

# Professional Mil-Spec Motorsport ECU Wiring Harness Construction

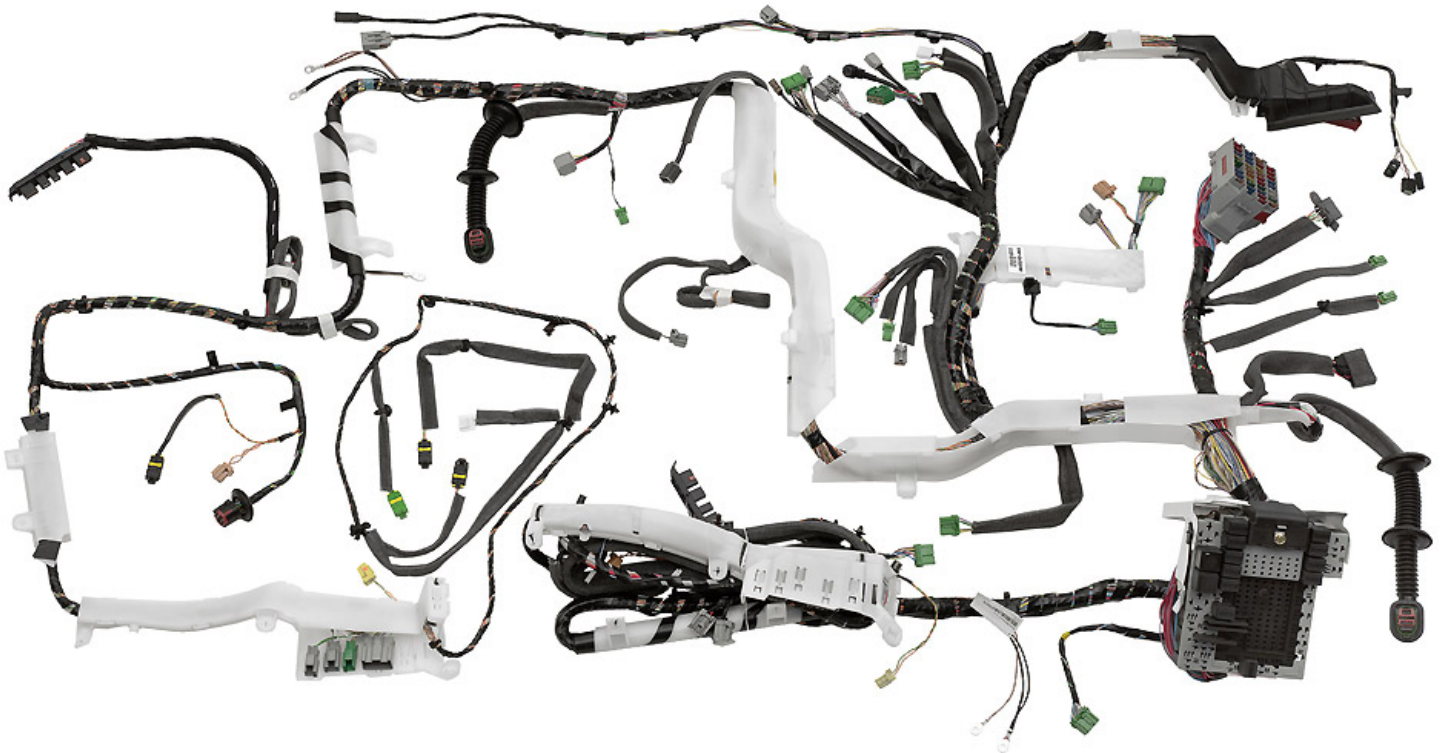
## Electrons

Getting electrical signals from point A to point B is pretty standard thing...Put a piece of copper wire between A and B and the job is done. A century of development has left us with increased specialization in wiring, connection devices, and everything in between point A and B. "Mil-Spec" or military specification, has become the buzz-word in motorsport electrical harness construction. Actually motorsport wiring has developed it's own specialized connectors but it's still largely constructed from aerospace components.

Perhaps "Race-Spec" will become the new buzz-word....Probably not with the trillions of dollars spent on drones, F22's and commercial aircraft.

This is not a definitive guide on building wiring harnesses as this could encompass two wheels, four wheels or no wheels. It does give you a perspective on motorsports ecu wiring and provides access to further literature for you to study and make your own decisions. We build ecu wiring harnesses for our production items and for our own racing activities.

## Production OEM Automotive Wiring



On one end of the scale there is OEM automotive wiring, like on your new passenger vehicle or truck, wherein costs are paramount and warranties are offered, in some cases, bumper to bumper for 100,000 miles. Pictured above is a production passenger car harness in GXL and TXL wires.

These vehicles and their myriad of up to sixty microprocessors, connectors, sensors, relays, and switches are tested for years on end in extremes of temperature, humidity, vibration, and electrical interference. There are no mil-spec metal shell connectors, no airframe tie wrapping or concentric twisting, and no epoxied or glue-shrunk connections...Only plastic connectors and crosslinked polyethylene GXL and TXL multi-strand copper wiring without any silver, tin or nickel plating. Guess what, they work just fine...amid increasing complexity, for years on end. A typical mid-sized car will have about 45-70 lbs of wiring.

One time we scrapped out a 20 year old Honda Civic and were amazed at how all the wiring was still in perfect shape...Connector seals were still sealed and clean inside and all the grime, water and heat had not caused any failures. Wiring was still flexible and not cracked. OEM specifications and engineering are pretty damn good.

In short, automotive grade wiring and connectors have a pretty good track record. Not glamorous, but in business, economics and bean counters seldom are.

## Motorsports Wiring



This has evolved from aircraft and military specifications wherein light weight and reliability are paramount. As motorsports evolved into an increasingly more sophisticated and expensive professional endeavor, specific motorsport connectors have evolved which are even lighter and smaller than their aerospace counterparts. These products don't have to meet oem production testing requirements...They just have to be reliable in a racing environment which is not the same as freezing in Siberia or bouncing down rural roads in your F150 pickup for decades.

Sort of serious in a Darth Vader, rubber-fetish way. Bondage and latex in the hell of an engine bay. Above are heat shrink boots sealing circular connectors and the DR-25 heat shrink wire protection.



Everything than can slow you down is the enemy....weight of the wires, weight of the connectors and any kind of outright failure, or worse, intermittent failure, which is harder to isolate. This is why F1 might be using tiny 30 gauge wire or why the new McLaren MP4-12C went to extremes in specifying hexagonal aluminum wire to save both space and weight.

Mil-spec circular connectors are the norm, full of all sorts of trickery like strain reducing service loops and concentric twisting for flexibility and more compact wiring harnesses. Reliability at 30,000 feet or going airborne at the Nurburgring...it's all the same thing...well, sort of the same thing.

The connector above features concentric (twist) wiring, service (strain relief) loops at the connector, lacing cord and Kynar clear shrink to hold

the wires tightly together near the connector. Kapton tape will cover the wires at the connector to protect them from the special adhesive-lined shapes or RBK Adhesive Lined Shrink. With the wires covered by DR-25 and the Connector sealed by the RBK, the harness will be protected from the environment and from abrasion.



Here a Deutsch Autosport connector has its Spec 55 wires wrapped in Kapton tape to prevent the adhesive shrink from grabbing the wires. The tape allows repairs to be made at a later date. Once the adhesive melts it really grabs the connector, the DR-25 wire covering, and anything underneath it.



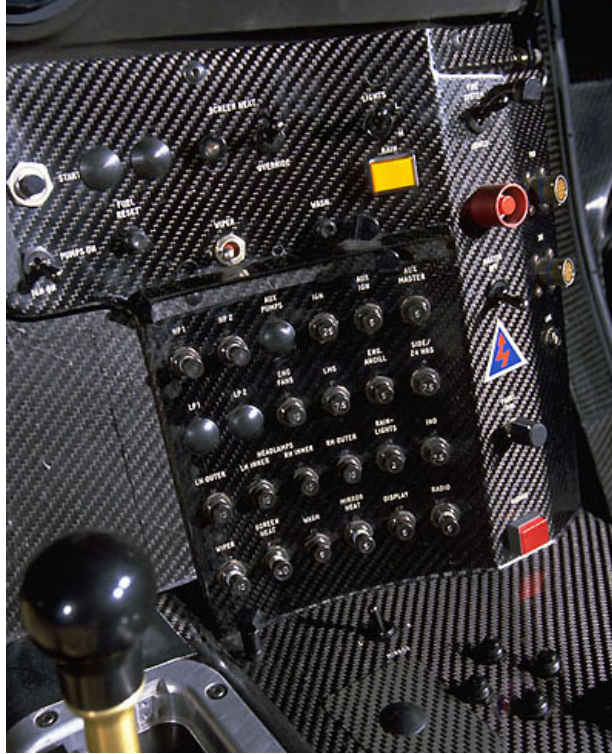
Low Static Kapton adhesive tape is commonly available in 1/4, 3/8" and 1/2" rolls. The silicone adhesive does not leave any residue. It is amber in color.

## Motorsport Wiring



Circular connectors, glue shrunk boots, Raychem DR-25 shrunk over concentric wound silver-plated Raychem Spec 55 XLTFE wiring and, of course, the requisite yellow shrink tube labels covered in Raychem RT-375 clear shrink tubing. Cosworth Pectel SQ6M ECU.

## Circuit Breakers not Fuses



Passenger cars use fuses everywhere whereas, in motorsports, re-settable aviation-style circuit breakers are preferred. Circuit breakers have the advantage of being re-settable which allows you to perhaps just "push it in" and get going until you diagnose the problem. You also don't need to replace a fuse. Harley used to use truck style thermal breakers...your bike would sign off due to some short and a few minutes later it would run again...but you didn't melt your wires.



W23 Series

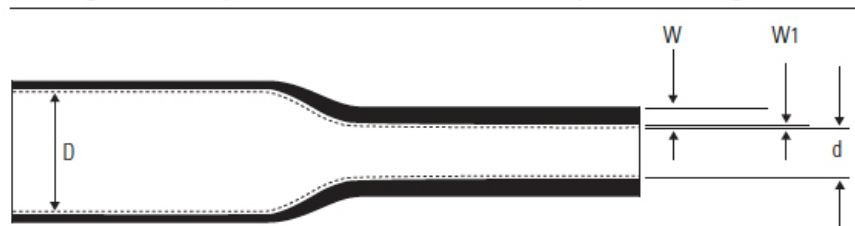
Tyco W23, ETA 483, and Klixon 2TC14 series push to set circuit breakers are a standard aviation item and are available in many amperages. They "pop up" when they trip and you push them down to reset them. If you are using the popular sealed WeatherPack silicone sealed fuse holders you can use Bussmann 227 series circuit breakers that are a drop in replacement, albeit pricey, for the cheaper one time fuses.

Breakers like the Tyco W23 are usually installed in panels that a race car driver can reach and reset. "Reach and reset" doesn't work on motorcycles. Space is also a premium on motorcycles.

Klixon 2TC14-X (green breaker) are available in varying amperages from 1A to 25A for about \$20.00. Higher end ETA 483 series are about four times more expensive. These are available from [Prowire](http://Prowire.com).

### Sealing backs of circuit breakers

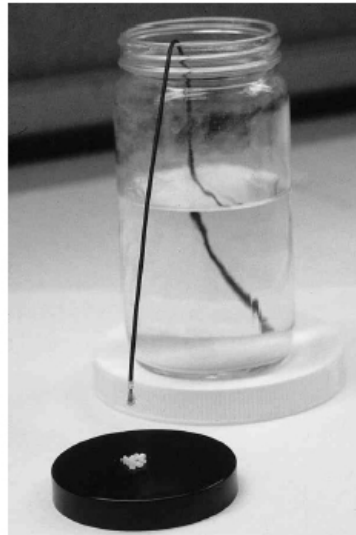
Semi-rigid selectively crosslinked heat-shrinkable encapsulation tubing



Raychem SCL heat shrink can be used to seal circuit breakers and other types of switched from the environment. Much niftier than trying to heat shrink a couple of screw terminals. It is a dual-wall adhesive lined shrink tube with a 2.5:1 shrink ratio.

A greater shrink ratio (4:1) can be accomplished by using [Raychem ES2000](#), or DSG-Canusa CDR adhesive-lined semi-rigid shrink tubing. Raychem ES2000 is available in small quantities (4' sticks) from various electronic suppliers like Mouser.

## Wicked Wicking



A salt deposit can be seen beneath the end of this 18-AWG, 19-strand wire. The other end of the wire has been immersed in salt water for 24 hours.

In case you doubt the need for epoxy or adhesive-lined terminations, the above picture gives graphic evidence of corrosion traveling down the voids between the strands of copper wires. Since we go to the Bonneville Salt Flats two to three times a year for up to a month, and everything gets bathed in salt, properly sealing the electrical connections is a major concern. Year one OK...year two fix one or two things...year three redo everything. Using adhesive-lined or epoxy-based sealing schemes we can keep corrosion out of our wiring harnesses.

