A Hotplate for microwave PCB assembly
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Abstract

This presentation will describe a simple hotplate for use when assembling circuits with SMD components. The hotplate is used to raise the base temperature of the entire assembly, enabling a low wattage soldering tool to be used. A method of bonding microwave PTFE substrates to copper sheet will also be described – this method is due to Luis, CT1DMK. Improved grounding of the circuits is obtained, in addition to giving mechanical stability to the PCB.

Introduction - Why a Hotplate?

Initially my need arose as a result of using a construction technique recommended by Luis, CT1DMK, for building microwave PCB assemblies – in this case a 2 stage 3cm preamp. The PCB was 10 thou PTFE, and the intended housing was a milled aluminium box, with an integral waveguide input. An immediately obvious problem was how to mount the thin PTFE board flush to the bottom of the box once I had made the through ground connections using rivets or wires? After the exchange of a few e-mails with Luis, he outlined a construction technique which solved this problem completely – he briefly makes reference to this method in his originals article on the 24GHz modules [1], but does not give any detail in that publication.

Following this technique, I discovered another problem, for which the hotplate was the solution. Since building the hotplate, some other potential applications for it in the shack have also been recognised.

CT1DMK method for PCB fabrication

Microwave PCBs are still mainly on PTFE substrate materials for amateur applications, although a few companies who serve the amateur microwave market are moving to more 'exotic' ceramic loaded substrates for a variety of reasons – one of them being the mechanical stability of the substrate, probably one of the major disadvantages of PTFE. But for most of us, particularly those who produce their own PCB's, PTFE is likely to be around for some time to come – at least it is available as surplus on occasions!

However, the poor mechanical stability does mean that care must be taken in the handling and mounting of assembled circuits, especially when using SMD components, as hairline cracks can be caused, which will not be visible, but will prevent the circuit from operating correctly. Another problem that is difficult to overcome is good quality grounding – of course we use 'through' rivets or wires to provide the ground, as it is not practical to have 'kitchen table' through hole plating lines for the average microwave amateur! Such connections give acceptable grounding at lower microwave frequencies, but at 3cm and above they are becoming increasingly inefficient. A side effect of these grounding methods is that the ground plane side of the PCB is not perfectly flat – which creates difficulties if the board is to be mounted into a milled aluminium box, such as those available from MicroMechanik [2]

By bonding the PTFE PCB to a thin sheet of copper, both of these disadvantages can be overcome.

Preparing the PCB

Before bonding the board, all ground and through holes (eg for mounting to the box) must be made. Don't drill PTFE – punch it! PTFE based boards do not drill cleanly, with strands of material left, and trying to clean these up can result in further damage to the PCB – punching leaves a clean hole, with no such problems.

First make your punch…

Typically 1.5 or 2mm is a good size – and where do you get this from? If you can get a leather-workers punch in a 1.5 or 2mm dia size, this will work excellently on PTFE board. Otherwise, the next time you have a damaged telescopic antenna, don't throw it away! From the top section (or the next one down) you will find the material for the punch – sometimes you will find that the top section is not hollow.

Take a short length of the tube, say 7 or 8 cm, and with a tapered round needle file shape one end to a knife edge all round – to do this you will need to work at the inside and outside of the tube – work as much as possible on the inside – see Fig 1, which shows a cross sectional view of the finished punching tool.

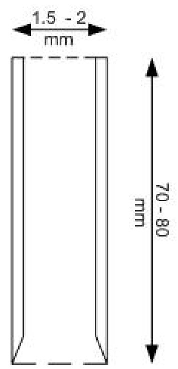

Fig 1 Cross sectional diagram of the punching tool

..then find a support..

To get a good clean punched hole, the support under the board is as important as the punch itself. Do not use soft wood, such as pine, as the work support – it's fine to place under sheet metal when drilling, but the PTFE board is too soft, and you will get a deformation of the board on the underside, as in Fig 2.

You need a firm support, either a piece of good quality hardwood, with a very fine grain, or even better a piece of smooth plastic faced board, such as an offcut from a kitchen worktop.

