The Electrical Panel

Safe wiring in the home starts at the panel — here's a guide to what you should find when you remove the cover

by Rex Cauldwell

The primary purpose of a residential service panel is to safely distribute electrical loads within the house. Manufacturers refer to residential panels as load centers. Commercial or industrial panels are called panelboards. The National Electrical Code (NEC) doesn't differentiate. In this article, I'm referring only to the residential type, which for simplicity's sake I'll call "the panel" or "the main service panel." Mobile home panels have different requirements and are not covered here.

Panel Location

The location of a main service panel should, if at all possible, be back-to-back with the meter. The meter base normally has a knockout in the bottom or back that is to be used for the wires exiting out the meter base and into the wall. I try to put this knockout back-to-back with the panel so I can come out of the meter base directly into the panel's gutter (the empty area to the left and right of the circuit breakers). This way I only need a few inches of conduit, if any, and I have minimized the *service entrance cable* (see "Glossary," page 27) run to around 3 feet. If the knockout is not in the correct position, I punch my own to bring the service entrance cable in where I want it. I try to mount the panel so that the main breaker is easy to reach — normally around 5 feet high. The NEC says the highest device in the panel — usually the main breaker — can be no higher than 6 feet 6 inches (see Figure 1).

In cases where the panel cannot be mounted back-to-back with the meter base, most localities require an additional *service disconnect* right next to the meter on the outside of the house. It consists of an enclosure with a main circuit breaker or a fused disconnect switch the same load size as the main.

This additional disconnect protects the service entrance cable between the meter base and the panel. If a short were to occur here (such as a nail being driven into the wires), the current would continue to flow, with no breaker to trip and shut it off. The excessive current could generate enough heat to melt the service cable insulation and cause a fire.

Basement panels. Putting the main service panel in the basement leads to some interesting problems. The worst is that water can enter through the utility meter base, flow down the stranded neutral into the panel, and corrode and eventually destroy the main and the circuit breakers. Overhead drip loops and silicon at the (alleged) watertight connector on top of the meter base may minimize water entrance from above, but water can still enter around the glass meter itself. One way to minimize the problem is to have the service entrance cable enter the service panel from the bottom or side of the box instead of the top, creating a drip loop to drain off the water. Still, this may keep the water out of the main breaker, but it doesn't keep it out of the box.

The best way to keep water out is to use individual service entry wires inside conduit (instead of the standard service entrance cable with a braided neutral). I run the wires into an LB (elbow with removable cover), then through a few inches of conduit pitched slightly uphill, and into the side of the panel. Any water flows down the wires, drips off, and can exit through the LB cover.

Besides water flowing into the panel, there is also the problem of airborne moisture from excessive basement humidity, as well as moisture seeping through basement walls. Both of these can cause rust and corrosion in the panel. Do not locate a service entrance panel in a basement unless it is dry.

If you must install a basement panel, be sure to provide a space between the concrete wall and the back of the panel. Code requires a 1/4-inch minimum space, but I recommend leaving at least 1 1/2 inches — the width of pressure-treated framing lumber attached flatwise to the wall for mounting the panel.

Lighting. A new requirement is that the panel must be illuminated, directly — by a light on the panel itself — or indirectly — by a nearby room light.

CAROLYN BATES

The Main Breaker

All electric current comes into the main service panel to the main breaker, or main. The main senses all the current the residence is using and trips when the amount the breaker is designed for is exceeded.

The size of the main service panel is not a matter of chance. It is calculated from a load formula in the NEC that takes into account the size of the house and the electrical demand of what is in the house. Standard service entrance panel sizes start at 100 amps and may increase, depending on manufacturer, in 25-amp steps up to 800 amps. The minimum load for a new house, by code, is 100 amps. However, 100-amp panels are now generally considered too small for the standard modern residence — 200-amp and 400-amp panels are more common.

