FUSE With Care . . . IT PAYS!

Just because it fits doesn't mean it's correct!

by Jim Essex

The tremendous growth of the electrical industry has led to a giant few understand, — ironically, the lowly fuse. They are everywhere, — and with good reason. Imagine, if you can, the state of the industry today if they weren't readily available and at low cost. Fires would be commonplace and millions would be wasted annually on expensive electronic and electrical equipment that failed. Or put another way, what would our costly circuits be worth if a malfunction of only one part could destroy thousands of dollars worth of equipment due to an overload? Fortunately, there are fuses in practically any size and shape to fit a particular circuit, — and the pocketbook. All are designed for a specific need, — tailored to suit your particular application. But there a few important rules to observe. For example, size alone, — in some applications, — doesn't necessarily mean it's the right fuse.

The auto industry is one of our earliest users of fuses on a mass scale. In its infancy, cars had no headlights, precluding fusing there. But in short order came not only headlights, but heaters as well, not to mention windshield wipers, panel lights, brake lights, etc. To reduce confusion, they adopted a simple code . . . if it fits, it's the right one. This was the SFE fuse line still in use in some applications today, although more recently fuse blocks are becoming uniform in length. For illustration, the SFE line, simply stated, related length to amperage capacity. Thus, a 6 amp fuse (¾″ long) was shorter than a 9 amp fuse (⅞″ long). Starting with the SFE 4 amp fuse at ⅝″, they increased in size to 1-7/16″ for the 30 amp fuse! Thus size was real handy in replacing car fuses, as you can see. If it didn't fit, it wasn't the correct fuse! fig A). Now, however, we have additional fuses which don't necessarily match this rule, like the "Buss" fuse *AGC series* which are all ¼″ diameter by 1¼″

long (fig B). Amperage range in capacity from 2½ amps to 30! In fact, fuses in this group go from 1/500 amp capacity (to protect sensitive meter movements) to 30 amp ratings for Diesel trucks and cars. And in the midrange, we have TVs and Hi-Fi's, all expensive equipment but protected 24 hours by fuses.

We have met the enemy and he is us!

Of course, there are limitations in fuses. Us! Failing to observe a few important points about them reduces or rules out their value altogether. One day a hurried salesman couldn't get his car windshield wiper going. He failed to observe the rating on a fuse he had handy. Inserted, it failed soon after. In disgust, he wrapped cigarette foil around it and drove off. Not long after, the motor burned out during a severe snow storm when the wiper jammed. Cost, — over $20.00 where a few cents and a little time would have served. Sense, also. Because it is. after all, common sense — and eyesight, that assures a winning combination; common sense, — to know which fuse to choose; eyesight, — to read correctly what's on the fuse. In a truck plant I know, — manufacturing fire engines, for example, — intricate lighting is part of the game. Wiring networks feed flashing lights, signal warning lights and compartment lights, to name a few. Three of the fuses have the same physical dimensions, yet range in amperage carrying capacity from 5 amps through 20 to 30 amps! Failure here to observe fuse markings could mean disaster.

When the fuse industry went into the manufacturing of fuses, it was the Society of Automotive Engineers who had the idea in mind that amperage would be related to fuse length. Now, according to a recent information release from James E. Weingartner Advertising manager for Bussmann Fuses, — who kindly made their latest information available, — fuses know no bounds where size, amperage, or dimensions are concerned today. And if what they have isn't available, they'll "tailor make" a particular fuse, — just for your application. He does point out, though, that frequently, a standard fuse or fuse mounting, readily available from wholesalers' stock, can be adapted or modified to meet your exact needs. They offer a staff ready to assist you to help solve your electrical design problems.

Readily available and listed in most catalogues, are fuses like AGX (formerly 8AG), AGC (formerly called 3 AG), AGS (formerly 4 AG). These fuses cover a variety of applications, ranging in capacity from 1/16 amp for the AGS on up to 50 amps, to the AGX ranging from 1/500 amp to 2 amps. These fuses differ from the old SFE ratings because they **do not**, as you'd expect, differ according to amp rating! They maintain a standard length, regardless of amperage capacity — as for example, — the AGS (formerly 4 AG) fuse. It is 9/32″ by 1¼″ long. The AGC fuses are ¼″ by 1¼″, — same length but a different diameter! Thus, you couldn't use an AGS fuse in a AGC holder. These are fuses in one family of amperage ratings but with the same physical properties, unlike the SFE previously mentioned. In other words, if your equipment needs require a fuse, the AGS will allow fuse choice anywhere from a low of 1/16 amp, up. But unlike the SFE, don't look for physical dimensions alone to guide you in deciding whether or not to put in say, — a 50 amp replacement. If you don't look at the rating stamped on the fuse itself, you could conceivably insert a 1/16 amp fuse by mistake, and you know what will happen.

A safe rule is to follow manufacturers recommendations wherever possible. In TVs of late, they're coloring mains fuses according to rating. These are the new line of "chemical" fuses and come in a rectangular plastic case with special lugs which fit into a matching socket. That type fuse, — and that alone, — will fit. Replace with a similar fuse having the same color. e.g. yellow with a yellow, purple with a purple, etc., and you can't go wrong.

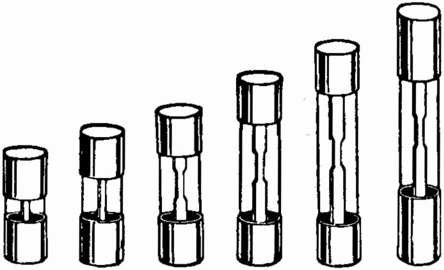
Summing up, you can get (I'm talking about glass barrel type fuses, now) an AGC fuse — formerly called 3AG, — in 30 amperes with a length of 1¼″. An SFE having different length but same amperage, would jump to 1 7/16″ but it would have a ¼″ diameter for both. The 4AG (now called AGS fuse) run to 1¼″ but with a larger diameter than the old 3AG (now AGC) of 9/32″. The 5AG (now AGU) run to 1½″ with a diameter of 13/32″. You'll be thinking by now that the letters mean different family groups according to size. You are right. When choosing a fuse, a simple guide might be: — Determine the physical dimensions of the fuse to be used. Then choose a fuse that has the current-carrying capacity the circuit requires. If you're working in a circuit — as, for example, a motor, — in which momentary surges occur but you don't want to sacrifice protection by going higher in fusing, choose a slow-blow fuse having a high enough time-lag. It can withstand heavy surges, yet blow quickly on shorts. These fuses have a fuse link which operates only on very high overloads or short-circuits and have a thermal cutout which functions on low overloads. The thermal cutout cannot operate quickly at any load, — hence a long time-lag is obtained. Yet, protection is afforded against short-circuits or continued overloads. Common types are the Buss FNM or MDR, essentially similar fuses but one has a glass tube and the other, fibre. (fig. C.)

Ambient temperature has an effect on fuse-blowing capability of a fuse as well, — although it is not of much consequence in most fuse applications the average technician has to deal with. But as a point of interest, Fusetron dual element fuse ratings are based on an ambient temperature of 70-80 degrees F. Higher or lower temperatures thus affect the carrying capacity. (see chart fig. C). For example, an ambient of 104° F. drops the carrying capacity 5%.

Often, technicians are confused by voltage ratings marked on fuses, — 32 volts, 125 volts or 250 volts. The voltage rating indicates the maximum voltage for which that particular fuse is designed and tested. For example, a typical voltage rating may be marked as 250 volts. This simply means the fuse will operate just as accurately on any circuit of lower voltage since it is the current in amps flowing through the fuse that causes it to open. If your application is for, say, 32 volts, and

BUSS fuses — SFE standard

All cuts actual size. Fuses of different amperages are of different lengths — to make it impossible to insert too large a size — thereby preventing over-fuseing.



Glass tube — diameter ¼ inch. Length as per table below. Test specification — carry 110%, open at 135% within 1 hour. Listed by Underwriters Laboratories, Inc. Made according to SAE specifications.

Voltage	Symbol & Amperes	Length Inches	Shipping Weight Lbs. Per 100
32 or less	SFE4	⅝	0.73
"	SFE6	¾	0.75
"	SFE7½	⅞	0.80
"	SFE9	⅞	0.80
"	SFE14	1$\frac{1}{16}$	0.82
"	SFE20	1¼	0.87
"	SFE30	1$\frac{7}{16}$	1.60

Fig. a

(Turn to page 27)

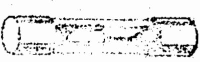
Fuse with care

(From page 21)

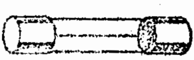
the fuse you get is marked for the same amperage but at 250 volts, it will work satisfactorily, but it may cost a little more.

Fuses are becoming more and more exotic every day, ranging from the simple glass-barrel type which you have to look at to detect whether it is "open" or not, to the new Buss fuses having a red button which extends from the fuse end telling you when the fuse has "blown". However, they are all there to basically protect your equipment, and let not the "penny-wise-but-pound foolish" syndrome affect your decision on whether to fuse or not! It is the ONLY WAY.

BUSS fast acting fuses for protection of instruments, etc.
¼ x 1¼ inch. Glass tube. Formely called 3AG.



AGC 1/500 to 1/32 amp.
MGB 1/16 and 1/3 amp.



1/16 to 2 amp.

Provide high speed action necessary to protect sensitive instruments or delicate apparatus.

AGC 1/500 to 1/32 ampere sizes and MGB 1/16 and 1/8 amperes sizes have bridge construction. This prevents physical damage to delicate element from rough handling or vibration.

1/16 to 2 amperes sizes have straight through element.

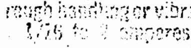
AGC fuses are listed by Underwriters Laboratories, Inc.

Test specifications — carry 110%, open at 135% in 1 hour or less. 1/100 to 2 ampere sizes also will open at 200% load in 5 seconds or less.

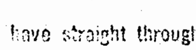
Voltage	Symbol	Amperes
250 or less	AGC	1/500, 1/200, 1/100, 1/32, 1/16, 1/10, 1/8, 15/100, 175/1000, 3/16, 2/10, 1/4, 3/10, 3/8, 45/100. 1/2, 6/10, 3/4, 1, 1 1/4, 1 1/2, 1 6/10, 2
250 or less	MGB	1/16 or 1/3

MGW & MGB fuses now called AGC.