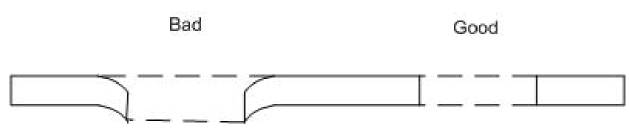

Fig 2 – Correctly and incorrectly punched holes sections

..and hit it hard!

Place the PFTE PCB on the support and place the punch in position – one good sharp hit with a hammer should cut cleanly through – if not a second hit will clear the hole. Because of the firm support you will probably find that you will need to re-shape the knife edge on the punch after every few holes. You will probably also find that the punch itself will gradually bend with use, and will need to be replaced every so often!

At the end of the punching process you should have opened up every grounding hole (for each of the decoupling capacitors, source leads of FETs and any resistors that go to ground) and the mounting holes. Refer to Fig 3. Make sure that they are all done, as punching will not work once the PCB is bonded to the copper sheet!

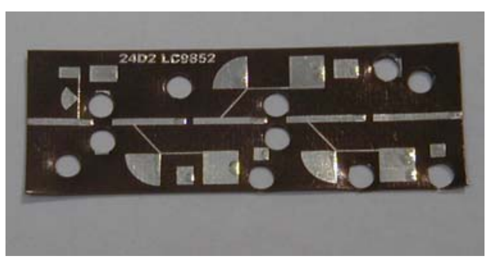

Fig 3 – Picture of punched PCB

Preparing the copper sheet

Use a thin sheet – typically 0.5 to 0.7 mm is fine for most 10G and 24G LNA's mixers etc. Cut the sheet slightly oversize for the PCB and ensure that it is perfectly flat, with no burrs. Clean the side to be bonded thoroughly, finishing with very fine plumbers wire wool (Stahlwolle) in 00 grade or finer to ensure a clean, grease free surface right to the edges of the sheet – do not touch the surface with you fingers once cleaned.

Bonding the sheet and PCB

Coat the cleaned and polished surface of the sheet with soldering flux (Loetfett) and place it on a flat surface that is heat resistant – a smooth faced brick or a piece of wood will do. Using a hot air gun, bring the whole plate up in temperature –as the flux melts it will evaporate and you can apply solder – build up a pool of molten solder on the sheet. Use too much solder, rather than too little – any excess will be squeezed out of the assembly anyway. As you get to this stage you can also place the prepared PCB, ground side upwards, in the hot air stream to bring it closer to the temperature of the molten solder.

Using tongs or pliers, place the PCB onto the molten solder aligning it as well as you can – the surface tension of the molten solder will tend to pull the PCB into place provided it is placed closely to start with. Remove the air stream and place a piece of smooth wood carefully on top and apply pressure until the assembly temperature has fallen enough for the solder to solidify. This pressure will force the molten solder up through the holes and out of the edges of the assembly. Fig 4 shows a bonded PCB/sheet before the clean up- operation.

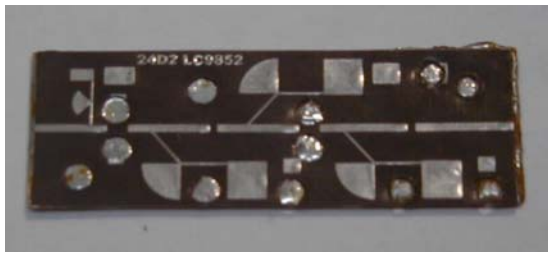

Fig 4 – Bonded PCB prior to cleaning up

Use a fine file to clean up the edges of the assembly and to trim it back to the final size – this is most easily done by holding the file in the vice and moving the work piece by hand. Placing the PTFE board in a vice may cause damage to the PTFE unless great care is taken. Surplus flux can be removed by washing the assembly in spirit alcohol.

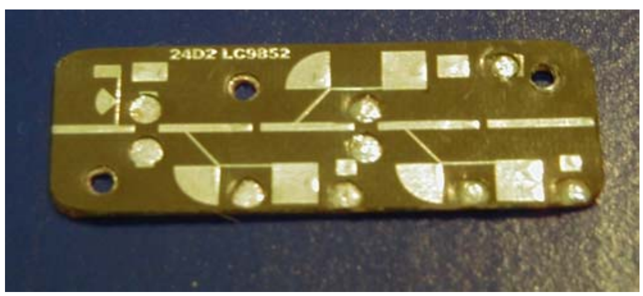

Fig 5 – Completed PCB assembly, ready for components

Finally open up any holes required through the copper sheet, eg for fixing the assembly to the box – Fig 5 shows the completed PCB assembly, ready for the mounting of components. Once all filing, cutting and drilling has been completed, wash the board again with spirit alcohol to remove any final small fragments of swarf and metal dust.

