

Another look at 3D printing and amateur radio part II

G-codes and print compensation

For my RepRap 3D printer there is an array of commands you can send to the printer to get it to do different jobs. These are known as G-codes, hence the file name. In fact, the .g files themselves are really just a list of these commands, one after the other. One useful G-code command is 'G32'. You can type this into the printer control software before printing an object: it will cause the printer to scan across the bed and measure any sloping or compensation that needs to be made. The result is that the printer will calibrate itself and your prints will come out better. You can search for wiki pages for more details about G-codes.

How strong are 3D printed parts?

I printed out a cylindrical box to take a matching coil for a vertical antenna, seen in **Photo 6**. This worked well and I was amazed at the strength of the 3D print: it almost feels that there must be a metal cylinder inside the plastic. Of course, a cylinder is a very strong structure and not all 3D printed parts are so strong. You can, however, make objects stronger by carefully considering how you print them out on the printer bed.

The printer creates objects by printing layer-on-layer. 3D printed objects therefore have a fine 'grain' going through them (a bit like the way plywood is made of layers of wood). If you are printing out an object that has a sharp bend in it, these areas could be weak spots as they might fail along one of these grain lines.

Photo 7 shows a small bracket I designed that has a lug to clip onto something. I printed it in two different orientations, side by side, as seen in **Photo 7**, so I could assess the effect of grain. The version on the left is much weaker than the one on the right. This is because when you bend the bracket it will tend to separate – peel, if you like – between layers and the lug in particular is prone to snap off. But in the right hand one the print is continuous along the length and much stronger. Only the holes might be a weak point: a screw that was oversized could force the layers apart. Part of the skill in designing objects for the 3D printer is to know how best to arrange them when it's time to print them out.

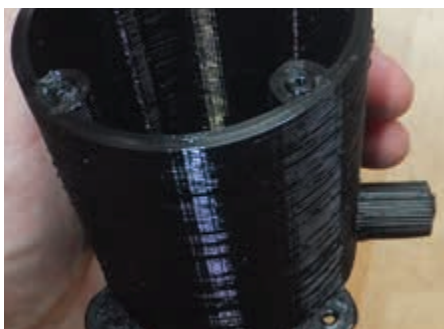


PHOTO 6: 3D printed former for an antenna matching coil.

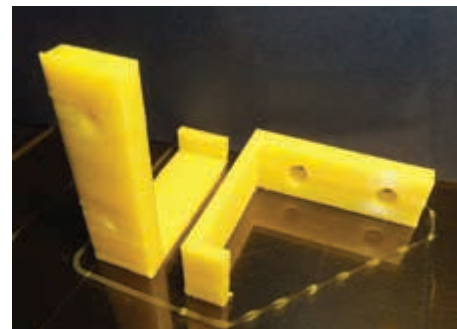


PHOTO 7: The bracket on the right is stronger because of the print layer orientation.

In this particular example there is not much strain on the bracket as it simply holds a lightweight radio in one place. If you use good quality filament it may be OK whichever way you print it. However, something requiring greater strength, for example the centre of a wire dipole that would be under stress from the weight of the wires and varying as the wind blows, it is worth choosing the print direction so that the strain will go along the print grain rather than across the grain.

23cm work and absorption

I designed a collinear array for 23cm, seen in **Photo 8**. I supported the dipoles at the voltage minimum so that the insulators would have minimal effect. However, it would be best if the plastic filament had low absorption at these frequencies. You can quickly check by putting a printed item in a microwave oven for 10-12 seconds to see if there is any warming or distortion (Note that it's a good idea also to include a half-filled cup of water opposite the part under test so that the oven is guaranteed to have some sort of load). Obviously, for RF applications you should use filament that does not get warm (or hot).

Blips and defects in printing

Sometimes small spots or blips of plastic occur on what should otherwise be a smooth surface. **Photo 9** is a good example, where I was printing out multiple copies of the 23cm antenna dipole support. You can (just) see the normal ridges, or layering, but you can

also see small spherical blips at odd places along the printed cylinder. These unwanted artefacts appear due to the way the printer goes around each time it prints a layer and can be a particular problem when you want to print out multiple copies of an object. When the printer moves from one spot on the printer bed to another (ie when going from one printed object to another) the nozzle must briefly retract the filament to stop a fine thread being created between the two places. If it is a bit slow in doing this, or does not retract enough, it tends to create fine 'wires' and blobs on the surface of the prints. The Slic3r software allows this filament retention time to be adjusted and it may be necessary to experiment to find the optimum result for a particular fibre or design.

