CUSTOM BATTERY PACKS
TECHNICAL ENGINEERING GUIDE

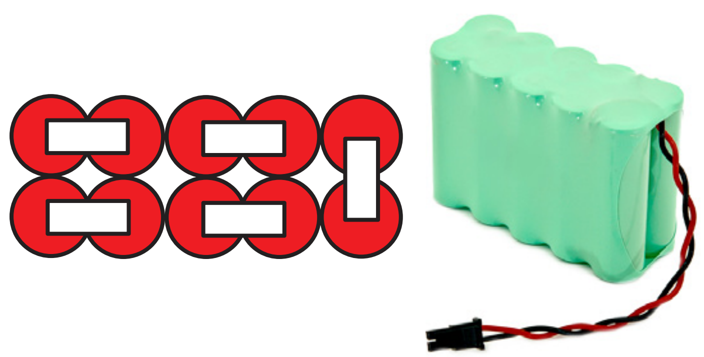
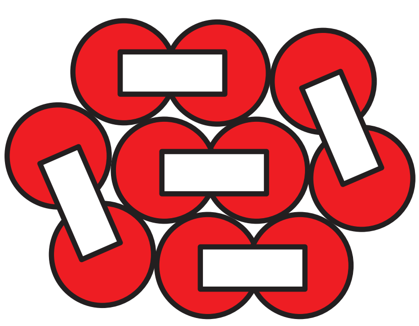
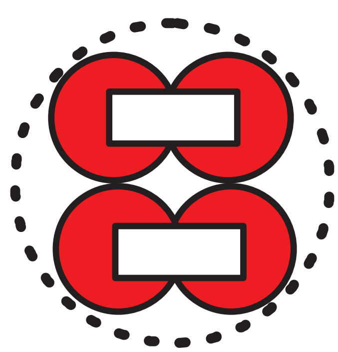
Delivering Quality Since 1952.

PURPOSE OF BATTERY PACKS?

Battery packs are used to provide power to devices that need to be portable, or need to be powered, but are in a location too removed from other power source options.

Cells, the basic building block of a battery, come in fixed voltages, which are defined by the chemistry. The voltages don't vary much within a chemistry family. The capacities do vary, however, since they are defined by the physical size of the cell. In order to meet your portable-power requirements, a battery pack can be designed, using various combinations of cells, to obtain the voltage and capacity requirements of the application.

The type of battery required is determined by the requirements of the device being powered: Device voltage, load-current, and recharge time requirements; environmental considerations; physical space available; weight constraints; regulatory and transportation requirements. The battery pack can be designed to meet these requirements by selecting the appropriate chemistry, and configuring the cells to meet the voltage, current, and capacity requirements. The number of cells; the size of the cell, and how the cells are assembled defines the shape and weight of the pack.

Configuration on Battery Packs	Multi-Row Cells
Linear or F Type 	**Cubic or Composite F Type** 
Nested Type Cells	**Circular Type Cells**
	

LINEAR OR L-TYPE CELLS

This is a stack of cells end to end.

These are usually constructed by standing two cells side-by-side, and welding a nickel strip across the terminals. The cells are positioned end to end by bending the nickel strip in a “U” shape. Allow a thickness increase of ½ to 1 mm per junction for this.

ELECTRICAL CONSIDERATIONS

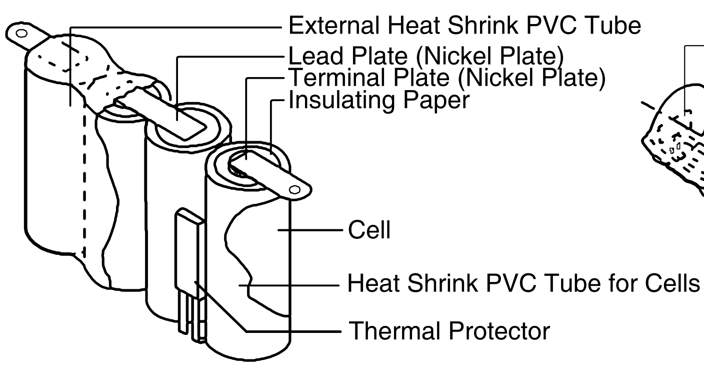
How many amp-hours do I need?
Cell capacity is rated in amp-hours or milliamp hours. The symbol for capacity is C or (It, current X time). This is amps times hours. Divide by hours and you get amps, divide by amps and you get hours. For example a 5 Ahr (Amp hour) battery is the same as a 5000 milliamp hour battery. If you want to discharge in 10 hours, you can get a current of 5/10 = 0.5 amps. If you need 100 milliamps current, then you can run for 5000/100 = 50 hours.

