Lipo ESR Meter Mark II User Guide

Please read entire document before using this meter

Always test packs as close to 72F/23C as possible as IR changes with temperature

Always connect MAINS first

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If the meter doesn't power up after mains are connected, **DO NOT connect the balance cable**, the cause is usually a totally dead pack, defective connector on the pack or reversed polarity. Isolate and fix the cause before you continue.

If the XT-60 connector is not what you use on your packs a high-quality adapter is acceptable with minimal noticeable changes in IR readings. It is also advisable that if you use mostly Deans or APP or EC3 or EC5… then by all means, unsolder this supplied connector and solder on your connector of choice and be extra careful to not reverse polarity.

Once you power up and the LCD screen lights up, you can plug in the balance connector ensuring the pack's negative is mating to the balance extension cables first black wire. It will show the voltages of each cell on this HOME screen by posting voltage of Cell #1 to the left of V1. Cell #2 will be to the left of V2…and all the way to a maximum of V6 for 6 cells.

The pack size from the factory is set to 1300mAh. If you have a different size pack plugged in, push and HOLD the left button for 1 second. When the button is released it will be in page 1 of 5 pages of pre-set pack sizes. **Page #1** is the most common sizes based on a survey of average users and will have 1300, 1800, 2200, 4000 and 5000 sizes available. If this list contains the pack size to be tested press the **SCROLL↓** button 5 times to select 5000 and then press the **Choose** button to select this pack size. From the screen you can either **Edit it** or **Use it** by pressing your desired button under these 2 options. Select **Use it** and your meter is ready for use for a 5000mAh pack from 1 cell to 6 cells.

If you do not see your pack size in Page 1, press the **LEFT** button to **SCROLL↓** and choose **>Next<** to search for your pack size. You can repeat as needed up to 4 times as the last page of presets is page #5.
Pack sizes are only available in 100mAh sizes so if you have a 1750 you will need to round up or round down. The end result is so minimal it will not matter if you round up or down.
If you decide to not change pack size AFTER you began the process press and hold the LEFT button it for 1 second and this will return you to the HOME screen.

How to change a pack size to a custom size.
If you have, for example, a 3300mAh pack, you can edit a pre-existing size from Page 1 to Page 5. We left some slots open on page 5 for this if you don't want to change any pre-defined mAh sizes.
From this, select **CHOOSE** and then edit the custom size as needed. In the case of the 3300 pack mentioned above, we press the → button 1 time to move from the ten thousand to thousand location. Now press the +1 button 3 times to edit the thousand to get to 3000. This can go from 0000 to 9000. Now press the → button 1 time to edit hundreds and the left button 3 times to get 300. This now matches your pack size so press the → button and the screen will show **You close: 3300mAh** and you can either **Edit it** or **Use it**. Select **"Use it"** and the screen will return to the HOME screen. That pack size is written and saved in the eprom and will always be there unless you change it.

From page 6 of presets there is an option of **Reset**. Doing this will reset all mAh values to the factory defaults.

Consider this: Use page 1 and page 2 for your packs and your buddies can use Page 3, or page 4 or page 5 and customize each page to match their most common used pack sizes. These can be overwritten over 10,000 times so don't worry about making changes, this function should outlast the meter AND you can always do a factory RESET to get rid of their custom sizes…but yours will be lost too.
Remember, when changing pack sizes, if you decide not to change sizes and want to keep the last pack size used, just press and HOLD the left button 1 second and it will revert to the HOME screen.

Once you have the pack size selected and are at the HOME screen the meter will recall the last time used option for **ESR:mΩ** or **ESR: max A**. You can push the Left Button to toggle between **ESR:mΩ** and **ESR: max A**.

In **ESR: max A**, the top line will show the **FoM** (Figure of Merit) and C rating. **NOTE that the C rating is a very conservative C rating** and should only be used as a reference but not the actual C rating the pack can deliver. This is done to protect you, the end user, from over stressing a lipo.
Line 2 will calculate the total pack voltage on the left and on the right will be the amps copied from the lowest performing cell in the pack based on the ESR values.
The lines under that will be each cells voltage and max constant amps.

