

Another look at and 3D printing amateur radio

A few years ago I wrote an article on how a 3D printer might be useful to the radio amateur [1] [2]. Since then I have continued to experiment and find it a fantastic tool for quickly prototyping ideas.

Plastic objects produced via 3D printing can be surprisingly strong and can be fine-tuned for many potential applications. However these are still early days for 3D printing and it is certainly not as simple as putting a piece of paper into a standard printer! So, as a follow-up, I want to describe some more things you can do with a 3D printer and some hints and tips to get the best 3D prints.

If you search the internet for 3D printed objects you will see some very beautiful and most unusual things. I can't say I am being very 'arty' in the way I use my 3D printer. For me it is all about making useful devices to help me prototype interesting ideas and to experiment [2]. It's on this basis that I feel 3D printing offers the radio amateur an outstandingly useful creative tool.

Fast and efficient prototyping

With a 3D printer you can make all sorts of useful things. Take for example the Hytera hand-

held holder shown in **Photo 1**. Let's say our first attempt at printing came out just a little too big. With standard materials you would have to go back in to the workshop and carefully make another holder from scratch, just slightly smaller. With a 3D printer all you have to do is adjust the scale factor: changing this from 1.0 to say 0.98 (ie from 100% to 98%), everything will then be reduced in size accordingly. Of course, you might only want to adjust only the height, leaving everything else the same. In this case you would simply only scale that length dimension. Further to this, once you are happy with the design it's easy to print out many identical items!

A brief summary and overview

A 3D printer creates objects by extruding a thin plastic filament (vaguely like thick fishing line) from a hot nozzle, building up the desired structure thin layer by thin layer on a moving printer bed. The combination of the bed movement (X and Y axes) and the nozzle movement (Z direction) creates 3D objects. (Variations on this are possible, for example moving the bed in the X axis and the print head in Y and Z).

There are many software packages that you can use to design objects for your 3D printer. Websites such as 'Thingiverse' hold thousands of 3D files that you can download to print out on a 3D printer (see the cog example next month).

There is not space here to go into these but my previous *RadCom* article [1] has some notes



PHOTO 1: Part of a simple 3D printed project: a holder for a hand-held radio. The 3D model is on the left and the finished item in use on the right.

and there is a page on my website that has a brief outline of how to get started using OpenSCAD.

In summary, the process from going to an idea to an actual printed object is like this:

- Create your object using 3D design software (eg OpenSCAD, which is free). So for example if you were making a dipole centre insulator you design it and then save it as 'dipole.scad'.
- Export your design as a standard STL format file, eg dipole.stl
- Transfer the file to software that converts the 3D file into a series of layers that the 3D printer can print out (eg the free program Slic3R). These are then saved in a '.g' file format that the 3D printer can use, eg dipole.g



PHOTO 2: Surfaces of 3D printed objects often have a characteristic 'roughness' that can act like a grip.

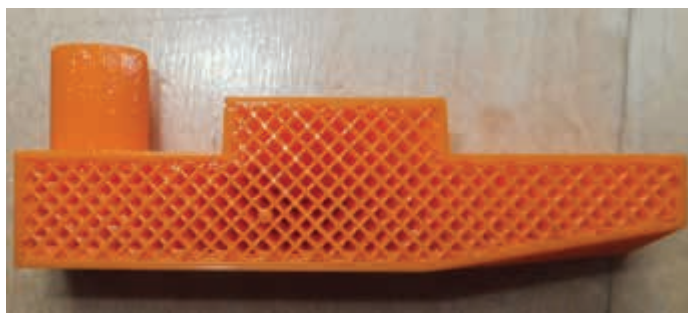


PHOTO 3: Example of the honeycomb structure used to save time, weight and filament, with little strength penalty. Solid fill can also be selected.

- Turn on the 3D printer, check it has enough filament to print your job (usually done by weight) and load up the .g file. Then use the control software that came with the 3D printer (I use Pronterface, which is free), select the file (eg dipole.g) and simply press or click 'PRINT'.

