INTRODUCTION to ELECTRIC AIRPLANES

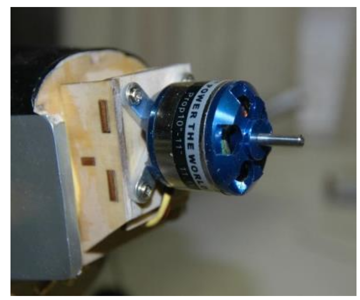
Electric aircraft are not new. They have been around for decades. The reason they are now popular is the motor is now brushless and much more efficient that conventional brushed motors.

The misconceptions are that electric aircraft are expensive, dangerous, and very technical. Dollar for dollar the electric system is much more economical than glow. All things considered, electric aircraft are safe when properly used and maintained. Technical, of course, but only if you are nerdy and have to know the inner workings of all the components – do you know how your computer works or your car?

The essential components are the motor, motor controller, and battery.

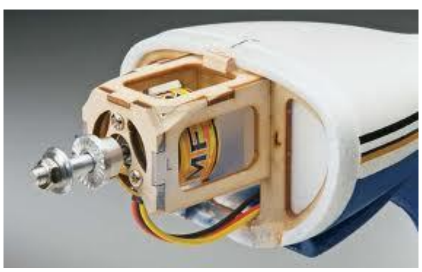
MOTOR For the nerds, check out ***Brushless DC electric motor*** on Wikipedia or other web sites for an in-depth understanding of senserless brushless electric motors and controllers.

The advantage over glow engines is much less vibration and uniform power output. A brushless motor has three connecting wires as compared with a brush type motor which only has two wires.



There are two mounting configurations: outrunner and inrunner.

The **outrunner** has a mounting plate on the back of the motor which is fastened to the firewall



The **inrunner** has the mounting holes up front so the motor is behind the firewall.

However the motor is mounted – it still has to be firmly fastened in place and the prop balanced.

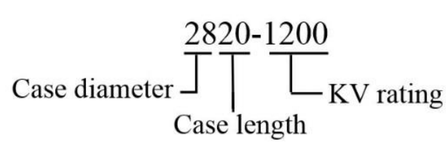
If you plan on purchasing a Ready-to-Fly, **RTF**, or Almost-Ready-to-Fly, **ARF**, that just needs a receiver and battery, you can hope that motor and controller included with the airplane is adequate.

MOTOR RATINGS This is one aspect of electrics than can be confusing.   The three essential motor ratings are physical size, power rating, and RPM.

Some manufacturers identify their motors by a unique label such as D26-A, or by comparison to its glow engine equivalent such a G40 which is equivalent to 40 size, or its physical size such as a 2820-1200.

For the first two examples, you gleam the motor ratings from the specification sheet that comes with the motor, or go on-line and get the ratings.

The last example is becoming the convention and can be interpreted as the case being 28 mm in diameter, 20 mm long, not including the end bears or mounting, and having a KV rating of 1200 rpm per volt.



In general terms, the larger the motor – the higher the power capabilities
The KV rating is the number of revolutions per second (RPM) per volt without a load (prop) on the motor.

Example: A motor with a KV rating of 1200 using a 3 cell Lipol 12.6 volt battery will result in a RPM of 15120 (1200 x 12.6).

In actual operation, the maximum RPM will be determined by the loading effect of the propeller. A small prop will result a higher RPM than a larger prop because of less loading.

The lower the KV rating, the higher the output power, or torque. Higher KV ratings, such as 4800 are used by helicopters – the KV is higher and the torque is less and a gear train is used to reduce the RPM and increase the torque to the rotor blades. Even higher KV ratings are used for ducted fans used to propel jets.

The power rating is in watts and is determined by using a wattmeter or multiplying the voltage by the current. 746 watts is equal to 1 horsepower.

Wow, this is getting too technical. **Not to worry** – you can use the motor size (and ratings) recommended by the airplane manufacturer, or consult a fellow club member that has the technical knowledge and experience with electric aircraft.