OEM harnesses employ silicone seals on thermoplastic connectors to address these issues. Any gap in the harness can provide a path to internal corrosion.

## Sealing with Epoxy

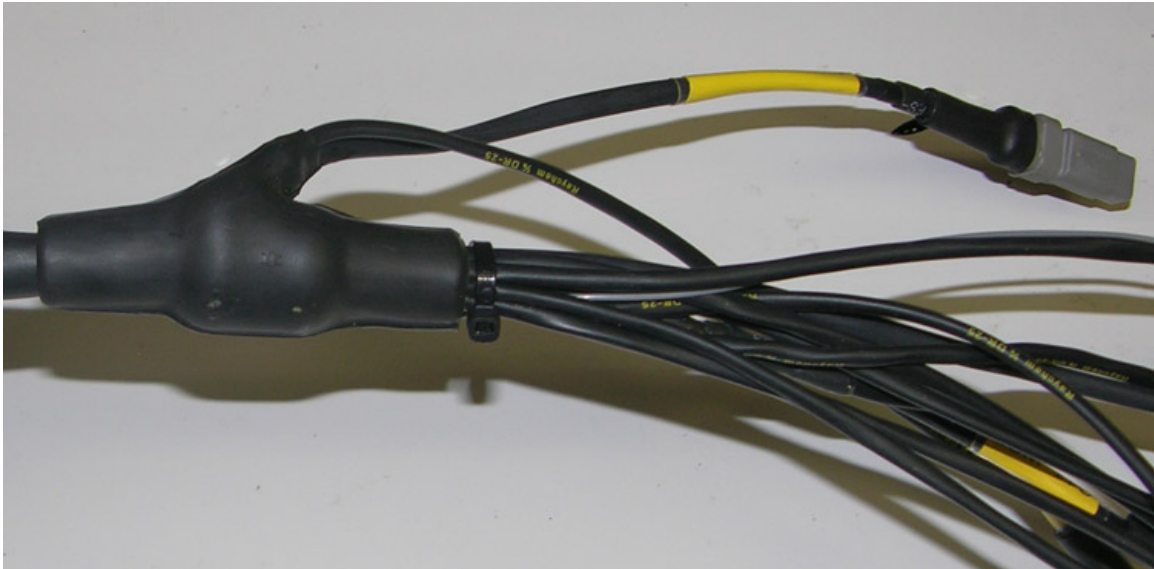


Sealing boots and shapes that do not have adhesive melt can be done with specialized two part epoxies. Abrading the inner surface and applying the epoxy to the connector and cable before the heat shrinking operation. Epoxy is not applied to the inside of the heat shrink. Here the connector is sealed to the cable using V25 Deray thin wall shrink tube (2:1) and sealed with epoxy.

## Resintech RT125 Harness Epoxy



The preferred epoxy for sealing wiring harnesses is [Resintech RT125](#). It is a two part semi-flexible epoxy that is mixed 50/50. You can purchase RT125 from [Prowire](#). These are standard 50ml cartridges. Note they have a shelf life. If you are using this in concert with adhesive lined boots do not apply the epoxy to the inside of the boot. Be prepared to do some clean up wiping as the epoxy hardens much later than the adhesive lined boots.



Here we have sealed the multiple branches under the Raychem boot with Resintech RT125 and shrunk the boot over the epoxy. It's a good idea to use an additional tie wrap strain relief at the multiple branch point.

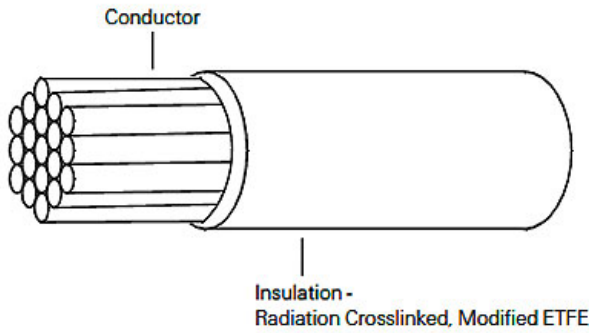
### Resintech RT125 Epoxy Mixing Gun



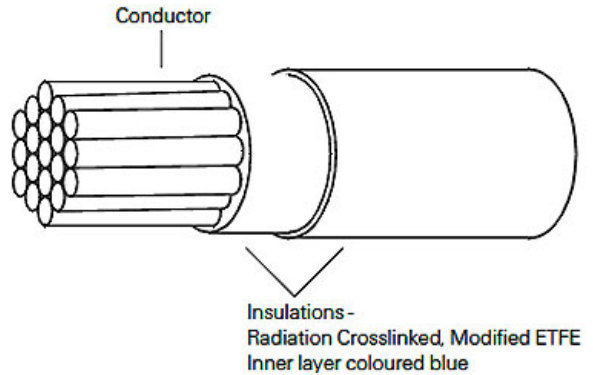
Resintech RT125 epoxy mixing gun. RT125 cartridges can be mixed by hand or you can purchase a epoxy mixing gun for 50 ml cartridges and several bags of mixing nozzles from Amazon. This makes the application of the epoxy a lot less messy. About \$35.00 well spent. You throw away the mixing nozzles after each application as the RT125 starts setting rather quickly. You should let the applied boot and RT125 harden as it can get a bit messy before you go off to the next sealing point.

# MIL-W-22759/32-35 and 41-46 or Raychem "Spec 55" Primary Wire

**SPEC 55 insulation system - single wall**



**SPEC 55 insulation system - dual wall**



Raychem Spec 55 wire has become the defacto standard for motorsports wiring. "Spec 55" is a trademark of Tyco Electronics. The actual designation is MIL-W-22759/32-35 and 41-44. MIL-W-22759/44 is the normal wire of choice with silver plated copper stands. Silver plated copper (SPC) strands have a higher temperature rating than does Tinned copper (TC) strands.

Spec 55 Single Wall or "interconnect" wire carries the designation 55A011-xx-xx. Spec 55 Dual Wall or "airframe" wire carries the designation 55A081-xx-xx.

"XLETFE" insulation refers to Cross Linked ETFE Polymer (Tefzel) which provides increases abrasion resistance over Tefzel insulation. Dual wall construction is commonly used in aircraft. ETFE is described as a "modified radiation cross-linked polymer".

Specification	Insulation	Conductor	AWG Range	Temp	Voltage	Wall	M27500 Symbol
MIL-W-22759/32	XLETFE	TC	30-12	150C	600		SB
MIL-W-22759/33	XLETFE	SPHSCA	30-20	200C	600		SC
MIL-W-22759/34	XLETFE	TC	24-00	150C	600	Dual Wall	SD
MIL-W-22759/35	XLETFE	SPHSCA	26-20	200C	600	Dual Wall	SE
MIL-W-22759/41	XLETFE	NPC	26-00	200C	600	Dual Wall	SM
MIL-W-22759/42	XLETFE	NPHSCA	26-20	200C	600	Dual Wall	SN
MIL-W-22759/43	XLETFE	SPC	26-00	200C	600	Dual Wall	SP
MIL-W-22759/44	XLETFE	SPC	28-12	200C	600	Single Wall	SR

Dual wall (normal weight) "Spec 55" will have an inner layer of a contrasting color (blue) to indicate when the wire has been nicked, abraded or cut.

TC refers to Tin Plated Copper. SPHSCA refers to Silver Plated High Strength Copper Alloy. NPC refers to Nickel Plated Copper. NPHSCA refers to Nickel Plated High Strength Copper Alloy. Note: 24-30 AWG should use SPHSCA conductor

Nickel has a higher melting point than does silver but this is of little consequence in motorsports ecu wiring.

## Alternative to MIL-W-22759/44 "Spec 55" Primary Wire

A less expensive and more commonly available wiring is the single wall Tin Plated (TC) Copper strand wiring MIL-W-22759/16. It could be argued that silver has a better conductivity and higher temperature rating than tin plating...but both offer increased protection against corrosion over bare copper wires.

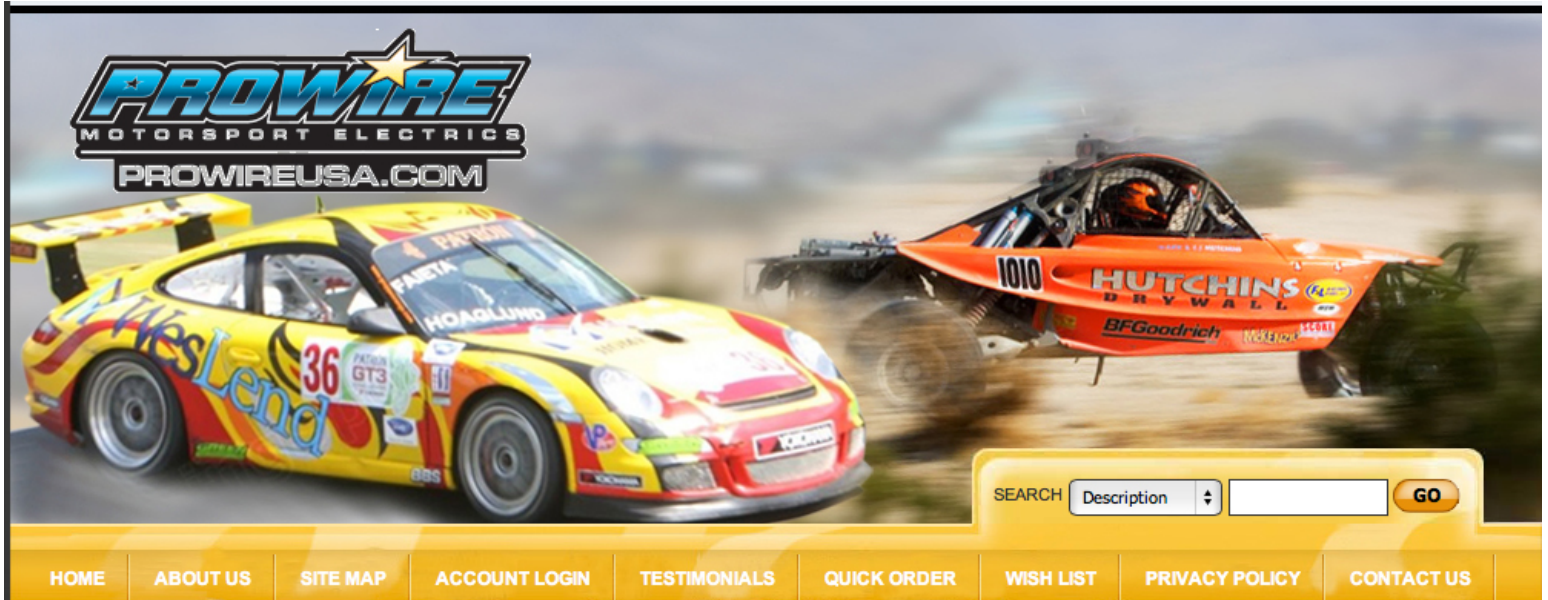
Specification	Insulation	Conductor	AWG Range	Temp	Voltage	Wall	M27500 Symbol
MIL-W-22759/16	TEFZEL	TC	24-00	150C	600	Heavy Wall	TE

The main benefit of Spec 55, MIL-W-22759/44, over the alternative MIL-W-22759/16 is that it is "tougher" i.e. it has better abrasion properties due to its irradiated jacket. This is less of a concern if the harness is sheathed in DR-25 heat shrink, which is a common motorsports practice. In short it is an acceptable alternative to the more expensive "Spec 55" wire.

In 20 AWG it weighs 5.18 lbs/1000 feet as opposed to Spec 55 20 AWG which weighs 4.3 lbs/1000 feet. It is also larger in diameter in 20 AWG .060" versus .050" for the Spec 55 wire.

Better plating and tougher wire versus cost savings for the /16 alternative.

## Where to Buy [Supplies](#)

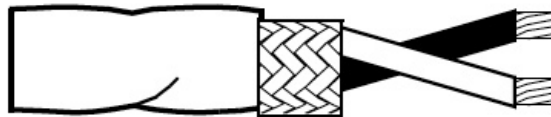


An excellent source for your wiring supplies for you go it alone types is [Prowire](#) as they stock about everything you need and sell in small quantities. It a good place to pick up your MIL-W-22759/16 wire and supplies. They have 140 Mil-Spec wire color combinations in stock. Quick service and excellent prices.