BUSS glass tube fuses, ¼ x 1¼ inch



AGC 3 and 4 and MTH 4, 5 and 6



AGC 5 to 30

Formely called 3AG.

Test specification — carry 110%, open at 135% within 1 hour.

Fuses rated for 250 and 125 volts listed by Underwriters Laboratories, Inc.

Voltage	Symbol	Amperes
250 or less	AGC	2 1/2, 3
250 or less	MTH	4, 5 or 6
125 or less	MTH	7, 8 or 10
32 or less	AGC	4, 5, 6, 7, 7 1/2, 8, 10, 15, 20, 25, or 30

Sizes larger than 30 ampere are not recommended as clips or fuseholders would not permit fuse to carry such high currents. If surges or starting currents make heavier fuse necessary, use MDL FUSETRON dual-element fuses.

Fig. B

FUSETRON dual-element fuses
13/32 x 1 1/2 Inch

Same as FNM above listed except glass tube instead of fibre tube.

Voltage	Symbol	Amperes
250 or less	MDR	1/10, 15/100, 2/10, 3/10, 4/10, 1/2, 6/10 or 8/10
125 or less	MDR	1, 1 1/2, 1 6/10, 2, or 2 1/2
32 or less	MDR	3, 3 2/10, 4, 5, 6 1/4, 8, 10, 15, 20, 25, 30, 35 or 40

FUSETRON dual-element
fibre tube — slow blowing fuses
13/32 x 1 1/2 inch

These fuses avoid needless blows from starting currents or surges. They have a fuse link which operates only on very high overloads or short-circuits— they have a thermal cutout which functions on low overloads — the thermal cutout cannot operate quickly at any load, hence long time-lag is obtained. Yet protection is afforded against short-circuits or continued overloads.

Test specifation — carry 110%, open at 135% within 1 hour.

125 and 250 volt sizes listed by Underwriters Laboratories, Inc.

Voltage	Symbol	Amperes
250 or less	FNM	1/10, 15/100, 2/10, 3/10, 4/10, 1/2, 6/10, 8/10, 1, 1 1/8, 1 1/4, 1 4/10, 1 6/10, 1 8/10, 2, 2 1/4, 2 1/2, 2 8/10, 3 2/10, 3 1/2, 4, 4 1/2, 5, 5 6/10, 6 1/4, 7, 8, 9 or 10
125 or less	FNM	12 or 15
32 or less	FNM	20, 25 or 30

Fig. C fibre type

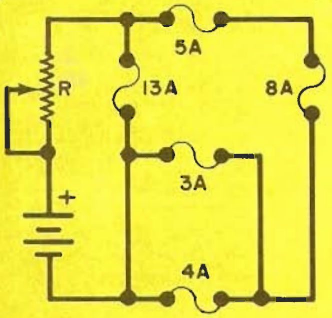
Prints courtesy Mr. J.E. Weingartner

Bussmann Mfg. Division. St. Louis, Mo.

FUSING QUIZ

One of the most important components in an electronic circuit is the fuse, which protects the entire system from current overload. Circuit designers, technicians, and hobbyists should be acquainted with the various types of fuses and how to use them.

To test your knowledge of fusing circuits, see how many of the following problems you can solve. For each of the circuits shown below, determine the order in which the fuses will blow as resistance *R* is slowly decreased to zero. Assume that the battery can deliver any required amount of current, and that each fuse has an internal resistance of one ohm, regardless of its current rating.



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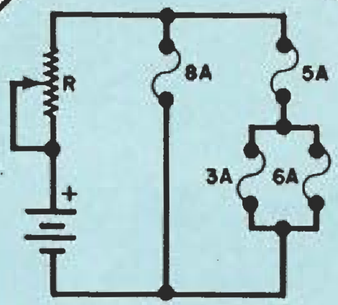

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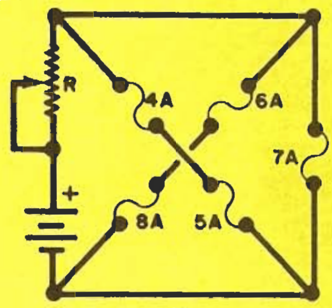

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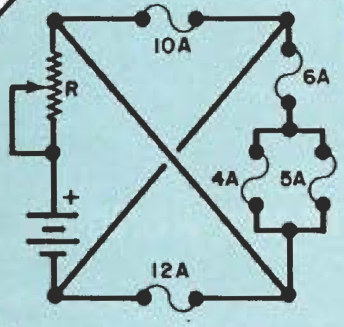

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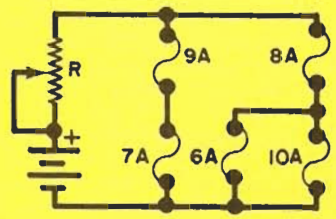

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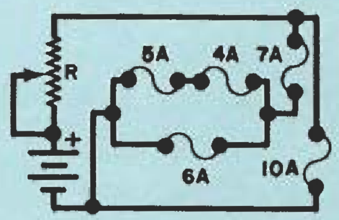

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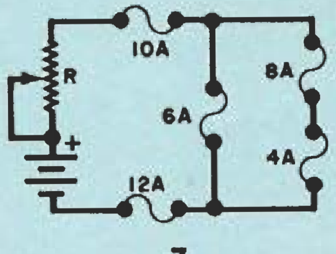

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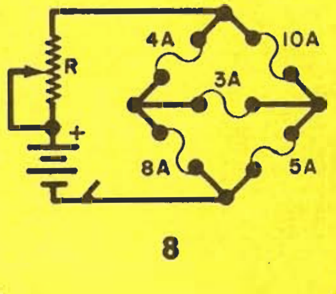

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ANSWERS

1. 5A, 13A
2. 5A, 8A
3. 7A, 4A, 6A
4. 6A, 10A, 12A
5. 8A, 7A
6. 10A, 7A
7. 6A, 4A
8. 4A, 5A, 3A

fuses—are they RESISTORS?

By **FRANK G. STIVER**

Their resistance has to be considered in low-voltage circuits

THE STUDY OF TRANSISTORS IS STILL constantly filled with comparisons and contrasts with vacuum tubes. One of the important differences between the two is that transistors are basically low-voltage, high-current devices while tubes work with low currents and high voltages. This basic difference has made it necessary for us to change some of our preconceived vacuum-tube ideas.

Recently I ran into two separate but identical situations that emphasized this basic difference. The problem in both was a transistorized regulated power supply that had poor regulation. One was designed for use in a laboratory, with several distribution points. When constructed and tested it provided over 4 amperes at 12 volts with better than 1% regulation. The other was rated at 6 volts, ½ ampere, with better than 1% regulation.

In both cases the cause of the voltage variation was not in the regulator. The poor regulation was due to a large (for transistors) voltage drop across a ½-amp fuse in the distribution line. At first when I measured a drop of over ½ volt across the ½-amp fuse, I thought there must be a bad solder joint at the holder. A measurement directly across the fuse quickly eliminated that possibility. My next thought was a bad internal connection in the fuse, but replacing the fuse resulted in an even larger voltage drop.

I finally got around to applying Ohm's law and found that ½ volt at the 400-ma test current I was using made the fuse resistance around 1.2 ohms. (After all, a fuse *is* a heat-operated device and must generate enough I^2R to activate it.)

I decided to investigate the resistance of fuses with other current ratings. Written material on the subject was very scarce; the best way of finding what I wanted to know was actually to measure the resistance of various fuses.

TABLE I—Measured resistance of medium-lag fuses.

Amp Rating	Measured Resistance (ohms)				
1/16	8.5	36.0	7.3	7.1	6.7
1/8	6.0	4.8	6.0	4.6	5.4
1/4	3.0	3.5	3.3	3.1	3.0
1/2	1.4	1.3	1.1	1.2	1.2
3/4	0.6	0.8	0.8	0.8	0.7
1	0.4	0.4	1.6	0.6	0.5
2	0.2	0.2	0.2	0.2	0.2
1/2 S-B	1.9	1.8	2.0	1.7	2.0

TABLE II—Manufacturers' resistance ratings of high-speed fuses.

Amp Rating	Resistance (ohms)	Amp Rating	Resistance (ohms)
1/100	263.4	½	2.7
1/32	40.0	¾	2.0
1/16	6.9	1	0.24
1/8	6.0	1½	0.13
1/4	4.7	2	0.10
3/8	3.0	3	0.060

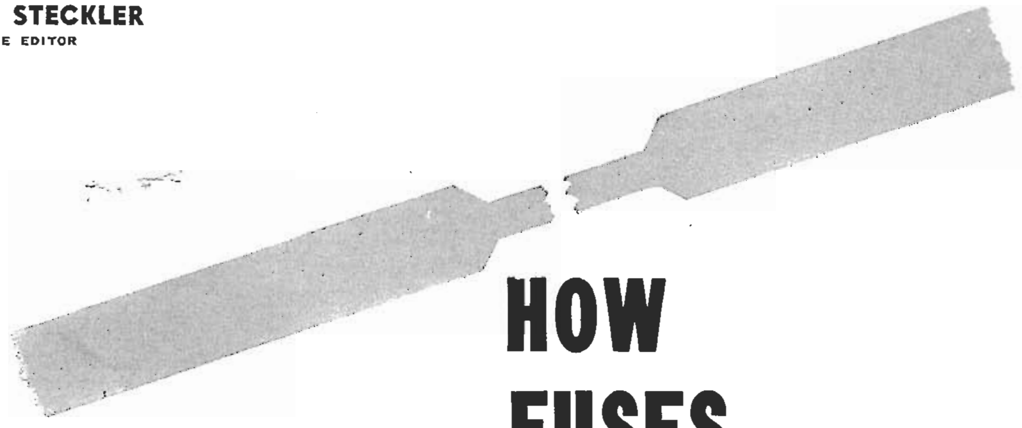
The results of my measurements on five fuses of each current rating are recorded in Table I. All fuses except the one ½-amp Slo-Blo group were the medium-lag type most commonly used in electronic equipment. Notice that resistance varies among fuses with the same current rating. I made no measurements on the high-speed fuses used in delicate test equipment. However, Table II lists the resistances quoted in the catalog of one of the leading fuse manufacturers.

