Fundamentals of relay technology

Fundamentals of relay technology and of solid-state relay technology

Application Note
105396_en_00

1 Fundamentals of relay technology

Electromechanical relays are used as interface modules between the process I/O devices, on the one hand, and the open-loop/closed-loop control and signaling equipment, on the other, for level and power adjustment purposes.

Essentially, electromechanical relays can be divided into two main groups: monostable and bistable relays.

With monostable DC or AC relays, the contacts automatically return to the release state when the excitation current is switched off.

In the case of bistable relays, the contacts remain in their present switch position when the excitation current is switched off.

Table of contents

INSPIRING INNOVATIONS

1.1 Coil side

Input circuits and voltage types

There are various kinds of input circuit depending on the type of relay used and the nature of the control voltage.

If pure AC relays are used (AC input), the input circuit is generally nothing more than a visual switching status indicator.

Unless otherwise specified, the frequency of the control voltage is 50/60 Hz.

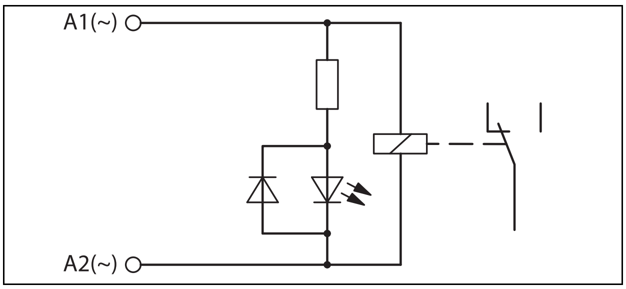


Figure 1 Block diagram of relay with AC input

In the case of a pure DC input, the most important addition to the circuit is a free-wheeling diode. This limits the voltages induced on the coil on circuit interruption to a value of approximately 0.7 V, which does not pose a danger to any connected control electronics.

As the free-wheeling diode can only perform its required function if the polarity of the voltage connection is correct, a reverse polarity protection diode is also integrated into the input circuit.

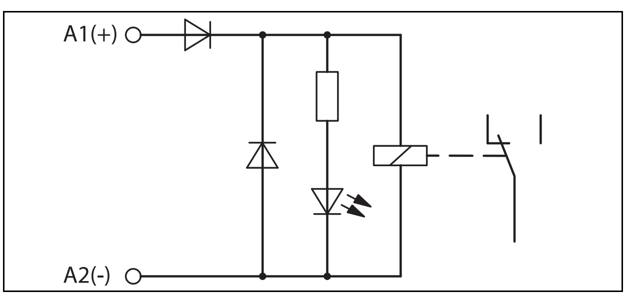


Figure 2 Block diagram of relay with DC input

To allow DC or AC voltage operation, a bridge rectifier is connected in the input circuit. The diodes are simultaneously responsible for performing rectification, freewheeling and polarity reversal protection functions. The interrupting voltage of the coil is limited to approximately 1.4 V.

To protect the input circuit against overvoltages, a varistor is also connected (depending on the type) upstream of the bridge rectifier.

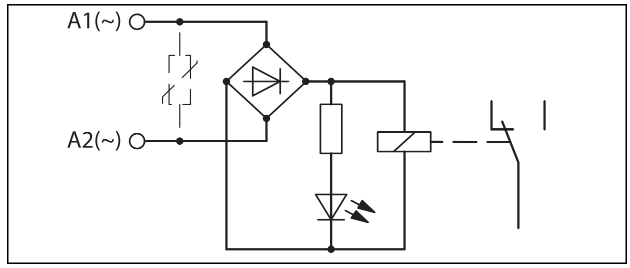


Figure 3 Block diagram of relay with AC/DC input

Bistable remanence relays with a double winding are only ever operated with DC voltage.

With these types of relay, there are three coil connections on the coil side. In addition to the common connection, there are separate connections for "setting" and "resetting"; these are controlled by short pulses only. As a result, the relays hardly heat up at all. Simultaneous control of both control inputs is not permitted.

A distinction is made between negative switching (M) and positive switching (P) types, depending on the polarity of the freewheeling and reverse polarity protection diodes.

