Jonathan Hare, G1EXG • j.p.hare@sussex.ac.uk

3D printing and amateur radio

A new world of possibilities: making your own plastic parts at home

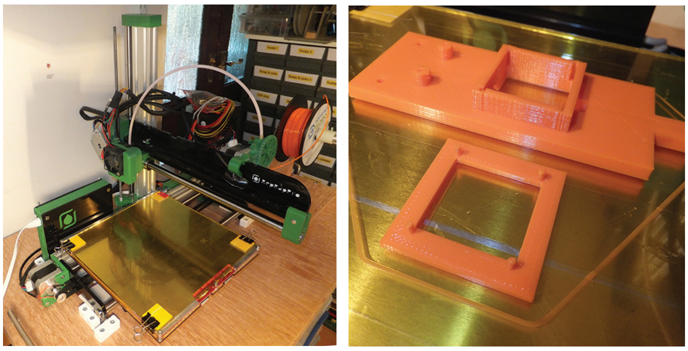

PHOTO 1: Left, the 3D printer with a reel of orange plastic filament. Right, a 3D printed object 'hot off the press'.

WHAT IS A 3D PRINTER? A 3D printer is a device that can fabricate three dimensional objects. Just as you can print an article from a PDF or document file using a standard printer, so you can 'print out' an object by sending a 3D file to a 3D printer. The printer described here uses a reel of plastic filament as the building material. Instead of printing ink on paper, it melts the filament producing a thin thread that it uses to build up, layer upon layer, the 'printed' object.

ORMEROD REP RAP PRO. There are currently many 3D printers on the market, costing from under £300 – and prices are coming down all the time. My 3D printer (**Photo 1**) is an Ormerod Rep Rap Pro [1] (supplied to me by RS Components), which came as a kit that I had to assemble, set up and calibrate. It took me about 10-12 hours to assemble the printer and a few evenings over a couple of months to properly set it up and overcome the odd technical problem, learn the software and so on [2].

WHY 3D PRINTING? Why would a 3D printer be useful? Well, **Photo 2** shows a prototype wind powered generator (anemometer) partly made from the orange 3D printed parts. The cups are connected via a four-way spreader to a threaded shaft and this is also connected to a magnet, which has the poles at the sides rather than top and bottom. There is a coil of wire around the magnet. When the wind turns the cups it spins the magnet and the rotating magnetic flux generates a current / voltage in the coil of wire.

The 3D printer allowed me to make a neat coil former around the magnet so that the wire could be as close as possible (to maximise the voltage). I could also design small sections to accommodate the rotating nuts that hold the magnet (middle image). This would be tricky and time consuming to make by hand but is easy to do on a 3D printer. I then thought it might be interesting to try a 3-cup version and simply modified the 3D software design to create a three-way spreader. I had also learnt from previous versions that this spreader often came lose on the shaft, so I now included a hexagonal countersunk hole to take a locking nut (right image). This countersunk hex hole would be quite hard to make with simple hand tools!

3D printing therefore provides a powerful way of prototyping ideas. Using the software you can easily change and modify designs, creating objects that would be hard or impossible to make using basic hand tools. If you want to try different magnets, or scale up or down in size etc, you can simply print out new versions of your ideas and perfect your projects!

HOW DOES IT WORK? Stepper motors are used to move a printing bed back and forth (along the X axis) and also drive a moving heated nozzle (Y and Z axis). A further motor supplies the heated nozzle with the plastic filament material. The hot nozzle (at about 200°C) extrudes a thin thread of plastic. The printing bed also has a built in heater (~50°C) so that the first layer of plastic will adhere to the bed, then the other layers build on this. The X and Y axis move about while printing but the Z axis only ever slowly rises as the 3D object emerges from the printing bed. An onboard microcontroller board deals with the complex task of co-ordinating the motors and heating control.

THE FILAMENT. Key to the success of the technique is to find a plastic that will melt reliably and uniformly when required to, yet will form a strong durable material when cooled. Many 3D printers use PLA or ABS plastics. PLA, polylactic acid, is a biodegradable polymer material with mechanical properties ideal for 3D printing [3]. It comes in many colours and reel lengths and is not that expensive. All the objects in this article can be printed out from one small (80m, ~250g) reel of PLA, which cost about £12 on eBay. Larger reels are even more economical (1kg costs about £20).

