The AC Power Supply and HOUSE WIRING

by Ray Marston

Ray Marston explains AC power distribution principles and looks at practical domestic AC wiring circuitry in this special feature

AC Power Distribution Basics

In all modern countries, national electrical power supplies are generated in extremely-high-voltage (EHV) 3-phase AC form (usually 50-60Hz) and are then distributed nationwide to the consumers via a network of cables and step-down voltage transformers. The network takes the basic form shown in Figure 1, which also shows (in brackets) the specific voltages that are used in the UK distribution system.

Thus, major power stations feed their 3-phase power into the *national grid* at 400kV, and individual *regional* consumer boards then tap into the grid via 400/132kV step-down transformers and distribute the 132kV 3-phase VHV (very high voltage) supplies to their own individual *district* consumer boards via VHV cable networks. The individual district consumer boards then tap into the VHV network via 132/33kV step-down transformers and distribute the resulting 33kV 3-phase HV (high voltage) supplies to their own individual district areas. These, in turn, further reduce the voltage via 33/11kV step-down transformers before further processing the supply and distributing it to *individual consumers* such as industrial, commercial, and domestic units within those areas. Note that this system is designed to minimise current-generated distribution power losses caused by the resistance of the distribution network's supply cables. Thus, an end-consumer who draws 1A (11kW) from the local 11kV supply will impose a drain of only 27·5mA on the national grid, which may derive its power (via cable) from a generating plant that is hundreds of miles away.

Figure 2 shows the basic form of a typical *area* AC electrical distribution path, in which HV supplies are distributed to various consumer groups. Thus, the 33kV supply that feeds the input of the area's 33/11kV step-down transformer may also be fed directly to heavy industrial units that have their own step-down transformer and power distribution systems, and the 11kV output of the step-down transformer may be fed to light industrial units that have their own AC power processing systems. The 11kV 3-phase AC distribution system is also fed to local commercial and domestic consumers via local sub-stations, which employ a step-down transformer to provide a '415/240V' 3-phase 4-wire output from the 11kV 3-phase 3-wire input.

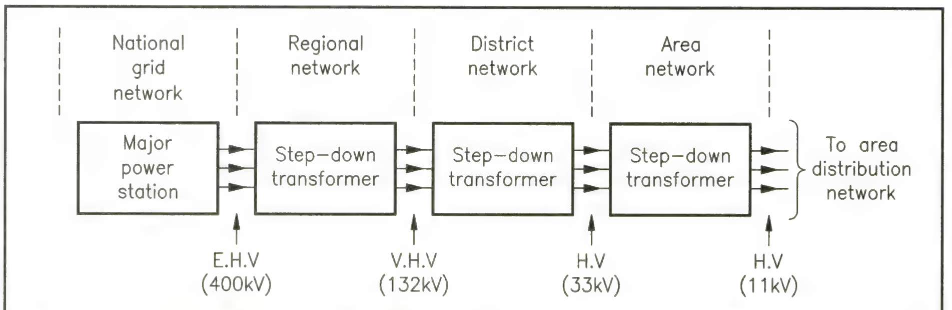

Figure 1. A single distribution path of a national AC electrical power distribution system (UK voltages are shown in brackets).

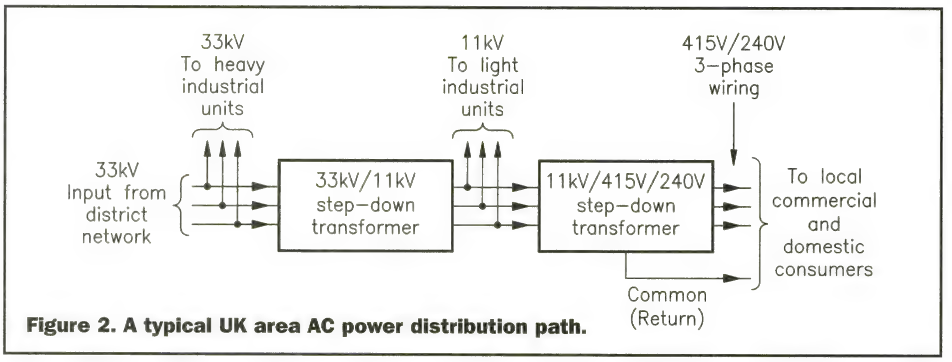

Figure 2. A typical UK area AC power distribution path.

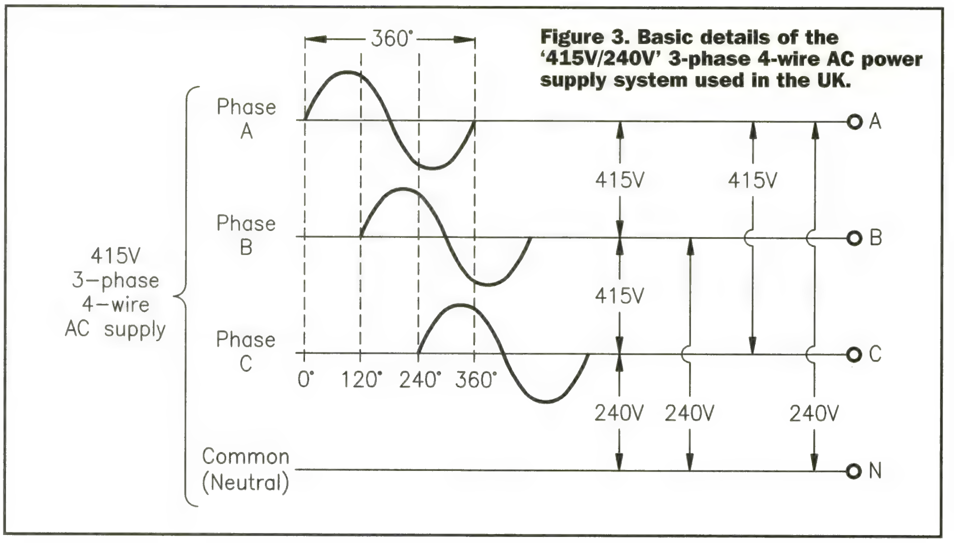

Figure 3. Basic details of the '415V/240V' 3-phase 4-wire AC power supply system used in the UK.

