The Kokam USA
Lithium Polymer Battery System

By
Fred Marks
President, FMA, Inc.

This document is a work in progress.
New information will be added as it becomes available.
Check the FMA Web site (www.fmadirect.com) for updates.

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FMA, Inc.
Exclusive North and South America distributor
for Kokam Lithium Polymer Cells

5716A Industry Lane
Frederick, MD 21704 U.S.A.

Phone: (800) 343-2934
Fax: (301) 668-7619

Web: www.fmadirect.com

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Introduction

A brief history

Lithium Polymer batteries are a new generation portable electric power source. They are different from other batteries used for RC. In 1959, when I became involved in RC, we had only carbon zinc batteries. Lead-acid batteries were used with a converter to generate 180V for the tubes used in transmitters, but about all else was done with carbon zinc.

The first time I ever saw anything other than carbon zinc used in RC was when the great Walt Good came to a meet in the early 1960s with some extraordinary cells he had obtained from Johns Hopkins Applied Physics Lab where he worked. The small Silver Cadmium cells were of great interest, but far out of reach of the average modeler.

Surplus wet Nickel Cadmium cells began to appear from the Nike missile program (they had to be replaced periodically) and found good use as glow plug lighters. In 1962, I obtained my first NiCd button cells from the ABC Battery Company. In due time, cylindrical NiCd cells came on the market with General Electric and Gulton as the first mass producers. It wasn't long until the Japanese acquired the technology and rapidly drove down the price of NiCds.

NiCd technology has seen steady if slow growth over the ensuing 40 years. NiMH became a new technology only in the early nineties and has grown a bit faster than NiCd. The primary attraction for NiMH was lighter weight and better environmental characteristics.

About 1980, Lithium Ion (Li Ion) cells began to be used for light duty, lightweight applications. Li Ion cells began to be modified for RC from retired cell phones and surplus sources only about two years ago. Li Ion cells can tolerate only modest discharge rates but found some use in powering electric airplanes.

Lithium Polymer (LiPo) cells began to see use in 2001 in a small way. The "small way" was primarily in the form of the Kokam Engineering Co., Ltd. 145 mAh cell.

Mr. J. J. Hong, President of Kokam, provided the following brief history of the development of LiPo technology:

> Early in 1980, Motorola and Sony decided to apply lithium ion technology to the mobile phone to reduce weight and improve energy density, even though there were safety issues as there are now. They developed a safety module, the so-called PCM (protection circuit module). Up to now there have been few accidents from Li Ion.
>
> Meanwhile, the Bellcore Lab in San Diego announced that they had developed the lithium polymer battery to increase energy density and safety by using a plastic pouch packaging/stacking method (different than Kokam's system) using an ion conductive separator named PVDF (polyvinyldifluoride) which has good binding characteristics at 100° C.

> Sony, Toshiba, Panasonic, Samsung, Saft, Varta, Valence, Ultra-life, Polystar and perhaps 30 companies bought licenses to commercialize the Bellcore technology during the last 10 years. No one was successful due to the difficulties of mass production technology when using this technology. Everybody gave up or went bankrupt. Sony started a new method which modified conventional technology with PVDF material only, but closely related to winding technology. With this material (PVDF), it is very difficult to achieve high power drain due to the limitations of the ion conductive material itself. Wound cells cannot achieve high discharge rates because of high current drain from the anode tab. Winding has a longer electrode which increases the internal resistance at high current draw.
>
> Kokam, too, evaluated Bellcore technology as an alternative, but realized that it is not a practical technology for commercialization due to the processing difficulty. Thus, Kokam decided to develop new technology with assistance from the Korean government agency named KIST (Korea Institute of Science and Technology). I invented a new system which permits Kokam to make the battery easier without losing any performance over Li Ion and provides better safety. Kokam acquired patents all over the world and started to design the full process and equipment suitable for mass producing Kokam cells. German and Chinese companies licensed our technologies.
>
> With the Kokam technology, we have successfully created the first 20C discharge rate commercial LiPo battery. All electric solar car champions are using Kokam batteries in 2002 and 2003 competitions.

In June 2002, FMA, Inc. and Kokam Engineering Co., Ltd. signed an agreement for FMA to serve as the exclusive agent for Kokam in North and South America. In October 2002, FMA, Inc. began actively shipping Kokam Lithium Polymer (LiPo) cells. As of this writing (fall, 2003) some 100,000 cells are being used in RC models.

At this time, FMA Direct has been actively promoting the use of LiPo cells and packs for a little over a year with gratifying results. In the past year, LiPo technology has advanced farther than NiCd technology advanced in nearly forty years. In 2002, the standard Kokam cell was capable of continuous operation at three to four times the multiple of capacity (3 to 4C) with 5C as the upper limit. In the past six months, Kokam has introduced, and FMA now has on the market, cells capable of sustaining up to 20C continuously with loss of but 12% capacity. Detailed performance data will be presented later. With the introduction of this new level of technology to the power tool and recreation industry, there is real confidence that cell cost for RC will decrease.

A general precaution

The use of LiPo cells in radio control applications is unique. All other applications require protective circuitry that prevents a) overvoltage during charging, b) discharge below 2.5V/cell and c) cell overloading. RC models can't tolerate complete loss of battery power (because the receiver and servos must be powered at all times during a flight), so protective circuitry is not an option. For this reason, the RC user bears special responsibility for the proper use of LiPo cells in radio control applications. This Application Note provides guidance for safe use of this new technology.

The FMA LiPo system

From the beginning of its involvement with LiPo technology, FMA has anticipated the need for a *system* of LiPo components. Several reasons influenced this approach:

- LiPo batteries require different chargers than other chemistries.
- The 3.7V cell output requires that packs and ESCs must be designed and sized differently.
- We wanted to make it as easy as possible for the NiCd/NiMH user to make the transition to LiPo.
- Finally, LiPo cells have unique safety and operating rules.

By providing all the elements needed (see next page), FMA hopes that LiPo will continue the rapid rate of acceptance and success seen to date.

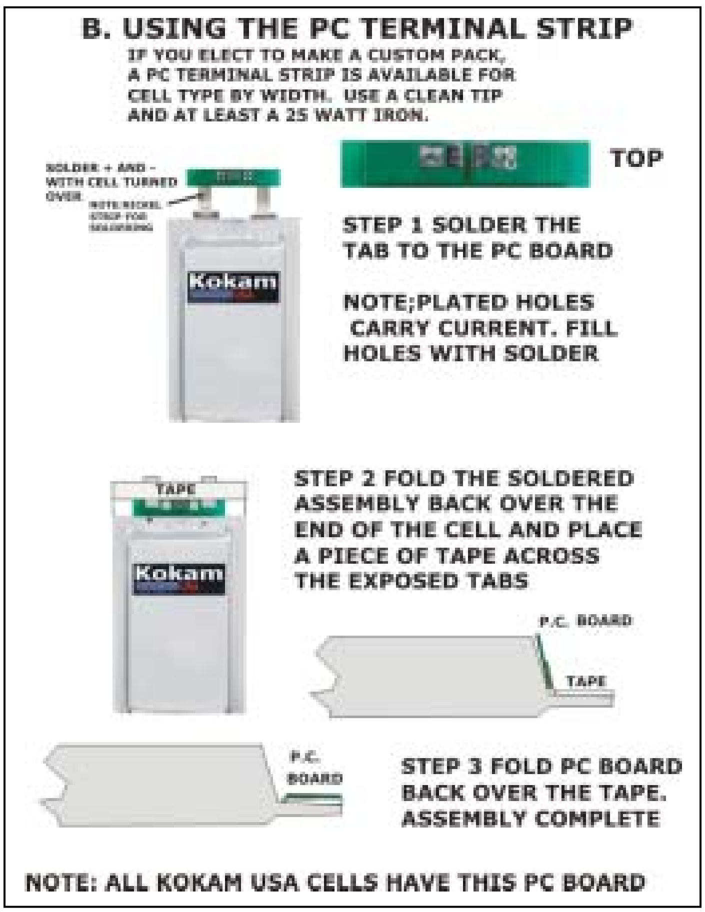

The Kokam USA Li Po System
Terminal board
Electronic speed control for Li Po
Voltage Regulator
Bare cell
26 lb. 2 oz. Tu-4 built by George Maiorana and flown by Dave Pinegar won first place in Team Scale at the 2003 U.S. Scale Masters meet, powered by Kokam Li Po cells.
Connector modules
Single cells
Chargers
Li-Po POWER!
Preassembled packs

Building LiPo packs

The basic cell

Using LiPo cells was challenging for early users, and only the most persistent did what it took to use them. The first cells had only bare tabs that were thin and fragile, and one tab was aluminum that required special solder and techniques.

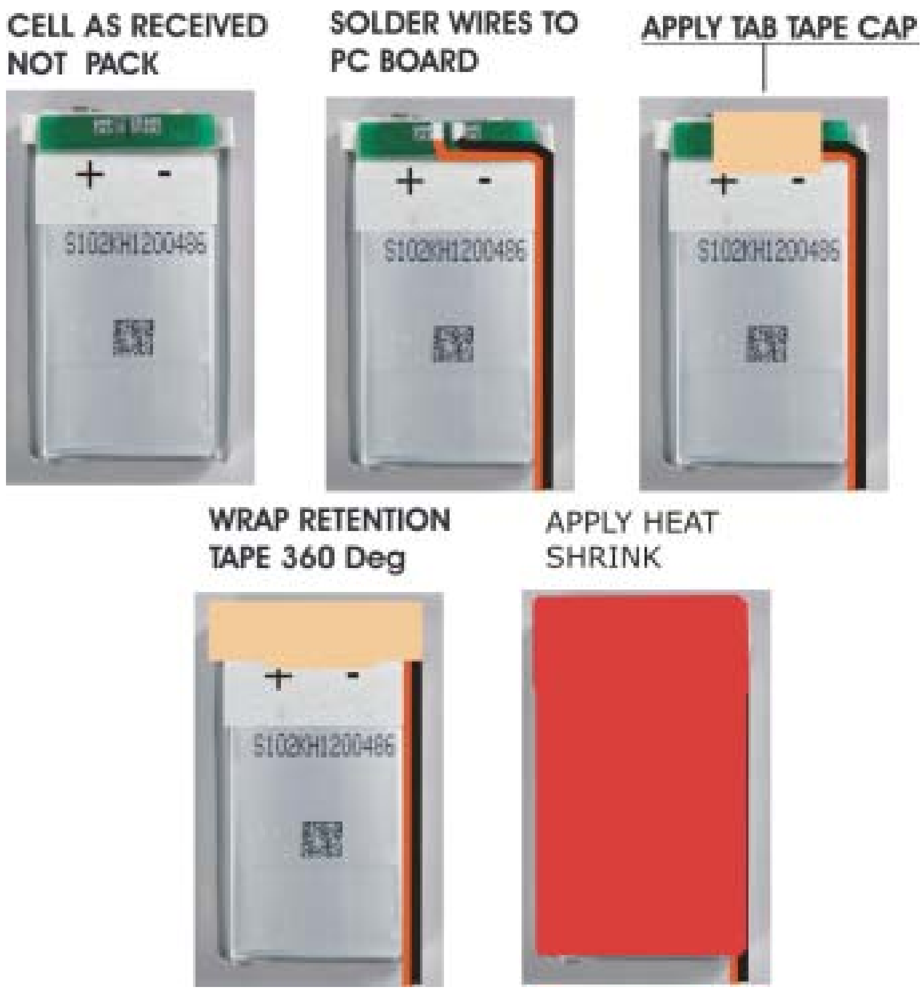
The first improvement was to add a solderable nickel tab to the aluminum tab. The next improvement was incorporating a small pc terminal board on each cell that made soldering as easy as for any cell with terminal lugs.



Note: Home construction of packs using bare tabs is not encouraged because poor technique can damage the plastic envelope where the tabs exit the cell. This can shorten cell life. Cells and packs should be manufactured by a professional pack assembly house. Assembly by end users is not covered by warranty.

Wiring an individual cell

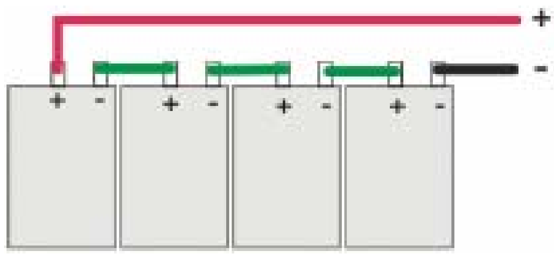
Some users want to design custom modules using individual cells with the terminal blocks. This approach starts with the standard Kokam cells, identified by the "T" suffix, e.g., 145T.



How cells are connected

Series connected cells

In a series connected pack, the negative terminal of one cell connects to the positive terminal of the next cell. Output voltage is taken from the first and last cells in the chain. In this example, four cells are connected in series. This is called a 4S pack.

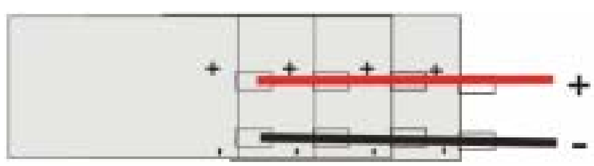


A series connected pack is used to supply more voltage than a single cell. The nominal output voltage from the example 4S pack is 4 x 3.7V = 14.8V.

> **Note:** When connecting cells in series, all cells must be the same capacity (mAh).

Parallel connected cells

In a parallel connected pack, all the cells' positive terminal are connected, and all the cells' negative terminals are connected. In this example, four cells are connected in parallel. This is called a 4P pack.

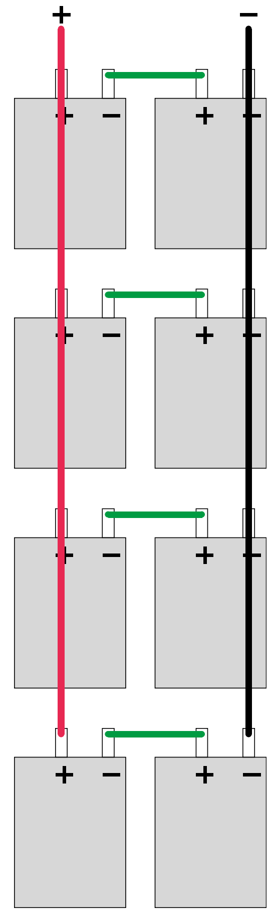


A parallel connected pack is used to supply more current than a single cell. The output capacity from the example 4P pack is four times the individual cell capacity. If the pack were made with KOK145 (145mAh capacity) cells, the pack's capacity would be 4 x 145mAh = 580mAh. It's nominal output voltage would be the same as a single cell, 3.7V.

> **Note:** When connecting cells in parallel, all cells must be the same capacity (mAh).

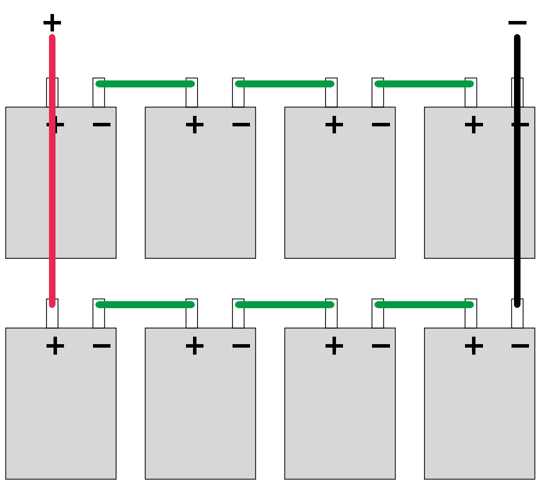
Series/parallel connected packs

Many RC applications require both higher voltage and higher current. LiPo packs can be assembled with both series and parallel connections.



The drawing to the right shows a 2S4P pack. It starts with four pairs of cells connected in series. Those four pairs are then connected in parallel. The pack's output voltage would be 2 x 3.7V = 7.4V. It's capacity would be four times the capacity of the individual cells.