SOFTWARE. There are many software options for drawing 3D designs. I used *openSCAD*, which is free and an easy to learn program. It gives great control of parameters such as shape, size angle of solid parts as well as control of bolt holes size etc. Once you have designed a 3D object you can save it as a standard 3D file format, .stl (eg antenna.stl). We then open this file in a 'slicer' program that slices the 3D file into thin layers and produces the .g file (eg antenna.g) that the printer uses to create the 3D object layer-by-layer. The .g file is transferred to the printer via an SD card, then you just press 'print' on the computer-printer interface. The printer 'homes' and starts to print out your object. As the printer is controlled by the onboard electronics and SD card files it no longer needs a computer connection and you can leave it to do its job.

PRINTING OUT. I was really impressed with the quality, strength and stiffness of the

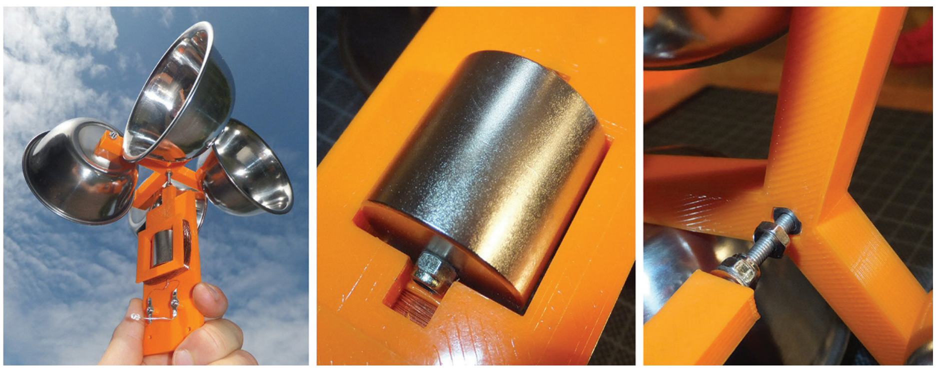

PHOTO 2: Left, a prototype 4-cup wind powered generator (anemometer). Middle, special magnet in its custom made housing and, right, the 3-cup spreader with hexagonal countersunk hole with fixing nut embedded (with another nut along the threaded shaft just about to be tightened onto it).

Jonathan Hare, G1EXG • j.p.hare@sussex.ac.uk

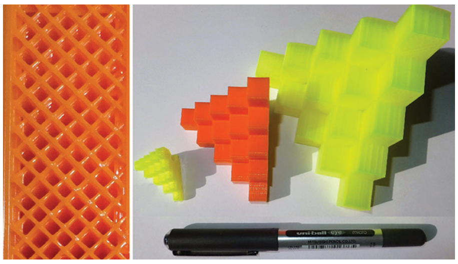

PHOTO 3: Left, the inner cross hatch fabrication in the printing process makes for economical use of the plastic filament, light weight parts with good strength. Right, a model printed at three different sizes (see text).

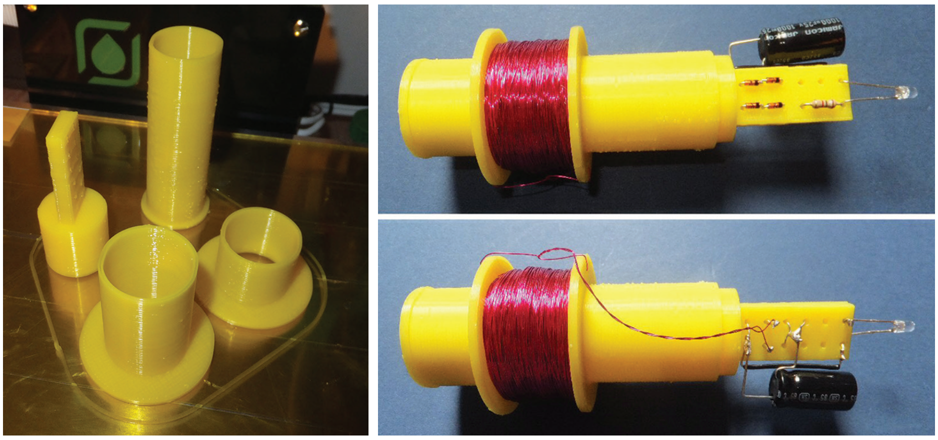

PHOTO 4: Left, four 3D printed parts for a shake-a-gen torch. Right, the completed torch.

