

LiPo batteries and temperature.

Most readers of this column will know the name of Wayne Giles as it has appeared here on several occasions. Wayne has produced several specialist pieces of testing equipment for me, but he also does a certain amount of his own investigation into areas which are interesting to him. There are also times when we are looking simultaneously at the same area and it is one of these situations which has induced me to begin this article with the following review. I should not really call it a shared investigation as Wayne has done most of the testing, but I am using this as an opportunity to draw our thoughts together in a logical way.

I have referred to the effect of heat in reducing Lithium Polymer internal resistance before, i.e. in allowing the voltage recovery which can occur at higher discharge currents, but we are beginning to feel that LiPo batteries have an operating range of temperature within which they are reliable, and outside of which they have problems. The problem is complicated in that some aspects of this are fairly obvious and immediate (such as thermal runaway and ignition), whilst others are not immediately noticeable. In this latter category we have the gradual but accumulative damage which gives rise to a progressive loss in performance with no obvious signs of distress.

Thermal Transfer.

Let me start with some basic physics about heat energy and temperature. If a solid body is left in a constant temperature environment it will adjust until its own temperature is the same as that of its surroundings. If we introduce an internal source of energy to the body (such as the passage of an electric current through a conductor) this releases thermal energy or heat into the core of the body and the temperature of the body rises. The extent of the temperature increase depends upon the quantity of energy converted into heat, the mass of the body, its thermal conductance, and its specific heat. As soon as the body has a higher temperature than that of its surrounds it begins to transfer thermal energy into these surrounds which begins to cool the body itself. The rate of this cooling depends upon the conductance of the heat energy through the body, the nature of the surface of the body, the surface area, the rate of heat transfer into the surrounds via radiation and/or convection, and the temperature difference.

This heating/cooling process is a balancing act, and in a steady state situation the body will increase temperature until the rate of energy input is balanced by the rate of cooling, at which point the temperature of the body will stabilise (though it will still be higher at the core than at the surface).

I am sure you will see how this example of behaviour is applicable to the discharge of our LiPo batteries. The discharge of the pack releases heat energy at the core of each cell with higher internal resistance and higher current draws increasing the energy released (on a square law basis). This energy causes the cell temperature to rise proportionately. The pack cools by conducting the heat to the surface of the cell where it can be transferred into the surrounding air and the more effective is this cooling action the lower will be the final temperature of the pack. Although our packs never reach a steady state condition (there are just too many changing parameters), the principles can still be applied and we can draw some relevant conclusions. To keep the pack temperature rise as low as possible we should have:-

1. as low a cell internal resistance as possible,
2. as low a current draw as is feasible,
3. cell geometry where the surface area is as high as possible compared to the mass,
4. no cells in contact with other cells (surface to surface contact prevented by separators),
5. a matt black surface to radiate heat away more effectively,
6. a gentle flow of air over and through the pack during use,

You will realise that the flyer can directly control 2. and 6., but that he may also influence the remainder by his choice of battery. From a personal point of view I have to say that I have not seen any cells with a black polymer case, but some suppliers do use a black outer sleeve for their packs.

Other Factors.

Just to reiterate a little then, I am suggesting that keeping your packs within a suitable temperature range during use and storage is important to their long-term usable life, and may be more important to this than we have hitherto thought. Notice that the reference to a temperature range means that there is a lower limit as well as a higher limit. The evidence here is far more intuitive but certainly it would appear that winter storage of LiPos needs consideration. There is also a problem with usage at low ambient temperatures where the performance of the packs is poor until the pack temperature has risen by self-heating, but also that normal use of packs suffering this kind of temperature fluctuation leads to accelerated deterioration and much reduced life. There is unfortunately a symbol clash in this area since we use the symbol "C" for both temperature in degrees centigrade (or celsius), and for multiples of pack capacity in charge/discharge (a 10C discharge of a 2000 mAh pack is at 20 amps). I hope you can avoid confusion by consideration of the context.

Wayne did some testing using various starting temperatures, the results of which bear out the earlier points (graph 1) but much more cycling would be needed to verify the reduced life theory. If our theory that it is self heating which does the damage is correct, then the user should take steps to avoid the sag. A pack which does not show it at a particular discharge in summer may well do so in winter. Therefore the user should downsize his prop choice or up size his pack capacity for winter flying. He also looked into the thermal factor in terms of pack sizes. The size we refer to is the individual cell size (usually reflected in the cell capacity, say 4000 mAh and above for a larger than average cell) and not the series count (or voltage, but note a recommendation for separators in multi-cell packs). It is a physical fact that larger packs restrict the cooling effect of the rate of loss of thermal energy so that a larger capacity cell will end at a higher temperature than a smaller one, all other factors being constant. To use some of Wayne's numbers, "if we consider a 2100mAh LiPo pack during discharge at a fixed C rating, it will be dissipating some power, lets say 50W, go to a 4200mAh pack at the same C rating and this power loss is now 200W (losses are a function of the square

