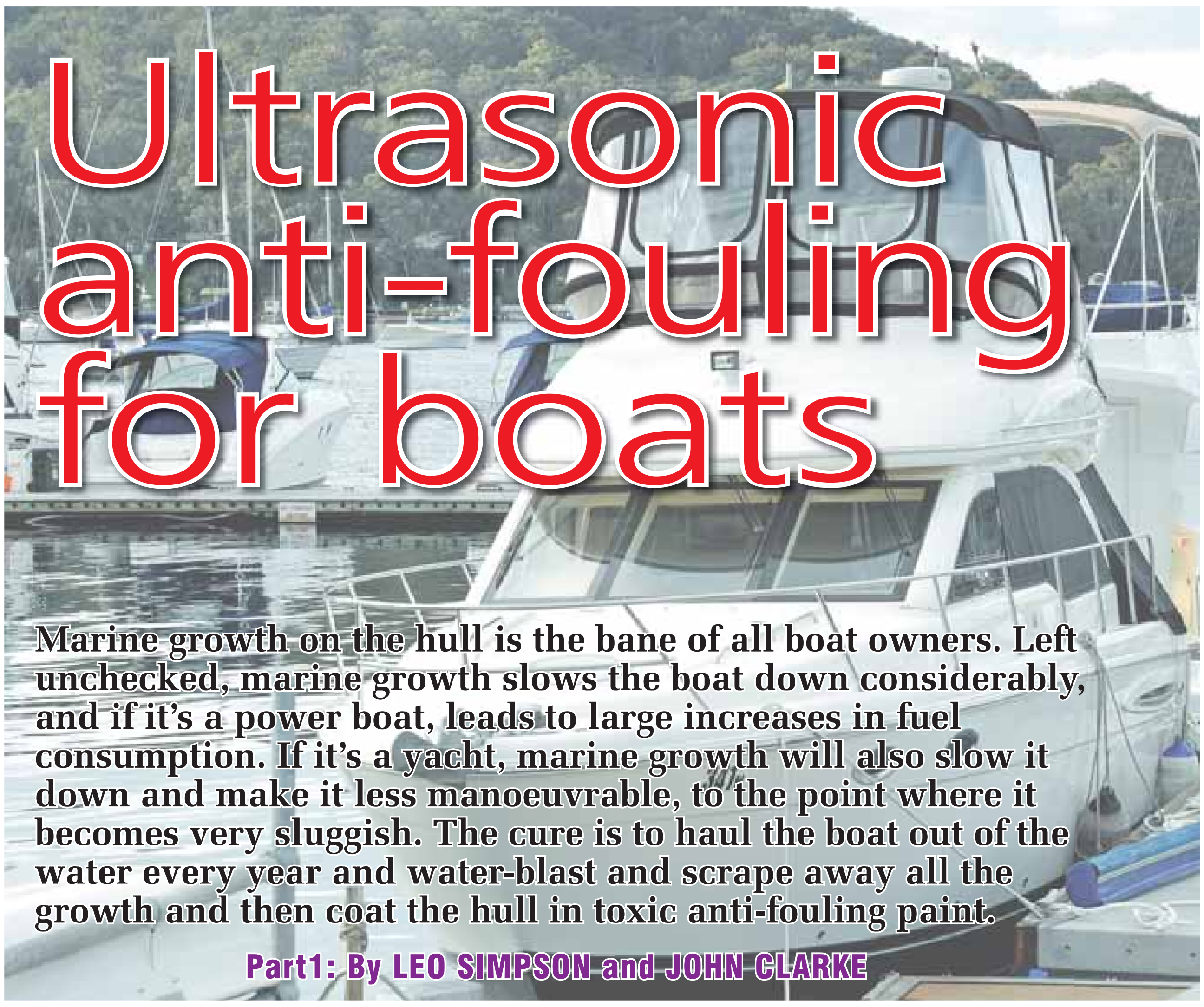


Ultrasonic anti-fouling for boats

Marine growth on the hull is the bane of all boat owners. Left unchecked, marine growth slows the boat down considerably, and if it's a power boat, leads to large increases in fuel consumption. If it's a yacht, marine growth will also slow it down and make it less manoeuvrable, to the point where it becomes very sluggish. The cure is to haul the boat out of the water every year and water-blast and scrape away all the growth and then coat the hull in toxic anti-fouling paint.

Part1: By LEO SIMPSON and JOHN CLARKE

EVERYONE knows that owning and maintaining a boat is expensive; the bigger the boat, the more expensive it is.

Many readers will be familiar with trailer sail-boats and power boats. These are relatively cheap to run and since they are not left in the water, they should never have problems with marine growth. However, once you have a boat on a swing mooring or tied up to a berth in salt water, marine growth is endemic and the warmer the water, the more severe the problem.

The vast majority of larger boats are moored year-round in warm, salty waters and so marine growth is a big problem. In years past, the solution was to coat the hull in an arsenic-based anti-fouling compound, but these were highly toxic to all marine life and have now been banned. This means that the anti-fouling compounds used now, while still toxic to marine growth, are far less effective.

