CHAPTER 5.4

RELAYS AND SWITCHES

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INTRODUCTION

The primary function of switches and relays is the transmission and control of electric current accomplished by mechanical contacting and actuating devices. In recent years, solid-state (nonmechanical) switching devices have come into wide use and their applications are extending rapidly.

ELECTROMAGNETIC RELAYS

The simplified diagram of a relay shown in Fig. 5.4.1*a* illustrates the basic elements that constitute an electromagnetic relay (EMR). In simplest terms, it operates through the use of a coil which, when energized, attracts the spring-loaded armature; this, in turn, moves a set of contacts to or from a set of stationary contacts. The most common EMR types are as follows:

General-purpose. Design, construction, operational characteristics, and ratings are adaptable to a wide variety of uses.

Latch-in. Contacts lock in either the energized or deenergized position until reset either manually or electrically.

Polarized (or polar). Operation is dependent on the polarity of the energizing current. A permanent magnet provides the magnetic bias.

Differential. Functions when the voltage, current, or power difference between its multiple windings reaches a predetermined value.

Telephone. An armature relay with an end-mounted coil and spring-pickup contacts mounted parallel to the long axis of the relay coil. Ferreeds are also widely used for telephone cross-point switches.

Stepping. Contacts are stepped to successive positions as the coil is energized in pulses: they may be stepped in either direction.

Interlock. Coils, armature, and contact assemblies are arranged so that the movement of one armature is dependent on the position of the other.

Sequence. Operates two or more sets of contacts in a predetermined sequence. (Motor-driven cams are used to open and close the contacts.)

Time-delay. A synchronous motor is used for accurate long time delay in opening and closing contacts. Armature-type relay uses a conducting slug or sleeve on the core to obtain delay.

Marginal. Operation is based on a predetermined value of coil current or voltage.

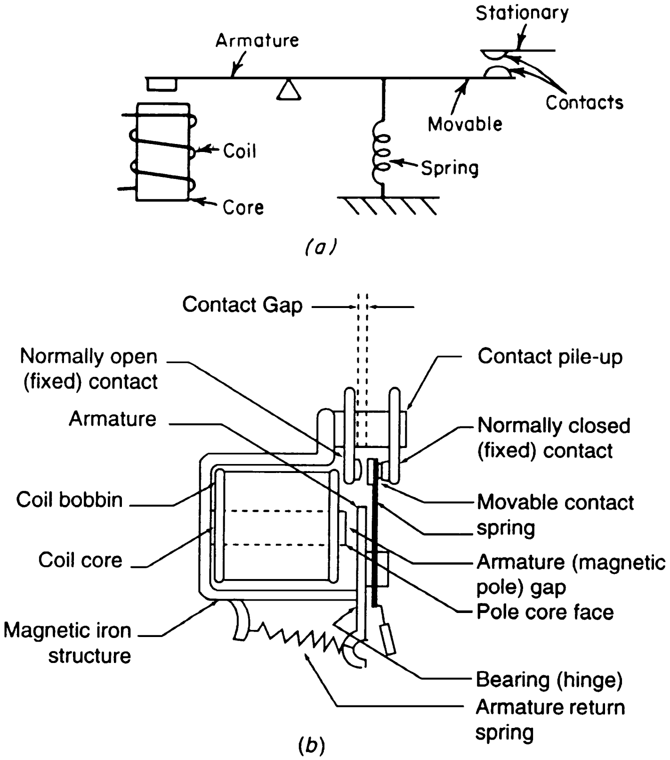


FIGURE 5.4.1 (*a*) Simplified diagram of a single-pole, double-throw, normally open rely; (*b*) structure of conventional relay (from NARM Engineers Relay Handbook, 4th ed.).

