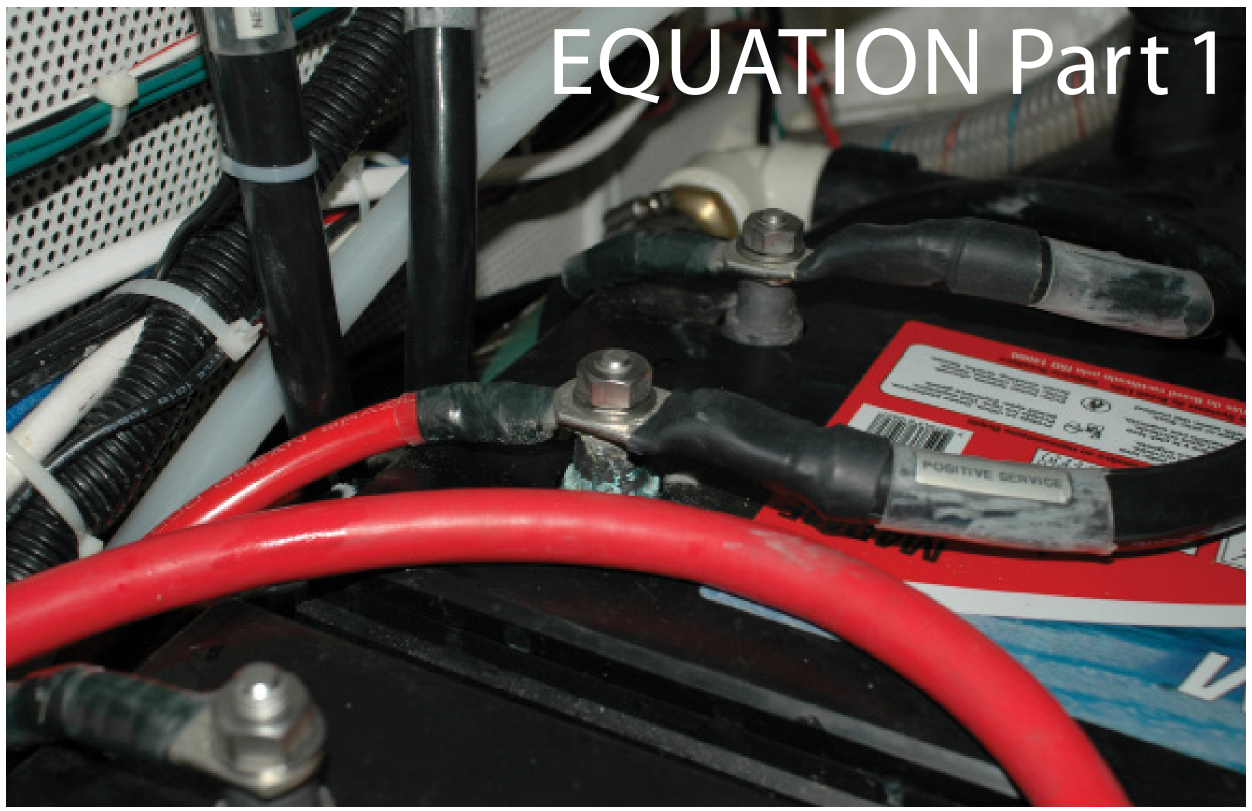
THE LARGE BATTERY BANK EQUATION Part 1



Story And Photography By Steve D'Antonio

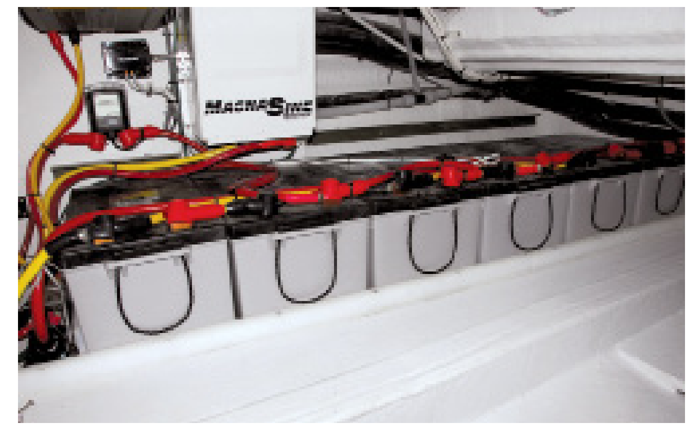
ONCE an exception, large house battery banks have become virtually *de rigueur*. In the not-too-distant past, two of the industry's ubiquitous 8D batteries were considered more than adequate, affording the user ample "quiet ship" time, often with power to spare. In the past decade, however, this energy reservoir has proven itself inadequate when measured against the demands of the onboard equipment, and those overseeing its use. Boatbuilders and refit yards, answering the clarion call of their customer bases, have dutifully responded by installing battery banks which they believe will support both the growing list of electrical accessories and the extended periods that skippers wish to use them.