3D printer kits v ready made

My 3D printer, a RepRap Ormerod (a rather old model now), was built from a kit. A ready-made printer can get you going straight away but the advantage of a kit is you get a much better idea of how the printer actually works. You will also be in a much better position to fix faults (which happen surprisingly often) and to fine-tune the device. Kits are usually cheaper too, so they provide an economical way of getting into 3D printing and learning about this fascinating topic.

Recent 3D printers can come with more than one printing head nozzle, so you can print in more than one colour or type of material etc. Printer head nozzles can also come in different sizes; small ones for fine work, larger ones for less delicate printing. It can be very useful to have a selection on hand; they're not too expensive.

There are many 3D printers available, some at very reasonable prices. It's worth doing a bit of research noting the feedback and comments that people make about each one. For example the Anet A6 HomeLab 3D Printer (Kit) shown on the *Elektor* website looks good value.

Whatever printer you decide to buy it's worth checking it can use standard filament reels and not only very expensive specially designed filament cassettes with a built-in chip. Remember those cheap inkjet printers that needed four £25 ink cartridges that only printed a few pages before they needed replacing...?

The ups and down of a 3D printer

My 3D printer has had many faults and breakages over the years but so far I have always got the device working again with a bit of trial, error and patience. So far I have replaced, or mended the nozzle, printer bed, filament drive cogs (the RepRap is provided with 3D files for many of the

parts of the printer so you can use your printer to print parts for your printer!), drive motors and more. Being a kit, these essential mods have been easier to do than if the printer had been a ready-made device.

My printer can be networked and run from a web interface. This means I can download files to 3D print directly from my PC, laptop, iPad and even a mobile phone. However, one day it stopped working and I thought that was the end of my printer. But it appears that the simple Arduino microcontroller board that drives the printer motors etc may have been hacked into by someone. So now I use it offline via a USB port with an old laptop driving it. Many 3D printers have SD card sockets so you can physically transfer files, greatly reducing the opportunity for outside interference.

Are filaments all the same?

3D printing filaments vary in length, size (ie diameter; I use 1.75mm), quality, finish and of course length. I have brought filaments from many different manufacturers and only had one or two problems. A quick search on eBay or Amazon will bring up hundreds of sellers for PLA (polylactic acid, a biodegradable thermoplastic) and ABS (Acrylonitrile Butadiene Styrene) 3D printer filament, some vendors being very good value. I have found the quality varies though. As a 3D printer prints layer by layer, a pattern is created on the surface of the printed objects. Some filaments produce a more pronounced layering effect than others. Often this creates a sort of 'grip' type effect (see **Photo 2**), which is not unpleasant and often does not spoil the usefulness of the object. Other times it just looks *wrong*. In this case you might try a few different manufacturers' filaments to see which produces the best effect for your project(s).

In the last few years many new filament material types have become available including composite types. For example, very flexible filament materials are available for printing parts that need to move a bit. I also have carbon-loaded filaments that are slightly conducting, as well as glow-in-the-dark materials – perhaps useful for antenna insulators when taking down portable setups at night!

Getting the best possible print

The first layer is critical. In use, the 3D printer bed will typically heat up to about 50°C, before the nozzle heats up (~200°C for PLA) and, only when they are both at the correct temperature, the printing starts. In most cases the 3D printer will start off by printing a border and then the first layer, which will be slightly larger (thicker) than the rest to make sure there is good adhesion to the printer bed. This first layer is crucial: if it does not attach itself strongly, the print will probably fail at some point during the printing process. Remember, the printer can only print on a previous layer – it cannot print out into open air – so if the first layer fails and the printed object comes off the printer bed, the nozzle won't have anything to print onto and the filament extruding from the nozzle will create a nasty mess. "Spaghetti and meatballs" is one picturesque description of the result.