The problem is even more severe for boats that are moored in canal developments, because there the water is warmer and there is little water movement, marine growth can be so rapid that anti-fouling needs to done as often as every six months.

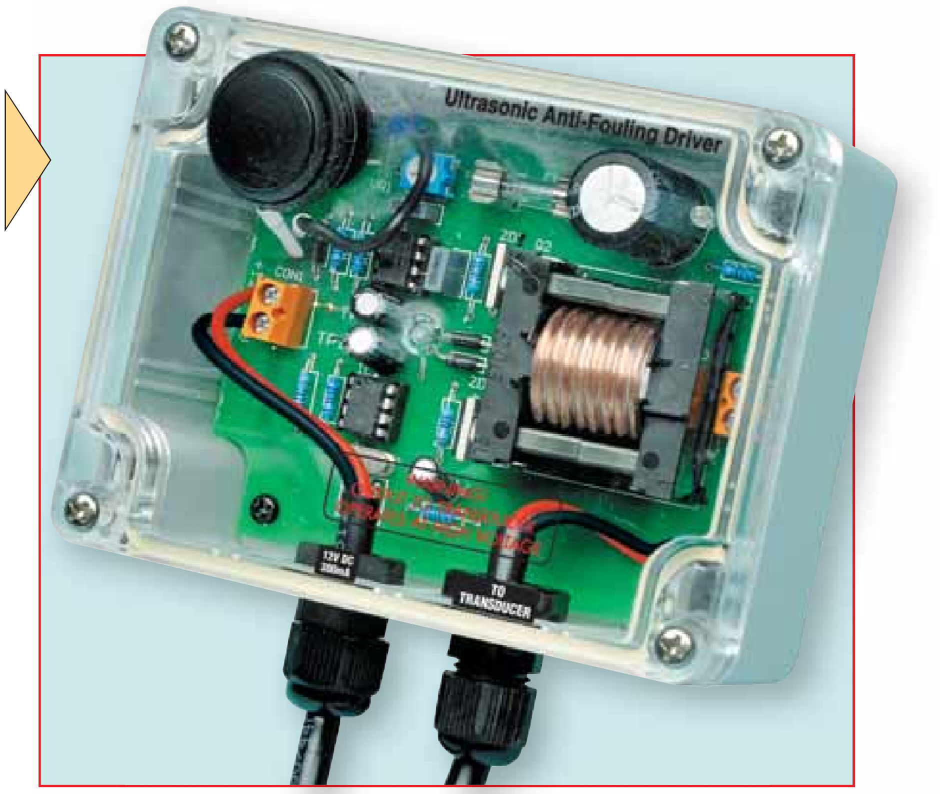
If a boat is not being used, marine growth can still rapidly take hold and there can be significant growth after only a few months. This is because anti-fouling coatings are 'ablative', which means that they depend for their operation on the boat moving through the water to literally wear off the surface and thereby expose fresh (and toxic) anti-fouling compound.

Ultrasonic anti-fouling

So, anti-fouling needs to be done at least once a year and in some cases, more frequently if the boat is seldom used or moored in a canal. If you do this work on your own boat, it is tedious, dirty and expensive (even hauling the boat out of water is expensive). If you pay someone else to do it, it is much more expensive. All boat owners would love to avoid this cost.

Now there is ultrasonic anti-fouling for boats. This electronic method means the end of chemical anti-fouling

Build it and keep the barnacles at bay electronically



The driver circuit is housed in an IP65 type ABS box with a clear lid. It produces the high-voltage pulsed waveform that's used to drive the ultrasonic transducer.

and a big reduction in cost for boat owners. It involves installing a high power piezoelectric transducer inside the boat's hull, and the ultrasonic energy keeps marine growth at bay.

How it works

The way that this works is that the ultrasonic vibration of the hull disrupts the cell structure of algae and this stops algal growth adhering to the hull. And because there is no algal food source on the hull, larger marine organisms have no reason to attach themselves to the hull – no food, no lodgers.

The principles of ultrasonic anti-fouling have been known for a long time. The effect was discovered 80 years ago by French scientist Paul Langevin, who was developing sonar for submarines. By accident, he found that ultrasonic energy killed algae.

He was working with high power transducers and it was assumed that cavitation was causing algal death. In recent times though, it has been found that high ultrasonic power and cavitation is not required to kill algae.

Instead, it has been found that ultrasonic frequencies can cause resonance effects within algal cell structures, and relatively low powers are still enough to cause cell death. So, if the boat's hull can be vibrated over a range of ultrasonic frequencies, algae will not be able to attach to it and other marine growth will similarly be discouraged.

Commercial ultrasonic anti-fouling systems have been available for the last few years, but they are very expensive, costing thousands of pounds to install. There is still a cost benefit though, and these systems are gradually becoming more popular as news of their effectiveness grows.

However, we should state at the outset that the manufacturers do not make blanket guarantees that ultrasonic anti-fouling systems work in every situation. We can understand that.

