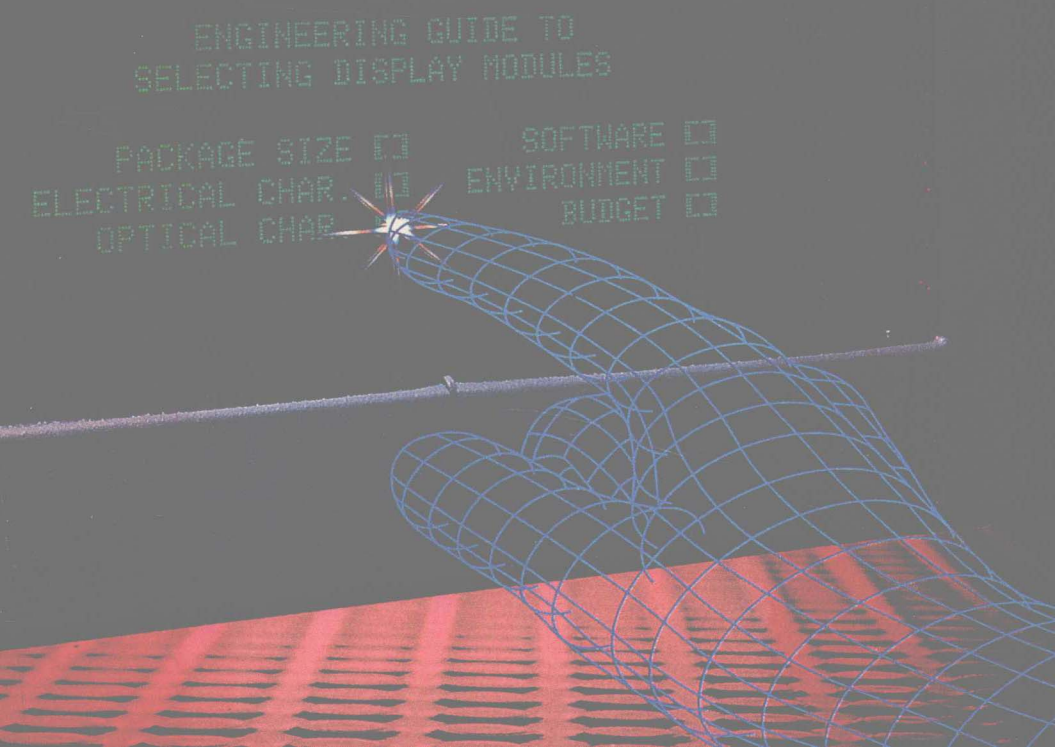
SWITCH ENGINEERING HANDBOOK

JOHN R. MASON



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To
Mary
John & Mahtab
Mike & Donna & Kelley & Michelle
Dave & Susan & McCoy
Melissa
Daniel

About the Author

John R. Mason is marketing director for the XCEL Corporation, makers of switches, panels, keypads, keyboards, and displays for the aerospace, industrial, and medical marketplace. His broad experience in the field of switch and related electromechanical technologies spans 26 years. Mr. Mason is considered one of the foremost authorities on switch technology and is the author of numerous publications on the subject. He resides in Valencia, California.

PREFACE

It is literally impossible to get through our daily routines without at least once, and probably dozens of times, coming into contact with a switch of some type or style. Our use of switches is so prevalent and so mundane that we hardly even think of their importance. Nothing electrical operates unless it is turned on, sometime, somehow, by a switch. The kitchen microwave gets started in the morning by the simple push of a finger... and this same push can start the launch sequence of a multibillion dollar space vehicle. Engineers tasked with designing control panels constantly evaluate switch devices to select the one most suited to the task, the one that is cost effective, the one that will withstand the environment, the one that will fit the design budget. Often, this evaluation is done with very little opportunity to really survey the switch marketplace and understand what is available, and just as importantly, what *isn't* available.

The engineer, always under time and budget constraints, can ill-afford the time it takes (and it can be considerable) to meticulously weigh the hundreds of possible switch configurations which meet the operational requirements of the system. Collecting catalogs is one way to try to keep up with the changing switch marketplace, reading trade journals and attending trade shows is another. But all this painstaking investigation means very little if the engineer doesn't have at least a fundamental understanding of switch technology which would provide a headstart on switch choice.