Sometimes when printing out large objects I find the corners rise up. Essentially, part of the first layer becomes unstuck and rises up above the current height of the printed layer. What can happen then is that these parts of the print build up higher than they should do. This results in a distorted print or worse: the printer nozzle may actually collide at some point with the object and knock it off the printer bed. If you spot what's going on early you can cancel the job and start again but if you have left the printer going while you are away you will come back to a horrible mess! The nozzle, being unaware that the object has been knocked off, continues printing filament into thin air, which usually folds back up and you very soon get a golf ball sized blob forming on the nozzle.

Many 3D printers use a glass sheet to print on (sometimes metal or fibreglass). You can print directly onto the printer bed but you may find that some filaments won't always stick to the glass. Many people use masking tape on top of the glass printer bed to help adhesion. You can also use Kapton tape over the glass. This is a very thin film layer that has good thermal conductivity,

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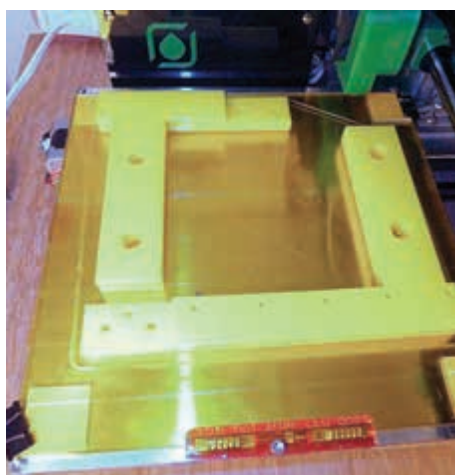


PHOTO 4: Large objects can be printed in several pieces and fitted together later.

high temperature stability (it was used on the *Eagle* spacecraft that landed on the Moon) and the filament can readily stick to it. Kapton tape can be brought in 'insulation tape' type sized reels, in which case you cover the printer bed in strips. I recently brought a 200mm wide reel that can go over the whole of my printer bed in one go.

For really awkward filament that won't seem to stick, you can coat the printer bed in a thin layer of watered-down PVA glue (allow it to dry before printing). After printing you can remove the printer bed, put it in the sink and use warm water to dissolve the glue, which will let you remove the 3D printed object. Overall, the best way to make sure you get good adhesion is to make sure the printer bed is very clean when you use it. I use a spray cleaner (eg AeroKlean 50) that is a pure solvent and leaves no residue. For best results you need to clean the printer bed *each* time you use it.

Removing the object from the bed

Once you have successfully printed an object you have to get it off the printer bed. Often this involved carefully levering it off the surface (make sure it's cooled down properly first). I have recently learned of some innovations to help this process, such as for example a thin spring steel sheet on top of the printer bed. After printing you simply slide off the metal sheet and object and then simply bend the sheet to release the 3D printed item.

Honeycomb centre

The Slic3r program default is often set up to create a honeycomb inside the 3D printed object, as exemplified in **Photo 3**. This saves filament plastic and creates lighter objects that are still very strong. From an amateur radio perspective this might or might not be a good thing. The dipole centre in my 40m inverted-V has been up for four years and has not shown any signs of mechanical failure. However, it was printed using the honeycomb default and recently I wonder if water has crept in over the years. If so it would take time for sunshine

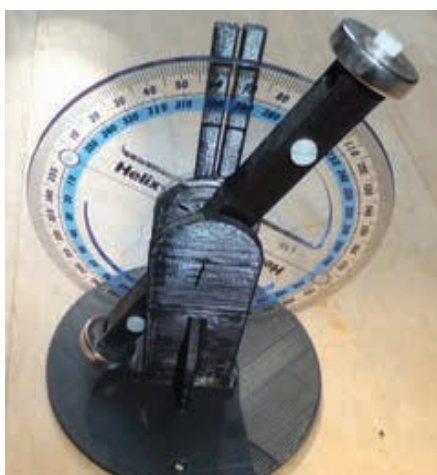


PHOTO 5: The arm of this magnetic field dip meter originally printed lop-sided (see text).

to evaporate the water and in winter might not go away at all, possibly freezing (and expanding, causing damage). You can normally change the software settings from 'honeycomb' to 'full' printing so that the printer will print fully solid objects.