Often a discharge or charge rate is given proportional to C. So a discharge rate of C/5 means C/(5 hours), or the constant current to fully discharge the battery in 5 hours.

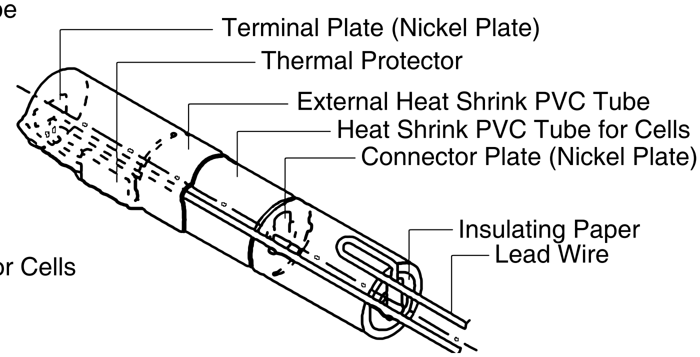
The calculation of run time versus current is a rough estimate, but is accurate under the right environmental and electrical conditions. The faster you discharge or the lower the temperature, the lower the capacity of a battery. This trade-off depends on the battery chemistry and construction. Usually the capacity of a battery is specified at a C/20 discharge rate at ambient temperature, so a 12 Ahr sealed-lead-acid battery will actually put out a steady 0.6 amps for 20 hours. However, if you discharge the same battery at a much higher 12 amp discharge rate, you would expect to run an hour, but you will only get about half of that due to the losses in the chemical exchange and internal impedance within the cell. Cells specially designed for high-discharge rates are available, which minimizes these losses.

CONSTRUCTION OF BATTERY PACKS

“F” Type Construction



“L” Type Construction



VOLTAGE REQUIREMENTS

The first question to answer is "how much voltage do I need?" The second is "how many cells in series do I need?" The voltage of any cell varies depending on its state of charge. The following table shows the range of the various chemistries:

Chemistry	Type	Nominal Voltage	Fully Charged Voltage	Fully Discharged Voltage	Minimum Charge Voltage
NiMH	Secondary	1.2 V	1.4 V	1.0 V	1.55 V
NiCad	Secondary	1.2 V	1.4 V	1.0 V	1.50 V
Lead Acid	Secondary	2.0 V	2.1 V	1.75 V	2.3 - 2.35 V
Li-Ion	Secondary	3.6 -3.7V	4.2V	3.0V	4.05 V
Li-Polymer	Secondary	3.6 -3.7V	4.2V	3.0V	4.05 V
LiFePO4	Secondary	3.2V	3.6V	2.0V	3.6V

So a 10-cell pack of NiMH cells would have 14 Volts when fully charged, and run down to 10 volts when fully discharged. Your system must be able to tolerate this voltage range, or request that Epec design and embed an output voltage regulator into the battery, so the output voltage is constant. Furthermore, if you want to be able to charge while your system is running, the system must be able to accept the charging voltage, which is always higher than the nominal or the fully charged voltage.

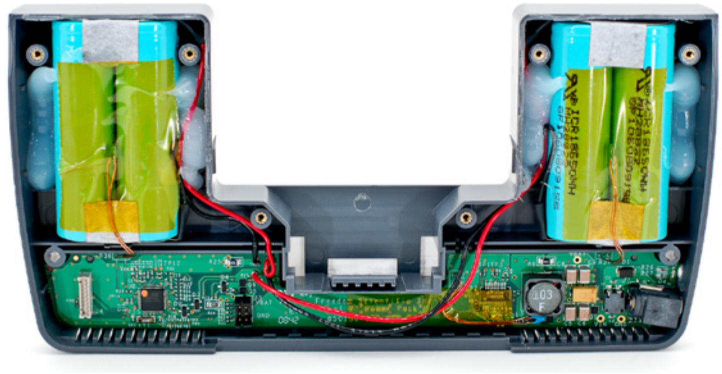
Matching Cells in a Pack
Be careful to match the cells in a battery pack. When a battery pack is near zero volts under load the weaker cells may go into reversal, and suffer damage and perhaps venting.