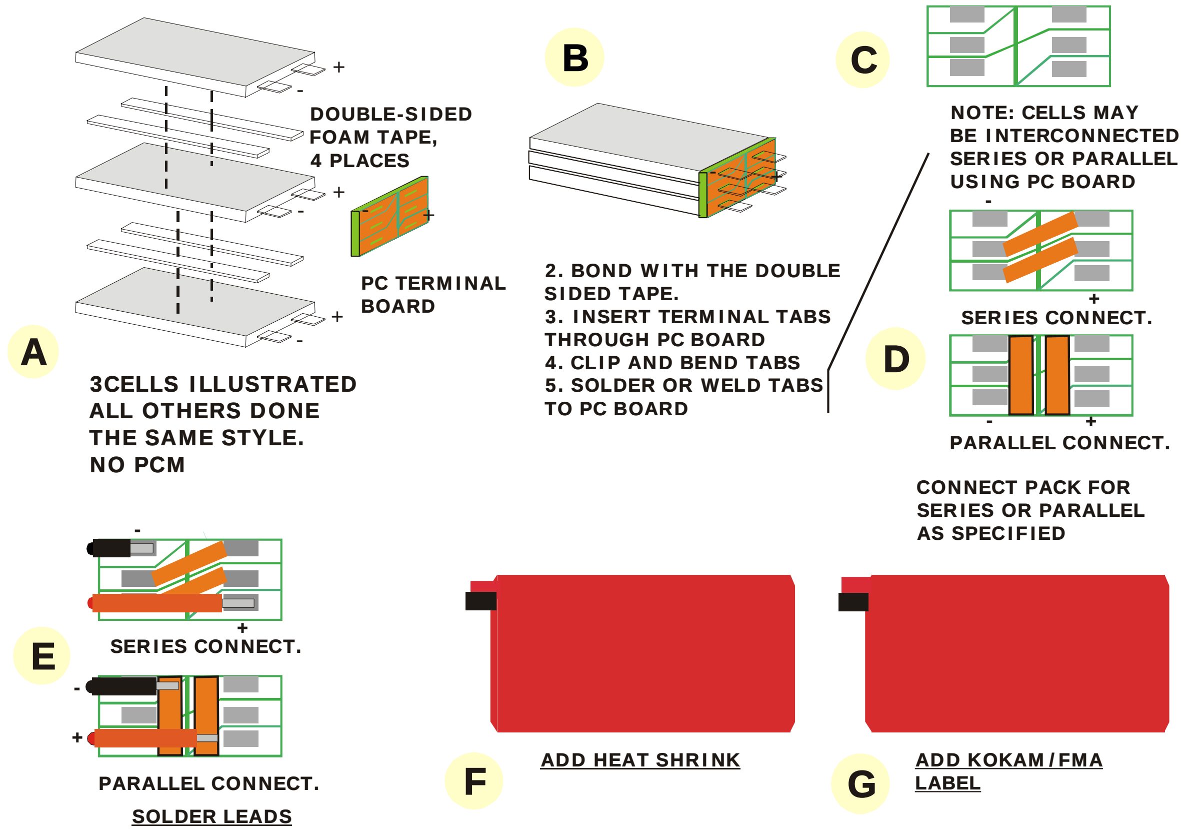
The drawing below shows a 4S2P pack. It starts with two sets of four cells connected in series. Those two sets are then connected in parallel. The pack's output voltage would be 4 x 3.7V = 14.8V. It's capacity would be two times the capacity of the individual cells.



Note: When connecting cells in series/parallel packs, all cells must be the same capacity (mAh).

How modular packs are manufactured

Kokam packs are assembled as shown below. The pc boards work extremely well and stiffen up the end of the pack. The pc board and, thus, the cell terminals are accessible. If heat shrink has covered a connection, it can be accessed with a sharp tool or by careful removal of a small square of heat shrink material.



GENERAL ASSEMBLY OF MULTI-CELL PACKS FOR R/C FROM KOKAM CELLS

The pack shown below is assembled in this manner.

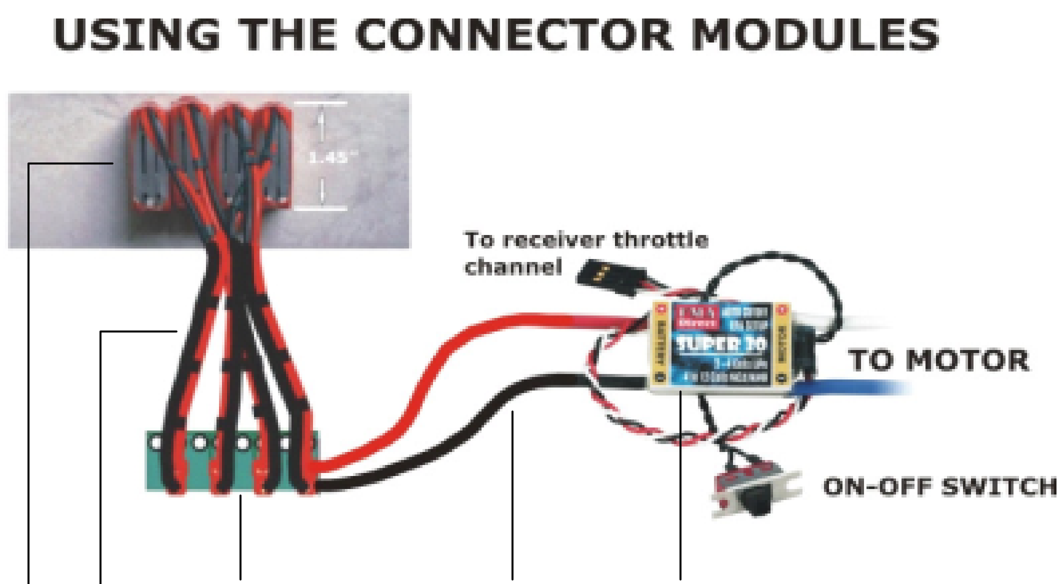
The LiPo modular pack connection system

Two key types of components provide a foundation for the system approach to LiPo power:

- Preassembled LiPo packs with attached wires and plugs.
- Connector modules that enable packs to be connected in almost any configuration.

With the LiPo pack system, users can quickly and easily build custom power systems with increased voltage, increased capacity or both.

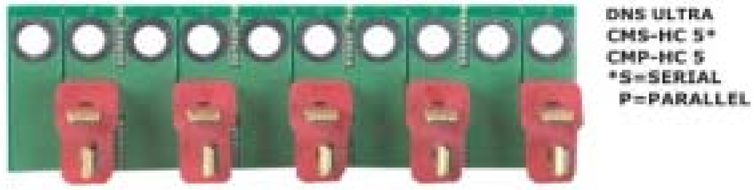
The photo below shows four preassembled packs plugged into a Parallel Connector Module. The Module is then attached to an ESC for powering an RC model.



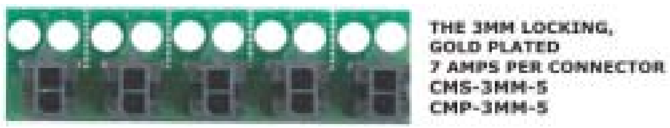
Connector Module
Wires from ESC
ESC
Wires preattached to packs
Four preassembled packs

Connector Modules are available in three sizes, with corresponding connectors, to handle a variety of power requirements:

- For high power applications:



- For moderate power applications:



- For low power applications:

The Connector Modules are made in series and parallel configurations with five connectors. Lines of tiny holes allow you to cut or snap off sections you don't need (removed sections are fully functional). Modules can be cascaded, that is, several modules can be plugged into another module, which can be plugged into another module, and so on.

These examples show how various configurations can be built very quickly:

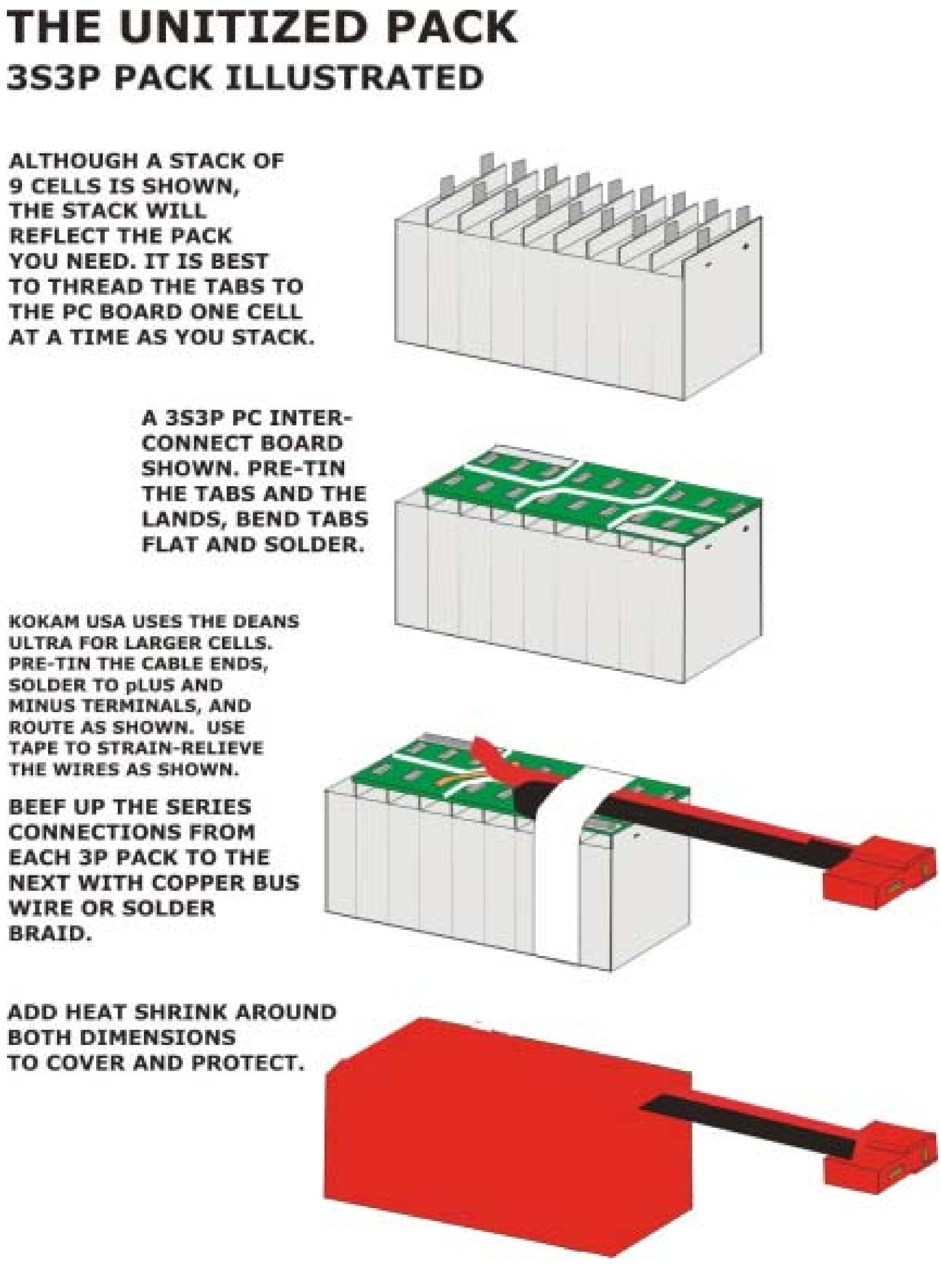
- Needed: a 2S3P pack (three parallel-connected packs of 2 cells in series). Solution: plug three preassembled 2S packs into a Parallel Connector Module.

- Needed: a 4S3P pack (three parallel-connected packs of 4 cells in series). Solution: plug two 2S packs into a Series Module; create two more assemblies just like it; plug the three assemblies into a Parallel Module.

Here's a real-life example: Greg Covey built a 3S4P pack for his Wipa Firecat using the Kokam USA Connector Modules. Says Greg: "The 3S4P Kokam 1200HC pack tripled my flight time while being 5oz lighter than the 10-cell CP1700 NiCd pack." Four 3S packs plug into a Parallel Module to make the 3S4P pack. You can even change pack configurations between flights. The CP1700 pack is 1700 mAh and weighs 19 oz. The total capacity of the LiPo pack is 4800 mAh and weight is 14 oz. The NiCd provides about 7 minutes flight time and the LiPo pack delivers about 21 minutes.

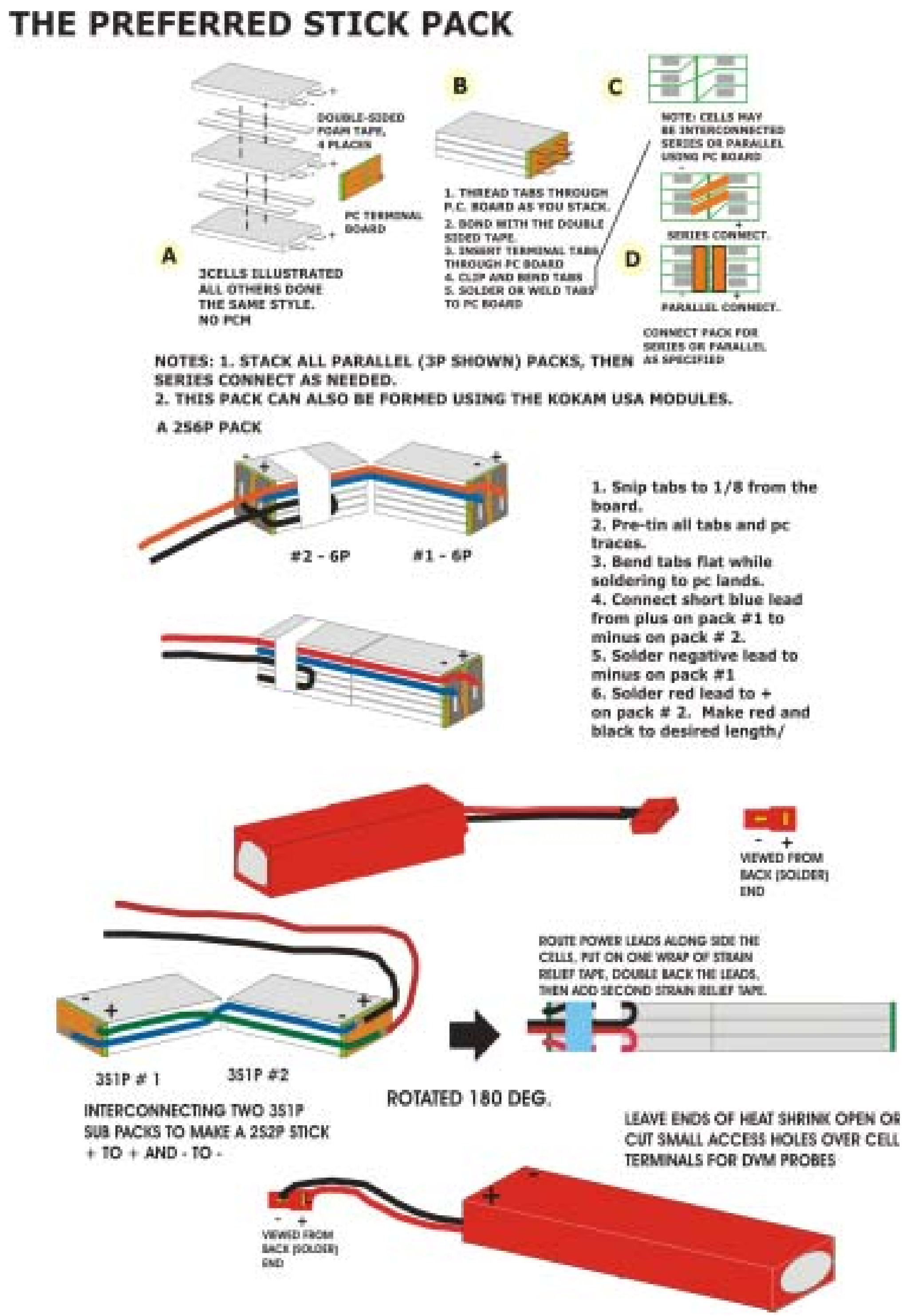
Unitized packs

By stacking LiPo cells and interconnecting them with a pc board, a pack of any configuration can be designed. However, this is a fixed pack, no longer flexible or modular. It has fewer connectors, perhaps even none (if you wire directly to the ESC) or a single female connector.