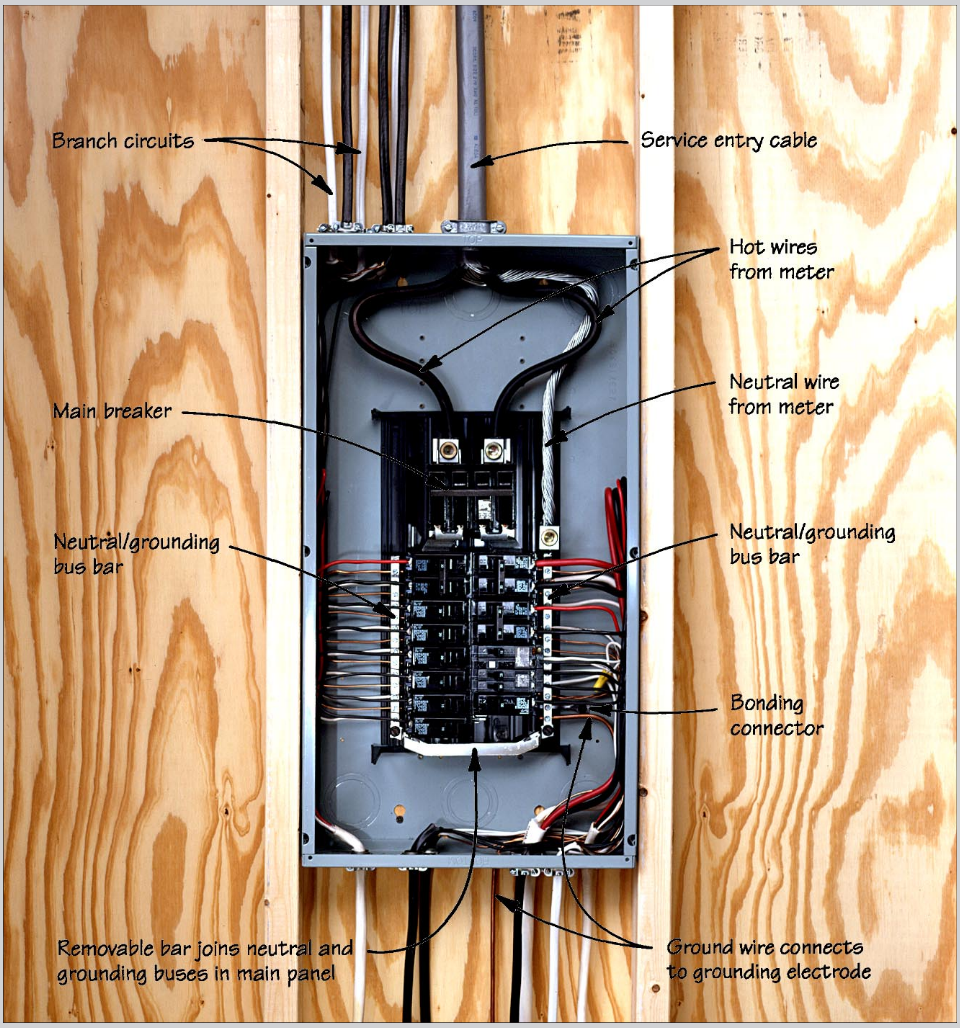
Hot Buses

With the main in the "on" position, or closed, current can flow down into two metal bars — usually copper or aluminum — called *buses*. Pushed onto tabs extending

Choosing a Panel

All panels are not the same — there are good designs and poor designs. Here's what I look for in a panel and what I try to avoid.

- I prefer a physically large panel — a 40/40 panel. This gives me lots of wiring room, avoids the "birds nest" of an overstuffed box, and allows me to use only full-sized breakers.
- I always use a main breaker with a full-sized handle — one that you can get three or four fingers on. I like a main that pulls down to turn off and pushes up to turn on. Avoid mains that have handles the size of your little finger.
- I prefer two full-length neutrals, one on each side, located right against the breakers. A short neutral bus, or a neutral bus only on one side, makes it difficult to wire the panel. Also, the neutral buses should not be located right against the side of the box because this blocks the knockouts.
- Stay away from stacked neutrals — the wires and screws get in the way of one another, making it necessary to remove several wires before you can remove the one you want.
- Look for a panel with tabs that keep the door from falling to the floor and amputating your toes when the screws are withdrawn. If a panel doesn't have this feature, I insert at least two long, self-tapping screws through the lid just above the panel top to allow the panel cover to hang from the box when all panel screws are withdrawn. The panel door should also fit both surface and flush mounting situations.
- Choose a breaker system that allows you to insert and withdraw the breakers easily. One brand makes you remove several mini breakers just to remove the one you want. Avoid this design like the plague. —*R.C.*