SMART BATTERY PACKS

A smart battery pack, provides the device with information about its power status, so that the device can conserve power intelligently. Smart battery packs can include many additional features and functionality such as fuel gauge integration, SMBus communication protocol, cell balancing, protection circuitry, and charger control.

The SMBus protocol architecture provides a means for keeping hardware costs low while also providing flexible functionality in a modular way. SMBus is a protocol that is a sub-set of the I^2C standard. Details and specifications for SMBus can be found at www.smbus.org.

A smart battery can manage its own charging, report errors, inform the device of low-charge conditions, predict remaining run-time, provide temperature, voltage and current information and continuously self-correct to maintain prediction accuracy.



BATTERY PACK ASSEMBLY

Heat Shrink Tubing
The most common way to hold the pack together is to use heat shrink tubing. Heat shrink tubing is typically made of polyvinyl chloride and varies in thickness based upon battery type and configuration.

Lead Wires
To connect the pack to a device, vinyl clad electrical wire that conforms to UL requirements is typically used. Red for the positive and black for the negative are the standard colors.

Thermal Components
- Negative Temperature Coefficient, NTC, Thermistors are typically used to prevent overcharge and overheat by sending the temperature readings to the battery charger using a third wire in common with the battery negative lead.
- Temperature cutoff, TCO, devices are one-time thermal fuses that interrupt the current flow if the battery pack is excessively hot. These components are connected in the direct current path of the battery.
- Positive Temperature Coefficient, PTC, devices are used to limit short-circuit current. These devices are classified as resettable fuses.

Connectors
The ends of the lead wires are usually connected to connectors specified by the customer to match their requirement for connection to the device.

Adhesive
There are several standard adhesives that are used to connect the batteries inside the pack that are standard in the industry. These are selected to meet specific UL and other regulatory requirements.

Nickel Strips
Nickel foil is used to spot weld packs together. Nickel is fairly low resistance, yet has enough resistivity to be spot welded. It is strong, has very good corrosion resistance, and will not oxidize easily.

Cell Size (cm)	Foil Thickness (cm)	Strip Width (cm)	Strip Length (cm)	Resistance (milliOhms)
AA	0.018	0.5	1.4	1.0
AA	0.025	0.5	1.4	0.76
Sub C	0.025	0.05	2.3	1.2
Sub C	0.025	1.0	2.3	0.6
Sub C	0.018	0.5	2.3	1.7
D	0.018	1.0	3.3	1.2
D	0.025	1.0	3.3	0.9
D	0.025	2.0	3.3	0.4

Protective Enclosures
The most typical type of protective enclosures are injected molded plastic or metal cases. These can be custom designed for every application.

Caution must be taken when designing a closed system, such as waterproof lights, weatherproof installations, etc. Some provision for venting outside the enclosure is necessary to prevent excessive pressure from building up within it. This is required in the unlikely event of a cell venting due to over-charge. GORE-TEX® seals, or relief holes behind the waterproof labels are commonly used for this type of application.

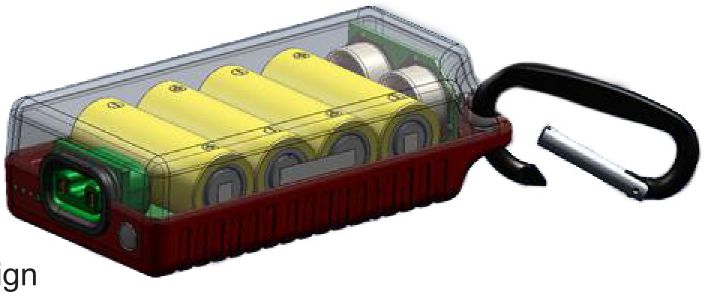
CUSTOM BATTERY PACK DESIGN SERVICES

At Epec Engineered Technologies we provide early design guidance, and design services in the following areas:

- Battery Chemistry Selection
- Battery Charger Selection/Design
- Battery Fuel-gauge Suggestions Based On Application
- Battery Safety-Circuitry Recommendations
- Battery Construction Suggestions
- System Architecture Guidance
- Regulatory Guidance and Education
- Production Test Equipment

We provide full turn-key services in product development, production of batteries, chargers, and batteries with embedded BMS control.