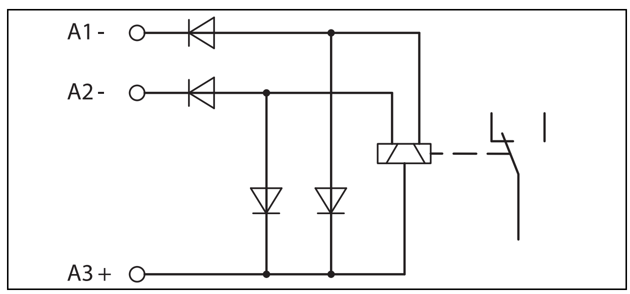


Figure 4 Block diagram of a bistable relay, negative switching type

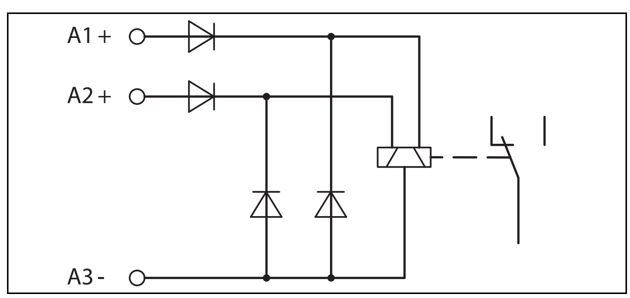


Figure 5 Block diagram of bistable relay, positive switching type

Operating voltage range

The ambient temperature prevailing at the location of use has a major impact on certain relay operating parameters.

As the ambient temperature increases, the coil winding heats up, causing the response and release voltages to rise. At the same time, the maximum permissible coil voltage decreases, which means that the usable working range becomes restricted as a result.

The diagram below illustrates how the operating voltage behaves as a function of the ambient temperature.

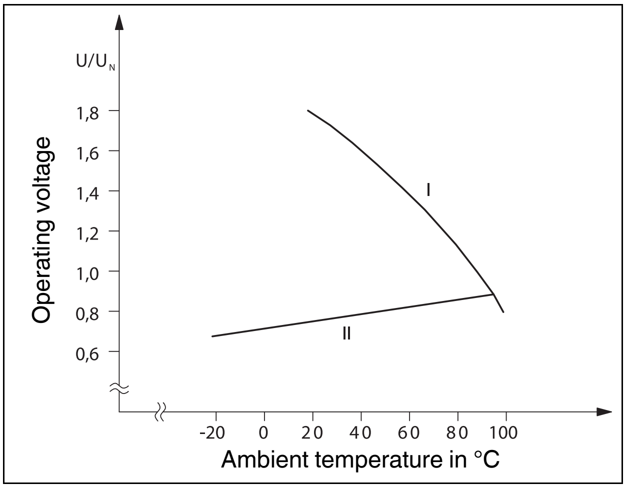


Figure 6 Sketch of a relay operating voltage characteristic

I Maximum permissible voltage with 100% operating time (OT) and assuming compliance with the coil temperature limit

II Minimum operate voltage

1.2 Interference voltages and interference currents on the coil side

When inductive or capacitive interference voltages are coupled into the long supply conductors of a relay, this can prevent the relay from operating safely and reliably.

If the coupled-in voltage exceeds the release voltage demanded by the IEC 61810-1 "relay standard", in extreme cases the relay may fail to release. In the case of DC relays, this release voltage is $\geq 0.05 \times U_N$; with AC relays, it is $\geq 0.15 \times U_N$.

The same disturbances can occur, when a relay with a low input power is controlled by an electronics module with an AC output featuring an RC circuit. The typical leakage current from RC elements of this kind (generally in the region of several mA) provides sufficient control power to prevent the downstream relay from releasing or even enough power to excite it.

The disturbance level of any interference voltages that are present can be reduced by connecting an RC element in parallel with the relay coil. This measure also subjects the interference voltage to a capacitive load, causing it to collapse.

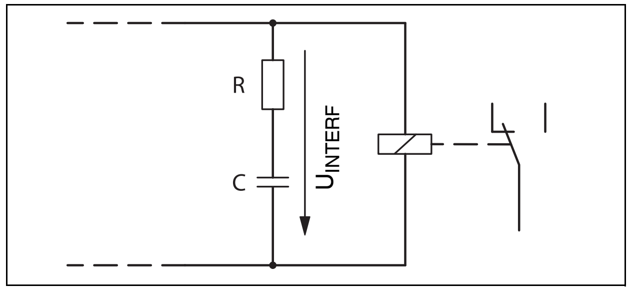


Figure 7 External RC interference suppression filter to prevent interference voltage coupling

The following values are recommended for the purpose of dimensioning the RC element:

– R = 100 ... 220 Ω
– C = 220 ... 470 nF

The SO46 series have been developed to provide even higher levels of immunity to interference. These products already contain an integrated RCZ filter. See, for example, PLC...SO46.

1.3 Contact side, contact materials

Given the wide variety of potential applications in the different industrial sectors, the relays used must be matched to the various tasks that need to be performed by selecting the right kind of contact material.