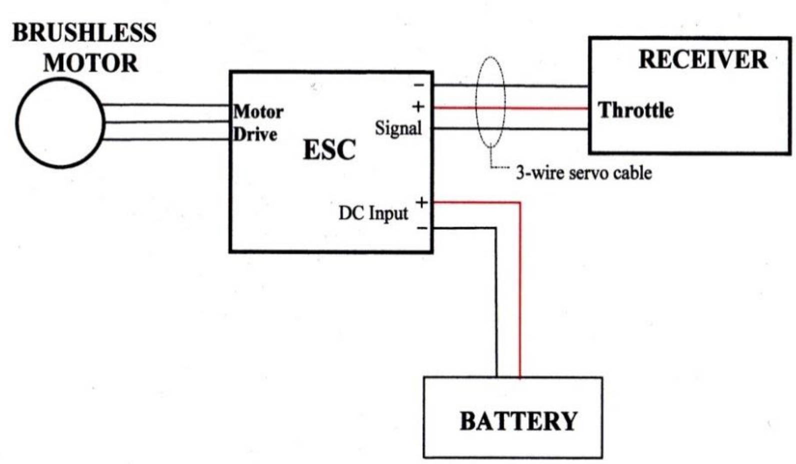
CONTROLLER The motor controller, called an **ESC** for **E**lectronic **S**peed **C**ontroller, is the interface between the actual motor and the throttle signal from the receiver. The ESC circuitry interprets the throttle level and supplies the current combinations of electrical pulses to motor.

The main rating for the ESC is the current rating, such as 25 A or 25 amperes. This rating is the maximum constant current that the ESC can handle, and should be de-rated, that is to say if 20 amps will be the maximum current for a particular model and motor – use a ESC with a higher current rating, such as 25 or 30 A ESC. If the prop hits the ground or runs into tall grass or whatever, the motor will demand more current and may burn out the ESC. There is little difference in the price of a slightly higher rated ESC, and much cheaper than having to replace a burned out controller. It also runs cooler.

In small to medium size electric aircraft, the ESC also includes a **BEC**, or **B**attery **E**liminator **C**ircuit. The BEC supplies the voltage to the receiver and servos. As shown in the illustration, an ESC with BEC has three sets of leads.

One set is the **motor leads** – three wires. These wires may not be color coded. If the motor runs backwards – then switch any two of the three wires to make the motor run in the correct direction.

The next is the three wire cable that plugs into the **throttle** channel of the receiver, the black (or brown) wire is the electrical ground, the red wire is the "battery" voltage to power the receiver and servos, and the white (or orange) wire is the throttle signal wire from the receiver to the ESC – this cable is identical to a servo cable and plugs into the Throttle channel of the receiver.



The third set of leads are the **battery** connections, which connects to the battery (makes sense) in which the positive lead is red and the negative lead black and **MUST** match the same colors as the battery leads. Later there are circuit diagrams showing actually "hook ups" including the type of connectors used.

Complexity of ESCs varies according to manufacturers. Most are programmable for such aspects as brake, battery type, cut off voltage, start mode, timing, and more. Check the information sheet that comes with the ESC.

ESCs include an **arming feature** for safety – very important. The simplest is where the motor will only become usable (armed) if the throttle is at its lowest level when a battery is connected. Once armed, the motor will only start when the throttle is advanced.

A useful feature of ESCs is the **cut-off** setting. Once the battery voltage reaches this voltage, the ESC stops supplying power to the motor but maintains the BEC so that you have control of the airplane for a "dead stick" landing. Once the cut off is reach and the motor stops, go to minimum throttle - then throttle up only if you need a little power for the landing.

BATTERY

The **lithium polymer** battery is the next major component of electric aircraft. LiPol batteries are significantly lighter and have a higher current capacity per size than nickel-cadmium (NiCD) or nickel–metal hydride (NiMH) batteries.