Figure 3 shows basic details of the above-mentioned '415/240V' 3-phase 4-wire AC power supply system. Important points to note here are that the AC voltages on the three supply lines are 120° out of phase with each other, that the rms voltage between each of the phase lines is 415V, and that the rms voltage between each phase line and the common (neutral) line is 240V. This type of system can thus be used for driving high-power 3-phase 415V electric motors by connecting the motor to all three phase lines, or can be

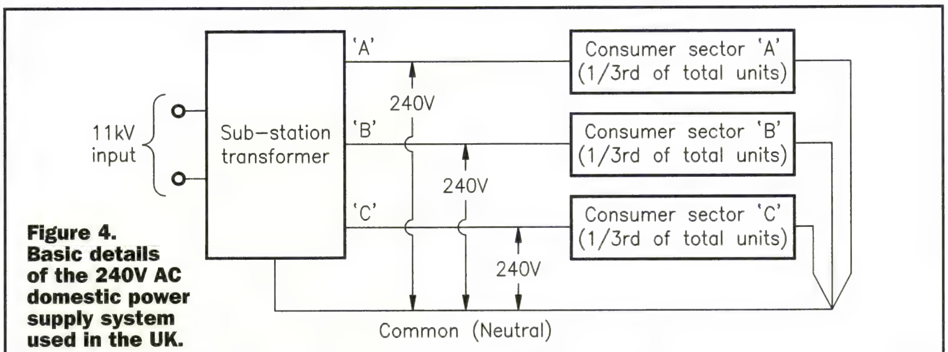

Figure 4. Basic details of the 240V AC domestic power supply system used in the UK.