It is interesting to note from Table I that the product of fuse resistance times rated current will give a drop centering around ½ volt across all fuses. It is also evident that, for any given current, a fuse with higher current rating will cause a smaller voltage drop.

Perhaps the easiest solution to the fuse resistance problem is to keep fuses out of low-voltage circuits where good regulation is important. Instead, whereever possible, such as in power supply circuits, let's put the fusing in the primary. If we *must* put fuses in the low-voltage circuits, let's be sure to use fuses with the largest fuse rating consistent with adequate protection, and remember that each fuse is a small resistor.

In conclusion: Low-voltage, high-current circuits, so common with transistors, force us to think of sources of resistance that can often be ignored in vacuum-tube circuits. Vacuum tubes operate at such high voltages and relatively small currents that the small voltage drop across fuses and meters can normally be ignored. In low-voltage, relatively high-current transistor circuits we must be very watchful of these small resistances. Otherwise even our good friend the fuse may become one of our problems. END

By LARRY STECKLER
ASSOCIATE EDITOR



HOW FUSES WORK

There's more to these tiny equipment savers than you realize

QUIETLY a screen capacitor shorts under continued stress. Current drain increases in the horizontal output tube. The flyback heats up. And a hair-thin filament inside a glass envelope melts away, restoring safety. This is what a fuse does!

Two leads in a line cord short. Sparks fly. Smoke starts to rise. And down in the basement a metal strip literally explodes. The current is cut off. That is what a fuse does!

The switch is thrown. Current is applied to a motor that doesn't start. The windings begin to heat up. Insulation starts to smoke. And a little pool of solder gets hot enough to melt, a spring lends its assistance. The circuit is opened and safe. That is what a fuse does!

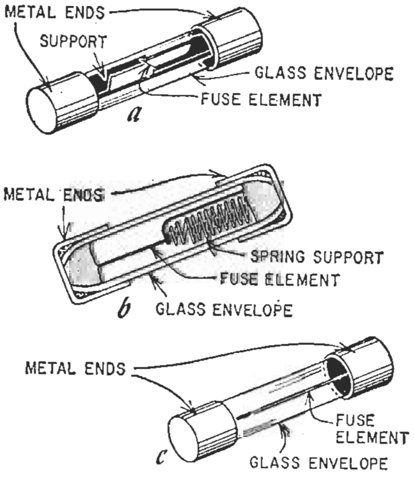


Fig. 1-a—Instrument fuse with anti-vibration mounting. b—Another type of anti-vibration mounting. c—Larger amperage fuses do not need anti-vibration mountings except in special applications.

A 10-volt meter is connected to a 300-volt source. The meter pointer heads for the pin at the top of its range. And a microscopic filament gives way. The meter pointer drops back to zero. That is what a fuse does!

These are examples of the important thing a fuse does—protects electrical circuits. But *how* does a fuse protect? What kinds of fuses are in common use? How do they differ? Where do you use them? These are the questions we will try to answer.

Pick up a fuse, any fuse. No matter what its shape or size, somewhere on its body are two important pieces of information—a voltage rating and a current rating. Let's see just what these ratings represent. We'll take the current rating first.

This is always in amperes or a fraction of an ampere and can range from 1/500 ampere up to any desired value. It simply represents the amount of current the fuse will handle without opening. Greater currents will make the fuse open.

The voltage rating isn't quite so simple. It represents the maximum voltage that can safely be applied to the fuse. A fuse rated at 250 volts can be used in any circuit as long as no more than 250 volts are applied. If more than 250 volts are applied to a 250-volt fuse, several things can happen:

▶ If the voltage is much higher than the fuse rating, it may arc across the fuse.

▶ When a fuse blows, a section of the fusible element literally explodes. But if too high a voltage is applied, this explosive force is greater as a larger section of the fuse link is vaporized. This can cause an under-voltage fuse to explode and send shattered case fragments into anything or anyone close by. The fuse is rated to withstand burnouts at its rated voltage, but will not stand up under excessive voltages.

▶ If a 250-volt 10-ampere fuse is used in a 250-volt circuit and the line shorts, the fuse blows. But no matter how much current goes through the fuse, it will not shatter when it blows.

Types of fuses

With some variations there are three basic types of fuses—fast-acting, standard and delay. The fast-acting fuse is

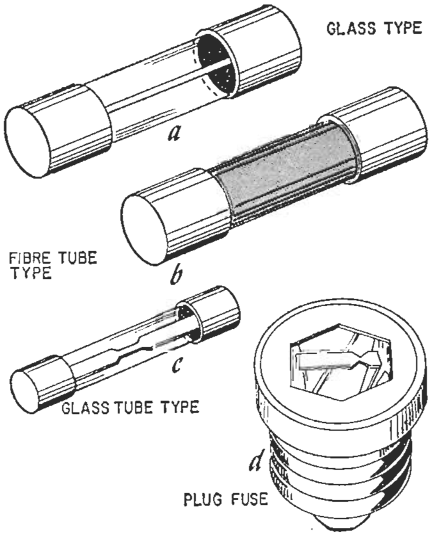


Fig. 2—Basic types of fuses: a—Cartridge type with glass envelope and wire fuse link. b—Cartridge type with fibre envelope. c—Cartridge type with ribbon element. d—Plug type with ribbon element.

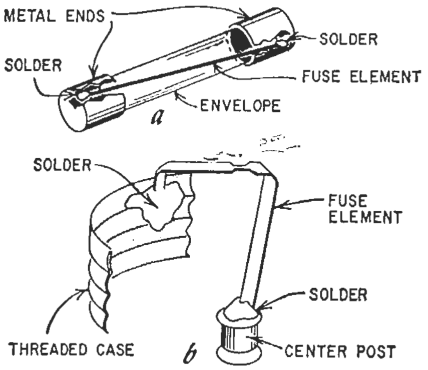


Fig. 3—Internal assembly of fuses. a—cartridge type; b—plug type.

designed to protect delicate meters and instruments. It is usually made only in values between 1/500 and 2 amperes. These fuses will carry their full rated current without opening, but a 200% overload will cause them to open in less than 5 seconds. Greater overloads will make them open even faster. For example, a 500% overload will open a fast-acting fuse in 3/100 second.

The smaller instrument fuses (1/500- to 1/32-ampere units) have extremely fine elements—some can barely be seen with the naked eye. Therefore they are supported bridge-fashion to protect them against vibration. Sudden shocks would snap such a fine element if it were not supported. The construction of this type of fuse is detailed in Fig. 1-a. In Fig. 1-b another type of anti-vibration mounting is shown. The 1/16- to 2-ampere sizes are illustrated in Fig. 1-c.

When we come to the standard types, we find a variety of sizes and shapes. Typical units are shown in Fig. 2. All of these are usually rated to carry 110% of their rated current without opening, yet will open in less than 1 hour if current goes up to 135% of the rated value. Again, greater overloads will blow the fuse much sooner, within fractions of a second in some instances.

The two major types of standard fuses are plug types (like those you use in your fuse box at home) and cartridge types that have either a glass, fiber or bakelite case. The elements are either a single wire or a flat ribbon (Fig. 2). In cartridge types this element is supported at each end (Fig. 3-a), while in plug types the mounting is a little more complicated (Fig. 3-b).

The amazing things about these fuses are the things not generally known. For example, let's take a plug type fuse that has just been subjected to a severe overload. The intense heat caused by the excessive current turns the fuse link into white hot gases under tremendous pressure. Naturally, there must be a safe way for these gases to escape. One manufacturer handles this problem by making the top cap of its fuse act as a valve (Fig. 4). The hot gases spread out along the mica window in the top of the fuse and escape through tiny notches under the edge of the top cap. This cools the gases and allows them to discharge safely.

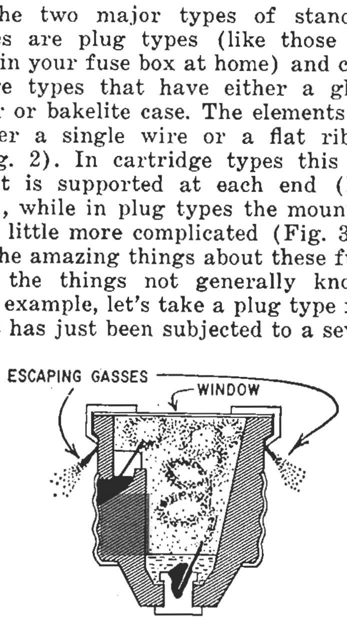


Fig. 4—When this type of plug fuse blows, gas escapes through vents around the cap.

Now to one of the most interesting of all, the slow-blow or delay fuse. The thing that makes these units so fascinating is that they work in a variety of ways although they all do the same thing. Basically, a delay fuse will tolerate a certain amount of overload and do so intentionally. However, if the overload continues for an excessive period of time, the fuse opens. Also, a delay fuse will blow almost instantly if the overload is many times too great.

These fuses are often used where motors (air conditioners, refrigerators, etc.) are in circuit, since such devices often draw starting currents several times greater than their running current. For example, a 7.5-ampere air conditioner needs a 15- to 20-ampere standard fuse to tolerate its tremendous starting current. But if the motor didn't start, it would draw enough current to burn out but not enough to open the fuse.

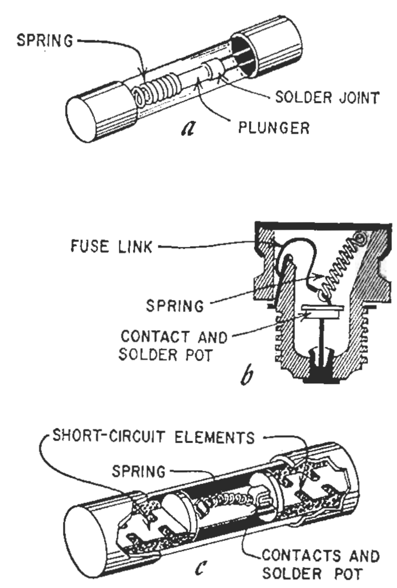


Fig. 5—Construction of various types of slow-blow and time-lag fuses.

When you use a slow-blow fuse, however, a 10-ampere unit will take the starting surge of 15 to 20 amperes without blowing but, if this surge doesn't taper off within a reasonable time, the fuse will blow. This could happen if a starting capacitor shorted.

