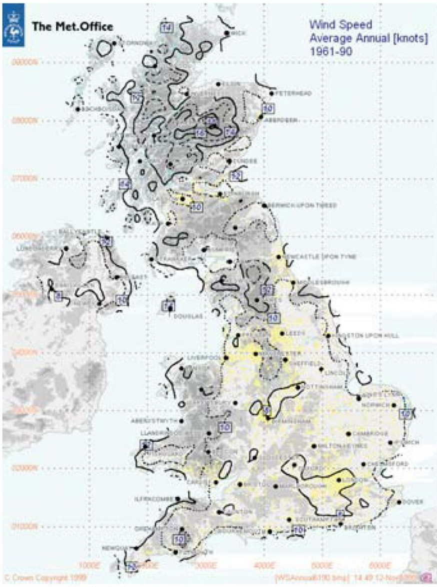
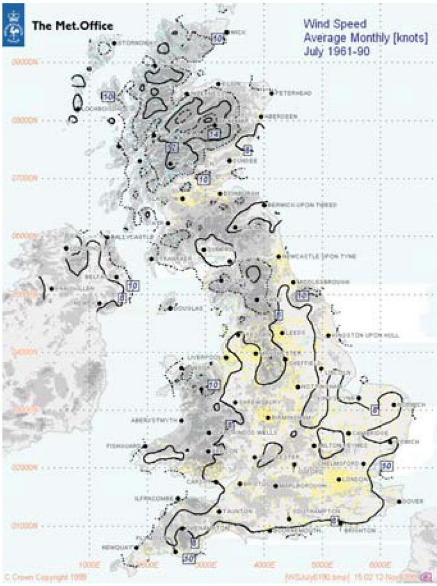




and discharge the battery. Others dispute the need for them. TF panels incorporate blocking diodes, so external diodes are not needed in any case. Multiple panels can be controlled by a single controller/regulator but each panel needs its own diode.

Some controllers can regulate a combination of solar panels and a wind turbine.

Regulation

For trickle charging with a panel output of no more than 1 watt for each 10 amp, hours of battery capacity, no regulation is required. Greater outputs need a regulator, although 'live-aboards' may choose to switch the panels on and off as required.

Maintenance

Panels have a good life expectancy these days, with many framed panels having a 20-year guarantee. However, semi-rigid panels have only a one-year guarantee, while fully flexible TF panels are guaranteed for three years.

Maintenance is minimal. Make sure the connections are sound and the surface clean.

Wind turbines

Wind is free, so it would seem logical to harness its energy to generate electricity. However, the average windspeed may not be enough to satisfy your needs. Average annual or seasonal windspeeds can often be obtained from the Internet for the region in which you will be sailing.

Types of turbine

There are two types of turbine: those with blades like a propeller and those that look more like a vertical cylinder.

The cylinder type

These are no more than trickle chargers with outputs in milliamps rather than amps. They will maintain the charge of a battery while the boat is on its mooring, but because they won't charge a discharged battery in 15 knots of wind, the weekly output is no more than around 15 amp hours. Because of the low output, they don't require a regulator.

With no whirling blades, this type is inherently safe and noise levels are very low. They are ideal for maintaining battery charge when the boat is not being used and there's no access to mains power.

The propeller type

With diameters of up to 1.2 metres and rotation speeds up to 2000 rpm, these machines can be dangerous, so they must be mounted well out of harm's way. On ketches they are often mounted on the mizzen mast, where they are in faster and less disturbed airflow, but generally they're mounted on a pole at the stern. Some skippers restrain blades with straps to prevent rotation when their power isn't required. In this case, they must be within reach but not too low to be a hazard.

Given the right conditions, these machines can contribute significantly to the on-board electrical demands. They can, however, be noisy. The noisiest seem to be those with long slim blades and this noise 'ululates' as blade speed varies in the turbulent airflow around the boat. The noise can disturb a quiet anchorage, and this type of turbine is banned from use in some marinas.

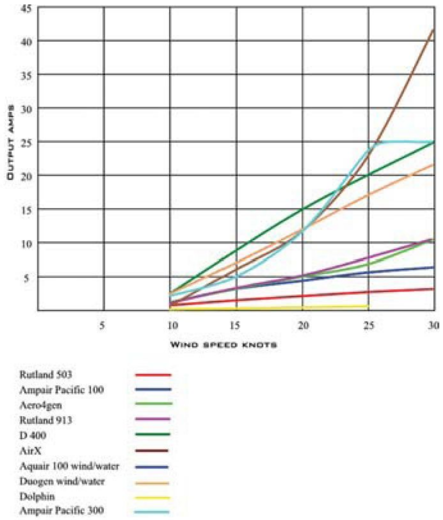
Vibration can occur with propeller-type turbines, often due to pitch differences on each blade, and this should be rectified to prevent shaking components loose.

Wind turbine output

Quoted output of a wind turbine is often the maximum that it will produce. Although output curves vary, a reasonable generalisation is a straight line output curve from zero at start-up speed to its maximum at around 30 to 40 knots. Start-up speed is around 6–8 knots for most models.

Wind speed

As an example, the summer average wind speed along the south coast of England is around 12 knots,



Wind generator outputs

Generator output	Amps at 9 knots	Amp hrs per day at 9 knots
Aero2Gen	0.3	7.2
Aero4Gen	0.8	19.2
Aero6Gen	1.6	38.4
Air X	1	24
Pacific 100	1	24
Duogen	1.5	36
D400	3.8	91.2
Rutland 503	0.4	9.6
Rutland 913	1	24

while on a trade wind passage the wind may average 25 knots. Because of the surface friction, wind speed at the height that the wind turbine will be mounted is reduced by as much as 50% and turbulence from the boat's structure and rig will reduce the turbine speed even more. Turbulence could be a factor in an anchorage as well. Anchorages chosen for their shelter can reduce the local wind speed and so inhibit the wind turbine's output.

Under way, the boat's speed will change the true wind speed, so that on a downwind passage, the apparent wind speed may be considerably reduced. Going to windward, although apparent wind speed is increased, turbulence from the mainsail will play havoc with the airflow over the turbine.

In the summer of 2005, I carried out tests on wind turbines for *Practical Boat Owner* magazine. The average wind in the summer along the UK's south coast at 3 metres above sea level is only 9 knots, and a selection of wind turbines gave the following results.

The role of the wind turbine for on-board power generation

Because of the factors outlined above, it's unlikely that a wind turbine will satisfy all of your electrical demands all of the time. At worst, in some places it's not worth fitting one at all. At best, it will almost certainly need to be supplemented by some other form of generator.

Commonly, 'live-aboards' supplement the wind turbine with solar panels, but the engine-mounted alternator can also be used. A careful analysis of your electrical demands and cruising area (and season) needs to be made to weigh up the cost and benefit of fitting a wind turbine.

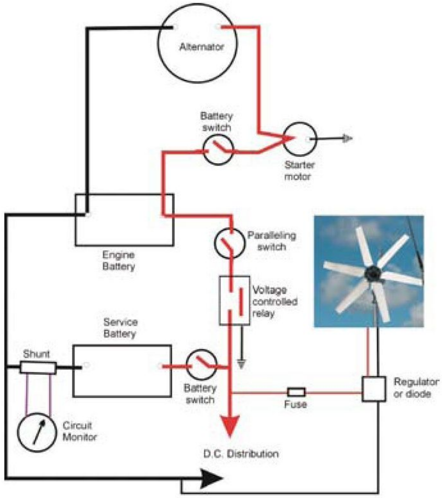
With prices varying from around £300 to £1000, the wind may be free, but the cost of generation certainly isn't. Only serious users of on-board power sources with no cheaper or alternative power should consider fitting a turbine, although a cylinder type could be useful for maintenance charging the battery of a boat on a mooring.

Connecting the turbine

Output of a turbine can be high, so the output cable must be fused to protect the cable should a short circuit occur. Obviously the fuse's rating must be greater than the maximum output of the turbine, and the cable must not only be of sufficient size to carry the current, but also sufficient to reduce the voltage loss in the cable.

The output should also be regulated to prevent overcharging the batteries. Regulators can be of the *shunt type*, which dissipate the excess power as heat, or electronic *switches*, which disconnect the turbine from the battery once the battery is charged.

Regulators are available to charge multiple banks of batteries and also to combine solar, wind and engine generators. These specialist regulators should be specified as part of the overall electrical generating system.



Wind Generator Circuit

Maintenance

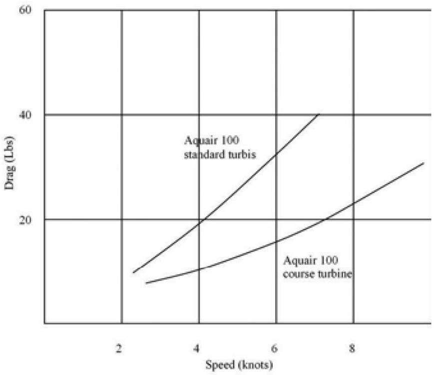
Generally, wind turbines require no maintenance, although it's prudent to inspect the tightness of connections from time to time, especially if there's any vibration. After several seasons' continuous use, there may be a need to replace the carbon brushes that pick up the current. Securing the blades against rotation when turbine output isn't required will prolong the life of the brushes. Some turbines have no commutator brushes on the generator, but they still need brushes on the slip rings that allow the turbine to align itself to the wind.

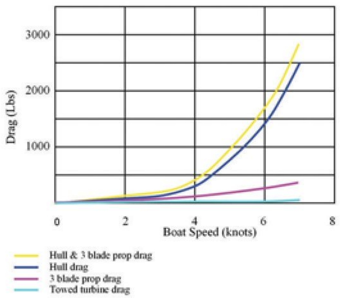
Always ensure that you turn the turbine out of the wind to stop rotation and then secure the blades to prevent their turning before you start any work.

Water turbines

A propeller-shaped turbine connected by a rope to a boat-mounted generator can be towed behind the boat. Equally, a turbine/generator unit can be mounted on a leg immersed in the water.

With the boat under way, electricity is generated due to the forward motion of the boat. The drag produced

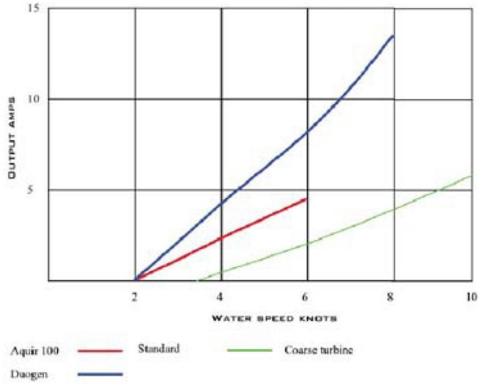




Comparison of towed turbine drag


Courtesy of Electric Energy, Ltd

by the towed turbine gives a slight reduction in boat speed, but users do not see this as a disadvantage. If the boat travels faster than the turbine's maximum design speed, the rotor will surface. Course pitch rotors are available for higher speed, and in marginal cases, heavier rope or a sinker weight can be used. The boat needs to be sailing at a minimum of around 3 knots before the turbine can be used.



Water turbine output

Continuous steady output of the towed turbine in amps is around half the boat speed in knots. So, cruising downwind at 6 knots one can reliably expect a daily output of over 70 amp hours. This can come close to fulfilling the boat's electrical needs.

The DuoGen, new to the market, has the water turbine mounted on the end of a counterbalanced arm that is lowered into the water.

Often, the generator can also be modified quickly to be driven by a wind turbine, so owners of this system can use it as a wind turbine at anchor or on short passages, but re-rig it as a towed turbine for long passages.

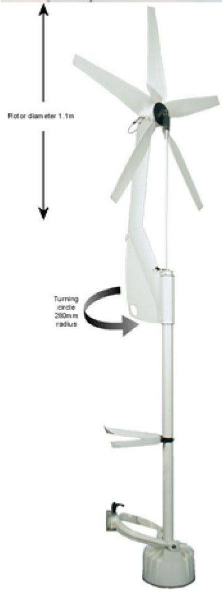
Removable propeller blades can be fitted to the Duo-Gen turbine, which is then mounted vertically to convert it into a wind turbine.

Connection

Electrical connection and requirements are the same as for a wind turbine.

Maintenance

No special maintenance procedures are required, other than those appropriate to a wind turbine, but a spare towed rotor needs to be carried to allow for accidental loss.



Switches and Relays

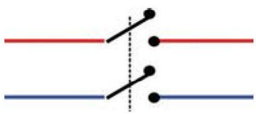
SWITCHES

A switch allows a circuit to be 'made' or 'broken' so that a light, motor or whatever can be activated or isolated.

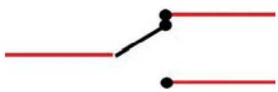
A switch has at least one pair of contacts that can be made or broken, but can be much more complicated. It can make or break several circuits at a time, or can be made to switch between one or more circuits, either individually or in unison.

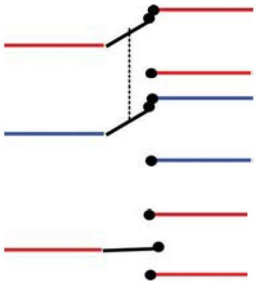
- Single pole, single throw (SPST), i.e. ON/OFF.

- Double pole, single throw (DPST), i.e. ON/OFF for two different circuits at the same time.



- Single pole, double throw (SPDT), i.e. switches between two different circuits.





- Double pole, double throw (DPDT), i.e. switches between two different circuits for two circuits at the same time.

Another variation is that double throw switches may have a centre 'OFF' position so that you may choose between OFF and either one or another circuit:

Obviously the DPDT switch may also be found with a centre OFF position.