ProwireUSA  
9260 Isaac St Suite B  
Santee Ca 92071  
Phone 619-440-9473  
Fax 866-224-7057  
[sales@prowireusa.com](mailto:sales@prowireusa.com)

### Twisted Pairs: Protection From EMI Interference

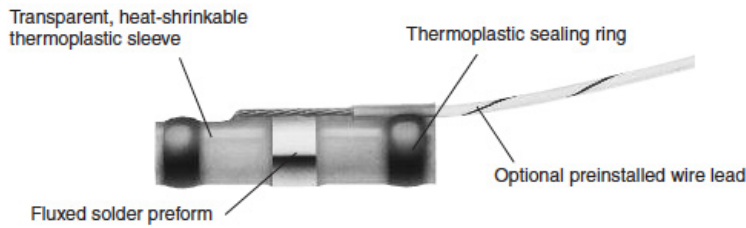
## 44A112X (600 V) 2 conductors



Crankshaft sensors, camshaft sensors, RS 232 and other communications should use twisted pair, shielded, wiring. 20 or 22 AWG is typical for twisted pair sensor and communications. We use 22 gauge with White and White/Blue wires for our two wire crank position sensors: [44A1121-22-9/96](#)

Twisting the wires reduces magnetically induced interference. Forcing the wires together reduces the loop area and therefore the induced voltage. Since the currents are flowing in minimum loop areas, magnetic field generation is reduced. Good idea to avoid signal problems due to noisy ignitions, coils etc.

## Typical SolderSleeve Device (illustration of shield terminator concept)

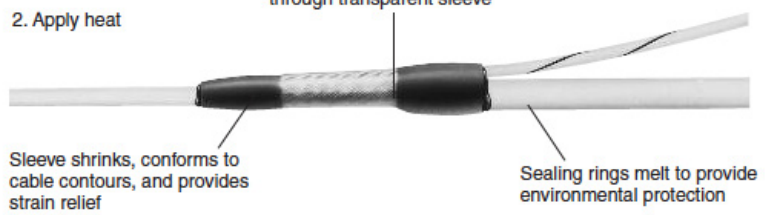


## Typical Installation

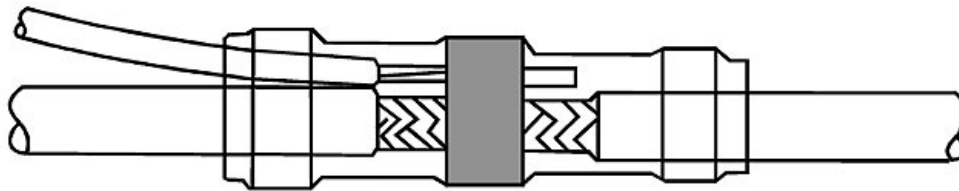
1. Insert prepared cable



2. Apply heat



Grounding of the shielded cable is accomplished by using dedicated solder splices. Section 8-3 of Tyco Electronics (te.com) main [Wire and Cable 27.9Mb Catalog](#) lists these solder splices. They are available with or without leads. We ground our shielded wire jackets directly at the SQ6M ecu.



[Procedures are defined](#) for grounding the of the shielded wires.

## Connectors



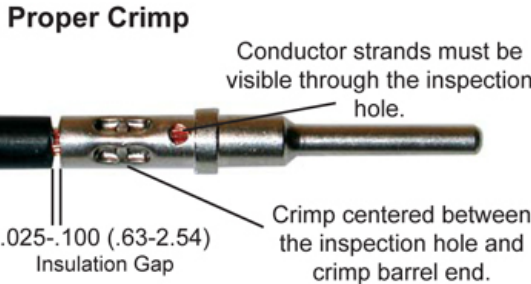
[Deutsch Autosport](#): Specifically designed for motorsport. Lightweight. Expensive. Requires Mil-Spec crimping and stripping tools. This is Cosworth Pectel SQ6M that we use on our ORCA motor [turbocharged Harleys](#). The color bands denote the connector shell keyway. The left and right connectors are 26 Pin 20 gauge of different keyway locations so you cannot mix them up. The center connector is a 55 pin 22 gauge connector. Figure on spending about \$400.00 for the associated connectors, sockets, and insertion tools for the SQ6M.



**Deutsch DTM Series** : Sealed thermoplastic connectors designed for harsh environments like engine compartments. Reasonably priced. Available from many sources, they offer watertight silicone seals that also act as a strain relief. Available in 2, 3, 4, 6, 8 and 12 pin contacts with size 20 contacts for AWG 16 to 24 gage wire. Either solid pins and sockets or crimped pins and sockets can be used. Solid pins are crimped and are easiest to work with. In no case should the pins and sockets be soldered.



Pictured above are 2, 3, and 4 pin DTM connectors with the optional shrink boot adaptor.



All of the pins and sockets are made from 98% pure copper and then plated. Standard plating is Nickel. For critical circuits, pins and sockets are plated with Nickel and then Gold. For lighting, power and control circuits choose Nickel. For critical and very low voltage and amperage circuits such as oxygen sensors that operate at 0-1 volt or 0-5V (wideband) and for data transmission circuits that operate at 5 volts, choose Gold. Type K Thermocouple wire should use Gold-Plated solid pins in the DTM two wire connectors.

Note: rear silicone seal will seal on smooth insulation from .053" to .120" O.D. Of importance is the fact they are rated at 100 cycles of engagement and disengagement. These are your affordable step below the very expensive Deutsch Autosport line.

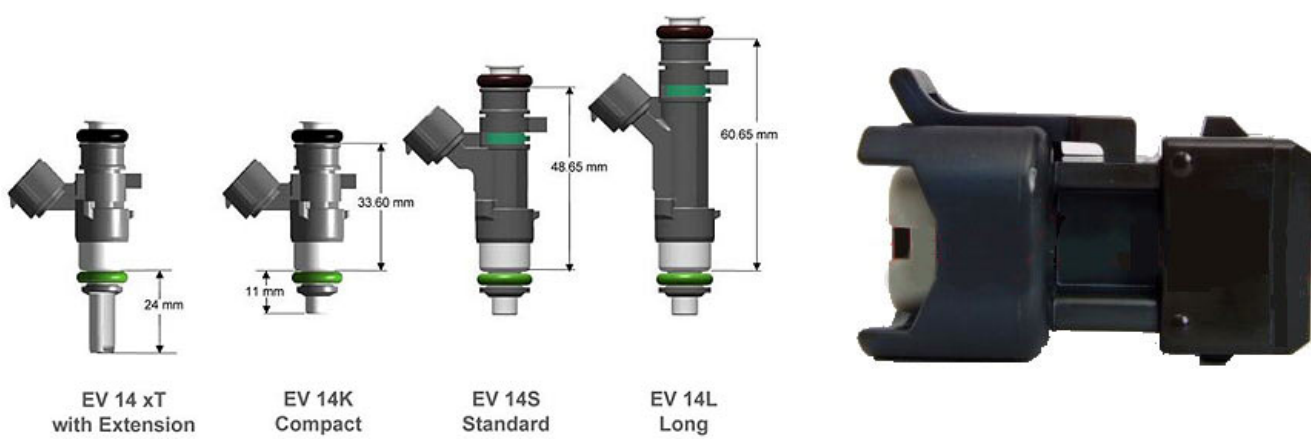


**Sureseal**: Interesting rubber push to connect seals. Like any specific connector they require specific tooling. These connectors are rated at 50 cycles of engagement and disengagement.



**Weatherpack**: Ubiquitous automotive silicone sealed thermoplastic connectors designed for harsh automotive environments. These connectors are validated to perform to specification for 10 cycles of engagement and disengagement, but up to 50 cycles probably will not see any signal degradation. In short they are excellent for oem use but a bit wanting in a motorsports environment where >10 engagement/disengagement cycles are normal.

Injectors and Connectors



The trend in injectors is to use the [Bosch EV14 injectors](#), which are high impedance, typically 12 Ohms, instead of the older style Low Impedance (2-3 Ohms) as the EV14's are very fast opening and very accurate. To use these you will need to use USCAR style injector connectors.

### Sealed K4 Toggle Switches

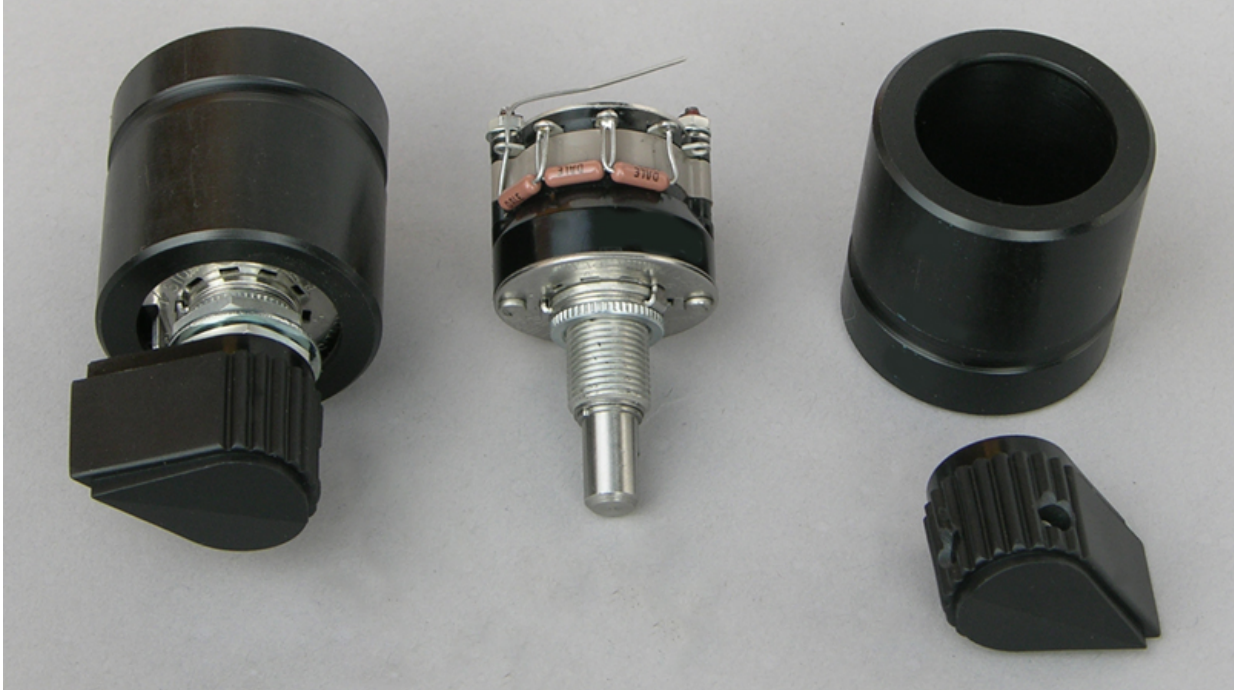


K4 Triple Sealed Switches are used in off road racing and other motorsports where moisture and dust are your enemy. [Complete K4 Catalog](#).

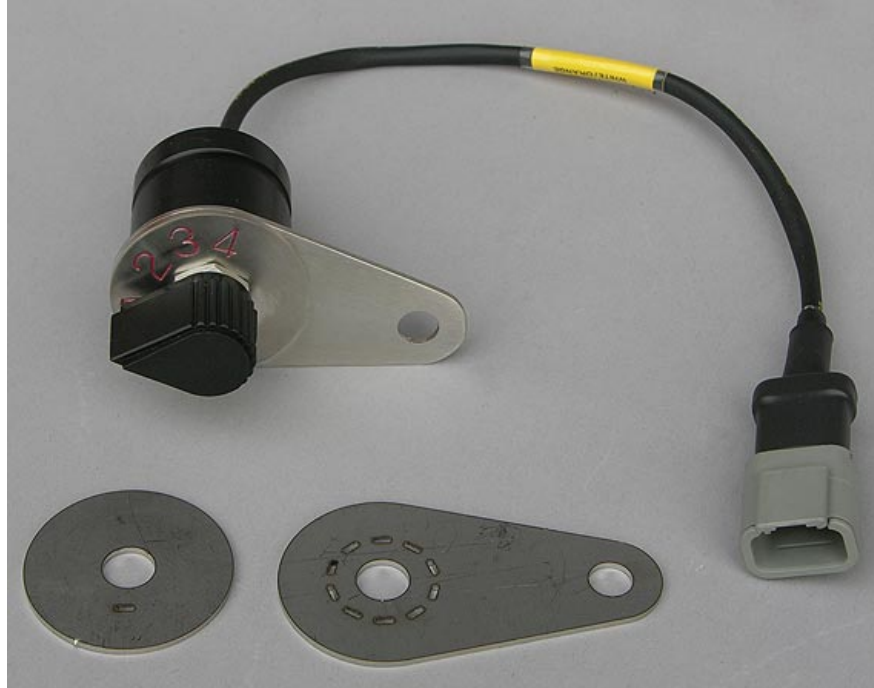
### Rotary Map Selection Switches



Rotary position switches are a fact of life in Formula 1...Fuel, suspension, traction control, braking bias and whatever the rules allow these days with the spec ecus from McLaren Electronics are all switchable on the carbon fiber steering wheel.