Performance Criteria

The design or selection of a relay should be based on the following circuit-performance criteria:

Operating frequency. Electrical operating frequency of relay coil

Rated coil voltage. Nominal operating voltage of relay coil

Rated coil current. Nominal operating current for relay

Nonoperate current (or voltage). Maximum value of coil current (or voltage) at which relay will not operate

Operate voltage (or current). Minimum value of coil voltage (or current) at which switching function is completed

Release voltage (or current). Value of coil voltage (or current) at which contacts return to the deenergized position

Operate time. Time interval between application of power to coil and completion of relay-switching function

Release time. Time interval between removal of power from coil and return of contacts to deenergized position

Contact bounce. Uncontrolled opening and closing of contacts due to forces within the relay

Contact chatter. Uncontrolled opening and closing of contacts due to external forces such as shock or vibration

Contact rating. Electrical load on the contacts in terms of closing surge current, steady-state voltage and current, and induced breaking voltage

Figure 5.4.2. illustrates some of the contacting characteristics during energization and deenergization.

General Design and Application Considerations

The dynamic characteristics of the moving system, i.e., armature and contact assembly, are primarily determined by the mass of the armature and depend on the magnet design and flux linkage. Typical armature configurations are clapper or balanced armature, hinged or pivoted lever about a fixed fulcrum; rotary armature; solenoid armature; and reed armature. Contact and restoring-force springs are attached or linked to the armature to achieve the desired make and/or break characteristics. The types of springs used for the contact assembly and restoring force are generally of the cantilever, coil, or helically wound spring type. Primary characteristics for spring materials are modulus of elasticity, fatigue strength, conductivity, and corrosion resistance. They should also lend themselves to ease of manufacture and low cost. Typical materials for springs are spring brass, phosphor bronze, beryllium copper, nickel silver, and spring steel.

Contacts. These include stationary and moving conducting surfaces that make and/or break the electric circuit. The materials used depend on the application; the most common are palladium, silver, gold, mercury, and various alloys. Plated and overlaid surfaces of other metals such as nickel or rhodium are used to impart special characteristics such as long wear and arc resistance or to limit corrosion.

The heart of the relay is the contact system that is typically required to make and/or break millions of times and provide a low, stable electrical resistance. The mechanical design of the relay is aimed principally at achieving good contact performance. Because of the numerous operations and arcing often occurring during operation, the contacts are subject to a wide variety of hazards that may cause failure, such as:

Film formation. Effect of inorganic and organic corrosion, causing excessive resistance, particularly at dry-circuit conditions.

Wear erosion. Particles in contact area, which can cause bridging between small contact gaps.

Gap erosion. Metal transfer and welding of contacts.

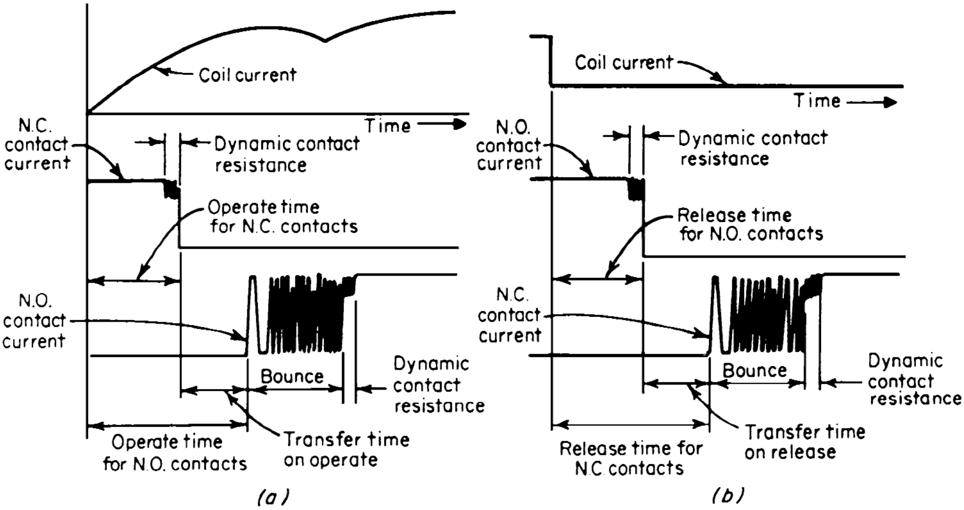


FIGURE 5.4.2 Typical oscillograph depictions of contacting characteristics during (*a*) energization and (*b*) deenergization of a relay. (*Automatic Electric, Northlake, IL.*)

Surface contamination. Dirt and dust particles on contact surfaces can prevent achievement of low resistance between contacts and may actually cause an open circuit.