The voltage, current, and power values play an important role when determining the suitability of contact materials. Other criteria include:

– Contact resistance
– Erosion resistance
– Material migration
– Welding tendency
– Chemical effects

In this way, the various contact materials (generally noble metal alloys) can be matched to the relevant areas of application.

The adjacent table provides details of some of the key materials.

Contact material	Typ. properties	Typ. applications	Guide values for the area of application*[1]
Gold Au	Largely insensitive to industrial atmospheres; low and constant contact resistances in the range of small switching capacities with nickel (AuNi) or silver (AuAg) alloys	Dry measuring and switching circuits, control inputs	µA ... 0.2 A µV ... 30 V
Silver Ag	High electrical conductivity; sensitive to sulfur, therefore often gold-flashed (approximately 0.2 µm); as protection; nickel (AgNi) or copper (AgCu) alloys increase the mechanical resistance and erosion resistance and reduce the welding tendency.	Universal; suitable for medium loads; nickel alloys (AgNi 0.15) for DC circuits with medium to large loads	≥ 12 V ≥10 mA
Silver, hard gold-plated Ag+Au	Properties similar to gold Au. When switching loads > 30 V/0.2 A, the hard gold plating (5-10 µm) is destroyed and the values and properties of the Ag contact are applicable. However, a reduction in the service life is then to be expected.	Suitable for control inputs and other small loads.	≥ 100 mV ≥ 1 mA
Tungsten W	Highest melting point; very high erosion resistance; greater contact resistances; very low welding tendency; susceptible to corrosion; often used as lead contact.	Loads with very high inrush currents, e.g., glow lamps, fluorescent lamps.	≥ 60 V ≥ 1 A
Silver nickel AgNi	High erosion resistance; low welding tendency; higher contact resistances than with pure silver.	Universal; suitable for medium to high loads; DC circuits and inductive loads.	≥ 12 V ≥ 10 mA
Silver nickel AgNi+Au	Properties similar to gold Au. When switching loads > 30 V/0.2 A, the hard gold plating (5-10 µm) is destroyed and the values and properties of the AgNi contact are applicable. However, a reduction in the service life is then to be expected.	Suitable for control inputs and other small loads.	≥ 100 mV ≥ 1 mA
Silver tin oxide AgSnO	Low welding tendency; very high erosion resistance for high switching capacities; low material migration	Application depends heavily on the relay type; switching circuits with high make and break loads, e.g. glow lamps and fluorescent lamps, AC and DC circuits. Due to different alloys and production procedures, partly also suitable for smaller loads.	≥ 12 V ≥ 100 mA (≥ 10 mA)
Silver tin oxide, hard gold-plated AgSnO+Au	Properties similar to gold Au. When switching loads > 30 V/0.2 A, the hard gold plating (5-10 µm) is destroyed and the values and properties of the AgSnO contact are applicable. However, a reduction in the service life is then to be expected.	Suitable for control inputs and other small loads.	≥ 100 mV ≥ 1 mA

1 * Values depend on the relay used and on further operating conditions.

1.4 Contact protection circuit

Every electrical load constitutes a mixed load with ohmic, capacitive, and inductive components.

When these loads are switched, the switching contact is in turn subjected to a load, to either a lesser or greater extent. This load can be reduced by including a suitable contact protection circuit.

In view of the fact that loads with a large inductive component are predominantly used in practice (e.g., contactors, solenoid valves, motors, etc.), these application cases are worth considering in more detail.

On interruption, voltage peaks with values of up to several thousand volts occur due to the energy stored in the coil.

These high voltages cause an arc on the switching contact which can destroy the contact due to material vaporization and material migration. The electrical service life is reduced considerably as a result. In extreme cases, the relay may fail in the very first cycle with DC voltage and a static arc.

A protective circuit must be used to suppress the formation of an arc. With optimum dimensioning, almost the same number of cycles can be achieved as with an ohmic load.