of the current) the bigger cell will have a lower ESR but not half, so that the likely losses are say 150 watts. The 4200mAh pack will be double the volume of the 2100mAh pack, so the power loss density will be increased by 50% (3 x power loss in 2 x volume). It now gets worse as the heat is dissipated from the surface of the pack and the rate of loss depends on surface area. Using a typical LiPo, measurements show that 100% increase in volume only increases the surface area by 20%, so now the larger pack is trying to dissipate 300% the power of the smaller pack over only 120% of the surface area. Even more bad news; the heat from the centre cells now has to travel much further to get to the surface and be dissipated, so that these centre cells are soon over safe temperatures. I have carried out physical measurements on the 4200mAh 4S and the 4200mAh 6S packs. Obviously at the same current the 6s pack is dissipating 50% more heat than the 4S pack. The increase in surface area is just 7%!.”

Advice.

I hope the above gives you some cause for thought, but it is only half of the story. It is not much use expounding a theory about the cause of a series of problems if the theory cannot be used to help avoid them, and in this case that means setting a working temperature range within which LiPos are reliable and long-lived. We can start with ambient temperatures, say 20° C for the UK, and consider how far above and below this value we would like to maintain our batteries. We do not know enough about the electro-chemistry of these units to be able to set exact values for the limits, but we can estimate some sensible values based upon experience.

With regard to the lower limit, I think we have to avoid the packs dropping below zero° C, even in storage. This does not mean that we cannot fly in freezing conditions. If your lipos are stored in your normal indoor living environment, i.e. at around 20° C (not necessarily in your home – remember the safety requirements for these packs), and are insulated during travel to, from, and whilst at the field, they will probably only begin to cool when taken out of the insulation to install into a model, but will then begin to warm up whilst in use in a model. An exception to this might be an electric glider with long periods of power-off flight, but otherwise they should never get below 10° C. We got used to the ability of Nickel cells to survive and work in extreme conditions but it seems that the internal resistance of Lithium cells is much more temperature dependant and therefore more liable to damage as temperatures reduce.

In the case of the upper limit then we cannot avoid some rise in temperature if the battery is discharged in use. Remember that this rise is always relevant to ambient so on a hot summer's day (if you can remember what these are?) they will start at 30° C and get hotter. I have done some very basic testing of temperature variation at different discharge rates using a modified Tenma thermal probe inserted between cells in a pack and an ambient temperature of 25° C, and you will see the results in graphs 2, 3, and 4. I made no attempt to cool the packs (worst-case scenario), but you will see how the temperature rises at a pretty linear rate until discharge is stopped and it then quickly starts to cool. The rate of temperature rise is dependant on the discharge rate but this is not a simple link. The greater the current, the more thermal energy is released and the greater is the final temperature on the completion of discharge. The LiPo was a two-cell 1300 mAh pack with separators (allowing me to slide the thermocouple between the cells) and had a low internal resistance, so it was in many ways an ideal pack in heating/cooling terms. Even then the temperature rises were 16° C over 11 minutes at 5C discharge, 30° C over 6 minutes at 10C discharge, and 37° C over 4.5 minutes at 15C discharge. It is not difficult to understand how a pack can get very hot when discharged at high loads, and why such extreme temperature fluctuations could cause the pack to deteriorate quicker than we might prefer.

It would be an ideal solution if we could put a numerical value to this upper limit temperature but I am not yet in a position to do this. My very limited testing here indicates that with good cells it is possible to keep the value below 75° C, particularly if they are small in size. I doubt that this is possible with larger cells where total continuous discharge is envisaged, and the limit here may have to be in the order of 85° C simply to operate such cells effectively, but I need much more data to extend this point. I will let you know how this progresses.

The Ultimate Charger?

I'm sure you have noticed that chargers/dischargers have been advancing (in technological terms) very rapidly. Any attempt by a modeller to choose what he considers to be an ideal charger is very much a “horses for courses” situation, and many would select simplicity before complexity, but if you are looking for a powerful unit to handle all possible situations then you are invariably looking at the top end of the range. I recently received such a unit on loan and have been mightily impressed by its performance. I am not sure that it can be described as “ultimate”, but it must be fairly close to it.