However, as is often the case with a proven system or technology that evolves slowly, the temptation to continue what's been done in the past while simply increasing the scale, is ever present. In my work as a systems consultant, I've seen a steady increase in the girth, capacity, and complexity of battery banks, often instituted by simply adding more batteries to an existing design or installation. In the vast majority of cases, little or no consideration is given to the consequences (both physical and electrical) that such exponential increases have on both the vessel and the battery banks themselves.

Above: Battery installations, particularly large banks, must be treated with respect. In this image, exposed terminals are an invitation for a short circuit, which could easily lead to a fire.

HOW BIG IS 'BIG'?

The reader is no doubt asking himself or herself, what defines a large battery bank? There's no specific definition, only my anecdotal experience and the evolution I've seen in the industry over the past two decades. In many cases, what was considered "large" a decade ago is now simply average and what passes for an unusually large battery bank today may tomorrow be considered commonplace, particularly with the increased popularity of hybrid electric propulsion systems, many of which are designed to accommodate significant house loads along with providing energy for propulsion. Therefore, my threshold for "large" is anything more than approximately 750Ah at 12 volts, which is the equivalent of three paralleled 8D batteries (typical 8D battery measurements are 20-3/4 inches by 10 inches by 10-1/4 inches, and 165 pounds), or 500Ah at 24 volts, often made up of four 8D batteries using a combination series and parallel connections. In reality, however, the criteria have as much or more to do with the number of batteries used in the overall house bank rather than the amp-hour capacity or voltage. Clearly, if smaller case sizes are used in the above equations, or even for smaller capacity banks, then the overall number of batteries in a given system would consequently grow. In keeping with current battery usage wisdom, it is recommended that the large battery banks described below are used as a single unit rather than piecemeal.



Left: While this large battery bank is easily accessible for routine inspections, it does contain a flaw; inverters should not be installed directly over batteries. Right: Batteries require ventilation for two purposes: to release hydrogen gas and to dissipate heat. This installation is conducive to neither. The "shoebox" lid will trap hydrogen gas while tightly packed batteries make heat dissipation problematic. Additionally, the tool left atop the battery presents a short circuit risk.

SAFETY FIRST

Many of the comments, suggestions, guidelines, and opinions that follow apply equally to all battery banks, from Lilliputian to Brobdingnagian. While larger banks magnify the consequences, a battery adrift in an engine compartment, hydrogen gas accumulation within a battery box, or overheated and arcing connections are of great concern in any installation aboard any vessel, regardless of the bank's size.

Whether you are a seasoned professional or do-it-yourselfer, safety should always be a factor when installing, working with or maintaining batteries. When working with large battery banks that incorporate more batteries and more connections, the likelihood of an accident increases. Most savvy marine electricians and mechanics have experienced the effect of a grounded tool making contact with ungrounded battery terminal and the impromptu arc welding exhibit it produces. Consider for a moment that the average starting battery is capable of producing such a display and it possesses a mere 500–800 cold cranking amps. Then, consider that a large house bank may be able to produce over 5000 cold cranking amps and several times that in fault current. Cause for handling with caution is clearly justified, as short circuits of any sort will almost certainly be catastrophic. Tools used to complete connections on such banks and related wiring should be fully insulated, even if that means the exposed metallic surfaces are wrapped with common electrical tape.