That is the purpose of this book: to give the engineer some insight into the functioning, construction, and, yes, even the physics of what makes switches work and why. Perhaps this book will give the engineer ammunition in the form of questions to ask the potential switch supplier, questions which can not only help the engineer specify precisely what is needed for the application, but also to verify that the manufacturer selected can, indeed, supply what the engineer needs and specifies, at a reasonable cost and on schedule. It is hoped this book will help the engineer develop an intuition about what will work, and what won't work, when confronted with having to choose from a headspinning variety of switch types, each with its own assets and liabilities. If this book gives the engineer even the slightest edge in the daily battle of time, schedule, and budget, then it has served its purpose.

When a particular switch technology is being considered, always consult with the switch manufacturer(s) about the technical details contained in this handbook; the switch business moves quickly, and what is valid today may be obsolete tomorrow.

John R. Mason

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In researching this book over the last year and a half, the author has had an opportunity to talk to people all over the world who are involved with switches. This group of "switch" people all shared one thing in common: an enduring interest in switches and switch technology. Whether it was the small, three-employee switch manufacturer in Germany, or the large, multiemployee circuit breaker manufacturer in the United States, I continually found an enthusiasm for the products they design and build, and an inquisitive nature about switch technology. It has been a pleasure meeting with and talking to these interesting people.

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John R. Mason

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CHAPTER 1
INTRODUCTION TO SWITCH TECHNOLOGY*

Electricity is a form of energy. Energy is defined as the ability to do work. Energy can be stored before it is used to accomplish useful work. When energy is stored, it is called "potential energy." For example, a simple flashlight battery is a source of "potential electrical energy." There are other forms of energy, but for the purposes of this handbook, we concentrate on electrical energy.

The stored electrical energy can be released and put to work, but it must be controlled to accomplish the desired work.

Electrical energy is particularly useful because:

- It is readily converted into other forms of energy and other forms of energy are readily converted into electricity.
- It is easily transported from one place to another.
- It can be controlled very precisely.
- It is usually readily available.

Examples of electrical energy being converted into other forms of energy are electricity into sound in a stereo speaker, electricity into rotary motion in a motor, electricity into heat in an electric heater, and electricity into light in an incandescent lamp. Examples of these same forms of energy being converted into electricity are sound into electricity in a microphone, rotary motion into electricity in a generator, heat into electricity in a thermocouple, and light into electricity in a solar cell.

Electrical energy is easily transported by means of conductors such as wires or bus bars, and is readily controlled by relays, potentiometers, and switches. Electrical energy is converted, transported, and controlled in an electric circuit. An electric circuit can be simple or complex. An ordinary flashlight is an example of a simple electric circuit consisting of a battery, which provides the electrical energy; an incandescent lamp, which converts the electrical energy into light; connecting wires, which transport the energy between the battery and the lamp; and a switch, which controls the electrical energy.

This simple electric circuit, like its complex counterpart, consists of three principal parts:

- A *source* of electrical energy

*Numbers in parentheses indicate items in the References at the end of this chapter.

- A *load* (converting device)
- A *complete path for current*

If any one requirement is not fulfilled, current will not travel in the circuit. A switch is used by an operator to open and close the path for current. As such, a switch is a basic element used for control of current in a circuit.

The *source* in the circuit is that device which provides the necessary energy to cause an electrical action to take place.

The *load* in an electric circuit is that device which converts electrical energy into some other form of energy. Regardless of the purpose of the circuit, a load is necessary to produce the desired output (energy conversion or signal development).

Energy is transferred between the source and load by means of an electrical current. This current travels from one terminal of the source, through the load, and back to the other terminal of the source. The source provides the energy which causes the current to travel this path. Unless this path is present, current cannot travel through the load; electrical energy will not be converted, and no useful work will be accomplished. Thus the last requirement for an electric circuit is a complete path for current.