The process has converted the relatively fragile PTFE substrate into a much more resilient structure which will not easily get damaged in the following processes – but it has now one disadvantage: the thermal sinking capability of the copper sheet, although it is only thin, is sufficient that an ordinary soldering iron is not powerful enough to make good ground connections.

So – I discovered the need for the hotplate!

Hotplate Design Concept

Having built a number of DF9LN OCXO's [3] I firstly examined the heater circuit used, since it is apparent from the design that it will work well in excess of the temperatures required for the OCXO application. It is a simple circuit – basically a power transistor as the heating element, with a solid state temperature sensor and an op-amp comparator to act as a controller – see Fig 6. I ran some experiments using a 100 x 75 x 6 mm aluminium plate as the heated surface and found that with a BDX 53 darlington transistor mounted in the middle of the plate, and an LM335 sensor near one corner I could achieve nearly 100°C with a collector current of approx 3A. This was the temperature at which the plate stabilised – ie when the dissipation into free air matched the heat input. At this temperature, given the thermal gradient from the transistor junction, through the packaging and into the plate, I decided it was as close to the maximum operating temperature as I wanted to go for reliable operation. Fig 7 shows the set-up I used for these tests.

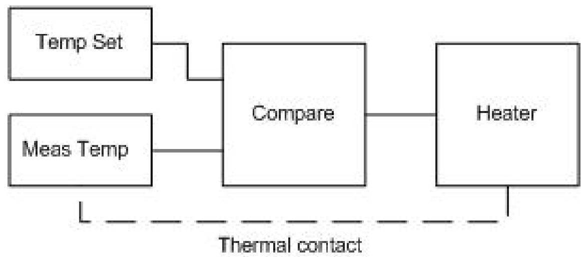

Fig 6 – Functional Diagram of DF9LN OCXO – Heater part

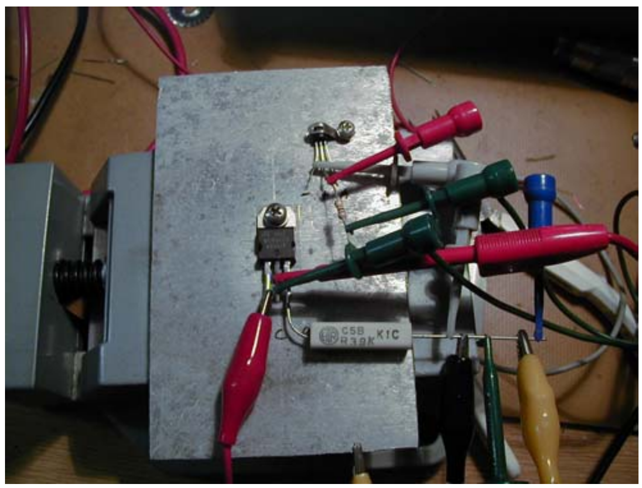

Fig 7 – Test Set-up for initial investigations

The BDX53 is capable of passing considerably more current, and could therefore take the temperature of the plate higher, but in the interests of reliability, I would recommend using resistors as heating element for temperatures higher than 100°C.

The LM335 was used, rather than the original KTY10-6 device, because it gives a linear output of 10mV/°K – as such it required minimal circuitry and processing to interface to a read out – a significant difference between this and the original application – when I built the DF9LN OCXO used for the GB3MHS 13 cm beacon, I added an LM335 so that the oven temperature could be read remotely [4]. (This was not a replacement for the KTY10-6 in the feedback loop, though)

For a prototype hotplate I decided that a simple potentiometer control of the temperature was adequate especially as there is no great demand for accuracy - ±5°C is quite good enough in this application – and the LM335 is far better than that. A moving coil analogue meter was to be used for the read-out – the resulting block diagram is shown in Fig 8

Hotplate Design Summary

In the block diagram you can see that the reference temperature is determined by the potentiometer, and is displayed by the meter when switch S1 is in the 'SET' position. When S1 is in the 'READ' position, the output of the LM335 is used to display the hotplate temperature – note that there will be a small temperature gradient across the plate, with hottest part in the centre, immediately over the heater element.

