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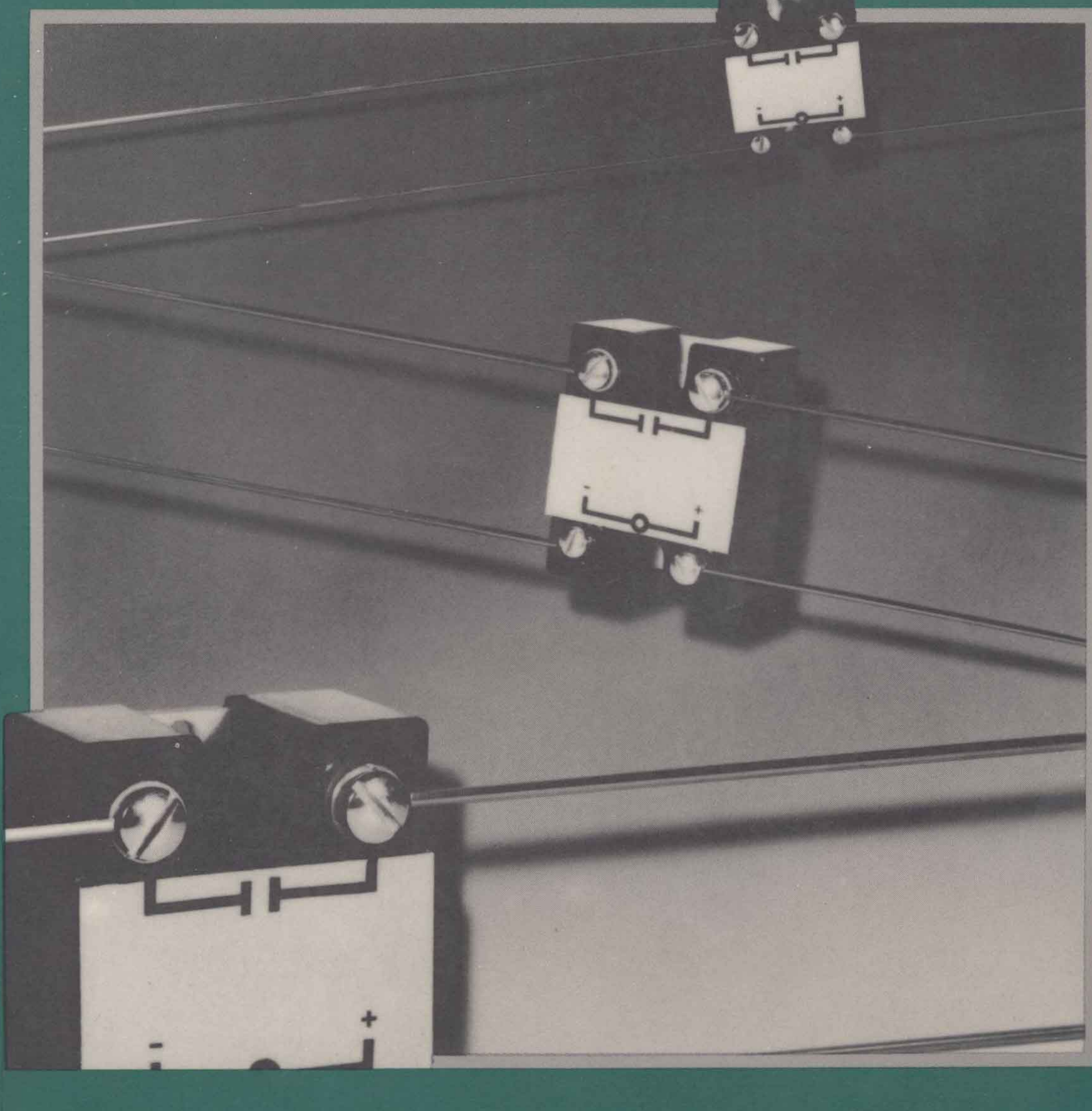
Solid-State Relay Handbook with Applications

Anthony Bishop



Solid-State Relay Handbook

with Applications

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Foreword

It was evident with the emergence of semiconductor technology in the 1950s that a new era of electrical power switching had begun. With the development of power thyristors, the designer gained a new dimension in switching performance (e.g., low noise, long life, fast switching speed, high reliability, and immunity to shock and vibration) hitherto unattainable with conventional switching methods.