WARNING!

This circuit produces an output voltage of up to 800V peak-to-peak to drive the ultrasonic transducer and is capable of delivering a severe (or even FATAL) electric shock. DO NOT touch the output terminals at CON2, the PC tracks leading to CON2 or the transducer terminals when power is applied.

To ensure safety, the PC board must be housed in the recommended plastic case, while the transducer must be correctly housed and fully encapsulated in resin, as described in Part 2.

It's this lack of a blanket guarantee that's probably holding back market acceptance. Most boat owners will be very cautious about investing several thousand pounds in a system that may not work in their case. That is where our design will be a game-changer. It will cost a fraction of the price of equivalent commercial systems, yet should have the same effects.

Specifications

Overall output frequency range: from 19.08kHz to 41.66kHz in 14 bands; frequency overlapping included between each band

Frequency sweep in each band: 12 frequencies ranging from approximately 80Hz steps at 20kHz to 344Hz steps at 40kHz

Signal burst period: 600ms at 20kHz, 300ms at 40kHz (1000 cycles/ burst)

Pause between each band: 500ms

Dead-time for push-pull driver: 5µs

Output drive: 250V AC (up to 800V peak-to-peak)

Low voltage threshold: 11.5V (switch-on voltage = 12V)

Supply Voltage: 11.5V to 16V maximum

Current drain: 220mA average at 12V driving a 3.6nF load

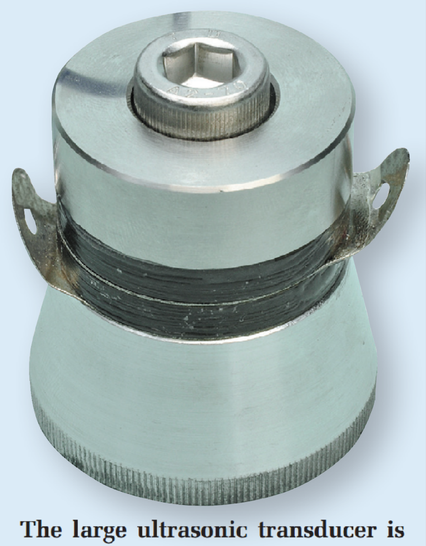
Peak current at transducer resonance: 3A

Quiescent current below 11.5V: 6.7mA

Our system works along the same lines as commercial systems. It uses a high-power piezoelectric transducer, which is attached inside the hull. It is driven with bursts of ultrasonic signal ranging between about 20kHz and 40kHz.

The reason for using a range of frequencies is two-fold. First, we want to drive the transducer over a range of frequencies so that various resonance modes of the hull are excited. Second, this range of frequencies is required to kill the various types of algae.

While a high-power transducer is used and we do drive it with very high voltages, the actual power used is not very great. The typical current consumption from a 12V battery is around 220mA (3A peak).


The large ultrasonic transducer is driven with high-frequency signal bursts ranging from 19.08kHz up to 41.66kHz.

Since the ultrasonic anti-fouling system should ideally run continuously, the 12V battery will need to be permanently on charge. This is no problem for boats in berths which have shore power (ie, 230V AC mains). For boats on swing moorings, a solar panel and battery charge controller will be required. We hope to describe a suitable system in a future issue.

So let's have a look at the ultrasonic anti-fouling driver. This is housed in a compact sealed plastic IP65-type case, with a transparent lid. There are two cable glands on one side of the case for the power supply cable and for the cable to the piezoelectric transducer, which is itself encapsulated in a high-pressure plumbing fitting.

The driver module is based on a PIC12F675-I/P microcontroller, two power MOSFETs and a step-up transformer. It can be powered from a 12V battery or a 12V 3A (or greater) power supply, if shore power is available.

Ultrasonic bursts

In more detail, the piezoelectric transducer is driven with bursts of high-frequency signal ranging from 19.08kHz through to 41.66kHz. This is done over 14 bands, with each band sweeping over a small frequency range.

The first band is from 19.08kHz to 20.0kHz and comprises 12 frequencies, with approximately 83Hz steps between each frequency. The other bands also have 12 frequencies, but with larger frequency steps. For the middle band at 24.75kHz to 26.31kHz, the steps are about 141Hz. For the top band, between 37.87kHz and 41.66kHz, the steps are 344Hz.

Each band overlaps the following band by a few hundred hertz. This overlap ensures that the whole range of frequencies is covered from 19.08kHz to 41.66kHz.

Each burst of signal comprises two separate frequency bands, each of 500 cycles. The burst period for the total 1000 cycles depends on the actual frequency bands that are in the burst – from 300ms to 600ms. There is a 500ms no-signal gap between each burst.

The two frequency bands for each burst are varied in a pseudo-random way so that the entire range of frequencies is covered within 16s. This sequence is repeated after about 64s.

Note that there is a concentration of signal about the resonant frequency of the transducer, between 35.21kHz and 41.66kHz.

