



Guide to Successful Dual Voltage Systems

DUAL VOLTAGE

Dual voltage electrical systems solve many power requirement problems in today's trucks, buses and motor coaches, but like any specialized technology, dual-voltage establishes its own rules. Since the inception of the automobile, the electrical system has been called upon to provide power to more and larger on-board components. In the early 1950's, auto manufacturers amended the, then standard, 6V system to become our current standard, 12V system, when it began to fall short of system requirements. We are in a similar situation now, as manufacturers contemplate higher voltage or dual voltage systems for our not too distant future vehicles.



GENERAL

For most of today's heavy equipment, a 24V system has been adopted. Diesel engine starter motors, air conditioner compressor motors and hydraulic pump motors are examples where it is advantageous, both mechanically and economically, to use a 24V over a 12V system.

The benefits of raising the system voltage are easy to understand. Raising the voltage to 24V, effectively doubles the power while keeping current the same, thus, allowing use of the same size wiring. This is demonstrated by the power law:

Power=voltage x current

THE NEED FOR DUAL VOLTAGE

Not all equipment or accessories, however, benefit from a 24V operating supply. 12V headlamps, for example, stand up to vibration better than 24V lamps due to their heavier, stronger filaments, thus giving them a longer service life. The 12V lamps are also less expensive and more readily available, making a 12V system more attractive.

Occasionally, 24V equipment is just not available. Items such as AM/FM/CD players, CB radios, RV accessories, certain communications radios, fuel injection controls, etc. are 12V only. Until recently, transmission and engine controls were all 12V. Additionally, in deriving the 3-to-5V supplies that logic circuits require, less power is wasted using 12V than 24V systems.

THE DUAL VOLTAGE SYSTEM

The 24V system normally consists of two 12V batteries connected in series, with a 24V alternator providing power. It seems that the most logical place to obtain 12V power is at the junction between the two batteries (see fig.1) However, a problem arises if the system is constructed in this fashion.

Consider the situation when the engine is off (alternator is not generating), and 12V power is used (see fig. 1). Load current comes only from the 12V "A" battery, none of which is being furnished by the top "B" battery. After a time, the 12V loads will discharge the "A" battery while

leaving the "B" battery charged up. Since the "B" battery has not been discharged it will not need any electrical current to recharge it; however, the "A" battery will.

