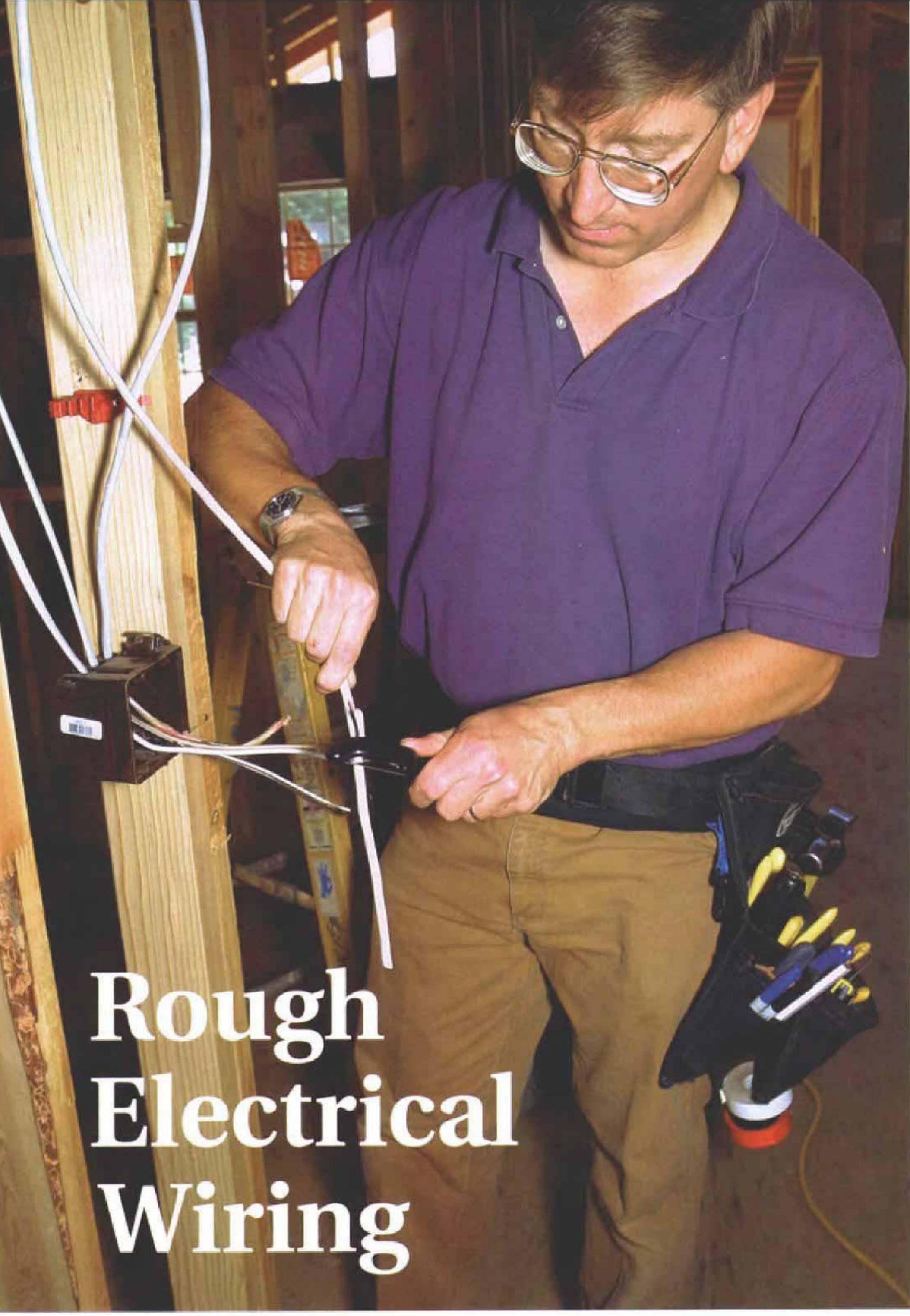


# Rough Electrical Wiring

Knowledge of the code and a few tricks ease wiring circuits for standard receptacles and lights

BY CLIFFORD A. POPEJOY

It seems that everyone who volunteers for Habitat for Humanity wants to build and raise the walls of homes. The barn-raising imagery associated with framing a house has strong appeal. But the crew of volunteers I work with gets a big reward from a different part of home building: We install the electrical wiring. I've helped motivated but unskilled volunteers successfully wire Habitat homes for years.