Inside the panel. *The author prefers this style panel, made by ITE Siemens, because the neutral/grounding bus bars on either side make it easy to wire neatly. The removable bar at the base allows the two sides of the neutral/grounding bus bars to be separated so the panel can serve as a subpanel.*

from these buses are smaller breakers that sense the amount of current individual circuits are using and trip if their designated current amount is exceeded. For example, 14 AWG (American Wire Gauge) wire may only have 15 amps of current flowing through it. If this amount is exceeded, the plastic insulation will overheat, eventually melting and shorting the wires together. The circuit breaker protects the wire by opening the circuit if more than 15 amps flows through it — as might happen if someone plugs several large appliances into a 15-amp circuit.

Neutral/grounding bus. The gutter should contain at least one neutral/grounding bus bar, though two, one on each side, are better. This bus is *bonded* to the panel — directly connected, metal to metal — and is also connected to an *earth ground*. Inspectors will always look for a bonding wire or screw to verify that the panel is bonded and thus grounded. In addition, all other non-current-carrying metal components of the electrical system — outlet boxes, conduit, and subpanels, for example — are connected by grounding wires through the main panel to the earth ground.

The NEC requires that the neutral and the grounding wires be joined together in only one location — at the point where the earth ground connects. Throughout the wiring system, however, the neutral and grounding wires must be kept separate. Otherwise, the grounding wires might become current-carrying and lose their ability to prevent shock.

In most residential panels, the earth ground connection is made at the neutral/grounding bus bar. However, if an additional service disconnect is used between the meter and the panel, the earth ground must connect at that disconnect, not at the panel. In that case, the panel will have to be wired like a subpanel, with the neutral and grounding wires sepa-

Clearances at the Panel

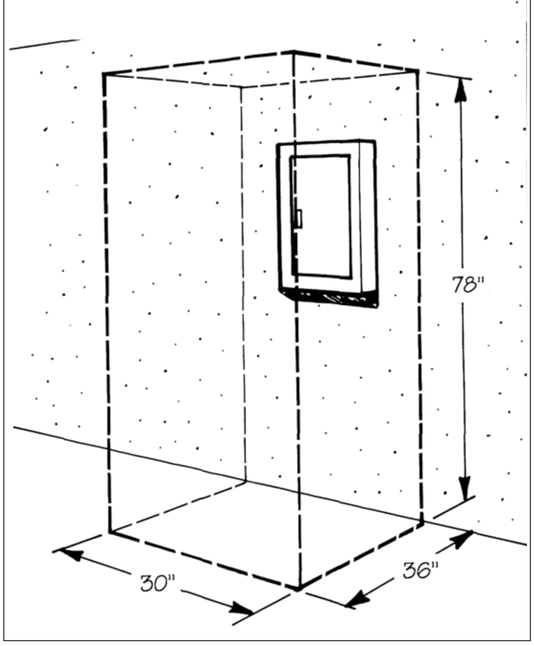


Figure 1. *Panel placement.* *For a 200-amp or smaller panel, code requires 3 feet of clear space in front of the panel, 30 inches wide, and extending from the floor to a height of 6 feet 6 inches. No pipes or ducts may cross this space. In addition, the door of the panel must be able to open at least 90 degrees.*

