LiPo Batteries:
Internal Resistance, Max. Current Draw, *true* C-Rating

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Acknowledgement

I would like to thank Mr. Mike J. Anderson of the Rideau RC Flyers (Ottawa, Ontario) for his contributions to this LiPo battery report.

His technical guidance and detailed vetting skills have been greatly appreciated.

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LiPo Batteries: Internal Resistance, Max. Current Draw, *true* C-Rating

In the January 2013 issue of Modern Aviation-Canada, Mike Anderson[1] introduces a very important concept for judging LiPo battery quality. He introduced a simple equation developed by John Julian (Melbourne, Australia) , Wayne Giles (U.K.) and Mark Forsyth (Malibu, California). The equation allows one to predict the maximum allowable continuous current from a LiPo battery, without thermal damage to the LiPo battery, which would shorten its useful life.

The equation is based on *internal resistance* of the LiPo battery and limit on heat produced within a cell during discharge. When cell internal heat dissipation is limited to 6-watts per Amp-Hr, the cell will degrade slowly in normal use and provide long life. (The 6W/Amp-Hr value is a number developed from years of field use and experimentation. As long as the heat generated inside a LiPo cell does not exceed 6-watts/ Amp-Hr, the LiPo battery will not be damaged due to heat). The 6-watts/Amp-Hr figure is much like the *Watts/pound* approximation used by RC modellers for many years to determine the size of battery power needed for Aerobatics, Sports, or Scale flying.

This equation is as follows:

$$\text{Max Amp draw} = \sqrt{\frac{6\,\frac{Watts}{amp-hr} X\ capacity}{internal\ resistance}} = \sqrt{\frac{6\,\frac{Watts}{amp-hr} X\ amp-hr}{ohms}}$$

By measuring the internal resistance, one can predict the maximum **continuous** current that can be safely drawn from the LiPo battery, without thermal damage to the LiPo battery.

As the LiPo battery discharges, it is the effect of the internal resistance that causes the output voltage to fall. (More on internal resistance in the Appendix)

This report will build on Mike Anderson's introduction to LiPo battery testing by providing details on how to measure the internal resistance of the LiPo battery.

[1] Mike Anderson; "How Good Are Your LiPos?"; Model Aviation-Canada, Vol.44, No.1; pages 54-55.

1. Measure the Effective Series Resistance (ESR) of the LiPo battery

This procedure will use the ESR Meter (designed by Wayne Giles). This meter has been designed specifically to measure *internal resistance* of a LiPo battery.
Other devices that have an ability to measure *internal resistance* of a LiPo battery are:
Junsi iCharger 3010B, Junsi iCharger 306B, or FMA Direct/Revelectrix PowerLab 8 Charger

a) If the LiPo battery has just been charged, let it stand at room temperature for an hour, to stabilize to room temperature.

b) Make a note of the LiPo battery temperature.

If you measure the internal resistance at a temperature of 72± 2 degrees F (22± 1 deg. C), Mark Forsyth has a data base for recording the internal resistance. He is accumulating internal resistance data for many different brands of LiPo batteries, so feel free to contribute your findings.[2]

c) Connect the LiPo battery to the ESR Meter. (See *ESR Meter-Operation*, and *Operating Notes*, in Appendix). The LiPo battery will power the ESR Meter.

d) To get a very accurate measurement of the LiPo internal resistance, it is best to measure the internal resistance of each cell, in the LiPo pack. Make a note of the internal resistance of each cell. Use the **highest** internal resistance value for your calculations that follow. (It is the weakest cell with the highest internal resistance that will get the hottest inside the pack).

Individual *cell* resistance values are found by plugging the ERS Meter's *search connector* to adjacent pins on the LiPo balance connector. (See *ESR Meter-Operation*, in Appendix).

Note and record the internal resistance of each cell in the LiPo battery. This provides useful information for early detection of cell aging or deterioration.

A LiPo cell's internal resistance will increase with age and amount of use.
When one of the cells in a LiPo battery shows much higher internal resistance than the other cells in that LiPo battery, this may a good time to consider replacing that LiPo battery with a new one.

Internal resistance in a LiPo battery has a negative temperature coefficient. As battery temperature increases, internal resistance decreases. When battery temperature decreases, internal resistance increases.