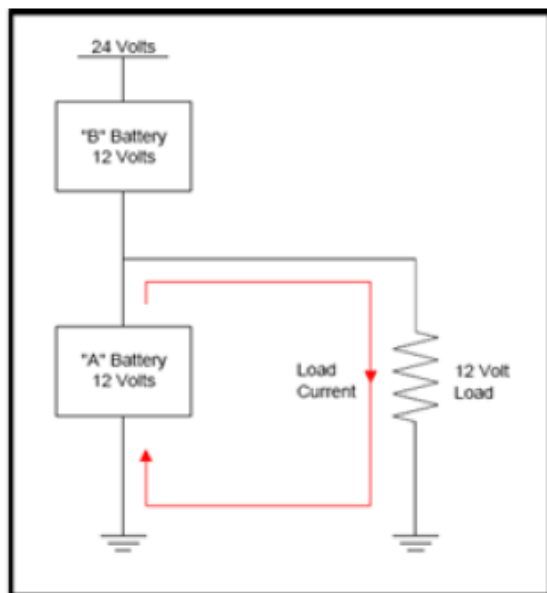


Figure 1 Load current path "A" Battery furnishing power

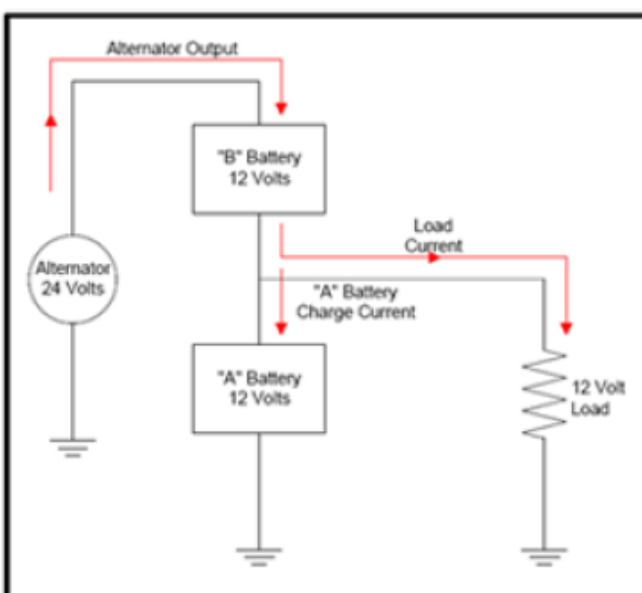


Figure 2 Charge current imbalance due to 12V load (Return current omitted for clarity)

In fig. 2 the engine is started and the alternator furnishes current to the load and to charge the "A" battery. All the current now flows through the "B" battery, since it is in series with the load and "A" battery.

When this happens, a condition exists where the "B" battery overcharges because it does not need recharging, and the "A" battery does not get the charge it requires. Charging current for the "A" battery is impeded by the already charged "B" battery and reduced by the amount of current that flows to the load. Even if there were no load at this point, the same problem would exist due to the imbalance of the battery charges.

When operating the system in this manner, the life of the batteries is dramatically shortened. The "A" battery fails prematurely because lead sulfate builds up on the battery plates, reducing the capacity. The "B" battery fails when its electrolyte "gasses" and evaporates and damage occurs to its plates and separators in the dry battery cells as a result of overcharging. Failure time can be as short as a few weeks for heavy 12V loads.

If there is no 12V load, a 24V system with a two battery "stack" can operate well without an equalizer. However, the batteries must be of the same type and age. Without a Battery Equalizer, current drawn from one battery and not the other will cause an imbalance. This imbalance accumulates over time. Because the effects of the imbalance are cumulative, battery degradation occurs even with very small loads, such as a radio, clock or small lamp.

THE EQUALIZER SYSTEM

The equalizer was developed as a solution to the problem described above. Technically, Equalizers are specialized DC-DC converters. These devices convert electrical power from one voltage level to another at relatively high efficiencies. Used in battery balancing applications, the Converters are called "Equalizers."

The term "Equalizer" is derived from the fact that these devices balance or equalize the charge states in the system batteries. In the case of 12/24V, dual voltage system, the equalizer output voltage is equal to half of the input voltage. This is true for many input voltages within the operating range of the device. The operation is as follows:

EQUALIZER OPERATION: ENGINE "OFF"

Figure 3 shows an Equalizer installation, with engine "off", and a 12V load applied. Assume that the batteries are equally charged to start with. As the load draws current from the "A" battery, the voltage on that battery begins to drop. Then, in order to maintain the output condition of half of the input voltage, the Equalizer output current increases. This raises the voltage across the "A" battery until both battery voltages become equal.