plastic prints. Depending on the intricacies of the print you do sometimes get a few extraneous flecks of filament on the surface but these can easily be removed by hand or knife. The printer usually creates a smooth outer layer, while the inside is built up of a cross-hatch lattice work creating a very rigid, but light structure (see **Photo 3**). For example I downloaded a pyramid shaped object (from the website Thingiverse) as a test shape. I used the software to scale this by x1, x2 and x3 (ie 300%). The step size of the largest pyramid is three times that of the smallest, so it should be $(3^3)=27$ times the volume *and weight* of the smaller one. However, because it is not solid plastic it turns out to be only about 15 times heaver. The exact details will no doubt vary depending on the software and printer settings and nozzle diameter used etc. 3D printing creates low density objects using less filament than I expected, yet producing light and strong structures – ideal for making all sorts of beautiful and useful things.

Photo 4 shows a shake-a-gen device that I use in a workshop for school children to demonstrate Faraday induction (electricity generation) **[4]**. It's a coil of wire around a magnet; when you shake the device the magnet moves in and out the coil of wire, creating enough voltage to light an LED. The participants can calculate the number of turns of wire required for the coil using a basic formula and knowing the strength of the magnet etc. 35mm film cans were ideal for the workshop but these are no longer made. So recently I designed a 3D printed version, the parts of which you can see just completed on the printer bed. In the printed version I add a small prototyping area for a rectifier and capacitor storage stage and so get ongoing light after a bit of shaking. I chose magnets with a central hole in them and so I also added a hole in the base of the shake-a-gen so that a shaft could be added to connect it to an engine etc.

The 3D printer really comes into its own, not only for being able to try out different ideas, modifications and innovations, but also because I can simply print out as many as I need for the workshop. I don't have to spend too much prep time making each part myself beforehand.

DESIGNING SOMETHING 3D. Let's look at the design process so you can see how we might actually make something useful for amateur radio – a simple dipole centre. I won't go into too much technical detail (the software has clear tutorials), just concentrate on the basic ideas. **Photo 5** shows the yellow inverted V centre and the antenna feed with open wire feeder. The two dipole wires are tied to the round anchor points while the ladder line comes in to the middle via two holes. The two feeder wires part, snake in and out of the holes for grip and are then soldered to the antenna element wires.

So how would you deign this in software? To save space I haven't printed out the code here but you can download the file from my website [4] and read through the notes. To create this shape is very simple. You could start off by defining the left hand round anchor point using a 'cylinder' command. "cylinder [(h=12, r=15, $fn=30)]" will define a cylinder of height 12mm, radius 15mm and of resolution $fn = 30. If $fn = 8, say, it would produce a polygon of 8 sides, an octagon. If we use $fn = 30 we get quite a round cylinder. We use 'translate' to place this object a few cm away from the axis centre. We repeat this for the right hand anchor point, but of course place it the other side of the centre. Then we create a solid block between them using 'cube' and also a section for the rope anchor point (it sits above the centre rather than to the side). The 'difference' function in the software allows us to use the 'cube' and 'cylinder' commands to create voids rather than just solids. Using this we can create holes for the rope and dipole anchor points and the small holes for the wires. There are a whole host of other software commands you can use, as well as mathematical functions, so you can create pretty much any shape you might want. So let's look at some more possibilities: an LF/HF receiving loop, mounting brackets for a FT-817 radio and some dipole centres.