You don't have to use all the terminals, so you can tailor the switch to suit your circuit.

Switches may have solder terminals or 'spade' terminals, the latter being easier to install in boat circuits as you can use crimp terminals to fit the wires.

Troubleshooting switches

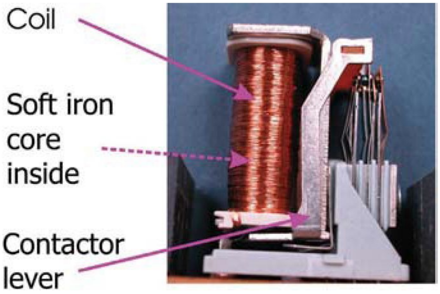
You can check the operation of a switch using a multimeter – with the switch 'open' the resistance should be infinite and with the switch 'closed' the resistance should be zero.

The more wire terminals there are on the switch, the more you have to think about which terminal does what. It's sometimes easier to draw a 'mini circuit' to see what's happening. Where there are only two, that's easy. With more it gets complicated.

- When you move the switch lever (or rocker), the terminals in use are usually opposite to the direction of movement – if in doubt check with the multimeter.
- Double pole switches have their 'paired' contacts on the same side (in the plane of movement of the switch).

RELAYS

Relays do the same job as switches. Instead of the switch being operated manually, a current passes through a coil of wire, which then becomes an electromagnet. When the electromagnet is energised, it moves a soft iron core inside the coil. The movement of this core operates contactors so that a current can flow through the circuit.



Usually, only a very small current flows through the coil, while the contactors can handle a much higher one. All the time the relay is energised, it is drawing some power from the boat's electrical system – generally a tenth of an amp or so, but it can be a lot more for larger relays.

Sometimes it's better to connect a normal switch and run a thinner wire, where it's a long length, and then use a relay to switch a heavy current on and off.

Like switches, the terminals may be of the soldered type or spades. Spade terminals are best suited for use on boats as you can use crimped terminals for your connections.

Relay contacts may be 'normally open', i.e. they close when energised, or 'normally closed', so that they open when energised. You may even find a combination of both on the same relay.

Where part of an engine-start system, these relays may be mounted on a base socket. You may find spares in an auto-accessory shop.

Automotive-type relays often have their terminal configuration marked on the side of the plastic casing. If not, you'll need to use a multimeter to check which terminal is which.

- The coil terminals will have a resistance of several hundred ohms or more.
- The contacts will have either zero resistance (closed) or infinite resistance (open).

Troubleshooting relays

- Check the coil resistance with a multimeter, if it's infinity, then the coil is faulty.
- Apply 12 volts to the coil terminals – you should hear a click.
- Measure the resistance across the contact terminals with a multimeter. The open (infinite resistance) ones should close and have zero resistance, as the contacts change over when the coil is energised.

Connections

CONNECTIONS

Connections are the heart of the electrical system and if we are not meticulous in making them, they can be its downfall.

- They must be secure.
- They must be supported so that the wiring is not taking any load which might make it liable to being pulled out.
- They must be protected from corrosion.
- They must be accessible.
- They should be identifiable.
- The strongest permanent joint, having the least electrical resistance, is a soldered joint made on new, bright wire. However, a soldered joint may melt in the event of a short circuit.

Corrosion is the enemy of all cable joints on a boat. Any exposed cable joint should be protected using silicone grease.

The connection may be a joint between just two wires or a joint between multiple wires. There are a number of different ways to make the joints and you need to consider if the joint is to be permanent or if it needs to be undone from time to time.

Signal wires are small in diameter because they carry a very small current. They are typically used for instrument wiring and are fairly fragile, thus they need special consideration when being joined.

There are two schools of thought on whether the end of a wire should be 'tinned' with solder or not (see chapter 'Soldering').

- Soldered joints use a *flux* to remove oxidisation from the surfaces to be joined. This flux may be acidic and can cause subsequent weakening of the wire.
- On small-diameter, multi-strand wire, stresses can be induced by movement at the junction of the soldered wire and the unsoldered wire.
- The screw of a screw terminal and the crimping process are both unable to 'squash' the soldered part of the cable and joints may be less secure.

Most technicians recommend that the ends of the wires should not be soldered.

Terminal blocks

These allow joints to be made and remade as required.

- Remove just sufficient insulation to fit into the terminal using a wire stripper.
- Insert the wire into the terminal and tighten the clamping screw, ensuring that the screw presses down on the centre of the wire's core.

'Chocolate box' connectors are *not* ideal for use on a boat. If used, seal the joints with silicone grease to prevent corrosion of the cable.

Connector blocks should be made from marine-grade materials, which rules out those bought from the local car shop. If they are to be used with small-diameter signal wires, such as those used for instrument connections, they should have a clamping leaf to hold the wire, otherwise the wire's strands may be broken as you tighten the securing screw.

Marine-grade 'bus bar' connectors should be used with crimped terminals, preferably self-sealing ones.

Never wind a wire around a bolt and screw the nut down on top of it – always use a crimped *eye* terminal. This is to ensure proper contact and security of the joint.

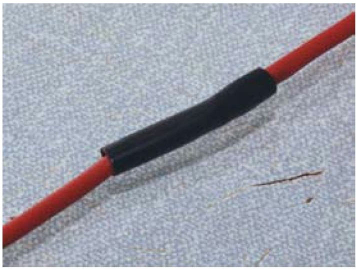
Splices

Splices are permanent connections between one or more cables. They can be made using crimped splices or the joint can be soldered.

If you crimp, it's best to use heat-shrinkable, self-adhesive cable splices.

- Remove just sufficient insulation from the end of the wire so that the wire will go into the terminal AND the insulation will be covered by the terminal's own insulation – this ensures that no bare wire is visible.

- Insert one wire into the terminal.
- Use a crimping tool on the part of the joint containing the wire, squeeze it *very tightly* to crimp the terminal onto the wire.
- Insert the other stripped wire into the other end of the terminal and repeat the crimping procedure.

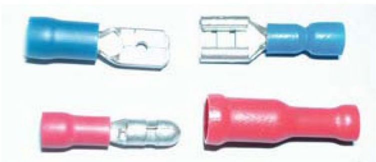


- Use of the correct force and the correct size of terminal for the wire will result in a secure joint.
- If you can pull the wires out easily, you'll need to remake the joint properly.

If you solder, cover the joint with heat-shrinkable, self-adhesive sleeving. Soldering has its own dedicated chapter.

CRIMPED CONNECTIONS

'Spade' and 'Bullet'-type terminals



These can be undone and remade as required. As with the crimped splice, the end of the wire is stripped, the wire inserted into the connector and crimped tight using a crimping tool. It's best to use heat-shrinkable, self-adhesive cable terminals.

Crimped connectors come in a variety of shapes and three different colour-coded sizes. Using an oversized connector will make a weak joint.

Crimping tools and connectors are available cheaply from car shops. The connectors are probably made of steel and the crimping tool will not allow sufficient pressure to be applied. They don't make very strong joints and wires are easy to pull out of the crimped joints.

Ideally, use a ratchet crimping tool, which, although more expensive, will make a secure joint. This robust tool exerts sufficient force to make a proper joint on any size wire that it's designed for. You use a repeated squeezing action and continue until the tool automatically releases at the correct pressure. It has three *anvils*, each of a different size. Each anvil is colour-coded – red being for the smallest crimp, blue a mid-sized one and yellow the largest.

The anvils are matched to colour-coded crimp connectors, each of a different size and designed for different-sized wires, NOT the colour of the insulation! You use the red anvil for red connectors, etc.

Wire	Red	Blue	Yellow
mm^2	0.25–1.65	1.04–2.63	2.63–6.64
AWG	22–18	16–14	12–10

Making a crimp connection

- Strip insulation from the end of the wire.

- The stripper jaws have four notches suitable for different wire core sizes.

- Insert the wire into the most suitably sized of the four 'V' notches.

- Squeeze and release the handles to strip the wire.

- Insert the bared wire into the connector.

- Squeeze the connector with the crimping tool to clamp the connector to the wire. Crimp connectors are colour-coded according to wire size – use the same colour crimp tool aperture as the connector and the correct colour for the wire gauge. If the wire is too small, double it over to make it thicker.

- Apply silicone grease to seal the terminal if required.

Making a heavy-duty crimp connection

- Cut the cable to length.

- Remove just sufficient insulation using a hobby knife …

- … so that the bared wire is the same length as the terminal's collar.

- Take the heavy-duty crimping tool.

- Place the terminal in the correct sized hole for the gauge of the terminal and cable.

- Place the crimper into the vice and push the cable into the terminal …

- … until it is fully inserted with no bare wire showing.

- Close the vice …

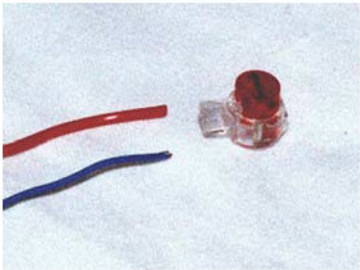
- … until the ends of the crimper in the jaws of the vice make hard contact.

- Place a cut length of adhesive heat-shrink tubing over the joint.

- Heat the heat-shrink with a hot air gun until it has shrunk and made a tight fit over the joint.

- The finished joint with a little adhesive visible at each end of the tubing.

SIGNAL WIRE CONNECTORS



These make a permanent joint between two or three small-diameter signal wires. Use 'Eton 23' or 'Scotchlok' type connectors that are gel-filled and seal automatically when the joint is made.

Signal wire connectors are not readily attainable unless you go to a specialist supplier, where they are available only by the 100. They have the advantage that they are designed specially for small-diameter signal wire, such as that used for instrument connections, and are light enough not to need direct support.

Making a signal wire connection

- Don't strip the wires.
- Insert the wires into the connector.
- Squeeze the top and bottom of the connector with a pair of pliers. The connector will pierce the insulation to make a good connection and seal the joint automatically with grease.

HEAT-SHRINKING

- Heat-shrink tubing is put over the joint.
- Heat is then applied using an electric hot air gun (a paint stripper – a hairdryer is too cool), which shrinks the tube to grip the wire and joint tightly.
- Some heat-shrink tubing is coated internally with adhesive, which melts when heated. This makes a very corrosion-proof joint.

INSULATING AWKWARD JOINTS

Where it's difficult to apply conventional insulation, such as a sleeve, liquid insulation is a very convenient alternative. This is painted on and the required thickness is built up in layers. This is very convenient on the connections at the back of small plugs and sockets.

CONNECTIONS AT THE BASE OF THE MAST

To allow a mast to be un-stepped, cables running down it must have connectors at its base. These connectors are often a cause of problems due to corrosion, but there are ways of minimising this.

Waterproof deck plugs and sockets

These are available in a number of different forms. The plug and socket have a waterproof joint, which, in time, may allow water to enter the pins and cables. Annual cleaning of the contacts is a good idea, as is some form of physical protection from damage to the cables.

Waterproof through-deck glands

An alternative to a deck plug is to lead the cables through the deck, using waterproof deck glands. The connections are then made inside the boat using some form of terminal. This method keeps the connections in a far less corrosive atmosphere.

Swan neck deck pipe

In this set-up, a curved large-diameter pipe passes through the deck. All the cables are run through the pipe so that connections may be made inside the cabin. While not absolutely waterproof, only large quantities of ‘green water’ passing over the foredeck will allow any to leak below. The advantage is that it is very easy to thread the cables through the deck, and nothing needs to be undone.

Keel-stepped masts

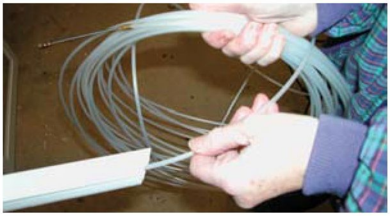
No deck joints are needed for keel-stepped masts, as the cables exit the mast below the deck.

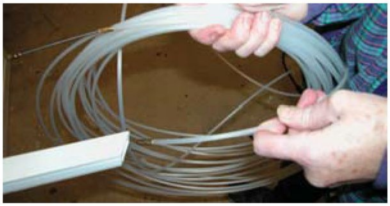
Wiring

Electrical wire used on boats should be tinned along its whole length. This is expensive, so most production boats have 'automotive-type' wire, which allows corrosion to spread along the strands of wire under the insulation. This makes it impossible to remake joints successfully. Where one end of a wire is located in a damp atmosphere, tinned wire should always be used.

Do not run wires through the bilge where their condition will deteriorate.

Use a push wiring threader to run wires through difficult places.

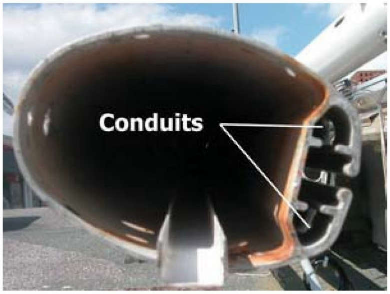




1. Insert one end into the conduit or gap through which you need to run the wire.
2. Then push the threader through.
3. Use the threader to pull the electric wire all the way through.

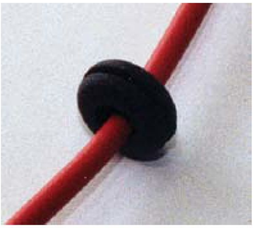
Some alloy masts have internal conduits, provided to carry wiring running up the mast. Wires dropped through the main section of the mast will slap and chafe. A push threader can be used to run mouse lines and cables up the mast's conduit.

I have pushed a threader successfully all the way up the conduit in a 15-metre mast.



TIPS

1. Run a mouse line in case you need to run another cable later. The mouse line can be run through the conduit (or other routes where a cable is run) at the same time as you install a cable with the threader. The mouse line is then left in place for the next time



you need it. The mouse line should be twice as long as its route, so that you don't pull it all the way through when you use it.