When working around large battery banks, or any batteries for that matter, take the following precautions: remove rings and bracelets. These items are often excellent conductors and if completing a short to ground could result in serious burns for the wearer. Wear safety glasses, even when working with "sealed" VRLA (valve regulated lead acid, which include AGM and gel) batteries. Spilled or splashed acid, or acid that becomes airborne as a result of an explosion, will cause damage to eye tissue, and even if sealed batteries are less likely to spill acid or explode, a short circuit is

Reprinted with permission. Copyright © 2012 Cruz Bay Publishing (888.487.2953) www.passagemaker.com

Battery Bank Equation Part 1

capable of discharging sparks whose nucleus may be formed by superheated or molten metal, the smallest particle of which could also cause serious eye damage.

Here is a final safety note that involves a serious but less acute issue: back injuries. In my experience as a marine industry professional, there seems to be a significant number of back injuries and missed work days following battery installation and/or removal. Given their weight alone this comes as no surprise. Batteries are also often installed in locations that offer poor accessibility, forcing those affecting the installation and/or removal to contort themselves into positions that make proper support of such loads impossible—it's no small wonder that injuries occur. In short, only folks with strong, healthy backs should install batteries. Cranes or block and tackle should be utilized for moving especially heavy or large quantities of batteries, and those doing the moving should be briefed on proper hoisting, lifting and skidding techniques, and safety protocols.

ASSESSING THE INSTALLATION AND APPLICATION

When I conduct a vessel inspection or review a systems proposal, one of the first criteria I must assess is the intent of the vessel's design. Such an assessment will determine the level of robustness and security that a large battery bank requires for safe, reliable operation. If the vessel carries a codification, such as an ISO stability standard or rating for instance, which ranges from, "A: ocean" to "D: sheltered waters" then its intended use is clear. In the absence of this information, it may be necessary to assess the vessel's overall design and the statements of the manufacturer (if you are the manufacturer then, in the absence of the aforementioned standard, consideration must be given to how you characterize the vessel's intended use or how it is perceived by your customers). If it's clearly designed for offshore bluewater passagemaking, then the standard for assessing the battery bank installation will be necessarily higher. If, on the other hand, the vessel is clearly designed for inshore or sheltered water use, then the design and security of the battery bank installation may reasonably reflect such an application.

SUPPORT AND SECURITY

Because of their considerable mass, large battery banks require special attention when it comes to ensuring that they remain immobilized under any sea conditions to which the vessel may be reasonably expected to encounter.

Clearly, any structure on which a battery bank rests must be capable of supporting the battery's weight and retaining the batteries' security mechanism. That is, if the batteries are securely fastened to the shelf as they should be, and the vessel experiences tumultuous sea conditions or high G loads, or it is knocked down, the shelf must continue to retain the batteries and the batteries' support structure(s) securely.

Additionally, the surface on which the batteries rest, or are contained within, must be resistant to abrasion, water damage, and attack from acid, and it should be capable of retaining spilled or leaked electrolyte. Herein lies another common problem with installations of SVRLA-style batteries when attempting to follow standards established by the ABYC and it revolves around their ambiguity. ABYC Guidelines, in section E-10, Battery Installations, are less than clear on the subject of containment of electrolyte, especially where SVRLA batteries are concerned, stating,

"Provision shall be made to contain incidental leakage and spillage of electrolyte.

In order to allow hydrogen gas (which is lighter than air) to escape, ventilation ports must be located at the highest portion of the locker and/or box lid. This under-bunk installation fails to meet this requirement.

NOTE: Consideration should be given to:

a. the type of battery installed (e.g. liquid electrolyte or immobilized electrolyte).

b. the boat in which the battery is installed (e.g. angles of heel for sailboats and accelerations for powerboats)."

This above protocol begs the following questions: What constitutes "incidental"? If the battery is an SVRLA, does this guideline negate the need for containment? Does a flooded battery require 100-percent containment? In other words, does it need a box? Just how much electrolyte is reasonable to expect an installation to retain when a sailing vessel heels? I've been asked these questions on many occasions by boatbuilders, professional systems installers, and boat owners alike. The answers are multi-faceted, and in some cases they remain debatable among professionals.

Depending on the type of vessel, I believe it's reasonable to expect that at some point SVRLA batteries may be replaced with conventional flooded batteries. In that case, spilled or leaked electrolyte becomes a very real possibility. Therefore, I advise those installing SVRLA batteries to take into account the possibility of such a retrofit in the vessel's future. At the very least, trays or liquid-tight fiddle assemblies should surround batteries or battery banks, and ensure that the shelves on which batteries rest are impervious to degradation from exposure to both electrolyte and water.

