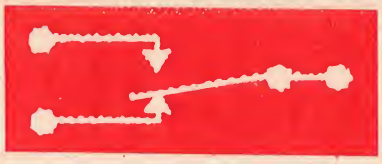

# Have semiconductors relegated relays to a second-class status?

"No!" says author Murray, for the relay still possesses characteristics not obtainable in solid-state devices. To prove the point, he compares their attributes.

DESPITE THE FACT that many traditional relay functions have been taken over by semiconductors, relays are not on the way out. They still offer superiority over solid-state devices in several competitive areas. Also, there are many applications that semiconductors are not yet capable of fulfilling. These are usually marked by very high steady-state currents or extremely high isolation requirements.

Unfortunately many design engineers do not have a firm grasp of all of the factors affecting the relay-versus-semiconductor choice. Some are unduly influenced by either the simplicity of the relay or the "in" status of the semiconductor. Judicious selection requires a point-by-point comparison of relative merits and shortcomings (see table).

### Semiconductors have longer life-span

Solid-state devices do not have known wear-out modes. When operated within specified limits, their life is indeterminate—far in excess of their auxiliary circuitry. Some types—the zener diode, to cite one—are now offered with "lifetime guarantees." In addition semiconductor longevity is not influenced by cycling.

On the other hand, relays have a finite contact life that is largely dependent upon the material used, the nature of the load placed across the contact terminals, and the environment of the application (temperature, humidity, etc.). The lifespan is affected by the relay's cycling capability; degradation occurs less rapidly when the relay is not subjected to repetitive cycling. Contact life typically varies between 20,000 and a few million cycles, depending, of course, on the type of relay involved and the load.

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### Relay switching speeds slower

With very few exceptions, the switching speed of relays is limited to a millisecond or slower. In addition this function is accompanied by a transient period (for contact bounce) that is several times longer than the corresponding switching transient time of semiconductors. Moreover the speed of operation is affected by the presence of low impedances in shunt with the coil. For example, a diode placed across the coil will extend the relay's release, or dropout, time.

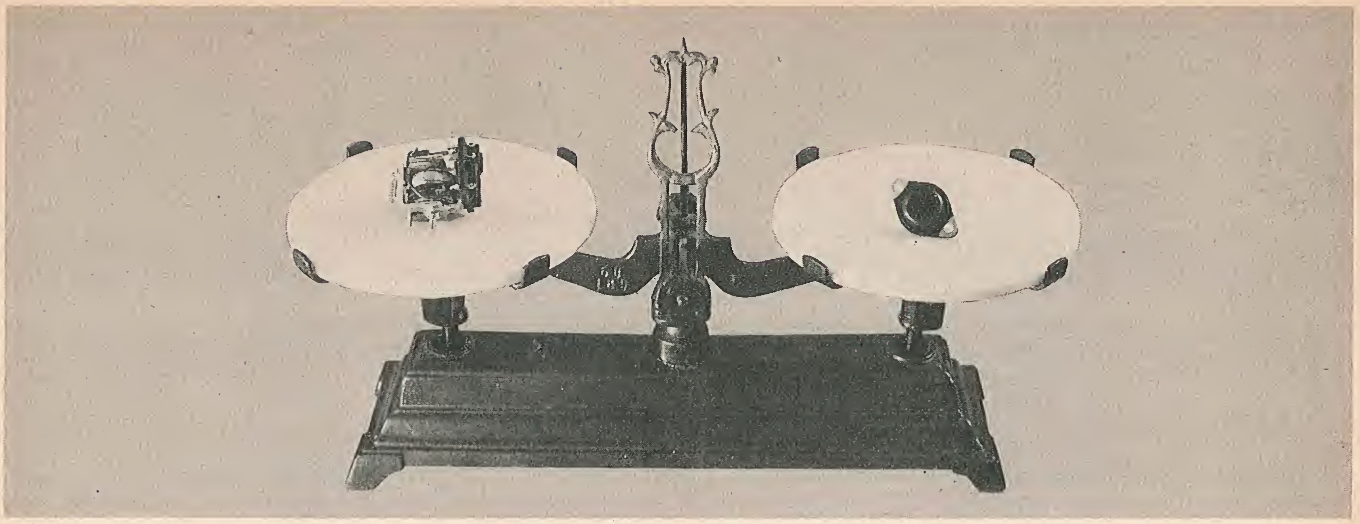
Solid-state devices exhibit typical switching times in the microsecond and nanosecond regions. A few microwave types—such as the varactor diode—achieve a switching speed faster than 1 nsec. The durations of transient signals are usually negligible in comparison with those of relays.

The power capabilities of relays generally exceed those of semiconductors in most electrical (as differentiated from electronic) applications. Thus, a figure of merit may be established whereby the product of switching speed and output power is used to make the judgment.