LF/HF LOOP. This is a table top receiving antenna that covers much of the LF and HF spectrum. If you are a flat-dweller or just need a small antenna to monitor the bands, this works surprisingly well. There is a nice sharp null in the pattern so you can rotate it to reduce noise. It is basically a six turn square loop (~45 x 45cm) brought into resonance by a tuning capacitor. A small single turn triangular coupling coil takes the

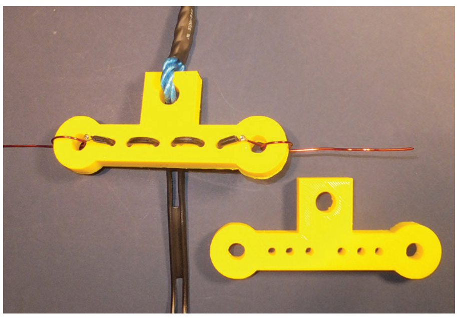

PHOTO 5: 3D printed dipole centres, shown as-made and in use.

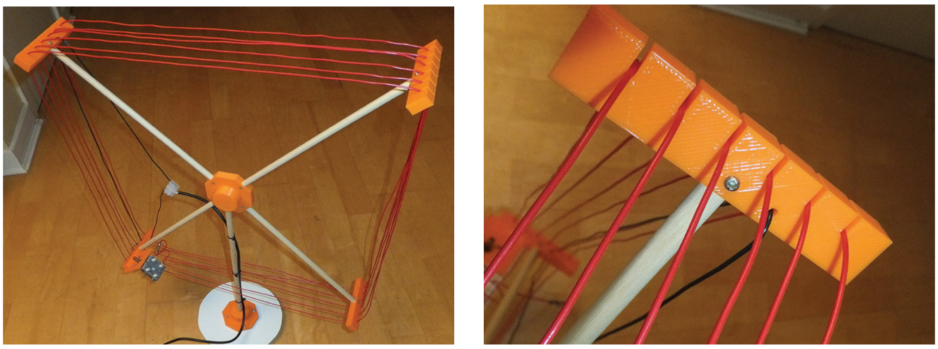

PHOTO 6: Printed components for the LF/HF receiving loop, with detail of the wire spreader.

Jonathan Hare, G1EXG • j.p.hare@sussex.ac.uk

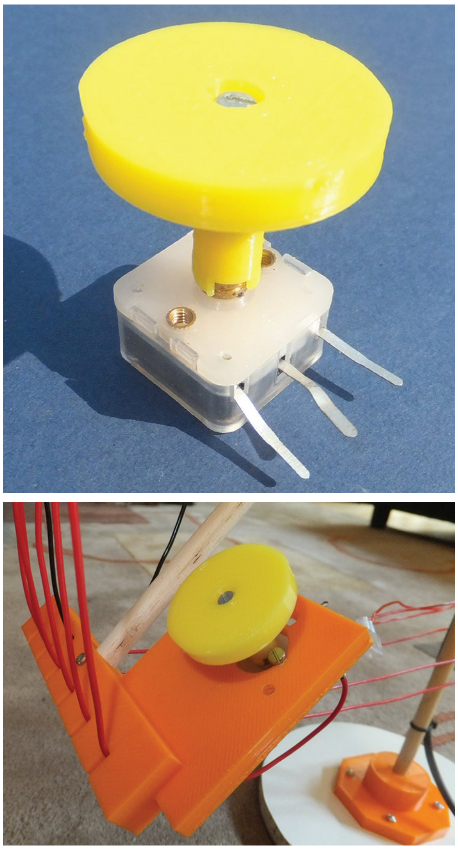

PHOTO 7: 3D printed knob for the small transistor radio type capacitor, and how the cap is mounted on the loop assembly.

signal to the receiver via standard coax. The loop covers both Top Band and 80m.

This 3D printed version consists of an octagonal base and centre piece and four spreaders to hold and space the turns of wire. One of these spreaders also includes a flat section to hold the tuning capacitor. Each spreader goes to a 300mm long dowel that slots into the centre piece. The long side of the triangular coupling coil is close to one side of the main coil; the other two sides meet close to the middle. The coax is joined via a connector block, just visible to the left of centre in **Photo 6**.