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[2] Report #1; " LiPo Performance Database"; http://www.rcgroups.com/forums/showthread.php?t=1578001

2. **Calculate the maximum <u>continuous</u> current that can be drawn from the LiPo without damaging the battery**

Max Amp draw = $\sqrt{\frac{6\frac{Watts}{amp-hr}X\ capacity}{internal\ resistance}} = \sqrt{\frac{6\ X\ capacity\ in\ Amp-Hr}{internal\ resistance\ in\ Ohms}}$

From the LiPo Performance Database, there is a 2190 mAh FlightPower EON 28C LiPo whose internal resistance was 12.7 mΩ.

∴ Max Amp draw = $\sqrt{\frac{6\ X\ 2.190}{0.0127}} = \sqrt{\frac{13.14}{0.0127}} = \sqrt{1034.6}$ = 32.2 Amp

Hence, a maximum **continuous** current of 32.2 amperes can be drawn from this LiPo without thermal damage to the LiPo. And if you did draw this continuous current, the battery would be discharged in

$\frac{2.190\ ampere-hour}{32.2\ ampere}$ = 0.068 hours = 4 minutes.

In his Model Aviation article, Mike Anderson has calculated the Max **Continuous** Amp Draw at various *internal resistance* values (from 3 mΩ to 15mΩ) for a range of LiPo battery capacity from 500 mAh to 6,000 mAh. This table is shown as follows:

Table 1: Maximum Continuous Current that can be drawn by the load without damage to the LiPo battery[3]

Cell Cap	MaxAmps @ 3mOhm	MaxAmps @ 6mOhm	MaxAmps @ 9mOhm	MaxAmps @ 12mOhm	MaxAmps @ 15mOhm
500	31.6	22.4	18.3	15.8	14.1
1,000	44.7	31.6	25.8	22.4	20.0
1,500	54.8	38.7	31.6	27.4	24.5
2,000	63.2	44.7	36.5	31.6	28.3
2,500	70.7	50.0	40.8	35.4	31.6
3,000	77.5	54.8	44.7	38.7	34.6
3,500	83.7	59.2	48.3	41.8	37.4
4,000	89.4	63.2	51.6	44.7	40.0
4,500	94.9	67.1	54.8	47.4	42.4
5,000	100.0	70.7	57.7	50.0	44.7
5,500	104.9	74.2	60.6	52.4	46.9
6,000	109.5	77.5	63.2	54.8	49.0

This is a very useful table. A spare copy is at the end of the Appendix.
Place the chart in your electric flight field box for reference.

[3] Mike Anderson; "How Good Are Your LiPos?"; Model Aviation-Canada, Vol.44, No.1; pages 54-55.

3. Calculate the true C-Rating of the LiPo battery

true C-rating = $\frac{calculated\ Max\ Amp\ draw}{capacity\ printed\ on\ battery\ label}$ = $\frac{32.2\ amperes}{2.190\ amperes}$ = 14.7 = **15**

Therefore, the true C-rating of this LiPo is 15C, not 28C, as stated on the battery label.

In his Model Aviation article, Mike Anderson has calculated the ***true* C-rating** at various *internal resistance* values (from 3mΩ to 15mΩ) for a range of LiPo battery capacity from 500 mAh to 6,000 mAh. This table is shown as follows:

Table 2: true C-Rating of LiPo battery for various LiPo cell capacities[4]

Cell Capacity	C Rating @ 3mOhm	C Rating @ 6mOhm	C Rating @ 9mOhm	C Rating @ 12mOhm	C Rating @ 15mOhm
500	63.2	44.7	36.5	31.6	28.3
1,000	44.7	31.6	25.8	22.4	20.0
1,500	36.5	25.8	21.1	18.3	16.3
2,000	31.6	22.4	18.3	15.8	14.1
2,500	28.3	20.0	16.3	14.1	12.6
3,000	25.8	18.3	14.9	12.9	11.5
3,500	23.9	16.9	13.8	12.0	10.7
4,000	22.4	15.8	12.9	11.2	10.0
4,500	21.1	14.9	12.2	10.5	9.4
5,000	20.0	14.1	11.5	10.0	8.9
5,500	19.1	13.5	11.0	9.5	8.5
6,000	18.3	12.9	10.5	9.1	8.2

Note: All C values below 20 are shown in pale blue to indicate batteries that have exceeded their useful life to power aircraft.

