Solid-State Relays for Thermostat Design

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The Design Challenge

The relay is the most failure-prone component in a residential thermostat. Mechanical relays wear out, generate audible noise, produce electromagnetic interference (EMI), and consume valuable printed circuit board (PCB) area. For engineering teams designing the next generation of smart thermostats, these limitations directly impact product lifespan, certification timelines, and field failure rates.

Solid-state relays (SSRs) eliminate these problems at the component level. This article presents a detailed technical comparison between mechanical relays and SSRs, using the MP9566 as a reference, and quantifies the advantages relevant to thermostat hardware design.

Mechanical Relay Limitations in Thermostat Applications

Contact Wear and Limited Lifespan

Mechanical relay contacts degrade with every switching cycle. Under a load, contact materials (typically silver alloy) experience friction, erosion, and increasing resistance. The rated electrical life is about 100,000 cycles under a load. A thermostat cycling 50 times per day accumulates about 18,250 cycles per year, meaning the relay can reach end of life within 5 to 6 years, often before the rest of the product.

Arcing and Safety Risks

Electrical arcing is a type of electrical failure in which current leaves its intended conductive path and travels through air or another nonconductive medium. The contact of the mechanical relay generates electrical arcing during switching. Contact arcing during switching generates high temperatures that erode contact surfaces and produce broadband electromagnetic radiation. In gas appliance control and other safety-critical applications, arcing creates fire risks. Arcing also contributes to EMI that can disrupt sensitive circuits nearby.

Switching Speed

Mechanical relays have total switching cycle times between 15ms and 25ms, limited by the inertia of the moving parts. This precludes pulse-width modulation (PWM)-based power control and limits temperature regulation precision to about ±1°C due to overshoot from the slow response.

Size

A typical 5A/24V_{AC} mechanical relay measures about 20mmx15mmx15mm, and requires an additional coil drive circuit that consumes significant PCB area and limits product miniaturization.

Solid-Stay Relay Architecture

The MP9566 is a MOSFET-based SSR in a QFN-20 (3mmx5mmx0.9mm) package. This AC switch integrates three functional blocks into a single IC:

1. Digital control interface: I^{2}C (SCL/SDA) or a direct enable (EN) pin for microcontroller unit (MCU)-driven on/off control.
2. Capacitive isolation barrier: kV-rated galvanic isolation between the low-voltage digital side and the high-voltage AC side.
3. Integrated gate driver and power MOSFETs: Back-to-back MOSFET configuration with a 0.12Ω on resistance ($R_{DS(ON)}$) for AC load switching.

This integrated IC eliminates the need for discrete coil drivers, flyback diodes, and snubber circuits that mechanical relay designs require.

Key Specifications

Some basic parameters from the MP9566 datasheet underline the differences between SSRs and mechanical relays. Table 1 shows key SSR parameters and the design advantages compared to mechanical relays.

Table 1: Solid-State Relay Key Parameters

Parameter	Value	Design Impact
Quiescent current (I_Q)	8.5μA	Extends battery/backup power life
On resistance ($R_{DS(ON)}$)	0.12Ω (back-to-back MOSFETs)	0.12W power loss at 1A vs. 0.225W power loss for mechanical relay
Control current	8.5μA for AC drive	Uses fewer MCU input/output (I/O) pins
Turn-on time	<2.2ms (I^2C command to on state)	10x to 20x faster than a mechanical relay, enables PWM control
Switching frequency (f_{SW})	125kHz (8μs cycles)	Supports fine-grained power modulation
Package	QFN-20 (3mmx5mmx0.9mm)	~95% PCB area reduction vs. mechanical relay
Zero-current turn-off	Enabled (default)	Eliminates inductive load voltage spikes, reduces snubber complexity
Protection	Over-current protection (OCP), short-circuit protection (SCP), over-temperature protection (OTP)	Integrated fault handling reduces external component count
I^2C diagnostics	Load-wire detection	Enables system-level fault monitoring

Head-to-Head Comparison: Mechanical Relay vs. Solid-State Relay

Reliability and Lifespan

SSRs provide improved reliability with unlimited electric life (loaded) and mechanical life (unloaded). Table 2 shows a comparison of the reliability and lifespan between mechanical relays and SSRs.

Table 2: Reliability and Lifespan Comparison – Mechanical vs. Solid-State Relays

Metric	Mechanical Relay	Solid-State Relay
Electrical life (loaded)	~100,000 cycles	Unlimited (no contact erosion)
Mechanical life (unloaded)	~1,000,000 cycles	Unlimited (no moving parts)
Environmental sensitivity	Degrades with vibration, humidity, and dust	Fully sealed QFN; unaffected
Failure mode	Contact welding or permanent open	Protected shutdown (OCP/OTP)
Operating temperature range	-40°C to +70°C	-40°C to +125°C

For thermostat applications, this translates to maintenance-free operation across the full product lifecycle. Field replacement due to relay failure is effectively eliminated, reducing warranty costs and improving the mean time between failures (MTBF).

Switching Performance

SSRs provide faster response speed for the ms to µs transition during switching. Table 3 shows a comparison of the switching speed between mechanical relays and SSRs.

Table 3: Switching Speed Comparison – Mechanical vs. Solid-State Relays

Metric	Mechanical Relay	Solid-State Relay
Contact close time	10ms to 15ms	N/A (solid state)
Contact release time	5ms to 10ms	N/A (solid state)
Total switching latency	15ms to 25ms	<2.2ms (command to on), 8µs (PWM cycle)
PWM capability	Not feasible	Up to 125kHz

The fast-switching speed enables PWM-based power control, which produces smoother temperature curves, reduces equipment start-stop stress, and can improve temperature precision from ±1°C to ±0.1°C. This is particularly valuable for inverter-driven heat pumps and air conditioners that require rapid control signals.