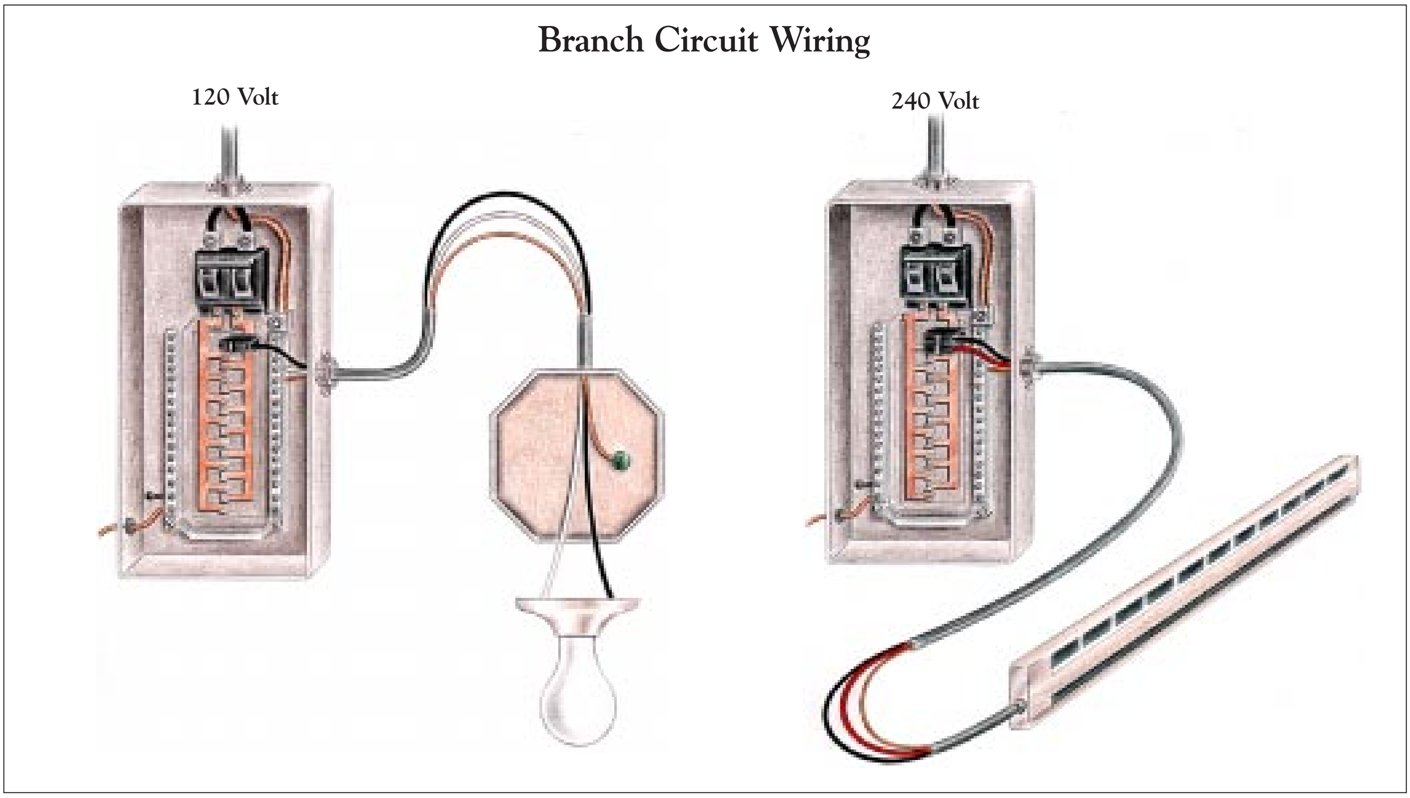
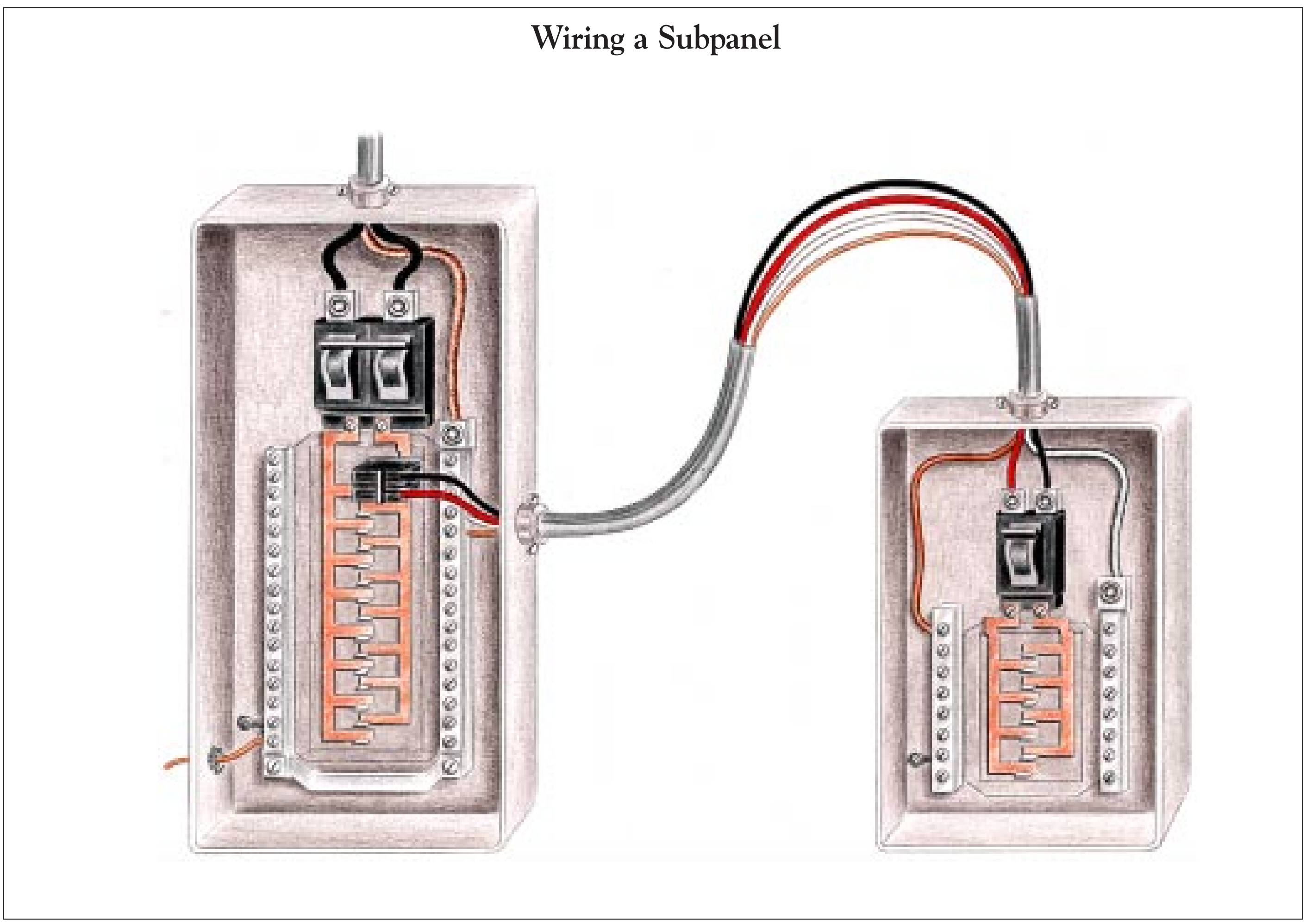