## Wiring begins with a plan and the right boxes

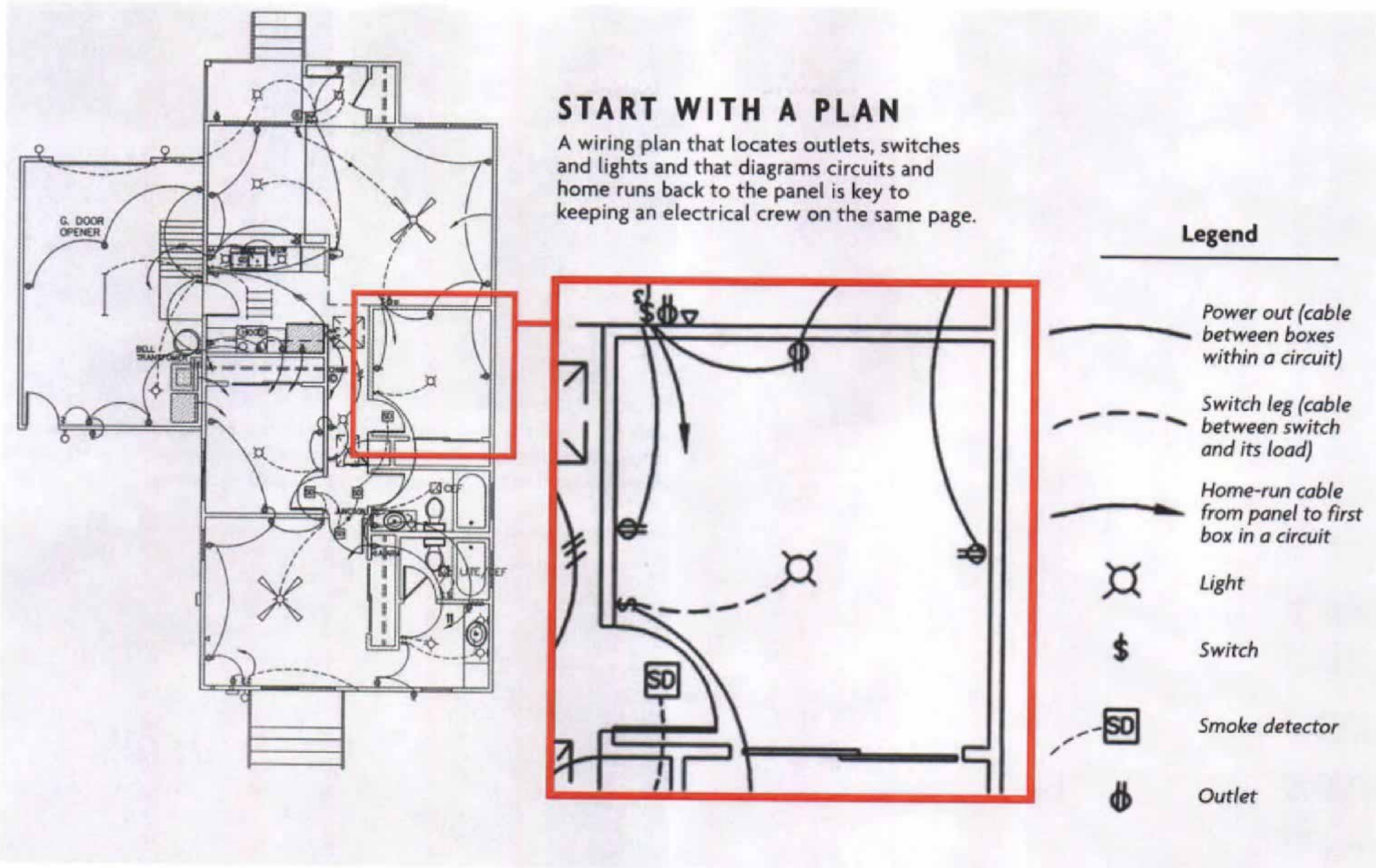
To be sure that I cover the bases and to keep my crew all on the same page, I develop an electrical plan before beginning (drawing facing page). Every switch, receptacle and light is indicated on this plan. Except for a few fixtures, such as bathroom fans and recessed can lights with integral boxes, each needs an electrical box to house the wire splices and to mount the device.