Portable Power Design:



- Mechanical Engineering
  - Plastic design with 3-D modeling
  - SLA prototypes, and polyurethane quick-turn molds
  - Production tooling design
  - Custom Label and Overlays

- Electrical Engineering & PCB Design and Layout
  - Custom battery, battery charger, and fuel gauge design

- Embedded Firmware Development
  - Custom battery and customer system interface development

- Automated Production Test Equipment Design and Development
  - Production test equipment development

BATTERY TEAM EXPERIENCE

We have key team members that have been active within the battery and battery-charger industry since 1996. Our battery team has over twenty-two years of experience in military, medical, industrial, and high-volume consumer industries providing Epec a distinct advantage when qualifying battery designs for use in these industries.

Epec's experience includes pioneering the development of custom safety circuits, battery chargers for the Li-Sulfur chemistry. We have extensive experience in the development of safety-circuits, fuel gauging, and battery chargers for Li-Ion, and Li-Polymer chemistries. As a result, our team has received numerous patents in their area of work.

BATTERY CHEMISTRIES

Chemistry	Nominal Cell Voltage	Energy Density (Wh/kg)	Energy Density (Wh/L)	Cycle Life @ 20C (see note below)	Comments
Li-Ion	3.6-3.7	100-250	250-360	300-500	Can be very expensive depending on form factor. Very high energy density. Very common in laptop computers, moderate to high-end digital cameras and camcorders, and cell phones. Very low rate of self-discharge. Special cells within the Li-Ion family are capable of high-discharge rates. More volatile than other chemistries if not manufactured with rigorous quality standards. Additional DOT and/or IATA testing regulations will apply.
Li-Polymer	3.6-3.7	130-200	300	300-1000	This type has technologically evolved from lithium-ion batteries. The primary difference is that the lithium-salt electrolyte is not held in an organic solvent but in a solid polymer composite such as polyethylene oxide or polyacr lonitrile. The advantages of Li-ion polymer over the lithium-ion design include potentially lower cost of manufacture, adaptability to a wide variety of packaging shapes, and ruggedness. Additional DOT and/or IATA testing regulations will apply.
LiFePO4	3.2-3.3	90-110	220	1000 and up	Very expensive. High energy density. Very common in power tools and medical devices. Very low rate of self-discharge. Capable of very-high discharge rates. More volatile than other chemistries if not manufactured with rigorous quality standards. Additional DOT and/or IATA testing regulations will apply.

BATTERY CHEMISTRIES

Chemistry	Nominal Cell Voltage	Energy Density (Wh/kg)	Energy Density (Wh/L)	Cycle Life @ 20C (see note below)	Comments
NiMH	1.2	30-80	140-300	500-1000	Inexpensive. Traditional chemistry has high energy density, but also a high rate of self-discharge. Newer chemistry has low self-discharge rate, but also a ~25% lower energy density. Very heavy. Used in some cars.
NiCd	1.2	40-60	50-150	1000-2000	Inexpensive. High/low drain, moderate energy density. Can withstand very high discharge rates with virtually no loss of capacity. Moderate rate of self-discharge. Reputed to suffer from memory effect (which is alleged to cause early failure). Environmental hazard due to Cadmium - use now virtually prohibited in Europe.
Lead Acid	2.1	30-40	60-75	500-800	Moderately expensive. Moderate energy density. Moderate rate of self-discharge. Higher discharge rates result in considerable loss of capacity. Does not suffer from memory effect. Environmental hazard due to Lead. Common use - Automobile batteries.
Alkaline	1.5	163	398	1	Moderate energy density. Good for high and low drain uses.
Zinc–air	1.65	470	1480-9780	1	Mostly used in hearing aids.