Fan cooling

If you are printing out long thin prints, like the insulation posts in the collinear array, they can become bucked and distorted. The problem is the hot layer of plastic deposited for each layer does not have time to cool properly and fully solidify before the next layer is deposited. I was recently printing out bird heads for a Brighton Science Festival 'Angry Gull' workshop (used to demonstrate forces and accelerations by gull poo trajectories!) but found the long beak would not print properly. As it's a small diameter, the printer tries to print successive layers before they have time to cool adequately. The next layer of course just adds more heat into the already hot plastic. The result is that as the beak prints out it is far too hot and does not solidify properly, but wobbles around as the



PHOTO 8: 23cm collinear array of dipoles mounted above a reflecting metal mesh using $\frac{1}{4}\lambda$ -high 3D printed supports.

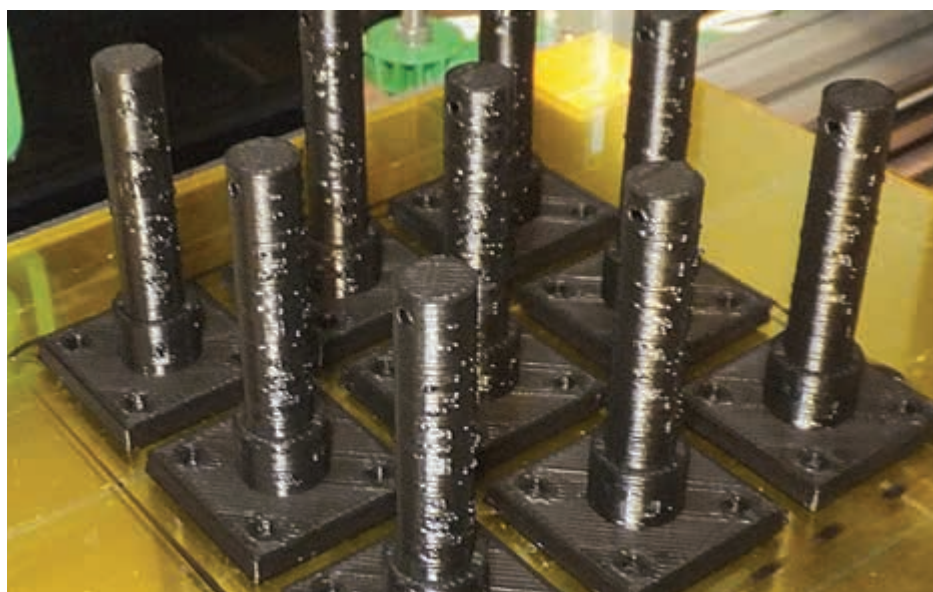


PHOTO 9: Small-scale mass production is easy with 3D printing, but if the printer isn't adjusted properly the surface finish may suffer.

printing nozzle tries to build up the remaining layers. The resultant printout quality is terrible, as seen on the left of **Photo 10**.

This kind of problem can be solved by placing a fan (or two) near to the part that needs extra cooling, as seen in **Photo 11**. PLA becomes hard just a few tens of degrees below the melting point so even a little cooling can help. The print on the right of Photo 10 was made with the assistance of fan cooling. You need to make sure that neither the fans or anything else will foul the moving parts of the printer, of course. This is an example of the advantage of a 3D printer kit; a ready made printer might be more difficult to modify.

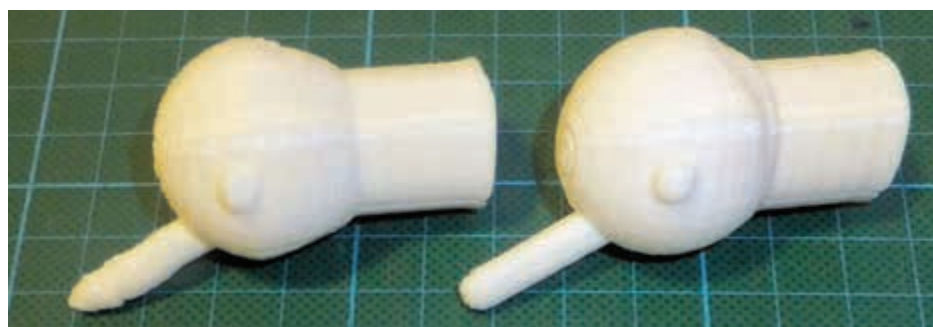


PHOTO 10: The item on the right was printed with cooling air blown over it, preventing the heat-related distortions on the left example.