Boxes commonly used in residential construction are made of PVC, fiberglass or steel (see "What's the Difference," pp. 118, 120). Generally, if nonmetallic sheathed cable (NM) is used (sidebar facing page), so are PVC boxes. However, I check with the building department to see if they require another type of box in fire walls. Metal boxes are costlier and are not generally used except for hanging heavy ceiling fixtures.

Box size has two aspects: the number of gangs (spaces for switches or outlets) and the volume. Volume most frequently comes into play with single-gang boxes, which are made in different depths and so have different volumes. The common single-gang box volumes are 18 cu. in., 20.4 cu. in. and 22.5 cu. in. (photo left, p. 79).

I use 18-cu. in. boxes for single devices (outlets or switches) that have one cable supplying power in and another cable leaving the box, either a switch leg (the cable that brings power from a switch to the light) or power out to another box. These boxes are adequate for a single device and two cables (sidebar p. 79). By the way, running multiple "power out" cables from a box can shorten the circuit, but length isn't a problem until a circuit approaches 150 ft. (combined length of both hot and neutral from panel to farthest outlet, or 75 ft. of cable). Excessively long circuits may develop an undesirable voltage drop if a high amperage load (such as a space heater or vacuum cleaner) is plugged in near the end of the circuit.

For most other situations, I prefer to use a 22.5-cu. in. box. Having just two sizes of sin-




**START WITH A PLAN**

A wiring plan that locates outlets, switches and lights and that diagrams circuits and home runs back to the panel is key to keeping an electrical crew on the same page.

**ON-LINE CONNECTION**

Check out a video clip of electrical wiring on our Web site at FineHomebuilding.com.

gle-gang boxes on site is easier than having three, so I don't have 20.4-cu. in. boxes handy. For times when a 22.5-cu. in., single-gang box would be overfilled, I use a 4S junction box and a plaster ring (photo right, p. 79). I rarely have box-fill problems in multigang boxes.

Light fixtures almost always are hung from 4-in. round boxes. If there is to be a ceiling fan, its box must be rated as such (see "Choosing and Installing a Ceiling Fan," *FHB* #142, pp. 98-103).

### Mounting boxes for code and convenience

There are three considerations to placing boxes: the distance between outlets, their height and the distance they protrude past the face of the framing. The latter aspect is the simplest: Electrical boxes either have tabs or a scale on their side to indicate setting depth. Choose the depth that brings the box flush with the finished wall. The Na-

## Nonmetallic sheathed cable

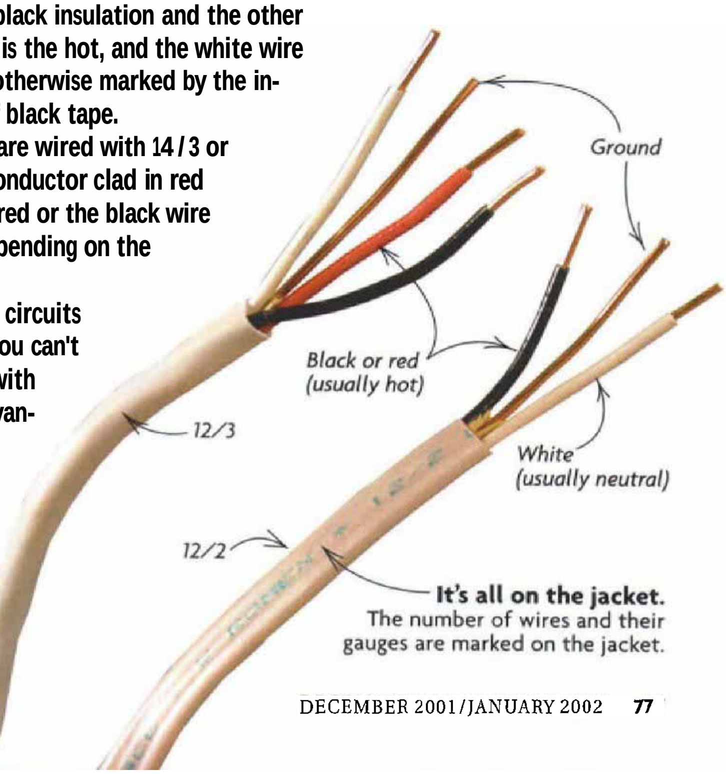
**Most wiring in new construction is done with nonmetallic sheathed cable (also known as NM cable, or Romex). Most of the NM cable used for a standard 15-amp lights-and-outlets circuit is 14 / 2 with ground. For a 20-amp circuit, 12 / 2 with ground is used. These designations mean that there are two insulated conductors in the cable, of either 14 ga. or heavier 12 ga., and one bare ground wire of the same gauge.**