We make up our own Rotary Map Switches that have to survive on a Harley-Davidson. We set these up for four map positions. Traction control maps, fuel and spark maps...all changeable on the fly. Four position switch pictured uses three resistors to set voltages from 5 VDC to 0 VDC in equal steps.



Here is the final assembled switch with the laser cut stainless steel mounting bracket and faceplate. Laser cut slots allow the faceplate and the mounting bracket to index to each other. We stamp the switch positions into the faceplate. The entire assembly is sealed for reliability. We label the color of the signal wire so it can marry up with the appropriate DTM connector on the wiring harness.



We machine the switch enclosure from Delrin plastic and encapsulate the rotary switch in epoxy to waterproof it and use DR-25 heat shrink and formed boots to protect the wiring and install a three position Deutsch DTM connector.



Eight Position Traction Control Rotary Switch. Seven resistors set voltages from 5 VDC to 0 VDC in equal steps.

### Wire Stripping...Thermal



Thermal wire strippers do not nick or cut or scrape the wiring. There are several manufacturers like Teledyne and Hakko. The [Teledyne Strippal®](#) Plus pictured to the left above is a self-contained hand-held stripper that either comes with a fixed or variable temperature control. The insulation melts and is stripped cleanly and quickly, readying the wire for crimping or soldering. To the right is the Hakko FT-801 thermal wire stripper.

### Wire Stripping...Mechanical



It's best to use a high grade mechanical stripper and not cheap autoparts store ones. On the higher end of the scale the Ergo Elite, pictured on the left, is an excellent wire stripper. The Ideal 45-177 Stripmaster Lite (16-26 AWG, Type E Teflon), on the right, is also an excellent choice.

### Crimping Tools



Daniels crimping tools are the defacto standard for motorsports connector pins and sockets. We also use specialized tools to crimp Weatherpack connectors and Deutsch connectors.



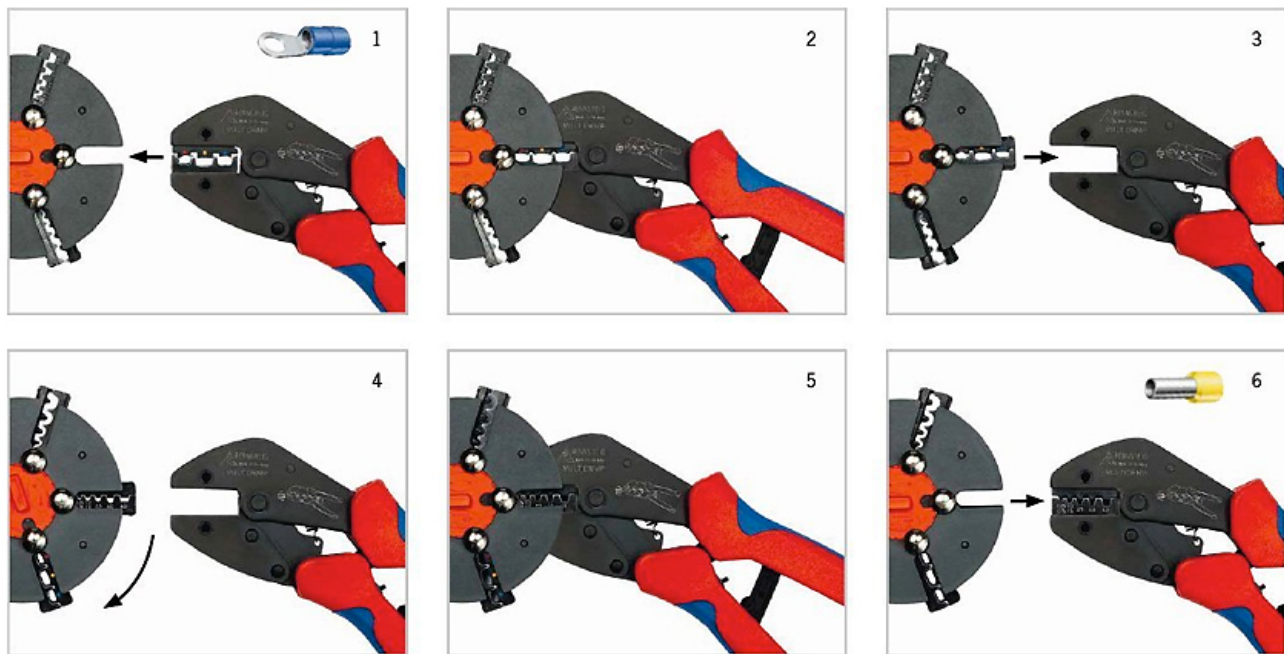
This is a selection of the crimping tools that we use to make our motorcycle harnesses. Daniels, Delphi, AMP, Rennsteig, and Deutsch crimpers. We don't do custom wiring harnesses except for our own products and racing.

### Ratcheting Crimper Rennsteig PEW-9



There are different types of crimps used for different purposes i.e. insulated or non-insulated connectors. The [Rennsteig PEW-9](#) shown here with a hexagonal crimp die for non-insulated splice connectors. These are moderately expensive, around \$120.00. No interchangeable dies as it is calibrated at the factory. The hexagonal crimp is a superior crimping method for splice connectors. For single splices 18/16/14 ga and for multiple of smaller wires.

### Rennsteig MultiCrimp Ratcheting Crimper



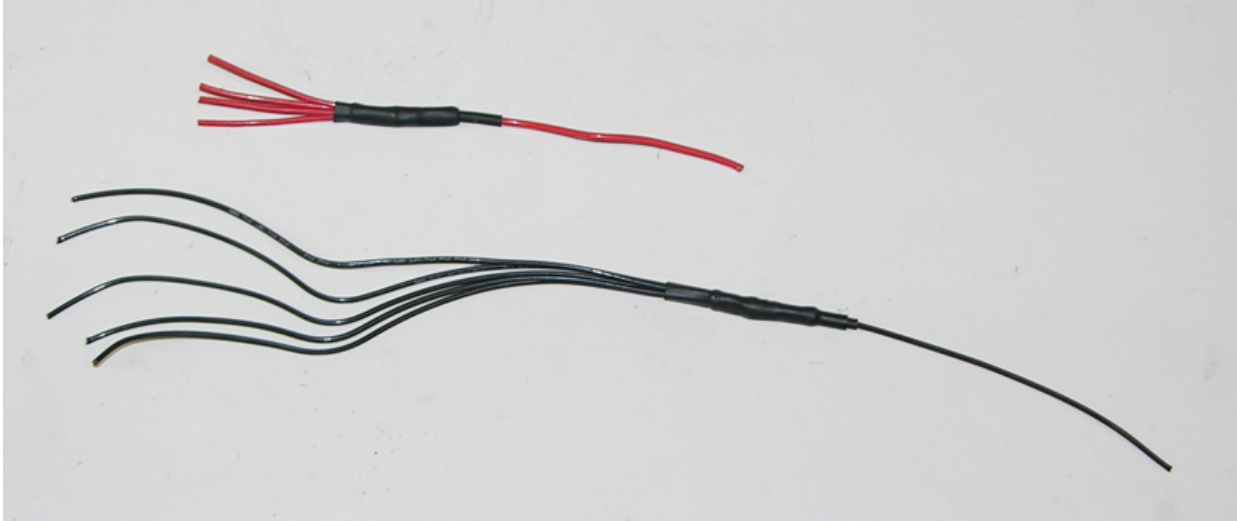
Rennsteig also has a MultiCrimp tool with interchangeable dies. About \$250.00. Fives dies are available. It normally ships with with:

- 1x (P/N 629 050 3 0 1) Die Set for Non-Insulated Plug Connectors (0.5 - 6.0 mm<sup>2</sup> | 20 - 10 AWG)
- 1x (P/N 629 060 3 0 1) Die Set for Insulated Terminals (0.5 - 6.0 mm<sup>2</sup> | 20 - 10 AWG)
- 1x (P/N 629 090 3 0 1) Die Set for End-Sleeves/Ferrules with and without Collar (0.25 - 6.0 | 24 - 10 AWG)
- 1x Tool magazine for up to 5 Die Sets

Less expensive ratcheting crimpers are available from Del City. Some aerospace items can be up in the thousands of dollars.

A good guide to crimping is in the [Molex Industrial Crimp Handbook](#). Page 18 of the Molex PDF describes the types of crimp dies.

### Splice Testing

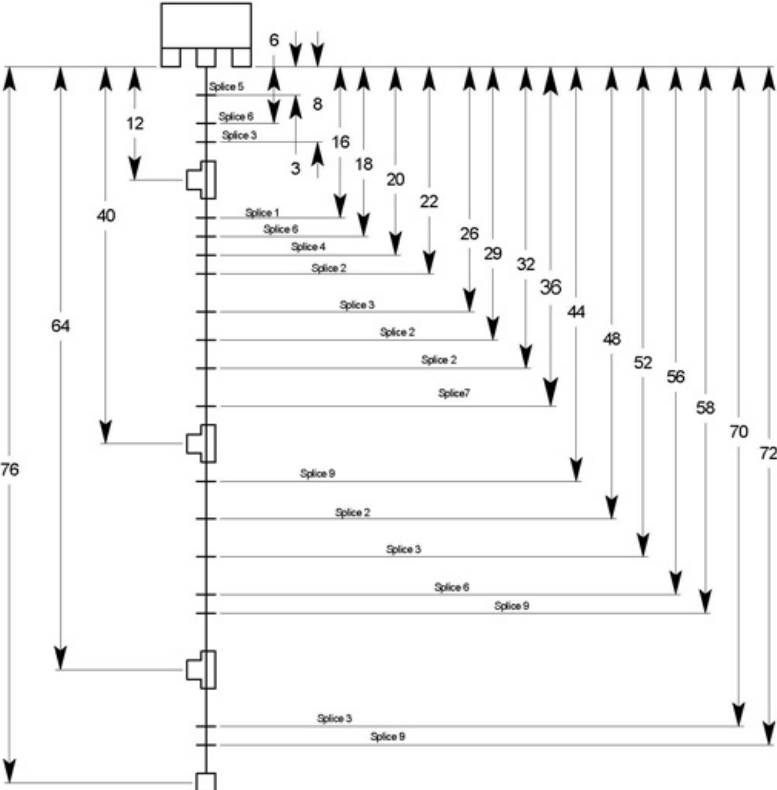


Here we have two multi-wire splices via step-down non-insulated butt connectors: (below) five 22 gauge 22759/16 black wires going into one black 22 gauge wire; and (above) four 18 gauge 22759/16 red wires going into one 16 gauge 22759/16 wire. The connections are glue shrunk. In the case of multi-wire butt splice connections we use 1/8" adhesive line shrink tube on the single wire and a larger size (3/16" or 1/4") over the entire splice. We make sample splices, in this case stripping the wires 3/8" and crimping them in the butt connector. Do not twist or solder the multiple wires together.

We don't have pull testing equipment so we simply take the test pieces and yank on the wires as hard as we can. Be careful to insure all wires are fully seated into the butt connector. Refine your crimper choice and crimp techniques until you can be assured your splices will not come apart. Not sophisticated but it works.

FYI: NASA-STD 8739.4: Minimum Tensile Strengths: 22ga 13 lb; 20ga 21 lb; 18 ga 32 lb; 16 ga 41 lb.  
 SAE AS7928: Minimum Tensile Strengths: 22ga 15 lb; 20 ga 19 lb; 18 ga 38 lb; 16ga 50 lb.

### Staggered Splices



We stagger our splices in each harness. Here we have staggered the splice joints for a Pectel SQ6M ECU. This avoids overlapping the splice points, which are sealed in adhesive shrink tubing.

### Pin and Socket Retention Testing



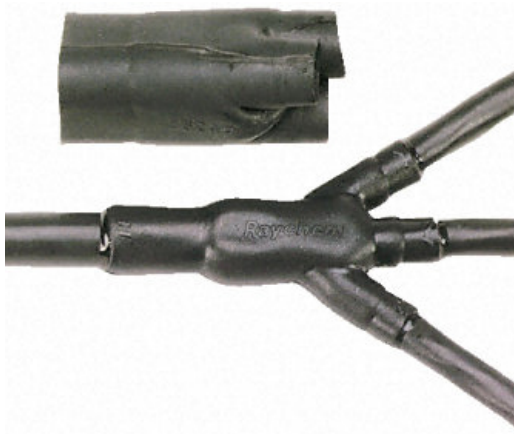
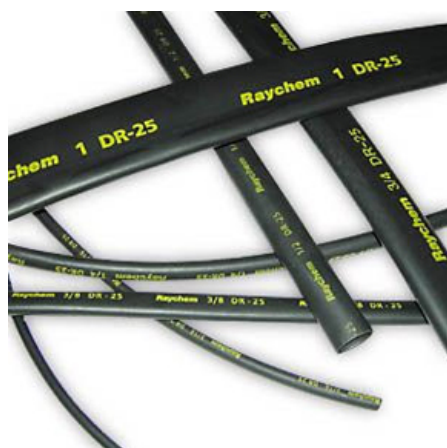
Daniels makes a [relatively inexpensive tool](#) to test retention of pins and sockets...Simply push until flush and the socket/pin is tested to about 30% of it's yield i.e. if it is actually seated.