* **Note:** A battery's characteristics may vary over load cycle, charge cycle and over lifetime due to many factors including internal chemistry, current drain and temperature.

BATTERY CHARGING SERVICE

As a supplier of rechargeable batteries and custom battery packs, Epec also offers an in-house charging service for our customers.

We have standard charging equipment and can create custom programs to meet all of charging requirements. This gives Epec the unique ability to deliver rechargeable batteries, and packs to our customers that are fully charged to their specs and can be immediately inserted into an end product.

BASIC BATTERY CHARGING METHODS

Constant Voltage
A constant voltage charger is basically a DC power supply which in its simplest form may consist of a step down transformer from the mains with a rectifier to provide the DC voltage to charge the battery. Such simple designs are often found in cheap car battery chargers.

The lead-acid cells used for cars and backup power systems typically use constant voltage chargers. In addition, lithium-ion cells often use constant voltage systems, although these usually are more complex with added circuitry to protect both the batteries and the user safety.

The Li ion charger is a voltage-limiting device that is similar to the lead acid system. The difference lies in a higher voltage per cell, tighter voltage tolerance and the absence of trickle or float charge at full charge. While lead acid offers some flexibility in terms of voltage cut off, manufacturers of Li ion cells are very strict on the correct setting because Li-ion cannot accept overcharge.

Constant Current
Constant current chargers vary the voltage they apply to the battery to maintain a constant current flow, switching off when the voltage reaches the level of a full charge. This design is usually used for nickel-cadmium and nickel-metal hydride cells or batteries.

Taper Current
This is charging from a crude unregulated constant voltage source. It is not a controlled charge as in V Taper. The current diminishes as the cell voltage (back emf) builds up. There is a serious danger of damaging the cells through overcharging. To avoid this the charging rate and duration should be limited. Suitable for SLA batteries only.

Pulsed Charge
Pulsed chargers feed the charge current to the battery in pulses. The charging rate (based on the average current) can be precisely controlled by varying the width of the pulses, typically about one second. During the charging process, short rest periods of 20 to 30 milliseconds, between pulses allow the chemical actions in the battery to stabilise by equalizing the reaction throughout the bulk of the electrode before recommencing the charge. This enables the chemical reaction to keep pace with the rate of inputting the electrical energy. It is also claimed that this method can reduce unwanted chemical reactions at the electrode surface such as gas formation, crystal growth and passivation. If required, it is also possible to sample the open circuit voltage of the battery during the rest period.

BASIC BATTERY CHARGING METHODS (continued)

IUI Charging
This is a recently developed charging profile used for fast charging standard flooded lead acid batteries from particular manufacturers. It is not suitable for all lead acid batteries. Initially the battery is charged at a constant (I) rate until the cell voltage reaches a preset value - normally a voltage near to that at which gassing occurs.

This first part of the charging cycle is known as the bulk charge phase. When the preset voltage has been reached, the charger switches into the constant voltage (U) phase and the current drawn by the battery will gradually drop until it reaches another preset level.

This second part of the cycle completes the normal charging of the battery at a slowly diminishing rate. Finally the charger switches again into the constant current mode (I) and the voltage continues to rise up to a new higher preset limit when the charger is switched off.

This last phase is used to equalise the charge on the individual cells in the battery to maximise battery life.

Trickle Charge
Trickle charging is designed to compensate for the self discharge of the battery. Continuous charge. Long term constant current charging for standby use. The charge rate varies according to the frequency of discharge.

Not suitable for some battery chemistries, e.g. NiMH and Lithium, which are susceptible to damage from overcharging. In some applications the charger is designed to switch to trickle charging when the battery is fully charged.

Float Charge
The battery and the load are permanently connected in parallel across the DC charging source and held at a constant voltage below the battery's upper voltage limit.

Used for emergency power back up systems. Mainly used with lead acid batteries.

Random Charging
All of the above applications involve controlled charge of the battery, however there are many applications where the energy to charge the battery is only available, or is delivered, in some random, uncontrolled way.

