

## Relays

A relay is defined as an electrically controlled device that opens and closes electrical contacts, or activates and deactivates operation of other devices in the same or another electrical circuit. Two types of relay technology are available, mechanical and solid state. A mechanical relay is essentially a combination of an inductor and a switch, where the electromagnetic force of the inductor causes a switch to change position. A solid state relay accomplishes the same function with semiconductor devices changing impedance to effectively activate or deactivate a circuit open or closed. This document is intended to be a general guide to aid the designer in the appropriate selection of a relay for the intended application. Detailed information on the selection and use of relays can be found in MIL-STD-1346.

Table 1. Military Relay Specifications

Military Specification	Description
MIL-R-5757	Relays for Electrical, for Electronic and Communication Type Equipment
MIL-R-6106	Electromagnetic Relays
MIL-R-28776	Relays for Electrical for Electronic and Communication type Equipment, Hybrid
MIL-R-39016	Relay, Electromagnetic, Established Reliability
MIL-R-28750	Solid State Relay
MIL-R-83726	Time Delay, Hybrid and Solid State Relays

## Packaging

Relays are available in a variety of unique package styles. The size and mass of the package are dependent on the electrical characteristics, power dissipation and environmental requirements. Relays are generally the larger size components of a system, where increased attention must be paid to clearances

and mounting, especially in high vibration level environments. Many package styles initially developed for unique applications have since gained wide acceptance.

## Failure Mechanisms and Anomalies

### FAILURE MODES

Table 2 shows the relative probability of the three principal failure modes for relays. Relays most commonly fail in the "stuck open" position where the mechanical switching element fails to close and the relay fails to carry a current. Relays are less likely to unintentionally close or remain closed after the switching current is released. For this reason, the reliability of relay circuits can be improved by using parallel redundancy.

Table 2. Normalized Failure Mode Distributions for Relays

Failure Mode	Relative Probability
Failure to Trip	55%
Spurious Trip	26%
Short	19%

Unlike most of the other electrical parts, relays (with the exception of solid state relays) contain a switching element that physically moves to make electrical contact. This makes them less likely to follow a constant failure rate or traditional "bathtub curve" profile. Instead, they are more prone to follow the failure rate curve for a mechanical part, with an increasing failure rate with age. Except for special high voltage and high temperature applications, solid-state relays are inherently more reliable and predictable for long life applications.

### Failure Mechanisms

The two most common failure mechanisms of relays are contamination and mechanical wear of the internal switching elements discussed as follows:

- a. Contamination is a major cause of early life failures. Sources of contamination are numerous, but they are often from the various chemicals used in the manufacturing operation (e.g., soldering fluxes and cleaning agents). Types of contamination can be divided into two categories: metallic and non-metallic. Metallic contamination causes shorted conditions or blocks the physical movement of mechanical elements. Non-metallic or gaseous contamination creates open circuits when it periodically deposits itself on contacts.
- b. A second major cause of early life failures in relays is mechanical wear of internal switching elements. In fact, the life of a relay is essentially determined by the life of its contacts.

Degradation of contacts is caused from high in-rush currents, high-sustained currents, and from high voltage spikes. The source of high currents and voltages, in turn, are determined by the type of load. Inductive loads create the highest voltage and current spikes because they have lowest starting resistance compared to operating resistance. This is especially true for lamp filaments and motors, which is why derating is more severe for these types of loads. The life of a contact can be further degraded if contamination or pitting is present on the contact. Physical wear can also occur to other elements within the relay. Some relays contain springs to provide a mechanical resistance against electrical contact when a switching current is not applied. Springs will lose resiliency with time. Relays can also fail due to poor contact alignment and open coils.