**One conductor has black insulation and the other white. The black wire is the hot, and the white wire is the neutral, unless otherwise marked by the installer with a piece of black tape.**

**Three-way switches are wired with 14 / 3 or 12 / 3, with the third conductor clad in red insulation. Either the red or the black wire can be hot, or not, depending on the switch position.**

**You can wire 15-amp circuits with 12-ga. wire, but you can't wire 20-amp circuits with 14-ga. wire. The disadvantages to using 12-ga. wire where you can use 14 ga. are cost and greater box fill; 12-ga. is also harder to work with.**

*—C.P.*




**It's all on the jacket.** The number of wires and their gauges are marked on the jacket.

Drawings: Sarah Lewis

**Going 'round the bend.** After drilling intersecting holes, the author strips the cable to expose an easily maneuvered single wire. He works this wire around the turn and uses it to pull the cable.

**Wire wheel speeds the work.** This tool (Mitchell Cryogenics; 816-795-7227; $75) feeds wire from 250-ft. coils without snags or kinks.

**Staying off the ladder is faster and safer.** A big drill can throw you off a ladder if the bit binds, so the author drills plates using an 18-in. long self-feeding ship-auger bit and a 24-in. extension. You make a lot of sawdust drilling top plates, so protect your eyes.

tional Electrical Code (NEC) has specific criteria on spacing boxes (sidebar p. 81).

I install outlet boxes at 18 in. from the subfloor to the bottom of the box in voluntary compliance with the Americans With Disabilities Act. This height makes a difference for those in wheelchairs or with limited flexibility.

I set the bottoms of the boxes for kitchen or bath countertop outlets at 42 in. above the floor. This height works well for a standard 36-in. countertop and 4-in. backsplash. Switch boxes in kitchens and bathrooms are set to line up with the outlets. In other rooms, I put switch boxes at 44 in. to align the top of the boxes with the drywall seam (photo p. 76).

## Drilling holes for wire is an exercise in connecting the dots

The NEC dictates how some circuits are wired. For example, there must be a 20-amp circuit dedicated to the laundry. Most inspectors interpret the code to mean that this outlet serves only the washing machine. Consequently, the cable runs from this outlet directly back to the panel, making what's called a home run. Drilling for this circuit is easy: a hole in the top plate into the attic above the box and a hole above the panel to drop the cable down.

The NEC does not limit the number of outlets on a lights-and-outlets circuit in a dwelling. The NEC requires one 15-amp circuit per 600 sq. ft. (areas that could be made into habitable space must be included), but you could put as many outlets on those circuits as you want. I go beyond the minimum and install half again as many circuits as required.

Each lights-and-outlets circuit has one home run that powers that circuit. I generally bring home runs into the box closest to the panel. To keep wire runs short, I group adjacent rooms on a circuit wherever possible. Often, I set up two or three dedicated lighting circuits along with several lights-and-outlets circuits with 12 or fewer outlets and lights on each. Some jurisdictions don't allow mixed lights-and-outlets circuits. I've found that this arrangement takes more wire and more time than mixing lights and outlets. For example, if an outlet is close to a switch box, it makes sense to drop power to the outlet.