2. Use grommets to protect the insulation where you run wires through bulkheads, etc.
3. Support cable runs regularly along their length.
4. Cable should not come under strain, which could cause connections to be pulled apart.
5. A very neat and secure way to protect and support cables is to run them in a corrugated trunking. If cables are already in place, split trunking is available that can be placed around the cables in situ.
6. If you need to run cables to terminals from the trunking, use 'Beta duct' trunking, which has holes and slots.

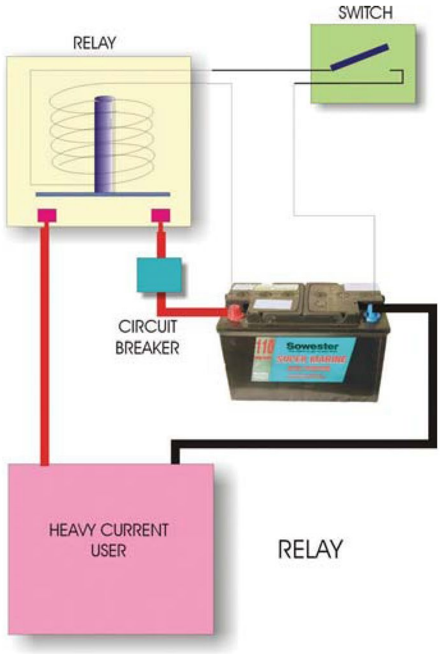
7. Make a wiring diagram of any new work.

HEAVY-DUTY CIRCUITS

A DC electric motor will overheat and suffer early failure if the supply voltage is reduced. Motors with high current requirements need special care with their wiring circuits to maintain an adequate voltage. Normally, a voltage drop of 10% is the maximum allowed.

The operating switch will not handle the required current, so a relay is introduced into the circuit. A relay consists of an electromagnet that can be operated by the low current; its contactors then carry the high current required to operate the motor, or whatever.

This keeps the switching current low, but heavy-duty contacts handle the high current load of the motor. Proper siting of the relay will keep the length of the high-current circuit to a minimum.



Starter motors and sheet winches

These are operated with the engine stopped.

Starter motors normally run for a very short time and have a relatively short run of very heavy cable. Provided connections are clean and well made, they make only small demands on a dedicated engine start battery.

Sheet winches may have relatively long cable runs and the demands on the battery system can be significant, so that voltage drop at the motor needs to be minimised. Adhere strictly to the manufacturer's wiring requirements.

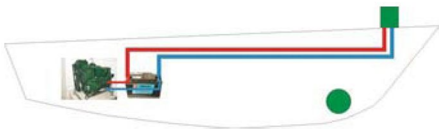
Bow thrusters and anchor windlasses

To keep voltage drop to a minimum, these are normally used with the engine running to prolong the life of their electric motors and to minimise battery drain. These units can't be powered directly from the engine alternator, as it won't produce enough current.

There are two schools of thought on powering these machines:

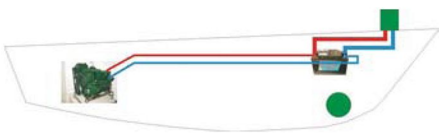
1. Use the domestic battery

   Long, very heavy and expensive cables run from the domestic battery bank. As these cables may carry up to 300 amps and may have a circuit length of 20 metres, a cross-sectional area of 200 mm^2 may be needed. That's a diameter of 16 mm! This is for a windlass with a 2000 lb pull. A more typical 1000 watt windlass will still need a cable of around 10 mm diameter.



2. Use a separate battery mounted close to the demand

   The heavy cable length is kept to a minimum by placing a dedicated battery close to the windlass or bow thruster. This is charged by a smaller cable from the engine. The charging cable needs to be rated to carry the maximum charging current only. The lower



cost of the lighter cable may outweigh the cost of the extra battery. The disadvantage of this method is the weight of this battery forward in the boat.

WIRE CURRENT RATINGS

A wire must be capable of carrying the maximum current in the circuit. All wires have a *current rating*. A 5 amp wire must carry no more than 5 amps. Note that wires bundled together can carry less current because they will heat up.

Wiring for sensitive equipment should not allow more than a 3% voltage drop. Normally this is more restrictive than the current rating because it depends on the length (both positive and negative) of the wires.

Other wiring may be allowed a 10% voltage drop along its total length.

Wire sizes required for a given length of cable run (Length is the sum of the positive and negative wires)

Wire size 3% voltage drop (Critical applications – bilge pumps, nav. lights, electronics, etc.)

	CURRENT (amps)								
LENGTH	5 a	10 a	15 a	20 a	25 a	30 a	40 a	50 a	100 a
5 m	16	12	10	10	8	8	6	6	2
10 m	12	10	8	6	6	4	4	2	1/0
20 m	10	6	6	4	2	2	1	1/0	4/0
30 m	8	4	4	2	1	1/0	2/0	3/0	
40 m	6	4	2	1	1/0	2/0	3/0	4/0	
50 m	6	2	1	1/0	2/0	3/0	4/0		

Wire size 10% voltage drop (Non-critical applications – windlasses, cabin lights, etc.)

	CURRENT (amps)								
LENGTH	5 a	10 a	15 a	20 a	25 a	30 a	40 a	50 a	100 a
5 m	18	18	16	16	14	14	12	12	6
10 m	18	16	14	12	10	10	8	8	4
20 m	16	12	10	8	8	8	6	4	2
30 m	14	10	8	8	6	6	4	4	1
40 m	12	8	8	6	4	4	2	2	2/0
50 m	10	8	6	4	4	2	2	1	3/0

continued overleaf

American wire gauge 'boat cable'

AWG	18	16	14	12	10	8	6	4	2	1	1/0	2/0	3/0	4/0
mm^2	0.8	1	2	3	5	8	13	19	32	40	50	62	81	103
Max. amps	20	25	35	45	60	80	120	160	210	245	285	330	385	445

Reduce current by 15% when run in engine compartment.
Standard UK wire sizes – 1, 1.5, 2.5, 4, 6, 25 and 40 mm^2.

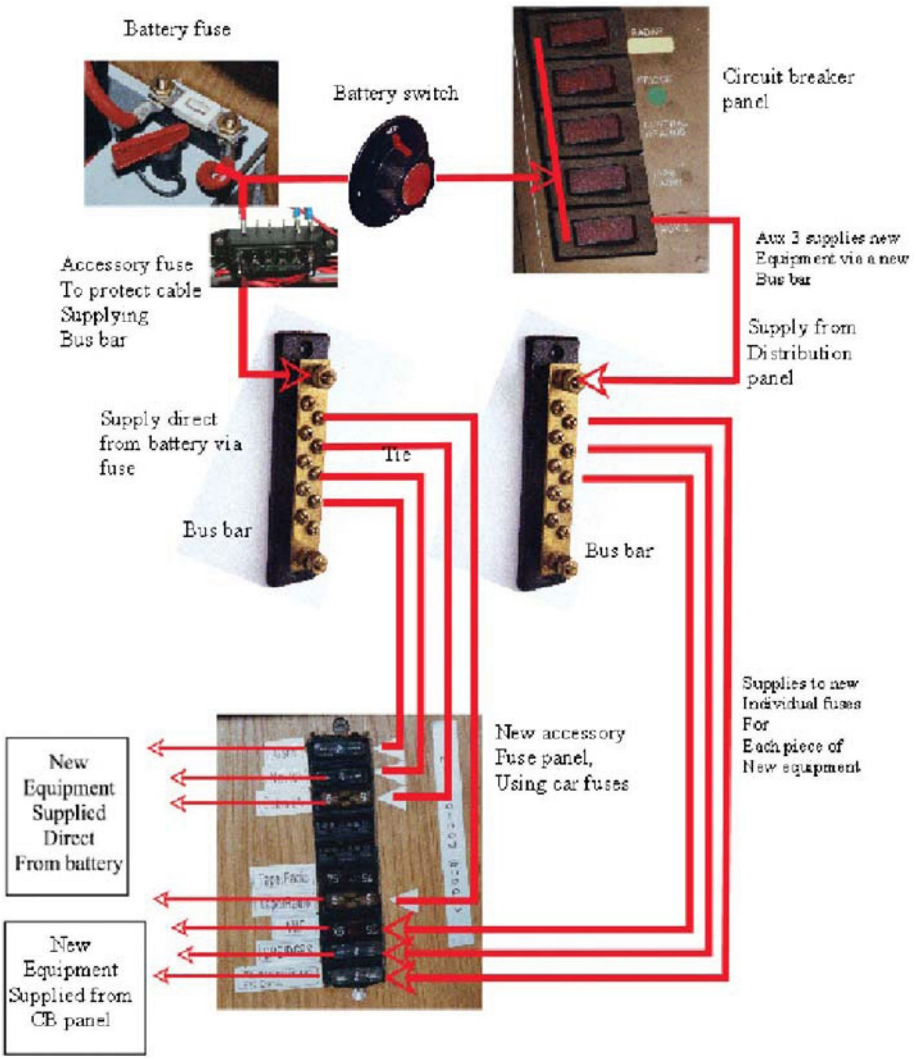
INSTALLING NEW EQUIPMENT

1. Check the wire size required, according to its length and the current it has to carry, from the table above.
2. Decide if you will need to power the equipment from the battery (e.g. a VHF radio) or the panel (e.g. a new GPS).
3. Run a new positive wire from the C/B panel or the battery to a new bus bar.
4. Run a new positive wire from the bus bar to a fuse holder (or circuit breaker).
5. Run a new positive wire from the new fuse holder to the new equipment.
6. Fit an appropriately sized fuse, as recommended by the equipment manufacturer.
7. Run a new negative wire from the existing negative bus bar or a new one as appropriate.

Note:

- If you have an ammeter, its shunt should be fitted in the negative battery cable.
- Equipment supplied direct from the battery MUST have the negative cable connected via the shunt and NOT taken direct to the battery's negative terminal.

Circuit protection



NEW PROTECTED WIRING INSTALLATION

Circuits

DC CIRCUIT MONITORING

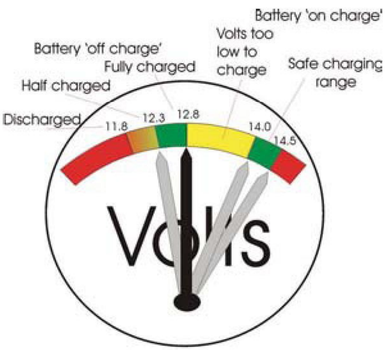
With any form of boat electrical system beyond the very basic, it's essential to monitor the flow of electricity to and from the boat's circuits, unless shore power is going to be available every night to keep the batteries fully charged.

System voltage

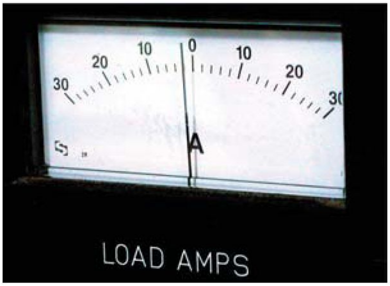
The voltage indicated by the voltmeter indicates whether the system is running from the batteries or is being charged.

System current

The current flow indicates the electrical demand being placed on the system.

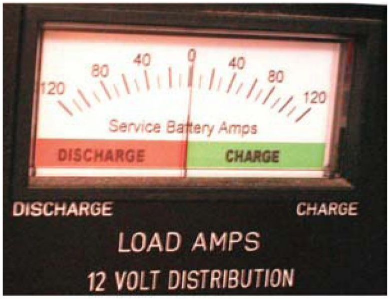


Half charged and full charge figures apply to a battery at rest, which a dedicated 'engine start' battery would be when the engine isn't running.



Used in conjunction with the voltmeter, a simple table can indicate the state of charge of the batteries.

BATTERY STATE OF CHARGE	BATTERY VOLTS			
	RESTED	0 AMPS	5 AMPS	10 AMPS
100%	12.8	12.5	12.4	12.2
90%	12.7	12.4	12.3	12.1
80%	12.6	12.3	12.2	12.0
70%	12.5	12.2	12.1	11.9
60%	12.4	12.1	12.0	11.8
50%	12.3	12.0	11.9	11.7
40%	12.2	11.9	11.8	11.6
30%	12.1	11.8	11.7	11.5
20%	12.0	11.7	11.6	
10%	11.9	11.6		
FLAT	11.8	11.5		



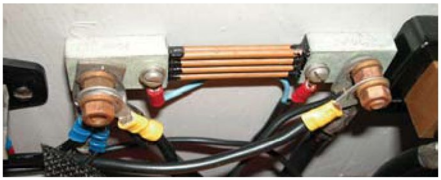
Suitably placed, an ammeter can measure the current entering or leaving the battery.

Battery state of charge

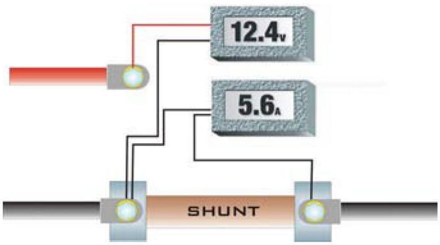
A sophisticated meter can measure the current entering or leaving the battery, indicate its state of charge and also how long the battery will last if the current drain continues at that rate.