The ratings for LiPol batteries are: cell configuration, current capability, discharge, and voltage. Over-all physical size may differ, depending on the manufacturer.

A single lithium cell has a **nominal voltage of 3.7 volts**. When fully charged the voltage is 4.18 to 4.21 volts, and fully discharged when 3.2 volts. Some may argue that you can discharge a LiPol battery down below 3.2, to as low as 3.0 volts – good luck and buy lots of spare batteries. ***LiPols are usually damaged if discharged below 3.0 volts.***

For longer battery life it is recommended that the battery voltage when discharged is around 3.7 to 3.8 per cell.

The **current capacity** is dependent on the physical size, the larger the cell size then the more the current storage capacity. A battery with a current rating of 2 amperes means that it can supply a current of 2 amperes for 1 hour.

Other than micro electric aircraft, more than one individual cell is required, so **cells are connected in series** – **NEVER** connect individual cells in parallel with each other. Two cells in series would then have a nominal voltage of 7.4 (2 x3.7) or a full charge voltage of 8.4 volts (2 x 4.2).

Multiple cells constitute a battery. The convention for LiPol batteries is the number of cells in **Series** with the same number of series cells in **Parallel**. Examples:

2S1P 2 cells in series and 1 (none) in parallel. The charged voltage would be 8.4 volts
3S1P 3 cells in series and 1 (none) in parallel. The charged voltage would be 12.6 volts
: :
6S2P 6 cells in series and in parallel with 6 cells in series. The voltage would be 25.2 volts

If more current capacity is required, series combinations are connected in parallel with identical series combinations.

An example would be two batteries, **4S1P** each with a capacity of 3 amps. The full charge voltage of each battery would be 16.8 volts, or 4 x 4.2, and when connected in parallel – the terminal voltage would remain as 16.8 volts. The current capacity of this example would become 6 amps, or 2 x 3 amps. **Be careful** if you attempt to make your own batteries – re-read and fully understand that all the individual cells in a battery MUST be identical and never connect individual cells in parallel.

BATTERY CAPACITY

This is essentially the current capacity of the battery, and usually stated in milliamps, i.e., 800 mA or 2,200 mA.

Milliamps can be also be stated in amps by dividing the mA rating by 1,000. A 800 mA is .8 A, the 2,200 mA is 2.2 A.

As for any battery type – this rating is the amount of current that can be drawn from the battery for 1 hour (60 minutes). The battery capacity, as stated on the battery must not be confused with the C rating.

C RATING

Now for the CURRENT DSICHARGE or **C** rating. An example is a battery that has a C rating of 20 means that you can draw current from it at 20 times its current rating. Example: if the battery rating is 2 amps (2,000 mA) - you can draw a **maximum** of 40 amps, 20 x 2 A.

There is a catch however so pay attention!

Remember that the current rating relates to an hour, or 60 minutes, so if you draw 20 times that rating, you can only do it for $1/20^{th}$ of the hour, or 3 minutes, 60/20. Wow, only 3 minutes? In this example you have two choices for longer flight time. One is to use a battery with a much higher current rating, i.e. 4 amps at a 20C discharge for 6 minutes. The second choice is not to fly full throttle, i.e., use a 2 A battery and only draw 10 A for a 12 minute flight/

Again, you don't have to be a math wizzzzzzz if you follow the manufacturer's recommendation, or consult a fellow flyer who has the experience and technical knowledge to suggest a battery for your application.

As an additional check – fly a limited number of minutes and check the status of the battery by taking a voltage reading. If OK, then recharge the battery and have another flight for a longer duration and again check the voltage. After three or four flights you will have a good idea of how long you can safely fly.

Care and Feeding of LiPol Batteries

When you purchase a new LiPol battery it is not fully charged but rather in **STORAGE** mode, approximately 50% charged, with a terminal voltage around 3.8 volts per cell.

You require a **Lithium Polymer specific charger**. ***Never use a NiCd or NiMh charger*!**

With the exception of some small low current batteries, our batteries have two sets of leads.