Such designs should be robust enough to resist deformation and the resultant possible failure of acid-resistant encapsulation. Timber shelving material that is merely coated with resin, for instance, is simply inadequate, in that, the resin film is extremely thin and relatively delicate and in the absence of fiber reinforcement lacks sufficient abrasion resistance to form a reliable, long-lasting acid-proof coating. Timber that ultimately is exposed to acid fails rapidly. Shelf designs that utilize timber or synthetic core material should be fully laminated with resin and glass fiber, and perimeter cleats should be well secured to the shelf, using fasteners and adhesives or epoxy bedding, to complete a rigid, long-lasting and liquid-tight, acid-resistant assembly.

Top: The security of a battery installation is critically important for every vessel, however, the standard becomes more stringent where offshore passagemaking vessels are concerned. Left: Light-duty web straps have no place in battery security. This one, knotted to the buckle, is inadequate for even the smallest battery installation.

It's worth noting that while extremely versatile, high density polyethylene (HDPE), often known by the trade name Starboard is a less than ideal choice of shelf material for a large battery bank. While it is resistant to acid, installations relying on it often lack sufficient structural rigidity. Therefore, they are unable to resist deformation when called upon to support the extreme loads imparted by large batteries and battery banks. Additionally, it is very difficult to make a liquid-tight cleat seal using HDPE, which means batteries installed on shelves made of this material would need their own, independent trays or boxes if acid containment is desired.

Commercially available or custom-made battery trays and boxes are an ideal solution for battery support, security, and electrolyte containment, provided they are compatible with the installation. I once questioned the need for battery boxes, particularly when one considers that the additional space negatively impacts inspection and service—until I witnessed the result of a battery explosion contained by one. The battery's "shrapnel" and acid were nearly fully retained by the stout plastic box. Still, such explosions are rare, and where large banks are concerned, the added real estate required by boxes, and the difficulty of installing batteries into them, may make them impractical and unnecessary in the case of SVRLA designs.

If boxes are utilized, ensure that they are properly ventilated to release hydrogen gas as well as dissipate heat generated in the charging process.

While boxes may be ventilated in several locations, it's important that at least one vent be located at the apex of the lid. Along with ensuring ABYC compliance, doing so will prevent the formation of a potentially explosive hydrogen gas bubble. In the battery systems I inspect, for those that utilize boxes, improper ventilation is among the most common oversight. I'll return to the issue of ventilation below.

Fasteners used to secure boxes, cleats, trays, shelves, or other securing methods must not be installed in a manner that will expose them to spilled or leaking electrolyte. If they are, it's possible that the heads of the fasteners will be compromised by the acid, leading to mechanical failure. Therefore, boxes and trays as

Reprinted with permission. Copyright © 2012 Cruz Bay Publishing (888.487.2953) www.passagemaker.com

Top: The shelf on which this very large (it weighs half a ton) battery bank rests is simply inadequate. The structure must be capable of retaining the batteries in the most tumultuous of conditions. Above: Plywood, while commonly used for battery shelves and boxes, is a poor material choice unless heavily encapsulated in fiberglass resin and fabric. This box has rapidly deteriorated as a result of exposure to acid.

well as custom-made shelves, may not utilize fasteners installed within the acid containment confines of these structures. In many cases, I encounter battery boxes and trays that are secured using fasteners screwed through the bottom of the box. This is a clear violation of this protocol and should be avoided. If the batteries are "leakproof," i.e. SVRLA, then hardware placement and failure becomes less of an issue. However, once again, if the existing batteries are ever replaced with those of the flooded variety, then the risk of hardware failure returns.