Gluing

Because the 3D printed pieces are made from hot solidified plastic, the parts are very clean. They glue very well using plastic glue or cyanoacrylate superglues. This can be useful if you need to join 3D printed parts. Even if your design includes interlocking lugs, a little touch of suitable glue can make the joint completely secure. A mix of superglue and talc will fill small gaps. Always wear gloves!

Boxes and enclosures

A 3D printer is great for making bespoke boxes and enclosures. If you are running an event for a group it's easy to use the printer to make many identical boxes that are perfect for your projects. Also if the box gets knocked, broken or dirty with use you can simply reprint a copy. If over time you change the project in some way you can redesign the box to incorporate the modifications.

Photo 12 shows an example – a terminal box for an experimental 5-element ZL special antenna. The box keeps the phasing network and capacitor dry while also providing the correct spacing and support for the two folded dipoles. The design includes self-tap screw holes to lock the folded dipole wire in place, securing and setting the correct spacing etc.

Templates

As mentioned, the 3D printer has a very good accuracy for printing out awkward or even regular shapes, for example the cog in **Photo 13**. It's also easy to design accurate hole placements in software and then print out a flat 'template'. The marker holes will be perfectly aligned using the printer. I have a page on my website that shows the sort of things you can quickly fabricate that can save a lot of time when marking up cases prior to drilling etc. Templates include details for BNC, N-type and SO239 sockets, IF coil pin positions, small panel meters and LCD bezel display etc.

Gears and cogs

It's useful to design and print out cogs and gears on a 3D printer to make all sorts of interesting machines (eg perhaps for parts for rotator controller dial or turning a small receiving loop antenna). This includes making replacement gears for the 3D printer that will print the gears! Gears are much more than just a circle with a lot of square teeth. If you study the way the teeth move and interact with each other as they turn you can see that the sharp corners of a square tooth would dig into side of the meshing cog causing wear, noise and inefficiency. The sides of the teeth are therefore curved, providing a very smooth interaction and less wear. There are number of carefully developed gear tooth shapes including the involute gear seen in Photo 13. These are all fairly easy to produce on a 3D printer.

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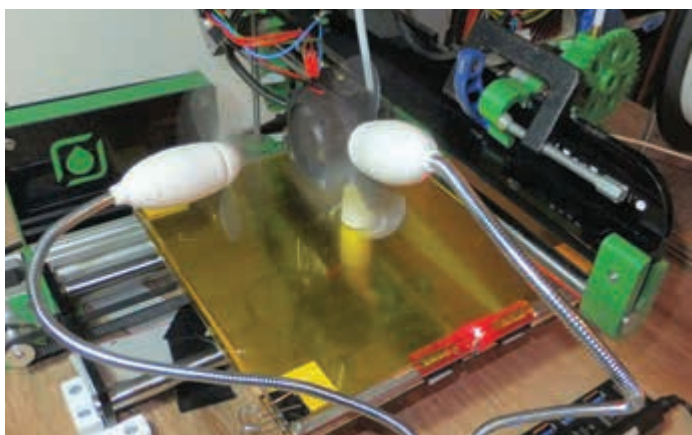


PHOTO 11: Fans positioned near the object provide localised cooling to ensure good print quality.



PHOTO 12: A 3D printed case (here with lid off) protects the matching components and firmly holds the driven elements of this ZL Special.