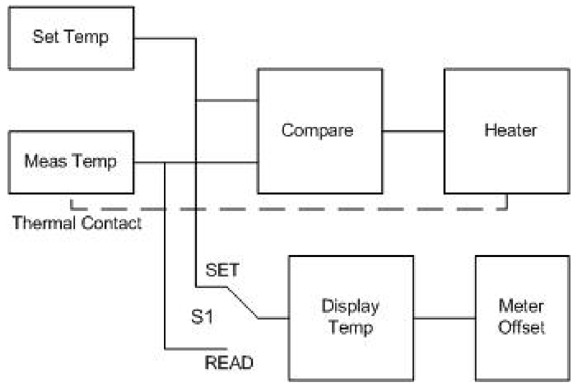

Fig 8 – Functional Diagram of Hotplate

The meter reference is 0°C – this is achieved by setting the –ve terminal of the meter at 2.73V dc, via trimmer P1 – since the LM335 gives 10mV/°K, then at 0°C it will give a 2.73V dc output – thus a 0 - 100µA meter can be calibrated (with an added multiplier resistor, in this case P2) to indicate 0 - 100°C over a 1V range

Control of the heater itself is by a comparator reading the LM335 output voltage and comparing it against the SET voltage from RV1 – the current through the transistor is limited by the emitter resistor to approx 3A.

Hotplate Circuit

Fig 9 shows the full circuit diagram. A single TL084 quad op-amp provides the comparator and the three non-inverting buffers used for voltage isolation. The amplifiers are run from a +5V dc supply via IC2 (78L05), which is also used to derive the SET and READ voltage inputs. This also limits the maximum base input voltage available to just under +5v, which limits the maximum drive that can be applied to the BDX53. The collector supply is directly from the +12V source, as is the supply for the LM335.

IC1a buffers the LM335 output voltage (READ), and this can be trimmed for accuracy with P3. IC1b buffers the potentiometer , RV1 (SET), and IC1d is the comparator. IC1c buffers the meter voltage as selected by S1. P1, 2, and 3 allow trimming of the reference 2.73V dc, the meter measurement range, and the LM335 output respectively. All connections to components off the PCB are made via 3 or 5 way jumper headers.

Construction

The heater transistor and the LM335 must be mounted directly to the underside of the hotplate, using M3 tapped blind holes. Obviously, the plate must be thermally isolated from its mounting – I achieved this by using a wood surround fabricated from 10 x 5 mm and 5 x 5 mm strips glued together to form an 'L' shape, giving a step to support the plate – see Fig 10. A PCB to hold the rest of the components (except the panel items) is shown in Fig 11, although for the prototype I used perforated board. The PCB is designed for double sided board – simply because it simplifies the tracking to have all the ground connections on one side. The component overlay is given in Fig 12. Use sturdy wires, capable of carrying the current, for the collector and emitter/ground connections of the heater - this ground can be commoned with the return side of the LM335. I have also grounded the hotplate itself, for ESP safety when working with GaAs and HEMT devices.