Cold welding. Clean contacts in a dry environment will self-adhere or cold-weld.

One of the major factors in determining relay-contact life is the arcing that occurs at the contact surface during the period in which the contacts are breaking the circuit. Contact life (and hence relay reliability) can be greatly enhanced by the addition of appropriate contact-protection circuits. Such circuitry can reduce the effects of load transients, which are especially deleterious. A variety of circuits may be employed using bifilar coil windings, *RC* networks, diodes, varistors, and so forth. As a rule of thumb, for compact relays with operating speeds of 5 to 10 ms, the approximate parameters for suitable *RC* networks are approximately *R*, as low as possible but sufficient to limit the capacitor discharge current to the resistive load rating of the contacts, and *C*, a value in microfarads approximately equal to the steady-state load current in amperes.

Details on the effects of various methods of suppression are given in the *19th Relay Conference Proceedings.*

Packaging

Relays are packaged in a wide variety of contact arrangements (see Table 5.4.1) and in many package configurations ranging from T05 cans and crystal cans to relatively large enclosures, as well as plastic encapsulation, and open construction with plastic dust covers. The packaging adopted depends on the environment and reliability requirements. If the environment is controlled, as in a telephone exchange, a relatively inexpensive and simple package can be used. In a military or aerospace environment, hermetically sealed or plastic-encapsulated packages are essential, to prevent corrosion of contacts. In this regard the reed switch has had great impact on relay design since it provides a sealed-contact enclosure in a relatively simple and inexpensive package. It has become widely used in the telephone and electronics industry because it has been able to extend relay life to millions of cycles. A comparison between the reed and typical conventional relays is given in Table 5.4.2. Solid-state relays (SSRs) are also used extensively. Table 5.4.3 compares SSRs with electromagnetic relays.

SOLID-STATE RELAYS

An SSR performs a switching function using semiconductor devices and technologies to provide electrical isolation between the control circuit (input) and the load circuit (output) without electromechanical moving parts or contacts, thus ensuring long life and high reliability. It should be noted, however, that SSRs can be very unforgiving when encountering overloads, voltage and current spikes, and other conditions that can "destroy" solid-state devices.

SSRs are used in commercial, industrial, and military applications throughout the world including sophisticated avionics and microprocessor-based systems applications. Increased functional integration and miniaturization are yielding SSRs with greater reliability, reduced system complexity, and improved performance characteristics. The modern SSR has become a complete electronic subsystem, which greatly aids the electronics engineer in connecting the world of the microprocessor to the world of motors and solenoids. See Table 5.4.3.

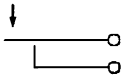
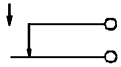
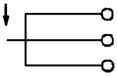
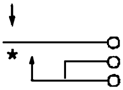
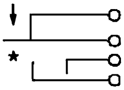
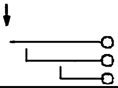
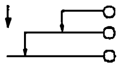
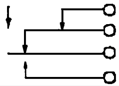
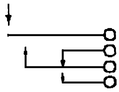
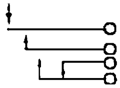
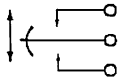
The primary advantages to the use of SSRs are

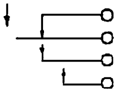
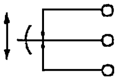
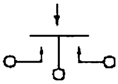
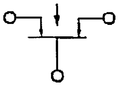
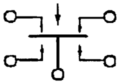
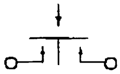
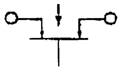
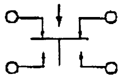
(a) Improved system reliability
(b) State of the art technical performance
(c) Improved system life cycle costs

Improved System Reliability

This advantage is related to the long-life characteristics of semiconductor devices. An SSR has no moving parts and suffers no contact degradation from arcing, erosion, or contamination. The absence of moving parts and contact chatter coupled with the low mass of semiconductor devices and proper construction and packaging techniques results in a virtual immunity to shock and vibration effects.