For decades, the electromechanical relay (EMR) had been the primary component used for switching electrically isolated circuits. However, with advancing technology, designers required compatibility with their logic circuits and performance matching that of semiconductors. Subsequently, in the early 1970s the solid-state relay (SSR) appeared on the market, incorporating semiconductor switching circuitry that had for years been the exclusive domain of the circuit designer. These four-terminal, prepackaged assemblies were functionally similar to the EMRs, including isolation between the input circuit (coil) and the output semiconductors (contacts), but there the similarity ended.

Since their introduction, SSRs have found acceptance in a broad number of applications, particularly in such areas as microprocessor-based equipment for industrial machine and process controls. Although the SSR made available the advantages of semiconductor switching in a convenient form, it has since been realized that they have certain characteristics which require special attention to ensure reliable operation. In selecting the proper SSR for the job, consideration should be given to load-related parameters, voltage/current transients, mounting methods, and thermal conditions, among others.

The purpose of this handbook is to give the reader insight into solid-state relays—what they are, how they work, and how to select, specify, test, and generally apply them. Suggested drive and protective methods are included, with application notes to help stimulate further design ideas. It is hoped that this publication will serve as a useful guide and ready reference for those interested in this state-of-the-art component.

Contents

1

Introduction to Solid-State Relays

1.1 What Is an SSR?

An SSR (solid-state relay) is a mechanically passive version of its older counterpart the EMR (electromechanical relay), providing essentially the same performance, but without the use of moving parts. It is a totally electronic device that depends on the electrical, magnetic, and optical properties of semiconductors and electrical components to accomplish its isolation and relay-switching functions (Fig. 1-1).

The solid-state relay industry, to date, has not been noted for its standardization of relay packages. However, the rectangular package (top center in Fig. 1-1), introduced by Crydom Controls in the early 1970s, has become an industry standard for power switching, with models ranging from 2 to 90 amps. The newer input/output (I/O) modules introduced by Opto-22 (bottom right in Fig. 1-1) have also established a commonality between manufacturers, and in many cases are pin-for-pin replaceable.

1.2 Hybrid SSR Versions

There are available certain relay types that combine the properties of both the SSR and the EMR. They are categorized and described as follows:

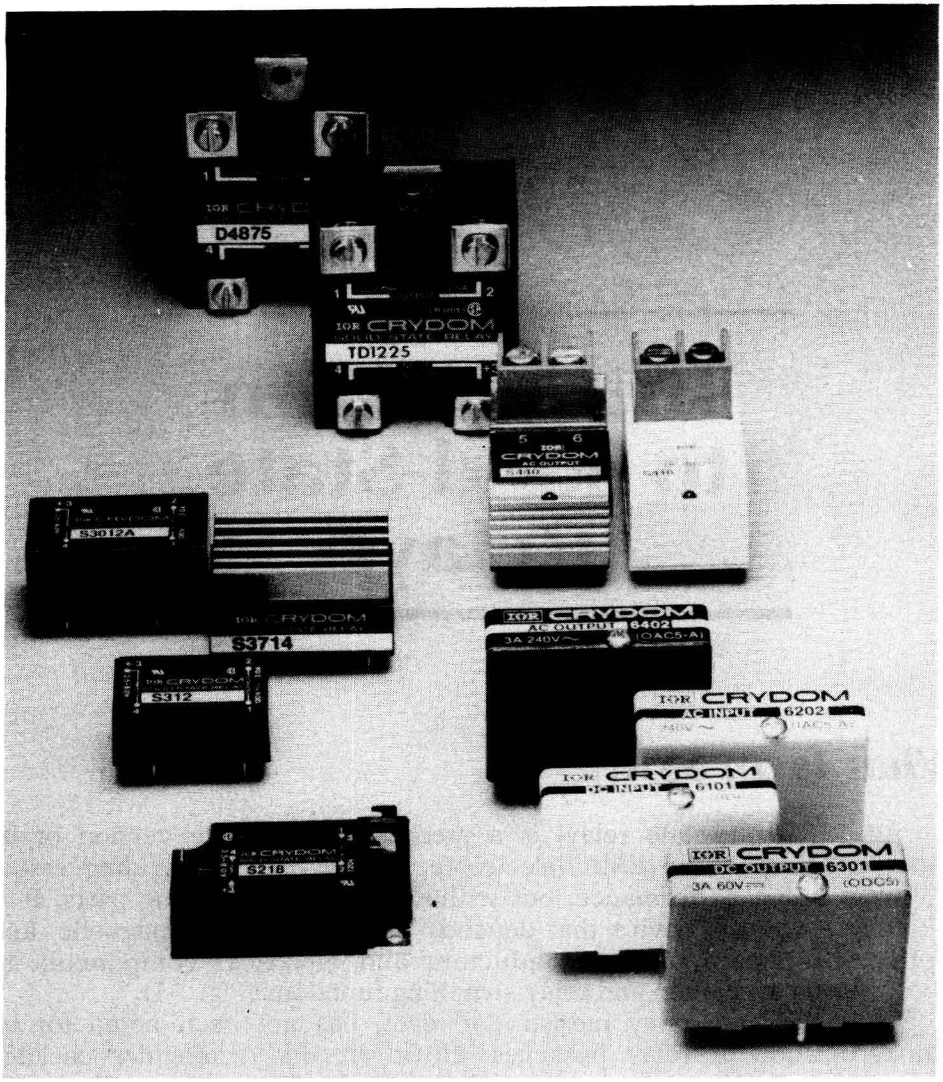


Fig. 1-1. ***Typical solid-state relay and I/O module packages.*** *(Courtesy IR Crydom)*

1. Hybrid Electromechanical Relay (HEMR)
   Utilizes semiconductors and electronic components for input and drive functions. Isolation is provided, and the output is switched by means of an electromechanical device.
2. Hybrid Solid-State Relay (HSSR)
   An electromechanical device (generally a reed type) providing input, isolation, and drive functions. The output is switched by means of one or more semiconductors.

A third type, which is in effect a parallel combination of an SSR and an EMR, has electronic sequencing components, a photocoupler, and a coil for its input and isolation functions. The output is comprised of a semiconductor switch in parallel with a set of mechanical contacts, each operating in a prescribed sequence (Fig. 11-5). This dual system now becoming available as a prepackaged unit is not yet categorized as a single component.

With time-delay functions added, the electromechanical or solid-state relay becomes a TDEMR or TDSSR. The applications section shows how SSR capabilities may be further extended by means of added logic.

1.3 Where Are SSRs Used?

Since its introduction over 15 years ago, the SSR has invaded most of the application areas of the EMR but has completely replaced it in only a few. Its major growth areas have been associated with the newer computer-related applications, such as the rapidly expanding field of electronic industrial-control systems—specifically, process control, machine-tool control, and energy-management systems that utilize advanced microprocessor-based programmable controllers. The input/output (I/O) modules described in Chapter 10 are a specialized type of SSR designed specifically for computer interface applications.

Because of their low input-control current requirements, SSRs can operate directly from most of the logic systems used in computers today—hence their attractiveness in this area. They can control a wide variety of loads such as motors, lamps, heaters, solenoids, valves, and transformers. The list of applications in which they are used is endless. The following are a few typical examples:

Security Systems
Fire and Alarm Systems
Dispensing Machines
Traffic Control
Navigation Equipment
Temperature Controls
Instrument Systems
Amusement Park Rides
Production Equipment
Test Systems
Vending Machines
Commercial Laundry
Office Machines
Medical Equipment
Lighting Displays
Elevator Controls

1.4 Why Use an SSR?

When properly used, the solid-state relay (SSR) provides a high degree of reliability, long life, and reduced electromagnetic interference (EMI), together with fast response and high vibration resistance, as compared to the electromechanical relay (EMR).

The SSR offers the designer all the inherent advantages of solid-state circuitry, including consistency of operation and a typically longer usable lifetime. This is possible because the SSR has no moving parts to wear out or arcing contacts to deteriorate, which are the primary causes of failure of the EMR. The long-term reliability of solid-state components has been well established, with idealized cyclic (MCBF) rates well into the billions, whereas the useful life of an EMR with a specified 1,000,000-cycle rating could be very short in a fast-switching application (e.g., 280 hours at 1 cps). With virtually no mechanical parts to become detached or to resonate, the ability of the SSR to withstand vibration and shock is also far greater that that of the less rugged EMR.

The input control power requirements of the SSRs are generally low enough to be compatible with most IC logic families (TTL, DTL, HiNIL, etc.) without the need for intermediate buffers or drivers (typically 10 to 80 milliwatts). Control power requirements are in the region of 200 milliwatts for a typical EMR. Some specialized SSR types known as buffered I/O modules are capable of being driven by the lower current of CMOS and NMOS IC logic systems, requiring only 250 microwatts, or less, to operate (Section 10). From the low level signal demands of SSRs, power loads up to 43,000 watts can be controlled with currently available models.