## Pull Testing



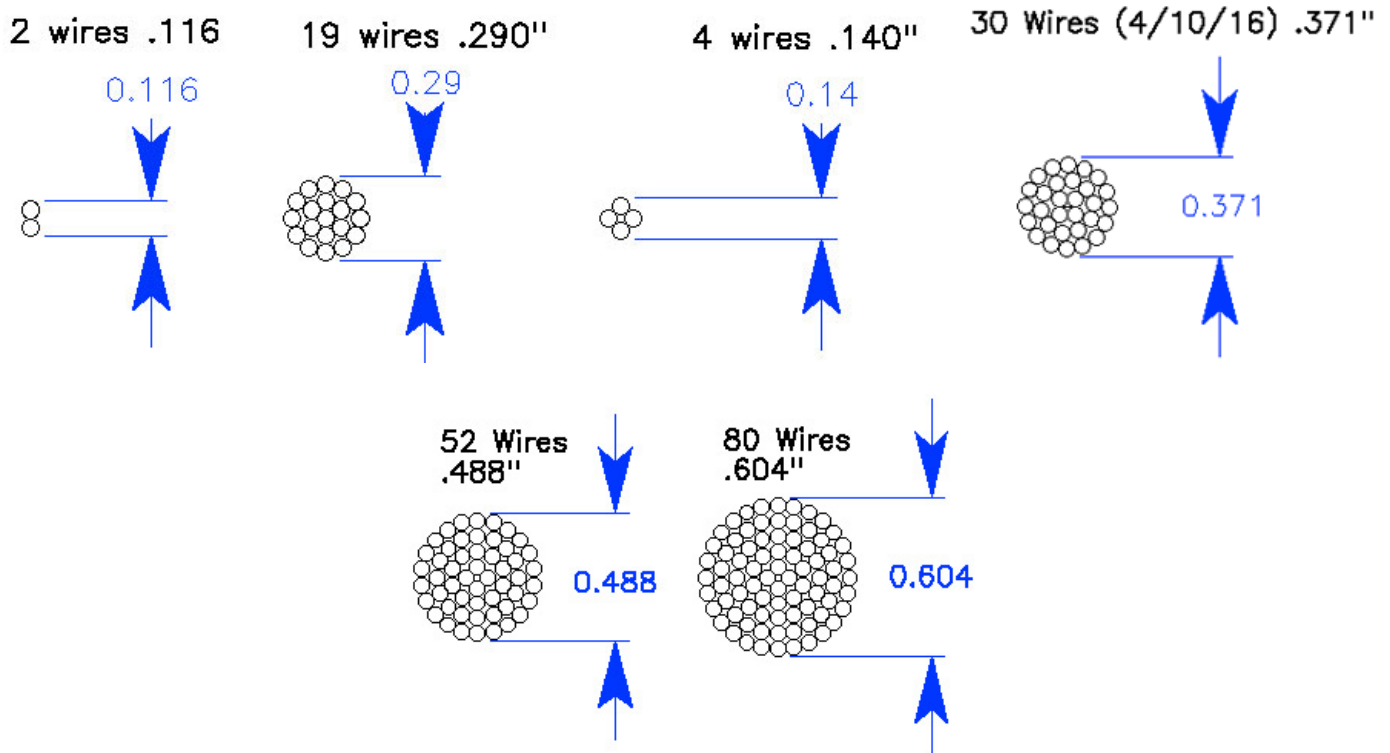
If you are a big buck operation and you need to test your crimp connection strengths you buy one of these from [Alphasron](#).

## DR-25 Heat Shrink and Molded Parts



You cover the mil-spec wire with DR-25 heat shrink and transitions are joined with Raychem or Hellerman molded parts, To seal the ends of the transitions or boots there are two options: Use adhesive lined boots (expensive) or use syringe-applied Resintech RT125 black epoxy on the

connector or the DR-25 wire cover. The shrink ratio is 2-1 or, in some versions 5-1. This environmentally seals the wires and connectors and provides a protective layer against abrasion.



To choose a size of DR-25 for your harness sections choose the largest size that will shrink firmly to your wiring cross-section diameter. In other words if your wiring bundle is 3/8" in diameter you don't use 3/8" DR-25 as it has a shrink ratio of 2:1 (.375 start to .1875 final). The above dimensions are for several diameters of 20 gauge Spec55 wires, .058" in diameter.



An alternative to DR-25 is Raceline 150 from [Whitmor Wirenetics](#). Basically the same specifications you just don't get "DR-25" printed in yellow. We all know how important labels are these days.

A second source for a less expensive alternative to Raychem DR-25 is [Deray V25](#) from [DSG-Canusa](#) which also has the same 2:1 shrink ratio as Raychem DR-25.

### Sealing DR-25 with Raychem ES2000



Semi-rigid 4-1 shrink ratio adhesive lined [Raychem ES2000](#) seals DR-25 to wires as well as serving as a strain relief for wire splices, terminals and other components.

### Heat Guns and Heat Blowers

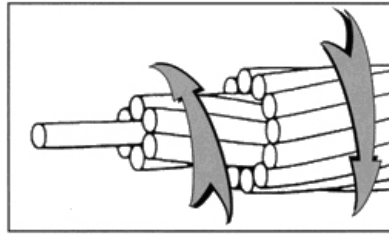


Heat Guns and Heat Blowers are different animals. The Steinel and the Snap-On to the left are Heat Guns whereas the Master Appliance pedestal mount is a Heat Blower. They all apply hot air but the Heat Guns are easier to work with, especially when dealing with Raychem Shrink Shapes and Boots as you must quickly rotate about the part to cause the controlled shrinkage. The larger Heat Blower is too unwieldy for this fine controlled shrinkage. Being able to regulate the temperature is also important.



Installing a 202K132 Raychem Boot on this Autosport Connector has to be done with a Heat Gun, not a Heat Blower. A Heat Blower will cause too quick and uncontrolled shrinkage and ruin the Boot.

## Concentric Twist Layers



### Concentric Cables

Smooth symmetrical cables can be built up about a core of more than one wire, though this is seldom done in practice.

### Wires in Concentric Cables

Number of Layers Over Core	Core of One Wire		Core of Two Wires		Core of Three Wires		Core of Four Wires	
	Wires per Layer	Total Number of Wires	Wires per Layer	Total Number of Wires	Wires per Layer	Total Number of Wires	Wires per Layer	Total Number of Wires
1	6	7	8	10	9	12	10	14
2	12	19	14	24	15	27	16	30
3	18	37	20	44	21	48	22	52
4	24	61	26	70	27	75	28	80
5	30	91	32	102	33	108	34	114
6	36	127	38	140	39	147	40	154
7	42	169	44	184	45	192	46	200

The stiffness of the harness will depend largely on how the underlying wires are arranged. The correct method is concentric twisting where successive layers are twisted in opposite directions...One wire surrounded by six wires, with each successive layer adding six additional wires i.e. 1-6-12-18. The twisting of the wires gives the harness additional flexibility and reduces strain on the wires. The above table provides some insight into the methodology.

## Tying or Lacing Wire Harnesses

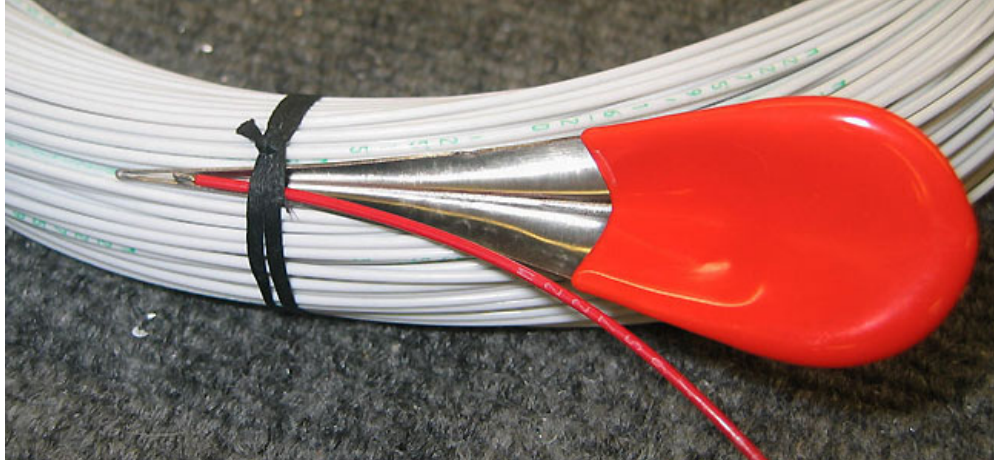


Mil-T-43435B Lacing Cord: Braided nylon lacing cord meeting specification MIL-T43435B, Type 1, Size 3, Finish B. A micro-crystalline wax with melting point above 55/ C ° 130° F and nonflaking characteristics it is compounded to develop excellent knot retention, yet not giving a waxy feel to the user. Used to tie wiring bundles together. Less bulky than plastic tie wraps which can actually cut into wires and, when cut, leave a sharp edge that can cut your hands.



Continuous loops should be tied in the above manner with continual lock stitches. Normally you just put a wrap and a square knot every 6-12".

## Wire Spoon



After you've laced your wire harness together with neat little square knots, how do you insert extra wires? The answer is a [Wire Spoon](#). Note that all the wires are white which is a normal practice in many applications. Spec 55 wire is normally available in 10 colors which makes keeping track of things much easier. Without laser-marking of each wire it can be a real chore to track down issues when all the wires are white.

For your information a typical late model Harley-Davidson Touring bike uses about 77 different wire colors (color and stripes) in its wiring harness.

## Portable Shrink Tube Thermal Printers



You can, however, label each wire with 1/8" 3:1 heat shrink labels near the terminations to keep track of things and use one color mil-spec wire. Low end heat shrink printers can be purchased way under \$100.00 or you can spend many thousands of dollars on commercial units. We label all our wires anyway, even with different colors.

BEE3+ unit from K-SUN pictured above is about as cheap as it gets. Lists for about \$250.00 but sells for about \$150.00 or less. It prints on 1/8" (single MIL-SPEC wire), 3/16", 1/4", 3/8", 1/2" and up to 3/4" wire shrink tubing. It also prints labels in widths of 1/6"(4mm), 1/4"(6mm), 3/8" (9mm) 1/2"(12mm) and 3/4"(18mm) widths. The catch is the cartridges are expensive. There is always a catch. Expendables. Oddly the 3/8" shrink tubing is only available in white.

The lower priced BEE3 unit will only print up to 3/16" shrink tubing. Best get the BEE3+.

Use either KYNAR or Tyco Raychem RT-375 clear 2:1 heat shrink over your printed labels.



The Kroy 5100 will print wire shrink tubing up to 1/2" I.D. and flat labels up to 1" in width. These are in the range of \$395.00 retail.