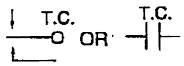
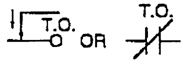
TABLE 5.4.1 Symbols for Relay Contact Combinations Established by American National Standards Institute (ANSI)

Form	Description	ANSI symbol
A	Make or SPSTNO	
B	Break or SPSTNC	
C	Break, Make, or SPDT (B-M), or Transfer	
D	Make, Break or Make-Before-Break, or SPDT (M-B), "Continuity Transfer"	
E	Break, Make, Break, or Break, Make Before Break SPDT (B-M-B)	
F	Make, Make SPST (M-M)	
G	Break, Break or SPST (B-B)	
H	Break, Break, Make, or SPDT (B-B-M)	
I	Make, Break,Make, or SPDT (M-B-M)	
J	Make, Make, Break, or SPDT, (M-M-B)	
K	Single pole, Double throw Center off, or SPDTNO	

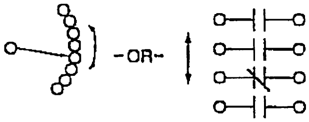
Form	Description	ANSI symbol
L	Break, Make, Make, or SPDT (B-M-M)	
M	Single pole, Double throw, Closed Neutral SP DT NC (This is peculiar to MIL-SPECS)	
U	Double make, Contact on Arm. SP ST NO DM	
V	Doule break, Contact on Arm. SP ST NC DB	
W	Double break, Double make, Contact on Arm. ST DT NC-NO (DB-DM)	
X*	Double make or SP ST NO DM	
Y**	Double break or SP ST NC DB	
Z	Double break, Double make, SP DT NC-NO (DB-DM)	

★Not to be confused with preliminary ("X") make

★★Not to be confused with a late ("Y") break

Special A	Timed close	
Special B	Timed open	

Multi-point selector switch



The heavy arrow indicates the direction of operation. Contact chatter may cause some electrical discontinuity in forms D and E.

TABLE 5.4.2 Estimated Load-Life Capability of Two-Pole Miniature Relays

	Dry reed. 0.125 A	Conventional crystal can. 5 A	Miniature power, 10 A
λ at 1×10^6 (%/10^4)	0.002	1.2	0.80
$R_{(0.999)}$(10^3 operation)	700	2.8	6.0
$R_{(0.90)}$(10^3 operation)	10,000	60	120.0

λ = failure rate in percent/10,000 h operation; $R_{(0.999)}$ = operating life with 99.9 percent probability; $R_{(0.90)}$ = operating life with 90 percent probability.

The technical characteristics of an SSR can reduce system complexity. Isolation techniques can prevent a series of secondary system failures from rippling through a system when a primary failure occurs. The lower power requirements can also contribute to reduced system power consumption, reduced thermal effects, and downsizing of system power supplies.

State-of-the-Art Performance

Many SSRs can be driven by either CMOS or TTL logic with no need for buffers or relay driver stages. Constant current input circuitry allows a wide control voltage range without need for external current limiting resistors or sources. They also allow a wide range of switching speeds to match user needs. Absence of moving parts provides clean bounce-free switching. This characteristic, coupled with zero-voltage turn-on and zero-current turn-off techniques, results in low EMI/RFI levels that are far below FCC and VDE specifications. The introduction of solid-state power FET relays has provided a quantum leap in switching technology with low “on” resistance with virtually no bipolar offset voltage. This allows them to switch low-level microvolt analog signals that have always been beyond the capability of bipolar solid-state devices, as well as high power levels with significantly reduced power dissipation.