Table 1-1. *Solid-State Relays (SSR)*

ADVANTAGES	DISADVANTAGES
Zero voltage turn-on, Low EMI/RFI	Higher voltage drop (on voltage)
Long life (reliability) $> 10^9$ operations	Significant power dissipation—may require heat sink
No contacts—handles high inrush current loads	Off-state leakage—can affect load or be hazardous
No acoustical noise	Cost
Microprocessor compatible	Only SPST easily
Design flexibility	Generally designed for AC or DC loads but not both
Fast response	Generally can't switch small signals such as audio
No moving parts	
No contact bounce	

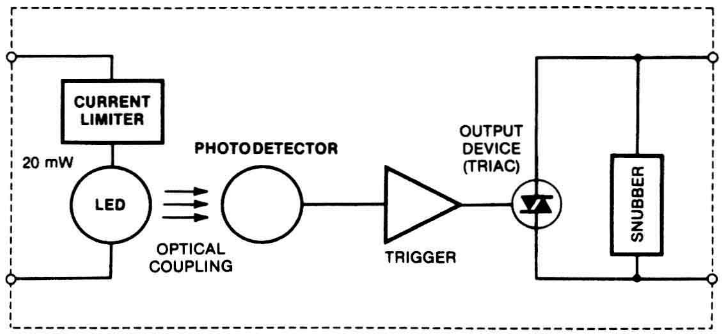
Table 1-2. *Electromechanical Relays*

ADVANTAGES	DISADVANTAGES
Cost	Slow response
Low contact voltage drop	Random (nonzero) turn-on noise
No heat sink required	Contact wear—short life
No off-state leakage	Poor with high inrush current loads
Multiple contacts	Noisy acoustical
Can switch AC or DC with equal ease (although ratings may not be equal)	More difficult to interface with microprocessors
Higher line power	

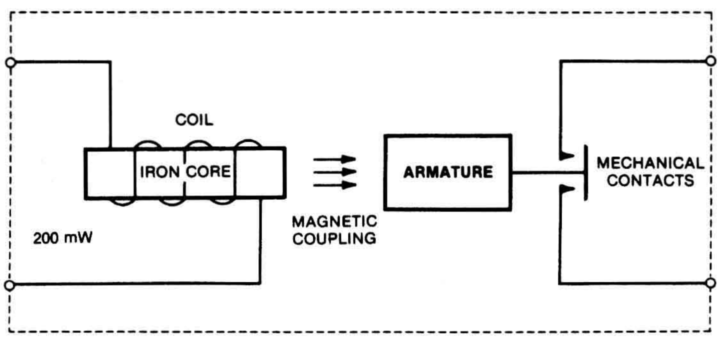
Compared to the EMR, the SSR provides a substantial reduction in EMI (electromagnetic interference). Controlled initial turn-on of the SSR at the zero crossing point of the ac line serves to reduce the high inrush currents associated with capacitive loads and lamp loads. The inherent zero current turn-off feature of thyristors used in AC solid-state relays, irrespective of zero voltage switching, provides a dramatic improvement over the arcing contacts of the EMR. With small step changes in power, proportionately lower levels of EMI are generated.

1.5 SSR vs. EMR

With all the aforementioned attributes of the SSR, one might predict the demise of the EMR. Obviously, such is not the case, since the EMR market is still many times greater than that of the SSR. Examination of Tables 1-1 and 1-2, listing the advantages and disadvantages of each, shows that they complement rather than replace each other. The strengths of one are the weaknesses of the other.



(A) AC solid-state relay (SSR).



(B) Electromagnetic relay (EMR).

Fig. 1-2. ***Solid-state relay and electromagnetic configurations.***

The SSR and EMR are fundamentally similar in that each has an input electrically isolated from the output that controls a load. Fig. 1-2 shows the basic configurations of both the SSR and EMR. In one case, isolation is achieved by photocoupling (Fig. 1-2A) and in the other by means of magnetic coupling (Fig. 1-2B).

Comparing the two relay types, the input circuit of the SSR is functionally equivalent to the coil of the EMR, while the output device of the SSR performs the switching function of the EMR contacts. The SSR is generally limited to a single-pole, single-throw (SPST) device, mainly because of the relatively high cost and volume per pole, whereas, additional poles (contacts) in the EMR add little to the cost or volume, limited only by the magnetic field strength of the coil. Multiple poles in SSRs will become more practical with the increased usage of integrated circuitry, where cost and volume are no longer primary factors.