For example, a 4,000 mAh LiPo with internal resistance of 3-mΩ has a true C-rating of 22.4.

This is calculated in the following manner:

1) Max Amp draw = $\sqrt{\frac{6\frac{Watts}{amp-hr}X\ capacity}{internal\ resistance}}$ = $\sqrt{\frac{6\ X\ 4.0}{0.003}}$ = $\sqrt{\frac{24}{0.003}}$ = $\sqrt{8{,}000}$ = 89.4 Amperes

2) *true* C-rating = $\frac{calculated\ Max\ Amp\ draw}{capacity\ printed\ on\ battery\ label}$ = $\frac{89.4\ amperes}{4.0\ amperes}$ = 22.36 = **22.4**

[4] Mike Anderson; "How Good Are Your LiPos?"; Model Aviation-Canada, Vol.44, No.1; pages 54-55.

In an e-mail exchange, Mike Anderson has presented an interesting perspective on C-rating.

With careful throttle management, one can achieve a flight time of 8-minutes.

This would represent an average current draw of $^{60}/_{8}$ = 7.5C

This shows that the average continuous current we all fly at is actually very low.

Precaution concerning *true* 'C' rating

Internal resistance (or **E**quivalent **S**eries **R**esistance, ESR) is a dynamic characteristic of a LiPo battery. As the LiPo battery ages, the *internal resistance* will increase. Hence, the measurement of internal resistance, by using the ESR Meter, provides a value that is a very good approximation of the *internal resistance*, at that time, and at that temperature.

The internal resistance should be measured periodically, (typically once a month) and the highest value (the weakest cell) written down. This will allow one to monitor the change in LiPo internal resistance, as the battery ages.

The *true* 'C' rating calculation is neither fixed nor guaranteed to be absolutely correct. The *true* 'C' rating is based on a 6-watt/Ah dissipation limit within the battery pack.

Recall that power dissipation is I^2R . Hence, as internal resistance, **R**, increases, the maximum recommended average current, **I**, must decrease, in order that we do not exceed the 6-watt/Ah dissipation limit within the battery pack.

4. Label the LiPo battery with the maximum continuous current output

- Apply a small label to the LiPo battery showing the *Max **Continuous** Amp Draw*.
- Periodically, measure the *internal resistance* of the LiPo battery and update this small label, as the LiPo ages and its *internal resistance* increases.
- Choose an electric motor size to accommodate the LiPo battery system.
- Excessive heat, more than 6-watts per ampere-hour of LiPo capacity, will cause thermal damage to the LiPo battery, and shorten its life.

APPENDIX

C-Rating of LiPo batteries

There are five things that we need to know about a LiPo battery.

As summarized by John Julian[5] (from Melbourne, Australia), the five most important features of a LiPo battery are:

1) **number of cells** (which determines the nominal battery voltage
2) **capacity** in milliampere-hours (which determines how much energy the battery can store)
3) **C-rating** (which determines how much current the battery can safely deliver)
4) **weight** of battery
5) **shape** of battery

The number of cells, the weight, and shape of battery are easy to determine.

The capacity in mAh and the C-rating are printed on the battery packaging.

However, the **C-rating** of the battery can be misleading. Does it mean that the LiPo can supply continuous current at the C-rating, until discharged? Or, can the LiPo battery supply this C-rating of current for a brief second or two?

Recall that the **C-rating** is defined as a multiple (or multiplier) of the ampere-hour capacity of the battery; a current that the battery is capable of discharging continuously over a full discharge cycle, in $1/C^{th}$ of an hour.

For example, a 20C-rating on a 2,200 mAh LiPo battery would mean that the LiPo will supply 20 X 2.2 Amperes = 44 amperes over a full discharge cycle, in $\mathbf{1/20^{th}}$ of an hour (or for **3 minutes**).

Three experimenters located in Australia (John Julian) , the United States (Mark Forsyth) and in the UK Wayne Giles) have derived an empirical expression to predict the maximum current that can be safely drawn from a LiPo battery, without damaging the LiPo battery, and shortening its life.