In principle, there are a number of possible ways of achieving an effective protective circuit:

1. Contact wiring
2. Load wiring
3. Combination of both wiring method.

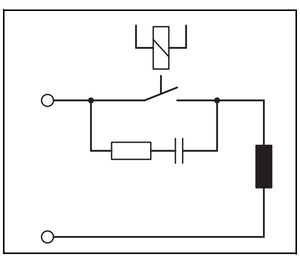


Figure 8 Contact protective circuit

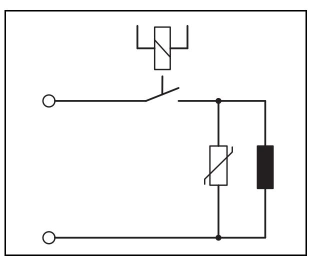


Figure 9 Inductive load protective circuit

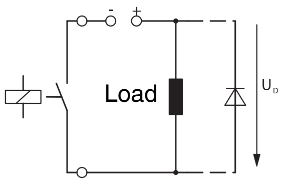
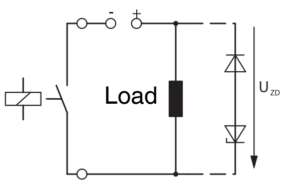
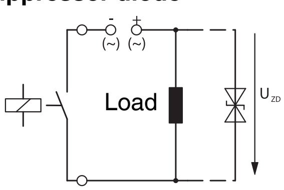
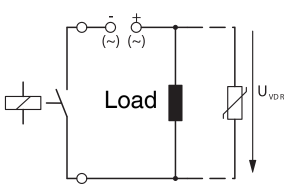
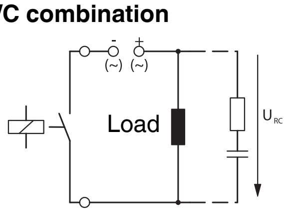
In principle, a protective measure should be directly implemented at the source of the interference.

Wiring a load should therefore be given priority over wiring the contact.

The following points are advantageous for the load circuit (image on right):

1. The circuit is only loaded with the induction voltage during interruption. By contrast, the sum of the operating voltage and the induction voltage is applied to the contact circuit.
2. When the contact is open, the load is electrically isolated from the operating voltage.
3. It is not possible for the load to be activated or to "stick" due to undesired operating currents, e.g., from RC elements.
4. Cut-off peaks of the load cannot be coupled into parallel control lines.

Nowadays, solenoid valves are usually connected using valve connectors that are also supplied with LEDs and components that limit the induction voltage. Valve connectors with an RC element, varistor or Z-diode often do not quench the arc and only serve to comply with the EMC laws. Only valve connectors with an integrated 1N4007 free-wheeling diode quench the arc quickly and safely, thereby increasing the service life of the relay by a factor of 5 to 10. Valve connectors with LED, integrated 1N4007, and free conductor end can be supplied on request as part of the SAC range.

Load protective circuit	Additional off delay	Defined induction voltage limiting	Effective bipolar attenuation	Advantages/disadvantages
Diode 	Large	Yes (U_D)	No	**Advantages** – Good effect in terms of extending the service life of the contacts – Easy implementation – Cost-effective – Reliable – Dimensioning not critical – Low induction voltage **Disadvantages** – Attenuation only via load resistor – Long off delay
Diode/Zener diode, series connection 	Medium to small	Yes (U_{ZD})	No	**Advantages** – Dimensioning not critical **Disadvantages** – Attenuation only above U_{ZD} – Minimal effect in terms of extending the service life of the contacts
Suppressor diode 	Medium to small	Yes (U_{ZD})	Yes	**Advantages** – Cost-effective – Dimensioning not critical – Limitation of positive peaks – Suitable for AC voltages **Disadvantages** – Attenuation only above U_{ZD} – Minimal effect in terms of extending the service life of the contacts
Varistor 	Medium to small	Yes (U_{VDR})	Yes	**Advantages** – High energy absorption – Dimensioning not critical – Suitable for AC voltages **Disadvantages** – Attenuation only above U_{VDR} – Minimal effect in terms of extending the service life of the contacts
R/C combination 	Medium to small	No	Yes	**Advantages** – HF attenuation due to energy storage – Suitable for AC voltages – Level-independent damping **Disadvantages** – Precise dimensioning required – High starting current inrush – Minimal effect in terms of extending the service life of the contacts

Switching small loads

Small loads must be processed mainly in applications where signals must be forwarded to control inputs (e.g., of a PLC).

With these loads, no switching sparks (arcs) occur on the contacts in the small load range.

In addition to the constant cleaning effect due to contact friction, this switching spark assumes the function of penetrating non-conductive contamination layers that are formed on the contact surfaces of power contacts.