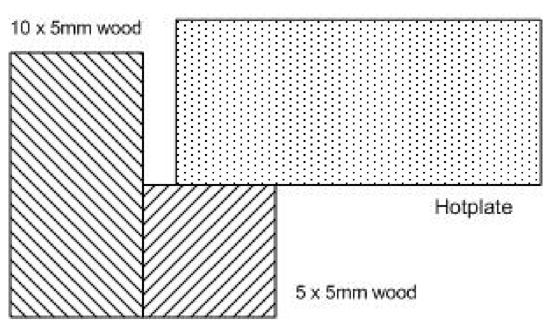

Fig 10 – Detail of support for hotplate

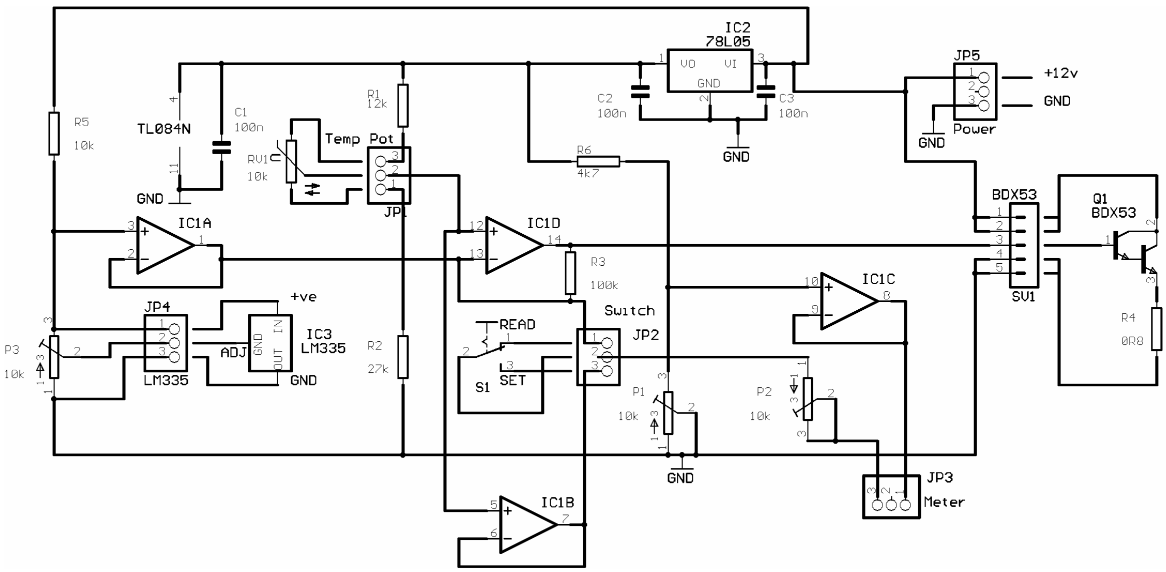

Fig 9 – Full circuit diagram of hotplate

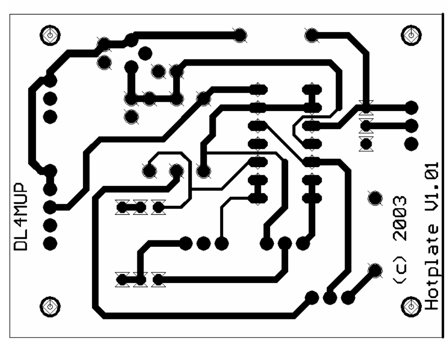

Fig 11 – PCB artwork for hotplate electronics

NOTE – due to the processes involved in reproducing this artwork, accurate dimensions of the final copy cannot be guaranteed by the author. Contact the author at g4hup@btinternet.com

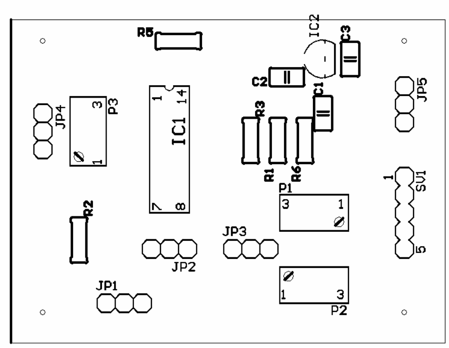

Fig 12 – PCB component overlay

The housing can be whatever you want to use – my own solution is shown in Fig 13. Another method could be to have separate enclosure for the hotplate and the electronics.

Fig 13 – Completed Hotplate

Adjustment

Once the circuit is completed and you have checked for any obvious short circuits and whiskers or solder bridges, check the output from the 78L05 before inserting the TL084 or connecting the LM335 and BDX 53.

Temporarily connect the –ve side of the meter to ground, and apply a measured 1v DC from an adjustable PSU to terminal 2 of JP2. Adjust P2 to give a reading of 100 on the meter. Remove the voltage source, and reconnect the meter –ve to terminal 1 of JP3.