The expression is as follows: Max Amp draw = $\sqrt{\dfrac{6\,\frac{Watts}{amp-hr} X\ capacity}{internal\ resistance}}$

This expression for maximum **continuous** current drawn from a LiPo is based on field use, and experimentation.

[5] http://www.rcgroups.com/forums/showthread.php?t=1577989 "A Simple LiPo Performance Tool"; thread #1

By measuring the *internal resistance* of the LiPo battery, and using the expression above, one can calculate the maximum **continuous** current that can be drawn from the LiPo battery without damage to the LiPo battery.

For example, if the measured *internal resistance* of a 2,200 mAh LiPo was 14.4 milli-ohms (or 0.0144 Ω), the maximum current that can be drawn from the LiPo battery without damage to the LiPo battery is:

$$\text{Max Amp draw} = \sqrt{\frac{6\,\frac{Watts}{amp-hr} X\ capacity}{internal\ resistance}} = \sqrt{\frac{6 \text{ X } 2.2}{0.0144}} = 30.3 \text{ Amperes}$$

And this shows that the *true* C-rating of the LiPo battery is only $\frac{30.3}{2.2}$ = 13.8 or about 14

- **The true C-rating of the 25C 2,200 mAh LiPo is only 14C.**

LiPoly Objective Performance Calculation Tool[6]

Another way to find out the *maximum rated current* and the *true* 'C' rating of the LiPo battery is to use the LiPoly Objective Performance Calculation Tool found at:

http://www.jj604.com/LiPoTool/

Using this on-line Internet calculator, enter: a) the *cell capacity* (mAh as printed on battery label) and, b) the measured *internal resistance,* into the calculation tool chart. The performance tool does a calculation and shows the "*maximum recommended average current draw to prevent pack damage*" and the *'C' rating of pack based upon the internal resistance measurement*."

This on-line calculator also provides a *figure of merit* (FOM) that can be used as a means to sort and qualify LiPo batteries. It is very useful when comparing battery packs of different sizes and from different manufacturers. The larger the calculated FOM, the better the LiPo battery.

The FOM is calculated as follows[7]:

$$\text{Figure of Merit(FOM)} = \frac{12000}{mAh\ capacity\ x\ internal\ resistance}$$

For example , a 1,300 mAh LiPo has a measured internal resistance of 5.31 milliohms

$$\text{FOM} = \frac{12000}{1{,}300\ x\ 5.31} = \frac{12000}{6903} = 1.74$$

[6] http://www.jj604.com/LiPoTool/
[7] Wayne Giles, Report #1: http://www.rcgroups.com/forums/showthread.php?t=1392662&page=1

Internal Resistance

Internal Resistance (IR) is an empirical (measured) value that describes observed behaviour; it is not a description of what the cell is doing. A LiPo battery used in the way modellers normally use it, behaves to a reasonable approximation as though it were a voltage source in series with a small resistance inside the battery – hence Internal Resistance. A LiPo is not however **actually** a perfect voltage source containing an internal resistor. It just behaves roughly **as though it was** and that makes it easy to make some predictions about battery performance without having to analyse the electro-chemistry of the internal workings in awful detail.

Critically it is important to understand there is no "internal resistor" so you can use some resistor rules (two cells in parallel have half the IR of one) but not others (IR varies dramatically with temperature in a way a resistor does not). That is why the Effective Series Resistance (ESR) term is really preferable.[8]

Cell internal resistance should be measured in the following manner:[9]

1) After 1 hour minimum rest to stabilize charge and pack temperature (or at 1C max charge rate if using FMA charger).

2) At measurement temperature of 72F (22C).

3) Using a reliable IR measurement method such as the (Wayne Giles) ESR/IR meter, an iCharger 3010B[10], iCharger 306B[11], or FMA Powerlab PL8[12].

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[8] John Julian; http://www.rcgroups.com/forums/showthread.php?t=1577989; thread #2
[9] Mark Forsyth, Report #2 at http://www.rcgroups.com/forums/showthread.php?t=1578001#post20484169
[10] ProgressiveRC; iCharger 3010B; http://www.progressiverc.com/icharger-3010-b.html
[11] ProgressiveRC; iCharger 306B; http://www.progressiverc.com/icharger-306b.html
[12] ProgressiveRC; FMA Powerlab PL8; http://www.progressiverc.com/fma-powerlab-8.html

Effective Series Resistance (ESR) Meter[13]

- To measure the performance of a LiPo, in comparison to any other LiPo (provided each battery is at the same temperature, when ESR is measured).
- To be able to calculate the maximum current which it is safe to take from a LiPo at a specific temperature

Figure 1: ESR Meter designed by Wayne Giles[14]

The ESR meter measures the "internal resistance" of the LiPo battery by drawing a 16-ampere current out of a cell in the LiPo battery, for 15-milliseconds and then measuring the voltage change between open circuit voltage and voltage under load.