Size of object

You obviously can't print an object larger than your printer bed. My machine has a standard bed of about 200 x 200mm. You could, in principle, print a maximum size object of about a 20cm cube but in reality you need to make sure the nozzle does not catch on the clips that hold the printer bed in place (you can just see these on the left of **Photo 4**). Large objects take a long time to print and if anything goes wrong you will have to start all over again, so it's better to print them out in parts and then join them together. **Photo 4** shows the backbone of a 23cm double-quad reflector antenna that I built this way. RF absorption properties of the plastic filament will be discussed next month.

Accuracy and hole sizes

If you design something to a specific size using the 3D software it will come out spot-on when 3D printed. It's particularly satisfying to print out a number of different parts on a 3D printer that when you assemble them they all line up perfectly.

However, although hole *positions* come out properly, the actual *size* of the holes may not be as expected. In one project I wanted to use four M3 bolts to fix a SO239 socket. If you design these in the software as 3mm diameter (1.5mm radius) holes then you'll find the M3 bolts won't fit! This is because the nozzle prints with a thin, but not infinitely thin, thread of plastic. Also the software builds up the edge, or side of a 3D printed object and this includes channels and tubes, like the bolt holes. Unlike the *position* of the hole, you need to make the size of the bolt holes a touch larger than in real life. I found that making the hole radius 0.25mm larger than nominal worked. So for M3

bolt we need holes 1.75mm instead of 1.50mm in radius. The exact increase will depend on the printer, the filament and the type of printer nozzle you are using, so you might have to experiment a bit. As a test, I made up a template with 1, 1.5, 2, 2.5 and so on up to 10mm holes, then measured what they actually came out as when 3D printed.

You could use the printed holes as pilot holes and drill them out, but I don't recommend it. This can work, as long as you are not removing too much material, otherwise you may expose the honeycomb of the 3D print. This will cause the structure to lose a lot of strength. I suggest you use the next-nearest-smaller hole size and then, if you have to, drill out the very minimal amount to get the perfect fit.

Avoiding lopsided prints

In one physics demo prototype I made (a magnetic field dip meter, see **Photo 5**) I printed out a balance arm about 100mm long with a 5 x 5mm cross sectional area. I included a small hole at the exact centre where a fine needle passed through to create an axis (or fulcrum). When I tested the arm I found it didn't balance at all: it always fell down to one side. Why? The problem was that the printing bed was not set up correctly. It was not quite perpendicular to the three print axes, so when it printed the 100mm arm it produced one end slightly fatter than the other. You might not notice this problem most of the time and I expect it often gets overlooked but on a sensitive balance arm it meant one side was heavier than the other, so of course it would not balance! One simple way around this is to simply save a new version of the file rotated by 90°, creating a much smaller error because it's across the width of the arm rather than its length. I tried this and it worked. On close inspection you can just about see that the arm is not quite square but because it is now symmetrical about the axis it balances OK.

A better way to solve the issue is to properly set up the printer bed so that everything is as square as possible. With my 3D printer this involves a mechanical adjustment followed by a software calibration (discussed next month) to account for the last tiny adjustment that's not possible by hand. In this example I had moved the printer prior to making that particular print and I must have knocked the arm so its adjustment had got out of alignment – you need to keep an eye on this from time to time even if you don't move your printer, as adjustments can drift over time.

Next month

We conclude this article with a look at some of the finer hints and tips for 3D printing.

Websearch

- [1] 3D printing & amateur radio: *RadCom*, Dec 2014
- [2] www.creative-science.org.uk/3D.html