One set is comprised of two heavy gauge wires, black (negative) and red (positive), which are the **battery terminal wires**, terminated in a high current connector such as a bullet connectors, Deans, or XT60. This connector mates with the battery leads of the ESC.

The second set of leads, of smaller gauge, are for **cell balancing**, and usually terminated in a JST type connector. This connector has one more wire than there are cells, i.e., a 3S1P will have 4 wires. The two outboard pins, black wire for negative, and red wire for positive, with the wire(s) in between varying in color. This is used for balancing individual cells during the charging, discharging, cycling, or storage when using your battery charger. This connector is used with a LiPol voltage tester, which shows the voltage of each individual cell. This connector is also used by some ESCs for monitoring individual cell voltages during flight to not only determine when the battery has reached cut-off but also whether the battery has become faulty – such as an open or shorted cell.

CHARGING Chargers vary in operation. The charger needs to know the number of cells, and the charge current. Some smart chargers are able to self-determine the number of cells by sensing the individual cell voltages via the balancing connector.

Normally you would charge at 1C, i.e., set the charge current at 2 amps for a 2 amp battery. To speed up the charging time, you can charge up to 3C, i.e., 4 to 6 amps for a 2 amp battery, and appreciate that **you shorten** the life by doing so. ***Patience is a virtue***. If the battery was just used and is still warm, then allow it to cool before charging.

Once started, the charge current will increase from no current to full current, charging each cell up to 4.18 to 4.21 volts, then the charge current ceases. The battery is now "full" but not necessarily balanced.

BALANCING When you start the Balancing function of your charger, the charger then charges or discharges each cell until each cell has the same voltage; a 0.1 voltage difference is usually allowable.

CHARGE-BALANCING Most smart chargers will perform both the charging and balancing modes as one step. When started, the charger firstly charges up the battery, then reverts to the balancing function and balances each cell to each other.

CYCLE The cycle mode of a charger when started will discharge the battery so that each cell is fully discharge, i.e., 3.2 volts per cell. It then reverts to the charge mode, or with some chargers, to the charge-balance mode. This mode is used to check the serviceability of the battery. If it takes a long time to charge or never reaches the "full" level, the battery is no longer usable and should be disposed of.

STORAGE New batteries come with individual cell voltages of approximately 3.8 volts. Some refer to this as the "sleep" mode. To activate the battery – put it in charge and then balance, or charge-balance. Used batteries that will be taken out of service for some period, such as winter, should be placed in the storage mode using your charger.

BATTERY LIFE

Reliable battery manufacturers claim their product to have 500 or more cycles before the capacity is reduced to 80% that would be 1.6 amps for a 2 amp rated battery. This assumes a charge of 1C.

Charging at higher rates will reduce the life – number of charging cycles.

High rates of discharge, especially if constant, will seriously shorten the life of the battery. You may have to increase both the capacity and/or number of cells if you wish to zoooooom zooooom at full throttle for the entire flight. A symptom of over taxing the battery is it will be very hot when you remove it after a flight.

Symptoms of a ***worn out battery*** are: puffy outside cases, and/or takes much longer to charge up and flight time reduced (high internal resistance), and/or cells will not balance (high internal resistance), one or more cells will not charge up at all (shorted), and while attempting to charge – the charger indicates problems, which may be open leads to the balancing plug, the terminal leads, or interconnections of the individual cells.

No not attempt to repair a faulty battery unless you have the technical skills.

A battery with one or more bad cells is no longer a usable battery.

SMART CHARGERS

Smart chargers are computer controlled and are programmed to do most, if not all, the thinking for you. The charger has two ports, one is to connected to the battery terminal leads (larger gauge red and black) wires and usually terminated in a Deans or XT60 high current connector, and the second is lighter gauge wires terminated in a JST (or similar) type of connector for electrical access to the individual cells.