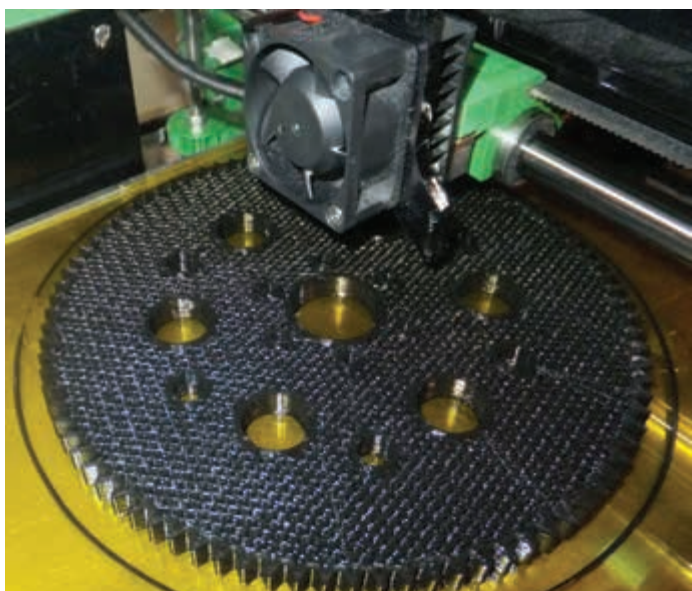


PHOTO 13: An involute gear is a complex shape but, correctly designed in CAD, is an easy object for the 3D printer.

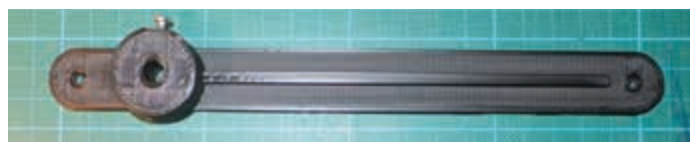


PHOTO 14: A long-arm knob for a high-Q loop antenna's tuning capacitor shaft to increase accuracy and reduce hand-effect.

Some important parameters for a cog include the thickness of the gear, number of teeth per mm, shape of the gear tooth and so on. Thingiverse [3] has examples of involute gears including OpenScad files that you can modify to make cogs and gears to your own spec. I am currently experimenting with a homemade lightweight 3D printed 12V rotator (using the cog shown, plus other smaller drive cogs) to turn a small 23cm antenna on top of an unguied mast, which means the rotator and antenna need to be a light as possible.

Just imagine...

The uses for 3D printing are very wide, particularly for one-off requirements. Photo 14 shows an extension arm I made for the tuning capacitor on a high-Q loop antenna: not only does this reduce hand-effect detuning, it also allows higher precision setting than a standard round knob (and also provides a degree of electrical insulation, at least when dry).

Professional and industrial 3D printing [5] can be done in many materials beside just plastics, such as ceramics, metals (including gold, stainless steel and titanium), rubber, chocolate, clay and even paper. Different techniques are used, not just filaments, but all of the techniques broadly come under the heading of 'additive manufacturing' – a field that is growing fast.

Michelangelo was allegedly once asked how hard it had been to create one of his most famous works, the huge statue of David. "It was easy", he said. "I just took a big lump of stone and chipped off all the bits that *didn't* look like David". Nowadays you can download a high resolution 3D model of his statue [6] and print your own, at any size you like, without having to worry about getting rid of all the left-over rubble. That's progress for you.

Maintenance and health & safety

A 3D printer is a complex and precision device and needs regular maintenance and attention to provide constantly good quality prints. Once a month or so you really need to check the printer bed alignment and remember to oil all the bearings etc. Dust, rust and dirt are all enemies of the 3D printer so I use dust sheets to cover it all up when not in use. Over the years I have used my 3D printer for my Creative Science Centre at Sussex University and the Brighton Science Festival, printing out hundreds of projects.

I always recommend you use a 3D printer in a well-ventilated space. I keep mine in my garage, as I felt it wasn't too healthy to be melting lots of plastic in the house. Some sources [4] suggest that 3D printing can emit ultrafine particles and volatile organic compounds (VOCs) and in any case one must take account of the hot surfaces and the potential for a 3D printer to be endlessly fascinating to inquisitive pet cats.

Thanks

I would like to thank Phil, G4UDU, Gordon, M00TA, John, 2E0JXX and Chris, MOVUE for inspiring project ideas, RS Components and Dr Adrian Bowyer from RepRapPro tech support.

Websearch

- [3] www.thingiverse.com/thing:41246
- [4] https://en.wikipedia.org/wiki/3D_printing
- [5] https://en.wikipedia.org/wiki/3D_printing_processes
- [6] <https://tinyurl.com/RC-1019-David>