How it's done

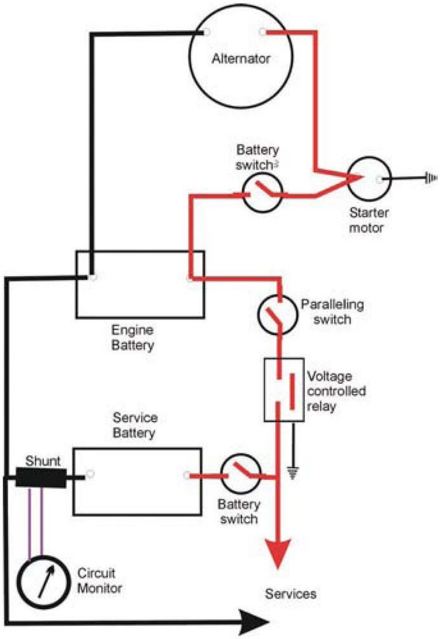
A special, very accurately calibrated resistor, called a *shunt*, is inserted into the negative cable of the system. The ammeter measures how much the voltage drops along the shunt and is thus able to deduce the current flowing through it using 'Ohm's Law'. The voltmeter measures the voltage between the resistor and the positive side of the circuit. The size of the shunt is determined by the maximum current flow in the circuit.



Because some items of equipment, such as the VHF or gas detector, may be supplied directly from the battery, fitting the shunt in the positive line will miss some of the current flow. Therefore, the shunt should always be inserted in the negative cable.



The shunt must be installed in the negative line close to the battery that it is monitoring, so that it measures ALL the current flowing in or out of that battery, including those items 'hot-wired' to the battery.



Circuit monitoring

CIRCUIT PROTECTION

Low-voltage DC circuits

If, for some reason, a live (known as the *hot* wire in the USA) DC positive wire is allowed to touch a DC negative wire, a large current will flow, because essentially there will be little resistance to current flow. This is known as a short circuit, because the current takes the shortest path back to the battery and thus bypasses the rest of the circuit. As a result, the wires carrying the excessive current will heat up, which, in turn, heats the wire's insulation and a fire may result.

A device must be introduced into the circuit to protect against an unusually high current. This will break the circuit if, for any reason, the current rises above that which the wire can carry safely.

The safety device may be a fusible link (a fuse), which has the capacity to carry very little more current than the wire can carry safely. The fuse will be destroyed if this current is exceeded, and will need to be replaced with another of the same value to restore the circuit. Keep spare fuses of all required ratings in case a fuse blows. Some fuses are *slow-blow* (anti-surge), in that they will not fail until an excessive current flows for some seconds, to allow for transient surges; others are *fast-blow*, which fail immediately an excessive current flows. Always replace like with like.

Alternatively, a circuit breaker can be installed in the circuit to break the circuit in the advent of an excessive current. Circuit breakers sense the rise in current either thermally or magnetically and *trip* to prevent an excessive current. They can be reset to restore the circuit. Some circuit breakers may incorporate an 'ON/OFF' switch. Others are not designed to act as a normal switch and these must be provided with a separate switch to activate the circuit.

When a fuse blows or a circuit breaker trips, it is normal to allow the circuit to be restored *once* only, before troubleshooting is carried out. This is because any small surge produced within the circuit could cause a sensitive breaker to trip or a fast-blow fuse to fail, even though no short is present. In the event of a recurrence, the cause must be found.

A fuse or circuit breaker in a wiring circuit protects only the wiring and not any component within the circuit.

Expert's tip

A fuse has an electrical resistance and, if used inappropriately, may cause a malfunction of a component. For instance, consider a central heating unit. This has a high start-up current and incorporates a circuit that shuts it down if the supply voltage drops below a critical value. If the heater supply cable has a high voltage drop and you protect the cable with a fuse rather than a circuit breaker, the heater may not start unless the battery is fully charged, because of the additional voltage drop across the fuse.

Circuit breakers have little resistance and would not cause the above problem.

Short circuits

These allow very high currents to flow (a DC circuit could allow 800 amps) and can result in an electrical fire.

Short circuits can be caused by a breakdown in insulation by chafing, ultraviolet light or contamination. They can also be caused when a wire becomes loose and detached from a terminal due to incorrect making of the joint or the joint coming under strain. This could allow the free end of the wire to touch another of opposite polarity.

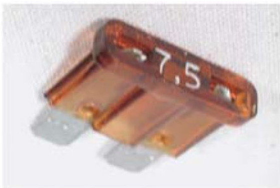
Fuses and circuit breakers

Equipment often has an internal fuse for self-protection. It's usually of a low value. Wiring supplying the equipment needs to be protected by a fuse or circuit breaker in case of a short circuit. The amperage rating of the fuse or circuit breaker must *never* exceed the current rating of the wire.

All distribution wires must be protected, including the battery, where there's a chance of positive and nega-

Inline fuse holder with glass fuse

Panel fuse holder with galass fuse



Automotive fuse

Heavy duty fuse

tive wires coming into contact – note, an equipment case may be connected to negative.

Multiple circuits are protected by only one fuse or breaker and this must be rated for the lowest rated wire.

Battery fuses mounted in the battery compartment should ideally be of the non-arcing variety, because of the risk of explosion from a gassing battery.

Pros and cons

Circuit breakers:

- are relatively expensive;
- can be reset;
- can also act as circuit switches in some cases.

Fuses:

- are cheap (as are fuse holders);
- may be inserted 'in-line' when you add an extra component;
- need to be replaced if they blow, meaning spares are required;
- 'age' with continued use and may blow under normal current conditions.

Siting of fuses/circuit breakers

Most, if not all, fuses and circuit breakers will be placed in full view on the DC distribution panel by the builder.

Subsequent additions, including those made by the supplier, often incorporate 'in-line' fuses that are hidden away, with their presence often unknown to the boat's owner. This practice is common, even among professional installers, and is to be deplored. If in-line fuses are to be used, their existence and location should be noted on the wiring diagram.

There will sometimes be a couple of spare circuit breakers on the panel, which may be used for additional circuits if they are of the correct rating.

If you run out of breakers, then you really should fit an auxiliary fuse or circuit breaker panel, or at least a fusebox in a known and accessible place.

Mains AC circuits

The reason for AC circuit protection is identical to the DC circuit, i.e. to protect the wiring in order to prevent fire. Additionally, there needs to be a different type of circuit breaker, which detects any minute flow of current to earth, to protect human life.

The distribution panel will have circuit breakers protecting individual circuits and should incorporate a special circuit breaker known as a *residual current device* (RCD) or *earth leakage circuit breaker* (ELCB) or *residual current circuit breaker* (RCCB). This will trip out for a very small current (0.03 amps–30 mA, or so) flowing to earth caused by an earth leak. A more detailed discussion of this topic is given in the chapter ‘Electrical Supply’.

In the UK, the wiring of items plugged into AC sockets (outlets), is protected by a fused plug. This fuse should never have a rating greater than that of the appliance’s mains cable.

FAULTS IN AN ELECTRIC CIRCUIT

Finding a fault in an electrical circuit entails a methodical approach, but luck can play its part.

Flow process of checking a faulty electrical circuit

If several pieces of equipment are protected by one circuit breaker or fuse:

- Check others on the same circuit by switching them on.
- Check, by observation, that the circuit breaker has not tripped or the fuse blown – remove the fuse and measure its resistance.
- Check the supply to the circuit breaker/fuse – if there’s an associated indicator light, its illumination confirms a supply.

- Fuse contacts can become corroded, check that they are clean by removing the fuse and cleaning it if necessary.

If there's shared wiring for part of the circuit:

- Check other items on the shared circuit by switching them on.

If only one item is affected:

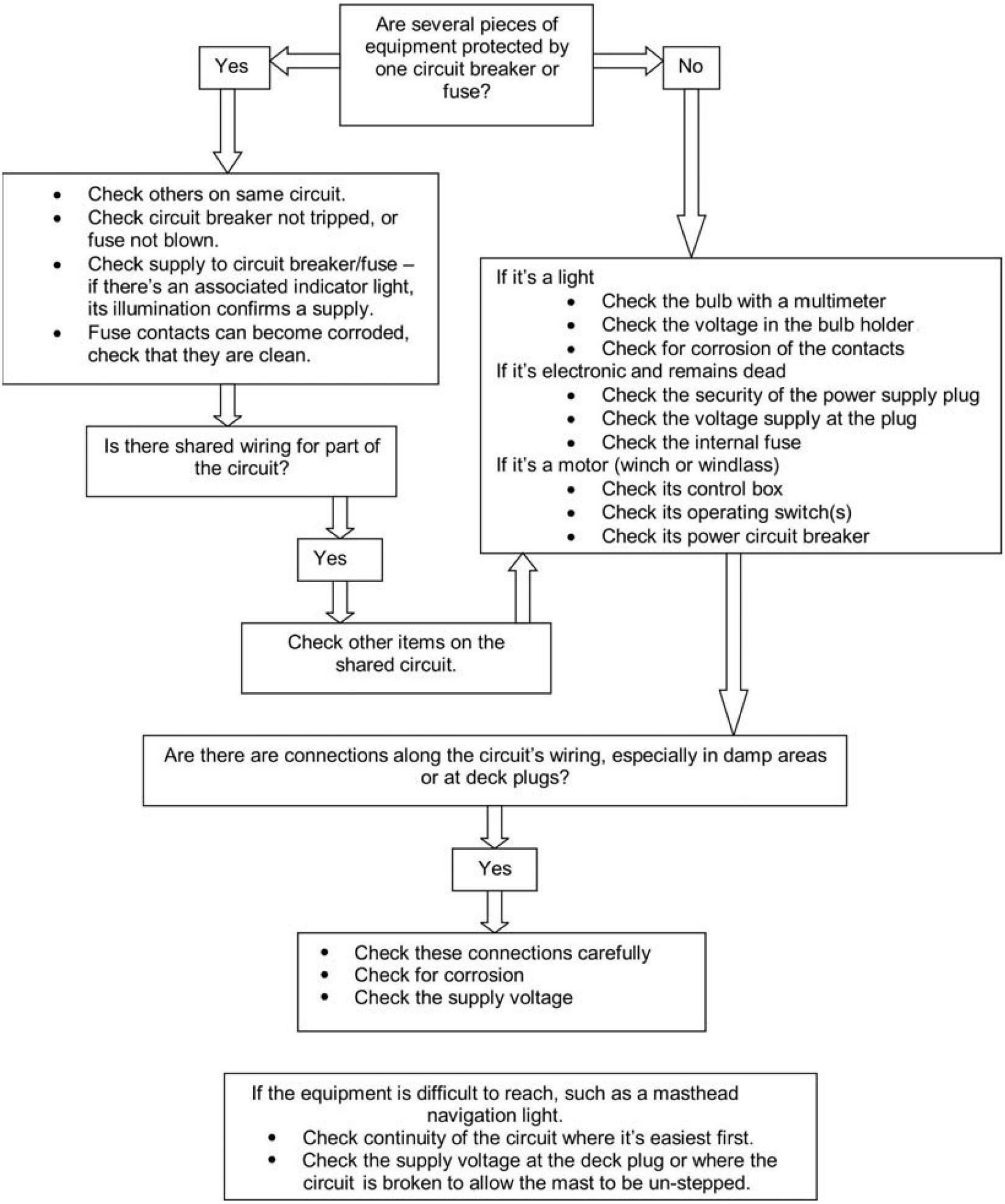
1. If it's a light:
    - Check the bulb with a multimeter.
    - Check the voltage in the bulb holder.
    - Check for corrosion of the contacts by removing the bulb.
2. If it's electronic and remains dead:
    - Check that the power supply is plugged in properly.
    - Check the voltage supply at the plug with a multimeter.
    - Check the internal fuse by removing it and measuring its resistance – this may involve opening the case.

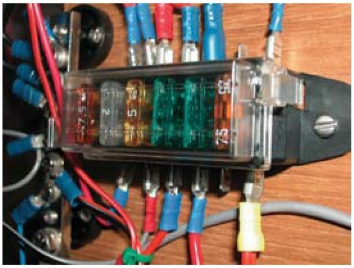
If there are connections along the circuit's wiring, especially in damp areas or at deck plugs:

- Check these connections carefully.
- Check for corrosion visually.
- Check the supply voltage with a multimeter.

If the equipment is difficult to reach, such as a masthead navigation light:

- Check continuity of the circuit where it's easiest first, using a multimeter.
- Check, using a multimeter, the supply voltage at the deck plug or where the circuit is broken to allow the mast to be un-stepped.


Are several pieces of equipment protected by one circuit breaker or fuse?
Yes
No
Check others on same circuit.
Check circuit breaker not tripped, or fuse not blown.
Check supply to circuit breaker/fuse – if there's an associated indicator light, its illumination confirms a supply.
Fuse contacts can become corroded, check that they are clean.
Is there shared wiring for part of the circuit?
Yes
Check other items on the shared circuit.
If it's a light
Check the bulb with a multimeter
Check the voltage in the bulb holder
Check for corrosion of the contacts
If it's electronic and remains dead
Check the security of the power supply plug
Check the voltage supply at the plug
Check the internal fuse
If it's a motor (winch or windlass)
Check its control box
Check its operating switch(s)
Check its power circuit breaker
Are there are connections along the circuit's wiring, especially in damp areas or at deck plugs?
Yes
Check these connections carefully
Check for corrosion
Check the supply voltage
If the equipment is difficult to reach, such as a masthead navigation light.
Check continuity of the circuit where it's easiest first.
Check the supply voltage at the deck plug or where the circuit is broken to allow the mast to be un-stepped.



Finding a fault in a wiring circuit

First check the fuse or circuit breaker as above. This may not be as obvious as it would at first seem. Panel-mounted circuit breakers are no problem.

Often, though, individual components are fused with an in-line fuse in some out-of-the-way place.

This is a short-sighted policy, often done to save time. All additional fuses should be grouped together and should ideally be panel-mounted.