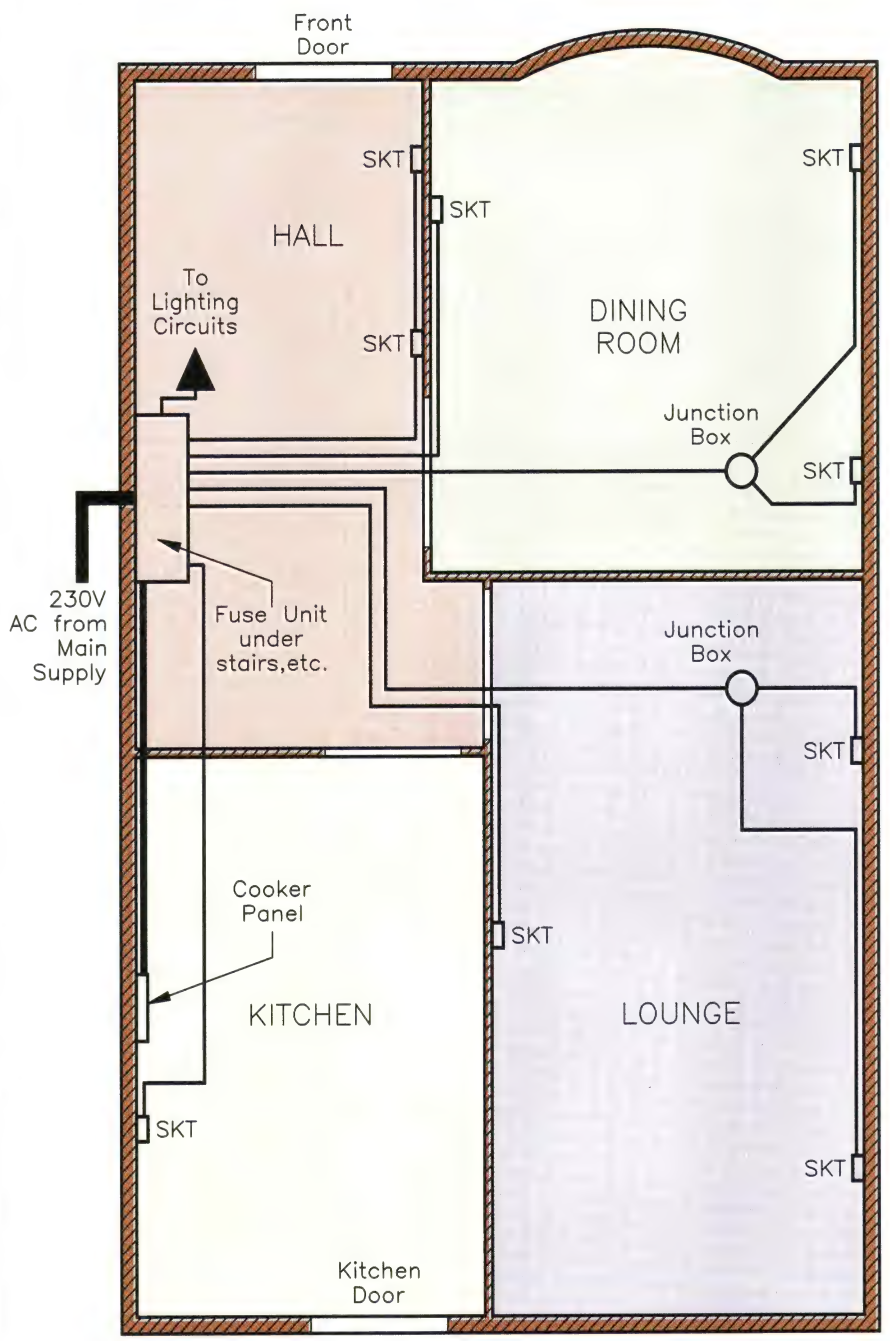

Figure 5. Typical old (pre-1947) 'radial'-style ground floor power wiring layout of a medium-sized UK house.

used to supply normal 240V AC power to domestic or commercial premises (etc.) via the common line and any one of the three phase lines.

One other important feature of the Figure 3 AC power supply system is that, because of the 120° phase shift that exists between the three supply lines, the sum of the three instantaneous voltages that appear between common and the three phase lines always equals zero. When, for example, the 'A'-line voltage is at its peak value of +340V, the 'B' and 'C' voltages are each at –170V, thus giving an overall sum of zero volts. Consequently, if identical loads are connected between each phase line and common, each phase line will supply an identical rms current, but zero rms current will flow in the common line. These simple facts form the basis of the normal 240V AC domestic power distribution system, which is shown in Figure 4.

In Figure 4, the area supplied by a local sub-station transformer is divided into three consumer zones or sectors, each of which consumes approximately one third of the total electrical units absorbed by the area. Each of these sectors is connected to the 240V AC supply provided by one specific phase ('A', 'B', or 'C') of the 3-phase supply, and via the sub-station's common line. Thus, if the system is perfectly balanced, the common line will always carry near-zero current, and if the system is severely disrupted (by the temporary removal of one complete sector from the system), the common line will carry a current no greater than that of the larger of the two remaining phase currents. Consequently, this basic 3-phase system allows any desired number of consumers to be supplied with a 240V AC single-phase 2-wire (plus 'earth') power supply, using only a 4-wire distribution system in which each wire requires a maximum current rating equal to one-third of the peak total current consumed by the system. This system is thus highly efficient in terms of power distribution costs.

Domestic AC Wiring Systems

Most ordinary houses are, as described above, provided with an ordinary single-phase AC power supply system. **In the UK, this is actually a 50Hz 240V supply that is regulated to within 6% of 240V (i.e., within the limits 224 to 256V), but is often called a '230V' supply to harmonise with the nominal 230V 'norm' of other European Community countries.** The supply is connected via a 3-wire '*phase*, *neutral* and *ground* (earth)' distribution network. A few large domestic premises (and many industrial units) are also supplied with a 3-phase 415V supply, for operating heavy-duty electric motors (for powering lifts, etc.).

In the UK, all 'modern' house wiring is designed to conform to safety regulations that were first laid down in 1947; these regulations have since been upgraded in fine detail, but are unchanged in essence. Thus, if you live in an old house that has not been rewired since 1947, it is probable that your old wiring has now reached a point where its rubber insulation has perished to the state where a total breakdown is imminent and the whole shambles is in danger of bursting into flames, and an urgent rewire – to modern standards – is probably required.

In all domestic UK buildings, electric power is fed into the house from the external 240V AC network and applied, via the building's electricity meter, to the individual household circuits via individual fuse units or, in modern systems, via a multi-fused *consumer* unit. The household circuits are, for convenience, classified as three distinct types, (a) power circuits (feeding power sockets, etc.), (b) lighting circuits and (c) accessory circuits (individual heavy-duty circuits feeding immersion heaters, cooker panels, etc.).

Old-style (pre 1947) electrical systems use a *radial* system of power circuit wiring, as shown in Figure 5. Here, each individual power socket or small group of sockets is treated as an individual circuit and is connected to the AC power line via its own specific fuse and length of 3-core cable; often, the phase ('live') and neutral lines of each circuit are individually fused. Such systems are inefficient; they require excessive amounts of cable and many fuses.

Modern (post-1947) UK systems of power wiring use a *ring* system of power-socket wiring. Figure 6 shows a typical example of such a system, in which the ring can be connected directly to the fuse box (consumer unit) or can be connected via a junction box, as shown. Here, a 3-core power cable is run from the junction box to the first (hall) socket, then sequentially to all of the sockets on (say) the ground floor and finally, back to the junction box again, so that a 'ring' of cable is formed. The ring is treated as a single circuit and provided with a single master fuse, but each socket plug is individually fused. Most modern houses are provided with two ring circuits, one to each floor. On the upper floor, the ring may be connected to the fuse unit via a junction box and feeder cable.

The ring system is very efficient in the use of 3-core cable. Power is fed to each individual socket via both sides of the ring, which are thus effectively wired in parallel and share the socket current. This factor enables a relatively light gauge of ring cable to be used. In practice, 2·5mm² PVC sheathed cable is used for most ring circuits, and any desired number of standard 13A sockets can be fitted to such a ring, provided that it does not serve a floor area greater than 100m²; such a ring must be fitted with a 30A (maximum) master fuse and can handle up to 7·2kW. The feeder cable to such a ring (if used) must be a 4·0mm² type. Note that most 2·5mm² cable has a maximum current rating of only 20A, so if such cable is used to make a multi-socket 'spur' that is tapped into the main ring, the spur must be fitted with its own 20A (maximum) master fuse.