Connect a nominal +12V dc supply to the hotplate – leave the BDX53 unconnected at this stage. Using a digital multimeter, adjust P1 so that the voltage at the –ve terminal of the meter is 2.73 V. Now apply an external voltage of 3.73V dc to the +ve terminal of the meter via P2, and adjust P2 for an indicated display of 100 on the meter scale. The meter is now set up to read 0 - 100°C. To set a different scale range, use an appropriate external voltage – ie for 150°C, the external voltage should be (2.73 + 150 x 10mV) = 4.23V.

Connect the multimeter to the slider of the potentiometer, RV1, and check the range of voltages available – the minimum voltage should be around 2.93V dc, and the maximum around 3.75V dc. These limits can be modified by adjusting the values of the R1 and R2 – you may need to use series/parallel combinations of resistors if you want to set precise limits – or replace them with trimmer potentiometers.

Now the TL084 can be inserted, and the LM335 connected. With S1 in the READ position, you should now see an indication of approx 20 on the meter – corresponding to the ambient temperature of the hotplate. Place S1 in the SET position and check the range of temperatures that can be set – return the setting to minimum afterwards.

Complete the circuit by adding the connections for the BDX53, and connect a DC Ammeter in the supply line, if your voltage source does not have a built in current meter. SET the meter to indicate 50°C, switch back to READ and you will see the meter indication slowly rising – it should also stop rising when it gets to 50 on the meter! While the heater is working you should see approx 3A being drawn from the supply, and as the temperature approaches 50°C this current will decrease gradually until is cuts out completely. If you continue to watch the current you will see the switching action of the circuit as it maintains the temperature of the plate.

If you have an accurate digital temperature measuring capability, you can measure the temperature of the hotplate after it has been allowed to stabilise for some time, and trim the output of the LM335 via P3 – but this degree of accuracy is only for purists – it is not necessary in this type of application!

Check that the hotplate operates correctly at higher and lower temperatures – it is now complete.

Using the Hotplate

Place the circuit board the hotplate and set the required temperature – allow the hotplate and board to thoroughly heat up for between 20 and 30 minutes. I have found that a temperature of around 90°C is needed for good soldering of the ground connections with a 'normal' temperature controlled iron (Weller 45W).

There is no method shown in this design for holding the PCB in position whilst it is being worked on – this is because I have not yet devised a solution that is mechanically simple, and can be easily fabricated with just hand tools. Some form of clip that is easy to make and use would be very useful, both for holding the assembly in place, and also to ensure a good thermal contact between it and the hotplate.

Variations

Having used the plate for building these PCBs, I would recommend that a wider temperature range is designed for – as you will see from above, around 90°C is in the right range of temperatures for this work, but that is at the top end of the range that this particular unit covers. A better top end limit would be perhaps 120°C or 150°C. To work at these temperatures, some changes to the concept would need to be made:

- Resistors should be used as the heaters, rather than transistors – with a max junction temperature of 200°C for silicon, the risk of damage to the device is too high.
- Connections to the heaters should use nuts and bolts, as solder will be unreliable at these temperatures – I did have some problems even at 100°C with wires becoming detached due to conducted heat out of the device softening the solder!

Using resistors, it would be easy to arrange, say, 4 power resistors around the hotplate, to give a better distribution of heat, with a series / parallel connection, so that they are switched by a single power transistor (which should be mounted on a separate heatsink!) The temperature sensor could be mounted centrally in the hotplate – see the concept diagram in Fig 14.

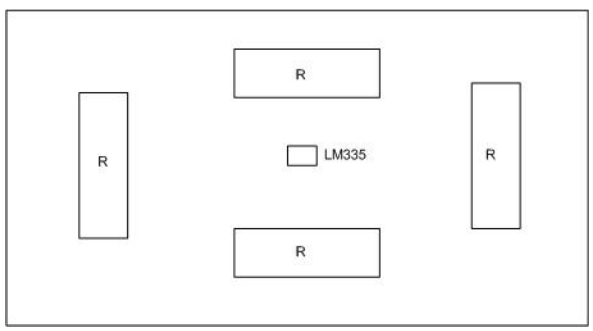

Fig 14 – Concept diagram for resistive heating

Note that the LM335, although specified for operation for up to 100°C only on the datasheets, has shown reliable operation up to almost 200°C in other heater applications, so can be confidently used up to 150°C at least. Do check the temperature ratings of the power resistors you intend to use – the bolt down Welwyn or similar types are a good choice.