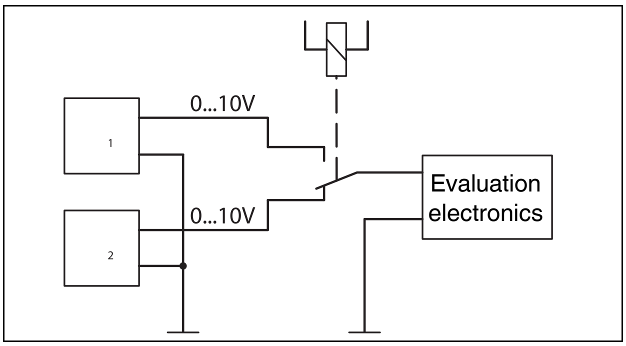


Figure 10 Application example: measurement point changeover

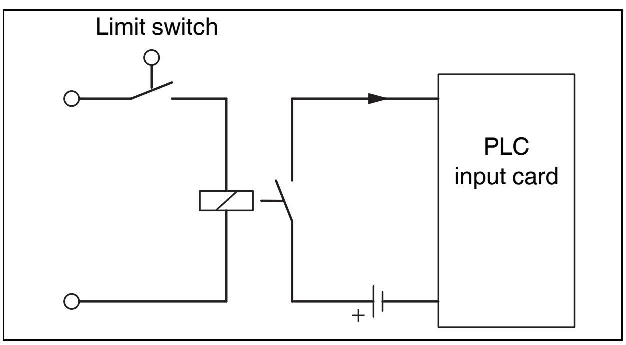


Figure 11 Application example: PLC input signal

These contamination layers are usually oxidation or sulfidation products of the contact materials silver (Ag) or silver alloys such as silver nickel (AgNi) or silver tin oxide (AgSnO). As a result, the contact resistance may rise so considerably within a short time that reliable switching is no longer possible in the case of small loads.

Due to these properties, the high-performance contact materials mentioned are not suitable for small load applications.

Gold (Au) has become accepted as the contact material of choice for these areas of application mainly on account of its low and constant contact resistances even with small loads and its insensitivity to sulfurous atmospheres.

For the smallest of loads and even greater contact reliability, double contact relays with gold contacts are used.

The slotted contact spring in this design provides two parallel contact points with even lower contact resistances and considerably higher contact reliability.

1.5 Switching large loads

A few important points also need to be considered with regard to switching processes in the large load range that involve power contacts made of either silver (Ag) or silver tin oxide (AgSnO).

A basic distinction must be made between switching DC and AC loads.

Switching large AC loads

When switching large AC loads, the relay can be operated up to the corresponding maximum values for switching voltage, current, and power. The arc that occurs during interruption depends on the current, voltage, and phase angle. This cut-off arc usually disappears automatically the next time the load current crosses zero.

In applications with an inductive load, an effective protective circuit must be provided, otherwise the service life of the system will be reduced considerably

Switching large DC loads

Conventional switching relays can only switch off relatively small direct currents (which contrasts with their ability to switch off the maximum permissible AC current), since there is no zero crossing to extinguish the arc automatically. This maximum DC value is also dependent to a large extent on the switching voltage and is determined, among other things, by constructional features such as contact spacing and contact opening speed.

The corresponding current and voltage values are documented by relay manufacturers in arc or load limit curves.

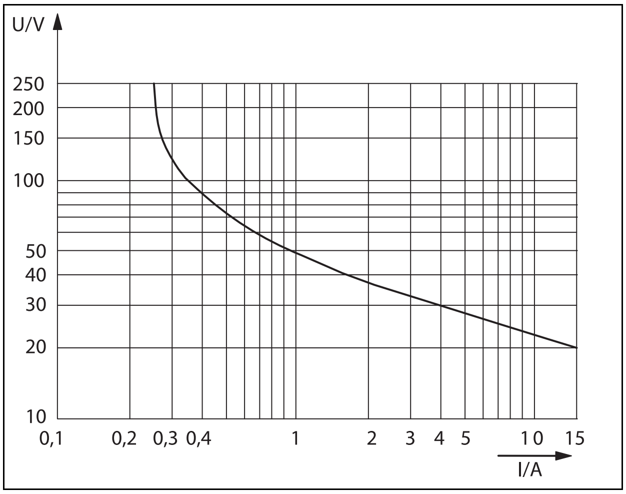


Figure 12 Example of a load limit curve (dependent on the type)

An unattenuated inductive DC load further reduces the values given for switchable currents. The energy stored in the inductor can cause an arc to occur, which forwards the current through the open contacts.

With an effective contact protection circuit, preferably free-wheeling diodes of the type 1N4007, the service life can be increased by a factor of 5 to 10 compared with unprotected or poorly protected inductive loads (see also chapter titled Contact protection circuits).

If higher DC loads than those documented are to be switched or if the electrical service life is to be increased, several contacts of a relay can be connected in series. See, for example, REL-IR... industrial relays.

Alternatively, solid-state relays with DC voltage output can also be used.