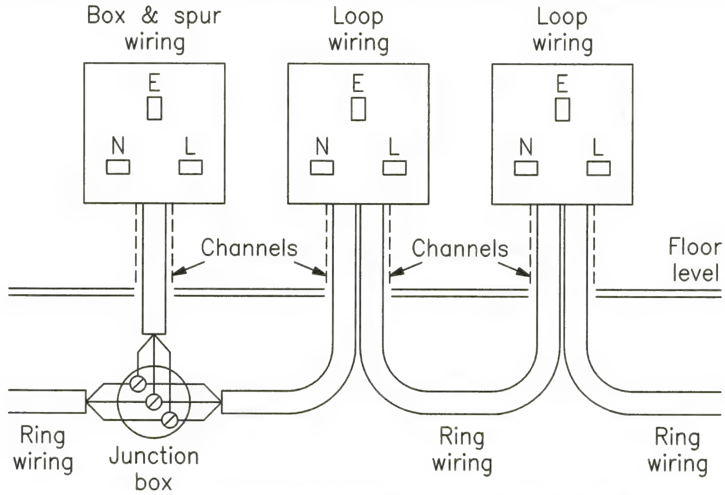

Figure 7. Alternative ways of connecting a power socket to the main AC power ring.

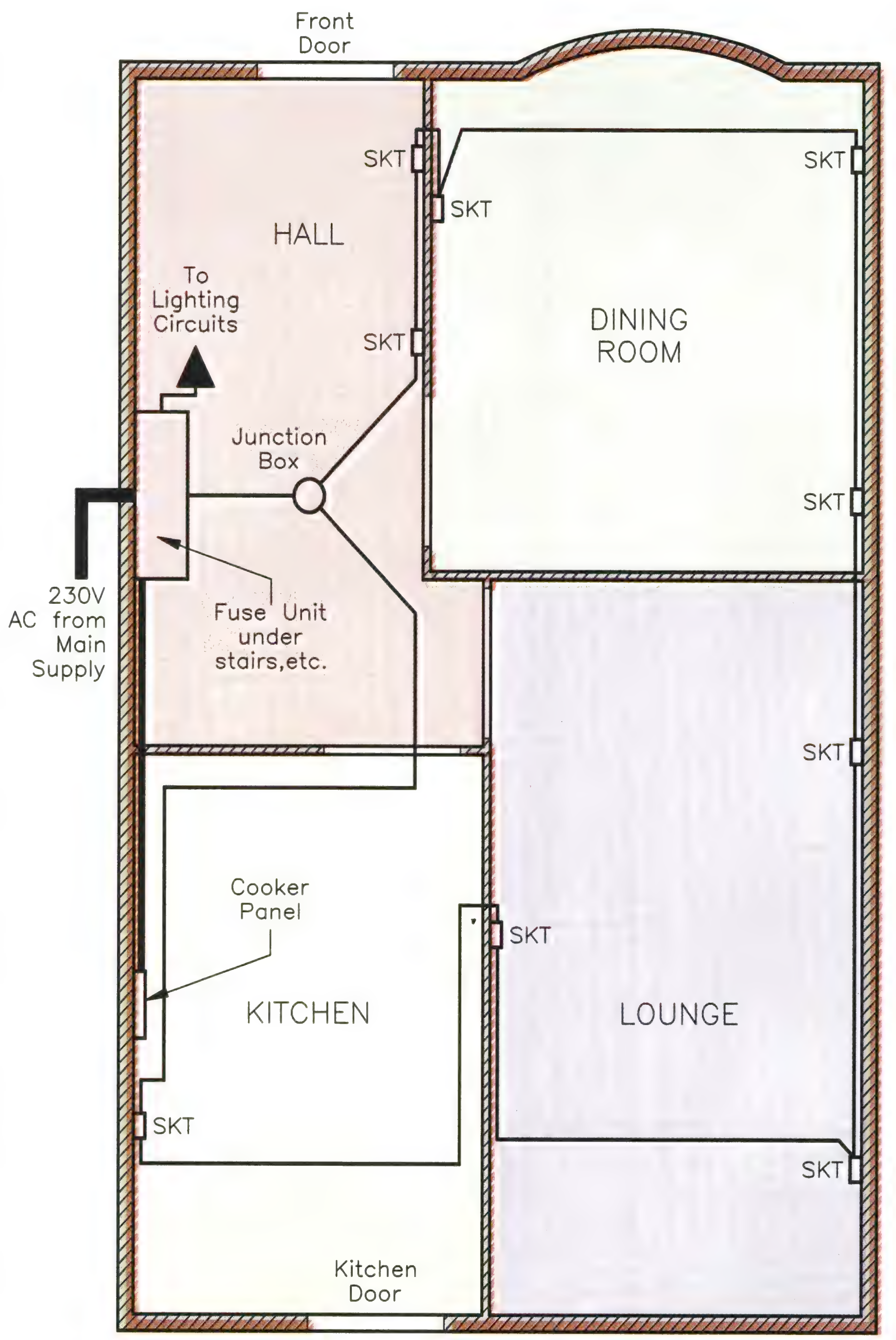

Figure 6. Typical modern (post-1947) 'ring'-style ground floor power wiring layout of a medium-sized UK house.