Power Consumption

The mechanical relay has a contact and a coil, which have resistances and power loss. Mechanical relays' contact resistance is typically 50mΩ to 100mΩ, while the coil resistance is generally higher and ranges from 10Ω to kΩ. For a direct comparison at a 1A load current, the contact power loss can be calculated with Equation (1):

$$\text{Contact Power Loss} = \text{I}^2\text{R} \tag{1}$$

Where I is the 1A load current, and R is the 0.1Ω contact resistance.

This results in a contact power loss of 100mW. Based on the contact power loss, the mechanical relay's total power can be calculated with Equation (2):

$$\text{Total Power} = \text{Contact Power Loss } + \text{Coil Power} \tag{2}$$

Where the coil power is 50mW to 200mW.

This references a similar relay that can be replaced by the MP9566 with a typical 50mW to 200mW coil power. The coil power varies with different voltage rating/coil resistance combinations, resulting in a total power of 225mW (100mW + 125mW).

For the MP9566, if the contact on resistance is 0.12Ω at 1A load current, then the contact power loss is 120mW based on Equation (1). The IC does not have a real coil (coil power loss) compared to the mechanical relay, but still needs a power supply (VDD) for internal operation. The VDD power loss can be calculated with Equation (3):

$$\text{VDD Power Loss (no coil)} = \text{I x V} \tag{3}$$

Where I is the supply current, and V is the supply voltage.

During operation with a 3.3V supply, the VDD power loss is 1mW (with a 300µA supply current from the MP9566 datasheet) based on Equation (3).

The SSR's total power can be calculated with Equation (4):

$$\text{Total Power} = \text{Contact Power Loss} + \text{VDD Power Loss (no coil)} \tag{4}$$

This results in a total power of 121mW.

The SSR reduces relay-stage power dissipation by about 47%. In addition, the SSR completely eliminates coil holding power since there is no electromagnetic coil to energize. For battery-backed thermostat designs, the MP9566's 8.5µA quiescent current (I_Q) is critical for preserving backup power.

Acoustic Noise

Mechanical relays produce audible clicking for each switching event. At 50 cycles per day, this can be disruptive, particularly in bedroom and conference room installations. The SSR offers the advantage of operating in complete silence (0dB switching noise), addressing a common user complaint with acoustic noise.

Safety and Arc Suppression

SSRs switch with zero arcing. Its default zero-current turn-off feature detects the AC waveform zero crossing and opens the circuit at the minimum current. This eliminates inductive voltage spikes at turn-off. Mechanical relay designs require snubber circuits (typically an RC network) to suppress voltage spikes. Removing the snubber saves BOM cost and PCB space, and eliminates a potential failure point.

The absence of arcing also makes the SSRs suitable for gas application control and other environments where sparks pose ignition risk.

Electromagnetic Compatibility (EMC) Performance

Mechanical relays generate electromagnetic interference through three mechanisms:

1. Contact bounce: High-frequency noise from multiple impacts during closure
2. Arc radiation: Broadband EMI during opening
3. Coil transients: Voltage spikes during energization/de-energization

These mechanisms can cause microcontroller unit (MCU) resets, sensor reading errors, and wireless communication disruption in smart thermostats.

SSRs eliminate all three sources of disruption with internal transient suppression circuits that further reduce conducted emissions. For engineering teams working toward CISPR 32 or FCC Part 15 compliance, this can significantly reduce EMC design efforts and shorten certification timelines.

Board Space and Integration

SSRs have a significantly smaller solution size and require fewer external components. Table 4 shows a comparison of the size and external components between mechanical relays and SSRs.

Table 4: Size Comparison – Mechanical vs. Solid-State Relays

Metric	Mechanical Relay	Solid-State Relay (MP9566)
Package footprint	~20mmx15mm + coil driver circuit	QFN-20 (3mmx5mm)
Height	~15mm	0.9mm
External components	Coil driver, flyback diode, and snubber	Few decoupling capacitors
Reduced PCB area	-	~95%

The reduced PCB area allows the integration of additional features (e.g. Wi-Fi/Bluetooth modules, additional sensors, larger batteries) without increasing enclosure size. The 0.9mm height enables thinner product profiles, which is a key differentiator in the smart thermostat market.

Environmental Robustness

The MP9566 operates across a -40°C to +125°C temperature range, compared to the -40°C to +70°C range typical for mechanical relays. Its fully sealed QFN package is immune to failure modes that mechanical relays are susceptible to in real-world HVAC installations, such as dust, moisture, and vibration-induced contact chatter.

Application Case Study: Smart Thermostat Retrofit

A smart home original equipment manufacturer (OEM) replaced mechanical relays with MP9566-based designs across its thermostat product line. Table 5 shows the metrics that were measured before and after the transition.

Table 5: Smart Thermostat Retrofit with the MP9566

Metric	Before (Mechanical)	After (Solid State)	Improvement
Product thickness	15mm	5mm	70% reduction
Switching noise	~4dB	0dB	Silent operation
User complaint rate	3.2% (primarily noise)	0.5%	84% reduction
Expected relay lifespan	5 years	>10 years	>2x
Control capability	Simple on/off	I^2C digital + diagnostics	Smart control enabled

Additional cost benefits included simplified inventory management (one IC covers multiple relay configurations) and reduced after-sales support due to fewer field failures.

Conclusion

For thermostat relay technologies, solid-state relays (SSRs) offer a clear upgrade path with a longer product life, smaller footprint, faster switching, lower power, silent operation, and EMC compliance. This article explored a fully integrated design with the MP9566 that reduced external component count and design complexity while adding digital control and diagnostic capabilities.

For detailed specifications, application notes, and evaluation boards, visit the MPS website explore our robust portfolio of power management solutions.