Once I have the plan in mind, I start drilling. I like to drill the holes in studs for horizontal runs first, 6 in. to 10 in. above the boxes. This spacing allows cable to be stapled near the box without being sharply bent, which can damage the insulation. Getting around corners is a small challenge, requiring me to drill intersecting holes through corner studs (photos top right, facing page).

Next come the holes in the plates. Above (or below, if wires are running to the basement or crawlspace) each switch box, I drill one $^5/_8$-in. hole for each cable (photo left, facing page).

I run the cable through the studs unless I need to drill two or more sets of sistered studs (at windows, for example). In this circumstance, I drill up into the attic or down into the crawlspace and run the wire around. Going through these studs would require drilling the hole with a 6-in. bit and switching to an 18-in. one, or drilling in at an angle with the long bit and nail-plating to protect the cable. On the other hand, I can punch through top plates quickly. But then I've got ladder work to run the wire and to staple it across the joists and up and down the studs.

## Wire wheel speeds the pulling

After I've drilled the holes to route the cable, it's time to connect the boxes. One tool makes this task efficient: a wire wheel (photo bottom right, facing page). Wire wheels pay off cable from a 250-ft. coil without kinking it. Kinks can damage the insulation, creating a future short circuit. Buy, borrow or make a wire wheel; you have to use it only once to realize that it's as much a basic electrician's tool as are side-cut pliers.

Running cable is a two-step process. First, I spot the wire wheel at each home-run box and walk the cable back to the panel. Because I'll run the cable in the attic or the crawlspace, I add extra length to reach from these places to the panel and to the box. I also add enough length so that the cable can follow the framing, making right-angle turns. Then I add a little extra and cut. There are usually several home runs that can run near each other to the panel. I mark their ends and

## More wires need bigger boxes

**Box-fill calculations are done to make sure there's enough room in an electrical box to accommodate safely the wires, splices, cable clamps (usually none in plastic boxes) and outlets or switches that you intend to put in the box.**

**The volume in cubic inches is usually marked inside nonmetallic boxes. If it's not, you can measure the inside dimensions of the box and figure it yourself.**

**Here's how to figure the size box that complies with the NEC.**

### STEP ONE

**Add up the wires and devices, A K A "conductor equivalents" (wires that start and end in the box—pigtails—aren't counted)**

**Each current-carrying wire = 1**

**All ground wires together = 1**

**All clamps together = 1**

**Each receptacle or switch = 2**

### STEP TWO

**Multiply the number of conductor equivalents (total from step one) by their volume factor in cubic inches (listed below)**

**14-ga. wire takes 2 cu. in. per conductor**

**12-ga. wire takes 2.25 cu. in. per conductor**

**10-ga. wire takes 2.5 cu. in. per conductor**

**If a box contains different gauges of wire, use actual volume factors for the wires and the largest volume factor for ground wires, devices and clamps.**

**EXAMPLE**

**A PVC box has two 14/2 cables, one 14/3 cable and one receptacle. The box has no internal clamps. What's the minimum box volume needed?**

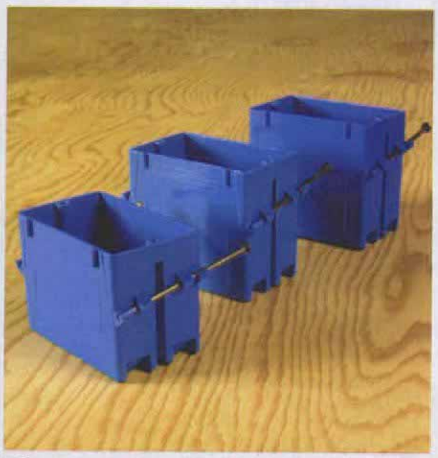
**Step 1. Count the conductors:**

| | |
|---|---|
| 2 conductors per 14/2 cable x 2 cables | = 4 |
| 3 conductors in the 14/3 cable | = 3 |
| All grounds together | = 1 |
| No internal clamps | = 0 |
| Receptacle outlet | = 2 |
| Total conductor equivalents | = 10 |

**Step 2. The volume factor for 14-ga. wire is 2 cu. in., so:**

**10 conductor equivalents x 2 cu. in.**

**= 20 cu. in. box**



**The mere wires, the bigger the box. Single-gang boxes come in three sizes, 18 cu. in., 20.4 cu. in. and 22.5 cu. in. Although smaller is cheaper, larger may avoid box-fill violations.**

**A 4-in. junction box selves most box-fill problems. Throw on a single- or double-gang plaster ring that comes flush with the drywall, and you've got a box that's hard to overfill.**

tape them together, then make one trip through the attic to the panel.