Stick packs

The unitized package is convenient in many models. However, some models either have a battery bay already fixed or may require a slim-line, stick pack. The unitized pack offers easy access to the cell terminals, but a stick pack can be stuffed in a bit more easily. The preferred stick pack configuration is shown below. The stick pack can be unitized as the sketch shows, or it can be assembled readily using the Kokam USA Connector Modules. All Kokam USA packs are essentially stick packs; most capacities will be available in preassembled packs up to 4S. However, a 1S, 2S, 3S, 4S, 5S, 6S, etc. pack can be formed and as many parallel as desired formed using the Connector Modules.



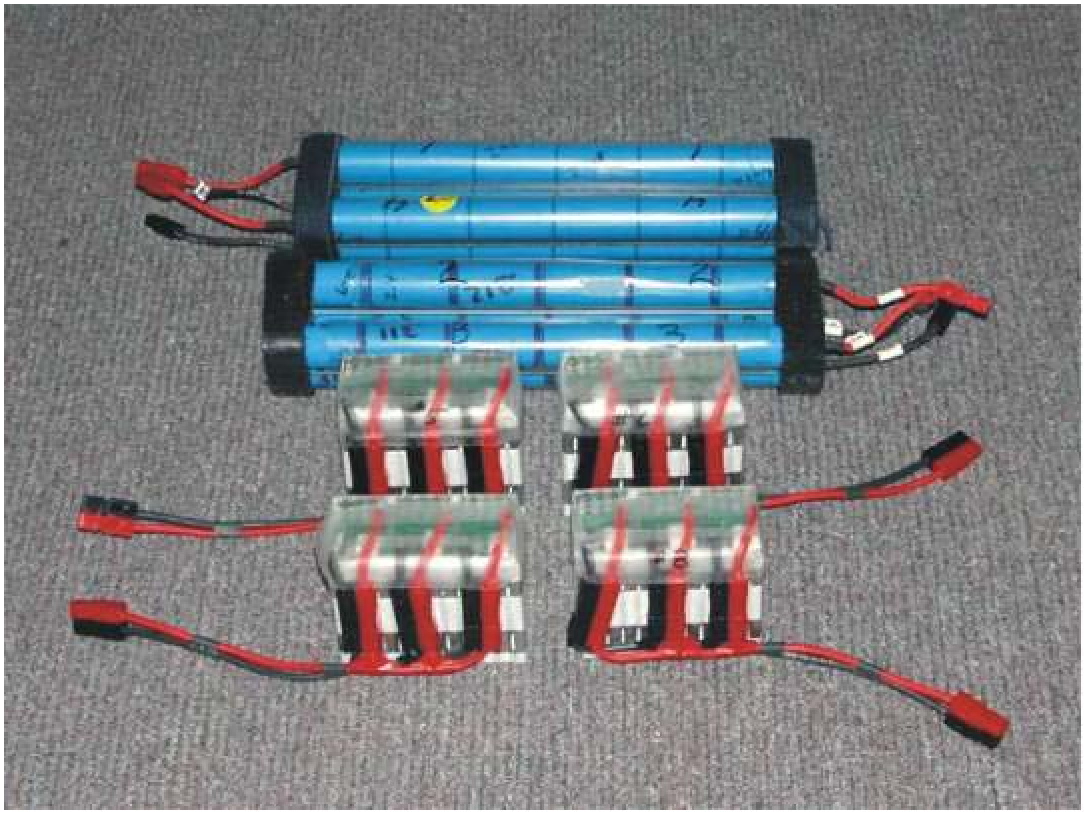
What LiPo packs can do

This beautiful giant scale model is powered by LiPo packs. It was entered in the 2003 U.S. Scale Masters meet and earned first place in Team Scale.

Tu-4 built by George Maiorana and flown by Dave Pinegar won first place in Team Scale at the 2003 U.S. Scale Masters meet. LiPo packs reduced weight from 29 lb 11 oz to 26 lb 2 oz, and doubled flight time.

George Maiorana, the builder, reports: “WOW says it all! Everything went excellent with the 4S3P 1500HC packs. The plane wowed Dave [Pinegar, the pilot], myself and everyone with its performance. Dave never had to use full throttle. 7.5 minute flights took the packs to 15.4V with plenty to spare. Took 3.5 hours to recharge at that level (1/3 C). Without the LiPo packs, we would not have been able to compete with the plane. The flight schedule would have been too long for the NiMH 3000.”

Here is how George Maiorana assembled four packs of 4S3P KOK 1500HC cells (bottom in photo below) to use in his Tu-4 airplane in place of the P3000, 3Ah NiMH packs (top in photo below). Weight saved is 3.6 pounds for twice the capacity (6Ah versus 3Ah). George chose the Sermos connector for compatibility with his system. The packs shown are 4S connected in parallel via individual connectors on the side of the pack. Note the use of clear medical tape over the top for access to the cell terminals for periodic balance checks.



The LiPo packs could also have been formed using the Connector Modules and preassembled 4S packs. By using Connector Modules, the packs can be unplugged and charged as sub-packs with a smaller charger.

One convenience of the modular system is that the connectors carry only a proportionate share of the current. In the 4S3P packs that George built, the total current delivered is an average of 27 to 30 amps. However, the individual 3P legs carry only 10 amps, so lighter connectors could be used until the collection point is reached (the connector at the left and right ends). Bear in mind that George's four packs drive four MaxCim brushless motors turning 16 inch, four-bladed carbon fiber props. What a project!

Kokam LiPo packs are exceptionally flexible. They are equally at home in a giant scale airplane, a helicopter, a 3D aerobat, park flyers and indoor models.

Related components

Speed controls

Once the pack is assembled, the last connection for electric-powered aircraft is to the speed control (ESC). The ESC controls the speed of a brushed or brushless motor from full-off to full-throttle. The ESC also provides what is known as BEC voltage, that is, it outputs a regulated 5 to 6V DC level to the receiver to power the receiver and servos. The primary concern regarding LiPo batteries is the ESC's cut-off voltage. Most ESCs sense battery voltage and cut-off the motor drive when battery voltage drops to about 5.2V.

LiPo cells have a nominal 3.6V operating voltage under normal load. This happens to be 3 times that of a NiCd or NiMH cell. LiPo cells must not be permitted to go below 2.5V/cell. If the pack is a 2S pack, then 2 x 2.5 = 5V, and a cut-off of 5.2V is fine. However, if the pack is 3S, a 5.2V cut-off would mean each cell would have to go to 5.2V ÷ 3 = 1.733V and the cells might not recharge.

Low Voltage Cutoff or LVC is the term used to describe what happens when an ESC determines that there is no longer sufficient battery voltage to continue running the motor on an aircraft. The ESC shuts off the motor to prevent the battery from discharging to the point where it will no longer power the receiver and servos. This provides the pilot adequate time to continue controlling the aircraft until it can be safely landed.

Most ESCs have a fixed cutoff point of around 5 to 5.5V. This has not created a problem for most installations using NiCd or NiMH batteries, particularly lower cell count battery packs of 6 to 8 cells. Those battery technologies are fairly forgiving in this regard. Although it really isn't good to deep-discharge any battery, NiCd/NiMH cells usually continue to operate even after deep discharge.

If lithium batteries are allowed to discharge below about 2.5V per cell under load, there is a chance they will not recharge. There are a few ESCs available with programmable cutoff points, but programming these products is often difficult and time-consuming.

FMA SUPER Speed Controllers

FMA is introducing a series of electronic speed controllers (ESCs) designed specifically to operate with LiPo as well as NiCd and NiMH batteries.

The first of these, the FMA Direct SUPER 30, is a 30A miniature aircraft speed controller with several unique features. First, it was designed to prevent damage to Lithium battery technology. The SUPER 30 is a radical approach to LVC. This computer-controlled ESC detects the unloaded battery pack voltage on power up. In less than 1 second, it characterizes the battery pack, determining the number of cells in the pack, and stores in memory the proper cutoff voltage for the particular battery. Then it continuously measures the battery pack voltage as you fly. When the measured pack voltage reaches the stored cutoff point, power is cut-off to the motor.

The SUPER 30 also provides two motor restarts, assuming your battery pack is in good condition. Based on requests from our customers, the latest computer code for the SUPER series controllers includes a user-programmable, fixed LVC that can be set at any level within valid operating voltage parameters of the controller. This feature does not eliminate the auto-cell detect feature—it is a new option that can be selected.

The unit includes a battery eliminator circuit (BEC) which is composed of a 1A, low dropout, 5V regulator. This enables the ESC to power the receiver without a separate receiver battery pack. At 1A, the unit can easily power from 3 to 4 standard or micro servos.

In addition, several functions can be controlled by a bank of tiny switches. For example, the brake can be disabled for use in electric helicopters. Also, the LVC circuit can be disabled, allowing the ESC to operate reliably with NiCd/NiMH packs with as few as 3 cells in series.

Finally, the SUPER 30 includes a one-time end point adjustment (EPA) procedure that custom tailors throttle response to a specific transmitter. The first time you use the SUPER 30, you will go through a simple series of steps to teach the computer about your transmitter throttle channel. After the procedure is complete, you move one of the switches. From then on, the custom end points are stored in permanent memory and recalled each time you turn power on. If you change transmitters, simply return the EPA setup switch back to ON and perform the setup again.

Speed controllers under development by FMA will allow the cut-off to be programmed at an optimum 2.8V. Most brushless controllers offer the same capability. Most other ESCs have a 5.3 V cut-off that will work with 2S LiPo packs.

Radio flight packs

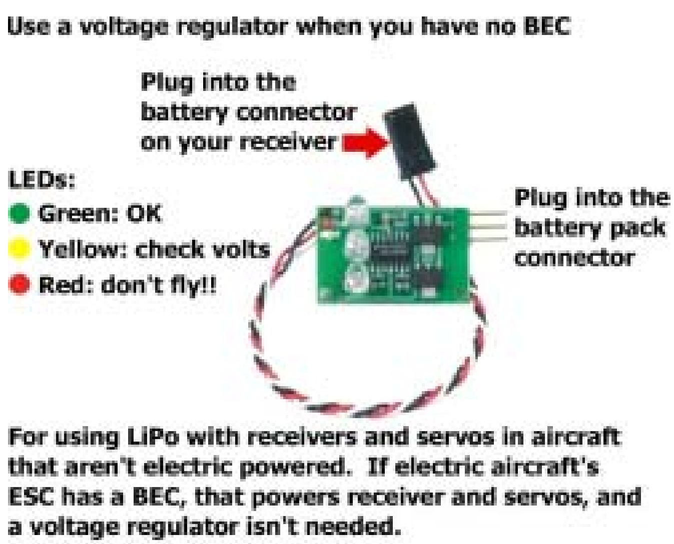
A Kokam radio flight pack is a 2S1P pack equipped with the standard RC 3-pin, polarized battery connector. The output of a fully charged 2 cell series lithium polymer battery is 8.4V. Currently there are no servos on the market that can operate at this high voltage. Thus, LiPo radio flight packs require a voltage regulator to reduce pack voltage to a level the receiver and servos can handle.

FMA SPORT VRLI

The SPORT VRLI voltage regulator connects between the switch harness and the receiver. It powers the receiver and up to five standard to medium torque servos (2A continuous current draw). The unit includes a low dropout (0.5V) regulator which provides a constant 5V output to the receiver/servos.

Three super-bright LED voltage indicators (green, yellow and red) help prevent deep discharge of Lithium battery packs. The VRLI continuously measures battery pack voltage and provides a clear warning of battery condition. For example, a fully-charged battery pack in good condition will show green. As the pack becomes discharged, or when the pack is under load, the yellow and red LEDs may light. When the yellow LED stays on and the unit won't recover to green, it's time to recharge the battery. The SPORT VRLI is also a great tool for identifying power problems such as an under-rated or failing battery pack or sticky linkages.

Simple, effective and necessary to protect a LiPo pack from deep discharge, the SPORT VRLI is the perfect match for LiPo powered on-board electronics in trainers and sport models. (The SPORT VRLI is not recommended for aircraft installations using digital or high torque standard servos.)



Safety

The safety record for Lithium cells in radio control applications is excellent, particularly considering that:

- Both manufacturers and modelers are learning how to use and handle the cells.
- Modelers use the cells with no protective circuit during charge or discharge.
- Many chargers and charging methods are used.

There have been a few reports of cells damaged by overcharge (we call them silver sausages because of their shape). In a very few instances, there has been venting with flames. In almost all cases, the cause has been known or was deduced from analysis of the situation. Nearly all these problems were related to charging. One non-charging incident involving a Lithium pack of unknown manufacture occurred because the modeler crashed an airplane and placed it in his car without removing the pack.

Potential cell damage causes include:

- Overvoltage during charge.
- Use of chargers not designed for LiPo chemistry.
- Sudden peak surge voltage from the charger when disconnecting.
- High current rapid charging by users who assumed LiPo can be charged at high current like some NiCd cells can.
- Incorrect selection of charge voltage.
- Excessive discharge rate.
- Use of aluminum soldering paste that deteriorates the tabs and causes a short circuit.
- Unreliable chargers. In some chargers with FET switching, the FET shorts when it fails and full supply voltage is applied to the cell. This can be avoided if appropriate crowbar protection or foldback is designed into the charger.
- Cell failure that creates an instant unbalance in the pack.
- Fundamental risk of lithium ignition with lithium is exposed to air entering through a damaged cell envelope.
- Faulty pack assembly.
- Physical damage and abuse. The author, for example, accidentally ran a T-pin through a fully charged cell, shorting all plates. That shortened that pin much faster than a pair of diagonal pliers!

All high energy density cells, including LiPo cells, are safe when handled, interconnected, charged and discharged according to manufacturers' recommendations, accepted industry practices and common sense. FMA provides a set of precautions for use of the cells and packs it sells. The precautions are listed on the next page, and are also provided on the FMA Direct Web site.

WARNING

Safety precautions
for Lithium Polymer and NiCd cells/packs stocked by FMA Direct

1. Never fast-charge any battery type unattended.
2. Never charge LiPo cells/packs at any rate unattended.
3. Only charge LiPo cells/packs with a charger designed specifically for lithium polymer chemistry. Example chargers include the Kokam USA, LIPO 402, LIPO 102 and LIPO 202; Bishop Power Products Apache S1215 and S1500; Great Planes Triton; and Schulze chargers with lithium charging capability.
4. LiPo cells can ignite because of unmatched cell capacity or voltage, cell damage, charger failure, incorrect charger settings and other factors.
5. Always use the correct charging voltage. LiPo cells/packs may ignite if connected to a charger supplying more than 6 volts per cell.
6. Always assure the charger is working properly.
7. Always charge LiPo cells/packs where no harm can result, no matter what happens.
8. Never charge a cell/pack in a model. A hot pack may ignite wood, foam or plastic.
9. Never charge a cell/pack inside a motor vehicle, or in a vehicle's engine compartment.
10. Never charge a cell/pack on a wooden workbench, or on any flammable material.
11. If a cell/pack is involved in a crash:
    a. Remove the cell/pack from the model.
    b. Carefully inspect the cell/pack for shorts in the wiring or connections. If in doubt, cut all wires from the cell/pack.
    c. Disassemble the pack.
    d. Inspect cells for dents, cracks and splits. Dispose of damaged cells (see below).
12. Dispose of cells/packs as follows:
    a. Discharge: with the cell/pack in a safe area, connect a moderate resistance across the terminals until the cell/pack is discharged. CAUTION: cell/pack may be hot!
    b. Discard:
       - NiMH: place in regular trash.
       - NiCd: recycle (cadmium is toxic).
       - LiPo: puncture plastic envelope, immerse in salt water for several hours, place in regular trash.
13. Handle all cells/packs with care, as they can deliver high currents if shorted. Shorting by a ring, for example, will remove a finger.
14. Always store cells/packs in a secure location where they cannot be shorted or handled by children.
15. When constructing a pack, use only cells of the same capacity (mAh).

FMA, Inc. and KOKAM USA, its successors, heirs and assigns are not responsible in any way for any and all bodily injurie(s) and/or property damage that may occur from the use of or caused by in any way the lithium Polymer and NiCd cells/packs stocked and or distributed by FMA, Inc. and KOKAM USA.