As designed, all voltages will update around 2 times per second and it is normal to bounce up and down a few thousandths of a volt.

The C ratings are generated from extensive work by John Julian, Wayne Giles and Mark Forsyth as they were gathering information over many months from users like you and came up with a calculation to estimate the maximum "safe" amps a pack can be discharged for the full 80% discharge without damaging any cells. This meter uses that calculation and an on-line version can be found here: http://jj604.com/LiPoTool/
This worked great until Hobby King came out with the Turnigy Graphene line and these performed unlike any lipo I have ever tested in the past. Since then many other companies have come up with much better performing cells and each, in their own way, may be equal or better based on weight, max amps or energy density and all are considered top of the line lipo's.
It is my opinion and **MY OPINION ONLY** that a lipo displaying 30C or higher at 72F on this meter is a true 45C battery but don't expect to get the maximum cycles possible out of it if you push it to it's limits.

If you press the left button the screen will toggle to **ESR:mΩ** and the top line will show **FoM** on the left and max amps on the right based on a reading copied from the lowest performing cell in the pack from **ESR: max A** .
On line #2 the meter will display total pack voltage on the left and pack mΩ on the right. You will notice the pack mΩ is not the same as if you add all cells and get a total mΩ value. This is due to the meter taking a 2 wire IR reading for pack mΩ and, like so many chargers and other IR testers, it must add the resistance of the main discharge wires from the meter to the pack including the connectors of choice. This adds a considerably higher resistance to the total pack IR and is why we use a Kelvin (4-wire) method of measuring internal resistance of individual cells.
On line 3 and beyond, each cell's voltage will be displayed on the left and ESR in mΩ on the right.

If a cell's reading is blank the balance tap may be plugged in improperly or voltage for that cell has fallen below 0.8 volts If a cell reads **Over_V** it is showing you that either the mains are not plugged in and/or the balance cable is not plugged in correctly or a balance tap wire is broken (OPEN). Any OPEN will cause the meter to not read correctly for 1 cell or more as the meter must have a common (negative) for each cell.

If you try to take a reading faster than 1 second, the internal buzzer will give a longer buzz and that is a reminder for you to not press the button faster than once per second. This is to protect the power FET from burning up if a button happy person tries to read, read, read… too fast and too long.

Some facts
If you press the button several times with 1 second intervals you will notice the readings to bounce up and down some. This is normal but to lessen the bounce we added an average. After the 4th READ we will average the last 4 values. If you press a 5th time we drop the 1st value and average the last 4 values. We will continue to drop the 1st values of the set as you continue pressing the button.

Remember, a pack will ALWAYS show higher resistance if you only test through the discharge lead. If you take an ESR reading with the balance connector and add the total mΩ of each cell it will be quite different. This is because you are performing a Kelvin (4-wire) method of measuring cell voltage separately through the balance leads and does NOTE add the resistance of the battery leads and connectors. This is the reason many chargers and most hand-held IR meters are not very accurate or consistent and why the Wayne Giles original ESR Meter and this Mark II ESR Meter are considered the Golden Standard of lipo IR measuring devices.

Hidden options:
Press and HOLD the right button when you plug in the main leads. Credits go to the first 3 gentlemen mentioned for all their hard work shared on RCGroups.com in the battery forum and their dedication early on to try to make sense of what is a "True C" rating and calling out manufactures C rating hype. Hopefully you know by now most lipo's sold today have grossly overstated C ratings but, unfortunately, if a seller doesn't exaggerate C ratings their sales will drop so they live in a vicious world. Presently (mid-2019) the highest true C ratings that Wayne and John have found is a true 55C. Do we need 55C? No, but in my testing for several of the largest lipo sellers in the USA and abroad I have found that as the true C of a pack increases so does the potential cycle life. I have tested one pack that has over 1,900 30C discharge cycles and it is still testing at 25C on these meters which makes it about as good an average new pack.