In some of the older TV receivers, slow-blow fuses were used to protect the high-voltage circuits. These sets developed transient pulses that would blow a standard fuse. By using a slow-blow fuse, however, the set manufacturer got a delay that was long enough to keep the fuse from blowing because of transients, as well as protection against severe shorts. So in a TV receiver, never replace a slow-blow fuse with a standard type or you'll probably find yourself coming back again because of a blown fuse, even when there is no trouble in the circuit. Conversely, if you are having trouble with standard fuses blowing, don't substitute a slow-blow fuse. These will not protect the circuit properly and could result in a flyback burnout because a shorted damper tube didn't blow the fuse in time to save the flyback.

Now, we've seen where slow-blow fuses are used, and why. But just how do slow-blow fuses work?

Three kinds of slow-blow fuses are shown in Fig. 5. The first (Fig. 5-a) is a cartridge type. An overload heats up the solder that holds the contacts together. If the overload doesn't last too long, the solder cools and everything returns to normal. However, if the overload doesn't clear up, the solder melts and the spring pulls the contacts apart, opening the circuit. If there had been a short in the circuit, the fuse element would have vaporized—just as it would in standard fuses—before the solder even got a chance to warm up.

The fuses shown in Fig. 5-b and -c work in the same fashion; the only difference is in their design. Fig. 5-b shows a plug type fuse and Fig. 5-c is what is termed a time-lag fuse. Such a unit is designed to give a long time delay for special applications.

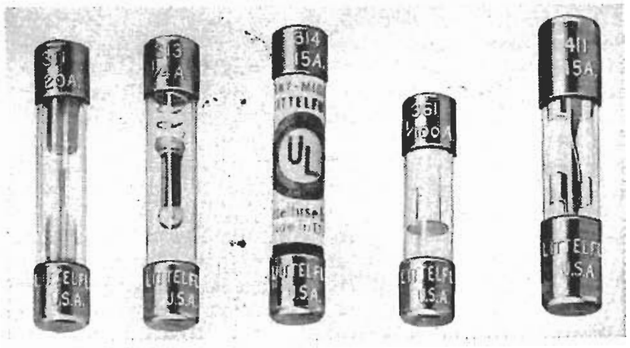
Special types

Another group of interesting fuses are the indicating types. These units let you know when they have burned out or opened. In some (Fig. 6-a), a little plunger comes out the end, or the top (Fig. 6-b). Other devices can be added to these fuses so that, when they open, the plunger will close a switch to turn a pilot or warning lamp on or off. Or, as one manufacturer is doing, simple attachments may be added to almost any type of fuse, to light when the fuse blows. These units are shown in Fig. 6-c. Indicating fuses are most often found where a large number of fuses are mounted on a single panel. Here they become necessary if a blown fuse is to be found easily and quickly. Therefore, they are commonly used in industrial and military applications.

FUSE IDENTIFICATION

Cartridge Types

LITTELFUSE TYPE	BUSSMAN TYPE	DIMENSIONS (INCHES) DIAMETER	LENGTH
1AG	AGA	1/4	5/8
3AG	AGC	1/4	1 1/4
3AB	ABC	1/4	1 1/4
4AG	AGS	9/32	1 1/4
4AB	ABS	9/32	1 1/4
5AG	AGU	13/32	1 1/2
7AG	AGW	1/4	7/8
8AG	AGX	1/4	1
9AG	AGY	1/4	1-7/16
SFE	SFE	1/4	Varies According to Amperage



Five types of cartridge fuses made by Littelfuse.

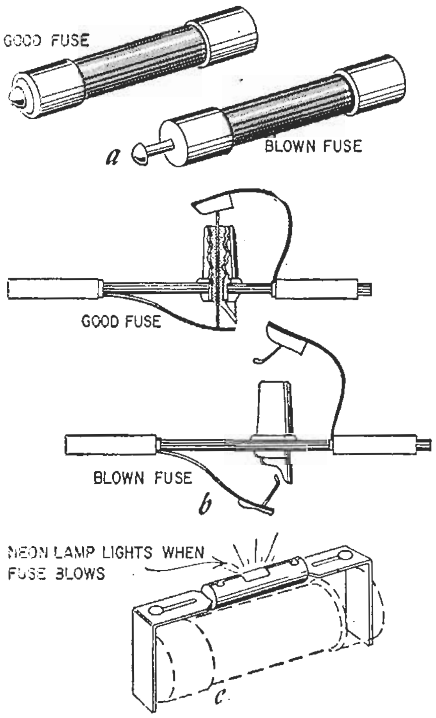


Fig. 6—Special types of fuses: a—Pin comes out end of indicating fuse when it blows. b—Grasshopper fuse springs apart, gives positive action. c—Another type of indicating fuse.

Still another special type fuse is the grasshopper. It has already been shown in Fig. 6-b where its application as an indicating fuse was shown. But even more important is its action when it blows. The two leaflike elements spring apart, giving a quick-acting fuse that is practical for high voltages. The spring action pulls the broken ends of the fuse so far apart that no arcing can occur across the gap.

Another type of fuse is the fusable resistor found in many recent-model TV receivers. This unit is a wirewound resistor with some specific ohmage rating—somewhere between 5 and 13 ohms. It provides two types of protection. It acts as a series resistance that protects rectifiers in the set against sudden voltage surges, and it acts as a slow-blow fuse for overloads. The unit is actually a wirewound resistor, but one that will burn out if the set draws excessive current.

A rather different type fuse is the chemical fuse. To date it is used by only one manufacturer (RCA), to protect the B-plus circuit of TV receivers. It looks like a standard cartridge fuse in size and shape, but instead of a glass cylinder surrounding the fuse element, there is a ceramic jacket. The fuse element itself is a metal wire covered with a special chemical coating. When it is in the B-plus circuit of a TV receiver, it passes current just like any other fuse. If the damper cathode arcs over momentarily, the short surge starts to heat up the wire in the fuse but doesn't last long enough to have any effect. (This same transient would burn out a standard ¼-amp fuse.) However, if there is a short that exceeds the current rating of the fuse and lasts longer than a few instants, the wire in the fuse gets hot enough to set off the chemical coating and the fuse element disintegrates. (This action is much faster than that of a slow-blow fuse and therefore provides greater protection.)

Fuse identification

There are two major manufacturers of fuses in the US today—Littelfuse and Bussmann. These companies use different codes to identify their fuses. For the technician who may run into a Littelfuse and has only Bussmann replacements, or the man who runs into a Bussmann fuse and has only Littelfuse replacements, we have listed both makes in a table that shows equivalent units.

When replacing fuses, an important factor is physical size. In automotive fuses, for example, only one amperage fuse will fit in a particular fuse holder since each amperage fuse is a different length—the higher the current rating, the longer the fuse. However, for other applications, many fuses will all have the same length. For example, in the 3AG series, all fuses are the same length, no matter what current rating they have. Also, the 20-amp auto fuse is the same length as all the 3AG fuses.

Therefore, when replacing fuses, always be sure that you are using a replacement whose voltage and current ratings are identical to those of the fuse that blew. And remember, if a fuse keeps blowing, something is drawing too much current—don't replace the blown fuse with one that has a higher current rating. It may not blow, but your wiring may overheat and start a fire. Or in a TV receiver you'll lose a $10 flyback transformer instead of a 25-cent fuse.

So where do we use the many types of fuses we have surveyed? Quick-acting units go into that expensive voltmeter or other delicate test instrument that small overloads may damage. The slow-blow types go wherever short surge currents are normal and where a standard fuse would blow, even though there is no fault in the circuit. And standard fuses are used about everywhere else.

But to play it safe, whenever you replace a fuse, use one that has identical ratings to the one that blew and you can't go wrong. You can track down a dead short with an ohmmeter; a slight overload will call for checking the parts that draw current off the line by removing them one at a time. When the current drops to normal upon removing a particular part, you know that it is the defective one. So don't take that little glass tube or screw-in device for granted. Use it properly and it can be a lifesaver.

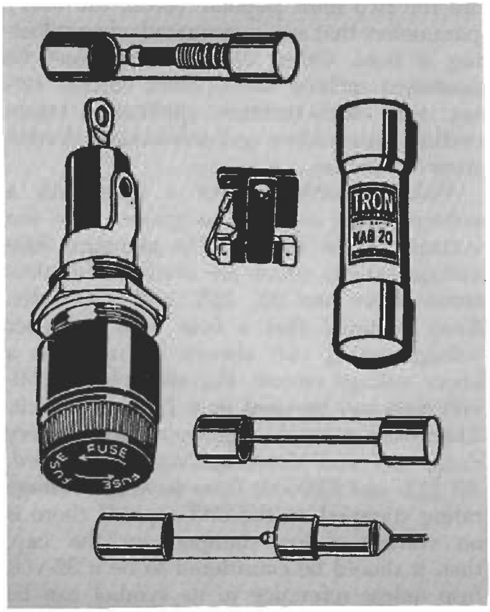
Thanks to Bussmann Manufacturing Div., Littelfuse Inc., and the Sight-master Corp., for supplying much information. END

Bussmann makes this assortment of fuses.

Fuses For Electronics

Types of fuses and where they are used.
How to select the right fuse for your circuit.

BY CHARLES W. JAMES
Special Applications Engineer
Bussmann Mfg. Div., McGraw-Edison Co.



FROM a strictly mechanical point of view, fuses may be placed into two general categories. The first category is the "clip-in" fuse, which must be placed into some kind of fuseholder or a pair of clips to perform its normal function. The other category includes those fuses that have leads soldered to the end-caps and are generally referred to as "pigtail" fuses. Pigtail fuses can be soldered directly into an electronic circuit or printed circuit board, without a fuse-holding device.

Time-Delay Fuses. One of the most popular fuses in use is the so-called "time delay" fuse (sometimes referred to as "slow-blow"). This is a general-purpose fuse with the ability to pass harmless transient currents and yet blow with sustained overloads or short circuits. It is usually constructed with a solder-alloy heat sink that can dissipate the heat generated by momentary transient currents and is spring operated when the current lasts long enough to cause the solder alloy to melt. This type of fuse is sensitive to ambient temperature and must be derated when applied in an extremely warm location in order to carry the load current.