Switching lamps and capacitive loads

Regardless of the type of voltage, all kinds of lamps and loads with a capacitive component impose extreme requirements on the switching contacts. The moment it is switched on, in other words precisely in the dynamic chattering phase of the relay, extremely powerful current peaks occur. These are often in the region of several tens of amps, and not infrequently are known to exceed 100 A, which results in welding of the contact. This can be remedied by using specially optimized "lamp load relays" that can cope with these inrush peaks. See, for example, PLC...IC type.

1.6 Switching capacity in accordance with utilization categories AC-15 and DC-13 (IEC 60947)

In practice, both the maximum interrupting rating for AC loads and the DC interruption values taken from the load limit curves provide only a rough guide for the choice of relay. In reality, this is insufficient, since real loads in the vast majority of industrial applications have inductive or capacitive components and the wiring of the loads can be totally different. As already described, this sometimes leads to considerable variations in terms of service life.

The IEC 60947 contactor standard tries to avoid these disadvantages by dividing the loads into various utilization categories (DC-13, AC-15...). This standard is also partly applied to relays. However, users must be aware of the fact that these values are only applicable in practice to a limited extent as well, since all DC-13 and AC-15 test loads are highly inductive and are also operated without any protective circuit at all (see section titled Contact protection circuit). Moreover, the switching capacity test in accordance with IEC 60947 only requires 6060 cycles to be performed by way of a minimum requirement.

A much more reliable way to determine the switching capacity and the anticipated service life is to refer to the specific application data. Using a comprehensive data bank, the service life can be accurately estimated for most applications and, if necessary, suggestions for improvement can be made. In the case of critical applications, the user is advised to gather service life information based on empirical data.

2 Fundamentals of solid-state relay technology

2.1 Control side

Solid-state relays for various voltage and power levels are available from Phoenix Contact for use as interface modules designed to match process I/O devices to control, signaling and regulating devices. The solid-state relay element which is actually located in the module is limited to one defined voltage range by virtue of its design. The current consumption on the input side fluctuates depending on the circuit architecture and voltage level.

To accommodate all industrial voltages of between 5 V and 230 V, an input circuit is provided. The inputs for DC voltage and AC voltage must always be differentiated.

DC input

Adjustments are made in accordance with the various voltage levels by adding electronics which have been especially adapted to the desired voltage range. In the case of most modules, a polarity protection diode provides reliable protection against destruction in the event of a control voltage being connected incorrectly. Specially tuned filters reliably suppress possible high-frequency noise emissions.

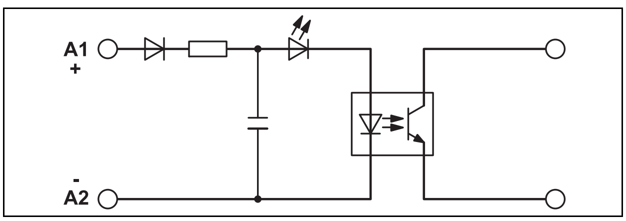


Figure 13 Block diagram DC input

AC input

The solid-state relay element requires a stable control voltage to ensure reliable operation. In the case of the AC input, this is achieved by connecting a rectifier and filter capacitor upstream. Rectifying is followed, in principle, by the same circuit architecture as the DC input.

The switching frequency always lies below half the mains frequency. Due to the filter capacitor, a higher switching frequency cannot be achieved. This would result in continuous through-switching.

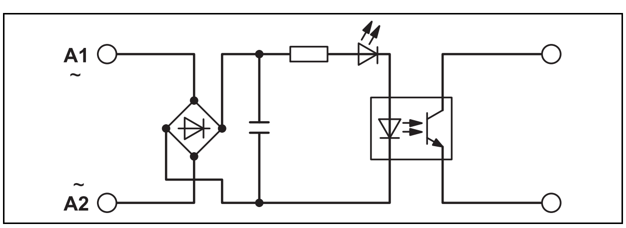


Figure 14 Block diagram AC input

2.2 Load side

Depending on the application and the type of load, the solid-state relay output must meet various requirements. The following are crucial:

– Power amplification
– Matching the switching voltage and the switching current (AC/DC), as well as
– Short-circuit protection

For these different applications, the solid-state relay element must also be processed using additional electronics on the output side.

DC output

In order to achieve the necessary output power, the solid-state relay element is supplemented by one or more semiconductor components.

The on-site user should nevertheless simply regard the connection terminal blocks of the output as conventional switch connections. Observing the specified polarity is the only essential requirement.