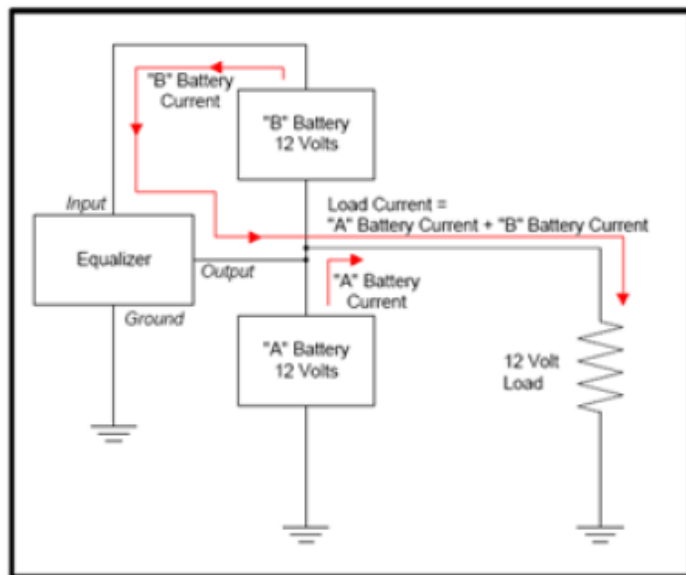


Figure 3
Current distribution: Batteries balanced
(Return currents omitted for clarity)

With an Equalizer installed, both batteries will maintain equal charges, and 12V-load power will be drawn from both batteries equally.

Notice that the current required to maintain the output voltage is taken from the "B" battery. In other words, the load power is actually furnished by both batteries, not just the "A" battery. The "B" battery will not furnish all of the power, because, if its voltage begins to drop, the voltage at the Equalizer output would then be greater than half the input voltage and the output current would reduce to zero. The "A" Battery would then furnish the load current.

As a consequence of the above operation, it can be stated that if one of the batteries is discharged, the battery with the most charge will finish power to the 12V load. This can be understood using the above description and considering that one battery has a reduced terminal voltage due to its' lower charge state. Eventually, the battery charges will balance, and then both batteries will furnish power to the load.

This section describes the battery equalization process for batteries at rest. The point here is that the Equalizer is operating even when the engine is off, which is common for these devices. Some models are equipped with Ignition inputs ("on-off" controls). This difference is normally determined by the application. Note: 24V loads do not impose a battery imbalance condition. Since the batteries are in series, all current delivered to the 24V load is, necessarily delivered by both batteries equally.

EQUALIZER OPERATION: ENGINE "ON"

Consider the situation with the engine running. The alternator is producing 28V¹, which is also the input voltage to the equalizer, as shown in figure 4. The equalizer now generates half of this (i.e.

14V) at its output. This provides the optimum charge voltage for the "A" battery. This also means that there must be 14V across the "B" battery; therefore, both batteries receive optimum charge voltage with the equalizer in operation.

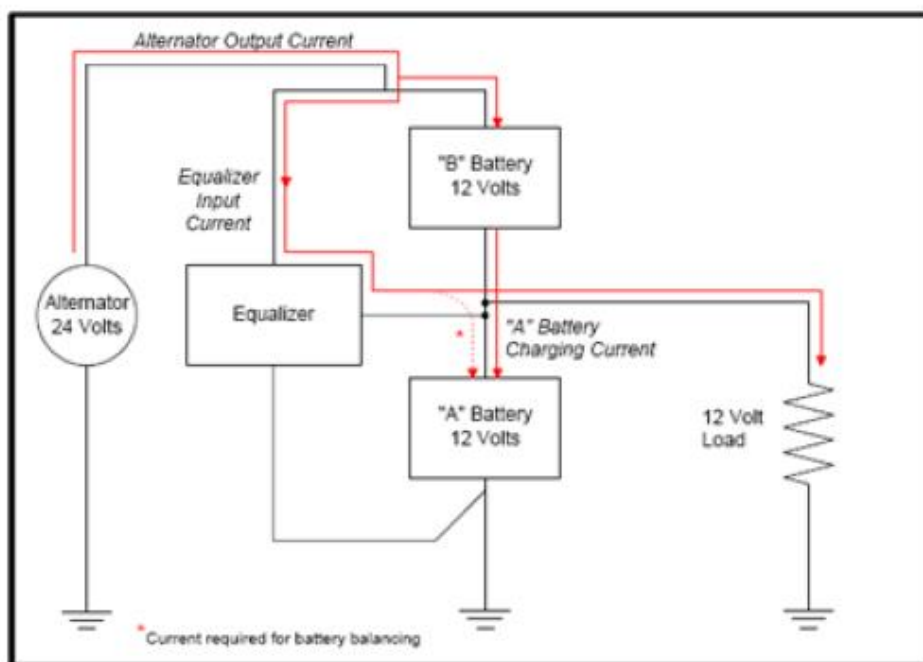


Figure 4
Charge current paths
(Return currents omitted
for clarity)