Some instruments have a 'built-in' fuse to protect them, but these rarely cause a problem. They are generally there to protect against connections with reversed polarity.

Lights

If a light fails to work, the bulb has probably failed or its contacts have become corroded, so check the bulb.

If the bulb is at the masthead, then some continuity checks will be worthwhile before going up the mast.

There are two ways to check circuit continuity:

1. Check the wire's resistance between two points. This may entail the use of a long extension wire for one of the probes – make sure it's of large enough cross-section to give minimal resistance.
   - Very high resistance indicates a break or poor joint.
   - Very low or zero resistance indicates no breaks.
2. Check the voltage between the positive and negative wires at points along the circuit using a multimeter. This will check both positive and negative (ground) wires in combination – it will not tell you which one has the problem, so you will then have to check the continuity of each wire separately, again using the multimeter.
   - The voltage at the far end of the circuit should be no less than 90% of the nominal voltage.

- Zero volts indicates a break in a wire.
- A large voltage drop indicates poor contacts or wire that is too small in diameter for the current it is carrying.

Wires that are run up the mast usually have a plug and socket joint at the deck, or have a connection inside the cabin, just below the mast. Deck joints are always vulnerable to corrosion, but interior joints can also be affected. These joints will always be the first port of call when something up the mast is not working but the other lights in the same circuit are functioning.

- If there's no voltage at the deck joint, the fault is between the switch panel and here.
- If there is normal voltage, then the problem is in the plug or up the mast.

Deck lights

Deck lights that have no lens are a particular problem. They have small halogen bulbs, which use little power relative to their light output, but get hot. It's for this reason that they have no lens, but it does make them susceptible to corrosion.

The two probe-like contacts will need to be cleaned and probably so will the socket.

Don't hold the glass bulb directly in your fingers – use a cloth or tissue – as grease from the hand will shorten the life of the bulb. Clean the bulb contacts with fine emery paper and the sockets with a very small twist drill bit. Because you may remove any protective plating in this process, the requirement for cleaning will become more frequent!

Pulpit-mounted navigation lights

These are particularly susceptible to corrosion, as they will sometimes be immersed as the bow ploughs into a wave. Ensuring that all the seals are as watertight as possible, using Vaseline or silicone grease, will help to keep corrosion at bay.

Check the lenses, visually, for condensation regularly and dry the inside as necessary.

Troubleshooting

Alternator not charging – generator warning light 'ON'

- Check the battery voltage. If the voltage is above 13.2 volts, it's probable that the bulb has failed.
- Stop the engine and check the alternator drive belt to see if it's too slack or broken.
- Start the engine.
- Increase engine revs to about half speed.
- You should see the voltage rise. The actual voltage will vary according to the battery state of charge.
- Unless the battery is heavily discharged, the voltage should always be above 13.2 volts.
- If you have an ammeter that shows the alternator output, a positive reading indicates that the alternator is charging, but the actual reading will vary according to the battery's state of charge.
- If the battery is being charged, the fault is in the warning light circuit.
- If the battery is not being charged, stop the engine and visually check all the alternator connections.

Battery not holding its charge

A battery will self-discharge over a period of time and wet cell batteries should be charged every month.

A 12 volt battery is made up of six cells, each giving a nominal 2 volts. If one cell is faulty, the other five cells will be discharged, trying to hold up the faulty cell. The battery will self-discharge rapidly and will never reach full charge. This is inevitable over time and the more deeply a battery is discharged on a regular basis, the sooner this will occur.

If you have more than one battery, it may not be obvious which one is at fault.

- Charge all batteries fully.
- Disconnect all but one battery from your system and then use this to try and start the engine.

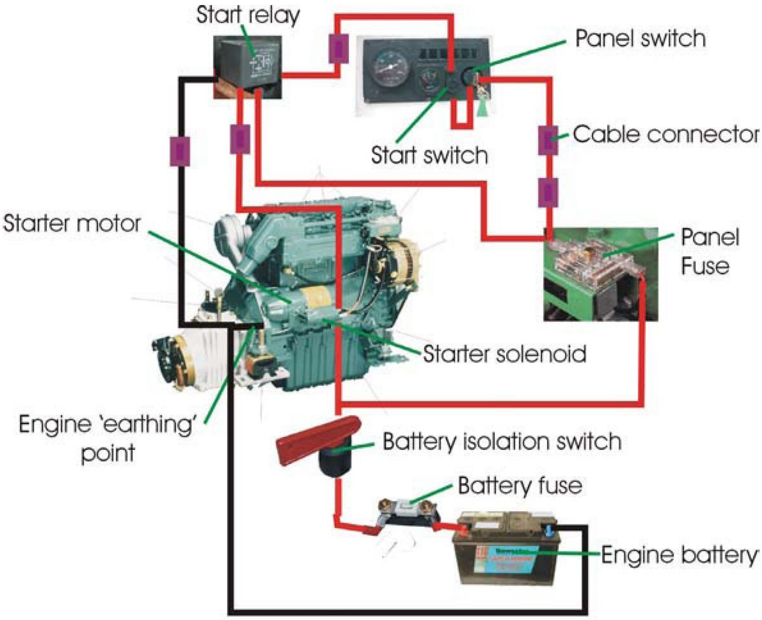
- Ensure the battery and starter motor terminals are clean and tight.
- On a sailing boat, turn off the cooling water sea-cock to prevent flooding the engine with water.
- Operate the mechanical stop control to prevent the engine starting. If the engine is stopped electrically, apply 12 volts to the stop solenoid.
- Operate the starter for 15 seconds and observe the voltmeter.
- The battery voltage should remain above 9 volts under the load of the starter motor.
- Low volts or the starter slowing down indicate a faulty battery.
- Check each battery in turn by using the battery switches to isolate all except the battery under test.

Engine starter motor not turning

Because the starter motor's current draw is so high, the starter button or key is not connected directly to the starter motor. Instead, a starter solenoid and often a starter relay are used to limit the current to much lower values in the starter circuit. This means there are several components that can fail in the circuit. There may be a fuse in the engine panel supply. More rarely, there may be a battery fuse on the battery itself, although this is, in fact, desirable.

The problem may be any one of the following:

- Any fuse in the starter or battery circuit
  - the panel will be 'dead'.
- The key-switch or button itself
  - if this is the problem, there will be no dimming of the panel lights as you try to start the engine.
- The starter relay
  - no dimming of the lights



Only the wiring associated directly with the engine start circuit is shown

– relay may or may not 'clunk', depending on which part has failed.

- The starter solenoid

  – no dimming of the lights

  – relay may or may not 'clunk', depending on which part has failed.

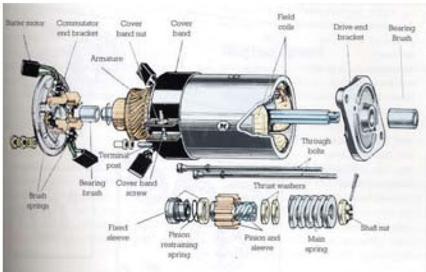
- Cable joints linking the components

  – a cable break can be found by the normal process

  – a corroded joint is more likely to be accompanied by a dimming of the panel lights

  – loose or corroded battery cables will cause dimming of lights – remember to check the negative cable joints, especially where one is clamped to the engine.

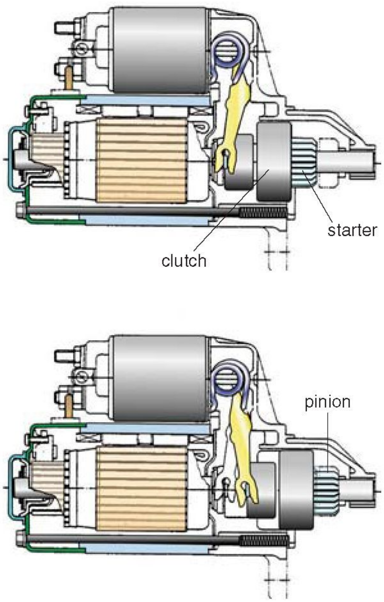
- The starter motor itself
  - panel lights may dim.
- Steel boats, and also some others, may have an isolating solenoid in the negative cable from the battery to the engine block. It's very easy to miss this.



Inertia starter motor

Starter circuit problems

Old 'inertia-type' starter motors use a spiral shaft to propel the starter pinion to engage with the starter ring on the flywheel. The mechanic's solution to problems with this mechanism was pretty drastic. On these inertia starters, connecting the main terminals on the motor will cause the motor to run and the pinion to engage. This is not for the timid, as very high currents will flow, the screwdriver (or whatever is used to make the link) may become welded to the terminals and sparks will fly. It can be justified only in the most exceptional life-threatening circumstances.

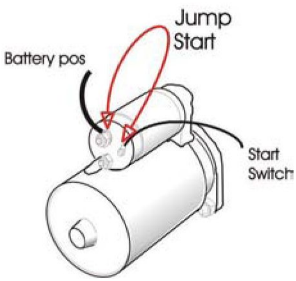


Pre-engaged starter

Sometimes the starter pinion sticks at the end of its travel and remains engaged with the flywheel starter ring. In this case, the starter motor has insufficient power to rotate the engine from standstill. The pinion can be wound back by applying a spanner to the squared end of the starter motor shaft (at the front of the starter) and rotating the shaft to disengage the pinion.

Modern 'pre-engaged' starter motors use a clutch to engage the pinion. Failure of the starter solenoid can't be overcome by linking the terminals, because the starter motor's clutch won't engage unless the solenoid operates.

The starter solenoid can be operated directly by applying 12 volts (or 24 volts) to the solenoid's input terminals. In fact, I have this system wired permanently in the engine compartment on my own boat, but with a hidden switch in the wire. This allows me to turn the engine over easily for maintenance purposes, as well as for emergency starting.



Hidden fuse revealed

Hidden fuse

Yanmar GM series starter circuits

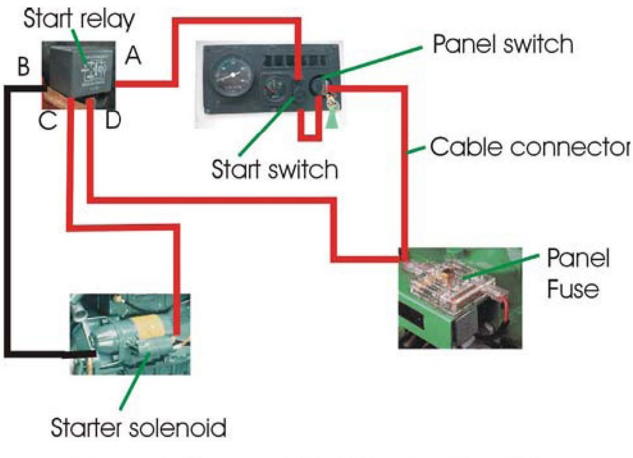
These engines have multiple connectors in the wiring loom to the engine start panel. These are likely to corrode and the starter button may not always work – accompanied by dimming of the panel lights. These connectors will need to be cleaned (or bypassed) or a starter relay incorporated in the circuit.

Yanmar GM series engines also incorporate a panel fuse in the wiring harness, but hide it away.

Solenoid/relay problems

As well as the solenoid itself failing, the supply voltage or the signal voltage may have failed.

- Check the supply voltage (12 V or 24 V).
- Check the signal voltage when the starter switch is operated.
- You should hear or feel the solenoid (relay) operate.

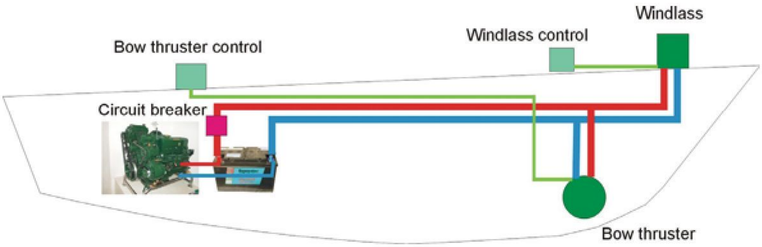


D - B (or any earthing point)		12 VOLTS (or 24 volts)
OPERATE STARTER SWITCH	A - B	12 VOLTS (or 24 volts)
(You should hear or feel a 'clunk')	C - D	ZERO OHMS

Power circuit problems

Faultfinding in a power circuit is a very similar process to that used for a lighting circuit. Very heavy current devices, such as bow thrusters, windlasses and winches, will have a relay situated between the switch and the electric motor.

There is often a heavy-duty circuit breaker as well, so finding the fault will require a methodical approach working from one component to the next.



- Check that the panel circuit breaker has not tripped. The 'pop-out' button will be visible, or a rocker type will be off.
- Check the heavy-duty circuit breaker in the same way.
- Check the switch is working by checking continuity with the switch 'closed'. You will need access to the back of the switch so that you can use a multimeter to measure the resistance across the terminals – it should be close to zero ohms.
- Check the voltage across the relay's supply terminals (the terminals connected to the switch) when the switch is operated. The voltage should be close to 12 (or 24) volts.
- Check that the relay operates by listening for a 'click' or feeling a 'clunk'. You can also check the resistance across the output terminals with your multimeter – the resistance should be low, a couple of ohms or so.

- Check the supply voltage at the electric motor using your multimeter – it should be close to full-circuit voltage.

If all these checks are satisfactory, the problem is likely to be in the windlass/winch itself. Windlasses mounted in the chain locker are exposed to very damp conditions and corrosion can be a problem.

Foot-operated switches on the foredeck are also subject to corrosion, but some are actually air-pumps rather than switches. Compressing the bulb of the pump operates a remote pressure switch away from the wet foredeck. A leak in the bulb or pressure line will cause failure.