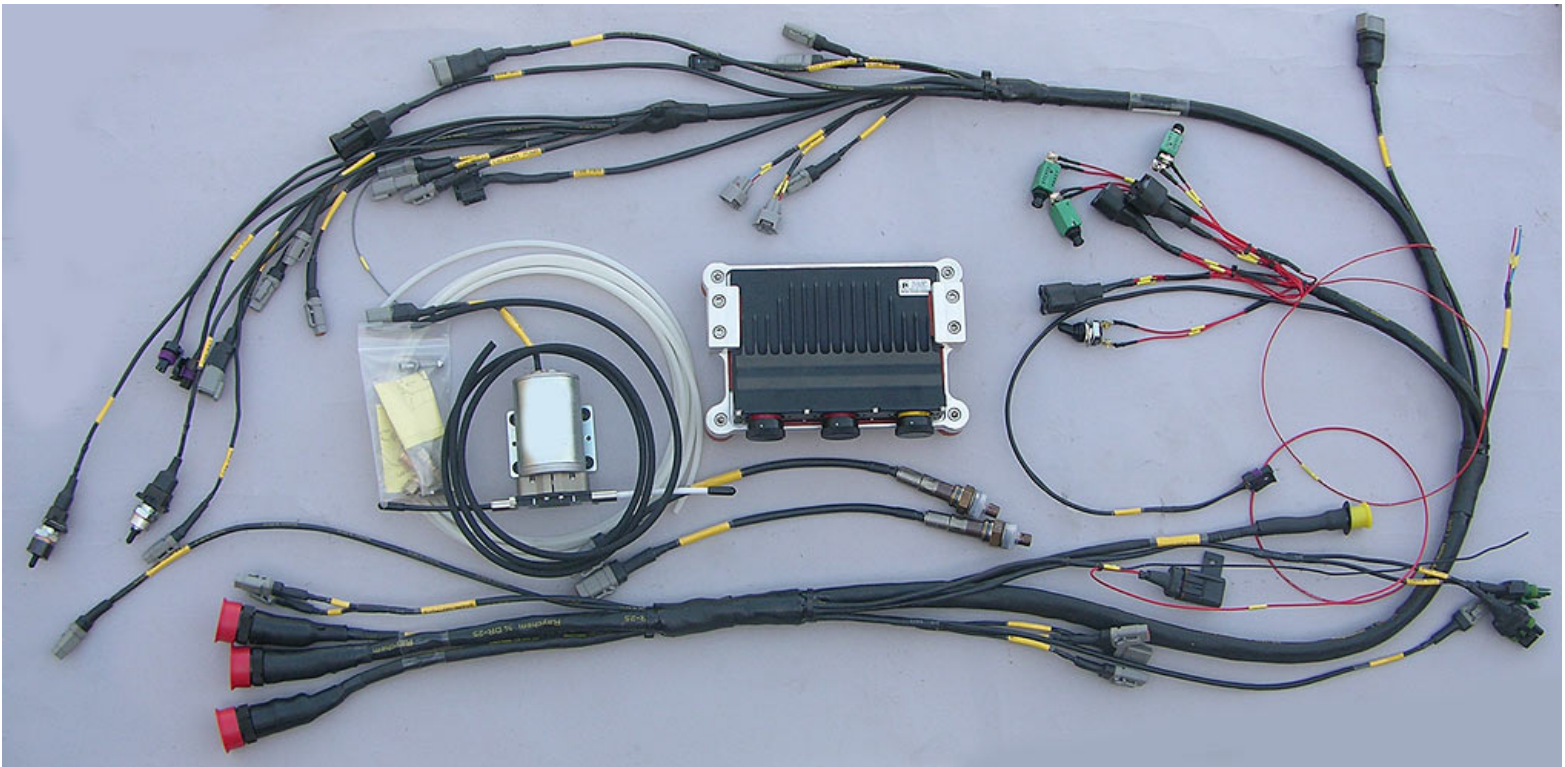
We twist the wires CW and CCW the best we can by the above format, but we always run into issues with 2-1 and 3-1 splices so we don't go the extra mile to put in dummy filler wires to get the 1-6-12-18 etc layers. We do the concentric twisting and secure the runs with Mil-T-43435B Lacing Cord. We label each wire with 1/8" yellow shrink tube covered by clear Raychem RT-375 clear shrink tubing.

We leave the exit branches about 4" longer than necessary and then trim the wires to length for the connector. You can slide the labels up and down the wire with a bit of force. Labels are necessary for us as we are constantly interrupted and brain fade sets in.

DR-25 1", 3/4", 1/2", 3/8", 1/4" and 1/8" is being used in this harness. Raychem 202A153, 202A142, 202A132 and 202A111 straight boots are being used with Resintech RT125 epoxy sealing the branches exiting the boots. Raychem ES2000-1, -2 and -3 tubing seals wires exiting the DR-25 on branch legs to sensors, circuit breakers, relays etc. Raychem ATUM is used to seal the back of connectors.



Raychem DR-25 covers the main harness and the branches. Connectors are installed and sealed. Each branch is labeled with the connector number as well as the function. Kapton tape covers exposed wires before they have Raychem boots heat shrunk. In this application we have over 50 outboard connectors to keep track of. Without documentation future issues as well as current assembly would be very difficult.



Labels on all connectors help keep track of things. Documentation is maintained on both the internal and external structure of the harness.

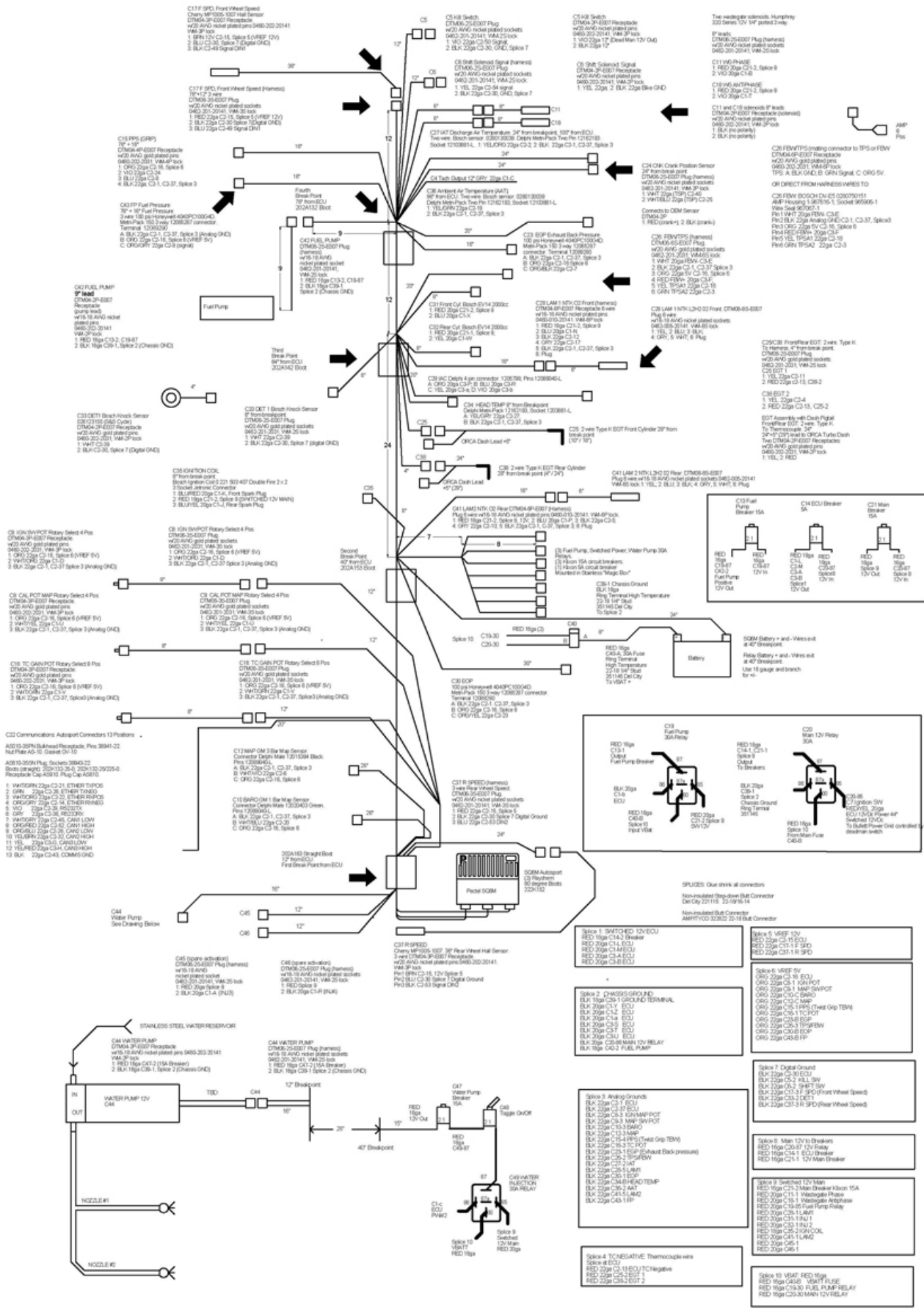
## Wire to Wire Splices



Wire to wire splices can be accomplished with [Tyco Raychem D-406](#), or Sumitube W79 adhesive lined shrink tube. Do not solder the wires together. Proper crimping is the preferred method. Alternatively, unshielded butt connectors can be used and sealed with adhesive-lined Raychem ES2000 heat shrink. Often wires will branch i.e. 1-2, 1-3 etc. and splices are necessary.

Raychem part # D-406-0001, Red in color, marked "Duraseal 18-22" pictured.

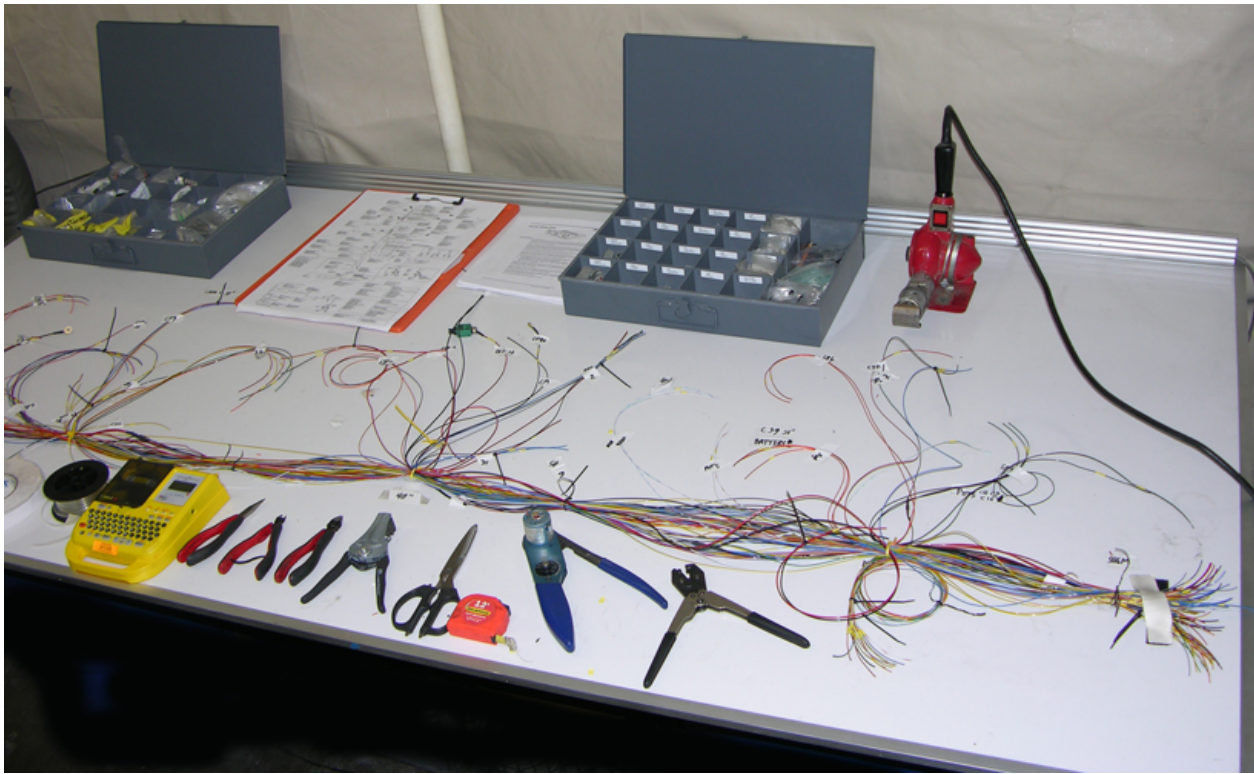
## Wire Harness Design and Initial Layout



We make an initial drawing of the wiring diagram but this will only aid in planning purposes. The actual harness has to be measured on the application with all the hardware in place. It is critical that there be no strain or interference issues and that serviceability is planned for.

Wires in this harness are MIL-22759/16 in 16/18/20 and 22 gauge. Deutsch DTM Plugs and Receptacles use a mix of gold and nickel plated pins and sockets. Deutsch Autosport Connectors are used for the [SO6M ECU](#) on this harness. Different wire colors prevent confusion and we also

label each wire. This particular harness has 49 outboard connectors. The SQ6M itself has 107 pins. In the case we are using 76 of them.