The charger is the Graupner Ultra Duo Plus 50, and the unit in my photographs is on loan from Gliders (thank you Peter). I do not have space here to cover the unit in depth so will outline the specification this month and describe the use of the item in next month's column. To be honest, this unit is a twin, since it has two separate halves, each of which can be used independently in any of the available modes. There are circumstances in which the two halves can be combined to achieve specific performance formats but I shall not cover this aspect at this time. The power to the Plus 50 can be through the mains (100 to 240 VAC) or through a DC supply (12V lead acid for field operation). The various ports are duplicated for each half of the unit and these include the output (two 4mm connector sockets), the balancing port (Graupner type EHR-8), and a temperature sensor socket (servo style). There is a single USB socket for the computer interface. Each half of the unit has its own pair of cooling fans and its own backlit display screen but the main operating controls are a knob (twist and rotate) and a set of six soft-press buttons which apply to scrolling and other display features. The operation of these can be switched between outputs as required.

This is no lightweight unit. It is 230 x 225 x 83 mm and weighs 2.2 kg. It is very nicely finished in a carbon cloth pattern and is supplied with a very complete set of accessories including mains cable, DC supply cables, 12 volt battery crocodile clips with 4 mm sockets fitted, USB computer Interface cable, JST balancing adapter, and two thermal probes (one surface unit for NiMH cells and one insertable unit for LiPo). At first sight the booklet supplied is minimal

since it is multi-lingual with only 4 A5 pages of English, but on investigation of the CD supplied you find that this contains not only the interface software, but a full 53 page English Instructions which is clear and concise.

The Plus 50 has many features which you would only expect to find on a top-class charger and these are available through both halves of the unit (either individually or simultaneously operated). They include

1. 1 to 18 NiCd or NiMH cell packs between 0.1 and 9.9 Ah
2. 1 to 7 LiPo, LiIo, LiFe and LiMn cell packs between 0.1 and 20.0 Ah
3. 1 to 12 cell Pb acid or gel batteries between 0.1 and 45 Ah
4. 50 battery parameter storage memories
5. A full selection of charge/discharge/cycle/maintenance/conditioning computer controlled programmes
6. Single cell operation
7. Battery storage charge programme
8. Full balancing on up to 7 series cells Lithium batteries
9. Model car tyre heating programme
10. Motor run-in and test programmes for brushed motors
11. Full protection against short-circuit, overload, and reversed polarity situations
12. Adjustable safety timer
13. Battery internal resistance display
14. Full supporting software for PC display of all features (both outputs)

I am sure you will see from these brief details that this is a serious piece of equipment, but as I said before, I will continue with my review in next month's column.

Contacts.