The controller circuit described above is suitable for these applications, since none of the temperature critical components is placed on the PCB. To modify the temperature range setting, the value of R1 (6k8?) should be changed, so that the minimum voltage from RV1 slider is still around 2.9v, but the maximum is about 4.4v for a 150°C design. On the output side, consider the combination of resistors in Fig 14 as a replacement for R4, and wire this in the collector circuit of the BDX53, instead of the emitter. Mount the BDX53 on a separate heatsink, not the underside of the hotplate!

Whilst this paper has shown a variable temperature hotplate, which can be used for multiple applications, there are also methods and devices available enabling the simple manufacture of fixed temperature hotplates – one such option is the Dallas Semiconductors DS1620 [5], which has the temperature sensor and control electronics contained in the single chip. It is specified up to 120°C, and requires few external components to make such a heater. It will also operate as a variable temperature sensor and controller, but requires a microprocessor to generate the data it needs.

Other Applications

Although this unit was designed to overcome a specific challenge, some other uses and applications have become apparent since it was built:

- Curing of silver loaded epoxy – such glues are also a method of assembling microwave PCBs onto supports to give mechanical strength and good grounding – they require to be cured at approx 50°C for an hour or so. By placing the assembly on the hotplate, this can be done without intruding into the culinary preparation area which is the protected domain of the XYL!
- The PCB bonding technique can also be applied to power amplifiers – especially at microwave frequencies, it is very important to ensure that the tabs on the device lie flush with the PCB tracks – this can be difficult, since the devices are usually much thicker than the PCB, needing the heatsink plate to be milled out for the device to sit in, or the use of a separate plate between the PCB and the heatsink to bring them into alignment. The first solution is OK for those with access to good machine shops, the second is easier, but results in a more complex assembly. By bonding a copper plate of the correct thickness to the PCB, there is a one-piece board to be assembled, with excellent grounding – but the downside is that more heat will be needed to solder it, since the thin copper plates of 0.5 and 0.7mm recommended for LNA assemblies will not be thick enough for power devices.

PCB's

1:1 artworks of the PCB, and copies of the circuit diagram and component overlay are available on request, for the cost of the postage. Manufactured PCB's can be made available, depending on demand. You can contact me at g4hup@btinternet.com.

Conclusions

This presentation has shown a method for improving the mechanical stability and electrical grounding of PCBs for microwave applications, and has also shown a hotplate accessory to facilitate easy working with the composite assembly resulting from the bonding process.

Acknowledgement

My thanks to Luis, CT1DMK, both for his assistance with my questions about his 10G and 24G designs, and also for permission to publish the bonding method in this paper.

References

[1] 24GHz Modules, Luis Cupido, CT1DMK: Dubus 3/98

[2] MicroMechanik (inh. Hubert Krause) – Supplier of milled aluminium boxes for 10G and 24G preamps etc – tel +49 2248 4895/Fax +49 2248 445295

[3] Oven Stabilised XO for VHF, Uwe Nitschke, DF9LN: Dubus 3/97

[4] GB3MHS – New 13cm Beacon at Martlesham; Dave Powis, G4HUP, UKW 43, Weinheim 1998

[5] DS1620 Digital Thermometer and Thermostat – Dallas Semiconductors. http://www.dalsemi.com

Additional Information

Following url's provide leather workers tools – note these links have been checked and updated March 2008 – prices quoted were correct in 2003, and have not been re-checked.

- http://www.theidentitystore.co.uk (UK)
- http://www.eleathersupply.com (USA)
- http://www.tandyleatherfactory.com (USA)

You need a ‘Drive Punch’ - but it seems as if these are being phased out of the catalogues at the moment, and being replaced by more expensive punches and sets, eg single punch is cat 3777-33 at GBP9-00

However, you can make a suitable punch from ‘spare parts’ for sets – eg from Identity Store (which is UK outlet for Tandy Leather):

Mini Punch set (cat 3003-00) has 1/16 to 3/16 punch tubes which fit a common handle-cost GBP7-50
Or just buy the Handle (cat 31767-00) cost GBP2-75 and Minitube size 00 (cat 3798-00) cost GBP1-50

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