Press and HOLD the left button when you plug in the main leads. That is me and I am NOT an engineer but the one with deep pockets to pay Greg for his hundreds of hours of work and his buddy Robert to do the PCB layout and my retired friend Carl White which did initial pre-release technical testing and Proof reading and editing of this user guide.

More extensive information can be found here:
http//www:liporatings.com
https://www.rcgroups.com/batteries-and-chargers-129/
http://jj604.com/LiPoTool/

The following is a snip from LiPoRatings.com and written by John Julian

Permission to use approved by John Julian

The full version of this writing with graphs can be found at LiPoRatings.com

What do we currently know about LiPo performance and IR?

The short story.

Internal Resistance (IR) is an empirical (measured) value that describes observed behavior; it is not a precise description of what the cell is doing internally. A LiPo battery, used in the way modelers 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 analyze the electro-chemistry of the internal workings in awful detail. The equations involved, and their solution, is not the stuff ordinary folks want to be involved in.

Here's the variables we know about:

1) Test method. IR of batteries is calculated either by measuring the DC voltage change between loaded and unloaded state1,or applying a known AC frequency and measuring the impedance. The latter is the standard industry way of doing it, is rapid and easy to do, and is fine for Quality Assurance in LiPo manufacturing - but it returns "IR" values that are significantly lower than DC values. The impedance of a LiPo is lower than its DC resistance as the LiPo has significant capacitance. Vendors like this, as it makes their packs look better than they actually perform in DC applications like ours. DC load methods are more realistic for flight packs but are very dependent on the time you apply the load for - and that's why values from the Wayne Giles ESR/IR meter, which is a pure DC load method, are sometimes different from values returned by some chargers, which stop charging briefly and measure the cell voltage difference between the charging and unloaded state.

   However, even if you use the same measurement method without fail there are still significant variables:

2) State of Charge. The measured IR varies a bit with the state of charge (SOC) of the LiPo but it's not actually a big variation. A LiPo is fully charged at 100% SOC and completely exhausted at 0% SOC. IR is minimum at 100% charge and rises very slightly as the pack discharges until you get to about 10% SOC at which point it shoots up.

3) Pack size. The measured IR for a particular chemistry is inversely proportional to the capacity of the pack. A larger pack contains a larger electrolytic pathway for the electrons to move across, so the resistance to travel is less. Think of how a single lane highway can accommodate only a quarter of traffic at the same speed as a four lane one. The "resistance" to traffic flow is 4x that of the bigger highway.

4) Age of the pack. IR rises as packs age. Provided there is no actual cell failure, it seems as though this is again dependent on cell chemistry and construction. Reliable genuine cycle life numbers are very hard to come by, but the collective wisdom is that "heavy" packs like the Turnigy Graphenes and Panthers have a much slower increase in IR over elapsed time and number of cycles than HV2 packs and lightweight graphene packs. It is plausible that this is related to internal temperature rise, as heat is pretty much the enemy of any consumer battery. Note that this is not an absolute judgment as a pack that runs hot will have lower IR (see 5 below) and may perform better even although it won't last as long.

5) Temperature. This is the Biggy. The measured value of IR is very dependent on the measurement temperature. Different chemistries have quite different IR vs. Temperature curves but all show a very dramatic increase in measured IR as temperature drops below room temperature. The changes can be large. A drop of 10°C can nearly double the IR value. That's why Wayne Giles, Mark Forsyth, John Julian and others are obsessive about emphasizing that IR must be measured at a standard temperature - normally 22°C or 72°F if you want to compare results of different packs. In practice no one has the means to measure the internal temperature of a LiPo so the standard advice is to leave the pack in a 22/72 degree environment for at least 2 hours before measuring IR. Of course, if all you want to do is an instant check on the consistency of each cell IR across a single pack, the temperature and state of charge can be ignored. This temperature effect also explains the good performance of some otherwise high initial IR packs. The large internal heat generation of a high current load rapidly reduces the IR and reduces the internal voltage drop. This is evident in high current constant load tests by a dip and then recovery in the cell voltages in the first seconds of discharge. If it doesn't destroy the pack prematurely it is almost certain it accelerates its demise. Such packs may "flare brightly but briefly". In practice they might still perform well for as long as required, depending on the expectation and requirement.