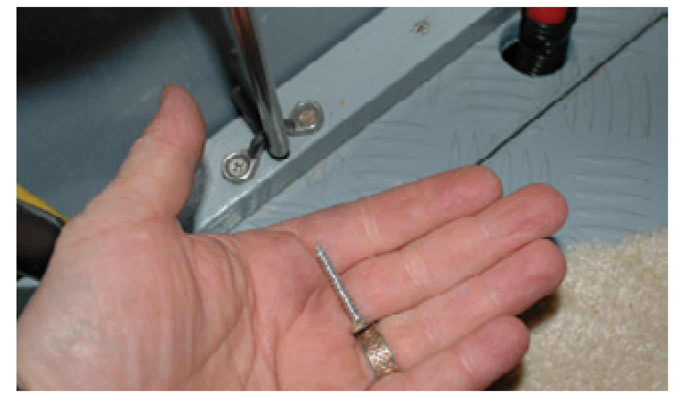
SECURITY

Convention and compliance with ABYC Standard E-10 necessitates that batteries remain stable, not moving more than 1 inch when a force of 90 pounds or twice the battery's weight, whichever is less, is applied. For the Standard, application of this force is through the battery's center of gravity, vertically, horizontally and parallel to the boat's centerline both fore and aft, horizontally and perpendicular to the boat's centerline both to port and to starboard. Each of these "pull tests" should have a duration of one minute. (I've paraphrased these guidelines and I strongly recommend that anyone designing, installing, modifying or maintaining a large battery bank review the chapter in its entirety).

While these guidelines set the bar high, it is (in my opinion) not high enough, and it's one of the few areas in which I'm not in agreement with the Standards. Allowing a battery to move 1 inch after it's considered fully installed, is an invitation to a host of maladies, including loosening of connections as well as cable and case chafe. My own guidelines call for complete immobilization of all battery installations, regardless of size. In no cases can I think of a benefit associated with allowing batteries this level of freedom for movement.

Battery and battery bank immobilization may be accomplished in a variety of ways. Clamping using insulated alloy or extruded FRP (because of its non-conductive properties, the latter is preferred) channel or box section strong backs, and threaded through bolted rod is an ideal method of ensuring that one or more batteries remain stationary under virtually any conditions, including a knockdown. Timber sections may be used in place of alloy or FRP, however, they should be stout, preferably laminated and fully epoxy encapsulated, especially for flooded cell installations. (In light of the labor required to meet that criteria, FRP would seem to make more sense.) If this method is used, remember to ensure that all hardware is located outside the electrolyte containment area. Typically, this approach is used for batteries that are installed in trays or on shelves. Strong backs can be oriented in such a way as to facilitate easy inspection and water service for flooded batteries. One advantage of installing batteries without boxes is that they can be more easily serviced and they can be inspected on a casual basis, each time the compartment is transited.

Synthetic web straps may also be used for battery security (not without caveats). Strap material must be impervious to acid and my preference is for buckles that are of the positive, metallic ratcheting variety rather than the simple friction-type, and preferably stainless steel. While plastic buckles are corrosion-proof, it's difficult to install them in such a way that they impart enough tension on a battery to ensure it remains completely immobilized. Some straps utilize plastic buckles that are notoriously difficult to release after they've been installed for months or years. If straps are used to secure batteries they should be retained by strap eyes rather than screws passing directly through the strap unless the screws' load is distributed over a wide area using a backing block and without damaging or piercing the strap. Fasteners securing straps should be through-bolts rather than tapping screws. In some cases, especially for smaller case sizes, tapping screws may be used. However, take into account the substrate into which they are fastened. It must be sound and its full thickness should be utilized. Additionally, the largest possible diameter fastener should be used, filling the hardware-mounting hole through which it passes.



Top: While web straps can be used to secure batteries, they must be durable, robust and properly secured to the shelf or vessel. Fasteners passed directly through a strap are inappropriate for the loads that are involved. Above: Ideally, hardware used for battery security should be through-bolts rather than tapping screws. Where tapping screws are used, they must be large enough to support the load and the substrate into which they are screwed must be capable of retaining them without failure.

VENTILATION

It is a commonly held misconception that SVRLA batteries do not vent hydrogen gas and therefore requires no such ventilation provisions. Rest assured nothing could be further from the truth, and some AGM battery manufacturers go to great lengths to point this out in their descriptive installation literature: "Even though VRLA batteries are designed to recombine these gasses internally, the recombination efficiency is less than 100 percent. Small amounts of hydrogen and oxygen are released from the pressure relief valve during charging." A concentration of just 4 percent hydrogen is combustible. AGM and gel batteries will, under the right circumstances (especially if overcharged or overheated) vent more than just small amounts of hydrogen and thus they too must be allowed to safely dissipate this gas. ABYC Standards make no distinction between SVRLA and flooded batteries; all require adequate provisions for dissipating hydrogen gas from the vessel in order to remain compliant. Therefore, avoid placing batteries in compartments or lockers that lack ventilation at their highest point (hydrogen is lighter than air and will rise to the top of any space). Remote vent plumbing must rise continuously to allow hydrogen to escape and to prevent water accumulation, which will prevent gas from being freely vented.