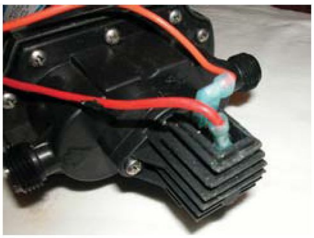
Water pressure pump fails to run

1. Check the fuse with a multimeter. As well as one on the panel, there may well be an in-line fuse in the supply wiring at the pump.
2. If the pump still does not run with at least one tap open, or fails to pump, then remove the wires from the pressure switch and join them together.
3. If the pump runs, the pressure switch is at fault.

Checking the pressure switch

It may be possible to check the pressure switch with the pump still mounted in position. If so:

1. Remove the pressure switch cover.



2. Push the micro switch button.
3. If the pump runs, the electrical switch is OK.
4. Push the pressure plunger to ensure that it moves in and out – it moves only about 2 or 3 mm but it should move. If it doesn't, it's seized and so can't operate the electrical switch. You will have to take the pump apart.

If you can't remove the cover with the pump in place, you will have to remove the pump:

1. Turn off the power to the pump.
2. Turn off the water supply, using a clamp if necessary.
3. Disconnect the wiring, undo the pipe work, remove mounting bolts/screws and remove the pump.
4. Reconnect the wires and switch the power back on.
5. Carry out steps 1 to 3 from the previous list of instructions.

If none of the steps above produces results, you will have to replace the pump.

Electric Motors and Alternators

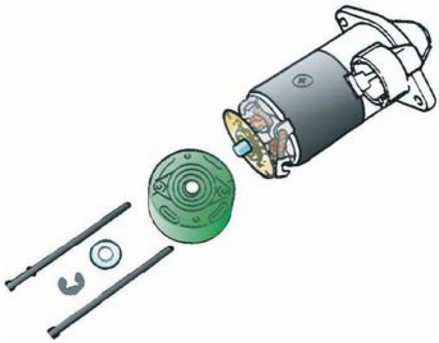
ELECTRIC MOTORS

Electric motors on most modern pieces of marine equipment are not repairable, and the motor will need to be replaced. Water pumps, for example, have service kits to repair the pump, but a failure of the motor will need a new motor, although the rest of the pump can be retained.

Heavy-duty motors, such as an engine starter motor, windlass motor or bow thruster motor, may have the facility for replacing the 'brushes'. Where an electric current has to be supplied to a rotating component, carbon *brushes* bear on the rotating conductor as the shaft rotates. The brushes (there are two or more) will wear down and at some time will need replacing. Sets of new brushes, their conductor leads and pressure springs may be available to replace the worn set.

In the leisure marine environment, starter, windlass and winch motors get relatively little use, and brush failure is not very common.

Where replacement is possible, the equipment handbook will give details of how to do the job and also the part number of the spares kit required. The engine handbook will not give details of replacing starter motor brushes, but the workshop manual will. On some motors only a cover needs to be removed, but others need some disassembly to access the brushes.



A typical electric motor

The brushes may be hidden under a removable band around the motor, behind a plate at the end of the motor or under a deeper rear cover.

- *First, disconnect the battery.*
- Remove the main cables from the motor and also any signalling wires (solenoid), noting how they should be reconnected. (A starter motor may have no negative cable as this may be supplied via the engine block to which the motor is bolted.)
- Remove the motor from the unit.
- Remove the cap at the end of the motor. (1)
- Remove the 'C' shaped retainer on the end of the shaft. (2)
- Unscrew and remove the very long bolts holding the end cover in place. (3)
- Remove the end cover to access the brushes. (4)
- Remove the brushes from their holders – you will probably have to lever the springs out of the way using a small screwdriver. (5) & (6)
- Generally, starter motors have the brush cables soldered in place because they carry very high currents. Unsolder the brush cables with a soldering iron. Use a de-soldering tool to remove excess solder from the terminal – you'll need to keep the old solder molten with the iron while you use the vacuum de-soldering tool to suck the old solder away.
- Replace the brushes. This will vary from machine to machine – they will withdraw from the carrier after you have released the pressure on the spring.
- Reassemble the motor.

(1)

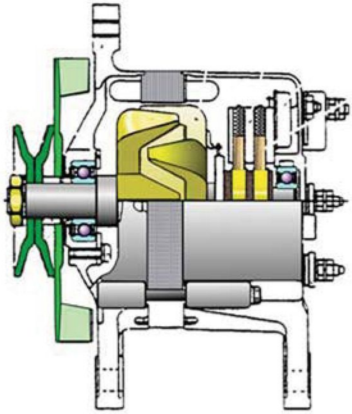
(2)

(3)

(4)

(5)

(6)



ALTERNATORS

A typical alternator

Like an electric motor, an alternator also has brushes, but these are usually hidden inside the casing and a degree of disassembly is required. Sometimes the brush conductor wire will need soldering in place. Alternator brushes suffer more wear than a leisure marine electric motor, but if an engine achieves only 100 hours a year, brush replacement is not likely to be required.

The engine handbook is unlikely to give details of how to change the brushes, but the workshop manual may.

The first job is to switch off the batteries and then disconnect their terminals so that there is no chance of any wire remaining 'live'. If you have the engine wiring diagram, reconnection of the wires will be no problem, but if not, make a sketch showing which wire goes where on the back of the alternator and then disconnect them all.

Some alternators, like the Lucas, have very easy access to the regulator and the brushes.

- Remove the alternator.
- Remove the two screws holding the cover in place. (7) & (8)
- Remove the screws holding the brush wires in place. (9)
- Remove the screws holding the brushes in place. (10) & (11)

(7)

(8)

(9)

(10)

(11)

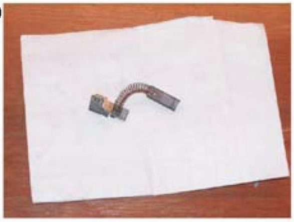
(12)

(13)

(14)

(15)

(16)



(17)

(18)

(19)

(20)

- Withdraw the brushes. (12)–(16)
- Detach the screw holding the regulator wire in place. (17), (18), (19)
- Detach the regulator. (20)

Other alternators, like the Hitachi fitted to Yanmar engines, require the alternator to be taken apart to get at the regulator and brushes. The sequence for fitting a smart regulator wire to a Hitachi is given in the next section.

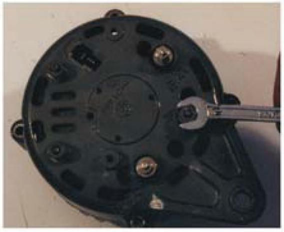
Smart regulators

If a 'smart' regulator is to be fitted, some alternators, such as the Hitachi fitted to Yanmar engines, will need to have the field control wire soldered internally to allow the regulator to operate.

The first job is to switch off the batteries and then disconnect their terminals so that there is no chance of any wire remaining 'live'. If you have the engine wiring diagram, reconnection of the wires will be no problem, but if not, make a sketch showing which wire goes where on the back of the alternator and then disconnect them all.

- Undo the two bolts attaching the alternator and remove it to the workbench.
- Remove the five 10 mm nuts at the back of the alternator, noting that three of them have insulating spacers. It might be a good idea to mark the alternator showing which three studs need the insulators. In fact it is pretty obvious as these three have bigger holes in the casing. (21) & (22)
- The two halves of the casing are clamped together with four long screws and these must now be removed. (23)
- Carefully prise the front of the alternator casing from the stator (stationary coil assembly), working your way around the perimeter. (24), (25)
- Separate the alternator unit into its three main parts. (26)

(21)


(22)


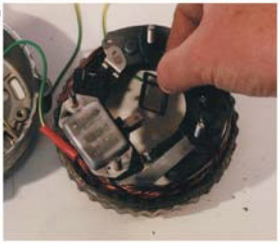
(23)


(24)


(25)


(26)


(27)

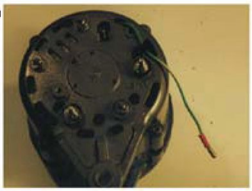

(28)


(29)


(30)


(31)


(32)


(33)


- You now have access to the stator, rectifier pack, standard regulator and the brush assembly. (27)
- Solder the new wire onto the regulator field terminal, as identified in the instructions (it should be marked 'F'). (29)
- Slip an insulating sleeve in place. (30)
- Note the carbon brushes and the rectangular brush assembly seal. (28)
- All is now ready for reassembly.
- Thread the new wire through the rear of the casing in such a way that it will not foul anything inside, and so that you can clip it to a slot with a cable tie. Put the brush assembly seal in place and slip the stator assembly into the rear casing, making sure that the seal is seated correctly. (31)
- In this figure a match has been inserted into a hole in the back of the case to hold the brushes in a retracted position prior to the insertion of the rotor. A match was used for clarity in the picture, but is not really strong enough to do the job. A suitable drill bit would be better. (32)
- Offer up the front casing and guide the bearing and armature gently into place. If any untoward resistance is felt, start again and check that the brushes are fully retracted, as they are easily damaged. Don't force it into place!
- Withdraw the drill bit and reassemble all the spacers, washers and nuts.
- Attach a connector to the new wire and you are ready to reinstall the alternator. (33)
- Tension the drive belt correctly and ensure the attachment bolts are secure. Complete the external wiring using the smart regulator's wiring diagram and you are ready to sample the pleasures of fully charged batteries.

The first time I did this, the work on the alternator took half an hour. The second time, to take some more pictures, took only 10 minutes!

Navigation Instruments

Modern boats have an array of instrumentation, sometimes fitted after delivery or as an upgrade on older boats.

The wiring-up of instruments often leaves much to be desired. Instruments may switch themselves off during engine start – see the section on 12 volt DC circuits on p. 37 for avoidance of this problem. The installer should provide a wiring diagram of the installation, but this is a rarity.

Avoid in-line fuses to individual instruments. Faultfinding is much easier if fuses are grouped together in an accessible ‘fuse centre’, not hidden away behind a panel. Again, this is a rarity.

Instruments should be sited where they are of most use to the helmsman/navigator. This is very often not at the chart table, but in the cockpit. Unless there is a dedicated navigator, radar and chart-plotters should be sited where they can be seen by the helmsman/skipper.

INTERCONNECTION OF INSTRUMENTS

The North American Marine Electronics Association (NMEA) has devised a language understood by instruments from many manufacturers, so that those instruments can talk to each other. The current version (2004) is NMEA 0183 v 2.3. Manufacturers do sometimes add 'sentences' of their own, but generally compatibility is good.

This enables you to choose different instruments from different manufacturers, according to your preference, and for the most part they will all interact together properly. However, sometimes they don't and you may get some 'buck-passing' between the manufacturers. You may find it preferable to get all the instruments from one dealer and specify in the order that you want them all to work together in the same system. If there's a problem, it's much more likely that your dealer will have success in getting an answer than you will.

Each manufacturer will normally have an 'in-house' language for its own instruments, in addition to NMEA. This is because they can achieve a faster communication speed and because they can develop special procedures without waiting for a committee to catch up. This has become especially so now that chart-plotters can show radar and fish-finder images at the same time.

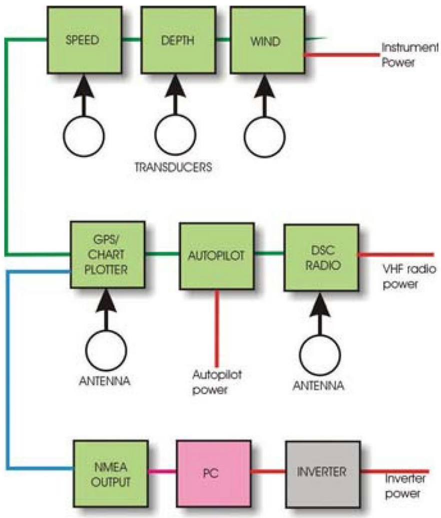
Instruments from the same manufacturer

This is the simplest option, both from the wiring and compatibility points of view. They will be guaranteed to work together.

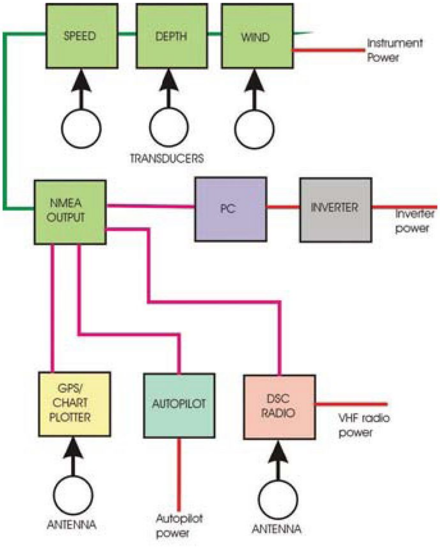
A single cable 'daisy chains' all the instruments together, and extra instruments can be connected at any time. This cable carries both data and power, and joints are made with simple plugs and sockets. The only extra cables are those to aerials (GPS, radio and radar) and transducers (speed and depth).

If you like the instruments from one manufacturer's range, this is a good way to go.

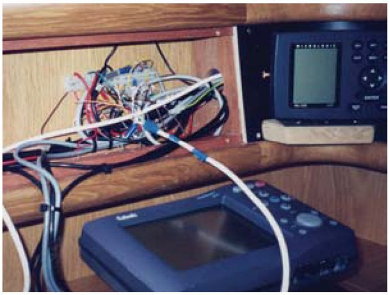
Sometimes, a particular range of instruments does not include one particular instrument, a radar, say. Adding only one 'foreign' instrument is not usually a problem, but do ask the supplying dealer first.