Circuit description

Now let's have a look at the full circuit diagram for the *Ultrasonic Anti-Fouling Driver* – see Fig.1. The PIC microcontroller IC2 drives step-up transformer T1 via two MOSFETs, Q1 and Q2. In addition, the microcontroller provides a low-voltage shutdown to prevent the battery from discharging below 11.5V.

The microcontroller runs at 20MHz (as set by crystal X1) and this allows it to provide the small ultrasonic frequency shifts listed above.

Pin 6 and Pin 7 of IC2 drive MOSFETs Q1 and Q2, which in turn drive transformer T1. Since these outputs only swing from 0V to +5V, we have specified logic-level MOSFETs, type RFP30N06LE. Their 'on' resistance (between the drain (D) and source (S)) is a mere 75mΩ for a gate voltage of 3V, and it drops even lower to around 23mΩ at a gate voltage of 4.5V. Their current rating is 30A continuous.

MOSFETs Q1 and Q2 are driven alternately and in turn drive separate halves of the transformer primary winding. The centre tap of the primary is connected to the +12V supply rail.

When Q1 is switched on, current flows through its section of the primary winding for less than 50µs, depending on the frequency, after which Q1 is switched off. After 5µs, Q2 is then switched on for less than 50µs. Then, when Q2 switches off, there is another gap of about 5µs before Q1 is switched on again and so on.

The 5µs period during which both MOSFETs are off is 'dead time' and it allows one MOSFET to fully switch off before the other is switched on.

The alternate switching of the MOSFETs generates an AC square-wave in T1 primary winding and this is stepped up in the secondary winding to provide a voltage of about 250V AC, depending on the particular frequency being switched and the resonance of the piezoelectric transducer load.

MOSFETs Q1 and Q2 include overvoltage protection to clamp drain voltages which exceed 60V. This clamping is required because a high-voltage transient is generated each time the MOSFETs switch off.

Protection for the gates of the MOSFETs is provided using 5.1V Zener diodes ZD1 and ZD2. This might seem unnecessary since the MOSFETs are only driven from a 5V signal, but the high transient voltages at the drains can be coupled into the gate via capacitance. These 5.1V Zener diodes also help prevent damage to the GP0 and GP1 outputs of IC2.

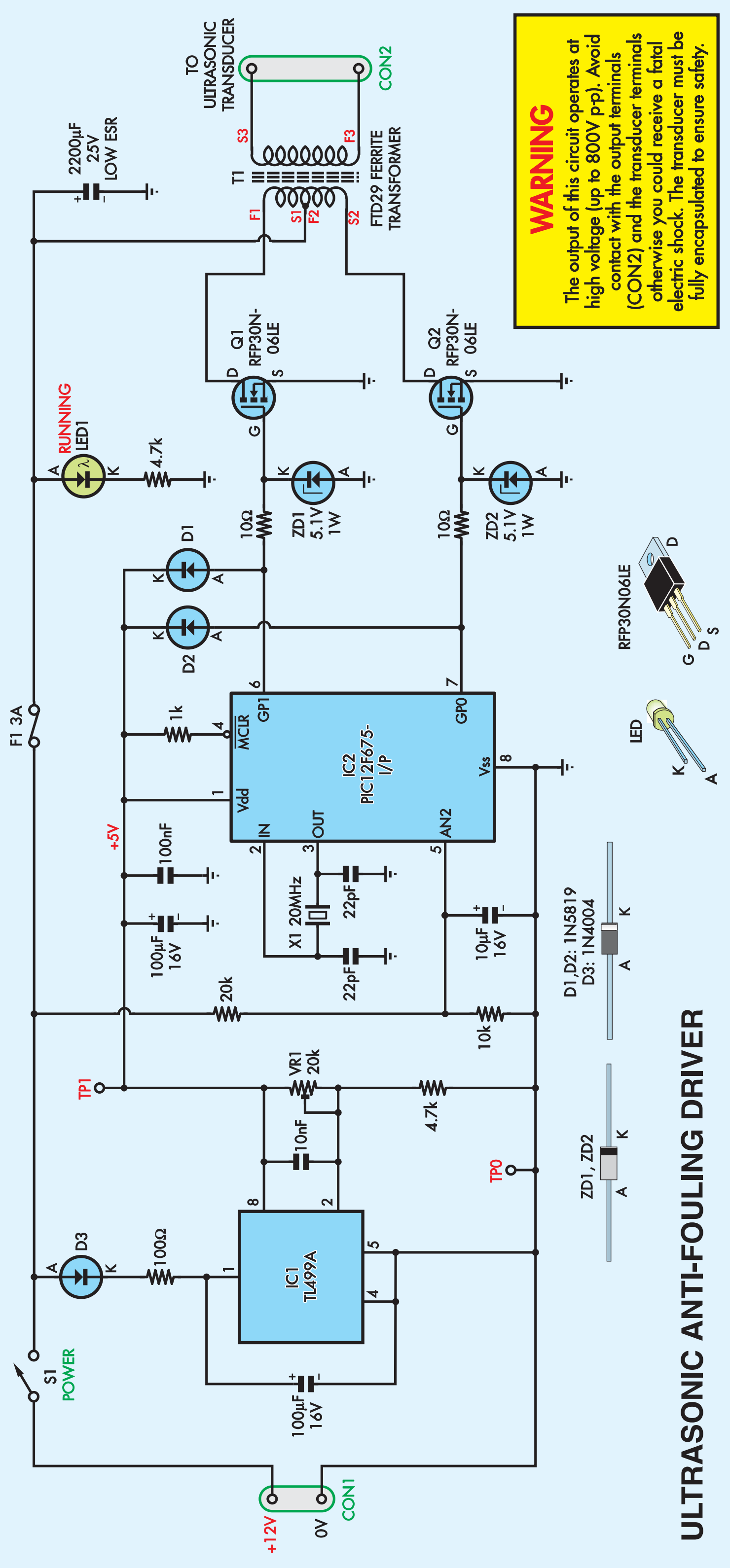
Further protection is provided for the GP0 and GP1 outputs of IC2 using Schottky diodes D1 and D2. These clamp the voltages at these pins to about +5.3V. They are in parallel with the internal protection diodes at GP0 and GP1.