Also, take into account the importance of venting the compartment in which batteries are located. Under bunk and settee battery installations are, for instance, notorious for lacking proper ventilation at their highest point.

While ventilation and removal of hydrogen gas is acutely important, failure to do so can lead to a catastrophic explosion—batteries also require ventilation to dissipate heat generated during the normal charging process. One of the most common flaws in large battery bank installations involves what I refer to as the battery sandwich. Typically, the heat generated within batteries is easily radiated to the surrounding air, keeping the batteries' temperature in check. However, a battery sandwich, as the name implies, utilizes a series of batteries that are packed tightly against one another. The batteries on the outside (the "bread") tend to insulate those on the inside of the pack and none are adequately ventilated. In some cases, I've measured central batteries in a bank, even a small one, as much as 30°F hotter than those on the perimeter.

The problem with battery heat generation, or the inability to dissipate such heat, is that the hotter they get, the faster the reaction rate and the worse the problem becomes, creating what's known as thermal runaway. In extreme cases, if allowed to persist, a runaway can lead to a battery fire and/or explosion. Fortunately, a resolution to this problem is very simple; ensure that a gap of no less than 1/4 inch (more is better) exists between any two batteries. Such an arrangement will ensure that battery heat can be safely dissipated, increasing battery life and decreasing the likelihood of a runaway scenario. It's important to point out that a thermal runaway can occur even in cases where batteries are properly ventilated. However, the problem is far more likely to occur if batteries are installed in a manner that inhibits heat dissipation.

A final note on ventilation, ABYC Standard A-31, prohibits the installation of battery chargers and inverters directly above battery banks of any size. Because most inverters, and some chargers, lack ignition protection, they can serve as an ignition source for venting hydrogen gas. Additionally, the fumes emanating from a battery bank may be corrosive and having them waft through sensitive electrical circuits may damage them or diminish their life.

Reprinted with permission. Copyright © 2012 Cruz Bay Publishing (888.487.2953) www.passagemaker.com

ACCESS AND SERVICE

In all cases, regardless of the battery type, case size or voltage, and irrespective of the method that is used for battery security, provisions for access should be an important consideration in the bank design and installation process. Flooded batteries require access for electrolyte level inspection and the addition of distilled water (batteries should only ever be maintained with pure, distilled water. Never add electrolyte to a battery other than at its initial dry filling).

The "water," is a diluted mixture of sulfuric acid, properly referred to as electrolyte. Its level should be filled no higher than the internal cell liquid level indicator. Typically, this is a tab that protrudes down and into the cell, the bottom of which indicates the fill level. Filling substantially above this indicator will almost certainly lead to electrolyte splatter during normal gassing. As more and more electrolyte splatters, the acid concentration level becomes more dilute as it's replaced with water.

Once acid is lost it cannot be replaced—only water that outgases or evaporates can be added back to the electrolyte mixture. Ultimately, the process leads to loss of capacity and eventual battery failure. For large banks, recombinant cell caps or permanently plumbed watering systems often make sense, particularly if batteries are difficult to access.

Even in the case of SVRLA batteries, periodic inspection for cable security, evidence of case failures or venting and corrosion must be provided. Burying batteries under or behind other batteries, in racks whose clearance between levels or shelves is too narrow or, worse, in areas that are inaccessible without the use of tools is simply ensuring that an owner or crew will be less likely to inspect and maintain the bank.

Chronic corrosion forming around one or more terminals is often an indication that the seal between the case and the metallic post or terminal has failed. If this occurs on a flooded battery, the results are not dire. The corrosion can be cleaned and the area between the post may be repairable using common sealant. However, if such corrosion makes an appearance around the terminal of an SVRLA battery, the results are nearly always detrimental. Because SVRLA batteries operate under slight pressure, this aids the chemical recombinant process (typically 1.5psi), a seal failure around a terminal, and the resulting loss of pressure and subsequent venting, nearly always results in diminished battery life. In short, chronic SVRLA post corrosion usually signals the death knell of such batteries.

In part two of this article we'll discuss over-current protection, fuse, and circuit breaker requirements, as well as preferred connection methods and wiring protocols.