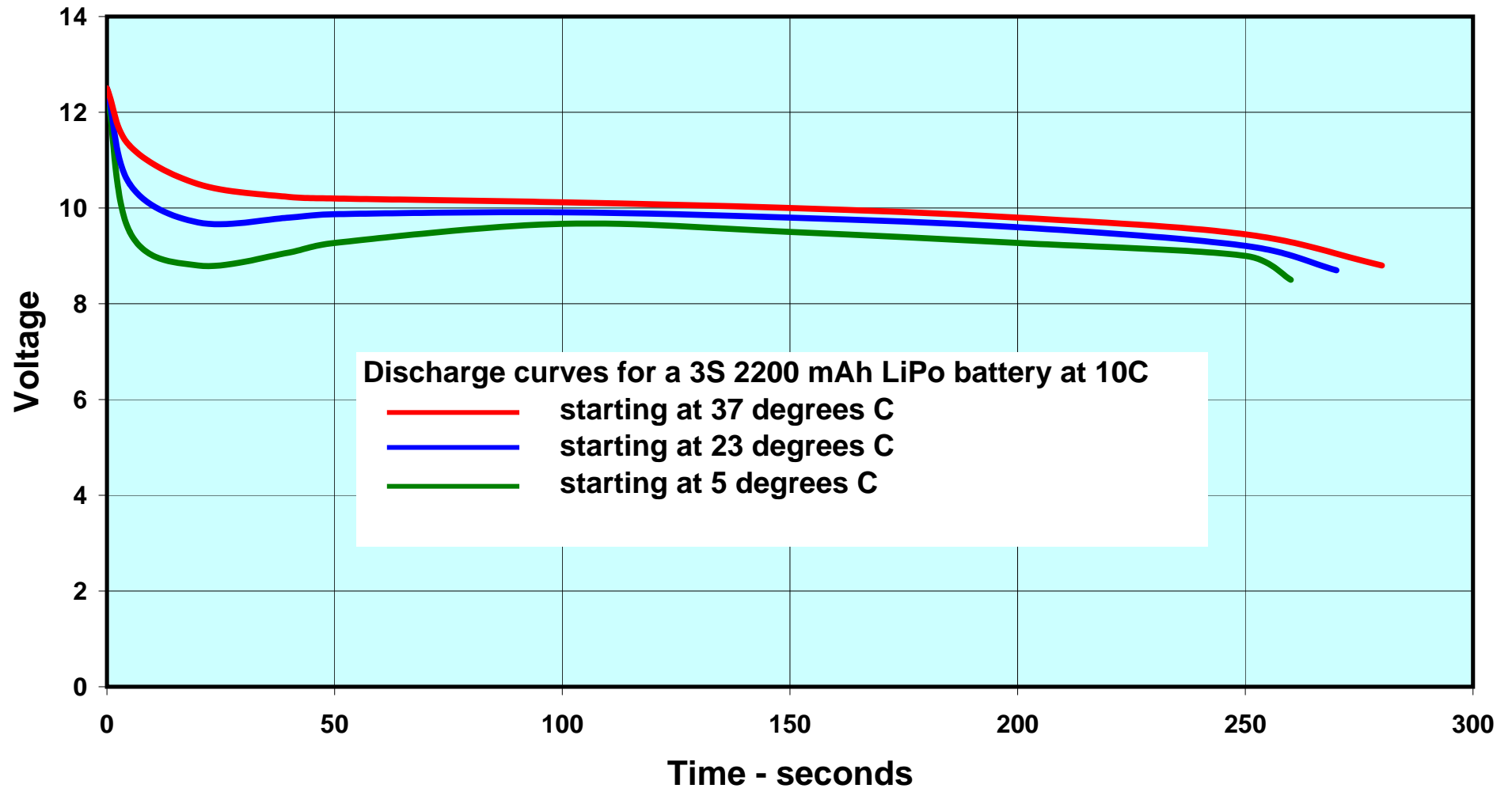
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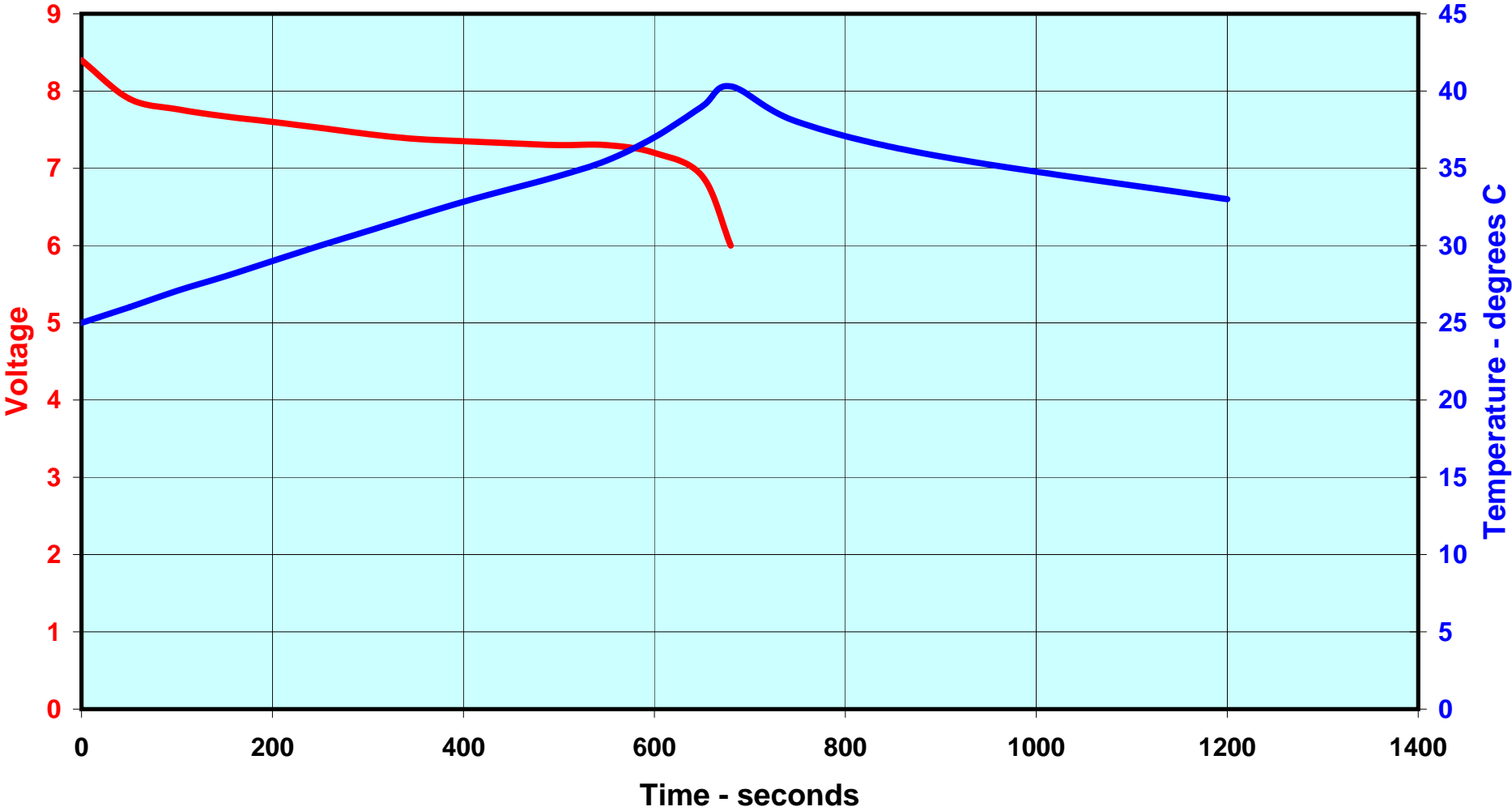
Photographs.