Next, with the wire wheel at the home-run box of each circuit, I pull the cable through the holes all the way to the box at the far end. Then I leave about 8 in. of cable hanging out of the last box and work back, pulling a loop of slack at each box.

## Stapling cable to the framing keeps wire from harm's way

I've found that it's better to pull all the cable, then fasten it to the framing. If you staple as you go, you may have to pull a lot of staples to stack another cable along the same route and then restaple. If several cables are going to be run on the same path, as happens near a multigang switch box, a cable tie stapled to the frame can fasten together all the cables.

The idea of stapling cable is to keep it from harm's way. The cable must be centered along the width of the stud, or an errant drywall screw can damage it. Cable standoffs ease fastening five or six cables along a stud to a multigang switch box (photo facing page). The labor savings more than offset their cost.

One important factor that determines cable's current-carrying capacity is ability to dissipate heat. Two or more cables tightly bundled for more than 2 ft. may lose as much as 50% of this capacity. Avoid this situation by not stapling cables atop each other or by running heavier wire.

## Make up the boxes, and all that's left is to tighten screws

With the cable for a circuit in place, I cut it to length so that about 8 in. sticks out of each box. I then eyeball where the cable en-

## SPECIALTY TOOLS SPEED WORK

Cable strippers remove the wire's jacket without damaging the conductor insulation.

Side-cut pliers trim the conductors evenly.

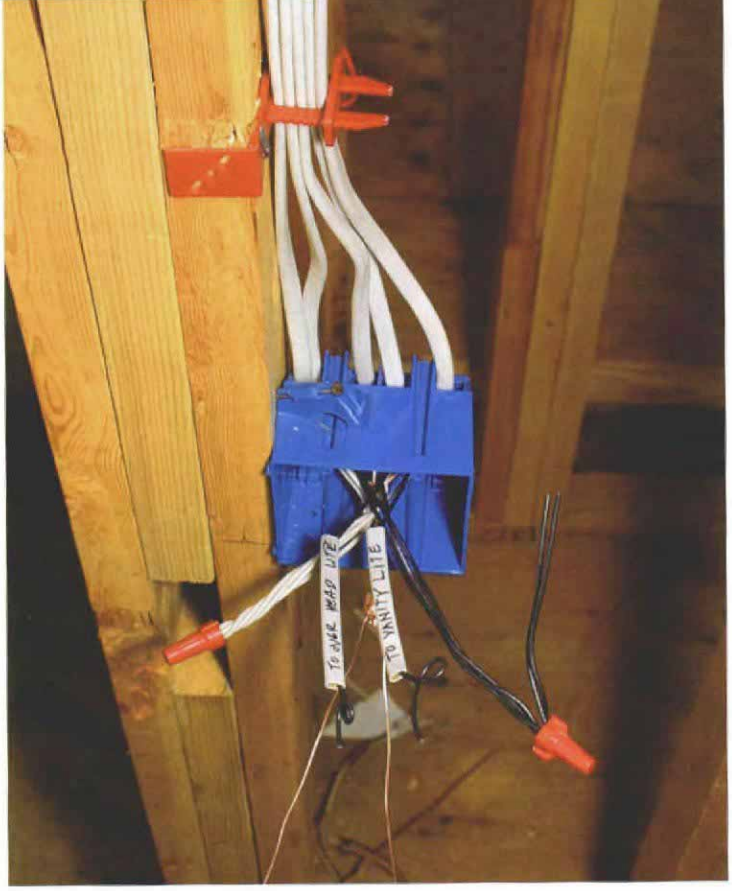
Wire-nut driver ensures tight connection.

Special side-cut pliers dimple-crimp the grounding connector.

ters the box and strip off the jacket so that ½ in. or so is left inside the box. Although some electricians use a knife to strip the jacket, I prefer wiring pliers made for this purpose (three common brands are Klein, Ideal and Craftsman). These tools make nicking the conductor insulation unlikely (photo top left, facing page).