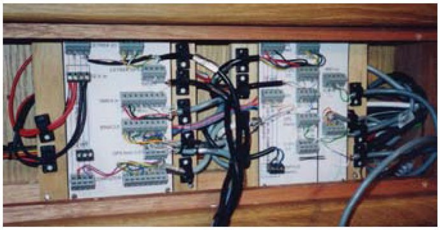


ALL NAVIGATION INSTRUMENTS OF SAME MAKE



MIXTURE OF MAKES OF INSTRUMENTS





Instruments from different manufacturers

Some makes will need an NMEA converter to be added to the system, but most newer instruments will have an NMEA output as standard. Wires will be required to connect each instrument, and wiring colour-coding will often differ. Careful thought must be given to the way in which the instruments will be interconnected, especially where a chart-plotter and GPS are connected to other instruments.

It's very easy to make a real tangle of wires if you are interconnecting a lot of instruments, unless a lot of thought and preparation is made.

- Start by making a wiring diagram.
- Consider where the connectors are to be sited – all in one place is best, but that may mean longer wiring runs.
- If possible, make up a circuit board with wiring connectors to take wires to each instrument.

Nylon connection blocks are not ideal for connecting small-gauge signal wires, and joint failures are likely.

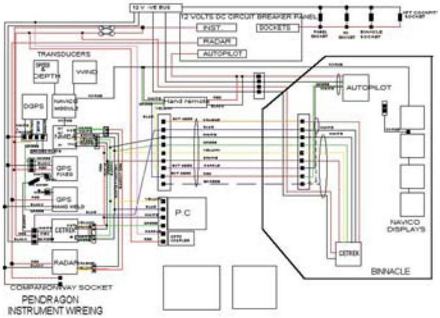
MULTIPLEXERS

If instruments from many manufacturers are to be incorporated, it would be sensible to install a multiplexer. In this, all the different NMEA sentences are fed into the multiplexer, combined, and a single multiplex signal containing all the data is sent back out to all the instruments requiring it. This avoids a lot of problems. Multiplexers may be obtained from ACTISENSE (www.actisense.com).

INSTALLATION OF INSTRUMENTS

Where you fit the instrument displays is very important. Left to his own devices, the boat builder or instrument installer will put the instruments in traditional places, often at the chart table. Consider how and when the instruments will be used. If you usually sail short-handed, then the main instruments need to be in the helmsman's sight and preferably reach.

However, mounting all the instruments on the binnacle means that the rest of the crew is kept out of the picture, so mounting them further forward in the cockpit has distinct advantages.



Although instruments these days are declared to be waterproof, often the connectors at the rear of the display are not. If this is the case, then the display must be mounted so that its rear is protected. A box can be built to achieve this.

Instruments in motor cruisers or boats with dual steering positions need just as much careful consideration as those fitted in the cockpit of a sailing boat.

- Where will you be helming from when you need that particular instrument?
- What instrumentation do you need at *both* stations?
- Does the instrument need to be seen by more than one person at the same time?
- Will the siting cause reflections in the windscreen at night? (some installations make it impossible to see through the windscreen at night, due to reflections from the instrument lighting!)

Make a mock up of the instrument layout before you cut holes in the boat!

PCs

I shall not be considering the use of a PC on board, only its wiring.

Power supply

Laptop PCs

These use a mains adapter to supply a suitable DC voltage. The problem is that this voltage varies, even in one manufacturer's range, so if you provide a built-in supply on the boat, it probably will be unsuitable for your next computer. For this reason, I use an inverter to supply 240 AC from my 12 volt system and run my computer from this using its dedicated mains adapter. Electrically this is not the most efficient arrangement, but it's kinder on the pocket when you change PCs.

An average laptop computer will draw around 4 amps from a 12 volt DC supply. This is roughly equivalent to the current taken by a fridge.

Desktop PCs

These are designed to run on mains AC voltage, although there are several 'marine' units that will run on 12 volts DC. Those requiring mains voltage can be run on shore power, an inverter or an on-board generator.

An average mains-powered desktop computer will draw up to 30 amps from a 12 volt DC system. For the average yachtsman who may want to use his computer under way, this is far too much current and is not a practicable proposition.

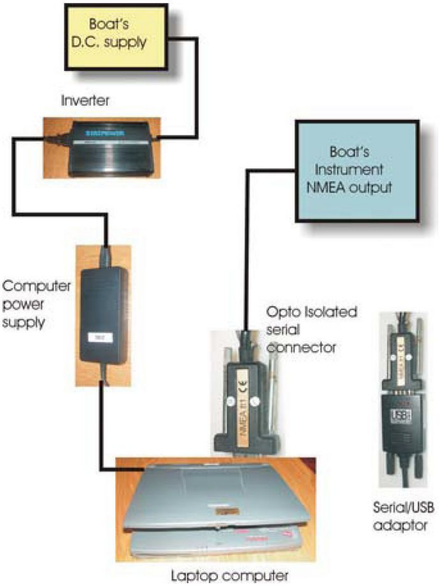
Normally, an inverter of sufficient power to run a desktop PC will be 'built-in' and the battery drain will be significant. I have seen a PC shut down because the battery voltage became too low, causing the inverter to switch itself off. This happened several times, and the owner had to accept that he would need to run his genset when using the computer. As he was going to use his computer for navigation, this was a definite disadvantage. He ended up buying a laptop computer as well! In any case, the hard drive in a laptop is much more rugged than that in a desktop.

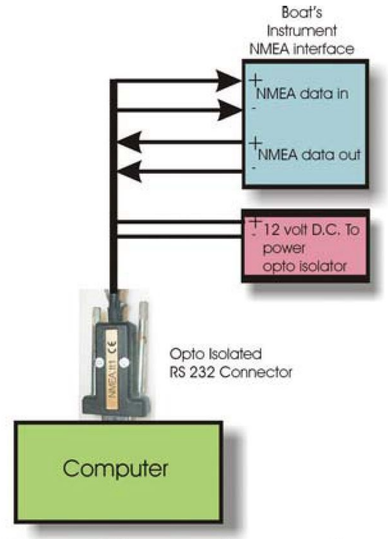
Connection to instruments

For use in navigation, your computer will need to be connected so that it can receive NMEA data via its serial or USB port. Most new laptops have no serial port, so it will probably need to be a USB connection. Currently, most NMEA data cables terminate in a serial connector, so you will need a serial/USB adapter.

It is preferable to use an 'opto-isolator' data cable to prevent voltage spikes upsetting the computer or NMEA data bus.

If you have more than about four instruments being supplied from a single NMEA source, you may have to fit an NMEA *buffer* to amplify the signals and provide sufficient output for the computer. This buffer will need a 12 volt power supply, as well as the NMEA input.





Instrument to computer connection

NMEA/computer connection

The connector will be supplied with a colour-coded diagram to aid connection to the boat's NMEA interface.

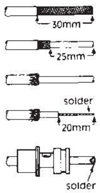
Siting the computer

Many people place their computer on the chart table. It is then susceptible to spray entering the companionway and also to being lent on by people wearing wet foul-weather gear or being operated by wet hands.

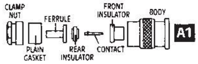
I use mine set up vertically on an open cupboard door, with operation by a remote mouse or tracker ball. A sacrificial cheap keyboard, or even a waterproof keyboard, may be used as well.

INSTRUCTIONS
To assemble PL259.

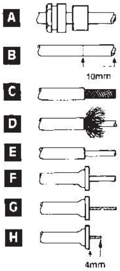
1. Unscrew the two parts of the plug and slide the barrel onto the cable.
2. Cut back outer sheath for 30mm **A**.
3. Cut back 25mm of the braid **B** revealing the dielectric.
4. Tease out the braid and fold back over the outer sheath as in **C**.
5. Now carefully remove 20mm of the dielectric and tin the conductor **D**.
6. Carefully screw the plug onto the cable until the folded back screen just disappears inside the plug. Don't go further or you could cause a short circuit.
7. Solder conductor into the prong and snip off any excess **E**. Then screw the barrel onto the plug.



INSTRUCTIONS
To assemble BNC connector.



Slide the clamp nut and plain gasket onto the cable **A**. Then cut back approx. 10mm of the outer sheath **B** exposing the braid **C**. Tease out the braid **D** and then cut it right back to the outer sheath **E** exposing the dielectric conductor cover. Then slide the ferrule over the dielectric and under the braid **F**. Using a sharp knife, trim the dielectric right back to the face of the ferrule **G** thus exposing the conductor which now should be tinned. Cut the conductor back so that 4mm is left showing, then assemble the plug in the order shown in **A1** making sure that the contact pin is soldered in place before fitting the front insulator. Plugs + sockets are assembled in the same way.



Courtesy of Index Marine.

COMMUNICATIONS RADIOS

VHF radio

A VHF radio is capable of transmitting at 25 watts. This requires a good power supply fused at around 7.5 amps, with cable heavy enough to cause minimum voltage drop. Generally, this means 2.5 mm^2 cable.

No matter how good the radio, a poor antenna installation will give poor transmissions. All antenna cable joints must be properly made and kept to a minimum, and the antenna itself must be correctly sited. Follow the manufacturer's guidance.

The radio may transmit perfectly well on 1 watt, but at the full 25 watts power, transmission will be poor or non-existent with a poor antenna. Reception is no indication of antenna performance, even though the transmitting station may be some distance away. Poor antenna connections can cause failure of the transmitter's output circuit, as can transmitting with no antenna connected.

In order to check the antenna installation, you need a standing wave ratio (SWR) meter.

All professional installers will have one, but one suitable for use by the boat owner is available for around £20 from a radio spares supplier. Without going into technicalities, an SWR meter measures how much of the signal is sent back down the cable rather than being transmitted. It is the only way to check an antenna installation, and instructions for its use will be supplied with the meter.

It has to be said that the majority of radio installers will not use an SWR meter to check the installation, and nor will they check the DSC operation of a DSC radio to ensure that the DSC is actually working. Only if a problem is reported will they delve deeper.

Connection of a DSC radio to a GPS

A DSC radio requires a position input from a GPS. As there is no full standardisation of the NMEA wiring colours, you will need to check the colour of the NMEA data outputs of your instrument system. Normally there will be a data +ve and a data –ve wire.

HF radio

Power supply and antenna connections are very important with an HF radio installation, as is the antenna itself.

In the long-distance cruising fraternity, it seems to be generally accepted that good performance of an HF radio installation is best achieved by a professional familiar with HF installation.

Anodes

CATHODIC PROTECTION

Sea water is an electrolyte, just as the liquid in your battery is an electrolyte. It will allow current to flow between two metal fittings immersed in the electrolyte if those fittings have different electrical potentials and they are connected together electrically.

Different metals will have differing electrical potentials when connected together and immersed in sea water. Their potential can be found on an anodic table of potentials, and in extreme cases they may be separated by as much as 1.5 volts. The metal at the higher voltage will be eaten away, and if the potential difference is greater than 0.25 volts, corrosion is almost certain to occur.

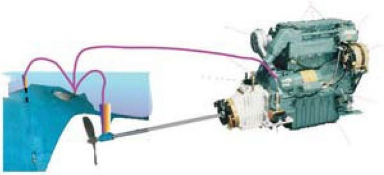
This all sounds a bit complicated, and indeed there are specialists in electrolytic corrosion, as the process is called, such as M.G. Duff. As far as a book such as this is concerned, what we need to know is how to protect vulnerable hull fittings. There's a little bit more on this topic in the section on A.C. circuits on p. 43.

Essentially, when used in sea water, external hull fittings are protected by a zinc *anode* wired into the same circuit as the fittings. The anode gives up zinc in order to protect the fittings themselves from corrosion. Indeed, these anodes are normally referred to as *sacrificial* anodes, because they sacrifice themselves.

To a lesser extent, electrolytic corrosion can occur in fresh and brackish water. In fresh water, the anode is made of magnesium. For use in brackish water, ideally use aluminium. Be guided by what other people use in that area.

ANODES

An anode must be fitted as close as possible to the fitting that it is protecting, and it must be connected to it electrically. On a glass fibre hull, the main protection is needed by the stern gear: the propshaft, 'P' bracket (if fitted) and the propeller. A steel rudder stock may also need protection. The anode must be able to 'see' all these components and be wired to them. This means mounting the anode as close as possible to the fitting and with no intervening structure.



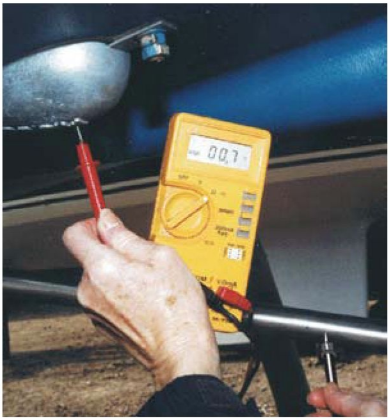
In Europe, the other skin fittings are rarely included in the anodic circuit, but in the USA, they often are. Because the sea water cooling intake is connected to the engine by the sea water in the hose, Westerly Yachts always had their cooling intake included in the anodic circuit. Wooden boats should not have their skin fittings bonded, because if they are, the wood surrounding the fitting will become softened.

The anode is bolted to the outside of the hull using special studs. Internally, the studs are connected to the engine block and the 'P' bracket and to the rudder stock, if necessary, by heavy copper wires run out of the bilges

There needs to be electrical continuity all the way from the anode to the propeller shaft and prop (and any other fitting to be protected). The resistance from the anode to the prop should not exceed a couple of ohms. If the propeller shaft coupling at the rear of the gearbox electrically isolates the shaft from the engine, some form of electrical bridge needs to be provided. This can be in the form of an electrical strap across the coupling, or electrical *brushes* bearing on the shaft.

- All connections must be kept clean and corrosion-free.