For practical reasons, the following criteria should be taken into account when selecting a suitable solid-state relay:

1. Operating voltage range (e.g., 12 ... 60 V DC)
   This determines the minimum or maximum voltage to be switched. The lower value must be observed in to ensure reliable operation. In order to protect the output transistor, the upper value must not be exceeded.
2. Maximum continuous current (e.g., 1 A)
   This value indicates the maximum continuous current. If this value is exceeded continuously, the output semiconductor will be destroyed. The dependence of the output current on the ambient temperature of the solid-state relay should also be taken into consideration. A derating. This shows the maximum load current as a function of the ambient temperature.
3. Output circuit
   The 2-wire output is similar to a mechanical contact. Only the polarity of the connections is specified and must be observed.

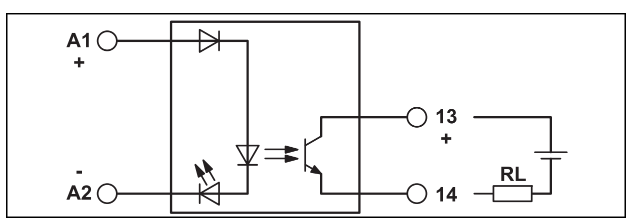


Figure 15 2-wire output

The 3-wire output is non-isolated and requires both potentials from the power supply source on the output side to be connected if it is to operate reliably.
When switched off, a permanent reference to the ground (negative potential) is established. In addition, this output circuit offers the advantage of an almost constant internal resistance.

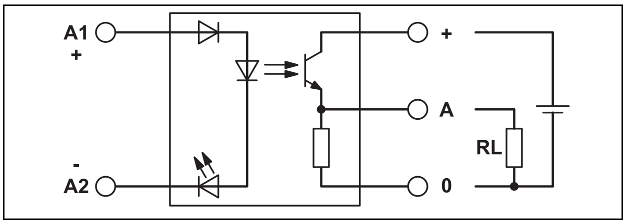


Figure 16 3-wire output

AC output

In order to control the switching and control devices for AC voltage, a semiconductor for AC voltage (TRIAC or thyristor) is connected downstream of the solid-state relay element.

As with the DC output, it is particularly important to consider the maximum operating voltage range and the maximum continuous load current as a function of the ambient temperature.

In addition, the maximum peak reverse voltage of the TRIAC (e.g., 600 V) is crucial with AC outputs. This must not be exceeded even in the case of voltage fluctuations or interference voltage peaks in order to prevent destruction. That is why the AC outputs of all solid-state relays from Phoenix Contact have an internal RC protective circuit to protect against interference voltage peaks.

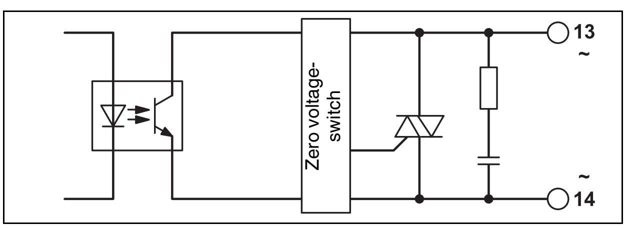


Figure 17 Basic circuit diagram of AC output

2.3 Protective circuits

The moment inductive loads (contactors, solenoid valves, motors) are switched off, surge voltages occur and these can reach very high amplitudes. Electronic components and switching elements are particularly susceptible to these. A protective circuit should therefore always be provided to prevent destruction.

A parallel connection to the load effectively reduces the switching surge voltage to a harmless level. Depending upon the solid-state relay output and type of load,

– a free-wheeling diode/suppressor diode (DC only),
– varistor (AC and DC) or
– RC element (AC only)

can provide the necessary protection

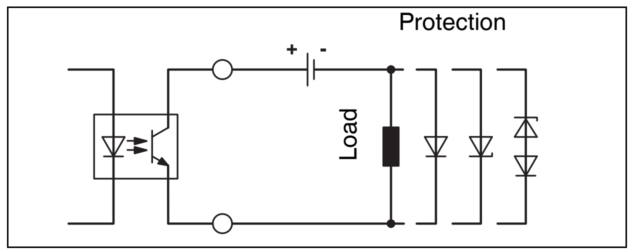


Figure 18 Protective circuit with DC voltage output

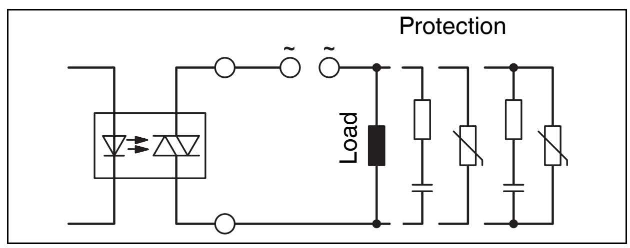


Figure 19 Protective circuit with AC voltage output

2.4 Application notes

Input solid-state relays acting in the direction from the I/O devices to the controller (signaling, controlling, monitoring)

Plug-in version:

– PLC-O...