THE BATTERY

When a charged 12V automotive battery is allowed to stand without a load, its terminal voltage is measured to be about 12.6V² at room temperature. To charge the battery, a 14V source is applied across its terminals, and current is allowed to flow into the battery. The amount of charge current that a battery will accept is determined by the state-of-charge of the battery and its capacity. At 14V, the battery will only take the amount of current required, or is capable of receiving, to charge it³. With this in mind, it is seen that a larger alternator will not charge a battery faster than a smaller one, providing the battery charging requirements and load requirements do not exceed the output limits of the alternator. **Given the proper charging voltage, the battery will determine the amount of current that it requires for charge.**

If the battery is "low" (discharged), the charge current will be high. 50 amps or more is not uncommon to charge a low battery such as a Group 27. Heavy charging may be in the 100 to 200-amp range for 4D or 8D types. As the charge is replenished, the charge current decreases to a few amps or less for a fully charged battery. If the charge voltage changes across a battery, so will the current into it. Increasing the voltage will cause the current to rise and vice versa. This can lead to overcharging or undercharging conditions of the battery, and a reduction of battery life. Because of this, it is very important to keep the system voltage regulated at the optimum level.

Some charging systems today are equipped with temperature sensing voltage regulators, which adjust the charge voltage automatically. This does not present a problem to the equalizer, as the output to input voltage is a fixed ratio, i.e. = half. The Equalizer will maintain proper battery balancing under all voltage conditions.

CONVERTERS VERSES EQUALIZERS

So far, only Equalizer operation has been examined. Some applications do not require this level of complexity to attain the desired outcome. For instance, one may only require enough power to operate a small radio on the vehicle. In this case, installation of an Equalizer may prove to be

"overkill" in cost, installation time and output power. For this type of application, a Converter may be the most economical solution.

For this instance, the term "Converter" is used to mean a DC to DC Converter that has a "fixed" output voltage. "Fixed" output voltage, means that the output voltage stays the same, regardless of the input voltage. These devices are used where an unvarying power supply is more appropriate and battery maintenance is not an issue. Examples of such applications are:

- 12V toll boxes used on 24V buses
- CB or entertainment radios on 24V farm or construction equipment
- Engine or transmission controller power supplies on 24V vehicles

These applications are typically lower power than equalizer applications and many require the fixed voltage feature. Converters are generally used in "batteryless" installations. As the term implies, there is normally no battery connected to the output of a converter. They are equipped with "Ignition" inputs, used to turn the unit "on" and "off", so that when the key switch is turned off, the converter output drops to zero.

In batteryless installation, the converter must be capable of supplying all of the current to the load. This applies to peak currents, even if they are only for a very short period of time. Output current rating is of particular importance when driving loads with high inrush currents such as motors or lamps. Inrush and high peak currents often determine the converter size, or whether an equalizer should be used. ***When sizing a converter to a questionable load, it is suggested that the factory be contacted to help answer questions and aid in the product selection.***

EQUALIZER AS A CONVERTER

As a side note, a Sure Power Equalizer can be used in a Converter application, where no battery is connected to the output. It should be realized that the output voltage will vary with the input in this application. Typically, the output variation will be from about 12.5V to 14V, for "engine-off" to "engine-on" conditions. The applicability here will be determined by the requirements of the load.

