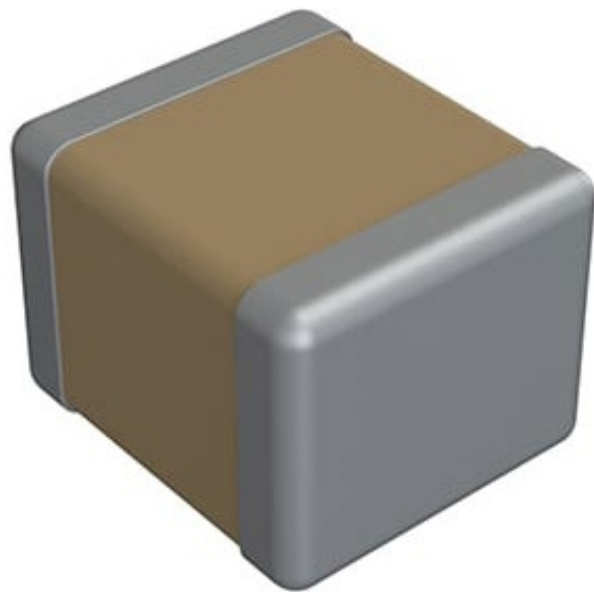


Figure 1: A representation of the Knowles Syfer 2220Y5000564KXT. (Image source: Knowles)

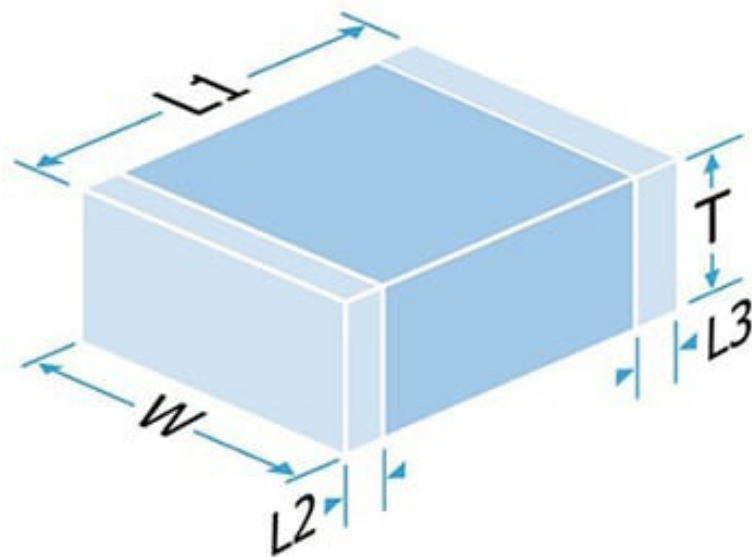


Figure 2: Illustration of StackiCap packaging for Knowles Sifer 2220Y6300105KETWS2 and similar MLCCs. (Image source: Knowles)

with ratings from 6.3 V to 12 kV. Knowles MLCCs are available in various dielectric materials with different temperature coefficients, dielectric constants, and aging rates.

Knowles' FlexiCap™ manufacturing approach utilizes a proprietary flexible epoxy polymer termination material applied under the usual nickel barrier finish that accommodates a greater degree of board bending than conventional capacitors. Its StackiCap™ range provides significant reduction in PCB real estate for an equivalent capacitance value in cases where board space is at a premium; for example, a standard 150 nanofarads (nF) chip in an 8060 case size is available in a much smaller 3640 case size.

The Knowles Syfer [2220Y5000564KXT](#) (Figure 1) is a FlexiCap surface mount MLCC that can store 0.56 microfarads (μF) of electrical charge—with a tolerance of $\pm 10\%$ —and is designed to handle up to 500 V. It is one part of a product family of DC rated MLCCs that range from 0.2 picofarads (pF) to 22 μF and in case sizes from 0402 to 8060.

The Knowles Syfer [2220Y6300105KETWS2](#) (Figure 2) is a StackiCap MLCC that can store 1 μF of electrical charge, with a tolerance of $\pm 10\%$, and is rated for 630 V.

Knowles CDE offers a wide selection of standard and custom screw terminal, snap-in, and board mount capacitors for use in critical applications, ranging from defibrillators and medical imaging, to radar systems and UPS power backup for large data systems.

CDE's [477XMPL002MG19R](#) is part of the XMPL polymer chip capacitor series for applications requiring higher voltage and/or capacitance requirements. With low ESR and

robust ripple current ratings, they outperform surface mount electrolytics of greater size and provide longer life, greater stability with temperature changes, and lower ESR at higher frequencies. Standard capacitance values of the series now range from 6.8 μF to 470 μF , with a maximum working voltage of 35 VDC in a molded package measuring 7.3 mm x 4.3 mm x 1.9 mm.