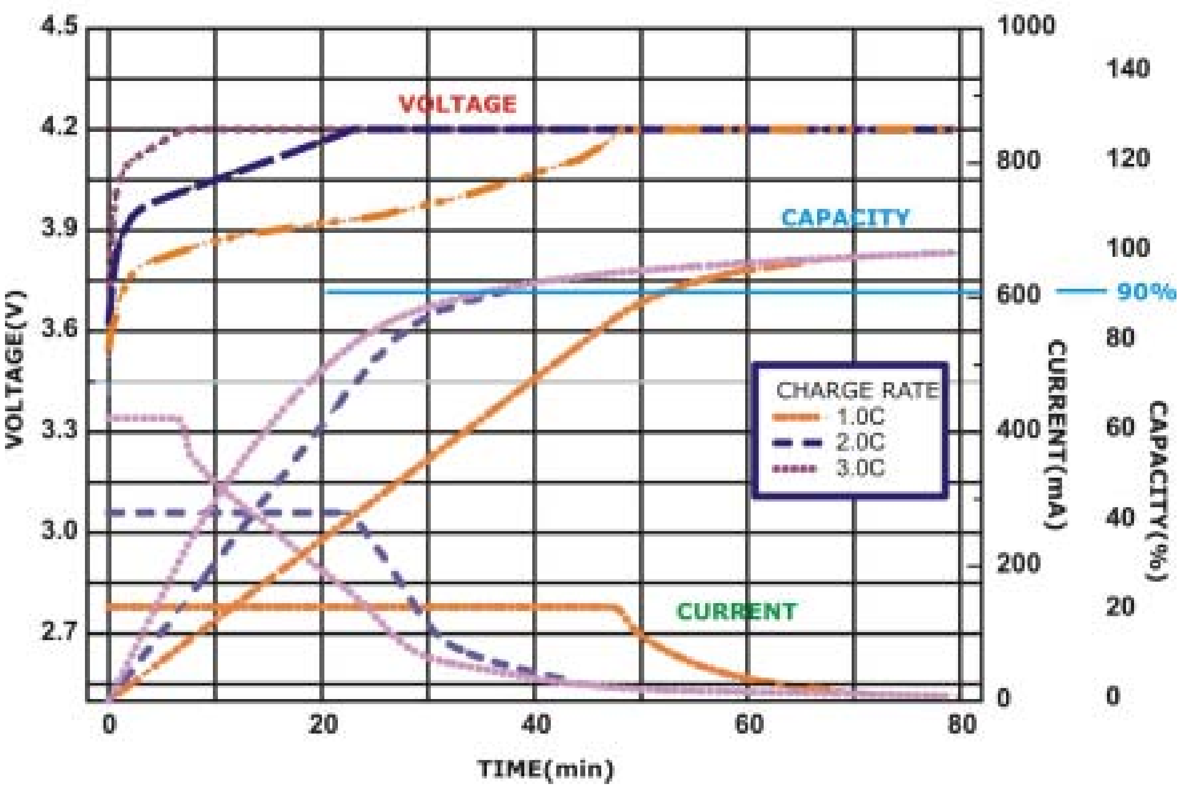
FMA, Inc. ● 5716A Industry Lane ● Frederick, MD 21704
Sales: (800) 343-2934 ● Technical: (301) 668-7614 ● www.fmadirect.com

Charging

LiPo cells are charged differently than NiCd/NiMH and all other chemistries except for Li Ion. The LiPo charge schedule is different and you **must** use a charger designed for either Li Ion or Lithium Polymer cells.

The charge schedule is easily controlled. The proper charger limits current to 1C, where C=cell capacity, e.g., 145 mAh. As cell voltage increases, so must charge voltage increase to force current through the cell until the voltage applied to the cell reaches a maximum of 4.235 V. As cell voltage rises to 4.235V, current approaches zero. When charge current falls to 0.1 C, the cell is full.

The preferred charge rate is 1C such that the cell can be charged to 90% capacity in one hour if the charger is designed to hold charge current at 1C without exceeding 4.235V/cell maximum charge voltage. Lower charge rates are acceptable if longer charge time is tolerable. LiPo cells **cannot** be charged at high rates such as 4C. The charge algorithm below shows that almost nothing is gained by charging at a rate higher than 2C.



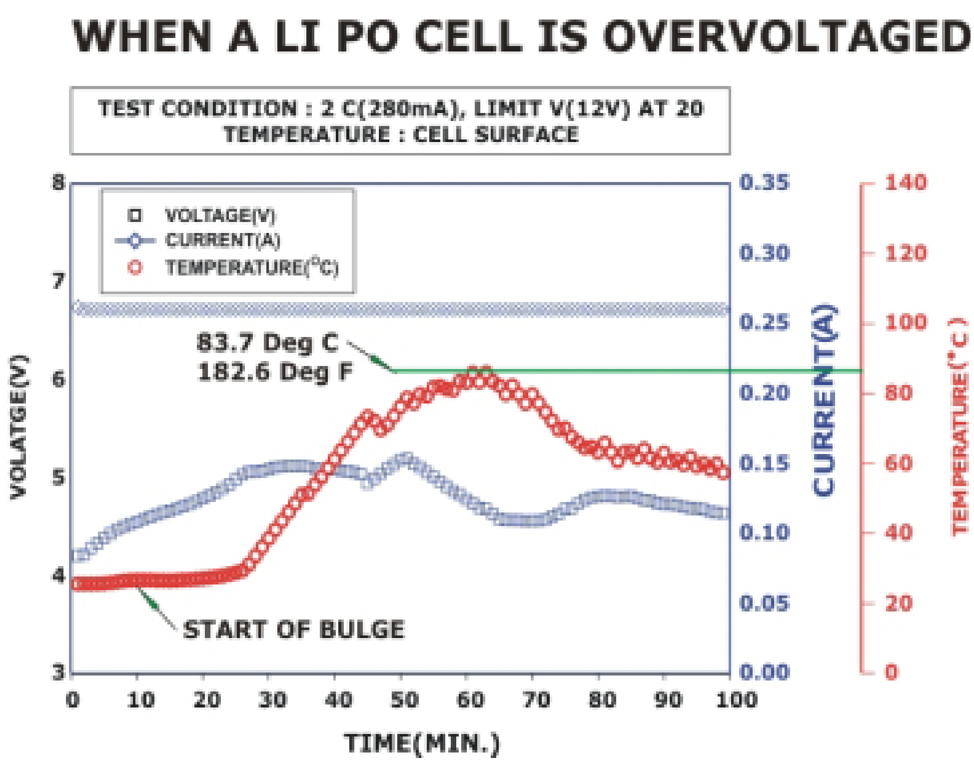
The above chart is very important, so study it carefully. The following charging guidelines emanate from the chart:

- Never exceed a 2C charge rate and accept that cycle life will be maximized by charging at 1C.
- Never exceed a maximum charge voltage of 4.235 VDC.

Results of overcharging

All high energy density cells used for RC, including NiCd, NiMH and lead acid, as well as LiPo, pose an electrical hazard. If wiring or interconnects are poor or become shorted, these cells are capable of delivering such high currents that the wiring can burn like a filament. Should the pack or wiring be in contact with flammable material, a fire will result.

Under conditions of abuse or error, Lithium cells can vent with flames. During charge, applying a charge voltage of more than six volts per cell for a period of 20 minutes can potentially cause venting and might cause flames depending on current setting.



Charging must be done such that no damage to life or property can occur if a short in wiring or cells, or venting with flames, occurs. All lithium cells have the potential for "venting with flames" if mishandled. This is because lithium is a metal that, under abuse, can ignite and burn. Aluminum does also. Finely powdered aluminum is the "fuel" used in solid rocket motors. It takes a very strong igniter to fire a solid rocket motor.

Lithium ignites in the presence of oxygen. If the cell envelope ruptures, oxygen enters and combines with the lithium, causing ignition. If the cell envelope does not rupture, then ignition will not occur.

LiPo cells, as with any rechargeable battery, react to overcharge. NiCd and NiMH cells react to overcurrent; LiPo cells react to overvoltage. This is why the charge algorithm shown above is carefully controlled to 4.2V/cell. A LiPo cell has some tolerance for overvoltage; it is not going to balloon and flame unless substantial overvoltage is applied. In the above graph, the charge voltage was set at a very high level—6.8V—right from the start. The cell did not react at all for 10 minutes, then began to swell. A plot of maximum thickness would follow the temperature curve as gasses are generated and heated. Those gasses, for any cell, come from break-down of the electrolytic as it begins to vaporize. It took almost an hour of overcharge before temperature and pressure rose enough to rupture the envelope.

The safety precautions listed earlier include the warning not to charge batteries unattended. The cell under test held out for almost an hour. Leaving any battery on fast charge for an hour without checking it is irresponsible. As stated in the precautions, the cell must be in a safe charging station. If a cell is found to be swelling during charge, remove the charge current immediately. Then allow the cell to cool before taking any other action. You can imagine that rupture of the cell could allow hot gasses and electrolyte to spew out.

Once the cell has cooled handle it as a fully charged cell with full energy available. This means you do not "poke a hole in it" in preparation for disposal. First, discharge the cell at a reasonable rate. This can be done by using clip leads to attach it to an electric motor, a resistor or some other electrical load. Do not hurry this—a slow, complete discharge to zero volts while still under load is a safe way to do the job. Once the cell is depleted, poke a small hole in the envelope, then immerse the cell in salt water for a few hours. After that, the cell may be disposed of in the trash.

Additional precautions are in order. If shorted, all high energy density cells (including LiPo cells) can heat rapidly, rupturing the envelope or case. A wiring harness connected to a cell or battery, if shorted, can glow like a filament and cause ignition of flammable materials.

Chargers

Appropriate chargers are available from FMA Direct. Charger specifications may be viewed at the Kokam/FMA Web site. In addition, other vendors sell appropriate chargers.

Avoid the use of chargers that automatically determine cell count. LiPo cells are nominally 3.7V under load. Cell voltage at full charge is 4.235V. Two fully charged cells, for example, output 8.4V. Three partially discharged cells may be 2.8V/cell x 3 = 8.4V. If two nearly charged cells are put on charge to "top them off", the auto-counting charger may incorrectly sense them as three discharged cells and set the charge voltage for three cells. The two cells will receive too much voltage and will definitely be damaged. It is the user's responsibility to assure a charger's voltage is properly set.

Charging through a protective circuit

On October 1. 2003, Kokam Engineering Co, Ltd. introduced Safety Guard, a protective circuit that regulates the voltage to a pack under charge to a preset and fixed value no matter what voltage the charger supplies. Its basic function is that of a Protective Circuit Module (PCM) normally used on an OEM pack. However, in RC use, it goes in line for charging a pack and need not be carried with the pack. This is a single-purpose unit that is set to a 2S, 3S or 4S pack voltage by fixed internal circuitry. A 2S pack must be charged via a 2S Safety Guard, 3S pack via a 3S Safety Guard, etc.

Safety Guard specifications state that the unit can protect a pack even with a 30V input. It would still be possible to plug a 2S pack into a 3S Safety Guard. However, that is far more unlikely than remembering to set cell voltage or count by any method, and vastly more reliable than an automatic cell count.

In effect, Safety Guard is intended to avoid application of an incorrect charge voltage to a pack. That is its primary use. A secondary use is as a PCM during discharge for systems needing less than 20 amps current. This means you could use it in line for up to Speed 400 motors. It will cut out if current exceeds 20 amps, a good protection from locked rotors in an aborted takeoff if you tip the plane on its nose and forget to throttle back. Theoretically, it could also save an ESC in that circumstance.

Safety Guard can also protect against undervoltage if your ESC does not have cut-off matched to LiPo characteristics. Most ESCs have built-in voltage cut-off, but voltages are set for NiCd and NiMH packs. Note that Safety Guard will produce a slight voltage drop from the FET in line with the current to the ESC. In addition, when battery voltage is cut-off, the BEC is also cut-off, so you would need a separate battery for the receiver and servos.

Safety Guard specifications

Maximum input voltage	30VDC	
Maximum charge current	20A	
Maximum output voltage	*Configuration*	*Voltage limited to*
	2S pack (8.4V ±0.05V)	8.7V ±0.1V
	3S pack (12.6V ±0.05V)	13.05V ±0.15V
	4S pack (16.8V ±0.05V)	17.4V ±0.2V
Dimensions	1.06" (27mm) wide x 1.4" (35.5mm) long x 0.35" (8.5 mm) high	
Overcharge indication	Red LED	

Charging in series or in parallel

LiPo packs may be charged in series or in parallel. Each approach has pros and cons. The Kokam USA Connector Modules permit either method. Unitized packs make it difficult or impossible to do anything other than series-parallel charging. Parallel charging results in the longest life and best balance.

When LiPo cells are connected in parallel packs, it is the same as having a cell with greater capacity. There is one important warning: the interconnections and solder joints must have absolute integrity or a cell can be over or undercharged in a parallel string. The factory-made inner strap welds have excellent integrity. Inter-cell connections made, for example, using aluminum paste solder may not.

A parallel string can be charged with one 4.2V charger, and every cell in the string will be perfectly balanced by being forced to that exact 4.2V. Why not use parallel charging for all packs? Some modelers do. It requires effort to separate a pack into strictly parallel sets for charging, although the Kokam USA Connector Modules do make that easy. With the Modules, a parallel pack could be made up of 1S (single) cells with each cell on an individual connector. On the other hand, if you need to charge 20 KOK 1500 cells in parallel, you'll need a 4.2V charger that puts out a whopping 30 amps to charge the pack in one hour.

Series charging lets packs be charged without disconnecting and reconnecting. If, say, a 4S1P pack is charged in series, the charge current for the KOK 1500 would be 1.5 amps, not 30 amps. The shortcoming of series charging is that it does not force the cells to stay balanced. Many argue that their LiPo cells do not drift into unbalance at the rate that NiMH or NiCd cells do. This will be true as long as you observe the guidelines in the next section.

If you charge cells or sub-packs in parallel, the Parallel Connector Module connects to the end of the charger leads. If series charging is done, then the Series Module connects to the end of the charger leads.

Packs may be charged in series-parallel by use of the appropriate set of Connector Modules. Suppose we want to charge a 4S3P pack used on the Tu-4. We could simply connect the pack's power connector to the charger's connector, then set the charger for 14.8V (for the 4S configuration). It takes the LIPO 402 charger about 3½ hours to charge the pack (the maximum 1.5 amp current is divided between three parallel packs, with each getting 500 ma.). If series-parallel charging is done, it is wise to check the individual cells periodically with a digital voltmeter make sure they stay in balance.

> **CAUTION:** Make the balance check when the pack is charged, not when it is discharged. At the end of discharge, the cells may appear to be out of balance, especially if a low cut-off voltage is used. This is discussed in "Cell unbalance and how to avoid it" in the next chapter.

Discharging

The most frequently-asked question for all cell chemistries is, "What capacity and voltage should my pack be to fly my particular model for XX minutes?" At FMA Direct, this question gets answered as best we can many times every day.