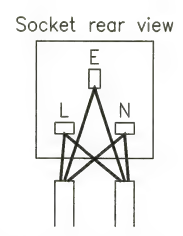

Figure 8. Basic way of connecting 'loop' wiring to a power socket.

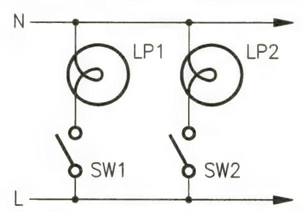

Figure 9. Basic domestic lighting circuit ('Earth' wiring not shown).

Modern Power Circuit Wiring

Rewiring the power circuitry of an average house to modern standards is a technically fairly simple task, but involves much dirty and hard work. Normally, the power ring is laid below the floorboards, and is connected to the individual power sockets by using either 'loop' techniques, or 'box- and-spur' techniques, as shown in Figure 7.

Before starting such a rewire, plan very carefully the precise layout of each basic wiring ring, and the desired number and positions of all of its power sockets. Flush-type sockets are fitted into special metal boxes, which must (usually) be set into a wall or plaster, in which a channel must also be cut to accommodate the socket's power wiring, which is fed upwards from the sub-floor power ring. The socket can be loop-wired into the ring by (1) making a loop in the ring's wiring, (2) feeding the loop up to the socket, then (3) cutting the loop so that two effective lengths of 3-core cable are available; finally, (4) the tips of the six 'cores' can be bared and wired to the socket as shown in Figure 8. Note that this loop technique requires two lengths of cable to be buried in the socket's wall channel; the alternative 'box-and-spur' technique (Figure 7) requires only one length of cable to be so buried, the other end of the cable being connected into the ring via a sub-floor junction box.

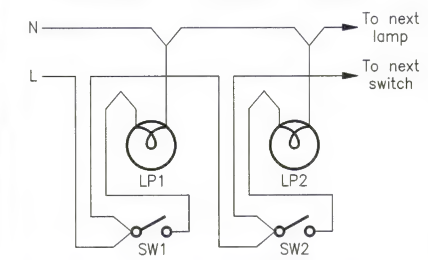

Figure 10. Old-style implementation of the lighting circuit (Earth wiring not shown), with three wires (plus Earth) running down to each switch.

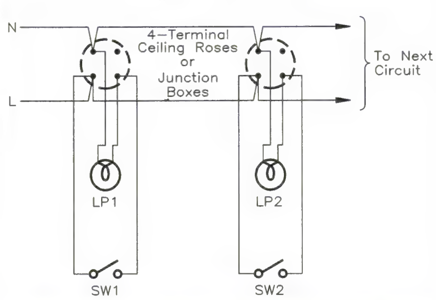

Figure 11. Modern-style implementation of the lighting circuit (Earth wiring not shown), with two wires (plus Earth) running down to each switch.