## **Reliability**

Selection of the proper relay type for a given application is the most significant factor affecting relay reliability. Many poor design practices are used when designing them into circuits. This is because relays are a relatively uncommon circuit element and often receive little attention during the design process. Whereas most designs will use hundreds each of microcircuits, resistors, etc.; relays typically number in the single digits. Therefore, designers are often less familiar with the intricacies of selecting the proper relay type and rating for a particular application. Some of the more common poor design practices are listed as follows:

- a. Paralleling contacting is where two relays are placed in parallel to handle the current that one of them cannot handle alone. The problem with this type of design is that mechanical switching occurs at relatively slow switching speeds. Therefore, for a brief instant, only one relay needs to carry the full current load. Further, switching speeds tend to slow with age, amplifying the affect over time. The preferred method is to use a single relay of sufficient current handling capability. If dual relays are used in parallel to increase reliability, each relay should be capable of handling the full current load.
- b. Transient surge currents are often difficult to measure and predict, especially when switching inductive loads. It is not uncommon for surge current to reach ten times steady state current. Protective devices should be used to limit surge current. The simplest solution is to use a relay with a substantially higher rated surge current than anticipated.

- c. A cold filament lamp draws between 3 and 10 times the steady-state current until warmed up. Relay contacts used for switching lamps should be able to withstand such current surges without the possibility of welded contacts.
- d. Relays are sometimes used in applications where they switch a redundant circuit element or an additional power supply current into a circuit. High surges occur in ac applications when the redundant current is not in synchronization with the original current.
- e. A typical misapplication is the use of small multipole relays in 112/200 volt 3-phase ac applications. Phase-to-phase shorting at rated loads is a strong possibility, with potentially catastrophic results.
- f. Caution must be applied when using relays to reverse motors, particularly where the motor can be reversed while running (commonly called "plugging"). This results in a condition where both voltage and current can greatly exceed nominal. Only power relays rated for "plugging" and reversing service should be utilized in these applications.
- g. A relay race condition occurs when one relay must operate prior to another from a separate drive circuit, but fails to do so. The problem usually occurs after the equipment ages or temperatures rise. Potential race circuits should be avoided. Where they must be used, extra consideration must be given to wear considerations, coil suppression circuitry, ambient temperature, drive power, and operate and release times.
- h. A slowly rising triggering current has an increased likelihood of causing chattering conditions. A problem occurs because back electromotive forces (EMFs) are produced when the armature closes to the pole face. This voltage is opposite in polarity to the driving voltage and can cause the relay to release immediately after initial contact. This process repeats and causes a chatter condition until a sufficient amount of drive current is available to overcome the back EMF.

## **Derating**

### **Continuous Current**

Derating of continuous current is dependent upon the load type and is shown in Table 3. Derating is more severe for inductive and filament loads, due to high current demands upon initial startup and increased propensity of voltage spikes.

If a relay is used to switch a combination of loads, the most dominant load should be used for derating purposes.

Some relay specifications will contain individual current limitations for capacitive, inductive, motor, and filament loads. For such specifications, limit current to either the current derived through Table 1 or the maximum current rating for the particular load type given in the specification, whichever is less.

### **Coil Energizing Voltage**

The voltage to energize or trigger the relay should be at least 110% of the minimum rated energizing voltage. Coil energizing voltage is not derated in the traditional sense of the term because operation of a relay at less than nominal ratings can result in switching failures or increased switching times. The latter condition introduces contact damage and can reduce relay reliability.

### **Coil Dropout Voltage**

The voltage to dropout or un-trigger a relay should be less than 90% of the maximum rated coil dropout voltage.

### **Temperature**

Limit ambient temperature to maximum rated ambient temperature as shown in Table 3.

*Note: Relay ratings may be given under the assumption that the relay case will be grounded. If such relays are used in applications where the case is not grounded, additional derating should be considered because the relay may lack arc barriers and contain smaller internal spacings.*

Table 3. Derating Requirements for Relays

Part Type	Derating Parameter	% of Resistive Load Rated Value in Environment		
		Category 1 Protected	Category 2 Normal	Category 3 Severe
<u>Relay</u>	Continuous Current	70 -- Resistive Load 70 -- Capacitive Load 50 -- Inductive Load 30 -- Motor 20 -- Filament (Lamp)	60 -- Resistive Load 60 -- Capacitive Load 40 -- Inductive Load 20 -- Motor 10 -- Filament (Lamp)	50 -- Resistive Load 50 -- Capacitive Load 30 -- Inductive Load 20 -- Motor 10 -- Filament (Lamp)
	Coil Energize Voltage	110, Maximum	110, Maximum	110, Maximum
	Coil Dropout Voltage	90, Minimum	90, Minimum	90, Minimum
	Ambient Temperature	10°C of Max Rated	20°C of Max Rated	30°C of Max Rated