APPLICATION NOTES: SIZING THE EQUALIZER

When selecting the size (output current) of an Equalizer, the 12V load requirements must be known. In general: ***The Equalizer should be no smaller than 120% of the average load.***

Example:

The 12V load is a fan motor with a constant current draw of 10 amps. The Equalizer should then be at: ***10A x 120%=12A***

Example: High Temperature

In situations where the ambient operating temperature will be high, first check to see if the ambient temperature is within the operating range of the Equalizer. If it is not, the equalizer will have to be relocated in a cooler environment. Select the location with the lowest temperature (see "Installation section").

In a high temperature environment, the Equalizer must be "de-rated" to assure adequate operation. "De-rating" at high temperature refers to operating the Equalizer at a lower output than it is capable of providing at lower temperatures.

APPLICATION NOTES: WIRING DIAGRAMS

Standard Connection (Figure 5) This diagram emphasizes the Equalizer connection points for best operation. Connect the Output and Ground wires directly to the "A" battery if possible. The Input wire should connect to the "B" battery "POS" terminal. It is assumed that the connection

between the two batteries is short and of heavy gauge. See "WIRE SIZING" section for more detail.

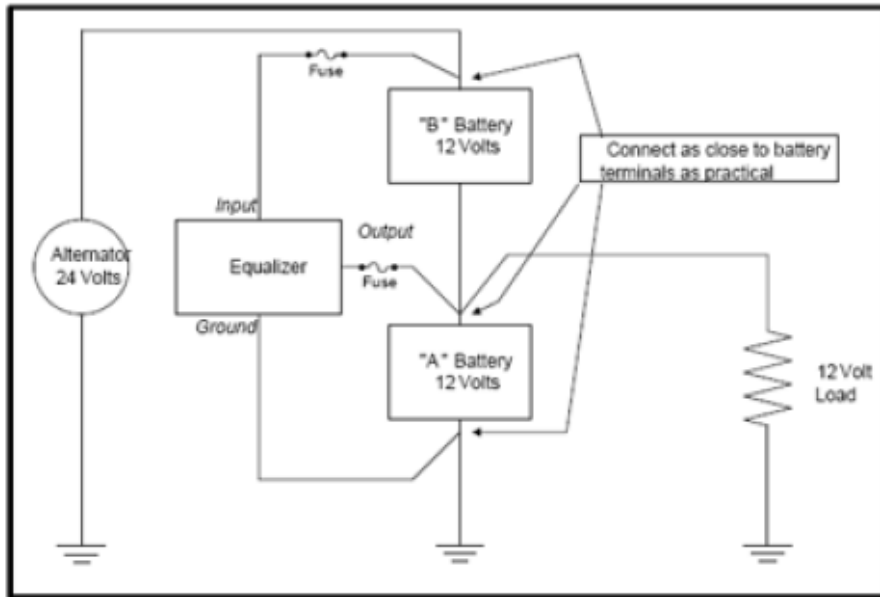


Figure 5
Basic Equalizer Connection

STANDARD CONNECTION

(Applies to all diagrams and instructions) Provide the appropriate fuse protection. Fuses protect the wiring in the event of a short to ground and should be sized approximately 25% above the current passing through the wire.

BATTERY DISCONNECT SWITCHES (Figure 6)

If a battery-disconnect switch is required in a system where an equalizer is installed, two disconnect switches must be used. Electrically, place one disconnect between the "B" battery "POS" and the Equalizer-alternator connection. Place the second disconnect switch either between the "A" battery "NEG" and frame ground (see Figure 6A) OR between the "A" battery "POS" and the Equalizer "12V" connection and the 12V Load (See Figure 6B). Figure 6B is most common on military applications. If only a single disconnect is used in the "A" battery NEG wire, the Equalizer will continue to operate, drawing power from the "B" battery. The "B" battery must also be disconnected in order to isolate the Equalizer from both batteries.