Fast-Acting Fuses. Another very popular fuse is the "fast-acting" (or "normal blow") fuse. This is usually applied in circuits where there are no transient or surge currents to hamper its operation. This fuse generally has a single-element, wire link construction, without any heat sinks to absorb momentary overcurrents. Fast-acting fuses thus blow very quickly on overloads and must be applied very carefully with regard to the amount of full load current. Quite frequently these fuses are used to provide short-circuit protection only and, therefore, can be sized at approximately 250-300% of the full load current. Ambient temperature has very little affect on the performance of these fuses.

"Very fast-acting" fuses are becoming increasingly popular for use in circuits that require extremely fast operation to protect critical components, such as meters or semiconductor rectifiers. Electronic equipment that has very little ability to withstand overcurrents requires this kind of protection. This fuse is constructed similarly to the "fast-acting" fuse except that the link is usually surrounded by a special filler material and the fuse body is made of ceramic or phenolic material The very fast-acting

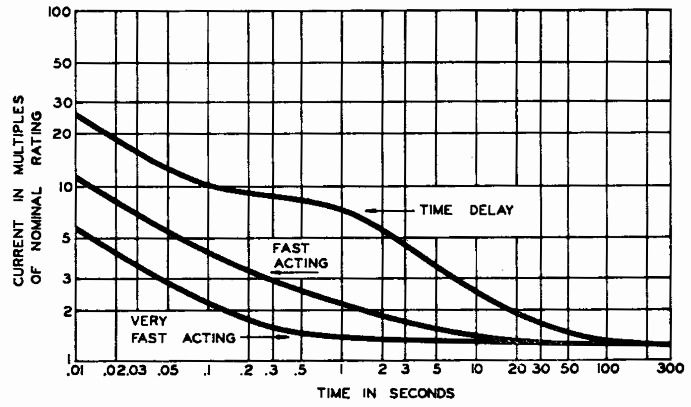


Fig. 1. Operating characteristics of three fuse types described in text.

fuse is essentially insensitive to ambient temperature.

Comparing Fuse Characteristics. Figure 1 shows the operating characteristics of the three types of fuses mentioned above. Consider that all three types carry a one-ampere full load rating but, as can be observed, the blowing time for each is considerably different for a given overload current. For example, when the overcurrent is 200% (2 amperes), the time-delay fuse takes 18 seconds to blow while the fast-acting fuse opens in approximately 1.4 seconds. A 2-ampere current, through a very fast-acting one-ampere fuse, causes the fuse to blow in 0.13 second.

It can be seen from the above that a knowledge of the circuit in which a fuse is applied is important. Will the circuit develop transient currents? How fast must the fuse operate when a short occurs? These and many other questions should be considered when initial circuit design is undertaken.

There are many fuses today which have been developed to meet special needs. Usually, the fuse dimensions or physical construction have been altered so that a special mounting means can be employed or so that an indicator can be built into the fuse to signal when it has blown.

These fuses have particular applications and are not considered to be general-purpose fuses. The fuses covered here are general-purpose types readily available on the market.

Criteria for Selecting Fuses. There are many considerations that should be given to fuse selection. Voltage and current ratings are the two most popular (often the only) parameters that are investigated when selecting a fuse. Other criteria that must be examined include short-circuit current rating, fuse characteristics, application temperature, fuseholders and mechanical dimensions of the fuse.

Voltage Rating. Select a fuse with a voltage rating equal to or greater than the voltage of the circuit. The standard fuse voltage ratings which are available for electronic fuses are 32, 125, and 250 volts. Keep in mind that a fuse with a higher voltage rating can always be used on a lower voltage circuit. For example: a 250-volt fuse can be used in a 125-volt circuit. The reverse procedure, however, can be very dangerous and *should always be avoided.* All 125- and 250-volt fuses have the voltage rating stamped on the end caps. If there is no voltage rating stamped on the cap, then it should be considered to be a 32-volt fuse unless reference to its symbol can be made elsewhere.

Automotive circuits use 32-volt fuses, while 125-volt fuses are often applied in the

TABLE I—EFFECT OF AMBIENT TEMPERATURE ON CURRENT-CARRYING ABILITY

Time-Delay Fuses		Fast-Acting or Very Fast-Acting Fuses	
Ambient Temperature °C	% Rated Current	Ambient Temperature °C	% Rated Current
40	95	40	98
60	85	60	95
80	75	80	92

input circuit of power supplies. Fuses rated at 250 volts, for example, may be applied in the B+ circuit of a TV receiver.

Current Rating. Once the voltage rating is determined, a fuse with an ampere rating greater than the expected circuit full load current should be selected. The generally accepted procedure is to choose a rating about 25% greater than the full-load current of the circuit, because fuses are built to carry their rated current in open air at room ambient; whereas they are usually applied in some type of enclosure and the enclosure temperature is often higher than room ambient.

An important point to remember is that the voltage rating described above does not in any way affect the *ampere* rating. A one-ampere, 125-volt fuse and a one-ampere 250-volt fuses have identical current-carrying capacities. Only the ability of the fuse to open a short-circuit current is affected by its voltage rating.

Another frequent mistake made in selecting the ampere rating of a fuse concerns the current waveshape. Many electronic circuits have unusual waveshapes, such as those in rectifier circuits. The object of a rectifier circuit is to produce a dc voltage from an ac source; thus, the normal thought would be to select a fuse for the dc circuit on the basis of the dc current that is flowing. This would be acceptable if the rectified wave were perfect; however, we know that in practical circuits, we do not need a perfect dc current and it is difficult to produce. Since the dc wave is not perfect, there is an rms value of that wave which, in many cases, exceeds the dc current value. Consequently, the fuse must be selected for the rms value. An example of this is the case of a simple half-wave rectifier with a one-ampere dc output and an rms value of the wave shape of 1.57 amperes.

The general rule to follow is to select a current rating based on the rms value of the current. Only when the rms value equals the dc value is it acceptable to pick the fuse size based on dc current.

Short-Circuit Current Rating. Should a severe short circuit occur in an electronic circuit, it is mandatory from a safety stand-

TABLE II—ELECTRONIC FUSE SELECTION CHART

Buss Catalog Symbol	Ampere Range Available	Voltage Rating	Characteristics	Dimensions Inches	Typical Application
AGX	1/500 to 2	250 or less	Fast-Acting	¼ x 1	Meters, Metering circuits, Instruments
AGC*	1/500 to 3	250 or less	Fast-Acting	¼ x 1¼	
	4 to 30	32 or less	" "	"	
ABC	¼ to 20	250 or less	" "	"	
	25 to 30	125 or less	" "	"	
MDL	1/100 to 1**	250 or less	Time-Delay	"	Power supplies, B+ Circuits, Motor & transformer circuits
	1-2/10 to 2-8/10**	125 or less	" "	"	
	3 to 30	32 or less	" "	"	
MDX	1¼ to 2	250 or less	" "	"	
	3 to 7**	125 or less	" "	"	
MDA	1/100 to 20	250 or less	" "	"	
	25 to 30	125 or less	" "	"	
FNM	1/10 to 10	250 or less	" "	13/32 x 1½	
	12 to 15	125 or less	" "	"	
	20 to 30	32 or less	" "	"	
BAF	1 to 15	250 or less	Fast-Acting	"	Meters, Instruments, Etc.
	20 to 30	125 or less	" "	"	
BAN	1 to 30	250 or less	" "	"	
GBB	1 to 10	130 or less	Very Fast-Acting	¼ x 1¼	Semi-conductor circuits
KAW	½ to 30	130 or less	" " "	13/32 x 1½	

*Pigtail Type would be GJV.
**Pigtail Type would be MDV.

point that the fuse clear the fault without rupturing. It is for this reason that fuses are given a *short-circuit* rating that goes along with their *voltage* rating and must never be exceeded.

A normal 125-volt circuit load current could be two amperes full load but, when a short occurs in the circuit wiring, the current might increase to 1000 or 2000 amperes. The fuse, in turn, must be able to open the circuit safely under this condition. Generally, short-circuit currents with magnitudes in the thousands of amperes are the exception rather than the rule in the case of low-energy electronic equipment. For most electronic devices, if a fuse of the proper voltage rating is selected, it will have an adequate short-circuit rating.

Temperature. How many times have you checked a troublesome circuit and found that the current was less than the fuse rating? Did you happen to check the temperature to which the fuse was being subjected as well? The effect of ambient temperature on fuse performance can be appreciable, especially where time-delay fuses are involved.

Table I shows the effect of temperature on the current-carrying ability of the various types of fuses previously discussed. If a time-delay fuse were to be selected for operation in an 80°C ambient and the circuit current were 375 milliamperes, then the ampere rating of the fuse should be at least ½ ampere. If the same temperature and current conditions were to be imposed on a fast-acting fuse, the fuse rating should be at least 4/10 ampere.

There are many applications where operating temperatures can be considerably higher than room temperature, especially in circuits where the components are enclosed by a cabinet or case, as in radios, TV's, power supplies, and amplifiers.

Time-Current Characteristic. Once the voltage and current ratings are decided upon, a major consideration is the time-current characteristic of the fuse. The circuit determines to a great extent whether a time-delay, fast-acting, or very fast-acting fuse is the correct choice. If harmless transient currents might occur, a time-delay fuse would be needed. If the circuit is a bridge rectifier, a very fast-acting fuse would be recommended.

Dimensions. Fuse dimensions are usually considered in initial design and can be critical when space is a factor. The most common electronic fuse dimensions are ¼" x 1", ¼" x 1¼", and 13/32" x 1½". A wide variety of mountings with a number of special features (if desired) are made for these fuse sizes.

Fuseholders. The most popular fuseholder for mounting on a chassis inside an enclosure is the ordinary Bakelite (phenolic) fuseblock which has fuse clips and wire terminals attached. For mounting the fuse in an enclosure or panel, the "panel-mounted fuseholder" is extensively used. This fuseholder has the advantage of being accessible from outside the enclosure.

Panel-mounted fuseholders with lamps to indicate a blown fuse are also available. These are particularly helpful where many fuses are used in the same area.

The pigtail fuse is, of course, the least expensive from a fuseholder point of view. However, a blown pigtail fuse is more difficult to remove from the circuit.