You select the type of battery, i.e., LiPol, NiCad, NiMH, etc. Each has different chemistry and corresponding charging regimes. Select the correct mode, i.e., charge then balance, charge-balance, discharge, etc. Next is the number of cells – some chargers can automatically determine them, and then select the rate of charging current.

The charger then senses the terminal voltage and number of cells, and if correct, commences the charging process. Charge current starts low and increases over time until the individual cell voltages peak at approximately 4.2 volts wherein the charging current reduces or ceases. If charging-balancing, the charger then addresses an individual cell, achieving peak voltage, then onto another cell, and so forth, until all the cells are within 0.1 volts of each other, and the charging process stops.

YOU GET WHAT YOU PAY FOR – cheap batteries and dumb chargers result in poor performance and frustration.

POWER SYSTEM SELECTION

Selecting the appropriate components: motor, ESC, battery, and propeller for an electric model airplane determine the over-all performance, ranging from sluggish to stellar.

If the airplane is purchased ready-to-fly, the manufacturer has made all the necessary decisions for you,

If the airplane is an ARF, the manufacturer recommends the components required, and your hobby store then supplies them.

For those that scratch build or are in the process of electrifying a glo-engine aircraft, the following rule of thumb applies:

- 20 to 50 watts per pound for powered gliders
- 50 watts per pound for casual flying
- 75 watts per pound for sport flying and sport aerobatics
- 100 watts per pound for war birds, aggressive aerobatics, and mild 3D
- 150 watts or more for all other performance

ELECTRICAL SYSTEMS

Ok, how does it all go together? Good question. Refer to each of the following four diagrams, from a simple "hook up" to more elaborate configurations.

Note that there is no ON-OFF switch in any of these systems – the li-pol battery remains unconnected until you are ready to fly. When the battery is connected, the "arming" protocol within the Electrical Speed Controller, ESC, then takes place and the airplane is ready for pre-flight testing and then zoom zoom.

What are not shown in these diagrams are the control surface servos - these plug into their respective positions in the receiver.

In all these systems, if the motor runs backwards, disconnect the battery and reverse two of the three wires going to the brushless motor

The Simplest System. This system is for small electrics. The Electrical Speed Controller or ESC includes a Battery Eliminator Circuit or BEC which can usually supply up to 3 amps of current to the receiver and control surface servos, sufficient for up to four mini or micro servos.