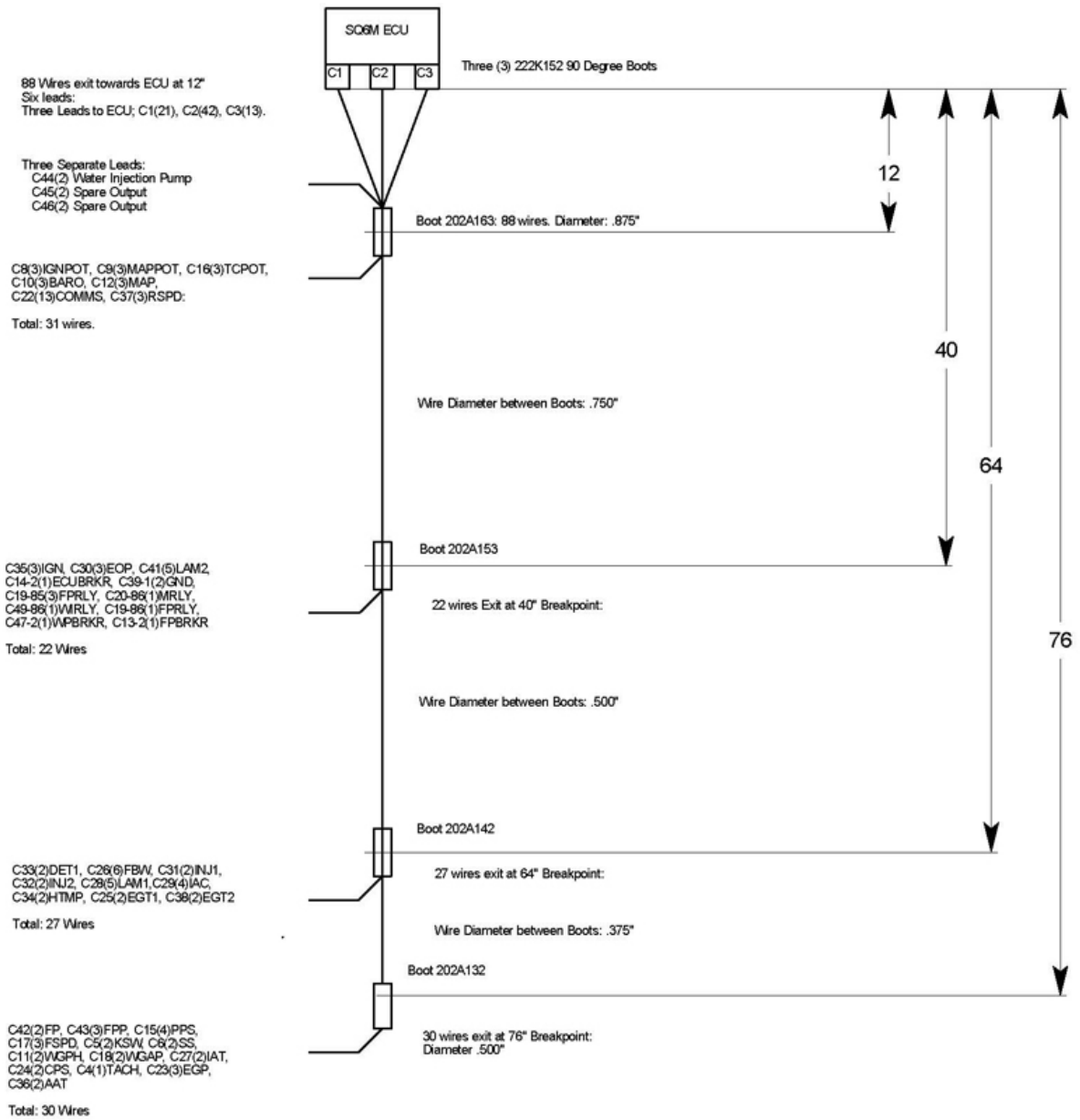
We use 4' x 8' whiteboard to layout the wiring harness. We use 3/4" adhesive tie wrap pads, plastic tie wraps, velcro, and white gaffers tape to hold the main harness and connector leads in place. The adhesive pads can be removed or relocated without damaging the boards surface.

# Wire Count & Diameters

C1: 21 wires to ECU. Diam .375". DR-25 1/2"  
 C2: 42 wires to ECU. Diam .500". DR-25 3/4"  
 C3: 13 wires to ECU. Diam .250". DR-25 3/8"

Total: 76 Wires to ECU Pins (21+42+13)

88 wires exit at 12". 76 Wires Minus/Plus 4-1; 4-2 and 2-1 splices.  
 Plus connector leads for H2O pump(2) and two spare two wire connectors (4).  
 $76+(4-1)+(4-2)+(2-1)+6 = 88$  wires



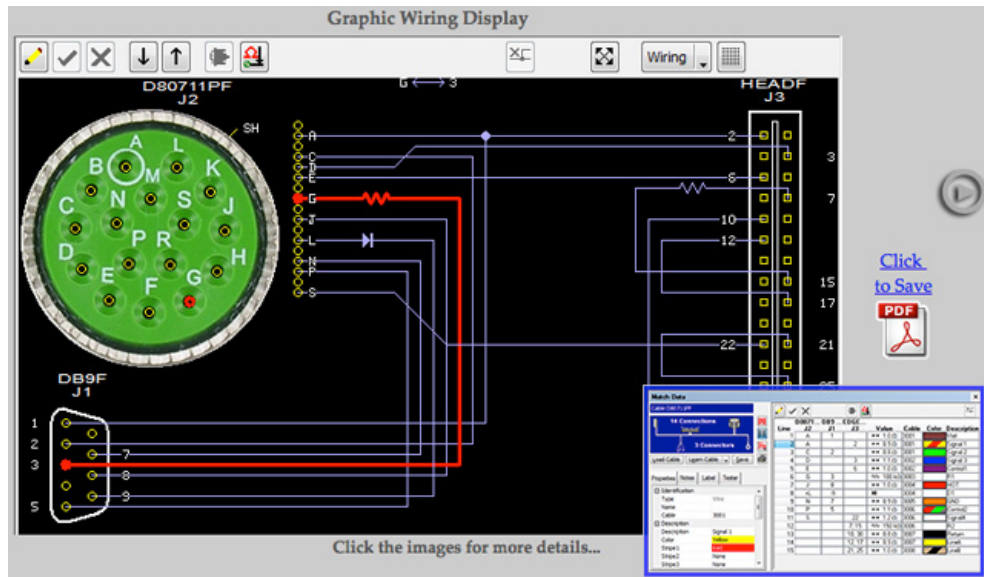
For planning purposes we determine which and how many wires exit the harness at each break point and also the diameter of the runs between the break points. Wire bundle diameter is important in choosing the correct diameter of DR-25 shrink tubing. 88 wires exit towards the SQ6M in this case with three separate leads going to each of the Deutsch Autosport connectors.

## Hi-Pot Testing



Hi-Pot testing is used in aerospace and high-end motorsports wiring houses to verify wiring harness integrity. Any poor connection, nick in wiring insulation, or short can be isolated and fixed. Simple continuity checks are OK but are not foolproof.

The hipot test is a nondestructive test that determines the adequacy of electrical insulation for the normally occurring over voltage transient. This is a high-voltage test that is applied to all devices for a specific time in order to ensure that the insulation is not marginal. [An explanation of Hi-Pot testing is offered by Cirris.](#) Cirris H2 and 1100H+ pictured.



Hi-Pot CableEye testers from [CAMI Research](#). PC based i.e. software driven Hi-Pot testing makes isolating things a lot easier.

## Wideband Sensor Wiring



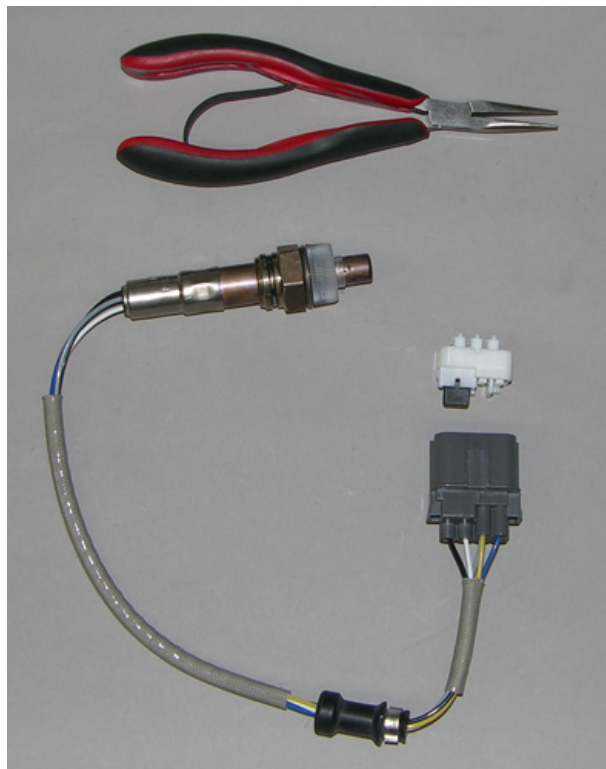
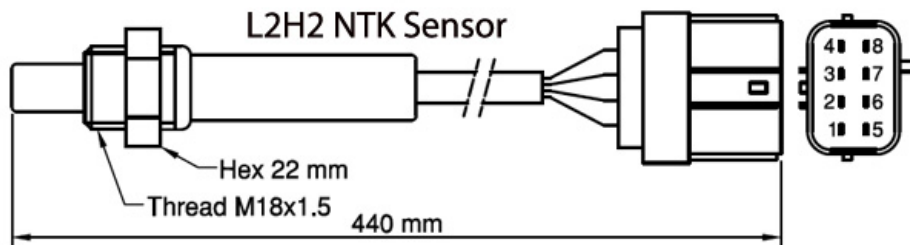
The Bosch LSU-4.2 (left) or the NTK (right) wideband sensors are typically married with six position Deutsch DTM connectors. In that they are five wire sensors the sixth position uses a seal plug. LSU 4.9 is the newest version and is not compatible with 4.2 electronics. Wiring colors for the different sensors is as follows:

**Bosch LSU-4.2 Typical DTM positions:** DTM Terminal 1, Red Wire, WB\_Pump; DTM Terminal 2, Black Wire, WB\_Cell; DTM Terminal 3, Yellow Wire, WB\_Com; DTM Terminal 4, White wire, WB\_Htr-; DTM Terminal 5, Gray wire, WB Htr+; DTM Terminal 6, seal plug.

**Bosch LSU-4.9 Typical DTM positions:**DTM Terminal 1, Red Wire, Pumping Current; DTM Terminal 2, Yellow Wire, Virtual Ground; DTM Terminal 3, White, Heater Minus (H-); DTM Terminal 4, Grey wire, Heater VBat (H+); DTM Terminal 5, Green wire, Trim Current; DTM Terminal 6, Black Wire, Nernst Voltage. [LSU-4.9 Data](#).

**NTK L1H1 Wire Colors:** Yellow Wire: Heater -; Blue: Heater Wire +; Black: Signal Ground; Grey: Nernst Cell Voltage; White: Ion Pump Current.

**NTK L2H2 Wire Colors (8 pin Sumitomo H90 Connector):** Pin1: Yellow Heater Wire -; Pin 2: Blue: Heater Wire +; Pin 3: Rc (cal resistor); Pin 4: Rc 0V; Pin 5: NC; Pin 6: Grey Wire Vs; Pin 7: White Wire Ion Pump; Pin 8: Black Wire Sensor 0V.

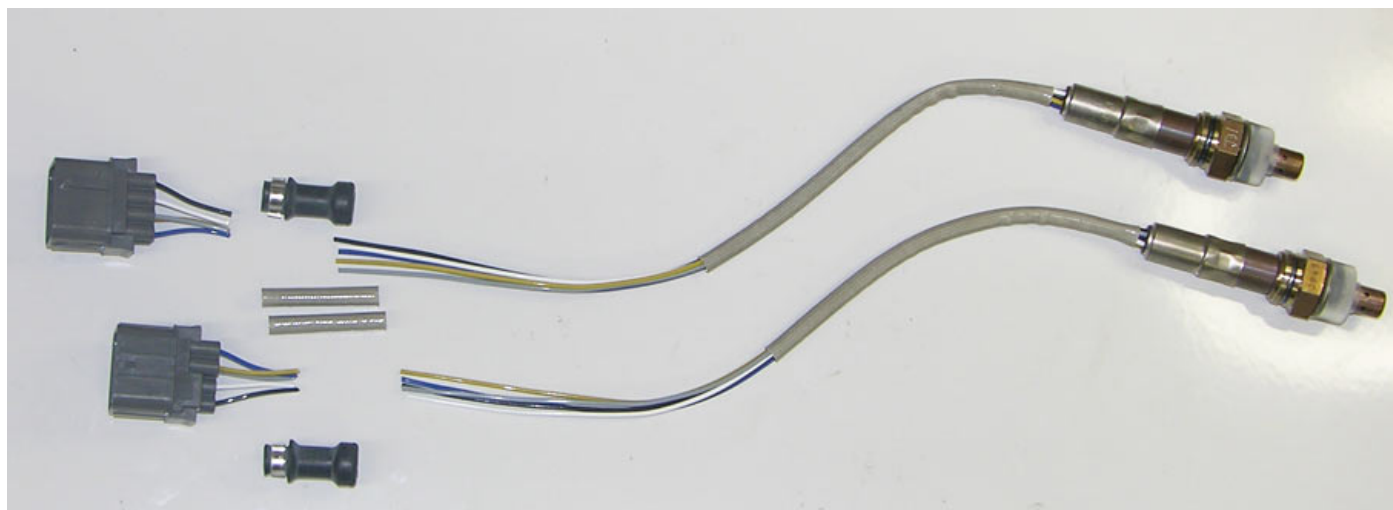


L2H2 Cal Resistor shown above between pins 3-4 which is read by oem application or devices like Motec PLM. These are individual to each