### Relays bear less g's

Semiconductor parameters are not appreciably affected by either vibration or shock. They typically withstand vibrations of 100 g's and shocks in excess of 250 g's. An acceleration test of 10,000 to 20,000 g's is commonly used in screening programs to eliminate parts with weak bonds or other mechanical defects.

Relays are able to withstand vibration levels of 20 to 30 g's and shock levels of 50 to



## Device comparison

| Circuit requirement | Relays | Semiconductors |
|---|---|---|
| 1. Life | Finite cyclic life. | Insensitive to cycling. |
| 2. Switching speed | Relatively slow (low audio). | Ranges from slow to very fast (beyond 1.0 nsec). |
| 3. Vibration and shock environment | 20 to 30 g vibration limit. | 100 g vibration limit or greater. |
| 4. Circuit transients | Relatively insensitive. | Very sensitive to voltage peaks. |
| 5. Input signal | Coil operates with wide range of ac or dc, relatively imprecise. | Requires dc power source, tolerates narrower variation of input signals, very precise and highly sensitive. |
| 6. Circuit isolation | Excellent isolation. | Lower isolation. |
| 7. Radiation environment | Less sensitive than semiconductors. | Sensitive—increased leakage and loss of gain occur. |
| 8. Output current | Greater maximum capacity, contact bounce present, contact resistance varies. | SCR types have high capacity but turn-off is difficult. |
| 9. System voltage | Handles ac and dc, high values easily accommodated. | Switches ac and high levels only with increased circuit complexity. |
| 10. Amplification | Not an amplifier, per se, although small signals can control large ones. | Sensitive—can handle low inputs, excellent amplification. |
| 11. Temperature | Good performance at high temperature, poor at low temperature. | Excellent low temperature capabilities, upper limit generally much lower. |
| 12. Weight and size | Heavy & bulky. | Smaller & lighter, although more auxiliary components are present. |
| 13. Cost | Cost of auxiliary components is low. | Low-cost devices available. |
| 14. Reliability | Dependent upon circuit complexity, electrical and environmental factors. | Excellent reliability. |
| 15. Design data | Sometimes not complete. | Readily available. |

150 g's without any accompanying opening or closing of contacts. They will survive considerably higher levels of vibration and shock when the contacts are not loaded or when contact transfer is acceptable. Vibration in excess of specified limits may cause contact chatter, thereby shortening life (as the contacts make and break the load).

When low currents are switched by a relay subjected to moderate vibration, signal modulation may occur. The contact resistance at these low signal levels can vary from 1 to 1000 ohms. If the impedance of the contact load is not considerably higher, the changes in contact resistance result in signal modulation at the resonant frequency of the contact, and as a consequence, malfunction.

### Relays more tolerant of transients

Semiconductor circuits usually require protection against externally generated transients. In particular, their voltage ratings cannot be exceeded for even short periods without the danger of misoperation, damage or destruction. The inverse-voltage ratings are especially susceptible.

Relays are relatively immune to transients of a shorter duration than their operating times. In virtually all relay applications, wider transients do not occur. In addition the switching of inductive loads with relays is less hazardous than with semiconductors, because the induced transient voltages are more easily accommodated by the relay.[1]

### Input signal accommodation a toss-up

Relays may be operated by a wide variety of dc and ac voltages. Their parameters are fairly stable with time and life. Operate and release times, however, vary considerably with voltage and temperature. Moreover, although a wide range of trigger signals is accommodated (a 50% tolerance on the low side of rated input is not uncommon), the lack of precision of the input leaves something to be desired. The relay is basically a go-no-go device that is not particularly input selective or sensitive.

Input signals may vary between wide limits without ill effects in semiconductor circuitry. In addition semiconductors are more sensitive than relays, and they also require less drive power. However, additional power supplies and circuit components are often required when the proper input voltages are not available. Further restrictions are imposed by the dictates of reverse ratings, overdrive and the inter-junction relationships which must be maintained.

### Isolation: relay lead narrowed

Relays will isolate inputs from outputs and unconnected output circuits from each other with a minimum specified insulation resistance of 1000 megohms. Except for the field-effect class of devices, semiconductor types require increased circuit complexity to even approach this degree of isolation. Moreover, semiconductor leakage currents increase with time, which further impairs their isolation capability. Solid-state devices cannot tolerate high ac voltages as well as relays.

### Semiconductors less radiation-resistant

Relays are less sensitive to radiation than semiconductors. A comparison of the maximum fast neutron (integrated) exposure that each can withstand and still remain useful shows $10^{15}$ neutrons/cm$^2$ for relays and $10^{13}$ neutrons/cm$^2$ for semiconductors.[2] However, recent advances in solid-state technology—particularly the field-effect types—have narrowed this gap. An exposure to high radiation results in a reduction of transistor gain by a factor of 10 to 20. Germanium devices are less affected than silicon types.