Battery voltage monitoring

The incoming 12V supply is monitored via a voltage divider consisting of 10kΩ and 20kΩ resistors and the resulting voltage is filtered and monitored by IC2 at pin 5, the AN2 input. IC2 converts this voltage into a digital value and this is compared against a reference value in the software. With an 11.5V supply, the voltage at pin 5 is 3.83V and below this threshold voltage IC2 cuts off the drive for MOSFETs Q1 and Q2. This prevents over-discharge of the boat battery.

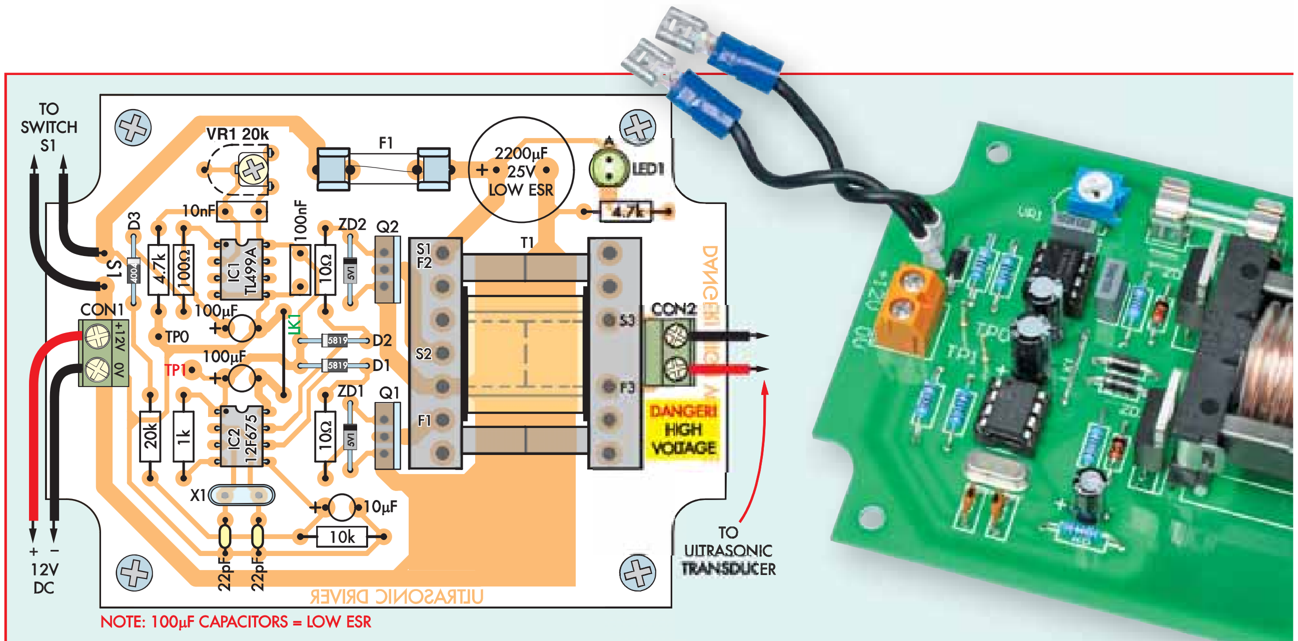
Once IC2 is in low-voltage shutdown mode, the supply voltage needs to rise to 12V before the MOSFET drive is resumed. This 0.5V hysteresis prevents the shutdown switching being on and off repetitively at the 11.5V threshold.

The 5V supply rail for IC2 is provided by a TL499A regulator, IC1. This is a low quiescent current regulator that can run in linear stepdown or switch-mode step-up modes. We are using it



ULTRASONIC ANTI-FOULING DRIVER

Fig.1: the circuit uses PIC microcontroller IC2 to drive step-up transformer T1 in push-pull fashion via MOSFETs Q1 and Q2. IC1 is a switch-mode controller IC and is used to provide the +5V supply rail for IC2, while ZD1 and ZD2 provide overvoltage protection for the gates (G) of the MOSFETs.