For 3-seconds, the computer internal resistance value is displayed on the LCD screen.

$$R_{internal} = \frac{(open\ circuit\ voltage) - (voltage\ under\ load)}{16\ amperes}$$

The brief pulse of current (for only 15-msec) is not long enough to heat up the cell in the battery which would affect the ESR (internal resistance).

For a 3S LiPo, the internal resistance is measured for **each of the three cells**, **via connection to the cell balance connector on the LiPo battery**. This measurement is a *4-wire Kelvin connection*. (The 4-Wire Kelvin connection is illustrated elsewhere in this Appendix).

Recall that ESR (internal resistance) has a negative temperature coefficient; that is, if the temperature of the battery goes up, the internal resistance goes down; and vice versa.

The ESR meter was designed by Mr. Wayne Giles, at [wm.giles@zen.co.uk] and is available from him in the UK.

The ESR Meter is also available from ProgressiveRC at [http://www.progressiverc.com/esr-meter.html].

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[13] Report #1 at http://www.rcgroups.com/forums/showpost.php?p=16303185&postcount=1
[14] Report #1 at http://www.rcgroups.com/forums/showpost.php?p=20038311&postcount=249

User Instructions for ESR Meter For 2 to 6 Cell LiPo Packs[15]

OVERVIEW

A LiPo pack can be considered as a perfect stable voltage source in series with a small series resistance: its ESR, or Equivalent Series Resistance. Also known as IR or Internal Resistance.

This resistance or ESR, is made up of the total resistances of each cell plus the resistance of the interconnections, the power leads and the contacts of the power connector. Once we have chosen a pack, the only "resistance" we have any control over is the connector which represents only a small percentage of the total.

It is the ESR which dictates how the pack is likely to perform, both in the short term; i.e. holding its output voltage and delivering more power, and in the longer term, its probable life in number of cycles.

Measuring ESR requires special equipment as a typical value is a tiny fraction of an ohm, and also because ESR is measured across a live power source, i.e. a cell or battery.

ESR – The effects

What does ESR do? In a nutshell, it drops volts, wastes power and heats up and damages the battery. Thus we are looking for the LiPo with the lowest ESR.

If we take a good 3S 2250mAh pack as an example with a pack ESR of, say 15 milliohms, then if the motor is taking 40A, the voltage delivered to the motor is 0.6V higher than a poorer pack with an ESR of 30milliohms. An extra voltage drop of 0.6V doesn't sound much but it is about 5.5% to 6% of the motor volts and will result in 10% to 12% less power at the prop. which is significant and noticeable. The other effect is that the better pack has an internal power dissipation of 24Watts heating it, whilst the poorer pack has 48W. So it gets a lot hotter and as a result is likely to have a shorter life.

The equation is complicated by the fact that the ESR has a negative temperature coefficient (heat reduces the ESR).

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[15] Mr. Wayne Giles, at [wm.giles@zen.co.uk]

Operation

The unit is self powered by the pack under test, the only control being an operate button.

ESR is measured at high current to simulate real operating levels.

When connected to the **pack**, the display will read the voltage of the pack.

If the *search connector,* respecting polarity, is plugged into two adjacent pin positions on the balance connector, the meter will automatically change mode and read the voltage of the **cell** corresponding to those two positions. Moving the *search connector* allows measurement of any cell in the pack. (Balance connector and individual cell wiring are illustrated elsewhere in the Appendix).

To take an ESR reading it is only necessary to press the operating button and the unit will display ESR for about 3 seconds and then revert to reading voltage.

In '**Pack**' mode it will read the ESR of the whole pack plus the connector and leads. This is a practical measurement as it is measuring the total resistance in the circuit that the ESC will see in practice.