- QEF181-1 The Tenma auto-range digital multi-meter.**
- QEF181-2 The Tenma set with probe to read temperature (ambient reading 21.7°C).**
- QEF181-3 The separators between the cells of the 2S 1300 mAh Loong LiPo.**
- QEF181-4 The modified thermocouple probe protected with tape.**
- QEF181-5 The thermocouple inserted between the LiPo cells.**
- QEF181-6 The thermocouple reading around 13°C above ambient during discharge.**
- QEF181-7 The full box contents for the Graupner Ultra Duo Plus 50 charger.**
- QEF181-8 The Plus 50 charging and discharging different LiPo packs simultaneously.**
- QEF181-9 The Plus 50 monitor screens prior to commencement.**
- QEF181-10 The Plus 50 screens during charging (left) and discharging (right).**

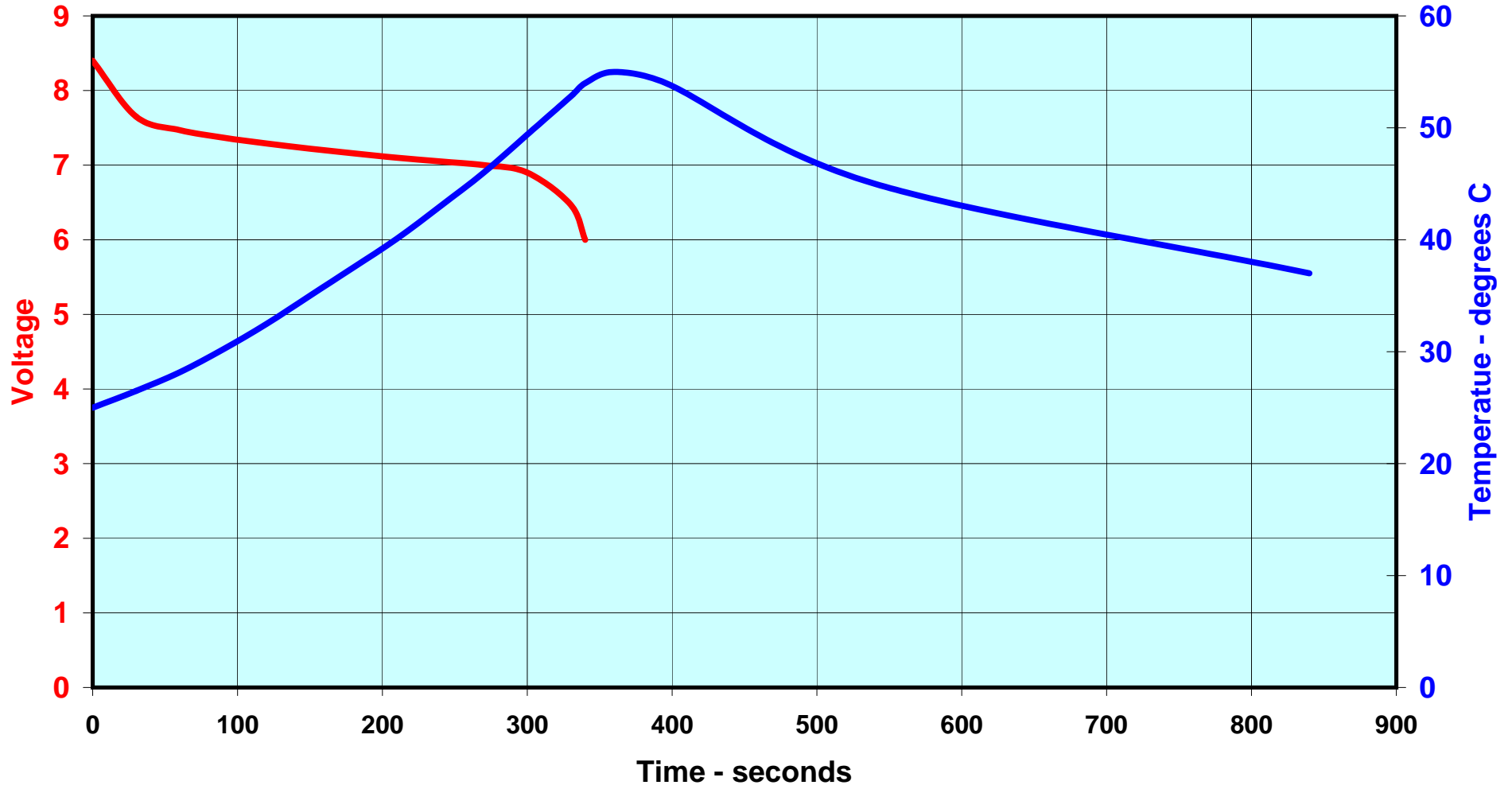
Graph 1 - Discharge at 10C - various start temperatures.