TABLE 5.4.3 Relative Comparison of Electromagnetic Relays (EMRs) vs. Solid-State Relays (SSRs)

Characteristic	EMRs	SSRs	Advantage
Life	From 100,000 to millions of cycles. Reed contacts are outstanding.	No moving parts. When properly designed should last life of equipment.	SSR
Isolation	Infinite dielectric isolation.	Not dielectrically isolated; however, several techniques are available to achieve up to 10 kMΩ.	EMR
EMI (RFI)	Can generate EMI by switching of its coil, thereby requiring special isolation (i.e., shielding).	Noise generated is negligible compared with EMR.	SSR
Speed	Order of milliseconds.	Up to nanoseconds.	SSR
Operate power	Uses more power than SSR.	Lower power requirements but requires continuous standby power.	SSR
Contact voltage drop	Relatively low voltage drop because of low contact resistance.	High voltage drop which is dissipated into heat.	EMR
Thermal power dissipation	Primarily concerned with dissipating coil power.	Higher voltage drop develops appreciable heat to be dissipated.	EMR

Improved System Life Cycle Costs. This aspect stems from the SSRs' greater reliability and reduced failure rate, which yields lower production costs, lower system acquisition costs, and reduced field repair costs.

Anatomy of an SSR. Every SSR consists of at least three parts: (1) input or control circuitry, (2) isolation, and (3) output or load circuitry.

Input. The input circuitry is classified as dc, ac, or ac–dc, depending on the control requirements. Input control circuitry may also include such features as TTL/CMOS compatibility, positive or negative logic control, series/parallel digital interface, and so forth.

Isolation. The isolation between the input and output may be accomplished optically, magnetically (transformer), or, in special applications, using a mechanical relay (typically a reed relay) to drive the output device.

Output. Output circuitry is also classified as dc, ac, or ac–dc, and may use a variety of output devices, depending on the application. For ac operation a thyristor (2 SCRs or triac) is generally used. For dc applications a bipolar device or power FET transistor may be used. For ac–dc operation power FETs are used, although bipolar transistors may be used for currents up to 100 mA. Additionally, the output may be single or multiple pole, single or double throw, and may incorporate such features as time delay, latching, break-before-make logic, and so forth.

SWITCHES

Switches are electromechanical devices used to make and break, or select, an electrical circuit by manual or mechanical operation.

An examination of manufacturers' and distributors' catalogs makes it obvious that switches come in a bewildering array of types, shapes, sizes, actuator styles, ratings, and quality levels.

Beside the basic ability of a switch to make, break, and carry the required electrical load (including the inductive or capacitive, low level or logic level effects), switches can be characterized in additional ways, usually dependent on the sensitivities of the application, such as electrical noise, capacitance, frequency, contact make or break speed, contact bounce, and ability to withstand various environmental conditions.

Contact Make/Break Time and Bounce Time. Make time is the time required by a switch contact to travel from an open position to a closed position. Break time is the time required by a switch contact to travel from a closed position to a fully open position. Bounce time is the interval between an initial contact and steady contact during which the moving contact bounces or makes intermittent contact as a result of its impact on a stationary contact.

Electrical Noise and Capacitance. Electromagnetic radiations may occur during make and break, causing noise interference in sensitive circuits or high-gain amplifiers. Arc suppression may be necessary to reduce such noise to acceptable levels.

Selection Considerations. Once the basic switch type, size, and rating has been selected, the exact configuration must be considered and tailored for the application. Each particular switch type, and sometimes each manufacturer, has its own list of options and peculiarities, so manufacturers should be consulted at an early stage.

For rotary switches, the number of decks (sections), poles per deck, positions per pole, shorting and/or non-shorting contacts, and coding need to be considered, as well as, on the mechanical side, factors such as shaft and mounting bushing configuration, push-to-turn, pull-to-turn, and spring return features.

For toggle switches, contact configuration (single pole normally open, single pole normally closed, double throw, multiple poles, and so forth), the desirability of the bathandle configuration, and whether a lock is required, are among the factors to be considered.