Propulsion parameters affecting pack design

Simplistically, if the following information is available for the model in question, the answer can be given accurately:

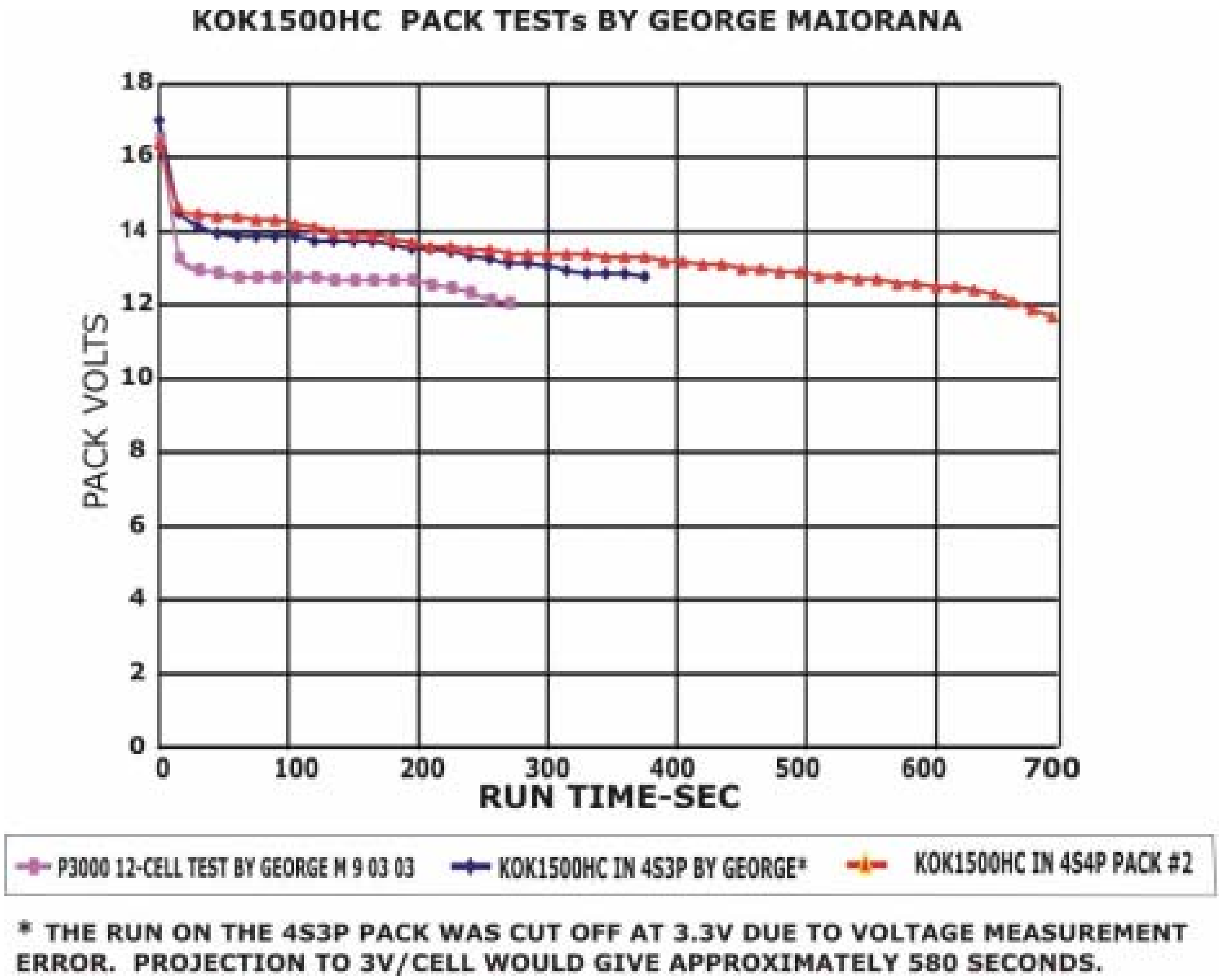
> How many watts does it take to fly the model the way you want it to fly?
> That is, at the very least, how many watts does it take to stay airborne?

Data in the graph on the next page was collected by George Maiorana as he tested the packs he planned to use in his Russian Tu-4 AEW scale model. This application serves as a pleasant case study of the impact of using LiPo packs in large models.

The original P3000, 3Ah NiMH packs are so heavy that the "service ceiling" for the Tu-4 was about 150 ft. By going to the KOK 1500HC packs shown earlier, over three pounds of weight was removed from the model and pack capacity was doubled.

(In another example, our friend Heyward Macdonald converted a Herr Starlite from NiMH to LiPo. Weight dropped 40%, from 8 ounces to 5 ounces. That one change made a real flyer out of a model that barely flew before the conversion.)

Note that the curve for the P3000 cuts off at 12V. This is because, as George says, “At 12V the airplane is coming down.” The average current drain for the propulsion combination in the Tu-4 is some 27 amps per pack. There are four packs. The average voltage for the P3000 pack, from the curve, is 12.5V. Volts x amps = watts; thus the Tu-4 takes 12.5V x 27A x 4 packs =1350 watts to stay airborne.



George had a decision to make: A 4S LiPo pack delivers nominally 14.8 V at about 2C discharge. From the curves, at a drain of 27/3, a 4S3P pack sustains about 13 V and, if projected to 12V, will give a run time of about 560 seconds (9 minutes) or about double that for the P3000 pack. Now, the average voltage at a drain of 6.75 amps per parallel pack is only 4.5C. As you will see later, the KOK 1500 delivers 100% capacity at 4.5C, so the entire 4.5Ah is available. Watts = volts x amps, so the 4S3P pack still delivers 13.5V x 27A x 4 packs (for 4 motors) = 1458 watts, or 8% more wattage. Since the pack can deliver that on average for 12.5 ÷ 60 = 0.2 hrs, the watt-hours = 303.2. Weight of the packs is 2112 grams= 2.112 kg. Thus the energy density is 303.2W ÷ 2.112kg = 143.56 watts/kg. This is reflective of the 4.5C current delivered relative to the 0.5C rated current. More about this later.

With weight reduced by 3.75 pounds, the airplane will not require as much wattage to fly. The 4S3P pack delivers an average 27A x 13.5V x 4 packs = 1458 watts or 8% greater wattage. The weight of the Tu-4 with the P3000 packs is 29.7 lbs. Reducing that weight by 3 lbs, or 11%, had a significant impact along with the 8% increase in available wattage.

Watt-hours available determines how long a model will fly. The watt-hours available from the LiPo pack derives from higher energy density and, in turn, from the fact that we have double the capacity even at lighter weight. Without taking advantage of the effect of weight decrease for the model, the 4S3P LiPo pack provides 2.4 times the run time. Assuming the Tu-4 will fly at voltage of 11V, then flight time will extend to 12 minutes for the LiPo pack or 2.57 times that for the P3000. The 4S3P LiPo pack delivers 13.5V x 27A x 0.2 hrs = 72.0 watt-hours compared to 12.5V x 27A x 0.08 hrs = 27 watt-hours for the P3000.

Energy-density is the key performance parameter that gives LiPo the big advantage over other chemistries. The specified energy density for Kokam LiPo cells is in watts per kilogram. Energy density, like capacity, is specified at a nominal discharge rate of 0.5C. As discharge current increases, energy density reduces with capacity. The advent of high discharge rate capability on this parameter is marked and is discussed later. LiPo enjoys almost a five to one advantage over NiCd and about three to one over NiMH.

Most modelers won't know the required wattage or much else about the propulsion system for a model. To help as much as possible, we offer some guidelines...

The voltage to be used is usually known or can arbitrarily be set. This is almost always determined by the motor used. Many DC magnet motors burn out if greater than specified voltage is applied. To a degree, pack voltage is determined by weight limitations. The light weight of LiPo cells gives considerable relief from this limitation. In any event, one can arbitrarily select a pack voltage so long as the wattage from the pack is sufficient to fly the model.

It is helpful to measure the current in a static run of the propulsion system with any given pack or even a power supply. If the model flies acceptably with a known voltage and average current drain, as for the Tu-4 discussed earlier, then the LiPo pack configuration needed can be defined reasonably accurately.

Several propulsion characteristics drive the wattage required:

- The power produced by the motor and its efficiency set the baseline. Most permanent magnet motors used are in the 50% efficiency range; coreless motors are a bit higher at, perhaps, 60%; and brushless motors (which almost universally have double ball bearings) run close to 80% efficient. Brushless is lighter, so the combination of a lighter, more powerful, more efficient motor with LiPo is a natural.

- If a gearbox is used, the gear ratio and efficiency of the gearbox have an effect.

- Prop selection has a major effect. One example serves to emphasize this point: Increasing prop diameter by one inch can increase current draw by as much as 25%.

LiPoCalc

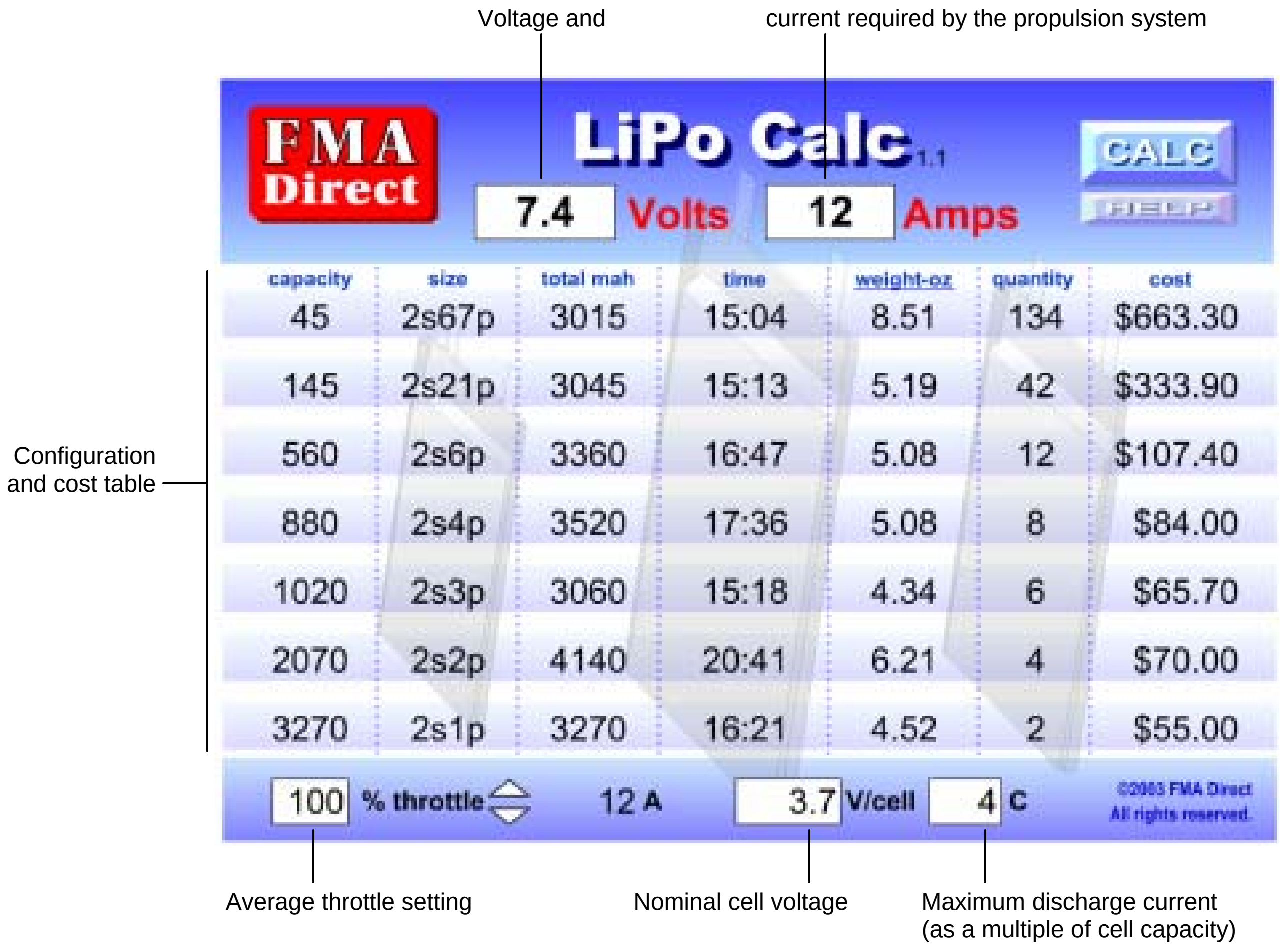
FMA Direct provides an online tool, LiPoCalc, for estimating the LiPo pack needed when various parameters are known.

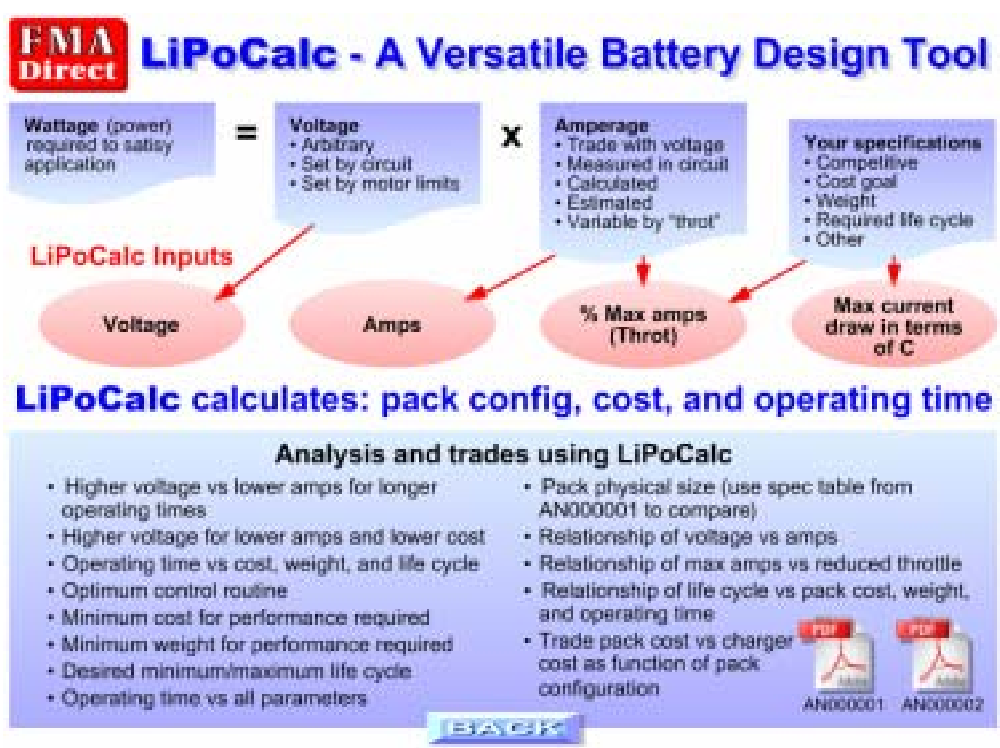
> LiPoCalc is available on the FMA Direct Web site (www.fmadirect.com): click Store, then click Kokam USA, then click the calculator icon near the top of the page.

LiPoCalc and its help page are reproduced below. LiPoCalc is driven by the wattage required to fly the model and the watt-hours needed to fly for an expected period. Be aware that LiPoCalc does not take into account the fact that cells lose capacity, therefore run time, and with increasing current draw.

ElectriCalc and MotoCalc programs are also helpful in calculating theoretical model performance.

To use LiPoCalc: Enter the five parameters, then click CALC. The resulting table shows various LiPo configurations—and their costs—that will deliver the required power.





Measuring and comparing cell performance

Availability of the new Kokam High Discharge Rate cells provided an opportunity to compare them to other Kokam and non-Kokam cells. The data has taken some time and the help from many to generate. It is a powerful set of data. We want to say thanks to all who helped generate this objective data independently of both Kokam Eng Ltd, Co and Kokam USA.:

- Don Srull, who started the testing in February 2003. Don's purchase and test of the Thunder Power 2.1Ah cell added greatly to the data in hand.

- Red Scholefield, who has put in many hours testing all the Kokam cells in the series drawn randomly from inventory stocked in by Kokum USA.

- Troy Goff of B-P-P, who generously posted the data in the form of discharge time versus voltage that permitted the E-TEC 1200 cells to be included.

- Jamie Marks, Greg Covey and JJ Hong for critique of the methods and findings.

- Red, Don, Tim, JJ Hong and Greg who critiqued the presentation method.

- JJ Hong and the staff at Kokam for the discharge curves in the specs.

About the data. Measurements were made on single cells, not packs. This makes comparisons truly valid. The curves are non-dimensional with regard to run time, which rises with cell capacity due simply to having a larger (thus heavier) cell, and with paralleling. Data recorded independently by Red and Don correlates almost exactly with the Kokam data. Recent validation tests by a U.S. Navy facility correlate precisely with the data in the curves that follow. Plots from the data are provided on the following pages.

Conclusions drawn from the data:

- The KOK 1500 and 2Ah cells operate satisfactorily to 10C with proper throttle management and will be specified that way. Both cells have continuous capability without excessive heating (about 50°C) up to 8C. Beyond 8C, a realistic duty cycle of 5:1 is specified. Continuous operation at 10C will cause the cell to heat and will shorten cycle life. It is not wise to design your pack to operate continuously above 8C. You may save money on the initial purchase, but it will cost more in the long run.