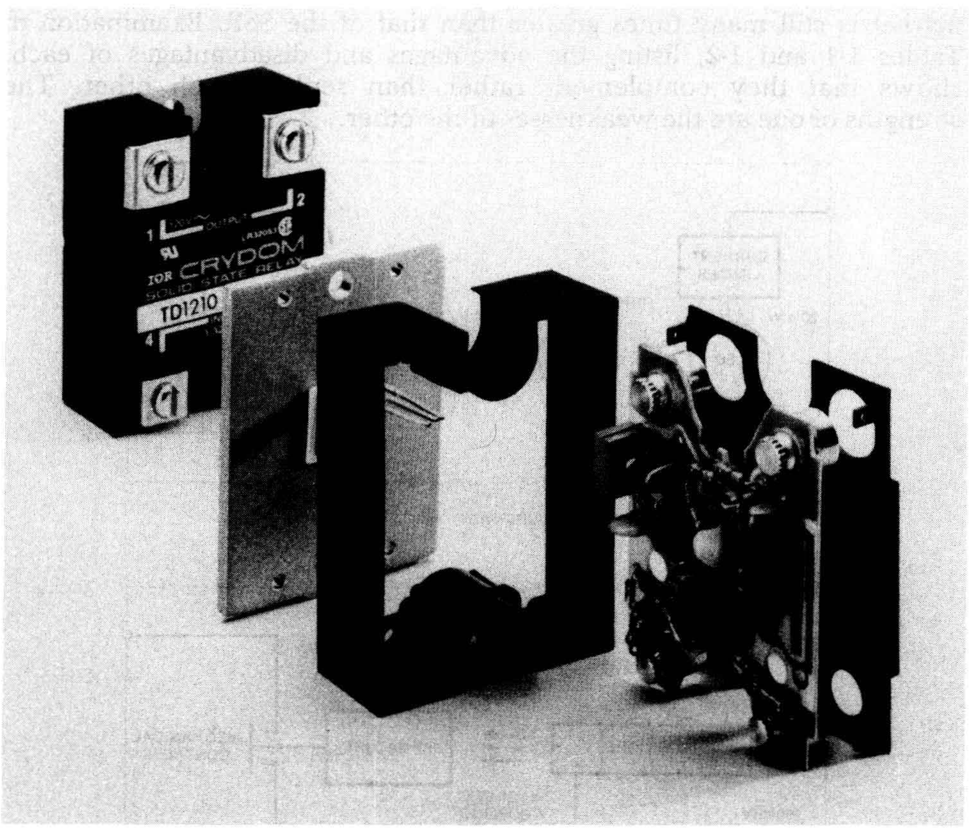


Fig. 1-3. ***An open view of a typical power SSR.*** *(Courtesy IR Crydom)*

An open view of a typical power SSR, showing the heat sink and output semiconductor assembly, together with the PC board and terminal assembly loaded with discrete components is depicted in Fig. 1-3. More recent models may contain surface-mount components or a single integrated circuit driver module.

Operating speed of the EMR is dependent on the time it takes for its mechanical mass to react to the application and removal of the magnetic field. Operating speed of the SSR is primarily determined by the switching speed of the output device, typically much faster—microseconds for DC SSRs, compared to milliseconds for EMRs. In most AC SSRs, response time is related to phase angle and frequency of the line, and because of the desired zero voltage/current features, may be deliberately prolonged. In the case of AC input control, the operating speeds of both the EMR and SSR are similarly extended due to phase angle and filtering considerations.

2

Coupling Methods

Generally, input to output isolation is achieved by means of optical coupling or by an oscillator-transformer combination. Other possible methods employing the "Hall effect" or piezoelectric devices have not been largely exploited in commercially available SSRs as yet. The Hall effect coupling method more closely resembles the EMR in that it utilizes an electromagnetic field (coil) to activate a field-sensitive Hall effect semiconductor device. The piezoelectric method, on the other hand, depends on the piezoelectric (crystal) element being physically stressed or vibrated (possibly by electromechanical means) to produce a voltage which, in turn, may be used to drive a semiconductor switch.

Both optical and transformer-coupled methods (shown in Fig. 2-1) provide about the same input to output isolation capability, typically between 1500 volts RMS and 4000 volts RMS. Insulation resistance is in the order of 10^9 ohms measured at 500 volts DC and a capacitive coupling of approximately 8 picofarads. Voltage isolation between input or output to case is usually specified with the same value as input to output isolation.

2.1 Optical (Photo) Coupling

Optocoupling is accomplished in various ways (Fig. 2-2), the more common of which are listed in Table 2-1, together with their relative characteristics in regard to SSR design.