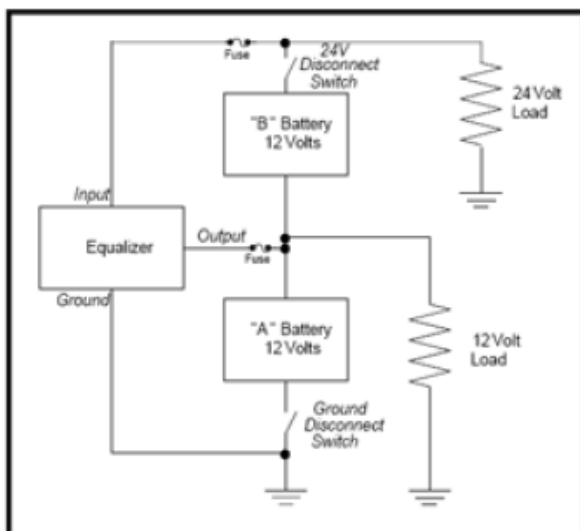


Figure 6A Battery Disconnect Switch Arrangement
24V and GND Disconnects

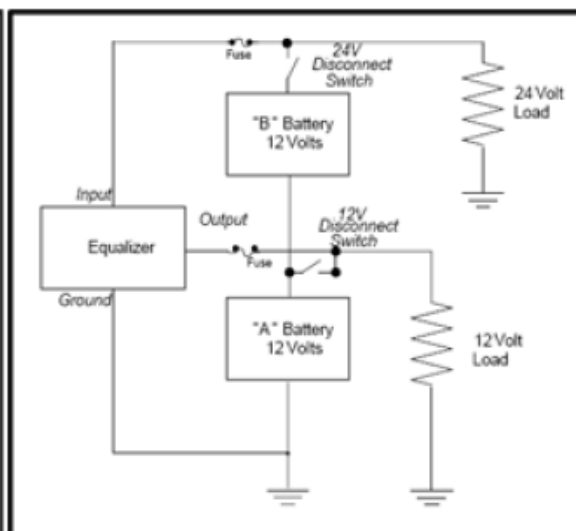


Figure 6B Battery Disconnect Switch Arrangement
24V and 12V Disconnects

REMOTE BATTERY CONNECTION (Figure 7)

For the application of an Equalizer supplying power to a remote battery (such as, on a trailer), the same rules apply as for the standard installation. Connect the load to the battery, not the Equalizer. Keep the leads as short as possible, especially the output leads, and size the wires accordingly (see "APPLICATION NOTES: INSTALLATION")

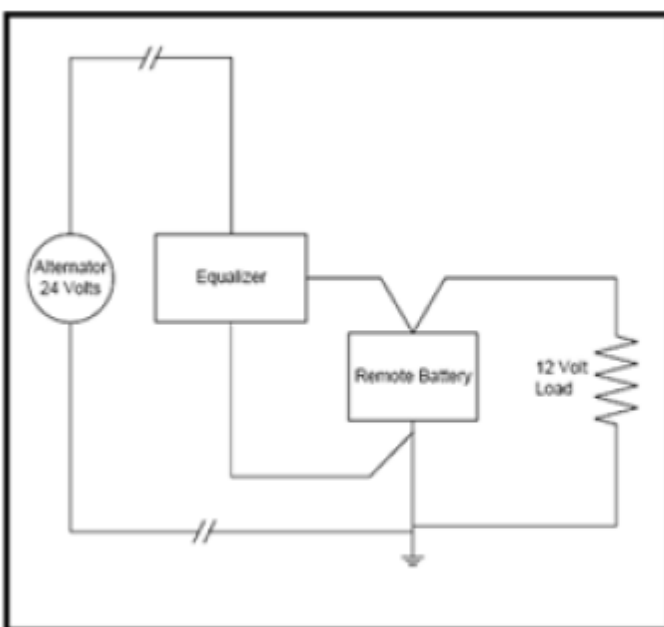


Figure 7
Remote Battery Connection

APPLICATION NOTES: INSTALLATION

There are several considerations to take into account when mounting the Equalizer, which will affect the operation and reliability of the system. Proper selection of mounting location can save frustrating hours of troubleshooting and "ghost chasing". Often the mounting location will be dictated by the available space, however, if possible, try to follow these basic rules:

MOUNTING POSITION

If it is possible, mount the Equalizer on a wall with the fins vertical. This is the best position for cooling, as hot air flows up from the bottom, drawing cool air through the fins. This assumes that there is nothing on either end of the Converter to obstruct the flow of air. The next best way to mount the Equalizer as it would be placed on a table. This, too, will draw cool air over the fins as the warm air rises, although, this is not as efficient as the vertical "chimney". The least desirable mounting position is with the mounting flanges up, or "hung from the ceiling". This position provides the least efficient method of cooling and should be used only if a better position is not possible.

AIR FLOW FOR COOLING

Assure that there is adequate ventilation. Heat is probably the single most important factor in the general reliability of electronic equipment. In the instance of electrolytic capacitors, which are used in most Converters and Equalizers, an increase of 10°C will decrease the average life by about one half. The Equalizer should be installed where there is airflow into and out of the mounting site. The mounting compartment should not be closed to outside air, so that heat can be removed by the flow of air. Mount the Equalizer where hot air, from the engine compartment, etc. will not be directed to it. The air may heat the Converter rather than cool it.

WIRE LENGTH

This section goes hand-in hand with the next section (WIRE SIZING).

Both length and size determine wire losses in high current applications. **Select a mounting location that will give the shortest cable lengths to the battery.** Long wires drop more voltage than short ones. This is due to the resistance of the wire, and the effects can be quite significant in terms of battery balancing. Under heavy load conditions, the battery and loads will receive less voltage since the loss in the output wire is subtracted from the output voltage. This loss also applies to the Input and Ground wires. Since the output voltage is dependent on the Equalizer input voltage, losses incurred in the input and ground wires reduce the amplitude of the output voltage. The above two loss effects are additive. If the wires are not sized properly, this can result in poor high-current performance, i.e. longer battery balancing times, where the equalizer will not be used to its full capability.

Another reason for short wires is electrical "noise" emissions. Equalizers and Converters generate a certain amount of electrical "noise". "Noise" is high frequency electrical signals, which emanate from the Equalizer or its connecting wires. Long power wires make excellent antennae for signals that can be picked up by radios, gauges, or worse, engine or transmission control circuits. AM radios are usually more sensitive to this type of electrical noise, but FM radios can also be affected.

Most installations will not have problems with this, due to the fact that, the batteries make excellent filters, and Sure Power builds filtering into the Equalizers and Converters to reduce the risk of noise related problems. However, in the interest of better performance, it is always best to keep wires as short as possible. This is true for all electrical devices.

WIRE SIZING

It is important to select the appropriate wire size for an Equalizer installation. It is also important to provide circuit protection to protect the wiring. If the wires have too much resistance, voltage drops across the wires will limit the amount of current to the 12V ("A" battery), increasing the charging of balancing time. In effect, the Equalizer will act "smaller" than it is. This is in addition to the power that is lost as heat in the wires, reducing the overall efficiency of the system.

The following procedure will provide an estimate of wire sizes required for an installation. In most applications this will be sufficient. Determine wire sizes for all high current wires.



For the output wire, calculate based on: **Maximum current = equalizer rated output current.**
 For input and ground wires, use: **Maximum current = 0.6 x (rated output current)**

Sure Power suggests that the voltage drop across any power wire should be no more than about 0.10V maximum.

Voltage Drop for Wire:

Go to the entry on the left side of table 1 that corresponds to the maximum current that the wire will have to carry.

The table entries to the right correspond to the voltage drop (per foot) that will be seen, if used with the wire gauge shown at the top of the chart.