Table II is a quick reference chart of fuses giving their voltage and current ratings, operating characteristics, dimensions, and some typical applications. ◆

AMATEUR STATION HELPS LAND TWO AIRCRAFT

Amateur radio station W6AJZ, Santa Monica, Calif., recently responded to an emergency call from KC4USP, National Science Foundation Radio, at Palmer Station, Antarctica. KC4USP reported that two Navy aircraft, returning to Christchurch, New Zealand, due to bad weather, were short of fuel and were not likely to make their destination. Due to abnormal radio conditions, Palmer Station had no contact with Christchurch and they asked W6AJZ to contact Naval authorities in the States to set up commercial communications with Christchurch and let them know that both planes were attempting alternate landings at Dunedin, New Zealand. It was urgently required that the alternate airport implement emergency conditions including the turning on of all landlights, adjacent city lighting, etc., to guide the troubled aircraft.

After W6AJZ had made telephone contact with Washington, where communications were available with Christchurch, the amateur station served for 45 minutes as a relay between Palmer Station and Washington/Christchurch. When all preparations had been completed emergency radio contact was secured. The Navy telephoned W6AJZ later that day to advise that both aircraft had landed safely. ◆

Fuses for the protection of electronic equipment

The construction, characteristics and design considerations of fuses

by R. A. W. Connor, F.I.E.E.

A "simple" fuse is the most widely used, and often the most overlooked and underestimated protection component in a circuit. Although the mechanical construction of a fuse is relatively straightforward, its operation is complex. As a result, much research and development has taken place to keep up with new technologies and devices.

This article describes how modern fuses, when chosen correctly and properly installed, provide cheap, accurate and reliable protection which in many respects is superior to other switching devices.

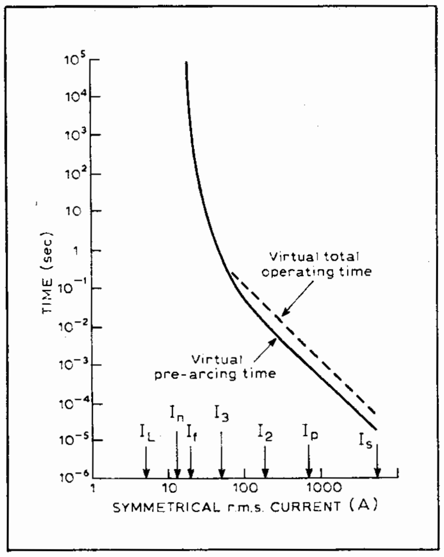
A FUSE, according to the IEC, is a switching device that by fusion of one or more of its specially designed and proportioned components opens the circuit in which it is inserted and breaks the current when it exceeds a given value for a sufficient time. The fuse comprises all the parts that form the complete switching device.

Fuses are the most common protective device and are used at rated currents up to above 2000A and in circuits operating at up to 132kV. Physically, a fuse is of simple construction but its operation is complex. The late H. W. Baxter of the ERA was one of the leading authorities and the results of some of his classic research over the period 1930 to 1950 has been published.

A fuse is one of a chain of components in a circuit, all of which rise in temperature with the passage of current. Under heavy overload or short circuit conditions there is no time for the heat to escape and the temperature of the fuse element rises rapidly to the melting point of the element. At small values of over-current a single break occurs in the element which gradually lengthens until arc extinction. At high values of fault current a large number of breaks occur almost simultaneously. With wire elements there may be 40 or more arcs per inch and the arc voltage may reach several hundred volts per inch particularly when there is a high inductance in the circuit. This high arc voltage quickly forces the current down to zero before the first peak of the fault current. Excess voltage, even a transient type, is however objectionable particularly to semiconductors, and upper limits are prescribed in many specifications. For a.c. circuits, part 1 of BS88 specifies maximum arc voltages of 1000V and 2000V with circuits rated up to 60V, and 61 to 300V respectively. Lower arc voltages can be obtained with fuses specially designed for semiconductor protection.

In a modern cartridge fuse the element is totally enclosed. For high current ratings and for specially designed semiconductor fuses the cartridge is usually filled with powered quartz, of controlled grain size, which is free from moisture and organic impurities. With this type of fuse, fire risk and damage is greatly reduced because of its ability to limit the current and thus reduce the let-through energy. Cartridge fuses are non-deteriorating and retain their characteristics almost indefinitely. The filler plays an important part in fuse operation because it cools and condenses the hot metal and vapour produced by arcing, and it also reduces the pressure on the cartridge wall. In addition, it is capable of extracting a large amount of energy from the circuit. This energy vitrifies part of the quartz which forms a fulgurite. As the fulgurite and remaining filler cools its resistance quickly increases and it is able to withstand full working voltage indefinitely. The size of the quartz particles is important because arcs are drawn into the interstices between the particles. But, because there are other conflicting requirements the choice of particle size is a compromise.

Fig. 1. *Typical t/I characteristic for a 13A plug top fuse to BS1362. Assumed values for I_p and I_L are 740A and 6A respectively.*



All fuses have an inverse t/I characteristic of the general shape shown in Fig.1. Current I_n is the rating of the fuse link, I_f is the minimum fusing current and I_L is the full load current of the equipment which should not be greater than I_n. Values I_2 and I_3 are higher currents used for descriptive purposes. The prospective current at the fuse position is denoted by I_p, and is the current that would flow if the fuse were replaced by a solid link of negligible impedance. The maximum current which the fuse is subjected, I_s, in the manufacturers certification tests must be greater than I_p. The current range 0 to I_n is the working zone and the complete fuse should carry any current in this range without overheating. The current range I_n to I_f is the non-operating zone and the ratio I_f/I_n is the fusing factor. This depends on the design of the fuse, and varies from about 1.2 with some designs of powder filled fuse, to as much as 2 with some semi-enclosed rewireable fuses. Any value of current above I_f causes operation of the fuse although it may take an hour or more with a current only slightly above I_f. A small current increase in the range I_f to I_3 results in a considerable increase in operating speed whereas a small increase in current above I_3 has only a small effect. With 3 pin plug top fuse links to BS:1362, I_s is 6000A which is well above any likely value of I_p. The value of I_p may be approximately determined by connecting a load at this position and measuring the supply voltage before and after application of the load. The accuracy is improved by using a heavy load. Current rating I_n of a fuse in the mains supply should be at least equal to the value of I_L, and must also be sufficient to cater for surges. However, it should not be too large because with lower values of I_n there is a better chance of clearing earth faults. The prospective earth fault current I_E on the 240V mains is $I_E = 240/Z_e$ where Z_e is the phase earth loop impedance at the fuse position. To meet the IEE wiring regulations I_E must exceed $3I_n$ when $I_f/I_n > 1.5$, and I_E must exceed $2.4I_n$ when $I_f/I_n < 1.5$. A low value of Z_e is

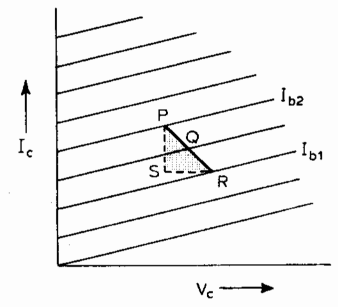
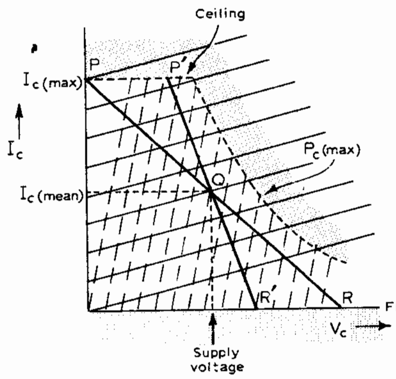
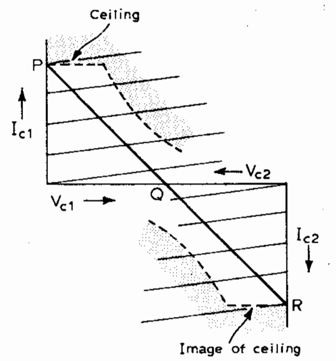


Fig. 3. *A load line PQR superimposed on a set of $I_C - V_C$ characteristics. The shaded area represents the power output.* ▼



▲ **Fig. 4.** *The ceiling and floor which limit the current excursions in a class A amplifier. PQR represents the optimum position of the load line. The dashed characteristics show the effect of negative feedback.*



◀ **Fig. 5.** *In a push-pull amplifier the floor is replaced by an image (skew symmetrical) of the ceiling.*

equal to the collector a.c. resistance the swings in collector voltage and collector current are small compared with the quiescent values. Admittedly this is an impractical form of amplifier because the output power would be minute, but the point is whether with such a small signal the optimum load is equal to the collector a.c. resistance.

It is interesting and instructive to try to answer this question using the transistor characteristics. Fig. 3 shows an idealised set of $I_c - V_c$ characteristics, the slope of which is equal to the reciprocal of the collector a.c. resistance. Q is the quiescent point representing the static values of collector voltage and current. Through Q is drawn the load line PQR, the slope of which is equal to the reciprocal of the load resistance. If the small input signal swings the base current between the limits of I_{b1} and I_{b2} then the output current swing is given by PS and the output voltage swing by RS. The area of the triangle PRS is proportional to the power output: in fact if the area is expressed in terms of the horizontal and vertical scales it is equal to four times the power output. As the load resistance value is varied, the load line pivots about Q and the area of the triangle varies. For very small load values PR is nearly vertical and side RS tends to zero, whereas for very high value loads PR is nearly horizontal and PS tends to zero. Between these two extremes there is a position of PR which gives maximum area of PRS.

The solution to this exercise is that the area is a maximum when the slope of PR is equal to that of the characteristics, i.e. when the load resistance is equal to the generator resistance, thus confirming the maximum power transfer theorem. As we have seen this is true provided very small signals are used, and this is a useful reminder that the equivalent circuit for active devices applies only to small signals.

What has been said about the impracticality of using the theoretical optimum load in an amplifier with normal signal amplitude will help us to understand the observation made earlier that the load resistance for a high-quality amplifier is usually many times the output resistance. Let us assume initially that the output stage is a single class A amplifier. The $I_c - V_c$ characteristics of a bipolar transistor are shown in idealised form in Fig. 4. The collector current swings above and below the quiescent value when an input signal is applied and there are limits to both swings if distortion is to be avoided. On the upward swing the collector current must not exceed the maximum value $I_{c(max)}$ prescribed by the manufacturer. Moreover the collector dissipation must not exceed the maximum $P_{c(max)}$ quoted by the maker.