NOTE: 100µF CAPACITORS = LOW ESR

Fig.2: install the parts on the PC board as shown in this layout diagram and the photo. Be sure to use a socket for the PIC microcontroller (IC2), but do not install this IC until after the setting-up adjustment has been completed.

in linear stepdown mode. Its output voltage is trimmed to exactly 5V using trimpot VR1. This is done to set the low-voltage shutdown threshold.

The circuit includes reverse polarity protection. IC1 is protected by diode D3 and in turn protects IC2. The MOSFETs are protected via their substrate diodes and fuse F1.

If the supply is reversed, the diodes conduct via the transformer's primary until the fuse blows. Before that happens, the supply is effectively clamped at around –1V, and thereby protects the 2200µF electrolytic capacitor from excessive reverse voltage.

The fuse also prevents the PC board tracks from fusing should the transformer be wound incorrectly or if one of the MOSFETs fails as a short circuit.

Assembly details

The *Ultrasonic Driver* is constructed on a PC board measuring 104mm × 78mm. This board is available from the *EPE PCB Service*, code 866. It has corner cutouts to allow it to be mounted in an IP65 ABS box with a clear lid, measuring 115mm × 90mm × 55mm.

Begin construction by checking the PC board for breaks in the copper tracks or shorts between them. Check also that the hole sizes are correct for each component to fit neatly. The screw terminal holes and transformer pin holes are 1.25mm, while still larger holes are used for the fuse clips.

Assembly can begin by installing the resistors and PC stakes. Table 1 shows the resistor colour codes, but you should also check each resistor using a DMM. The PC stakes are installed at TP0 and TP1 and at the external wiring points for switch S1.

Follow these with the diodes, which must be oriented as shown. Note that there are three different diode types: 1N5819s (Schottky) for D1 and D2, 1N4004 for D3 and 5.1V Zener diodes for ZD1 and ZD2.

IC2 is mounted on an 8-pin IC socket, so install this socket now, taking care to orient it correctly. Leave IC2 out for the time being though. IC1 can also be socket mounted or it can be directly soldered into place. Again, ensure the orientation is correct.

Crystal X1 and the two 2-way screw terminal blocks can be installed next. Make sure the screw terminals are oriented with the opening toward the outside edge of the PC board. Q1 and Q2 must be mounted so that their tabs are 25mm above the PC board. Their metal tabs face transformer T1.

LED1 is mounted with its top 30mm above the PC board (its anode has the longer lead). The capacitors can now go in, followed by trimpot VR1. Make sure that the electrolytic capacitors are oriented correctly.

Transformer details

Fig.3 shows the transformer winding details. The primary winding

Table 1: Resistor Colour Codes

☐	No.	Value	4-Band Code (1%)	5-Band Code (1%)
☐	1	20kΩ	red black orange brown	red black black red brown
☐	1	10kΩ	brown black orange brown	brown black black red brown
☐	2	4.7kΩ	yellow violet red brown	yellow violet black brown brown
☐	1	1kΩ	brown black red brown	brown black black brown brown
☐	1	100Ω	brown black brown brown	brown black black black brown
☐	2	10Ω	brown black black brown	brown black black gold brown

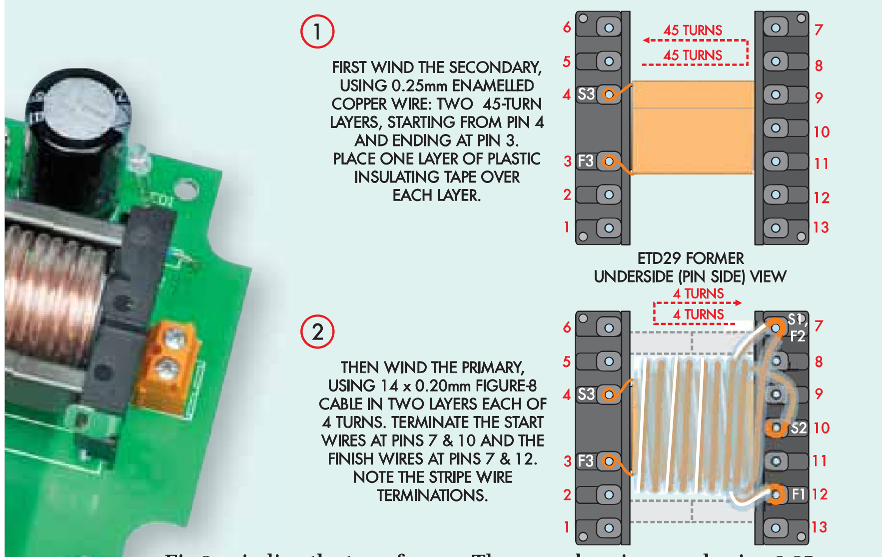


Fig.3: winding the transformer. The secondary is wound using 0.25mm enamelled copper wire, while the primary is wound using the specified figure-8 cable – see text.

uses eight turns of figure-8 14mm × 0.20mm wire, wound in two layers, to give a bifilar winding. The secondary uses 0.25mm enamelled copper wire wound in two layers of 45 turns each, with insulation tape between the two layers.