Rocker switches are similar to toggles so similar factors apply. They also provide the option of illumination. Keypads and keyboards offer such a wide range of options that manufacturers should be consulted at the outset of the selection process.

For a simple on-off situation, a two-position rotary or two-position toggle, a push-push, or a push-pull switch are good choices. For data input applications, a numerical keypad and/or a keyboard is an obvious choice.

Application Notes. Switch selection must not overlook the ergonomic factors of the application. When a rotary switch is among the options, its choice will help minimize the panel space required.

Pushbutton switches often require the operator to view them in order to operate them, whereas toggle and rocker switches can be operated by feel. Rotary switches can sometimes be operated by feel, with the practiced operator counting clicks to position the knob correctly. Numerical keypads can be operated by touch, but special keyboards, notably the flush type, require eye contact for correct operation.

Switches designed to carry high electrical loads are physically large in order to accommodate the larger contacts to handle the load and dissipate heat, while switches designed for low and logic level loads can be very small, like subminiature toggles and DIP switches.

Standards. Switches used in appliances and equipment that handle line power will require a UL (Underwriters Laboratories) listing for use in the United States, a CSA listing for use in Canada, and other listings for use in other countries. These listings require the listing agency to run or observe special tests of the product to be listed, and continuous follow-up testing to prove that they can meet the necessary safety requirements. There are no universal tests or listing agencies although there are efforts being made in that direction.

Many switch standards are available from the Electronic Industries Association, the U.S. Department of Defense, Underwriters Laboratories, and others.

Ratings. Switch manufacturers publish one or more ratings for their products. Each represents a point on a load versus life curve, usually developed from testing at room conditions unless otherwise noted. Although not always stated, each load-life curve represents a given set of life limiting criteria: typically a certain maximum allowable value of contact resistance, a minimum value of insulation resistance between adjacent contacts or between contacts and ground (mounting bushing, case, or similar reference point), and a minimum value of dielectric strength (breakdown voltage across insulation). Increasing the ambient temperature during the test will generally result in higher values of contact resistance and reduced insulation resistance, which can equate to shorter life. These should be weighed against the application requirements. Typically the use conditions are more lenient than the test conditions for the load-life curve. For instance, many electronic circuits are of the high impedance variety where contact resistances of 20 or 50 milliohms are insignificant, but where insulation resistance can be important.

Arcing. Typical power loads will cause an arc to be drawn when a circuit is broken, which causes electrical erosion of the contacts. The erosion products are conductive, and if deposited on insulating surfaces, can result in a reduction of insulation resistance and dielectric strength. Higher currents produce hotter arcs and more erosion. Inductive loads also increase arcing. Fast making and breaking of contacts, as in snap-acting switch types, reduce the effect of arcing. Reduced barometric pressure, as in high altitudes, reduces the dielectric strength of air, which enhances the effect of arcing, so a switch should be derated for high-altitude operation.

Life tests for rating purposes are usually run on a continuous basis. This gives the contacts little time to cool between carrying high loads and breaking arcs, whereas typical applications require switches to operate infrequently, giving the contacts plenty of cooling time, and resulting in an application life that is longer than the test life.

Many switch applications in electronics do not switch power loads; they are more likely to handle low level or logic level loads. Typical low level tests are run at 30 mV and 10 mA, while logic level tests are run at 2 to 5 Vdc and 10 mA or less. Low levels can be troublesome because they are run below the melting voltage of the contact material and below the breakdown voltage of contact contaminants.

Contact pairs will be of the butt type, wiping type, or a combination of these basic types. Even small amounts of lateral wiping action between contact pairs can provide significant cleaning of the contact faces, thus minimizing contact resistance but creating some mechanical wear of the contact surfaces. Butt contacts will exhibit less wear but have higher contact resistance. Most rotary switches used in electronics have a considerable amount of wiping action, while sensitive or snap action switches and some types of toggle/rocker switches are closer to pure butt types (although most have a slight amount of wipe).

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