- The KOK 340HSC is phenomenal with loss of just 12% capacity at up to 20C. Out to 6.8 amps, the 340HSC keeps pace with the 2.1Ah T-Power cell and exceeds the E-TEC 1200.

- The KOK 700HD is not quite as "stiff" as the other three Kokam HD cells, but still loses only to 43% capacity at 10C. This performance is about the same as the E-TEC 1200.

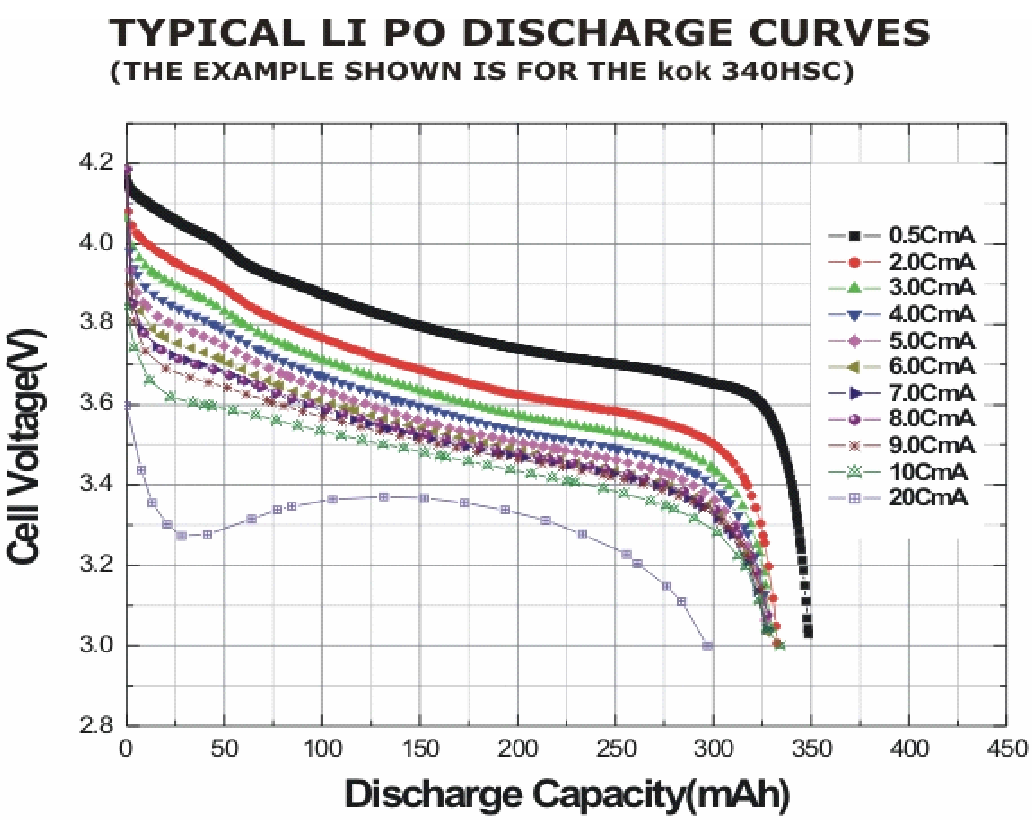
How the curves are generated

Although the true indicator of cell performance is displayed in specific energy and specific power that reflects the weight of the cell, most data sheets and presentations in the media show discharge voltage versus time. LiPo manufacturers have tended to display performance as cell voltage versus discharge capacity. Imagine, if you will, trying to display sets of data for a number of competing cells for multiple families of the curves for one set of cells shown in the next figure. The jumble of data would be totally confusing.

The focus the first curve below is the point at which the cell is depleted. For the cell selected, the end point is arbitrarily 3V. Each curve is for a different discharge rate as a multiple of baseline capacity. The first step is to validate the baseline capacity for a representative sample of a given cell. That is the end-point for the 0.5C curve.

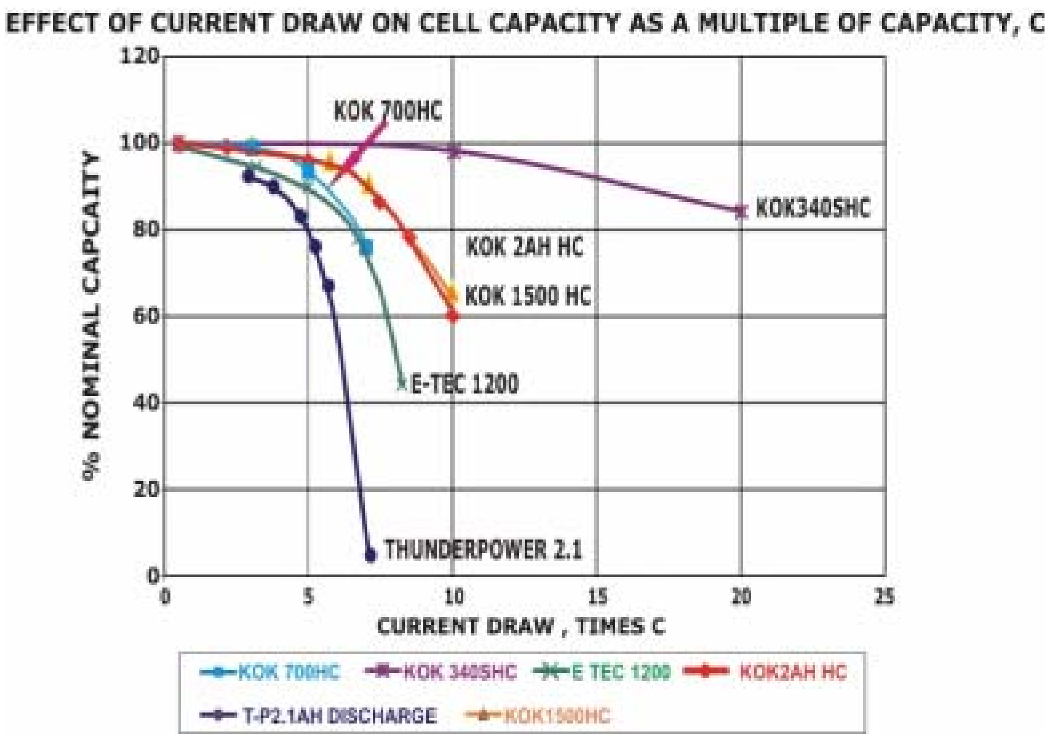
The locus of points formed by the end points at different discharge rates is of great interest, because it is a quick and direct measure of cell performance in the RC environment. With that data in hand, the measured capacity for each end point as a function of absolute discharge rate in amps and in terms of multiples of baseline capacity can be calculated. For example, the baseline capacity for the KOK 340 cell shown below is 350, per the curve at 0.5C. The capacity remains relatively undiminished at rates up to 10C (94.3%) and falls only to 85.7% at 20C.

Data recorded independently by Red and Don correlates precisely with the data taken in factory qualification tests and that gives us great confidence in the factory data. The percentage of the nominal capacity achieved by a cell at increasing discharge rates is the ratio of the measured capacity at cut-off divided by the baseline rate (cell rating at 0.5C) converted to %. The rate can be presented as absolute rate in amps or as the rate as a multiple of the rated capacity. Note that the international standard for rating cells cautions against using XC to reflect discharge current since C = mAh, not mA. However, it is a convenient way to compare, even if not pure.



The next graph below shows the KOK 340 as the topmost curve. As noted above, out to 10C, capacity is reduced very little. From 10C to 20 C, the drop is still relatively shallow. The same data was run for each of the cells plotted. Though not the accepted way to do it by international standard, the data are presented as multiples of C. The data points may be converted to amps by multiplying the capacity of the cell by the multiple. For example, 340mAh is 0.340Ah, so 20C = 6.8 amps.

Note that the rates from 2C to 10C group so closely at 3V that they show as one data point when distributed as “times C” versus % Nominal Capacity. The original KOK cells and the Thunderpower and E Tec cells plotted show the same steep decline (as the “old” KOK cells) as capacity drops below 85%. Each curve represents a set of curves just as those for the KOK 340; only the end of discharge capacity is shown below.

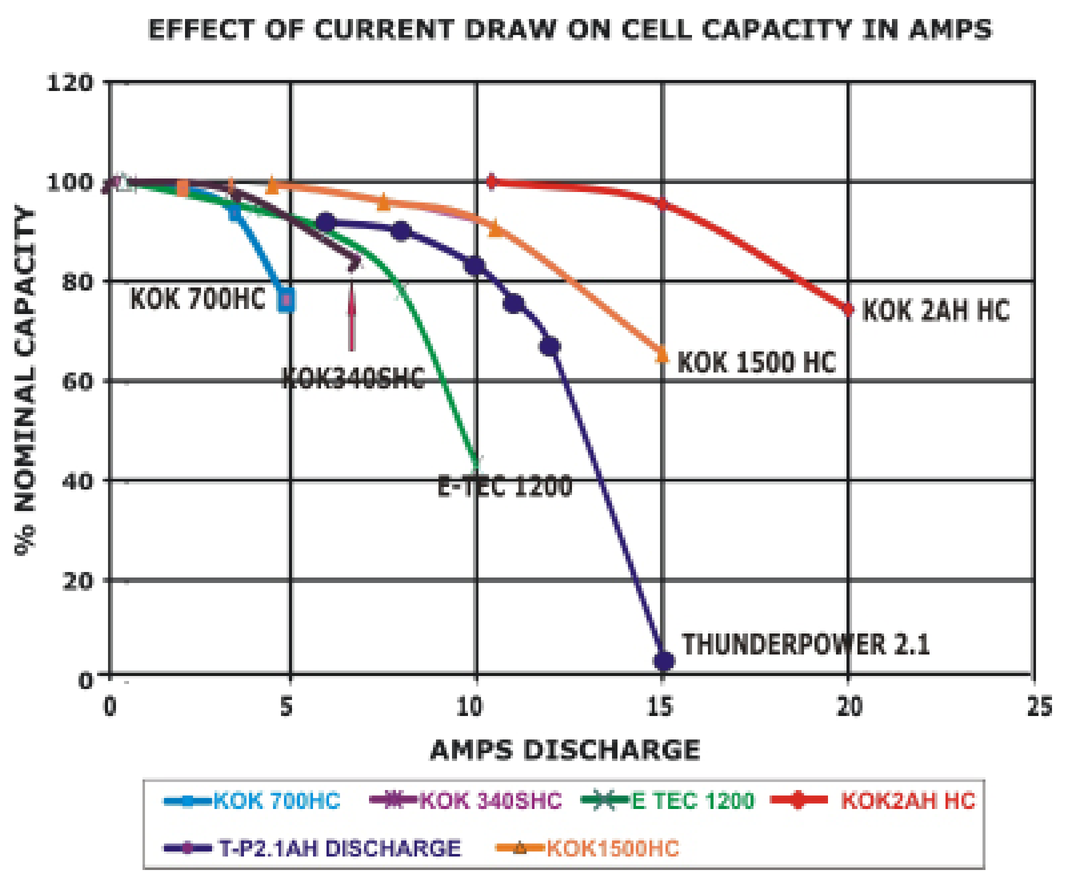


As a general rule, LiPo cells should not be forced to deliver continuous current above the multiple of C where the curve bends sharply downward. In the unique case of the KOK 340, that does not occur and the cell can be operated continuously up to 20C. However, please recognize that run time is going to be very short at a 20C discharge rate. As a “rule of thumb,” heating and deterioration of cell capacity will result when cell capacity is depressed below about 85%. Kokam USA specifies cell performance as times C for continuous operation with bursts to a higher multiple, say 10C. When operated in normal RC applications, the cell is not usually driven continuously at high multiples. However, this is a matter of pack design. If you design your pack to operate at very high multiples in order to save weight or reduce cost, then you must expect shortened life.

The Thunderpower cells have about the performance of the first generation Kokam cells, now replaced by the new HC cells plotted in the charts. The E Tec cells have slightly higher discharge capability than the original Kokams, but significantly lower than the new generation Kokams. The following is a quote from Thunderpower literature: "Thunderpower designs our pack around 3 to 4 average discharge and 5 to 8 bursts..." Thus, high current discharge can be achieved only by paralleling large packs of Thunderpower cells, in the range of 8Ah (8Ah x 4C = 32 amps). Like the first generation Kokam cells, the Thunderpower pack cannot operate much above 5C as shown in the curves above. The weight of that pack is 17% higher than for the KOK 1500. Each T-P 2100 weighs 41 grams, thus the 4S4P pack of that cell required to deliver 30 amps weighs 16 cells x 41 grams/cell = 656 grams. At the 4.5C rate, the T-P 2100 delivers 82.5% or 1.73Ah. In Don Srull's tests, the T-P cells under that load measured 127.7 Wh/kg.

In the next figure, the data are presented as actual current drain versus % nominal capacity. This gives a much more direct way to see what the cell is expected to deliver without the need to do the multiplication. The above example can be read directly. A Thunderpower 2.1Ah cell can sustain 8 amps at 4C and 85% capacity. A KOK 2Ah cell can sustain 17.5 amps at 85% capacity; more than twice the current drain. This means the user has a great deal more flexibility in application.

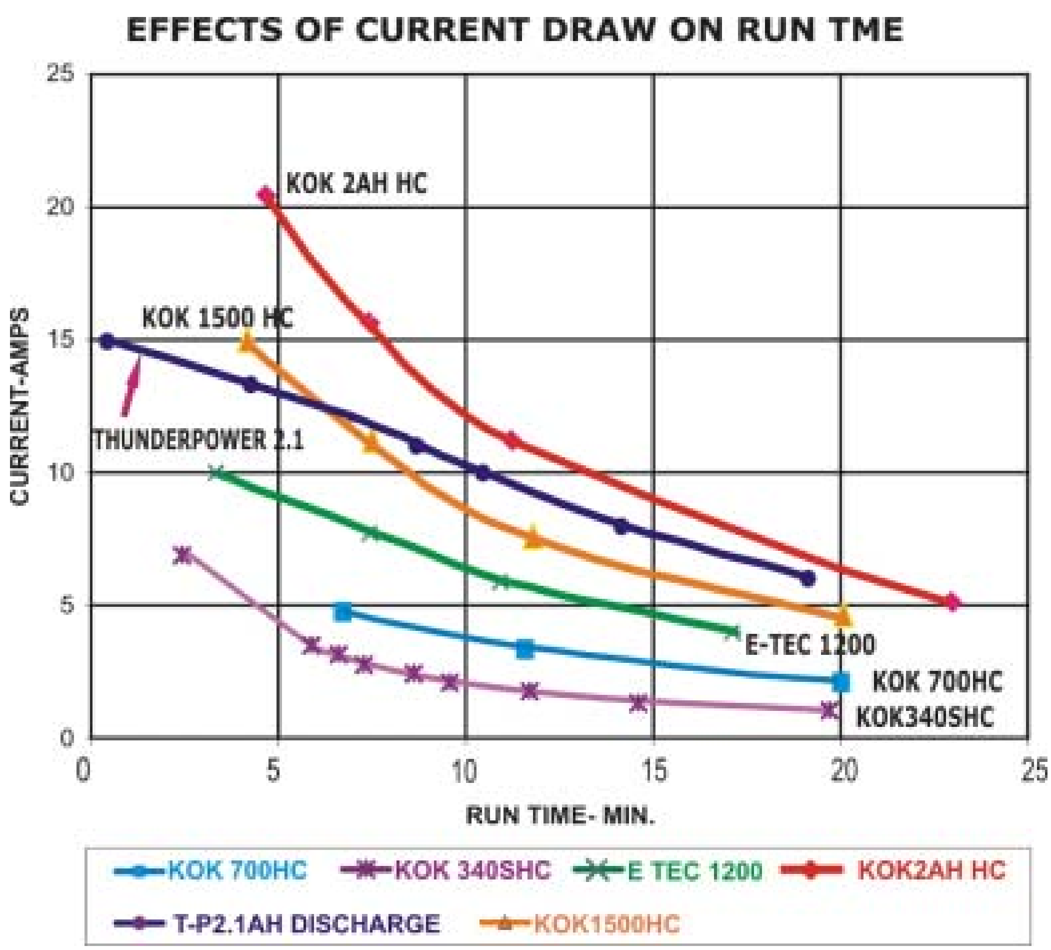
As cells are paralleled, the capacity and discharge current available multiply by the number of parallel cells. For example, a 4S3P pack of KOK 1500s (12 cells) will be able to handle most helis and similar applications instead of 16 E-TEC 2100s. The savings in weight will permit the aircraft to fly at lower throttle settings and, thus, as long as the larger, more expensive pack of 2100s.