Modular version:

– DEK-OE...
– EMG 10-OE...
– SIM-EI...
– OPT...

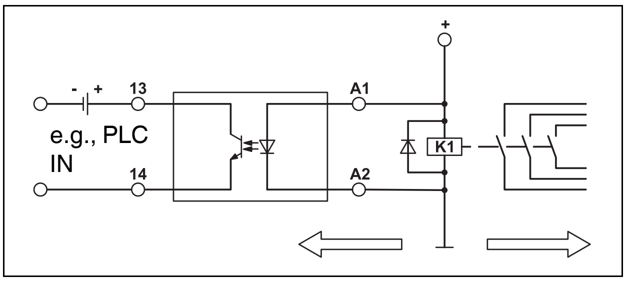


Figure 20 Example: Load contactor monitoring (DC contactor)

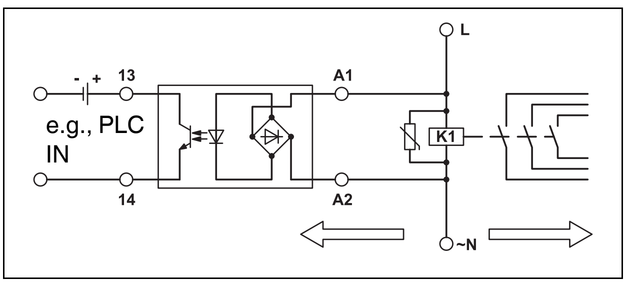


Figure 21 Example: Load contactor monitoring (AC contactor)

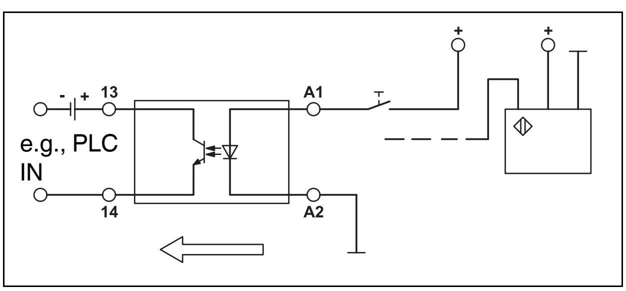


Figure 22 Example: Position indication with limit stop contact or initiator

Output (power) solid-state relays acting in the direction from the controller to the I/O devices (switching, amplifying, controlling)

Plug-in version:

– PLC-O...

Modular version:

– DEK-OV...
– EMG 10-OV
– EMG 12-OV
– EMG 17-OV
– OV...
– OPT...

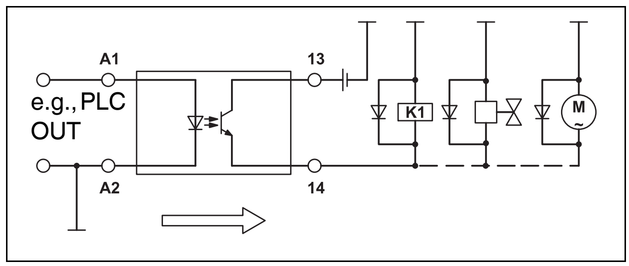


Figure 23 Example: Switching the contactor, solenoid valve or motor (DC load)

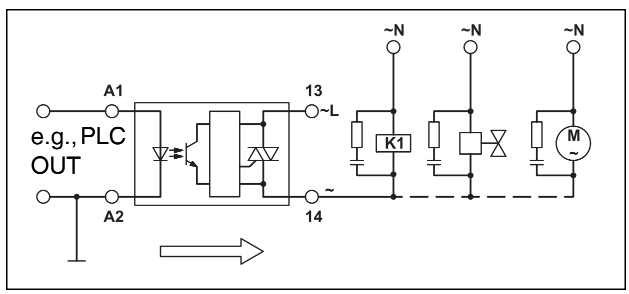


Figure 24 Example: Switching the contactor, solenoid valve or motor (AC load)

Remarks

[1]) Ground (minus) potential from the input and output of the solid-state relay should not be connected.

[2]) DC loads must be provided with an effective protective circuit (e. g., diode).

[3]) AC loads must be protected with a varistor or an RC element.