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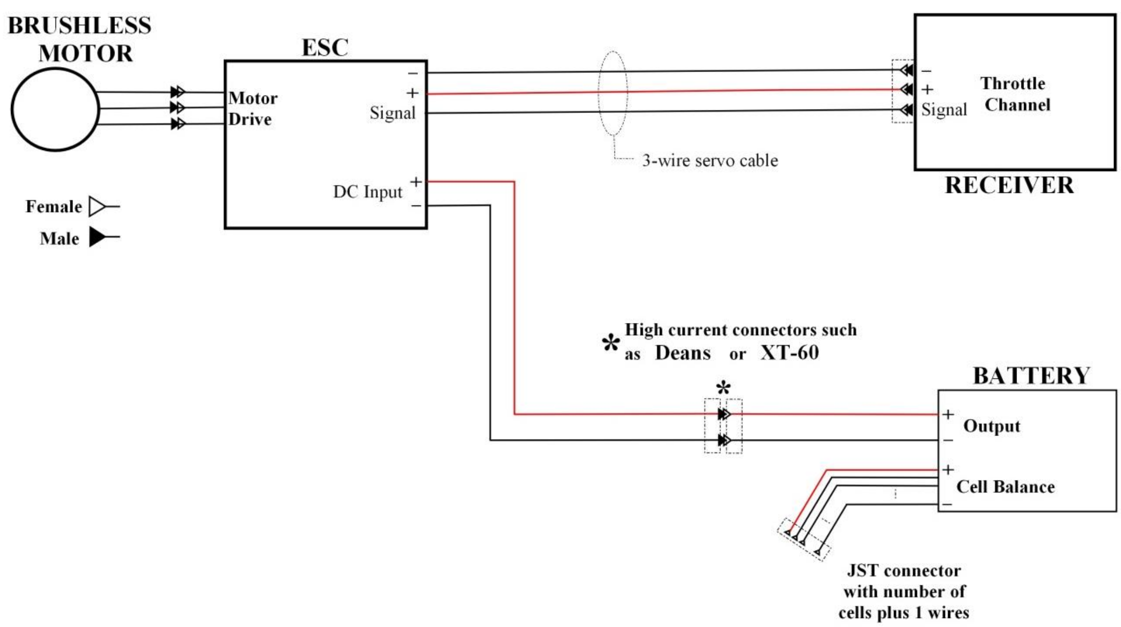