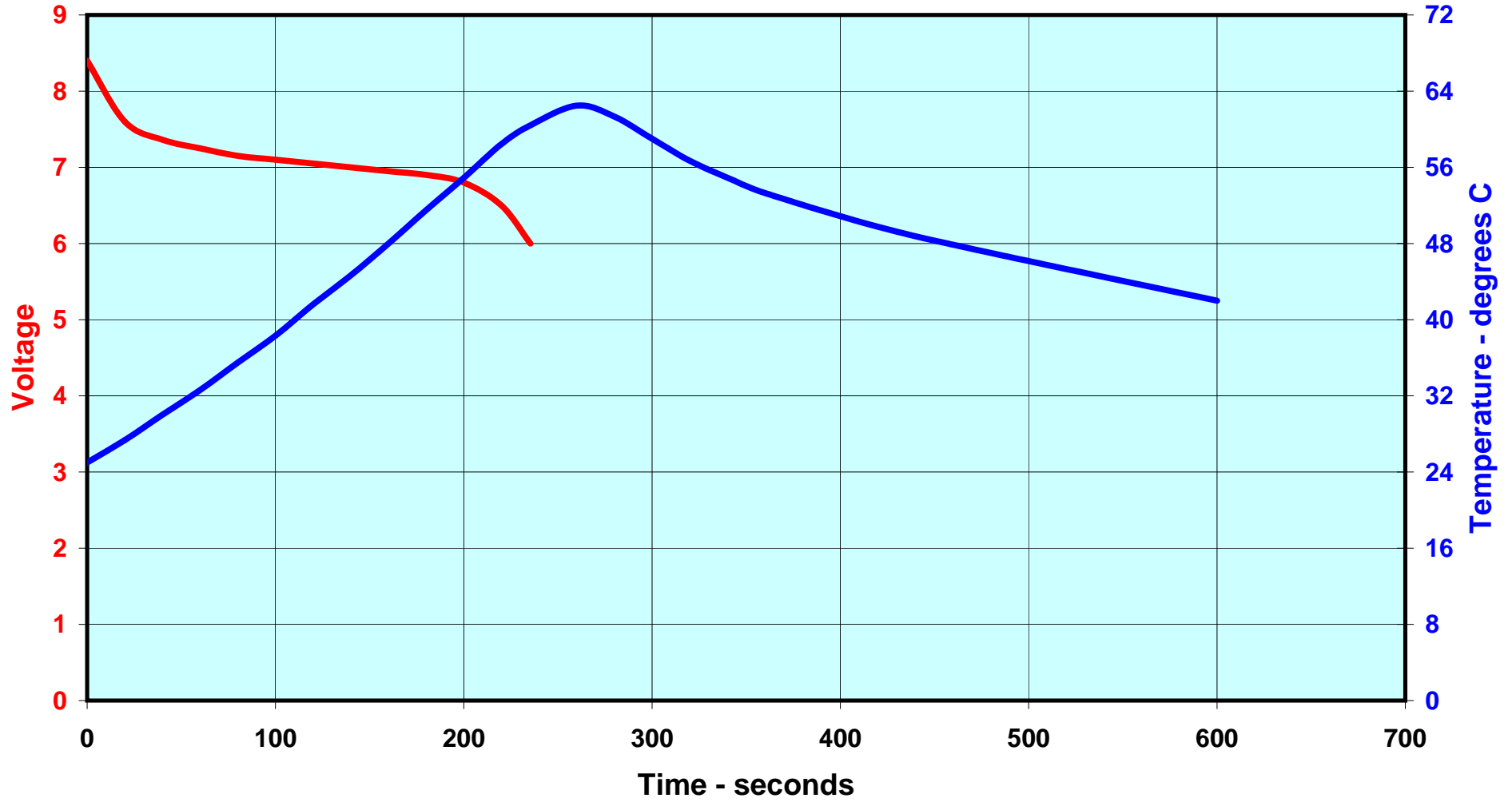
Graph 2 - Temperature plot for Lipo discharge at 5C