A switch performs its function by opening or closing the path for current in a circuit. When the path for current is open, the load is disconnected from the source, and there can be no current in the circuit. When the switch closes the circuit, the requirements are met and current travels through the load. This action by the switch is referred to as "making and breaking" the circuit. For our purposes, then, the basic definition for a switch is:

"A switch is a device for making or breaking an electric circuit."

The definition suggests the ultimate in simplicity—that a switch need be no more than the bare ends of two wires that can be touched to *make* a circuit or separated to *break* a circuit.

If we touch or separate the two bare wires of our "switch" while current is flowing in the wires, an arc appears between the two wires. Arcing is a natural phenomenon attendant to switching, the arcing being more intense on break (or separation) because of the induced current created by the collapsing magnetic field. Because arcing is damaging to switch contacts, much of switch design is devoted to taming the arc. As will be seen later in this chapter, the physics of arc extinction is a complex science, and many switch engineers have devoted entire careers to the understanding, and conquering, of this phenomenon.

Obviously, even though the two bare wires meet our fundamental definition for a switch, a device is needed to permit opening and closing the circuit in a more sensible way. A great improvement over our crude bare wire "switch" is the familiar knife switch with its hinged copper blade, break jaw, and insulated handle and base. All switches today can trace their lineage back to this crude, but effective, switch which, for all its simplicity, did exactly what it was designed to do: make a circuit and break a circuit in an efficient, straightforward manner.

All switches have a common denominator (Fig. 1.1) in basic components:

- The *actuator,* which initiates switch operation
- The *contacts* made of low-resistance metal that make or break the electric circuit
- The *switch mechanism,* linked to the actuator, which opens and closes the contacts

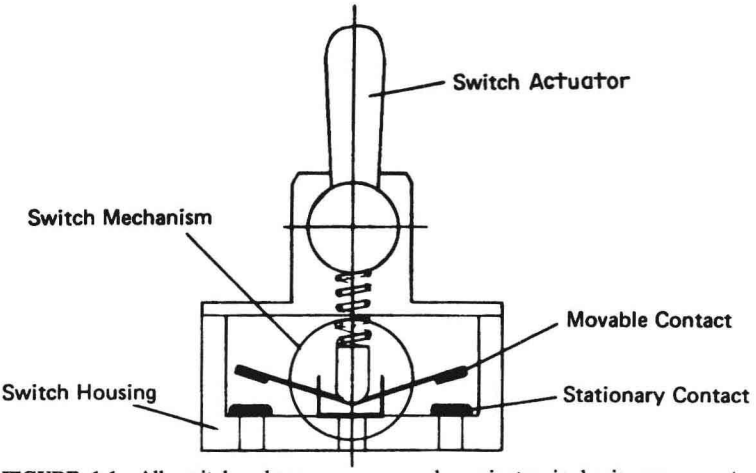

FIGURE 1.1 All switches have a common denominator in basic components. [*Adapted from (4).*]

If the original knife switch is compared with one of today's high-precision avionic-grade pushbutton switches, the same three basic components of a switch are in evidence. However, our advanced knowledge of such areas as vibration analysis, metallurgy, and polymer chemistry has pushed modern switches to high levels of performance and reliability.

The fact that a switch is nothing more than a device for making or breaking a circuit might suggest that the technology is equally simple. Nothing could be further from the truth! The discussions of switching technology in this and the following chapters emphasize to the reader that switch design is a complex interaction of a wide variety of disciplines, from chemistry to human factors, requiring careful attention to detail by switch manufacturers, regardless of whether the switch is destined to control an appliance in the innocuous ambience of a contemporary kitchen or to initiate the imaging system operation of an earth-launched probe in the hostile environment of deep space.

VOCABULARY OF SWITCHES

Three major terms designate a switch's function—*pole, throw,* and *break.* A single-pole, single-throw, single-break switch will be used to define these terms. This switch is also abbreviated SPST, for single-pole (SP), single-throw (ST).

Pole

The term pole refers to the number of conductors that can be controlled by the switch. In our example, the single-pole switch is capable of interrupting the current in a *single* conductor of the circuit (Fig. 1.2*a*). A double-pole switch, by comparison, is capable of simultaneously interrupting the current in two separate

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