I mark some cables to smooth the installation of the switches, outlets and fixtures. One identifying convention my crews use is to bring switch legs into the box through the top hole closest to the stud. We bring the home-run cables into the boxes from the hole closest to the stud. Switch legs where there's more than one in the box, and load sides of ground-fault circuit interrupter (GFCI) protected circuits need to be labeled with a fine-point marker.

I label these cables on a slug of jacket, slip it onto that cable's hot conductor and bend the tip of the wire back on itself to keep the label in place (photo right). For switch legs that aren't labeled, I loop the end of the wire to identify it. For three-way switch circuits, I twist the travelers loosely together and wrap the common wire tightly around its travelers. Trimming them at a 45° angle marks load-side conductors of GFCIs.




**Multiple cables call for organization. The red clamp above the box holds the cable out of harm's way, but loosely enough to dissipate heat. Labels on the hots help to get the switches right at the finish.**

Most inspectors require all the ground wires to be spliced together at rough inspection. Grounds are grouped together toward the bottom of the box, neutrals to one side and hots to the other side. I twist together the grounds with side-cut pliers (photo top right, facing page), slip on a crimp sleeve about 2 in. from the front of the box over the twisted grounds and dimple-crimp it (photo bottom right, facing page). I leave one long ground wire to attach to each device in the box, and I trim the others. The splice is pushed to the back of the box with my pliers, and I leave the ground wires for the devices sticking out the front of the box.

I splice the hots and the neutrals for the outlets and the neutrals only for the switches now, too. This task is done by stripping back about ½ in. of insulation from the conductors, adding in a short pigtail for each device and connecting them with the right size wire nut using a WCD driver (3M Corp.; 800-245-3573; www.3m.com; photo bottom left, facing page).

The last part of rough in is folding the wires back into the boxes in a Z- or M-shape. I keep all the wires at least 1 in. back from the face of the box. I don't want the drywaller's cut-out router to massacre those wires. It's no fun to repair splices at the back of the box. ❑

Clifford A. Popejoy leads a volunteer crew wiring houses for Habitat for Humanity in Sacramento, CA. Photos by Andy Engel. For more information on house wiring, see *Code Check Electrical* by Redwood Kardon and *Wiring a House* by Rex Cauldwell, both published by The Taunton Press.

## Code highlights

**The National Electrical Code (NEC) is a thick tome, much of which doesn't apply to most residential wiring jobs. Below is a quick summary of common residential code issues encountered during rough inspection.**

- ❑ **Box fill (see sidebar, p. 79).**
- ❑ **Use 12-ga. wire for 20-amp circuits, minimum of 14 ga. for 15-amp circuits.**
- ❑ **Minimum ¼ in. of cable jacket is inside boxes.**
- ❑ **The kitchen gets a minimum of two dedicated 20-amp circuits; the dining room and laundry room each get at least one.**
- ❑ **One exterior outlet goes in front and in back of house.**
- ❑ **Kitchen outlets must be within 18 in. of the top of the countertop.**
- ❑ **Wall outlets are every 12 ft. and within 6 ft. of each side of doors, no more than 60 in. above the floor. Fixed panels of sliding doors count as wall space.**
- ❑ **Any wall space of 2 ft. or more has to have an outlet, except halls and baths.**
- ❑ **Kitchen countertops 12 in. or longer and islands get outlets at least every 4 ft., and within 2 ft. of each side of sinks.**
- ❑ **Cables are fastened to framing at least every 54 in.**
- ❑ **Cables are stapled within 8 in. of box.**
- ❑ **Nail plate over cables if hole in framing is less than 1¼ in. from face of the member.**
- ❑ **Cables run along sides of joist, not top.**
- ❑ **Cables running perpendicular to joists go through holes or on 1x boards, unless there is less than 18 in. of headroom.**
- ❑ **Each room entrance and each end of a hall get a light switch.**
- ❑ **Ceiling fans need specially rated boxes.**
- ❑ **Don't drill trusses.**
- ❑ **Hallways longer than 10 ft. get an outlet.**