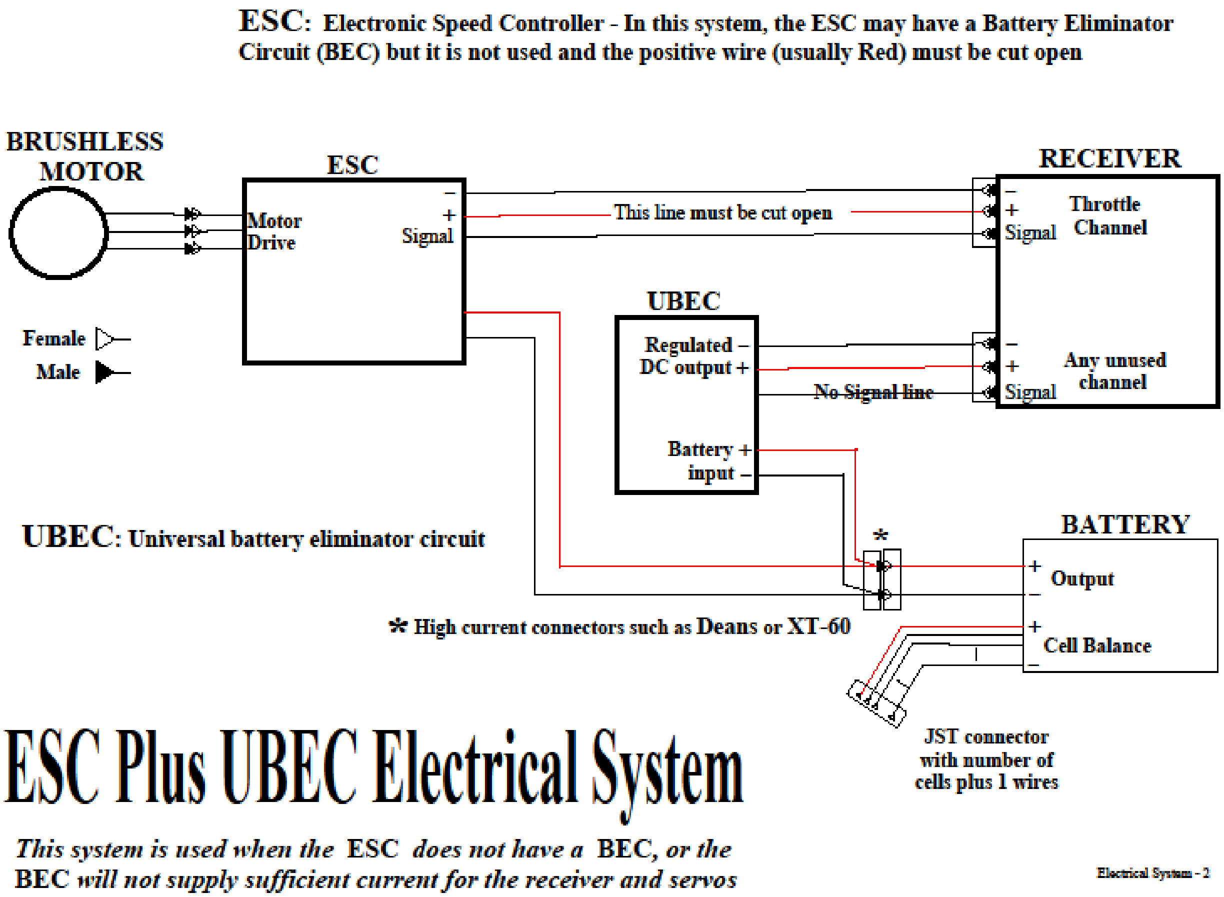
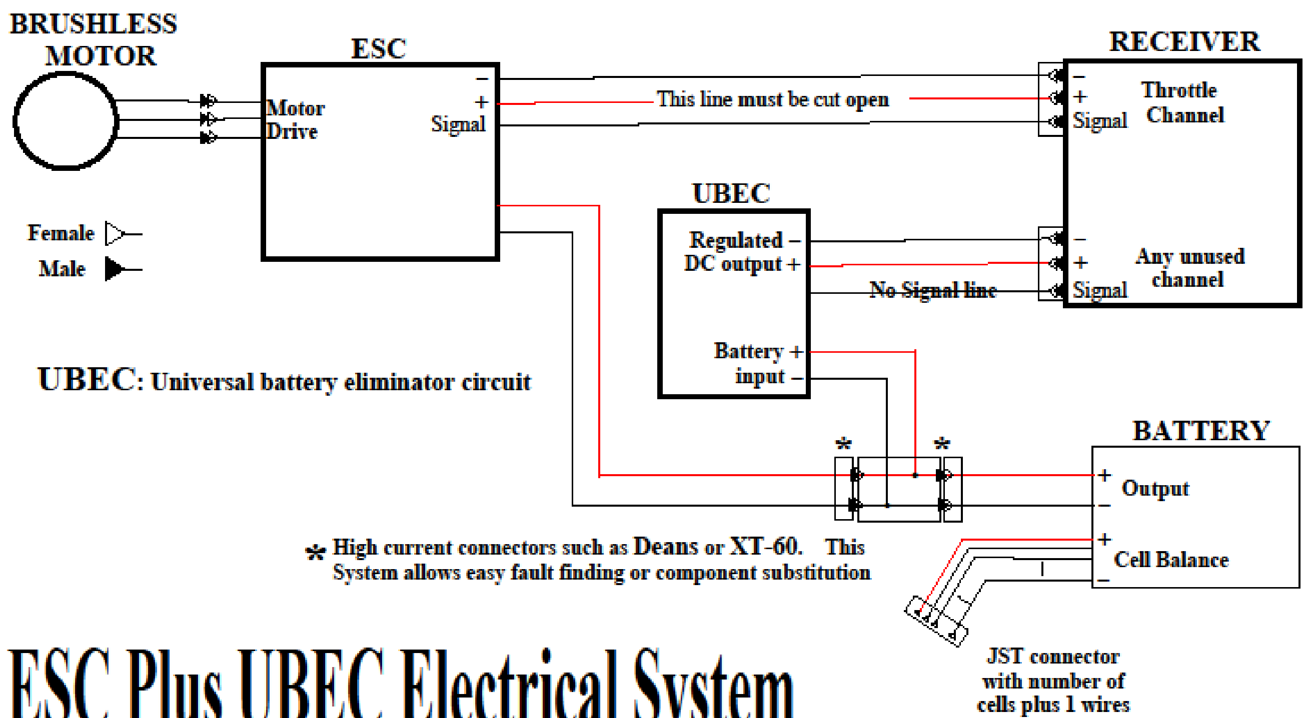