This applies to automotive applications where the energy depends on the engine speed which is continuously changing.

The problem is more acute in EV and HEV applications which use regenerative braking since this generates large power spikes during braking which the battery must absorb. More benign applications are in solar panel installations which can only be charged when the sun is shining.

These all require special techniques to limit the charging current or voltage to levels which the battery can tolerate.

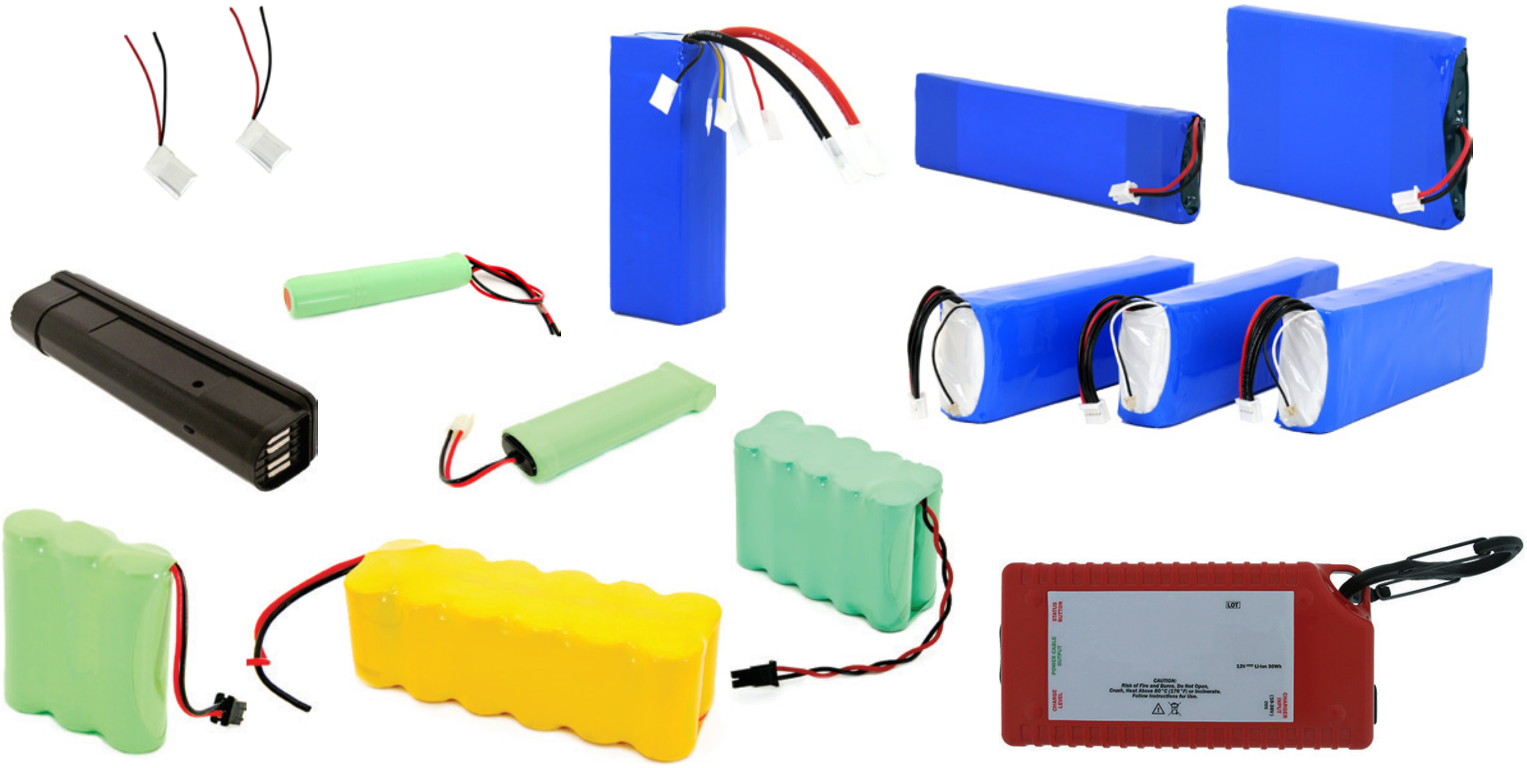
CUSTOM BATTERY PACK PRODUCTS

Battery Pack Applications Include:

- Medical Equipment
- Handheld Electronics
- Safety & Security
- Tools & Applications

Our Battery Capabilities Include:

- Primary Batteries (Non-Rechargable)
- Rechargeable Batteries (Secondary)
- Custom Battery Packs
- Supply Chain Management



SHIPMENTS OF LITHIUM BATTERIES

Lithium batteries are considered hazardous materials and are subject to various regulations. When offering for transport different rules will apply depending on the power requirements of the design, whether they are rechargeable or not, and on how they are transported (land, air or ocean). By law the shipper carries all the responsibility when offering Lithium Batteries for transport.

International shipments by air are regulated by the International Civil Aviation Organization (ICAO) Technical Instructions and International Air Transport Association (IATA). For shipments by ocean the International Maritime Dangerous Goods (IMDG) code is used.

Shipments in the USA are regulated by Title 49 of the Code of Federal regulations (49 CFR). The ICAO and IMDG codes are updated every two years. 49 CFR and IATA are updated annually. Anyone who is directly responsible for the shipment of hazardous materials must be trained in their specific function (49 CFR, §172.702(b)).

UNITED NATIONS TESTING

The UN Publication "Recommendations on the Transport Of Dangerous Goods Model Regulations" & its counterpart "Recommendations on the Transport Of Dangerous Goods Manual of Tests and Criteria" are the internationally recognized authority for the testing, packaging, and shipping of Dangerous Goods.

Epec follows these documents and provide our customers with safe, tested battery assemblies that can weather the rigors of transport. New battery assemblies requiring testing are certified for transport against a series of tests as applicable.

T.1 Altitude
This test simulates air transport under low-pressure conditions.

T.2 Thermal
This test assesses cell and battery seal integrity and internal electrical connections. The test is conducted using rapid and extreme temperature changes.

T.3 Vibration
This test simulates vibration during transport.

T.4 Shock
This test simulates possible impacts during transport.

T.5 External Short Circuit
This test simulates an external short circuit.

T.6 Impact
This test simulates an impact. (Cell Only)

T.7 Overcharge
This test evaluates the ability of a rechargeable battery to withstand an overcharge condition.

T.8 Forced Discharge
This test evaluates the ability of a primary or a rechargeable cell to withstand a forced discharge condition.

UN REGULATIONS

Please visit http://www.iata.org/ and http://live.unece.org/ for more information regarding the UN Regulations and Testing.

IATA UNECE

EPEC'S NETWORK OF PARTNERS

AMERICA'S OLDEST. A HISTORY OF INNOVATION.

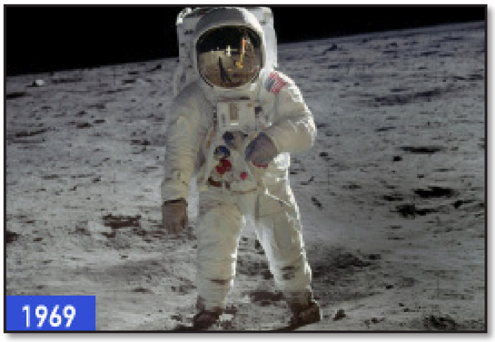
Since 1952 Epec has been connected to the development of the PCB and the electronics industry.

Epec was formed through the merger of Electralab and Printed Electronics Corp (EPEC), who were proudly two of the five founding members of the IPC, the 2,900 member trade association supporting the $1.5 trillion global electronics industry.

From pioneering innovation in the PCB industry with R&D, training and setting professional core values, the legacy of Epec has now passed to a new generation of very bright young people, and continues the great tradition of imagination.

1952

1957



1969

CERTIFICATIONS

We are very proud of the high quality products we manufacture. Over the years, we have received an impressive collection of quality awards from customers both large and small.

ISO9001 Certified

ITAR

RoHS3

CONTACT US

Our knowledgeable staff has many years of experience in the industry. We welcome the opportunity to put our skills to work for you! Please contact us with any questions or requests.

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