While this may seem confusing, the secondary winding is done first. To do this, first strip the enamel from one end of the 0.25mm enamelled copper wire using some fine emery paper or a hobby knife to scrape it off. Pre-tin the wire end and wrap it around pin 4 on the underside of the transformer bobbin and solder it close to the bobbin.

Now wind on 45 turns side-by-side to make the first layer. The direction of winding (whether clockwise or anticlockwise) doesn't matter. Cover this winding layer with a single layer of plastic insulation tape. Now continue winding in the same direction back across the insulation tape to complete 90 turns. Terminate the wire onto terminal 3, then cover the secondary winding in a layer of insulation tape.

The primary winding, made from the figure-8 cable, is first stripped of 10mm of insulation at one end and the two wires are soldered to the bobbin at pins 7 and 10, with the grey polarity stripe to pin 7. Now wind on four turns, making sure the wire lies flat without twists, so that the striped wire stays to the left. The four turns should fully fill the bobbin and the next four turns will be on the next layer (there's no need for insulation tape between them). Terminate the striped wire end onto pin 12 and the other wire to pin 7.

Once wound, slide the cores into the former and secure with the clips. These clips push onto the core ends and clip into lugs on the side of the bobbin.

The transformer can now be installed on the PC board. Note that its primary side has seven pins and the secondary side has six pins, so it can only go in one way. That completes the PC board assembly.

Mark out and drill the hole in the lid of the case for switch S1 – see photo on p29. When mounting the switch, make sure that it is firmly seated in the clear lid. If it tends to pop out of place, you will need to use some silicone sealant to ensure it is firmly anchored (*and waterproof*).

Software

All software program files will be available from the *EPE* website at **www.epemag.com.**

Although we do not supply pre-programmed microcontrollers, you can purchase the programmed micro featured in this project from: **parts@siliconchip.com.au**

Parts List

1 PC board, 866, available from the *EPE PCB Service*, size 104mm × 78mm
1 IP65 type ABS box with clear lid, 115mm × 90mm × 55mm (Jaycar HB6246 or equivalent)
1 50W ultrasonic transducer with 40kHz resonance (Jaycar AU5556 or equivalent)
1 ETD29 ferrite transformer (RS Components 231-8656) with 2 × 3C85 cores, a 13-pin former and 2 retaining clips (T1)
1 IP65 10A push-on/push-off switch (S1) (Jaycar SP-0758)
1 300mm length of 14 × 0.20mm figure-8 wire
1 3m length of 0.25mm enamelled copper wire
1 100mm length medium-duty hookup wire
1 3A M205 fuse
2 M205 PC fuse clips
2 2-way screw terminals with 5mm or 5.08mm pin spacing
1 8-pin IC socket
2 IP65 6.5mm cable glands
1 20MHz crystal (X1)
4 PC stakes
4 M3 × 6mm screws
2 6.4mm female spade lugs
1 20mm length 3mm-diameter heatshrink

Semiconductors
1 TL499A switch-mode controller (IC1)
1 PIC12F675-I/P programmed microcontroller (IC2)
2 RFP30N06LE MOSFETs (Q1,Q2)
2 1N4733 5.1V 1W Zener diodes (ZD1,ZD2)
2 1N5819 1A Schottky diodes (D1,D2)
1 1N4004 1A diode (D3)
1 3mm LED (LED1)

Capacitors
1 2200µF 25V low ESR elect.
2 100µF 16V low ESR elect.
1 10µF 16V electrolytic
1 100nF MKT polyester
1 10nF MKT polyester
2 22pF ceramic

Resistors (0.25W, 1%)
1 20kΩ
1 10kΩ
2 4.7kΩ
1 1kΩ
1 100Ω
2 10Ω
1 20kΩ horizontal trimpot (VR1)