Figure 2. *Tracing the current.* *In a typical 120-volt circuit (left), a single-pole breaker taps 120 volts of power from one of the panels's hot buses. The current flows along the hot wire to the load (the light bulb) and returns through the neutral wire. To protect against shock, the bare grounding wire carries back any current that leaks to metal parts of the fixture. It carries an insignificant amount of current as long as no short circuit occurs. In a 240-volt circuit, such as for an electric heater (right), a double-pole breaker taps both of the panels's hot buses. The alternating current flows through the two hot wires, and the grounding wire carries no current.*



ILLUSTRATIONS BY ROBERT HUNTOON

Figure 3. *Use heavy four-wire feeder cable* *to hook up a subpanel. At the subpanel, you must separate the neutral bus from the grounding bus in order to preserve the integrity of the grounding path. By code, the neutral and grounding circuits can only join at the main disconnect, where the earth ground connection is made.*

rated (see "Subpanels," below).

Bus connections. With 120-volt circuits, the hot (black) wire connects to a *single-pole* breaker terminal while both the neutral (white) and grounding (bare copper) wires connect to the neutral/grounding bus bar (Figure 2). However, with 240-volt circuits, such as water heaters and baseboard heaters, the black and white wires connect to the *double-pole* breaker terminals, and only the grounding wire connects to the neutral/grounding bus. (Technically, this isn't quite up to code since the white wire is supposed to be used only as a neutral, but it is commonly done. Some electricians use black tape on the white wire to indicate that it is a hot wire, not a neutral.)

Some 240-volt circuits, such as for clothes dryers, have a red wire in addition to the black, white, and grounding wires. The red and black wires connect to a double-pole breaker and the white and grounding wires connect to the neutral/grounding bus. This is because dryers have both 120- and 240-volt circuits — the element is 240 volts and the controls and accessories are 120. The neutral wire provides the return path for the 120-volt circuit.