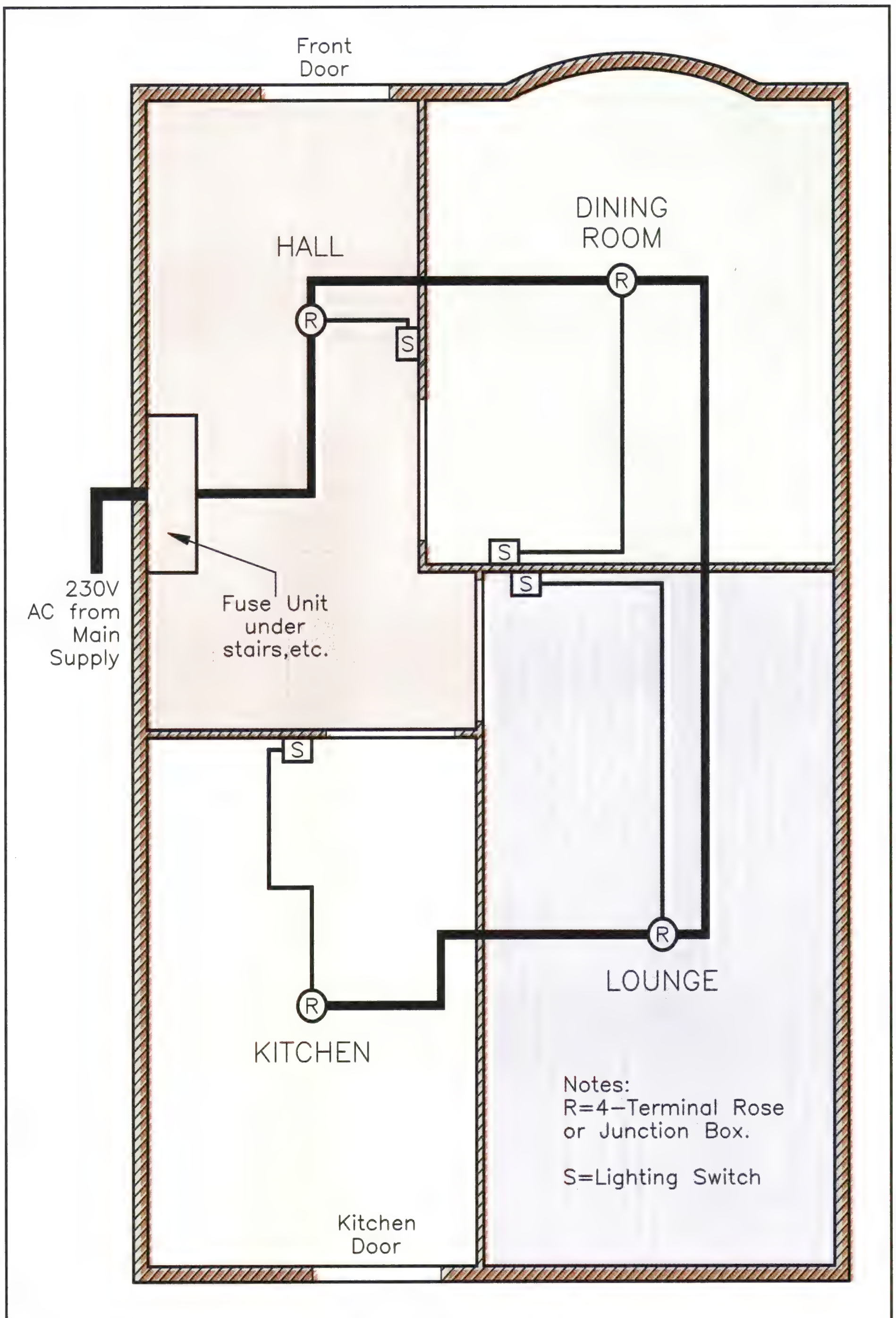

Figure 12. Basic modern ground floor lighting circuit of a medium-sized house.

Modern Lighting Circuit Wiring

The basic AC lighting circuit of a domestic system is deceptively simple, as shown in Figure 9. Note in particular, that the light switch is used to connect the lamp to the live (L) side of the supply, thereby ensuring that an electric shock cannot be received from the lamp (when changing a bulb) when the switch is open ('off'). Also note that all lamp-plus-switch circuits are wired in parallel, across the supply lines, in 'radial' form.

The physical implementation of the Figure 9 circuit is not simple. Figure 10 shows the old-style (pre-1947) method of implementation, in which Neutral (N) goes to one side of each lamp and the Live line is looped from one switch to the next. Note that this method requires three wires plus Earth (E) to be run down to each switch. In practice, the old-style wiremen often ignored the 'polarity' rules and switched the Neutral line, so that the lamp socket remained permanently (and dangerously) 'live'.

Figure 11 shows the modern wiring method, which requires only two wires (plus Earth) to be run down to each switch. The system makes extensive use of 4-terminal ceiling roses or junction boxes. In practice, $1mm^2$ 3-core 'twin and earth' (T & E) cable is used for wiring most domestic lighting circuits.

Figure 12 shows (in simplified form) the basic modern ground-floor lighting layout of a medium-sized house. The power feed is taken from the main fuse box and runs, 'radial' style, to all the roses of the ground floor lights. Light switches are wired to the roses via additional cable. Once again, the system looks deceptively simple. In reality, the wiring to the roses runs above the ceiling; thus, the ground-floor's wiring must be laid by partially raising the carpets and floor boards on the first floor, and the wiring to the wall-mounted switches must be made by cutting suitable channels in the plaster, between the ceiling and the switches. Also, it is usual to apply multi-way switching (rather than switching from only a single point) to hall and landing lights, and this can be a very time-consuming task.

Figure 13 shows the circuit and implementation of 2-way light switching. In practice, 3-core 'twin and earth' cable is used to connect SW1 to the ceiling rose, and 4-core '3-core and earth' is used to interconnect SW1 and SW2, which are changeover switches. A lot of channelling work may be required to implement this system.

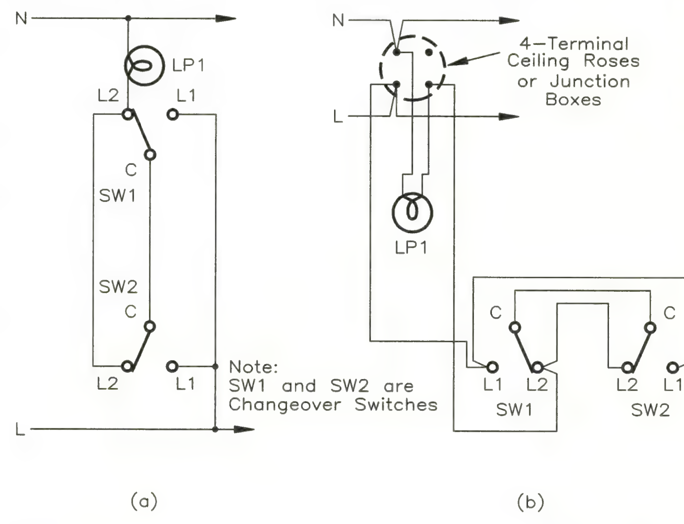

Figure 13. Circuit (a) and implementation (b) of modern 2-way light switching (Earth wiring not shown).

Figure 14 shows the electrical circuit involved in 3-way light switching, such as is often used in a hallway, in which the light can be controlled from either end of the hall and from an upper floor. This circuit uses two changeover switches and one standard 'intermediate' switch (available from most electrical retailers). This circuit is very time consuming to install and requires a lot of channelling.

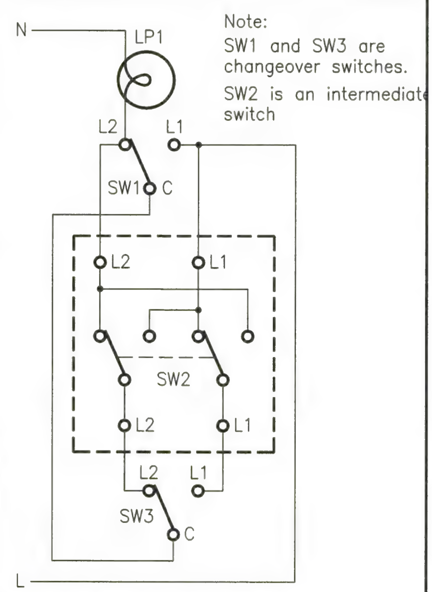

Figure 14. The electrical circuit used in modern 3-way lighting.