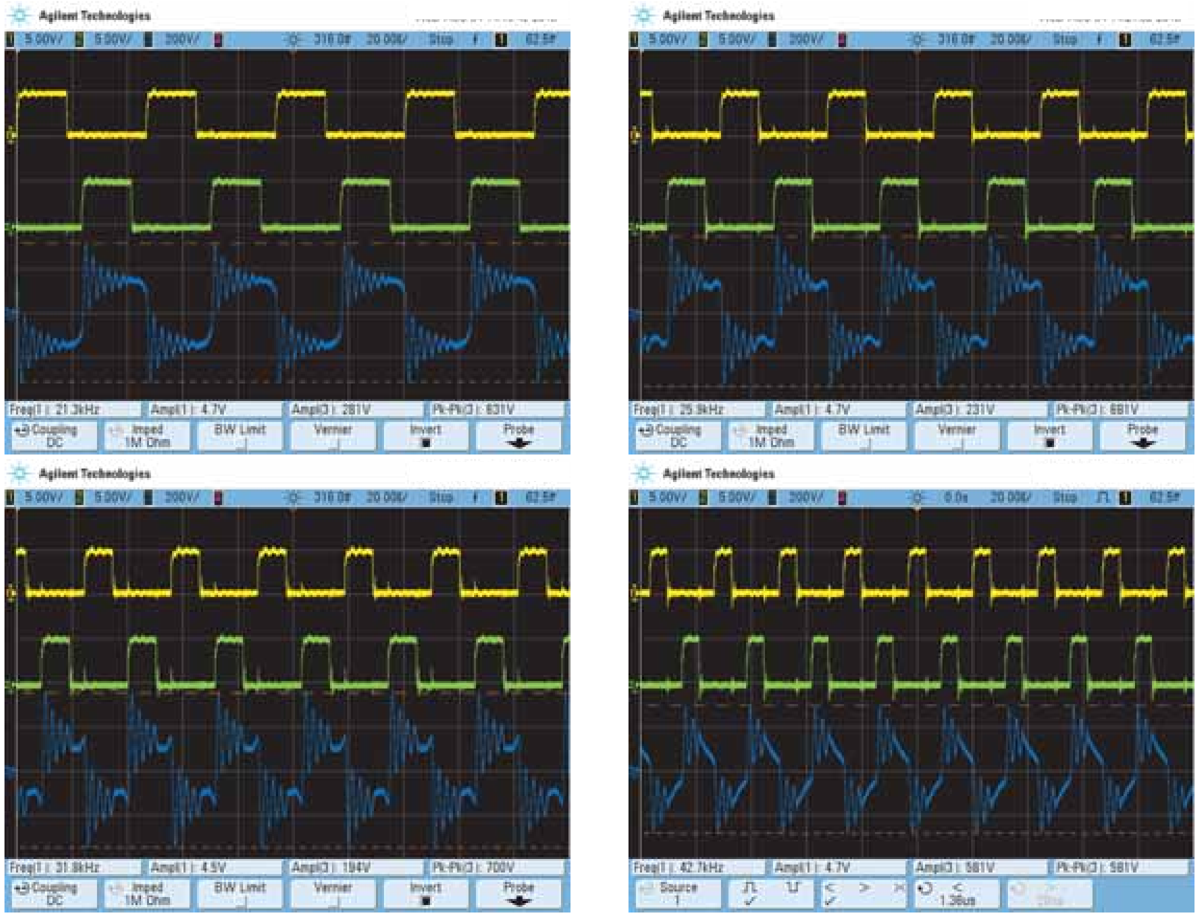
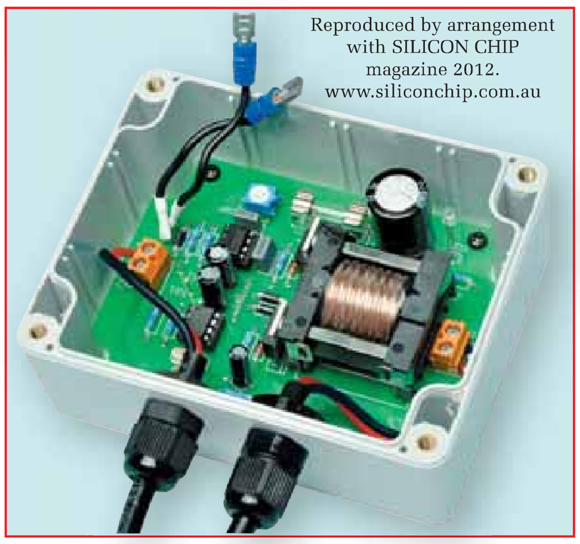


Fig.4: the yellow and the green waveforms in each of these scope grabs show the alternate gate signals for MOSFETs Q1 and Q2, while the lower (blue) trace shows the resulting high-voltage waveform in the secondary of the transformer. Four scope grabs are shown here to show the range of frequencies covered and these are varied in a pseudo-random sequence.



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Driver board mounted inside the case. Do not apply power to the completed unit unless the transducer (which must be fully encapsulated) is connected – see text.

Two holes are required in one side of the box for the power lead cable gland and for the cable to the ultrasonic transducer. These cable gland holes are located 27mm up from the bottom of the case and are positioned as shown in the photos. They are both 12mm in diameter.

Adjustment

Before going further, remove fuse F1 and check that IC2 has NOT been fitted to its socket. This ensures that no high voltages appear at the output during adjustment. That done, secure the board in the case using four M3 x 6mm machine screws into the integral supports, then connect a DMM set to read DC volts between TP1 and TP0. Apply power and adjust VR1 for a reading of 5V.

Now disconnect the power and install IC2 and the fuse. Once this has been done, do not apply power again unless the transducer is connected and then only after the latter has been fully encapsulated – see warning panel.

Next month, we will describe how to encapsulate the piezoelectric transducer in a standard high-pressure 50mm male adaptor. We will also show you how to install the finished transducer assembly and driver module in the hull of a fibreglass cruiser.