Branch Circuits

Typically, a 200-amp panel has from 16 to 40 *poles* for individual circuits. A panel is described by two sets of numbers. For example, the type of 200-amp panel I usually install is referred to as a 40/40 box. The first 40 refers to the number of standard size breakers the box can hold (the number of full sized spaces, one breaker per pole); the second number refers to the total number of circuits. If the second number is larger, it means that mini breakers are allowed in the panel. Thus, a 30/40 panel can hold only 30 standard breakers, but it can hold a total of 40 breakers if the half-sized mini breakers are used at specific bus tabs provided for them. (I don't like to install mini breakers. Because they are smaller than standard breakers, the homeowner will sometimes turn off two circuits when trying to turn off just one. Also, in my experience, mini breakers cannot withstand heat or wear-and-tear as well as standard size breakers.)

A code violation often occurs with mini breakers. Though you should never install more breakers inside a panel than it is designed for, some people have found that by removing a small metal tab on the back of some brands of mini breakers, it is possible to install them onto bus slots not intended for them. In this way, it's actually possible to install 80 breakers in a 40 breaker panel. Of course, this violates the NEC and voids the manufacturer's warranty. Good inspec-

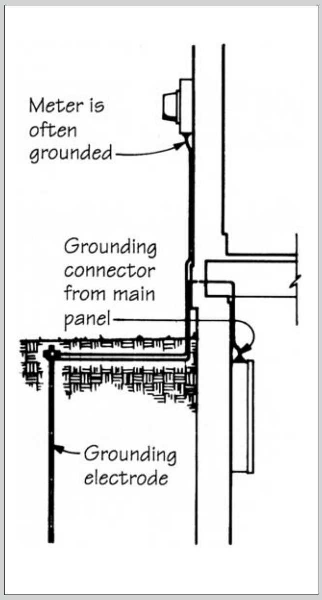
Glossary of Electrical Terms

Balanced Loads:
Results when the circuit breakers in a panel are arranged so that the total loads on each of the hot buses are approximately equal. Most 240-volt circuits, which draw an equal amount of current from each bus, are automatically balanced. However, 120-volt circuits, which draw from only one bus, must be arranged on the buses to create a balance.

Bonding:
To join together all the metal parts of the electrical system, such as switch boxes, panel enclosures, conduit, and the meter base. This prevents shock by ensuring a continuous path back to ground.

Bus:
A metal bar in the panel to which incoming and outgoing wires connect. There are two **hot buses** running down the center of the panel, each of which is connected to one of the incoming hot wires of the service entrance cable. Circuit breakers attach to the hot buses and control power to individual branch circuits. The **neutral/grounding bus bar** is connected to the incoming neutral wire and also to a wire leading to earth ground. The neutral and grounding wires of branch circuits connect to the neutral/grounding bus.

Ground:
According to the NEC, "a conducting connection, whether intentional or accidental, between an electrical circuit or equipment and the earth, or to some conducting body that serves in place of the earth." The purpose of grounding is to provide an intentional, low-resistance path to the earth for accidental excess current. The excess current may come from external sources, such as lightning or surges in the utility lines, or from accidental short circuits within the building. In residential electrical systems, bare copper **grounding wires** connected to all metal components provide a continuous ground path back to the main panel, and from there to a **grounding electrode** located in the earth outside the house.



Neutral:
In standard 120/240-volt residential service, the neutral is the grounded conductor coming from the utility. The neutral line provides the 120-volt potential for lighting and small appliance circuits. The neutral is grounded both at the utility transformer and at the point of the main service disconnect — usually in the main panel.

Pole:
In a residential service panel, the terminals on the hot buses to which circuit breakers attach. A **single-pole** circuit breaker attaches to one pole on either hot bus and taps 120 volts ; a **double-pole** breaker attaches to two poles, one on each bus, and taps 240 volts.

Service Disconnect:
The main breaker controlling incoming power from the utility, usually located in the panel. Code requires that the neutral conductor be grounded only at the service disconnect. In situations where an inspector requires a disconnect at the meter — for example, where the panel is too far from the meter — the neutral must be grounded at the first disconnect, not at the panel. In that case, the main panel is wired as a subpanel, with neutral wires isolated from the grounding wires.