Relay pick-up and dropout voltages, on the other hand, increase by 5-10% when exposed to the same amount of radiation. Radiation increases the leakage current levels in relays. The insulation ability of the relay also diminishes when it is subjected to radiation.

### Output current: Relays take high road

Relays have a very wide range of current handling capabilities. Their upper limit figure exceeds that of the semiconductor. Solid-state devices are presently limited to just under 1000 ampers. SCRs, which have the highest capabilities of semiconductor devices, are more difficult to turn off than turn on. Thus, for the switching of high currents, the relay is the simpler, more versatile unit.

With low-level currents, the semiconductor has two advantages: It is able to amplify the input signal, and it is not subject to cycle-to-cycle variations in voltage drop across the device. Relays can't achieve either of these advantages. The output of semiconductor circuits, however, drifts with time and temperature, thereby necessitating compensation techniques. The relay's output circuit is, by comparison, less temperature-sensitive.

The voltage drop across the device is lower in relays that in solid-state devices. But the relay contact drop will vary from cycle to cycle. Misses can also occur with relays (a miss being a high contact resistance that occurs on one cycle and that disappears on subsequent cycles). Unlike semiconductors, though, the relay output is less affected by the nature of the load—that is, neither matching nor buffering is required.

### Output voltage: relays get the nod

Relay contacts can handle ac, dc, RF—virtually any type of voltage. Their output voltage range is from millivolts to thousands of volts. The switching of ac voltages with semiconductors entails the use of complex circuitry. Moreover, for high voltages, several solid-state units must be used.

### Amplification: semiconductors a natural

The relay is not generally considered an amplifier *per se*—yet it will efficiently turn a very high current on and off with a small signal. The greatest power amplification from a relay can be achieved when one relay is used to switch several circuits carrying high currents. This property of amplification is limited to the low audio range because of slow relay switching speeds.

It is well known that solid-state devices are superior to relays for amplification, particularly at low-signal levels and for higher-speed waveforms. Although this amplifying property is a natural one, it often isn't put to use in switching applications. Moreover even though the input signal may be faithfully reproduced (something relays cannot achieve), some distortion is introduced into the output, even when it isn't wanted, as a result of this property.

### Weight, size favor semiconductors

When simple functions involving power or several control circuits are involved, relay circuitry is usually far less complex than its semiconductor equivalent. For example, considerable solid-state circuitry is required to replace a six pole, double-throw relay switching four amperes. Thus, size may favor the relay on these occasions.

However, the weight of the relay is usually much greater than the combined weight of the semiconductor and its associated components. Low-level switching applications generally favor semiconductors, because of savings in both weight and size. This is particularly true since the advent of microelectronics.

### Cost: no clearcut victor

Generally speaking, applications incorporating relay circuitry are less complex, requiring fewer components, than their semiconductor equivalents. From the standpoint of cost, this would appear to favor the relay. However, the price of semiconductor components—particularly the plastic-encapsulated types—has continued to drop. Solid-state devices are available today in the same cost range as passive components (resistors, capacitors, etc). Prices must be checked to determine which of the two is cheaper.

### Temperature: relays a close second

Both devices are normally rated to operate over the same temperature range. The gain and other key semiconductor parameters vary with temperature. But so do relay operating voltages and switching times.

Relays have a potential for operation at higher temperatures (200°C or more) than semiconductors. However, the low-temperature capabilities of solid-state devices exceed those of relays. Moreover, although compensation methods are available for both, the techniques for semiconductors are more precise and offer greater over-all thermal stability—for example, when matched transistors are used.

### Reliability: circuitry is the key

Assuming that cyclic and environmental considerations are not too severe for relays, circuit complexity will be the chief determinant in comparing reliability. Increases in the complexity of power supplies or other auxiliary equipment should be considered. The sum of the failure rates of all parts should be obtained for the circuit employing relays and the circuit employing semiconductors. The designer is referred to MIL Handbook 217 for a guide to relative part failure rates.[3]

### Semiconductors: design data abounds

Relay manufacturers have not been as prolific as their semiconductor counterparts in supplying information for design. Needed, for example, are more data to permit realistic prediction of failure rates; coil-life data; information on pickup voltage and coil resistance variations with temperature; contact bounce figures, and others.

Semiconductor manufacturers on the other hand typically bombard potential users with analogous information. The net result may be a tendency on the part of designers to lean towards the solid-state devices. ■ ■

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3. Reliability Stress Analysis For Electronic Equipment, MIL-Handbook 217 (WEPS).