Accessory Circuit Wiring

'Accessory' wiring is used for connecting fixed wired (non-plugged) appliances to the AC power supply, and comes in two basic types, being for either less-than-13A light-duty use, or for greater-than-3kW (= 12·5A at 240V) heavy-duty use.

Light-duty accessories include items such as electric door bells that are AC powered via step-down isolating transformers, electric clocks, small (less than 3kW) fixed electric heaters and fans, hot-air hand dryers, air extractors, and small air conditioning units or dehumidifiers, etc. Such units may be connected to the fused consumer unit via individual wiring spurs, or can be connected to one of the main ring circuits. In the latter case, the accessory must be connected to the ring via a fused connection unit (often called a 'fused spur unit') and must be controlled via a double-pole switch, which may be incorporated in the accessory or the connection unit, or may be connected in series with the wiring.

Figure 15 shows three alternative ways of wiring fixed light-duty accessories to an existing ring circuit. In (a), the accessory incorporates a 2-pole switch and is connected to the ring via a simple fused connector unit and a junction box. In (b), the unswitched accessory is connected to the ring via a fused connector unit that incorporates a 2-pole switch and via a junction box. In (c), the unswitched accessory is connected to a switched fused connection unit that is loop-wired into the ring circuit.

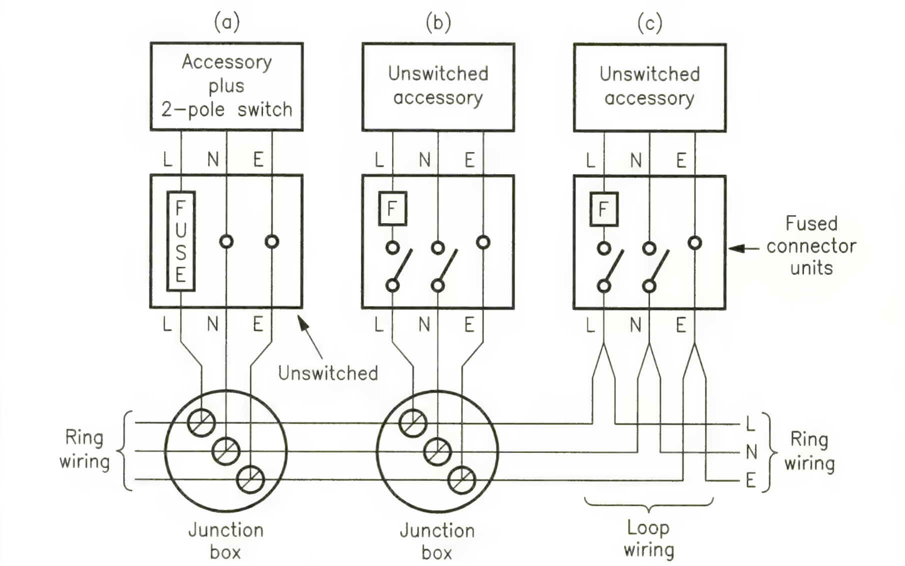

Figure 15. Three alternative ways of wiring fixed light-duty accessories into an existing ring circuit.

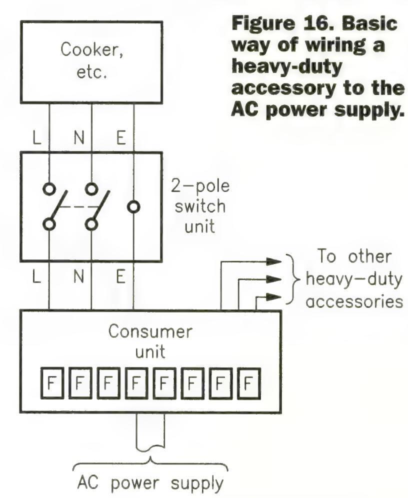

Figure 16. Basic way of wiring a heavy-duty accessory to the AC power supply.

Heavy-duty accessories include items such as electric cookers, water heaters, and storage heaters, etc., which must each be connected to the consumer unit via an individual wiring circuit and a 2-pole switch that is placed close to the accessory, in the manner shown in Figure 16. The circuit does not have to be individually fused, since overload protection will be incorporated in the part of consumer unit that feeds the circuit.

Practical Rewiring Hints

Electrical rewiring is a technically simple but physically arduous, dirty and time-consuming task that can save the keen DIY enthusiast a huge amount of money. To gain access to underfloor wiring areas, you will usually have to move lots of furniture, lift large areas of carpet, and raise several floor boards in each room. You will have to crawl about beneath the floorboards, and may have to drill holes through joists and beams to facilitate wiring runs. If you are adding new flush-fitting power points or lighting switches to a house, plaster (and sometimes bricks) will have to be