Conclusion

Capacitors are vital electronic components, and selecting the right one is crucial in product design. Fortunately, Knowles and Cornell Dubilier Electronics provide access to a vast selection of common types with multiple variations, as well as special types designed for specific applications.



This month in history

1861

October 24

First transcontinental telegraph completed

The first transcontinental telegraph line in the United States was completed when eastern and western sections were joined between Nebraska and Utah. Messages that had required days or weeks could now cross long distances in minutes. The line strengthened national communications and quickly made the horseback Pony Express economically obsolete.



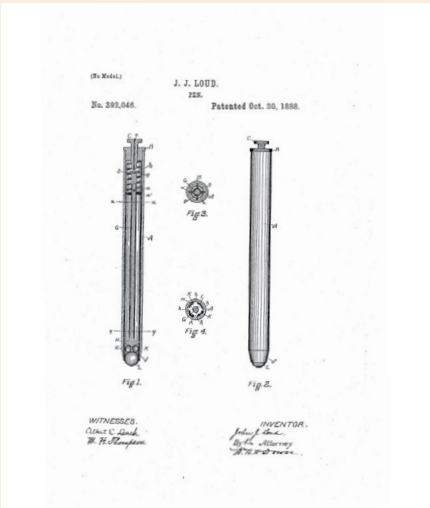
The first pole of the transcontinental telegraph was placed in July of 1861, and, miraculously, it was completed just a few months later with two thousand miles of single-strand wire and more than twenty-seven thousand poles.

1888

October 30

John Loud receives ball-tipped pen patent

John J. Loud received United States Patent No. 392,046 for a pen using a rotating ball at its tip. He intended the instrument to mark rough materials such as leather and wood rather than ordinary writing paper. The design did not become a mass-market product, but it established an early patented form of the ball-point principle.



John Loud had set out to make a tool to write on leather, which then-common fountain pens could not, and developed the ball-point pen to do so.

1949

October 21

An Wang files core-memory patent

Computer engineer An Wang filed a patent application for a magnetic pulse-transfer device related to ferrite-core memory. Magnetic cores could retain binary states without continuous power and could be selected through intersecting wires. Core memory became the dominant form of main computer memory from the 1950s into the early 1970s.



An Wang, cofounder of Wang Laboratories, held thirty-five patents connected to computer technology.

1954

October 18

First commercial transistor radio announced

Texas Instruments and Industrial Development Engineering Associates (IDEA) announced the Regency TR-1 pocket radio. The set used four germanium transistors and operated from a compact battery, eliminating the warm-up time and fragility of vacuum tubes.



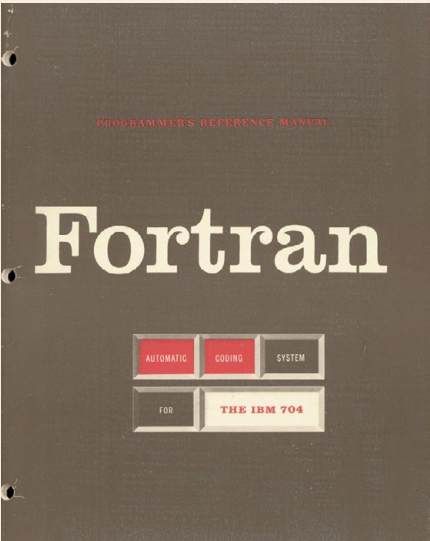
The TR-1 went on sale in November and became the first commercially produced transistor radio.

1956

October 15

First FORTRAN reference manual released

IBM released the first reference manual for FORTRAN, the Formula Translating System being developed for the IBM 704 computer. The language allowed scientists and engineers to express mathematical procedures in a more familiar form than machine code or assembly language.



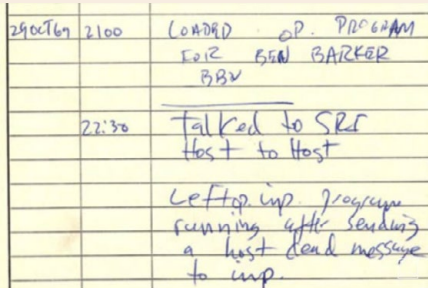
FORTRAN became one of the most durable programming languages in scientific and technical computing.

1969

October 29

First ARPANET message sent

UCLA programmer Charley Kline sent the first host-to-host message on the ARPANET to a computer at the Stanford Research Institute. The team attempted to type LOGIN, but the remote system crashed after receiving the letters L and O. The brief transmission demonstrated communication between the first two nodes of the packet-switched network that helped lead to the Internet.



Log entry noting the first 'host-to-host' electronic message.

We've got the new products your ideas deserve



We have over 400,000 new, name-brand products in stock and ready to ship—with more added daily. If you can design it, we can help you build it.

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