Graph 3 - Temperature plot for Lipo discharge at 10C

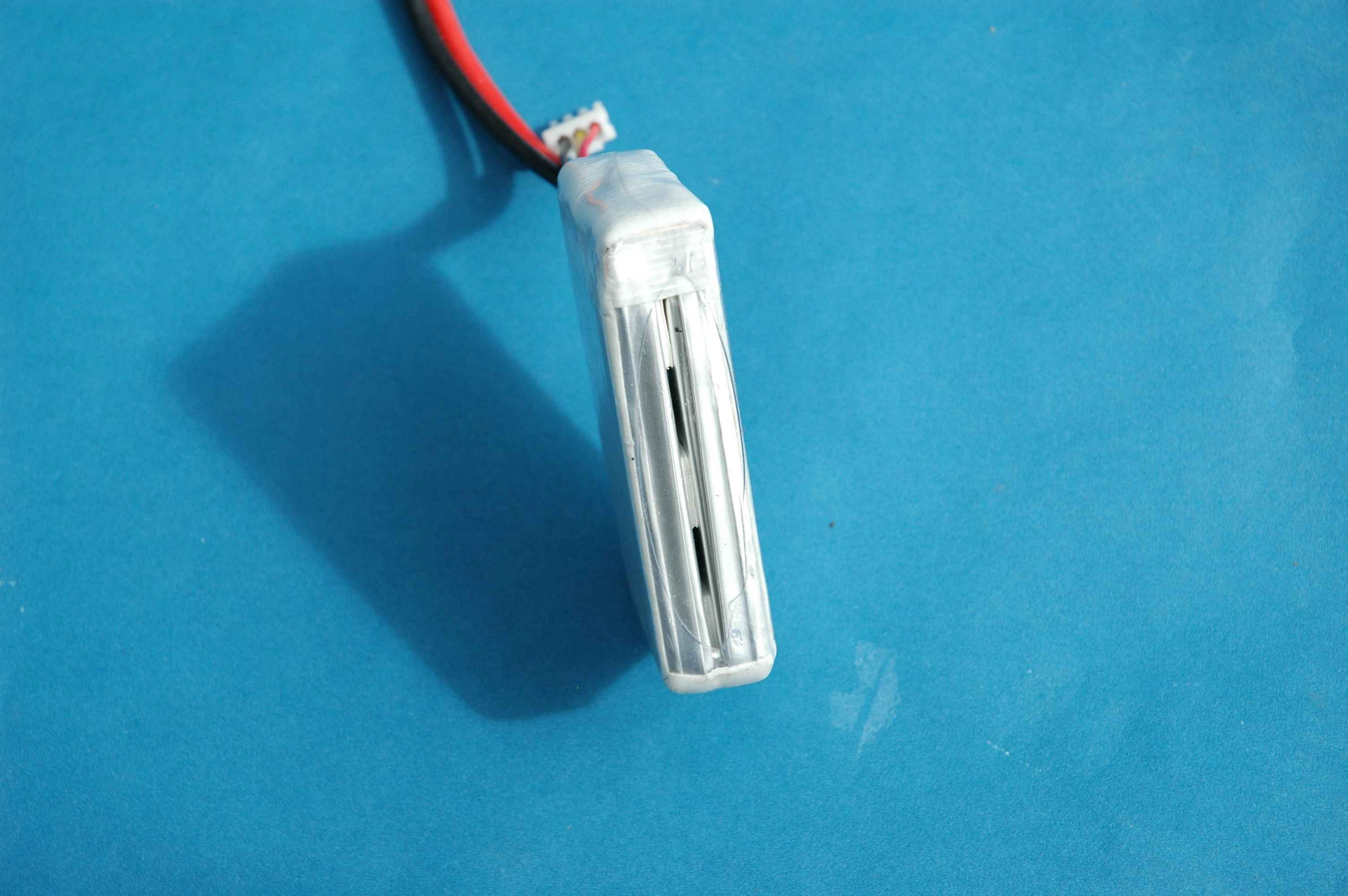


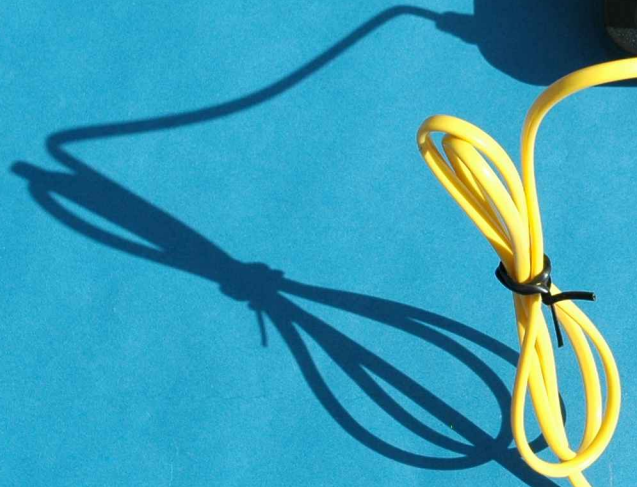
Graph 4 - Temperature plot for Lipo discharge at 15C