Data in the last two curves aid in formulation of LiPoCalc described earlier. LiPoCalc , at this writing, is being updated to reflect the new generation of Kokam LiPo HC cells.

The third determinant of pack design is the flight duration desired. One of the advantages of LiPo cells is that they can be paralleled to obtain much longer duration than a pack of NiCd or NiMH cells. For the same weight as a pack of NiCd cells, five times the capacity can be obtained from LiPo.

The curves below plot flight time at various current draws. Flight time is calculated as the actual capacity measured for the cell at a given discharge rate (Ah) divided by the current drain (amps). Ah/A = run time in hours x 60 min/hr = minutes of run time.



Salient observations include:

- Paralleling cells reduces the current drain per parallel multiple proportionately. This also reduces the current draw as a multiple of C which, in turn, increases the amount of current the paralleled pack can handle. For example, a 4P pack of KOK 1500s can handle 60 amps peak and 48 amps continuously. It can also deliver nearly the full 6Ah capacity at a current draw of up to 42 amps. The impact of this on pack design and cost is discussed later.

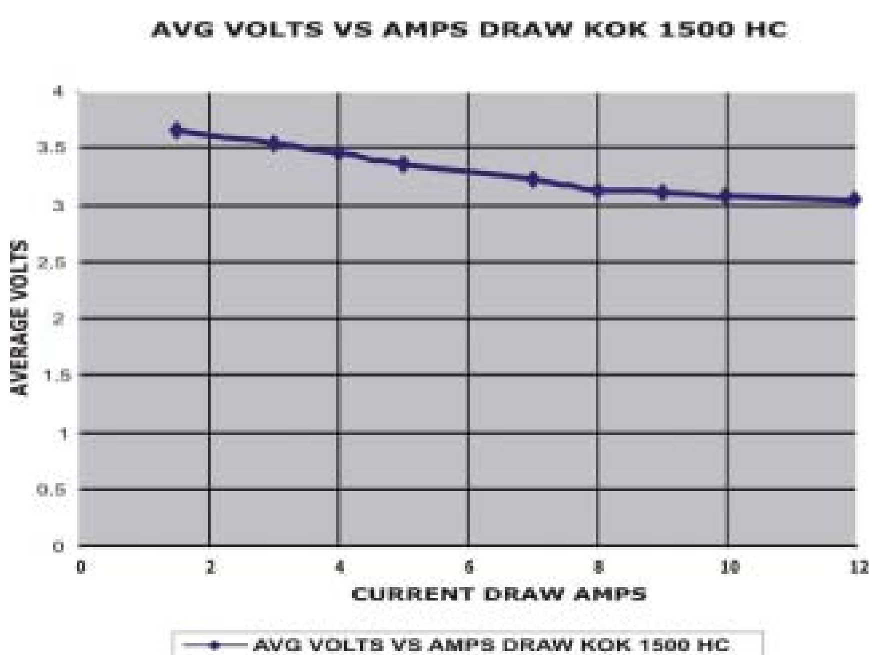
- The run time available is computed for you by LiPoCalc from the curves below. The effect of having a cell lose capacity rapidly under increasing current draw is most visible here. Note from the XC curves that the Thunderpower, E Tec and the Kokam 700 fall off faster with increasing load than the KOK 340, KOK 1500, and KOK 2AH. As a result, the latter three produce relatively greater run time at high current compared to the former. This is reflected in the swing upward as current increases. The first three tend to flatten at higher current drain. If the cells are run at very low current drain, all converge at some point far to the right. For many applications, high discharge capability contributes nothing. For power tools and RC, high discharge contributes greatly.

Voltage depression

Cells of all chemistries have internal resistance. (Invent one that doesn't and you have the battery world by the tail!) Voltage depression is why you have to "add a cell" when using NiMH cells. Voltage depression is the most visible feature in plots of voltage versus time at various discharge rates. A cell that is "stiff" has less voltage depression than others. One component of watts delivered is voltage; the other is amps. Capacity inAh is amps x time. Most battery test instruments record voltage versus time. It isn't hard to measure the voltage during a discharge run. One can use a DVM with a PC port (Radio Shack, for example, sells one) to record discharge data.

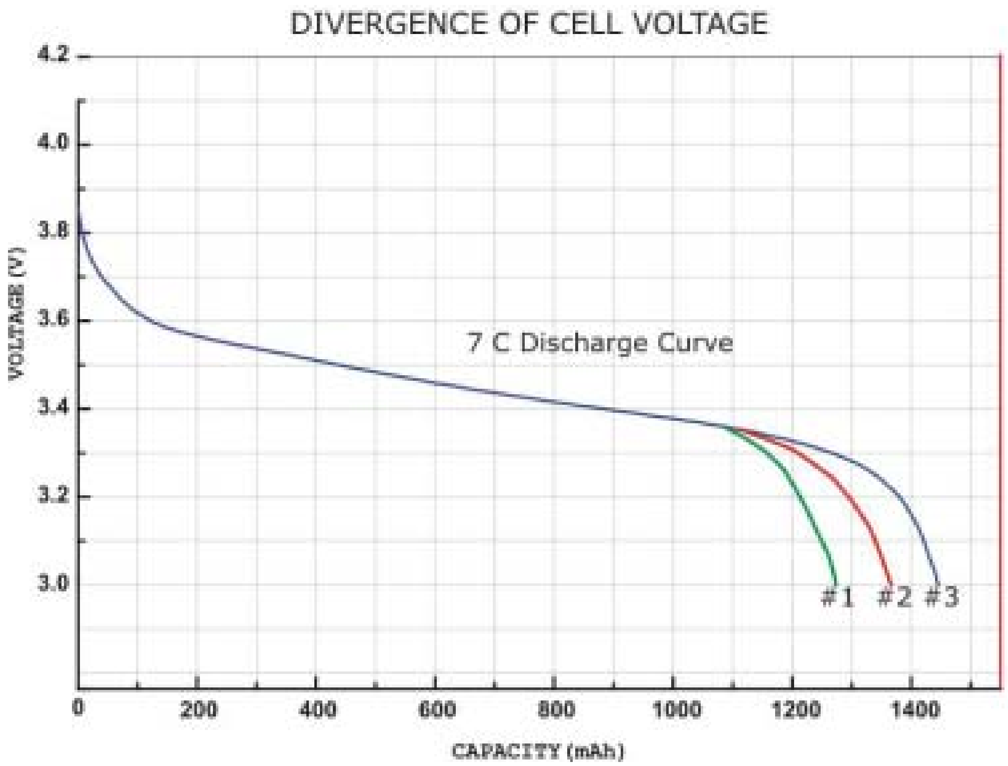
The challenge is getting a constant discharge rate. Driving a motor that changes load, speed, and other characteristics as the motor heats and as voltage falls is not satisfactory. With no control over these variables the data is questionable. Discharging with light bulbs or fixed resistors has the same shortcoming. However, if the set up has a current sensing and control arrangement, then it will produce valid data. The expensive professional battery test equipment used by Don, Red and battery manufacturers has that capability.

Each test reported above recorded voltage versus time. As noted earlier, the mass of curves would be impossible to follow. For now, the time was taken to plot the locus of points for the KOK 1500 as follows:



Cell unbalance and how to avoid it

Whether a pack is made up of NiCd, NiMH, or LiPo, cell unbalance can occur. No two cells in a pack come down off the break in the discharge curve at exactly the same time because capacity varies slightly from cell to cell. Remember that the rated capacity of cells is a "nominal" capacity. That is, many cells are tested at rated current (0.5 C) and the normal distribution defines the capacity. The curve below shows in exaggerated fashion what happens as cells in a pack discharge.



The voltage starts initially at 4.2V, but with any significant current flow, falls to the nominal 3.7 to 3.6V and continues to decrease slowly. Each cell delivers its capacity and voltage drops rapidly at the end of capacity. Cell 1 dumps first, then cell 2, and finally cell 3.

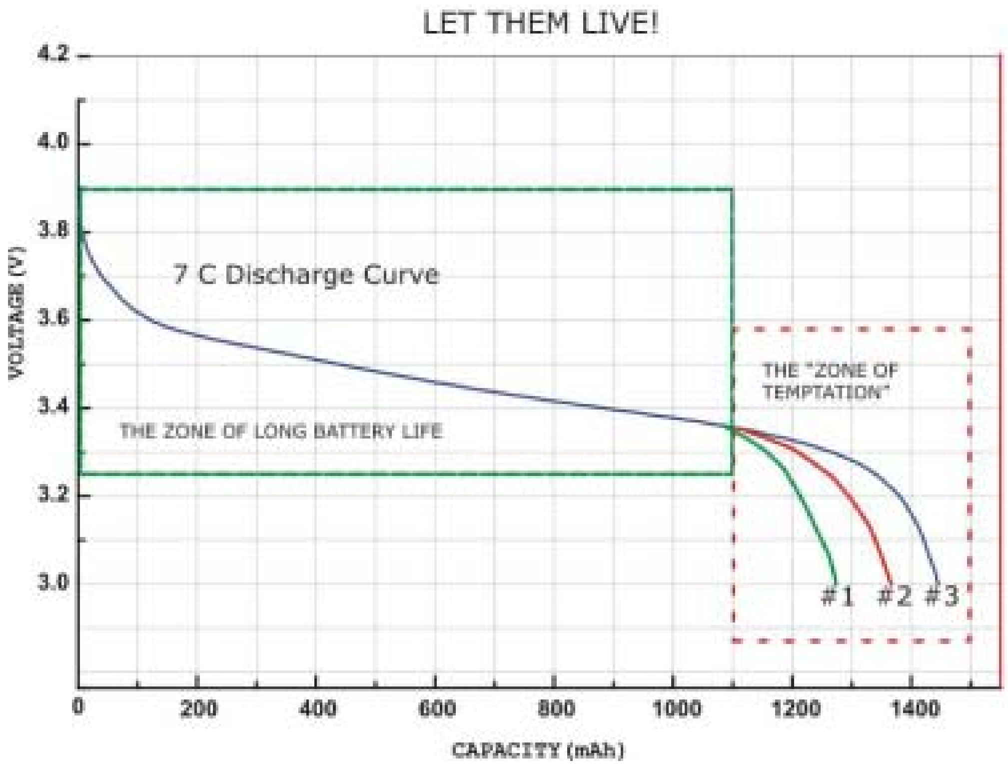
In a pack, the average drop arrives rapidly after the first cell goes down. Cut-off occurs when average pack voltage reaches the voltage set in the ESC. When that happens, cell 3 will have the highest voltage followed by cell 2 and cell 1. If cell voltages are measured at this time, most certainly, unbalance will be seen. However, as the pack is recharged, the cells come into balance.

CAUTION: If a cell is found to be out of balance by more than about 0.2V from the average of the pack, then that cell should receive an individual charge to see whether it comes into balance.

During preparation for and competing in the Scale Masters, George Maiorana kept careful track of the packs and cells by periodically measuring individual cell voltages. He reported that the cells all came to within about 100 millivolts of each other on the charge after the competition. You don't need to check balance each time, just occasionally. The frequency depends on how much you fly.

Avoiding the “zone of temptation”

The regimen of competitive electric car racing has demanded the use of matched cells, cell formation, cell balancing and other techniques. LiPo cells provide so much more capacity and energy density that those practices aren’t required.



Earlier, the curve above was used to illustrate how cells run out in discharge and the voltage diverges. That divergence can lead to cell damage if one cell goes below 2.5V and is driven there for more than a moment. As cells age, the divergence may become more pronounced, particularly near the end of cycle life. Grading and selecting cells adds cost to a pack, and car racers are willing to pay extra to get that competitive edge. They drive packs right down to the last mA and the traces above result. NiCd and NiMH cells are more tolerant of being driven down almost to zero.

The minimum voltage for LiPo is conservatively set for protection of the cells. There is really very little to be gained by driving the cells to the bitter end. The above curves are exaggerated to show that there is a divergence. In fact, the difference between the break point on the curve and the cut-off is only about 1% of total capacity.

When using LiPo packs, we recommend that you:

- Set the cut-off above 2.5V, or nearer 3V in most situations.
- Avoid designing your pack so that it has to operate at the maximum allowable discharge rate.
- Stay out of the “zone of temptation.”

For aircraft, the “zone of temptation” is usually entered by repeatedly restarting after the first cut-off occurs.

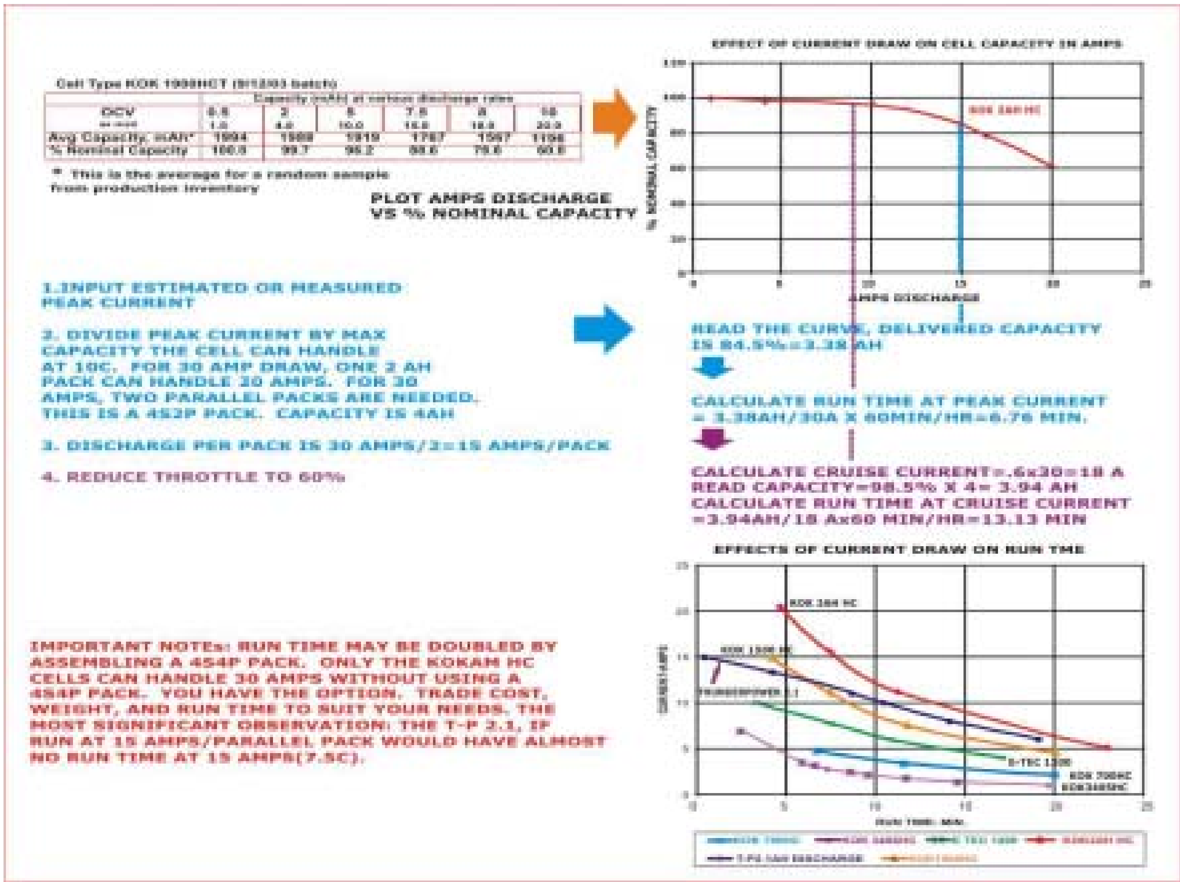
As with many rules, there is an exception. The Kokam HC cells, when operated right up against the maximum allowable discharge are a little above the 3V line. A sudden application of throttle in that situation could cause a motor cut-off. Thus, the cut-off for the KOK 700, 1500 and 2AH should be set for 2.8V. In general, experience is showing that most airplanes have stopped flying before cut-off occurs, so this may be a moot point.