Bottom Line:

IR measurement is not a substitute for the proper load testing that is reported on this web site. But, provided you maintain consistency in test method and conditions, it is a very convenient, quick and non-damaging way to get an indication of the relative quality of different packs.

Note that you can use individual cell IR or total pack IR (the sum of the individual cell IR values since all the cells are in series) whichever suits. Individual cell IR, normally using the highest individual IR value as the IR "bottleneck", has the advantage that you can compare the quality of packs of different cell counts directly without any mental arithmetic.

Why is Internal Resistance useful?

The long story

To repeat: Internal Resistance (IR) is an empirical (measured) value that describes observed behavior; it is not a precise description of what the cell is doing internally. Critically, it is important to understand there is no actual "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 ESR term, used here to mean Effective Series Resistance, is really preferable. ESR is normally used for Equivalent Series Resistance which is the series resistive in-phase component of a reactive AC circuit which also has inductive and capacitive values. When applied to LiPo measurement, it just means the effective resistance to current flow within the battery measured in Ohms. Importantly, IR is a measured number not an intrinsic property**, so that different methods of measuring IR give different numbers.**

Of the various tools used to measure IR, the Wayne Giles ESR/IR meter uses the Kelvin (4-wire) method of measuring cell voltage separately through the balance leads to avoid errors caused by resistance of the battery leads and connectors. At least one other meter and most chargers that report an IR number use the 4-wire method. A number of Wattmeters also report an IR value. If they have only two wire connections to the battery and load, it can be assumed that the IR values are nonsense. It has been determined that although the numbers measured by different methods are all slightly different, they are generally fairly consistent across different batteries if using the same method.

The important caution is that, when comparing IR numbers, you can only reliably do so if you know at least:
- The test temperature; AND
- The method used to measure them.

Why use this number?

If it is so prone to measurement variables, why use IR at all? Well, C rating is largely now meaningless since that also needs to be specified under particular conditions - and never is, and never will be, since it is not in the manufacturer's interest to do so. However, a great deal of practical experience by a number of knowledgeable folks over several years and in several countries suggests that, properly specified, IR is a "good" measure. It is fairly easy to do with the right equipment, easy to understand and, with relatively few controlled conditions, values can be compared. Practical experience to date has shown it is a good guide to real performance. For example, there is some evidence that different manufacturer's batteries respond differently to temperature - IR predictions for Brand A vs. Brand B in Norway in winter and Arizona in summer are a reasonable predictor of actual behavior.

What is the importance in practice?

Typically, a LiPo discharged under increasing currents displays a set of voltage/time curves something like this picture.

{Graph removed}

The graph is of measured cell voltage on the Y axis against elapsed time on the X axis at very high constant current discharge rates for a high performing pack. As the discharge current goes up the cell voltage drops because there is a higher voltage drop within the cell due to IR and the heat generation within the cell increases4.
Note how that as the discharge rate increases - measured as "C" which equals the actual current divided by the manufacturer's mAh rating - the available voltage to the power system drops and the final pack temperature rises eventually at high enough C, the cell simply cannot maintain any useful voltage.

Temperature rise is a function of the internal heating (high IR and/or higher current means that more heat is generated inside the battery), the physical configuration of the battery (big batteries have lower IR but poorer surface/volume ratios, multiple cells have poorer heat dissipation than a single cell since they have less surface area exposed), and the external cooling conditions (ambient temperature, air flow etc.).