Service Entrance Cable:
The three-wire cable (two hot wires and a neutral) carrying current from the meter to the service disconnect and the main panel. The service entrance cable is usually enclosed in conduit or is a heavy sheathed cable.

tors normally check for this type of violation.

Balancing the Loads

The way most panels are internally arranged is that when one breaker goes in, the next is automatically inserted on the opposite pole. If every branch circuit pulled the same amount of current, this arrangement would automatically *balance the loads* on each hot bus. However, since all circuits do not have equal loads, most electricians will try to arrange the circuit breakers so as to keep the current on one bus nearly equal to the current on the other bus. Because alternating current continually reverses polarity, this arrangement causes the loads on the neutral bus to cancel each other out, which in turn allows (by code) the electrician to use a smaller size neutral entry wire.

For the most part, 240-volt circuits balance themselves, since the double-pole breakers tap into both buses and usually pull equal amounts of currents from both sides. With 120-volt circuits, though, it's up to the electrician to create a balanced arrangement.

To do this, I first look for continuous loads. If there are two lighting loads that are on most of the time, these can balance each other, as can two freezers or a freezer and a refrigerator. The important thing is not to balance appliance against appliance, but to balance the total load in a circuit against the total load in another circuit. If any part of the house has a circuit that is always being used, balance this against another part of the house that has such a circuit. If your shop has two heavy-duty 120-volt motors that might be on at the same time, balance these against each other.

In laying out a panel, I usually place circuits that require heavy current, such as heat pumps, electric baseboard heaters, or electric furnaces, at the top of the panel bus. This lowers the heat given off by the bus by minimizing the distance, and thus the resistance, the current has to flow through. This in turn increases the life of the panel.

Subpanels

A subpanel is a panel that is located downstream from the main service panel (Figure 3). With a subpanel, instead of running separate wires back to the main panel, one feeder cable can supply a number of branch circuits at a point distant from the main service panel — as long as the main panel has the needed capacity. Subpanels are very useful in remodeling work, where a subpanel can supply all the power for an entire addition. However, the feeder cable is expensive, so a subpanel may not always be cost-effective.

Subpanel wiring. A subpanel has to be wired with the bare grounding wires isolated from the neutrals. The white wires (neutrals) must "float" — that is, connect to nothing other than the electrically isolated neutral bus and then through an insulated incoming neutral back to the main service panel's neutral/grounding bus. The subpanel's bare grounding wires connect to a separate grounding bus, bond to the panel, and then return back to the main panel's neutral/grounding bus. The rule of thumb is to separate the neutral from the grounding wires at the subpanel and reconnect them back at the main panel. Some panels, like the ITE Siemens, are designed with split neutral buses that can be used as either subpanels or main panels.

Feeder cable. Special four-conductor cable is used to connect the main panel to the subpanel; it has three insulated conductors and a bare stranded grounding wire. Another option is to use metal conduit to connect the main service panel to the subpanel. In theory, the metal conduit can act as the grounding conductor and therefore eliminates the need for the grounding wire. However, I don't recommend this because the chances for a lose connection that breaks the ground path are great.

A breaker in the main panel controls the power to the subpanel. This protects the wires feeding the subpanel in case they happen to short out. Since this breaker also protects any overloading of the subpanel, a main breaker in the subpanel isn't required — you can use what is called a lugs-only panel, where the incoming wires connect directly to lugs the way service entry cable connects in the main panel. However, if the subpanel is more than a few feet from the main panel, a main breaker in the subpanel is more convenient even though it costs a little more.

Marking the Panel

The "map" of the panel scrawled on the inside of the panel door, showing which breaker controls which circuit, usually leaves a lot to be desired. A better method is to use individual blank white stickers for each circuit, labeled with large, clear letters. If there is more than one main service panel (for example, three 200 amp panels for 600 amp service), I label them: 1 of 3, 2 of 3, and 3 of 3 in large letters on the front. In a few cases I have written on the outside of the box the circuits that were on the inside. By code, you must keep all the mains in one location near the entry. If there is a disconnect in a separate place, be sure to have a permanent label on the boxes telling its location. This is so that if an emergency occurs, such as a fire, all the power can be cut off quickly. ■

Rex Cauldwell is a master electrician and owner of Little Mountain Electric Co., in Copper Hill, Va.