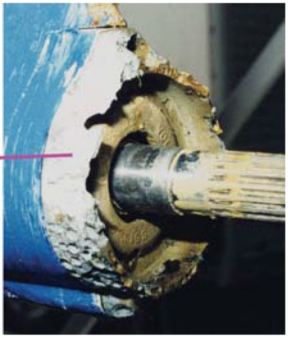
- New nuts and fan washers should be used each time the anode is changed.
- Wire can become corroded.
- If the anode is not eroding, it's probably not connected!
- Test for continuity with the multimeter. Ideally, resistance should be no more than a couple of ohms, but multimeters may not be too accurate at very small resistance readings.
- Use your long multimeter probe lead to check the resistance from the 'bonding' cable to the external anode (outside, not its bolt).
- Check for continuity from the anode to the propshaft, propeller and the 'P' bracket.



Propellers mounted on rubber bushes

Some propellers are mounted on rubber bushes so there can then be no continuity between any anode and the propeller. The prop is then protected from dezincification only by its own propeller anode. This is often very small and may not last the season, so it will need to be inspected mid-season.

Very corroded saildrive leg anode



Volvo Penta saildrives

The latest models of Volvo Penta compact saildrive engines have their gearboxes electrically isolated from their engines. On these engines, on no account must there be any electrical bridge between the two. Check your handbook to see if your engine/gearbox is isolated. Protection of the propeller and leg is provided solely by the leg anode.

With a standard prop, the anode will just about last a year. Folding props with heavy bosses may need to have the anode replaced mid-season to avoid corrosion of the prop.

This prop hub is already showing signs of dezincification through electrolytic corrosion. Note that a reddish colour indicates surface dezincification.

Suspended anodes

Where extra anodic protection is needed, a hanging anode can be suspended in the water close to where the protection is required. This anode is sometimes called a *guppy*. The anode is connected electrically to a wire, the other end of which is clipped to a component that is electrically connected to a fitting in the 'bonding' circuit. For example, the ground circuit could be extended by connecting a bonding wire to a cockpit fitting, and the guppy cable could be clipped to this as required. If the saildrive leg is electrically isolated, ensure that the guppy is connected to the gearbox and not to the engine.

Steel hulls

The steel from which the hull is built also needs to be protected by anodes, the siting of which should be determined with the help of a specialist, such as M.G. Duff.

Aluminium hulls

Aluminium hulls or superstructures can be wasted away within months if electrolytic currents are set up. This is a very specialist area and thus advice from one of these specialists is mandatory.

Aluminium anodes

Recently launched by Performance Metals (www.performancemetals.com) is a series of aluminium/indium alloy anodes. These work equally well in fresh, brackish and sea water, and they work immediately after relaunching.

Aluminium/indium is lighter than zinc and also 0.05 volts less noble, so it gives more protection for aluminium and steel than does zinc. Importantly, it is claimed to have 40% greater life than zinc.

Protecting aluminium stern-drives against electrolytic corrosion is particularly difficult, and aluminium/indium anodes could bring significant gains over using zinc anodes.

GROUND PLATES

Some radio and navigation receivers and transmitters require a 'ground plane' if they are to give satisfactory performance. This requires a large metallic surface immersed below the water. One way to achieve this is to connect the ground circuit to the iron keel. A better way is to use a 'sintered' bronze *ground plate* attached to the exterior of the hull below the waterline

The ground plate is full of minute holes and fissures so that its actual surface area is much greater than it would seem. The ground plate is electrically connected to the electrical ground of the boat's DC system.

Soldering

Soldering is the technique of joining two metals together by melting another metal onto their surfaces as a form of 'adhesive'. Soldering doesn't fuse the metals together as in welding.

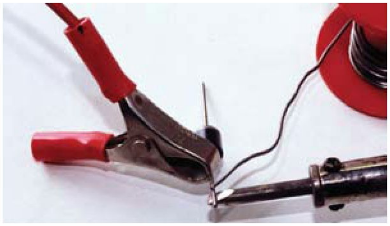
For joining copper electrical wires, we use a solder of tin/lead alloy, which has a relatively low melting temperature.

The process of soldering causes oxidisation on the surfaces to be joined, and this prevents adhesion of the solder to the other metal surfaces. For this reason, a *flux* has to be applied to prevent oxidisation. For our purposes, the easiest way to do this is to use proprietary *multicore* solder, where an acid-free flux ('rosin flux') is stored in minute cores within the solder, which is provided in the form of a wire.

SOLDERING IRONS

The heat to melt the solder is provided by a soldering iron. The size and power of the iron are important. There should be only enough heat to raise the temperature sufficiently in the region of the joint. Too much heat may cause damage to adjacent areas, such as the wire's insulation; too little, and the solder will not melt.

Small electronic components, such as transistors and diodes, will be destroyed by too much heat, and even the smallest iron will be too big. To get over this problem, a temporary *heat sink* is attached to the wire between the component and the soldering iron, and soldering should be accomplished quickly using a hot iron. The heat sink draws excessive heat away from the delicate component. A small crocodile clip with sufficient mass will do the job.



For most boat wiring, a 25 watt iron, or its equivalent, will be fine. For soldering heavy-duty cables, this will be insufficient, but soldering may not be the best method of joining heavier cable anyway.

The size of the tip should be appropriate for the size of the job to be tackled.

On the boat, a 12 volt iron is very useful.

If mains voltage is available, a 25 watt mains-powered iron can be used, although a second, larger iron of up to 100 watts can be useful for some bigger jobs.

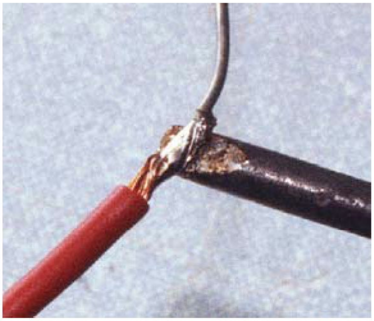
A gas-powered soldering iron is very versatile, as it can be used for cutting, heat-shrinking and sealing rope as well. A word of warning here: I have found that the catalytic heater of cheaper gas irons lasts for a very short time. Since using a more expensive 'professional' iron I have had no such problems.

SOLDERING TECHNIQUE

Soldering is not at all difficult, but a bit of practice helps.

- Switch on the iron and allow it to achieve its full temperature. This can be checked by touching the solder to the tip to check that the solder melts.
- Clean the tip of the iron on a damp cloth or sponge.
- Apply a small amount of solder to the hot tip in order to *tin* it.

- If the tip has become burned and pock-marked, restore its condition using a file.



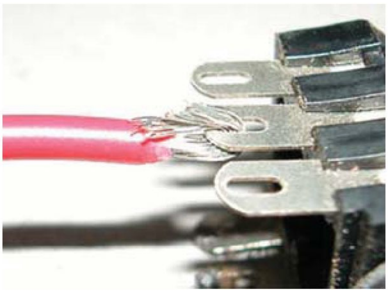
- The surfaces of the area to be soldered must be clean and free of corrosion – this means they must be bright.
- The surfaces must be *tinned* before making the joint – this is the application of a thin layer of solder to the areas to be joined. Heat the wire with the iron, and with the iron still in contact with the wire, melt some solder onto the wire. Then repeat for the second wire.
- Hold the two wires together and apply heat. The tinning should melt and join the wires together. If necessary, apply more solder wire to the joint, not to the iron's tip.
- The resultant joint should be bright and shiny. If it has a dull, crinkled look, it was not hot enough or the joint was moved before it had cooled – this is known as a dry joint. It will have high electrical resistance and poor mechanical strength and must be remade.

Some form of clamping may be required if you run out of hands! It's also very useful to have a holder in which to safely rest the hot soldering iron.

Heavy-duty joints

Soldering heavy cables may be achieved by using a gas blowtorch, as used for plumbing. There's a big danger of melting the wire's insulation and a better option is (usually) crimping using a professional heavy-duty crimping tool.

MECHANICAL STRENGTH



Soldered joints must not be relied upon to give mechanical strength. Support the wire on either side of the joint.

If more mechanical strength is desirable, twist the wires together before tinning them and then make the joint. This will be difficult to unsolder if you need to break the joint.

Some electrical components have a lug with a hole in it, to which the wire is soldered. Loop the bared untinned wire through the lug. Now heat the lug and wire with the hot iron and apply the solder to the wire AND the lug together to make the joint. If you don't twist the wire, it will not be difficult to unsolder.

UNSOLDERING JOINTS

It is sometimes much easier to undo a soldered joint if most of the solder is first removed. To do this you need a de-soldering tool.

- Heat the joint so that the solder melts.
- Apply the tip of the tool to the hot joint and suck off the melted solder.
- Reheat the joint, which should then be easy to undo.

If you don't have a de-soldering tool, melt the solder and pull the joint apart. If there's a lug with a hole, the hole will immediately fill up with solder again, so if you are going to remake the joint, try and wipe the solder off with a wet rag – it's better to buy the correct tool if you are going to tackle this sort of job.

Power Consumption

Everybody's electrical power needs are different. What you need to do is examine your sailing lifestyle and make an attempt to assess how much electricity you are going to use, on average, each day.

To that end, I've made an attempt to guess what the average boater might use in various conditions, so that you can adapt my figures to your type of boating. The numbers are for a 12 volt system. If yours is 24 volts, the amps and Ah/day will be halved. See the tables on pages 34–36 for reference.

A modern cruiser could easily consume 115 Ah for a 12-hour passage under sail. Frugal use of electrical power could reduce this to 35 Ah.

The picture differs somewhat if we are at anchor or moored without recourse to shore power.

On a modern cruiser, 24 hours moored could typically consume 80 Ah. Frugal use of power could reduce this to 35 Ah per day. Additionally, if a diesel-powered heater is used, expect to consume 4 Ah per hour running.

If we have access to shore power, then the picture changes radically.

What is not obvious in this last case is that we may also need to charge our depleted batteries. In the case above, we are using 14 amps DC current, which must come from the battery charger, so if we've a 30 amp battery charger, only 16 is going into the battery to charge it up. Taking into account charging efficiency and other factors, that's going to take around 16 hours to fully charge our batteries if we need to put 200 Ah back in.

An additional consideration is that the total possible AC load far exceeds the amperage of the 240 volt power supply. Although an overload should trip our on-board circuit breaker first, we could trip the pontoon breaker. That may make us very unpopular with our neighbours, as often this breaker can be reset only by marina staff.

USEFUL TABLES

BATTERY STATE OF CHARGE	BATTERY VOLTS			
	RESTED	0 AMPS	5 AMPS	10 AMPS
100%	**12.8**	**12.5**	**12.4**	**12.2**
90%	**12.7**	**12.4**	**12.3**	**12.1**
80%	**12.6**	**12.3**	**12.2**	**12.0**
70%	**12.5**	**12.2**	**12.1**	**11.9**
60%	**12.4**	**12.1**	**12.0**	**11.8**
50%	**12.3**	**12.0**	**11.9**	**11.7**
40%	12.2	11.9	11.8	11.6
30%	12.1	11.8	11.7	11.5
20%	12.0	11.7	11.6	
10%	11.9	11.6		
FLAT	11.8	11.5		

BATTERY STATE OF CHARGE

MINIMUM WIRE SIZES

Wire sizes required for a given length of cable run (Length is the sum of the positive and negative wires)

Wire size 3% voltage drop (Critical applications – bilge pumps, nav. lights, electronics, etc.)

	CURRENT (amps)								
LENGTH	5 a	10 a	15 a	20 a	25 a	30 a	40 a	50 a	100 a
5 m	16	12	10	10	8	8	6	6	2
10 m	12	10	8	6	6	4	4	2	1/0
20 m	10	6	6	4	2	2	1	1/0	4/0
30 m	8	4	4	2	1	1/0	2/0	3/0	
40 m	6	4	2	1	1/0	2/0	3/0	4/0	
50 m	6	2	1	1/0	2/0	3/0	4/0		

Wire size 10% voltage drop (Non-critical applications – windlasses, cabin lights, etc.)

	CURRENT (amps)								
LENGTH	5 a	10 a	15 a	20 a	25 a	30 a	40 a	50 a	100 a
5 m	18	18	16	16	14	14	12	12	6
10 m	18	16	14	12	10	10	8	8	4
20 m	16	12	10	8	8	8	6	4	2
30 m	14	10	8	8	6	6	4	4	1
40 m	12	8	8	6	4	4	2	2	2/0
50 m	10	8	6	4	4	2	2	1	3/0

American wire gauge 'boat cable'

AWG	18	16	14	12	10	8	6	4	2	1	1/0	2/0	3/0	4/0
mm^2	0.8	1	2	3	5	8	13	19	32	40	50	62	81	103
Max. amps	20	25	35	45	60	80	120	160	210	245	285	330	385	445

Reduce current by 15% when run in engine compartment.

Standard UK wire sizes – 1, 1.5, 2.5, 4, 6, 25 and 40 mm^2.

GALVANIC CORROSION TABLE

METAL	POTENTIAL volts
Magnesium alloys	−1.6
Galvanised iron	−1.05
Zinc	−1.03
Cadmium	−0.8
Alumnium alloys	−0.75
Mild steel	−0.65
Lead	−0.55
Type 304 stainless steel(A2) (active - oxgen starved)	−0.53
Copper	−0.36
Admiralty brass	−0.29
Manganese bronze	−0.27
Slicon bronze	−0.18
Type 316 stainless steel(A4) (active - oxygen (starved)	−0.18
Inconel	−0.17
Titanium	−0.15
Silver	−0.13
Type 304 stainless steel(A2) (passive)	−0.08
Monel	−0.08
Type 316 stainless steel(A4) (passive)	−0.05
Platinum	+0.21
Graphite	+0.25

See page 125, chapter 12