Normally up to a certain discharge rate the voltage curve falls with increasing current and continues to decrease with time. However, at some fairly high current, the curve dips, and then rises again as the internal heating of the battery accelerates the chemical reactions inside and produces more volts. This is the blue line in the graph. The battery is certainly being abused at this point and will have a short life. Wayne Giles and Mark Forsyth developed a simple tool to predict a “reasonable” maximum current drain based on the heat dissipation inside the pack calculated from the measured internal resistance. It is available on John Julian’s website here at: http://jj604.com/LiPoTool/
The aim of the maximum current calculator is to give a very simple tool to estimate the maximum current any particular battery is capable of while maintaining a decent cell voltage and limiting the internal thermal heating.

It is not a theoretically derived tool but one based on a number of years of observation of the performance and heating of batteries under test and in flight. The conclusion is that placing a limit on the power dissipated in the battery as a function of its capacity is a remarkably good guide to the maximum current rating. This has proved true over a range of commonly used battery sizes down as far as the tiny single 150mAh cells used in the micro fliers from Parkzone. It is a conservative estimate and suggests a maximum current for any pack that will optimize both performance and life of the pack.
Note that other Lithium chemistries may be different, and you should not assume that "known" facts for other packs, such as the common LiIon cells or LiFe, necessarily apply to model flight packs.

As emphasized previously, actual IR values are **very** dependent on how you measure them. This cannot be over emphasized. Unlike "intrinsic" properties like weight and size, the values are not invariant. If you measure the weight of a sealed LiPo pack5then, assuming your instruments are accurate, you should get exactly the same weight (allowing for a miniscule variation in the force of gravity at a different location) as anyone else. IR is not like that. It is a "derived" value and depends on the simplifying model you assume for a real LiPo. A real LiPo is a very complex little electrochemical factory and most of us don't pretend to understand exactly what is going on inside in all its detail. Like most things in electricity however the behavior can be simplified by a model that puts together a few well understood fundamental components that mimic the behavior of the real thing. A battery model may consist of several ideal voltage sources, several ideal resistors, several ideal capacitors and several ideal inductors and possibly some complex temperature dependent components. The simplest practical approximation to a real LiPo is a single ideal voltage source in series with a single internal resistor. The more current you pull, the bigger the voltage drop over the internal resistor, the more the voltage drop at the pack terminals and the more the internal heating. But this is an oversimplification. Real LiPos don't behave like this. However, adding more and more "corrections" makes it impossible to do any meaningful analysis and predictions so this very simple model is pretty good **provided** you keep all the other variables constant. The 5 key variables that need to be controlled were listed in the first section. Of these, the one that probably cause the most cases of differing results for the same pack is temperature.

Here is a set of curves showing dependence of IR on temperature for a number of different Turnigy packs of the same size
{Graph removed}
They were measured with the ESR/IR meter over a temperature range mostly from 50°C (122°F) down to well below freezing (0°C).

Analysis of a large number of these curves shows no straightforward mathematical equation that fits the curves. They seem to be unique for each pack chemistry.

The 5 significant take away messages are:

- All curves show a decrease in IR with increasing temperature.
- As it gets significantly colder the IR shoots up extremely rapidly. This is recognized in cold climates as the “Winter failure” problem if you do not pre-heat your LiPo packs.
- Curves for different chemistries, even from the same vendor, can cross over. This means that a pack which might have higher IR at room temperature than another could actually perform better than the second when it warms up.
- The curves demonstrate how vital it is to standardize on test temperature. There can be over 50% difference in cell IR value for exactly the same cell measured at 20° (68°F) and 30°C (86°F).

What is meant by the statement that the value of IR is “dependent on the measuring method”?

No one suggests that the value of IR is **only** dependent on measuring method but it is a critical factor to understand. What is meant is this.

There is no actual resistance inside a LiPo that we can measure with an Ohmeter and get the same and identical result no matter when or who the measurement is done by. The "internal resistance" is a component in a simplified conceptual model as noted previously. We know it is not entirely accurate and folks doing more sophisticated work on things like electric traction batteries may use a much more complex model with a greater number of individual elements to analyze. But for most of us, this is beyond practical and the simple model is good enough to predict performance. All “modeling” in science is a compromise between simplicity and accuracy of similitude and this compromise is at the simplicity end of the spectrum.