Table 1 shows the frequency that the loop covers versus number of turns of wire for two different tuning capacitors: a 500 + 500pF ('Large cap') and a small transistor radio type ('Small cap'). In both cases the two sets of vanes are connected together. It is difficult to find knobs to go on these small capacitors (they don't have the usual 6mm shaft) so I 3D printed a knob to fit – see **Photo 7**. The bolt is M2.5 x 20mm.

TABLE 1: LF/HF loop data (see text).

No of turns	Large cap f_{min}	f_{max}	Small cap f_{min}	f_{max}
6	0.9MHz	4.6MHz	1.7MHz	4.8MHz
5	1.1MHz	5.4MHz	1.9MHz	5.6MHz
4	1.2MHz	6.5MHz	6.8MHz	2.3MHz
3	1.6MHz	8.3MHz	2.9MHz	8.9MHz
2	2.2MHz	12MHz	4.0MHz	13MHz
1	3.6MHz	21MHz	6.7MHz	23MHz

FT-817 MOUNTING BRACKETS. The Yaesu FT-817 has front strap attachments but it does not have mounting holes like you might find on a larger radio. I have designed some simple fixing brackets so that you can mount the radio into a box or onto a panel etc (**Photo 8**). I have printed in orange, yellow and white to highlight the differences and show up clearly in photos, but you would probably want to print them out in black to match the radio.

There are five brackets: a front pair (orange) that slot into the radio's strap fixings, a side pair (yellow) and a small one for the rear (white). The front pair go under the radio via countersunk two screw / bolt holes. These brackets curve around the top of the radio and secure it. The side brackets have three fixing holes (also under the radio) and make sure the radio can't drift sideways. Each bracket also includes a slot near the top of the radio that can take a flat bungee or strap. A small rear bracket that goes on last and secures the radio so it can't slide out.

You could also 3D print all the brackets onto a flat base as a one-part device. I didn't, partly to save on filament and also because having separate brackets is more versatile.

DIPOLE CENTRES. The datasheets on PLA filament claim good UV stability so you should be able to make objects that go outside. Following on from the Inverted V centre, **Photo 9** shows a couple more dipole centres that might be useful for portable operation, where a bright yellow / orange colour is easy to see in long grass etc.

They will take a standard SO239 and I have included channels in the structure so that you can feed in the antenna wires from the round anchor points. The left hand version also has a larger case that could take a torodial balun, but you will have to modify the code for your particular sized toroid. The idea with these simple devices is that once these have been made they can be weatherproofed by filling with sealant.

FINAL REMARKS. I have chosen these examples because I found them to be useful and fun to make. There are of course all sorts of other possibilities for 3D printing in amateur radio including microphone holders, front panels for projects (eg PIC LCD bezels), boom supports for Yagi elements, replacing broken knobs on old equipment, custom made fittings for old / foreign parts etc. Please see my website [4] for other ideas and hints and tips.

I would like to thank RS Components for the donation of the Ormerod Printer.

WEBSEARCH

[1] https://reprappro.com/documentation/ormerod/
[2] For my short review of the Ormerod Printer: www.creative-science.org.uk/3D/JPH_Ormerod_review_2014.pdf
[3] Royal Society of Chemistry article (*The Mole*, November 2014) – www.rsc.org/eic/mole
[4] www.creative-science.org.uk (click on 3D Printing)

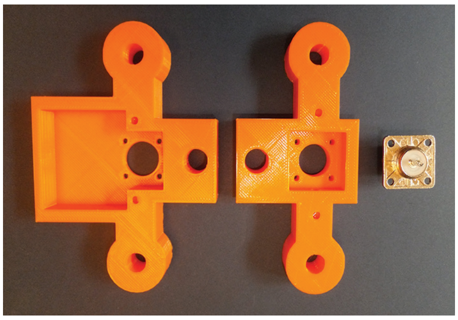

PHOTO 9: Two variants of dipole centre with space for SO239 socket.

PHOTO 8: Mounting brackets for the FT-817. A bracket is screwed to the base at the back to stop the radio sliding, and a securing strap keeps it from falling out.