### Design and Material

The construction methods and materials of each type of relay differ. Considerable differences exist between the materials and processes used to manufacture relays. A relay, in its most basic form, is a combination of a switch and an inductive element. In solid state relays, the inductor is replaced by a semiconductor element. The military specifications and standards are listed in Table 1, and other information can be found in MIL-STD-1346. The following lists the major categories available:

- a. A reed relay is operated by an electromagnetic coil or solenoid which, when energized, causes two flat magnetic strips to move laterally to each other. The magnetic reeds serve both as magnetic circuit paths and as contacts. Because of the critical spacing and the frailty of the arrangement, the reeds are usually sealed in a glass tube.
- b. A solid state relay incorporates semiconductor or passive circuit devices. As the name implies, it contains no moving parts, and therefore has low switching noise and essentially no bounce or chatter. Solid state relays also have long life and fast response times. Their main disadvantage is a limited number of applications for which they can be used.

c. A latching or magnetic latching relay is a bistable polarized relay having contacts that latch in either position. A signal of the correct polarity and magnitude will reset or transfer the contacts from one position to the other.

*Note: In addition to the categories listed above, mercury, bimetal (thermal), and contractor relay technologies are also available.*

### **Facility Assessment and Quality**

Quality and reliability levels of relays may be expressed as the number of switch cycles before wear-out rather than the more traditional failure rate. Vendors consider rated number of switch cycles to be the guaranteed minimum number of cycles the relay can withstand under normal operating conditions before failure (intermittent or constant). Relays manufactured to the military standards have a failure rate level designator as shown in Table 4 (levels established at 90% confidence level for qualification and 60% confidence level for maintenance of qualification).

Quality is further dependent on the ruggedness of the package and how well the internal switching elements are sealed against influences of the outside environment. Commercial grade relays and relays found in COTS equipment are not routinely acceptable for use in Military environments.

Table 4: Failure Rate Level Designators for Relays

Failure Rate Letter Designator	Failure Rate Level (%failures per 10,000 Operations)
L	3.0
M	1.0
P	0.1
R	0.01
S	0.001

### **Sampling**

The trend in Military procurements is to specify end item performance requirements rather than specifying specific sampling plans. Sampling plans differ between vendors, and the particular part vendor must be consulted if test and inspection sampling rates are needed.

### **Process Controls**

If process controls or SPC requirements are needed for a particular application, consult the individual vendor detailed information.

### **Part Assessment**

Relays typically do not require additional screening or testing by the user at the piece part level.

### **Handling and Storage Precautions**

No special handling precautions are necessary for relays. Mechanical relays are not considered ESD sensitive, and solid state relays are normally rated at Class 3 ESD sensitive. Care should be exercised when handling hermetically sealed relays to retain the hermetic seal.

### **Closing Comments**

Solid state relays are generally preferred over electromechanical relays due to decreased chatter noise, increased reliability, and more consistent performance with age. Exceptions are relays used in high temperature environments.

Special mounting considerations are necessary for mechanical relays in high or vibration environments because relays are typically high mass parts and can switch unintentionally when subjected to shock. Particular care is needed in airborne applications. Relays should not unintentionally switch even during absolute worst case operating conditions. In addition, the designer should take into account the wear of springs in long life applications.

Arc suppression techniques should be used to protect relay contacts of intermediate and power level devices to increase long term reliability. Arc suppression usually consists of external circuitry (e.g., diodes) to limit current surge.

To increase reliability, relays can be designed into circuits with parallel redundancy. The relative probability of a relay failing in the open position is substantially higher than failure in a closed position (see Table 2), thereby improving reliability in parallel redundant configurations. However, parallel redundancy should only be used to increase reliability, not to increase the current handling capabilities of a relay circuit.

For relays used over a wide temperature range, account for increased switching current demand at higher temperatures. As a general rule of thumb, coil resistance increases with temperature at a rate of  $0.004 \Omega/\Omega/^\circ\text{C}$ .

If a relay is rated under grounded case conditions, the relay should only be used in applications where the case will be grounded. Use in an ungrounded application may cause a personnel hazard.

When using relays to reverse motor loads while running, use only relays specifically rated to reverse switch motor loads.