Although we cannot directly measure an internal resistance in Ohms, what we can do is measure current and voltage with precision when we put a load on the battery. The drop in voltage divided by the current has the value of Ohms and is a measured value of the 'internal resistance'.

So, we know we can measure voltage and current to high accuracy, and the various meter and chargers measuring IR are unlikely to suffer from lack of precision. However, there is one big variable that is not present in normal resistance measurement. How long, and how often, and in what manner do you load the battery to get the measured voltage drop. This is what is meant by "Measured IR values are **very** dependent on how you measure them." Extremely precise meters that are properly calibrated will return different results if you load the cell for different times, or use several pulses and average rather than a single pulse, or measure the voltage rebound during charging when the charge current is removed and so on. None of these values is intrinsically the 'correct' one. Provided the meter/charger is well designed to be stable and accurate, then any of them can be taken as correct.

Three things follow:

- If you want to monitor the performance of your own packs then you should always use the same method and tool under the same conditions. Temperature constancy is the big one as noted earlier.
- If you want to compare IR values with others you need to know how the IR values were measured. You cannot directly compare a value from Wayne's ESR/IR meter with that from a typical charger as they are measuring the IR differently.
- The big question is how you relate a particular IR value to "real life" performance. No one who is serious about LiPo IR has ever suggested that measuring IR is a proper substitute for actually testing packs under load conditions. The sort of comprehensive and well controlled testing that you see reported on this web site. What IR measurement is, is a very quick and simple way to get a reasonable approximation of how a pack will perform in actual service. That approximation in the case of the Giles meter is based on a great deal of empirical evidence. That is, Wayne and others have tested lots of different packs and found that the IR value measured by the meter correlates pretty well with most LiPo pack performance if you make a simple assumption that the internal heat generation calculated from the measured IR value should be kept below a maximum. The important point is that this is empirical - that is, based on a lot of observation of real performance and not some theoretical reasoning. This simple assumption is taken together with a second. The meter design uses a DC pulse load that was again derived empirically by observation of a lot of load curves to give repeatable and representative results. The second assumption that the DC load should be measured after the initial drop has leveled out, but before significant internal heating occurs also seems a reasonable one.

The LiPoTool calculator at http://jj604.com/LiPoTool/ uses these simple findings to predict a "safe" maximum current for any pack. This is a bit arbitrary and deliberately conservative to maximize the life of the LiPo. You can certainly discharge packs at higher currents but eventually you will see shortened lifetimes, puffing etc. We know that some of the modern graphene formulations can do better than predicted by the LiPoTool and we suspect this is because of their very low intrinsic internal resistance to begin with so that internal heating is less with this kind of pack. The Turnigy Graphene/Panthers seem to manage this and provide high C rates but still a long cycle life. Other graphene formulations have higher internal resistance initially but this drops off as they heat up so they may perform similarly at high rates. The question of their longevity is a matter for real world experience.

1. Unloaded means that no current is drawn from the pack, loaded means that a significant current is being pulled from the pack. The exact value, time and sequencing of the current load is an important variable that explains the different values of IR that are obtained by different meters and chargers.
2. High Voltage: typically, 4.35V/cell rather than 4.20V/cell.
3. The first instrument designed solely for hobby purposes, developed by a professional electrical engineer in 2010 as a DIY project, and updated recently by Rick Distler.
4. The cell voltage curve is on an expanded scale on the Y axis from 3.2V - 4.2V to show up the differences more clearly.

{referencing a removed Graph – The unedited version can be viewed at LiPoRatings.com}

5. A LiPo does not gain or lose mass when charged or discharged since it is fully sealed unlike some other battery chemistries like lead acid.

IF meter fails to power up with a 1 cell or 2 cell battery, open unit and replace the internal 9V battery