In '**Cell**' mode it will read the ESR of just the individual cell that the search wire is connected to via the balance connector, excluding all other leads and connectors. In the '**Cell**' mode the instrument is using a true 4 wire Kelvin connection enabling the user to very accurately compare the ESRs of each individual cell in the pack. (A 4-Wire Kelvin connection is illustrated elsewhere in the Appendix).

SPECIFICATION

Mode	Measurement Range	ESR Resolution	Accuracy	Voltage Res.	Voltage Acc.
Pack	0 – 250 Milliohms	0.3 Milliohms	<3%	40mV	<0.5%
Cell	0 – 30 Milliohms	0.04 Milliohms	<2%	10mV	<0.3%

Measurement current: 16A. (for 15-milliseconds)
Maximum Pack Voltage: 30V.
Protection: Unit is protected against reverse polarity on both main power and search wire inputs.
Range: The unit can measure any LiPo pack of 2 to 6 cells in the range of 500mAh – 6000mAh.
Size: 45mm x 100mm x 130mm (1.8” x 4” x 5”)
Weight: 200g (7 oz)
Standard Connector: Deans

(Do not attempt to measure packs of over 6 cells. Meter will suffer permanent damage).

OPERATING NOTES

(a) Temperature

The ESR of any LiPo is dependent on temperature; the lower the temperature, the higher will be the ESR.

When comparing two packs therefore it is essential that you do so at the same temperature. Leave the two packs together for an hour or two to ensure this.

To demonstrate this, take a cell reading of cell 1 on a pack. Hold the palm of your hand against the flat side of cell 1 for only 15 seconds and take another reading. You will see that the ESR has fallen slightly. The ESR of LiPo packs can vary by 30 to 90% for a temperature change of 10^{o} to 30 ^{o}C (50 to 85^{o}F).

(b) Winter Flying

The above demonstrates why it is important to warm your LiPos before use in cold conditions. If you launch with cold LiPos the voltage and power level is much lower, often to the point where the ESC could shut down on undervoltage. The current through the LiPo will heat it up (and damage it!), reduce the ESR and the power will gradually rise. This is why so many LiPos fail in cold weather. Therefore pre-warm your LiPos in winter.

(c1) Interpreting Values - "Pack" Readings

In this mode the meter measures the total resistance of the cells + the resistance of the links between cells + resistance of the leads + the resistance of the connector. This is the effective resistance in the circuit in real conditions. You can assume that leads plus a good 50A connector have a resistance of about 2 - 5 milliohms. (i.e. Pack ESR = $\sum$ Cell ESRs + 2 to 5 milliohms)

Try to take readings at the same temperature, say 22^{o} C so that you know what is a good reading for a particular pack size. For example, a good 3S 2250 20C pack will be about 15 – 20 milliohms whereas a poor pack will be 40 milliohms or more.

Some packs have a higher ESR but also a high temperature coefficient so that their initial voltage drop is higher but reduces due to self-heating. They may finish at the end of their discharge with a similar performance to the lower ESR pack, but they are hotter, more highly stressed and likely to have shorter lives.

Be suspicious of any LiPo which appears to show improving performance during a flight.

(c2) Interpreting Values - "Cell" Readings

In Cell mode, the meter reads only the ESR of the cell corresponding to the two adjacent pin positions on the balance connector. The reading is taken as a 4-Wire Kelvin connection so that only that specific cell is measured and very accurately. (A 4-wire Kelvin connection is illustrated elsewhere in the Appendix). No other wires or contacts are included in this value so that you can now accurately compare all the cells in the pack. Some makers claim that their cells are "Resistance matched" and this can be checked.

When a pack is damaged or dying, it is invariably one cell which is deteriorating and this will be shown in the ESR value rising, so you can track the degeneration of your LiPos and know which are the better ones.

(d) Voltage Readings

In default mode, the meter will read the pack or cell voltage, dependant on mode. It is not intended as a precision Voltmeter as the resolution is limited, but it is accurate and consistent enough for general use and cell voltage comparison purposes.

(e) Current Operating Level

The unit uses a 16 Amp constant current pulse to measure the ESR of a pack. This is large enough to facilitate an accurate measurement of a large capacity pack but small enough to be acceptable to a small LiPo without damage. (The pulse lasts for only 15-milliseconds).