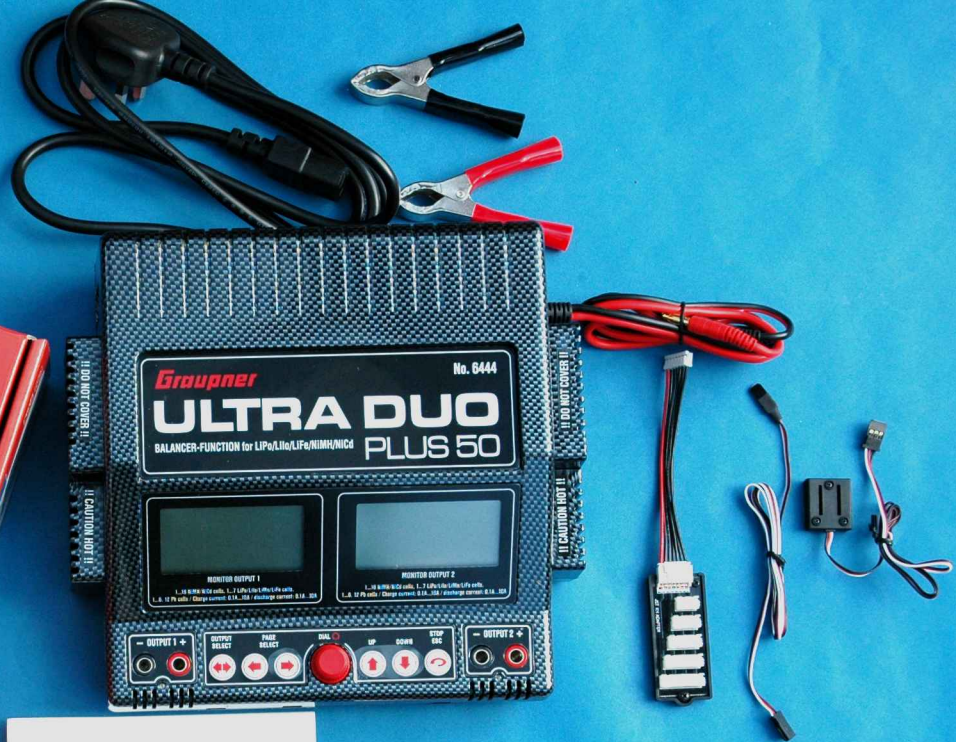












COVER II

ULTRA DUO PLUS 50

BALANCER-FUNCTION for LiPo/LiIo/LiFe/NiMH/NiCd

CAUTION HOT II

MONITOR OUTPUT 1

1...18 NiMH/NiCd cells, 1...7 LiPo/LiIo/LiMn/LiFe cells,
1...6, 12 Pb cells / Charge current: 0.1A...10A / discharge current: 0.1A...10A

MONITOR OUTPUT 2

1...18 NiMH/NiCd cells, 1...7 LiPo/LiIo/LiMn/LiFe cells,
1...6, 12 Pb cells / Charge current: 0.1A...10A / discharge current: 0.1A...10A

OUTPUT 1

OUTPUT SELECT PAGE SELECT DIAL UP DOWN STOP ESC

OUTPUT 2

ULTRA DUO

BALANCER-FUNCTION for LiPo/LiIo/LiFe/NiMH/NiCd

PLUS 50

[CC/CV] CHARGE

TIME	0:00:15
CAPACITY	11mAh
VOLTAGE	12.471V
CURRENT	+ 3.21A
RESISTANCE	0mΩ
BATT TEMP	0.0°C

MONITOR OUTPUT 1

1...18 NiMH/NiCd cells, 1...7 LiPo/LiIo/LiMn/LiFe cells,
1...6, 12 Pb cells / Charge current: 0.1A...10A / discharge current: 0.1A...10A

[LINEAR] DISCHARGE

TIME	0:00:57
CAPACITY	35mAh
VOLTAGE	12.644V
CURRENT	- 2.22A
RESISTANCE	0mΩ
BATT TEMP	0.0°C

MONITOR OUTPUT 2

1...18 NiMH/NiCd cells, 1...7 LiPo/LiIo/LiMn/LiFe cells,
1...6, 12 Pb cells / Charge current: 0.1A...10A / discharge current: 0.1A...10A

OUTPUT
SELECT



PAGE
SELECT



DIAL



UP



DOWN



STOP
ESC



OUTPUT 2