To find the total voltage drop for a specific gauge wire, multiply the length of wire required for the installation by the chart entry for that wire gauge. **Voltage Drop = Wire length (in feet) x chart entry**

VOLTAGE DROP ⁴ (Volts / foot)										TABLE 1
AMPS	4/0	3/0	2/0	1/0	1	2	4	6	8	10
					AWG	AWG	AWG	AWG	AWG	AWG
25	.0012	.0015	.0019	.0025	.0031	.0039	.0061	.0100	.0155	.0255
50	.0025	.0031	.0039	.0049	.0063	.0079	.0122	.0200	.0310	.0510
75	.0037	.0046	.0058	.0074	.0094	.0118	.0182	.0300	.0465	.0765
100	.0049	.0061	.0077	.0098	.0125	.0157	.0243	.0400	.0620	.1020
125	.0061	.0076	.0096	.0123	.0156	.0196	.0304	.0500	.0775	.1275
150	.0074	.0092	.0116	.0147	.0188	.0236	.0365	.0600	.0930	.1530

⁴ The chart shows approximate voltage drops for stranded wire at 68° F.

Example:

The output wire in an Equalizer is required to carry 75 amps (Equalizer maximum output), and will need to be 5 feet long. For best performance, we do not want the voltage drop to be any more than 0.10V when the current is 75 amps. From the chart, we see that #4 AWG wire has 0.0182V loss per foot. **The total loss is: Voltage Drop (#4 AWG) = 5ft x 0.0182 V/ft. = 0.091V.** This is the best choice in terms of economy and performance. #6 AWG cannot be used, since the drop for it would be: Voltage Drop (#6 AWG) = 5ft x 0.0465 V/ft. = 0.150V, which is greater than desired.

GENERAL APPLICATION INFORMATION

- Crimp wire lugs to reduce resistance and increase reliability.
- Always use fuse circuit protection to protect wiring. Sure Power recommends fast acting fuses and can assist with Equalizer fusing recommendations.
- Connect loads to the battery, not equalizer output. The common connection should be the battery post. (See fig. 5 and 6)
- Don't rely on the chassis for ground return. Install a ground wire. This is particularly true in battery balancing applications. Steel has higher resistance than copper and bolts tend to corrode or rust, degrading the connections.
- Don't weld to the vehicle with the Equalizer connected. If the vehicle is to be welded, disconnect the cables to the Equalizer.

BATTERY REVERSAL

Before starting the engine after an Equalizer installation, be sure that both "A" and "B" batteries are charged. The incredibly high starting current can cause the charged battery to reverse the voltage on a discharged battery. With the equalizer connected normally, it then "sees" a reverse power connection. If, as typical, the discharged battery is the "A" 12V battery, any 12V accessories, gauges, etc. connected during starting, will also have the reverse voltage applied to the power connections. This may result in damage to these items. Sure Power Equalizers are protected against Battery Reversal.

MAINTENANCE

Very little maintenance is required for the Equalizer. Generally, keep the fins clean so that the unit will cool as it should. Do not allow oil, dirt, etc. to build up on the surfaces, as it acts like insulation, inhibiting the cooling ability of the fins. Keep material from clogging the space between the fins, blocking the flow of air. Periodically check the connections as described below. Clean as required.

CONNECTION PROBLEMS

Symptoms:

- Hot wire of connections
- Discolored stud, nuts
- Low or no output

The best way to check a good connection is by measuring the voltage across it. The higher the reading, the worse the connection is. A "good" wire connection should drop less than about 0.025V (25mV) when about 100 amps are flowing through it. Measure from wire to stud with a digital voltmeter. Before measuring the Equalizer connections, start the engine and turn on heavy 12V loads. This will make poor connections easier to find.

Heat is telltale sign of bad connections. Look for discoloring of studs or nuts from excessive heat. If the system is operating, the connections can be felt to see if they are generating heat, however, USE CAUTION. High current connections can be very hot if the connection is poor.

For more information contact www.waytekwire.com