There are other causes of current limitation: in valves, for example, attempts to drive the anode current above a certain value cause the grid to go positive with respect to the cathode so that distortion occurs in the input circuit as a result of damping due to grid current. A similar limitation occurs in junction field-effect transistors, the input circuit of which also conducts when the gate potential equals that of the source. Because of these limitations collector current must not enter the upper shaded area in Fig. 4: the boundary of this area consists of a straight line representing $I_{c(max)}$ and a curve representing $P_{c(max)}$.

Similarly the greatest negative excursion of the collector current is that which causes its value just to reach zero. Thus the area below $I_c = 0$ is another region which must not be used. The quiescent point Q is located midway between the base line (which we can call the floor) and the lower limit of the upper shaded area (the ceiling). The load line must pass through Q and, to use the full range of collector current, must touch the ceiling and the floor at its ends. It should also use the full voltage excursion between zero and twice the supply voltage: its position is thus fixed at PQR. This represents a load resistance given by the supply voltage divided by the mean collector current. It is thus independent of the a.c. resistances of the transistor.

The effect of applying voltage-derived negative feedback is to replace the $I_c - V_c$ characteristics shown solid in Fig. 4 by a new set (shown dashed) much more vertical (implying a lower effective collector a.c. resistance), more evenly spaced (showing improved linearity) and more closely spaced (indicating reduced gain). The manner in which these new characteristics may be deduced was given in an earlier article.* According to the maximum power transfer theorem the slope of the optimum load line should be equal to that of the dashed characteristics (as shown by $P'QR'$) but clearly this is impractical because, to utilise the full voltage excursion, the current would extend well into the shaded areas as in the emitter-follower example considered earlier. The application of feedback has no effect on the position of the floor and ceiling: it, therefore, has no effect on the load line and on the value of the load resistance.

It is, of course, more usual to use a push-pull pair operating in class B in the output stage of a high-quality amplifier. The output voltage is not now accommodated between a ceiling and a floor because the half cycles of signal are handled alternately by the two transistors. There is therefore no floor as in Fig. 4. Instead the load line is bounded by two ceilings, the lower of which can be regarded as a skew-symmetrical image of the upper ceiling situated below the zero-current axis (Fig. 5). Nevertheless the result is that the optimum load line is confined between the two ceilings and fixed in position by the need to exploit the available swings in current and voltage. As before the application of feedback replaces the near-horizontal characteristics by near-vertical ones but has no effect on the position or slope of the load line. Thus the value of the optimum load is unaffected by feedback which is used to improve linearity and to reduce the value of the output resistance. ☐

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* *Wireless World* August 1976, p.66.

therefore necessary with high current rated fuses. In urban areas with cable sheath earthing, Z_e is likely to be less than 1Ω and I_E greater than $240A^2$. Difficulties in obtaining a sufficiently low value of Z_e are more likely to arise with overhead services particularly in areas of high soil resistivity. The Electric Supply Authority can often render assistance both in testing and in obtaining a good earth.

Tests at various currents between I_f and I_s are made in order to plot the t/I characteristic. In the range I_n to I_3 these may be made at a reduced voltage. Fig.2 shows a typical current in a fuse during a high current test in which the melting of the fuse element prevents the current reaching the maximum value. The graphical method of determining virtual pre-arcing time is superimposed in Fig.2. and shows that:

$$I^2_p\, t_{vp} = i^2dt$$
$$t_{vp} = i^2dt/I^2_p$$

where I^2_p is the prospective current, t_{vp} is the virtual pre-arcing time, and i is the instantaneous value of current during the pre-arcing period. The virtual arcing time may be determined in a similar manner and can be added to the virtual pre-arcing time to give the virtual total operating time. The virtual pre-arcing time is drawn to show the mean value of the test results and the virtual arcing time is taken as the maximum value of the test results. Fig.1 shows that the arcing time is only significant at high fault currents.

The only current known to the user apart from the load current is the prospective current, I_p. The user needs to know a time value as shown in Fig.2 so that it can be multiplied by I^2_p to obtain the heating effect of the current. Equipment can then be selected and designed to withstand this with a safety margin. Manufacturers usually present this as a characteristic with I^2t in A^2s as the ordinate and I_n as the abscissa. Fig.3 shows total operating I^2t and pre-arcing I^2t for each value of I_n.

It is fortunate that fuses have an inverse time/current characteristic as this enables suitably chosen fuses to operate satisfactorily when in series. It is not practicable to examine or replace every fuse that has experienced a through fault, but discrimination can be achieved if the total energy let through by the minor fuse, total I^2t, is less than the pre-arcing energy I^2t_{vp} of the major fuse. In general, discrimination is achieved if the current rating of the major fuse is twice that of the minor fuse although a lower ratio is often possible when I_p is relatively low. Difficulties arise when different types of protective equipment are involved. Discrimination cannot always be achieved when rewireable fuses or miniature circuit breakers are in series with cartridge fuses. In Fig.4 the 45A rewireable fuse discriminates with the 80A cartridge fuse up to about 500A. With fault currents above 500A the cartridge fuse operates first.

Two fuses are sometimes used in the mains supply to apparatus with the erroneous belief that this is twice as good as one fuse. If the fuses are of the same type and current rating, the fuse in the neutral lead may operate first. In this condition the apparatus remains at a dangerous potential above earth. A single fuse should be used in the live lead. Sometimes the earthed chassis of equipment is accidentally or deliberately connected to the neutral. This is most undesirable for a number of reasons. Such a connection encourages part of any short circuit current to flow through the metal work to earth. This fault current may originate from other apparatus in the same premises or even from apparatus in adjacent premises. If the local earth and sub-station earth have low resistances, very high currents can flow without any effect on the fuse in the apparatus. Secondly, the neutral is used to carry unbalanced currents from other phases of the supply network and usually differs from earth by a continuously varying potential of up to several volts. The corresponding current will therefore fluctuate and cause hum and other difficulties particularly when the parallel earth paths have a low resistance. Thirdly, and even more important, the danger that arises in the event of a broken neutral. Although this is a very rare occurrence, if the break occurs between the apparatus in question and the sub-station, considerable load currents from apparatus in all premises beyond the break can flow to earth through this connection. Again,