How do we get from the curves to LiPoCalc?

With the data presented in the above curves and the input parameters listed under LiPoCalc, LiPoCalc can help you define what battery pack is needed based on your application requirements. If you know the voltage and peak current, plug them into LiPoCalc and it does the rest.

The process that creates the input for LiPoCalc is diagrammed below. The test data are taken at constant current using precision battery test equipment. Cell capacity dissipated is measured every few seconds to generate an Excel spreadsheet. The data file tabulates capacity available to cut-off voltage, the constant current, and current as a multiple of the baseline C. The capacity at cut-off is divided by the actual measured capacity at cut-off, and converted to % nominal capacity. This makes available to LiPoCalc either a mathematical curve equation or a look-up table.

Given the peak current expected (bursts) and selecting the operating voltage or the voltage limit for the motor to be used, the capacity expected for those conditions can be read from the curve or drawn from a look-up table. This operation sizes the pack to sustain the peak current expected. The capacity that could be expected if the current were held continuously at peak is the value used to compute how many parallel packs would be needed. The pack must be sized to handle the peak current.



LiPoCalc displays the pack required (for example, 4S if you need a nominal 14.8V). In the LiPoCalc illustration below, 30 amps is the target current. The 2AH HC pack is the arbitrary choice. Looking at the discharge curves above, the cell is capable of delivering up to 20 amps (10C), so a pack as small as 2P could deliver up to 40 amps peak and 32 amps continuous. The 30 amp load would impose a load of 7.5C that is conservative for the 2AH HC cell. The cost for such a pack will be approximately half that of a 4P pack.

Run time as displayed on the curves can be placed in a look up table or calculated. Run time is the capacity to cut-off (Ah) divided by average current (A) multiplied by 60 min/hr to yield minutes of run time. This is static run time. In the air, props/rotors unload and current consumption reduces by some 10 to 15%.

Cost is read from the catalog price sheet for the pack required.

Effect of high discharge capacity on pack design

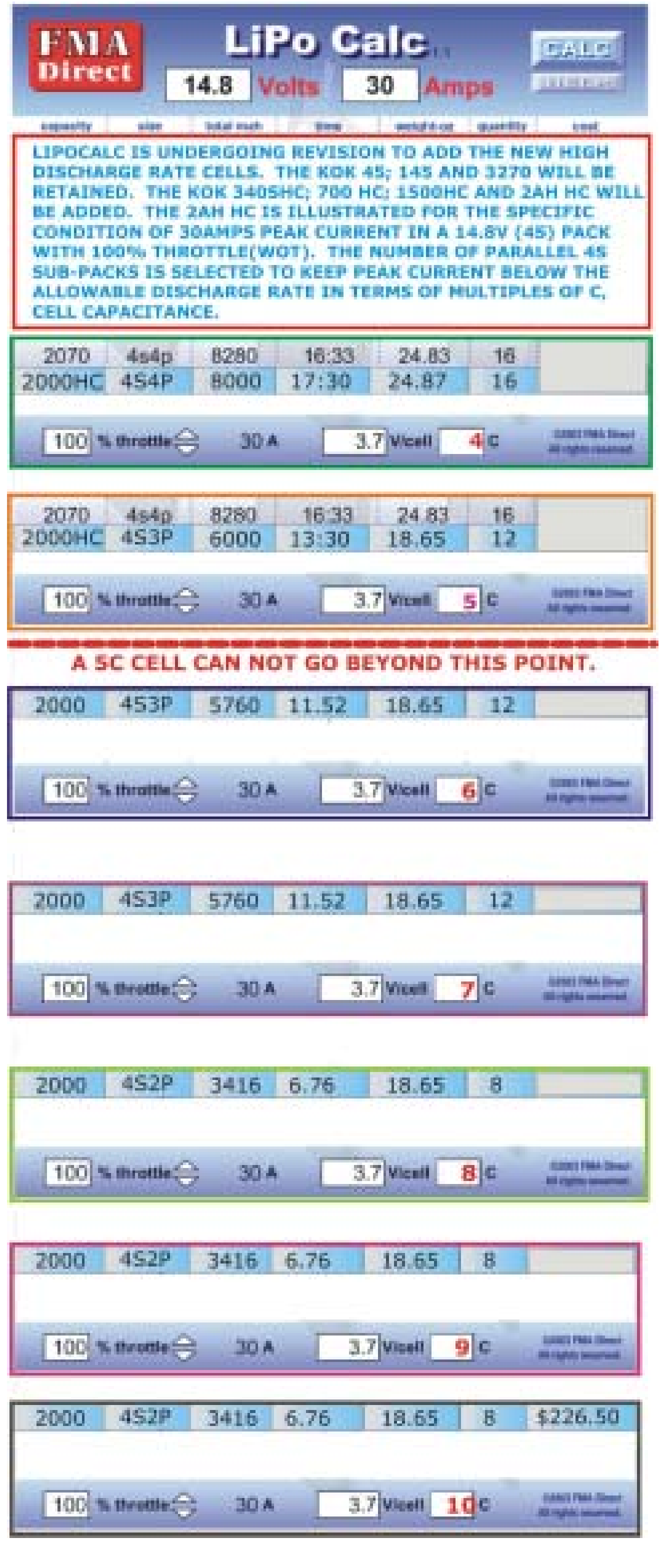
Much has been made of the effectiveness of high capacity (8Ah or so) packs. In 2002, Kokam USA presented analyses to show that use of parallel packs of Kokam 3.27Ah cells (for example) to build packs of 6 to 10Ah would be very effective for use in larger models. Such a pack, even with a 4C discharge, could deliver 40 Amps current.

Some opted to produce such packs and laid out the claim that the packs were "high discharge rate." Yes, the *packs* are that, but the *cells* are not high discharge rate. The curves in the previous section clearly show that. The curves also show the effect of having cell discharge rate increased such that all the Kokam cells can be used at truly higher discharge rates than the first-generation Kokam cells and other LiPo cells.

The effect on pack design is that the user may now tailor a pack to do what is needed without excess size, weight, capacity and cost associated with paralleling cells capable of 4 to 6 or even 7C. Of course, the KOK 340HC is the leader with its 20C capability. The first advantage is that the HC cells hold capacity of 60 to 80% even at discharge rates of 10C and hold 100% capacity farther into the increased rate. This, in turn, reflects in much longer flight time per cell. Kokam USA has set the level at which cell capacity degrades to 85% as the max continuous current for the HC cells. This is a conservative level designed to minimize cell heating and ensure longevity.

Based on the Tu-4 data, the average current drain calculated to be 14 amps. A 4S2P pack would have saved an additional 1.25 lbs to bring the airplane to about 25 lbs; a 15% reduction. Since each pack can sustain 15 amps peak, a 4S2P pack could be used. The flight time would be (3Ah [for a 2P pack] ÷ 14A) x 60 = 12.8 minutes. That correlates well with George's measurement that found on 1.75Ah had been used.

The illustration of LiPoCalc below is for the specific application of the big Tu-4. The airplane flies quite successfully with a large margin in performance and duration. The 7.5 minutes required to perform the flight routine used just 1.75Ah from the 6Ah pack. This computes to an average current drain of 14 amps per pack or a total of 56 amps at an average of 13V for watts consumed of 676. The illustration is not extended to a 60% throttle setting, but it is clear that the model was flying on less than ½ throttle most of the flight. It is important for the future that we have in-flight measurement capability via the upcoming Flight Recorder so that some of these figures defining aircraft performance can be refined.

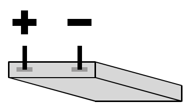
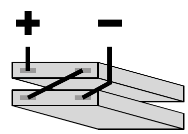
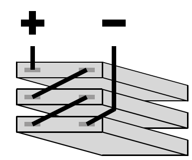

FMA Direct
LiPo Calc
14.8 Volts
30 Amps
CALC
LIPOCALC IS UNDERGOING REVISION TO ADD THE NEW HIGH DISCHARGE RATE CELLS. THE KOK 45; 145 AND 3270 WILL BE RETAINED. THE KOK 340SHC; 700 HC; 1500HC AND 2AH HC WILL BE ADDED. THE 2AH HC IS ILLUSTRATED FOR THE SPECIFIC CONDITION OF 30AMPS PEAK CURRENT IN A 14.8V (4S) PACK WITH 100% THROTTLE(WOT). THE NUMBER OF PARALLEL 4S SUB-PACKS IS SELECTED TO KEEP PEAK CURRENT BELOW THE ALLOWABLE DISCHARGE RATE IN TERMS OF MULTIPLES OF C, CELL CAPACITANCE.
2070 4s4p 8280 16:33 24.83 16
2000HC 4S4P 8000 17:30 24.87 16
100 % throttle 30 A 3.7 V/cell 4 C
2070 4s4p 8280 16:33 24.83 16
2000HC 4S3P 6000 13:30 18.65 12
100 % throttle 30 A 3.7 V/cell 5 C
A SC CELL CAN NOT GO BEYOND THIS POINT.
2000 4S3P 5760 11.52 18.65 12
100 % throttle 30 A 3.7 V/cell 6 C
2000 4S3P 5760 11.52 18.65 12
100 % throttle 30 A 3.7 V/cell 7 C
2000 4S2P 3416 6.76 18.65 8
100 % throttle 30 A 3.7 V/cell 8 C
2000 4S2P 3416 6.76 18.65 8
100 % throttle 30 A 3.7 V/cell 9 C
2000 4S2P 3416 6.76 18.65 8 $226.50
100 % throttle 30 A 3.7 V/cell 10 C

“So, what do I need for my bird, since it isn’t a Tu-4?”

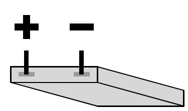
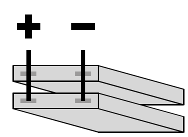
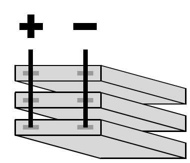
LiPoCalc will do a very good job of sizing a pack if you know the input parameters. However, as stated earlier, that question is the one we hear most often. The tables below are provided to get you into the ball park. It is virtually impossible to cover every combination of propulsion package in use or coming on the scene. However, we will attempt to provide as much information as can be assembled right now.

First, standard inventory packs can be assembled in series or parallel using the Connector Modules as shown in the next diagram. Need higher voltage? Plug packs into a Series Connector Module. Example: plug a 2S and a 3S pack into a Series Connector Module to get 18.5 Volts output (all cells must have the same capacity).

Nominal voltage output from serial packs

	1S (1 cell)	2S (2 cells in series)	3S (3 cells in series)
			
Voltage	3.7 Volts	7.4 Volts	11.1 Volts

Peak burst current output from packs connected in parallel

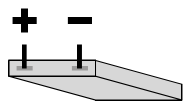
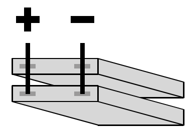
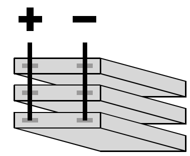
		1P (1 cell)	2P (2 cells in parallel)	3P (3 cells in parallel)
				
Cell capacity, mAh	KOK145 at 6C	0.7 Amps	1.4 Amps	2.1 Amps
	KOK340SHC at 20C	6.8 Amps	13.6 Amps	20.4 Amps
	KOK700HC at 10C	7 Amps	14 Amps	21 Amps
	KOK1500HC at 10C	15 Amps	30 Amps	45 Amps
	KOK2000HC at 10C	20 Amps	40 Amps	60 Amps
	KOK3270 at 5C	16 Amps	32 Amps	48 Amps

*Peak burst current is a cycle consisting of less than 12 seconds of peak current followed by 50 seconds at 50-60% of peak current.

Need higher current or longer flights? Plug packs into a Parallel Connector Module. Example: plug four 1S packs into a Parallel Connector Module to get 4 times the output of a single cell (all cells must have the same capacity).

The table above is for the peak current expected. The table below is for continuous operation. Remember that pack size is set by the peak current while duration is set by the average duty cycle.

Continuous current output from packs connected in parallel

		1P (1 cell) 	2P (2 cells in parallel) 	3P (3 cells in parallel) 
Cell capacity, mAh	KOK145	0.7 Amps	1.4 Amps	2.1 Amps
	KOK340SHC	6.8 Amps	13.6 Amps	20.4 Amps
	KOK700HC	4.2 Amps	8.4 Amps	12.6 Amps
	KOK1500HC	12 Amps	24 Amps	36 Amps
	KOK2000HC	16 Amps	32 Amps	48 Amps
	KOK3270	10 Amps	20 Amps	30 Amps

Here are some typical continuous current requirements for various kinds of models:

Indoor flier	up to 2 Amps
Speed 300	up to 8 Amps
Speed 400	up to 12 Amps
Speed 600	up to 30 Amps
Bigger aircraft	30 to 50 Amps
Cars/trucks	20 to 35 amps

The next page lists example applications. Your specific application will vary because of airframe weight, gear ratios, motor efficiency, prop, wiring losses and ESC performance. However, these will get you into the ball park. Please send us your inputs and applications.

LiPo power suggestions for various electric aircraft types and sizes

Model type	Model wt.	Typical motor/drive	Current draw	Kokam cell/pack	Comments
Micro and indoor	< 4oz	Didel or home built gear drive with coreless motor	150 to 300mA	KOK45 or KOK145, 1S1P (if receiver and actuator will operate at 3V)	
Indoor and backyard flyer	3 to 8oz	N20 with gear drive	400 to 800mA, 1A peak	KOK145 2S2P, KOK340 2S1P	
High performance indoor and backyard flyer	4 to 8oz	KP01 with gear or direct drive	1 to 2A	KOK340 2S1P	
Park flyer		Speed 280/300	<8A	KOK340 3S1P	Measure motor current and limit to 8A average using throttle end point adjustment (EPA) to prevent motor burnout. Cuts drain by 1/3 for longer flights.
Park flyer	8 to 16oz	Mabuchi brushed, Astro 010 or small brushless outrunners		KOK340 2S1P, KOK700 2S1P, KOK1500 2S1P	
Park flyer	10 to 20oz	12V brushless	<10A	KOK1500 3S1P	
Park flyer		Speed 400 with gear or direct drive	<12A	KOK1500 2S1P or 2S2P	Measure motor current and limit to 12A using throttle end point adjustment (EPA) to prevent motor burnout. Use parallel packs to increase flight time.
Big park flyer, glider		Brushless outrunner with gear or direct drive	<25A	KOK1500 3S or 4S and enough in parallel to provide desired duration	
Aerobatic		Speed 450/600, usually direct drive	<27A	KOK1500 3S3P (gives 4.5Ah at 6C for >15min flights and 96% capacity), KOK2AH 3S3P (for 25 to 30min flights)	
Pylon racers, high performance powered gliders			<27A	KOK340 2S3P or 3S3P	
Micro helicopter	10 to 30g		250mA	KOK145 2S1P or 3S1P	
Mini helicopter	5 to 10oz		4A continuous, 6A peak	KOK340 2S1P or 3S1P	
Mid-size helicopter		Brushless or high quality Speed 400	12A continuous, 15A peak	Low cost: KOK1500 3S3P Long duration: KOK340 3S4P or 3S5P, or KOK2AH 3S1P or 3S2P	

Specific aircraft

Model type	Model wt.	Typical motor/drive	Current draw	Kokam cell/pack	Comments
MIG 15 converted from free flight	6.9oz with NiMH, 6.5oz with LiPo			KOK1100 2S1P	15 to 20min flights. (From Don Srull.)
60-size Extra 300S	4lb (63in span)	MaxCim 13D brushless with 16x10 prop 	55A	KOK2AH 5S5P	Does knife edge. 15min flights with average 60% throttle. (From Greg Covey.)
Logo 10 helicopter	22oz with NiCd, 13.8oz with LiPo		20A	KOK1500 3S3P	Flight time increased 50% over 10 3.3Ah NiCds. (From Steve Neu.)
Logo 10 helicopter	9.4oz		20A	KOK2AH 3S2P	12.5min flights. (From Steve Neu.)