(f) Error Readings

If the main input is reverse connected to a pack, the unit will not be damaged, but the display will not appear.
Reversing the cell measuring *search lead* (much more likely) will again cause no damage, but the meter will not change mode or read the cell voltage.

The lowest voltage at which a battery pack can be measured is 7.0V, so that a very small or tired 2 cell LiPo may give a false reading unless fully charged..

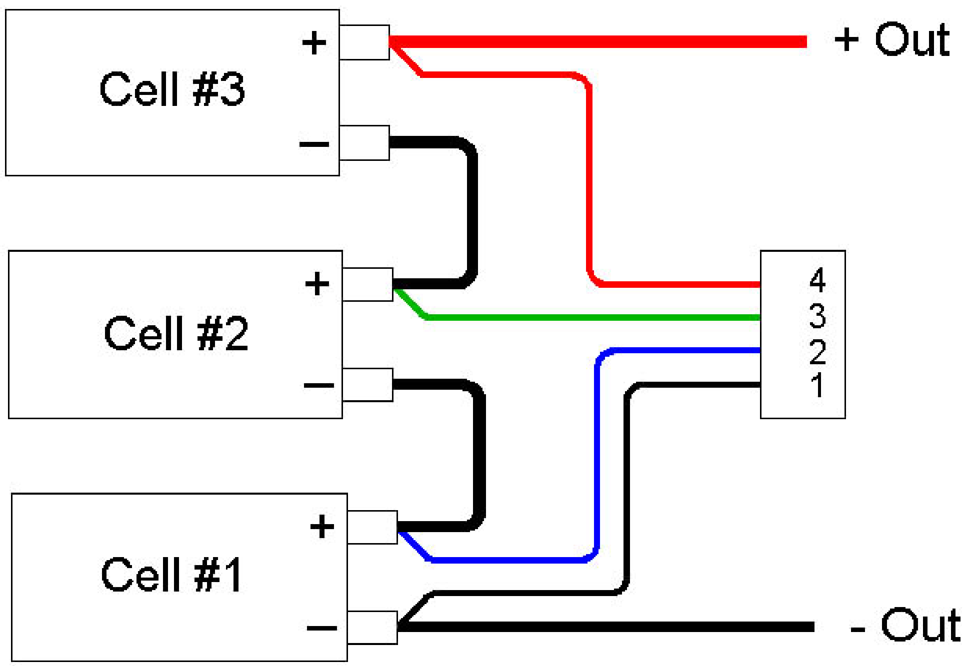
(g) State of Charge

The ESR of a LiPo is largely independent of its state of charge, unless the pack is completely exhausted, which is unwise in any case. It is possible to connect the meter in parallel with a working load (ESC + Motor) and monitor the ESR as the discharge proceeds. This will clearly demonstrate the self heating effect and consequent fall in ESR as the battery temperature rises.

Cell Balance Connector

Here is a typical 3S LiPo balance connector wiring scheme as posted by Lucien Miller in San Marco, California[16]

Figure 2: 3S Cell Balance Connector



There are numerous physical types of balance connectors. This is an example of a balance connector that provides voltage sense lines to the three cells making up this LiPo battery in 3S configuration.

When the ESR Meter's ***search connector*** is plugged into two adjacent pin positions on the balance connector, the ESR meter will read the voltage of the cell corresponding to those two positions.

Cell #1 (-) to balance connector pin: 1 and Cell #1 (+) to balance connector pin: 2
Cell #2 (-) to balance connector pin: 2 and Cell #2 (+) to balance connector pin: 3
Cell #3 (-) to balance connector pin: 3 and Cell #3 (+) to balance connector pin: 4

When measuring the internal resistance on a cell by cell basis, make a note of the balance connector wire colours or make a note of the balance connector pin number, (if visible), to identify which cell is being checked for internal resistance. Different battery manufacturers will use different wire colours at their balance connector. The colours are not important, but it is important to associate a cell with its wire colour pair, for future measurements that will be repeated on the same cell.

[16] Report #47; http://www.rcgroups.com/forums/showthread.php?t=441307&page=4

4-Wire Kelvin Connection[17]

Four-terminal sensing (4T sensing), **4-wire sensing**, or **4-point probes method** is an electrical impedance measuring technique that uses separate pairs of current-carrying and voltage-sensing electrodes to make more accurate measurements than traditional two-terminal (2T) sensing.