It is not as puzzling as it appears….

Seek assistance from a fellow flyer who has the technical knowledge and experience and it will all come together

ESC: Electronic Speed Controller - In this system, the ESC may have a Battery Eliminator Circuit (BEC) but it is not used and the positive wire (usually Red) must be cut open

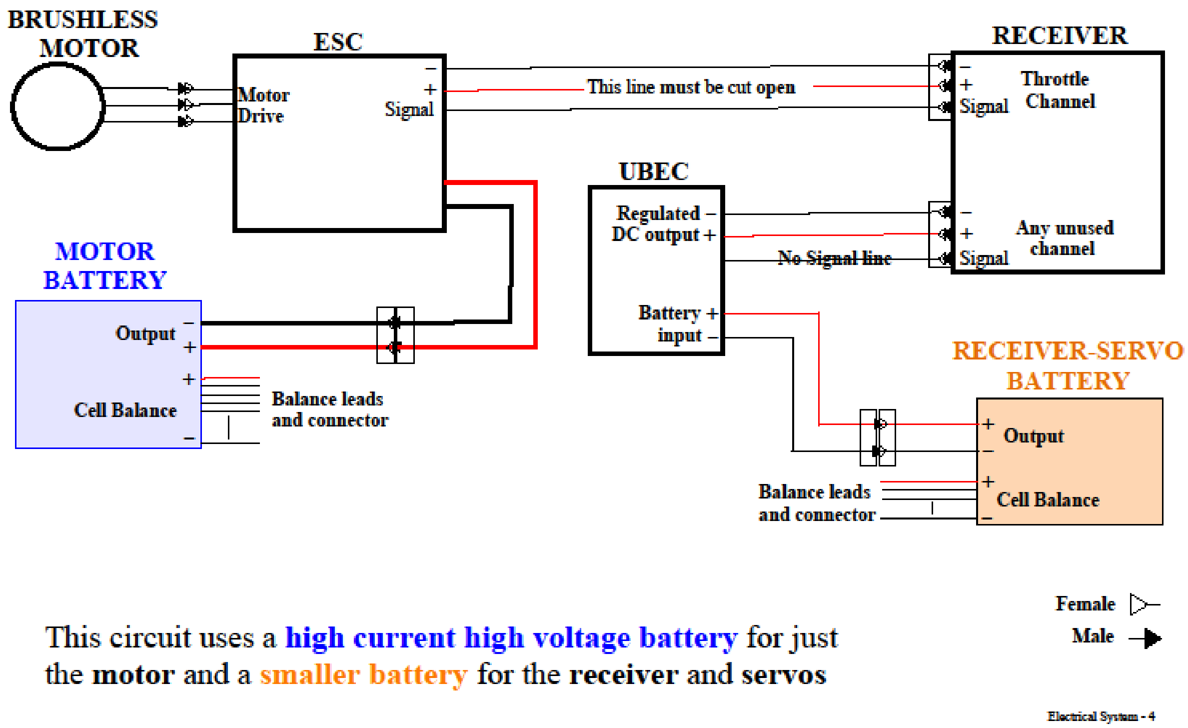


ESC Plus UBEC Electrical System

This system is used when the ESC *does not have a* BEC*, or the* BEC *will not supply sufficient current for the receiver and servos*

The above system is similar to the previous system, and is easier to initially wire up and fault find.

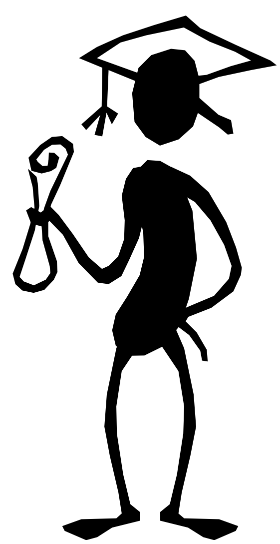
ESC Plus UBEC Electrical System



This last system is for much **larger electrics** and uses a separate li-pol battery for the receiver and servos.

It would be unwise to substitute a NICAD battery for the receiver and servos as you would lose the advantages of Li-Pol battery maintenance.

Done.... at last.
This is by no means the complete and authoritative dissertation on the application of brushless electric airplanes using lithium polymer batteries.
It is only an introduction.



Are you ready for the exam?

Fine Print: This is a revised version, and is likely still full of errors and/or omissions. Your comments are welcome. Contact Bill Grundy at bgrundy@eastlink.ca

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