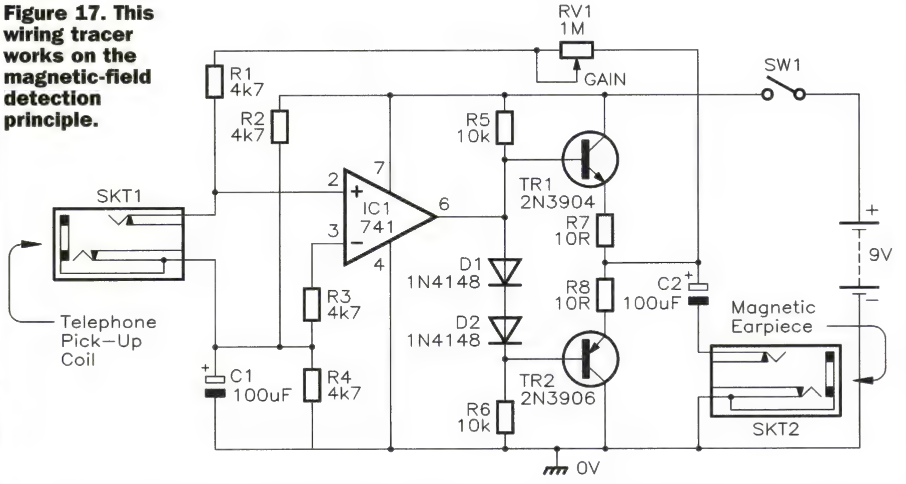

Figure 17. This wiring tracer works on the magnetic-field detection principle.

The Figure 17 wiring tracer works on the magnetic-field detection principle and is used to trace 'live' wiring that (ideally) is actually passing current to a load. The wiring is located by sweeping across its suspected path with an ordinary telephone pickup coil until its 50Hz magnetic field induces a signal in the pickup coil. This signal is amplified by op-amp IC1 and power-boosted by the Q1-Q2 (etc.) amplifier, to finally produce a distinct 'hum' sound in the magnetic earpiece.

The Figure 18 circuit acts as a simple beat-frequency oscillator (B.F.O.) metal detector that is used in conjunction with a hand-held AM (long-wave or medium-wave) radio, and can be used to locate heavy-duty wiring or metal plumbing. The circuit is simply that of an L-C oscillator, in which the inductance of L1 (and thus the frequency of oscillation) is influenced when L1 comes near most

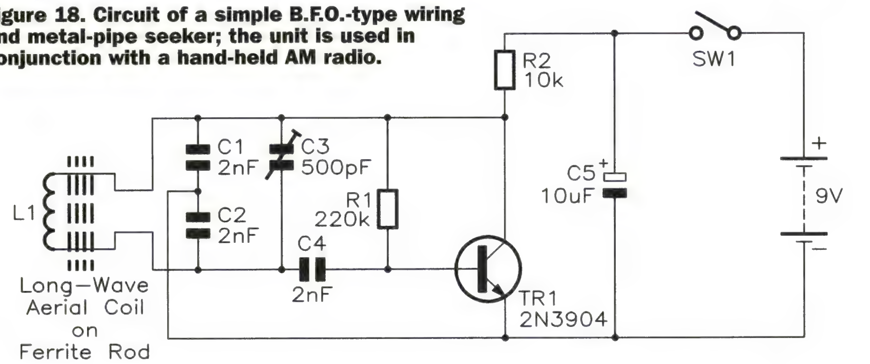

Figure 18. Circuit of a simple B.F.O.-type wiring and metal-pipe seeker; the unit is used in conjunction with a hand-held AM radio.

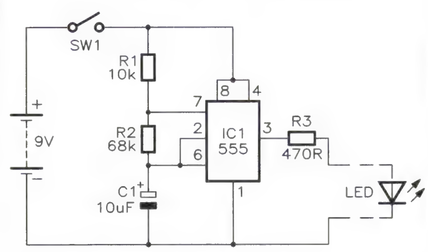

Figure 19. This 'marker beacon' circuit can be used to indicate the positions at which pilot holes break through into dark places.

channelled to accept new cable runs and must be repaired afterwards. Essential tools for these jobs include two 2·5in. bolster chisels, a lump hammer, and a good power drill.

Before starting your first rewire, buy or borrow at least two good DIY books on the subject, and study them carefully. One highly recommended book is the Collins *Wiring & Lighting* DIY Guide, available from Maplin (Order Code WT56L), which gives step-by-step instructions on most practical aspects of house wiring. When you are ready, plan your new wiring layout with great care, giving lots of thought to the positioning of new power sockets, light switches, and ceiling roses, etc. In many houses, most of the original switch and power-socket wiring and floor-to-floor feeder cabling, etc., is fed via metal conduit (tubing), and your rewiring task may be greatly simplified by re-using this conduit, as explained in some of your DIY books.

Figures 17 to 19 show some useful rewiring aids. The Figure 17 and 18 circuits can be used for tracing old wiring and conduit, and the Figure 19 circuit acts as a 'marker beacon' that can be used to indicate the loft or under-floor break-through positions of pilot holes drilled through ceilings when installing new feeder cable runs or when re-positioning ceiling roses, etc.

common types of metal. In use, the unit and the small radio are switched on and the radio is tuned until a low 'beat' note is heard from its speaker; this 'beat' note should change when the unit's 'search head' (L1) is placed near metal. Hidden wiring (etc.) can then be located and its path traced by sweeping across its suspected route with the search head.

Finally, the Figure 19 'marker beacon' circuit consists of a simple low-frequency '555' astable multivibrator that pulses the LED on and off at a slow rate; the LED should be soldered to the end of a fairly stiff length of 2-core flex, so that it can easily be passed through small drilled (pilot) holes, etc. ELECTRONICS