The key advantage of four-terminal sensing is that the separation of current and voltage electrodes eliminates the impedance contribution of the wiring and contact resistances.
It is used to measure very low resistances.

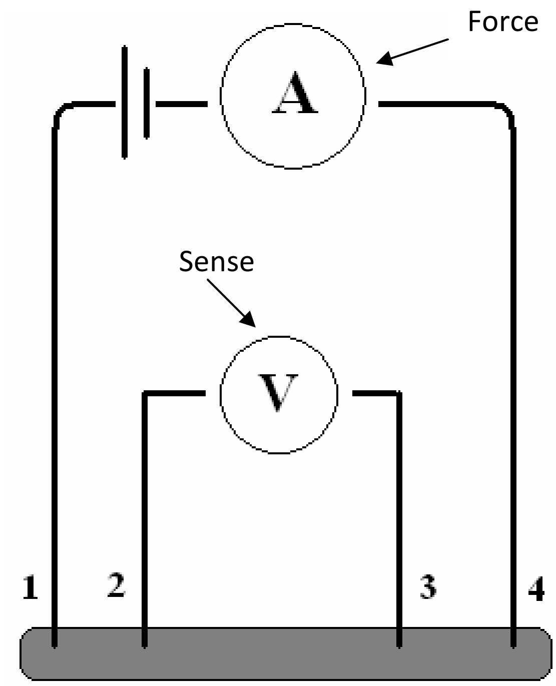


Figure 3: 4-Wire Kelvin Contact

When a Kelvin connection is used, current is supplied via a pair of **force** connections (current leads). These generate a voltage drop across the impedance to be measured according to Ohm's Law $V=RI$. This current also generates a voltage drop across the force wires themselves.

To avoid including that in the measurement, a pair of **sense** connections (voltage leads) are made immediately adjacent to the target impedance.

The accuracy of the technique comes from the fact that almost no current flows in the sense wires, so the voltage drop *across the sense wires* is extremely low. Hence, measured voltage drop is very close to the actual voltage drop.
Essentially, they are the same; measured = actual.

[17] http://en.wikipedia.org/wiki/Four-terminal_sensing

{Tear-out copy of table for your field box}

Table 3: Maximum continuous current that can be drawn by the load without damage to the LiPo battery[18]

LiPo battery Capacity	Max Amps @ 3 mΩ	Max Amps @ 6 mΩ	Max Amps @ 9 mΩ	Max Amps @ 12 mΩ	Max Amps @ 15 mΩ
500 mAh	31.6 amp.	22.4 amp.	18.3 amp.	15.8 amp.	14.1 amp.
1,000 mAh	44.7 amp.	31.6 amp.	25.8 amp.	22.4 amp.	20.0 amp.
1,500 mAh	54.8 amp.	38.7 amp.	31.6 amp.	27.4 amp.	24.5 amp.
2,000 mAh	63.2 amp.	44.7 amp.	36.5 amp.	31.6 amp.	28.3 amp.
2,500 mAh	70.7 amp.	50.0 amp.	40.8 amp.	35.4 amp.	31.6 amp.
3,000 mAh	77.5 amp.	54.8 amp.	44.7 amp.	38.7 amp.	34.6 amp.
3,500 mAh	83.7 amp.	59.2 amp.	48.3 amp.	41.8 amp.	37.4 amp.
4,000 mAh	89.4 amp.	63.2 amp.	51.6 amp.	44.7 amp.	40.0 amp.
4,500 mAh	94.9 amp.	67.1 amp.	54.8 amp.	47.4 amp.	42.4 amp.
5,000 mAh	100.0 amp.	70.7 amp.	57.7 amp.	50.0 amp.	44.7 amp.
5,500 mAh	104.9 amp.	74.2 amp.	60.6 amp.	52.4 amp.	46.9 amp.
6,000 mAh	109.5 amp.	77.5 amp.	63.2 amp.	54.8 amp.	49.0 amp.

Note: table is based on LiPo not exceeding an internal heat dissipation of 6-Watts/ ampere-hour

[18] Mike Anderson; "How Good Are Your LiPos?"; Model Aviation-Canada, Vol.44, No.1; pages 54-55.