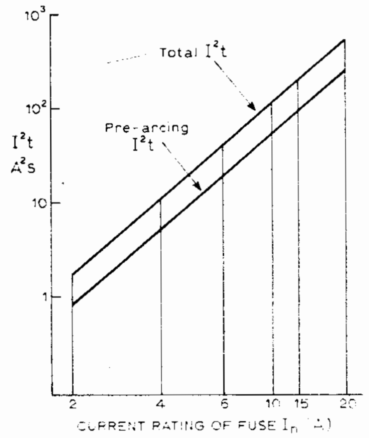


Fig. 3. *Typical I^2t values for a family of fuses.*

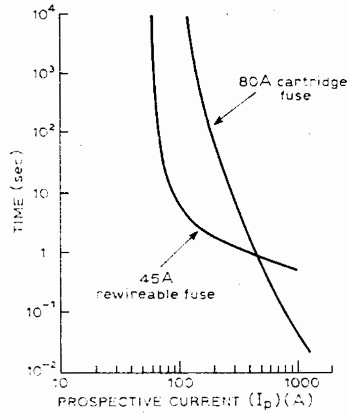


Fig. 4. *T/I characteristic of cartridge and rewirable fuses.*

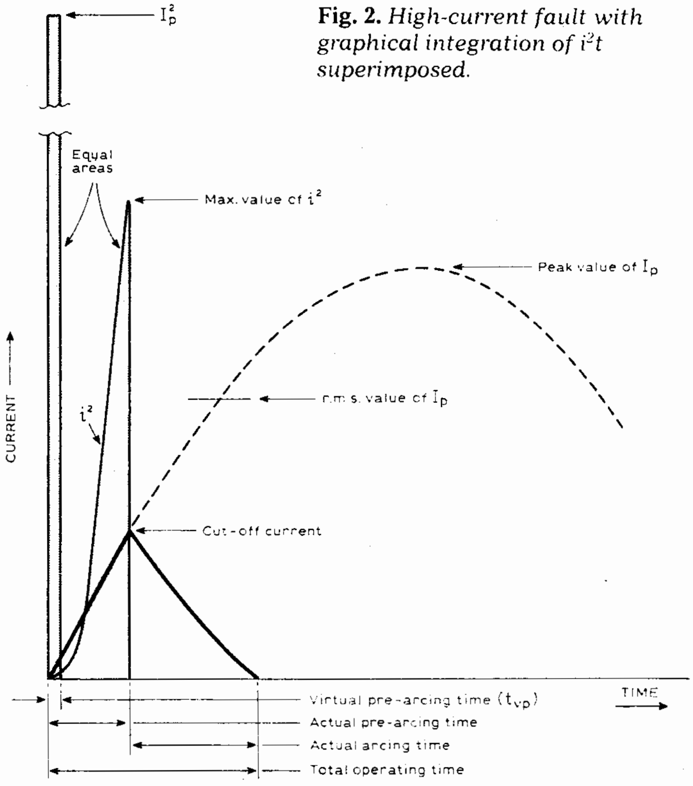


Fig. 2. *High-current fault with graphical integration of i^2t superimposed.*

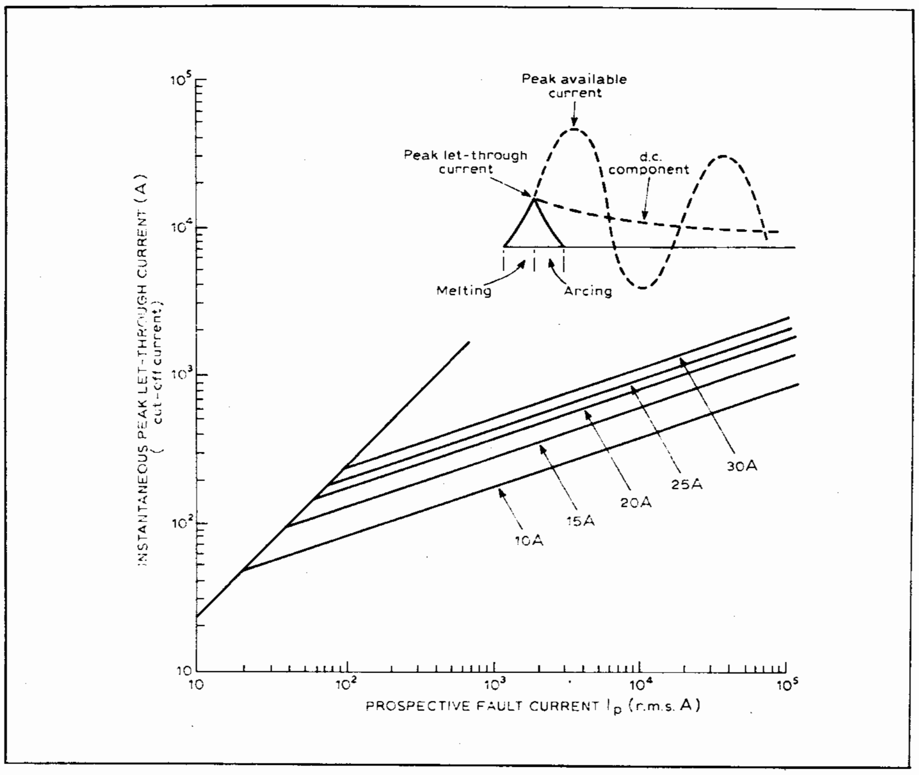
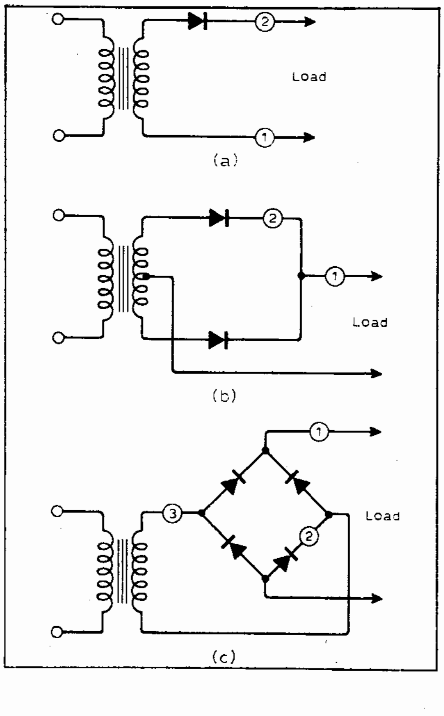


Fig. 5. *Cut-off characteristics for a family of 250V semi-conductor fuses.*

Fig. 6. *Half-wave rectifier with a single diode (a). The d.c. load current (1) is 1A, the r.m.s. diode current with a resistive load (2) is 1.57A. Full-wave rectifier using two diodes (b). The d.c. load current (1) is 1A, the r.m.s. diode current (2) with a resistive load is 0.785A, and with an inductive load is 0.707A. If only one fuse is used in the centre tap lead there is no protection for an undamaged diode. Full-wave rectifier (c). The d.c. load current (1) is 1A, the r.m.s. load current (2) for a resistive load is 0.785A, and for an inductive load is 0.707A. The r.m.s. current in the transformer secondary (3) for a resistive load is 1.11A, and for an inductive load is 1A.*



the fuse on the apparatus is completely unaffected. Furthermore, even if the local earth has a fairly low resistance, the metalwork of the apparatus may rise to a dangerous potential.

Cut-off characteristics are usually presented on equal decade logarithmic paper, and an example for a family of semiconductor fuses is shown in Fig.5. The 45° line is the transition point and is the asymmetrical fault current which is the limit of cut-off. There is no precise value but it is usually considered to be about 2.4 times the r.m.s. symmetrical fault current for circuits of less than 1000V. Cut-off currents for the individual fuses correspond to a slope of 1 in 3 because at currents greater than the transition value the cut-off current is proportional to $\sqrt[3]{I_p}$. In Fig. 5 all of the fuses exhibit cut-off at I_p values above $10I_n$. At very high values of I_p the cut-off current is quite small, particularly with fuses of lower current ratings.

Temperature rise is the difference between the actual temperature at the fuse position and the ambient temperature. Under a steady current the temperature rise of a fuse will increase until a steady condition is reached when the heat dissipated is equal to the heat input, I^2Rt Joules where R is the resistance of the fuse. At currents up to I_n the temperature rise is approximately proportional to I^2 but usually increases at a greater rate for currents above I_n. Small overloads can therefore result in a large increase in temperature. A fuse may either gain heat or loose heat to the connecting cables. A considerable proportion of the total heat can be due to the resistance of the terminations and contacts. Some specifications give maximum permitted temperatures of fuses and the components parts. For example, BS 88:1975 Part I for cartridge fuses up to 1000V a.c. and 1500V d.c. gives a temperature rise limit of 65°C for bolted tin plated contacts and terminals. Some specifications do not give temperature rise limits but specify either maximum permitted power loss or maximum resistance. For a particular fuse and a given current rating, the ratio of steady state power loss at current rating/cold power loss, is mainly constant. Because the ratio of temperature rise at rated current/stable condition hot power loss, is also reasonably constant this amounts to specifying the maximum temperature. Power loss in a fuse increases with the increased current rating. With a 32mA fuse it is about 1/3W while at the other extreme a 1250A fuse may lose 100W. Because a fuse is a temperature sensitive device it may have to be derated in ambient temperatures above 40°C. Alternatively, it may be uprated if subjected to artificial cooling.

Potential drop across fuses with low current ratings may exceed the voltage of the equipment being protected. At the rated current a 32mA low breaking capacity fuse to BS:4265 has a maximum potential drop of 10V. Corresponding values for 1A and 6.3A fuses are 1V and 0.2V. These high values at low current ratings are due to the very fine wire used for the elements.

Some of the factors affecting the correct choice of fuse current rating have already been mentioned. With semiconductors, however, it is also necessary to distinguish between r.m.s. and average values. Current ratings of fuses are invariably given in r.m.s. values whereas average values are given for diodes and thyristors. A comparison of these currents for half-wave and full-wave single phase rectifiers assuming that i_{peak} is 1.0A shows tifiers, assuming that i_{peak} is 1.0A, shows that,

	I_{peak}	$I_{r.m.s.}$	$I_{average}$
half-wave rectification	1.0	0.50	0.318
full-wave rectification	1.0	0.707	0.637

When semiconductor rectifiers are used it is also necessary to take account of the fuse position in the circuit. The three most commonly used single phase rectifier circuits are show in Fig. 6 with currents at various positions assuming that the d.c. load current is 1A. Values for other currents will be in proportion. It should be noted that the published average current for some diodes may have to be derated to $0.8I_{av}$ for battery or capacitive loads. With large installations several diodes may be used in parallel and a multi-phase arrangement can be used. It may then be desirable to connect a fuse in series with each diode in addition to main fuses. Ideally, the t/I characteristic of the fuse should be below that of the semiconductor by a safe margin. Semiconductor manufacturers obtain their I^2t values in less than 10ms by using a half sine wave at higher frequencies. These I^2t values can be compared with the I^2t/I_p characteristics of the fuse if the operating times are

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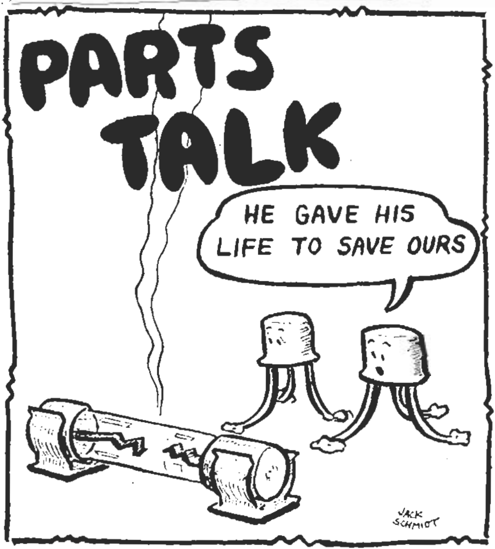
PARTS TALK
HE GAVE HIS LIFE TO SAVE OURS
JACK SCHMIDT

QUESTIONS ABOUT FUSES

THIS is where I stand up and show my ignorance about fuses, perhaps to the amusement of the more knowledgeable ones. I was most interested to read Mr Connor's article in the January issue because, in my work mainly as a designer of electronic circuits and during my university training, I have not had to learn nor have been taught much about these humble components. I sometimes idly wondered how they behaved apart from the fact that they are likely to fuse if the rated current is exceeded. I have even been confused enough to believe that transient or anti-surge fuses, which I infer are better described as time-lag fuses, were designed to guard against transients. In future I shall try to remember that the obvious assumption that occurs to me because of the names is the wrong one.

I get the impression that, out of the various types, only a limited range (generally unmarked as to their speed of operation) is available to the general public or amateur constructor, presumably due to lack of demand. Perhaps a little technical advertising on behalf of the manufacturers might stimulate designers like myself to use fuses in less conventional applications, especially if they are now being developed successfully to protect semiconductor devices.

I would like to ask two questions of Mr Connor (or of his obliging expert Mr Newbury of Brush Fusegear) which other readers might also be interested in.

First, can he give me some typical examples of the range of speed characteristics available and how these speeds are defined when considering different types of I/t fusing characteristics?

Secondly, is it safe to use fuses in normally pulsed conditions (e.g. without premature ageing and failure) as long as the average power dissipation ($\propto I^2 t/T$) is below the rated value and the pulse width t is somewhat shorter than the pre-arcing time for current I? I suppose that in this case the speed of operation on a fault current could be limited by either average or pulsed power considerations assuming one effect to be dominant.

P. K. Cockings
Borehamwood
Herts

Mr Connor replies:

I would like to thank Mr Cockings for his letter, but would point out that it was not possible in a short article to cover the points he has raised. I assume his questions refer to miniature fuses of current ratings 32mA to 10A. These are covered by British Standard 4265 and IEC Specification No. 127 which give maximum and minimum pre-arcing times for class F and T types only. The accompanying figure, showing operating speeds of miniature fuses, is reproduced from a recent paper by P. G. Newbery and Prof. A. Wright ("Electric fuses," *Proc. IEE*, 124, 11R, Nov. 1977) which gives a review of all types of fuse at present in use and also refers to future developments. It will be seen that there is a wide difference in operating speed between the super-quick acting (FF) and the