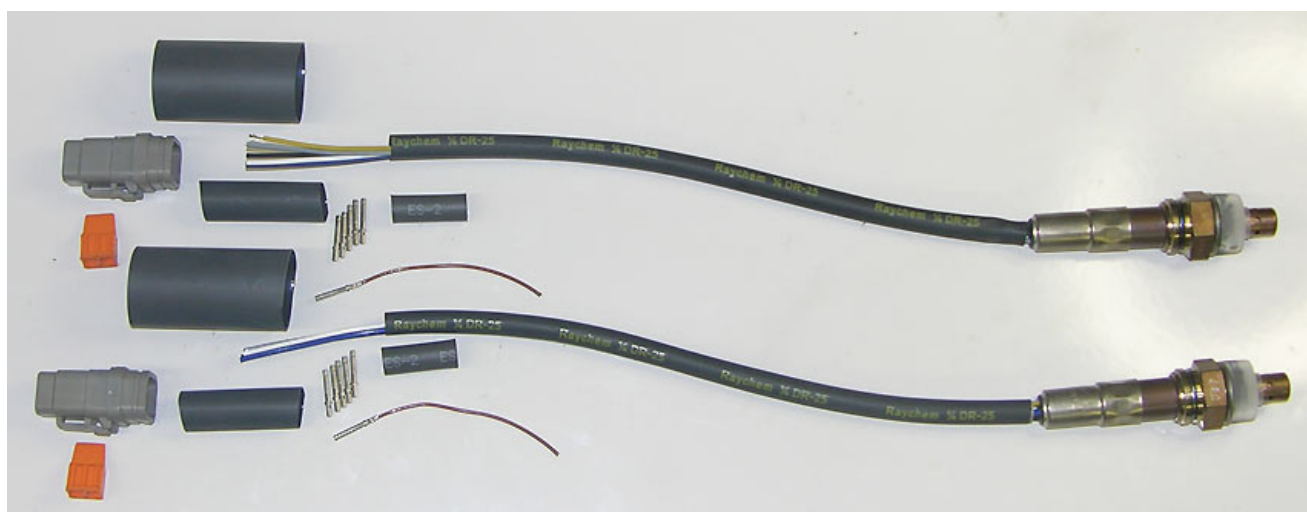
sensor. High end ecus like the [Pectel SQ6M](#) we use do not use a Cal Resistor.

In general NTK sensors are higher temperature rated. We use them pre-turbo with pressure compensation tables as under rich conditions they show richer under boost pressure and leaner in lean conditions under boost pressure. Pectel SQ6 / SQ6M controllers are designed for the NTK L2H2 sensors. NTK sensors are tolerant of leaded fuels whereas Bosch LSU-4.9 are not. Connectors for the L2H2 LZA-09-E1 sensors are available from [Ballenger Motorsports](#).

## NTK L2H2 LZA-09-E1 Sensors



Cut and remove connector with calibration resistor. Leave longer silicone heat sheath.



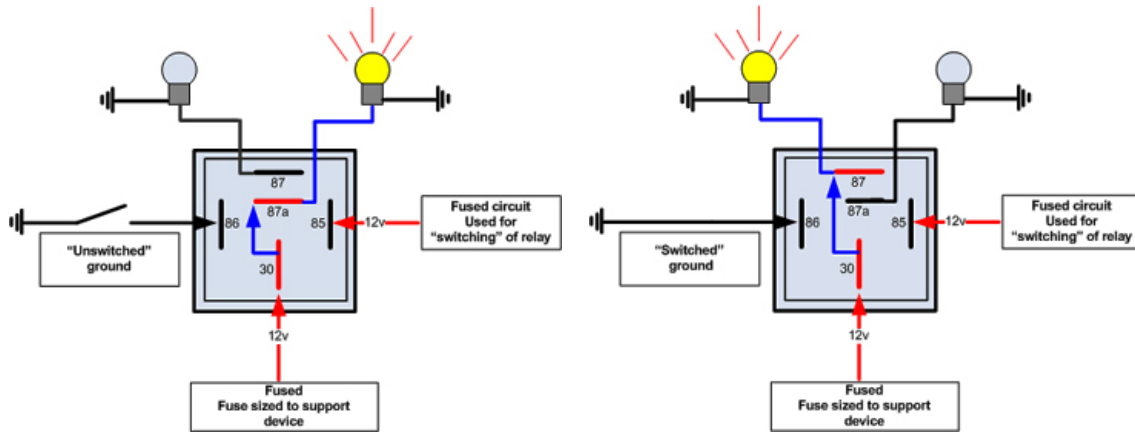
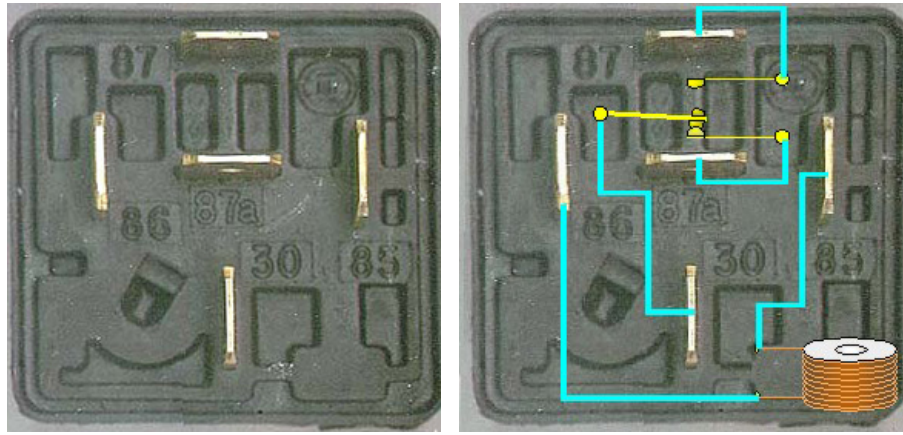
Cover wires with 1/4" DR-25 overlapping the long NTK silicone heat sheath. Heat shrink the DR-25 and seal both ends with 1" ES2000-1.



Heat shrink 11mm label and seal with RT375 clear. Slip over 1.5" ATUM 12-3. Strip wires, crimp pins or sockets and insert these in the connector. Filler wire with pin or socket for the unused pin 6. Heat shrink the ATUM 12-3. Slip 2" ATUM 24-6 over the sensor and heat shrink to the DTM six position connector.

When mounting the NGK/NTK wideband lambda sesor pre-turbo you need to create pressure compensation tables in your ECU. We made a [Backpressure Lambda Calculator](#) that shows how lambda reading are skewed under exhaust backpressure.

## Automotive 30A Relays



We use Hella or Bosch 30 Amp relays in our wiring harnesses. This is a pictorial reference as to how they work.

## Corrosion Protection



At the Bonneville Salt Flats the salt air and salt eats everything. Internal cavities in relays turn into green gardens. Starter relays and switches die sooner or later. Cadmium plated hardware corrodes quickly. Battery terminals and any metal exposed that isn't stainless or chrome plated begins its ugly descent to mother earth from whence it came. [Boeshield T-9](#) is the best thing we've found to protect metal surfaces. WD-40 seems to disappear after a time. This stuff stays.

## Literature

[Raychem Spec 55 Wire](#) (XLTFE Polymer) The standard for high end motorsports wiring.

[Mil-STD-861 Color Codes](#) For Mil-Spec Wiring. 100 possible combinations. 10 colors are normally available.

## Master Catalog Raychem Heatshrink Products

[Raychem Heatshrink Products](#) Covers everything including tubing, all molded shapes (with dimensions), tools, and materials

## Wire Covering

[DR-25 Heat Shrink](#) Used to cover ETFE wires in wiring harnesses. Has a 2-1 shrink ratio. Single Wall. Motorsports std.

[DSG-Canusa Deray V25](#) a less expensive alternative to DR-25

[Raychem RT-375](#) Clear heat shrink tubing. Use to cover your yellow/black wire heat shrink labels.

[Kynar Clear Heat Shrink](#) Tubing to cover wire and cable heat shrink labels.

## Adhesive-Lined Shrink Tubing

[Raychem ES2000](#) Adhesive heat shrink. Semi Rigid 4-1 shrink ratio. Sealing wire transitions. Strain relief.

[Tyco\\_RBK\\_Dual Wall](#) Adhesive heat shrink. Used to seal wire transitions and connectors. Less flexible than ATUM. Strain relief.

[Raychem SCL Heat Shrink](#) Used to seal shapes like switches and relays in lieu of specific "boot". Adhesive lined. 2.5:1 shrink ratio.



[Tyco ATUM semi-flexible](#) Adhesive-lined heat shrink. Sealing Boots and transitions and shapes. 3-1 and 4-1 shrink ratio available. Here a three wire Cherry Hall Sensor has 1/4" DR-25, Resintech RT125 epoxy sealing the DR-25 ends, and 16mm ATUM semi-flexible adhesive shrunk to the assembly. Available in small quantities from suppliers like Mouser. Last digit is Color Code. Black is "0" (Zero).

3-1 Shrink Ratio: Diam in mm	4-1 Shrink Ratio: Diam in mm
ATUM-3/1-0	ATUM-4/1-0
ATUM-6/2-0	ATUM-8/2-0
ATUM-9/3-0	ATUM-12/3-0
ATUM-12/4-0	ATUM-16/4-0
ATUM-19/6-0	ATUM-24/6-0
ATUM-24/8-0	ATUM-32/8-0
ATUM-40/13-0	ATUM-52/13-0

[DSG-Canusa CDR](#) Adhesive lined shrink tube. 4:1 shrink ratio. Semi-rigid. More rigid than Tyco ATUM. Splice covering.

[DSG-Canusa CPA](#) Adhesive lined shrink tube. 3:1 shrink ratio. Connector sealing.

## Molded Parts

[Raychem Heatshrink Products](#) Covers everything including tubing, all molded shapes (with dimensions), tools, and materials

[Raychem Molded Parts](#) Heat Shrinkable, adhesive-lined, for wiring harness transitions and connectors.

[Hellermann-Tyton Molded Shapes](#), Heat shrinkable up to 5-1 ratio shapes for transition and connector sealing.

[Resintech RT125](#) Wiring Harness Epoxy.

## Wire Stripping

[Tyco Wire Stripping Guide](#)

[Teledyne Stripall Thermal Stripper](#)

[Ideal Wire Processing \(Stripper\) Catalog](#)

## Motorsport Connectors

[Deutsch Autosport \(connectors\) Catalog](#)

[Deutsch DTM Series Connectors \(thermoplastic\)](#)

[Sureseal Rubber Connector](#)

## Circuit Breakers

[ETA 483 Circuit Breaker](#)

[Tyco W23 Circuit Breaker](#)

[Klixon 2TC14 Circuit Breaker](#)

## Standards

[NAVAIR Aircraft Electrical and Electronic Wiring](#) (Over 1000 pages) 12.8 Mb. Lots of mil-spec reference #'s, data and techniques.

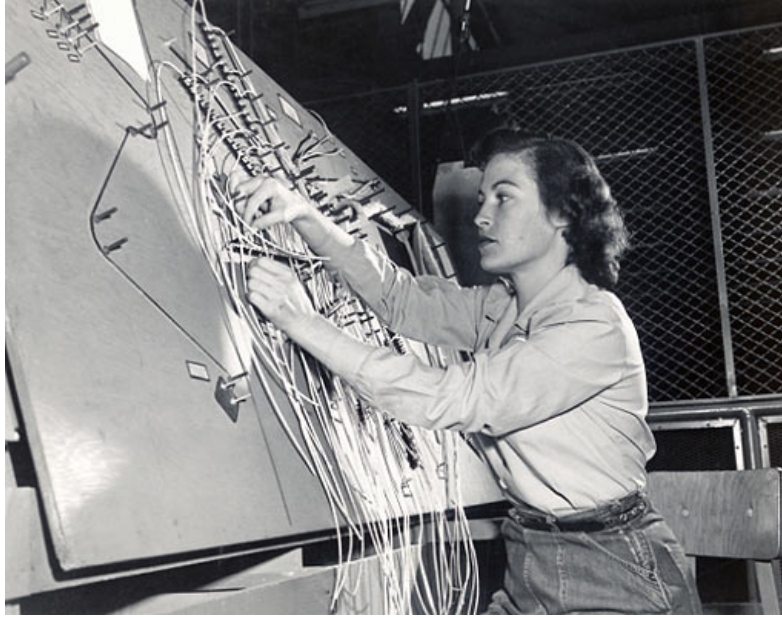
[Wire Harness Lacing Techniques](#)

[NASA wiring and Harness Standards](#)

[IP Protection Ratings Chart](#) Explains "IP" or Ingress Protection ratings of connectors from water, dust, etc..Not a military specification.

## WWII Wiring Harnesses





In WWII we were cranking out bombers and fighter aircraft faster than they could be shot down. Extremely high crew losses were backed up by a system of production and training not seen since. Women were a major part of the work force and kicked butt. After the war their jobs were taken away from them. There went 50% of the talent.



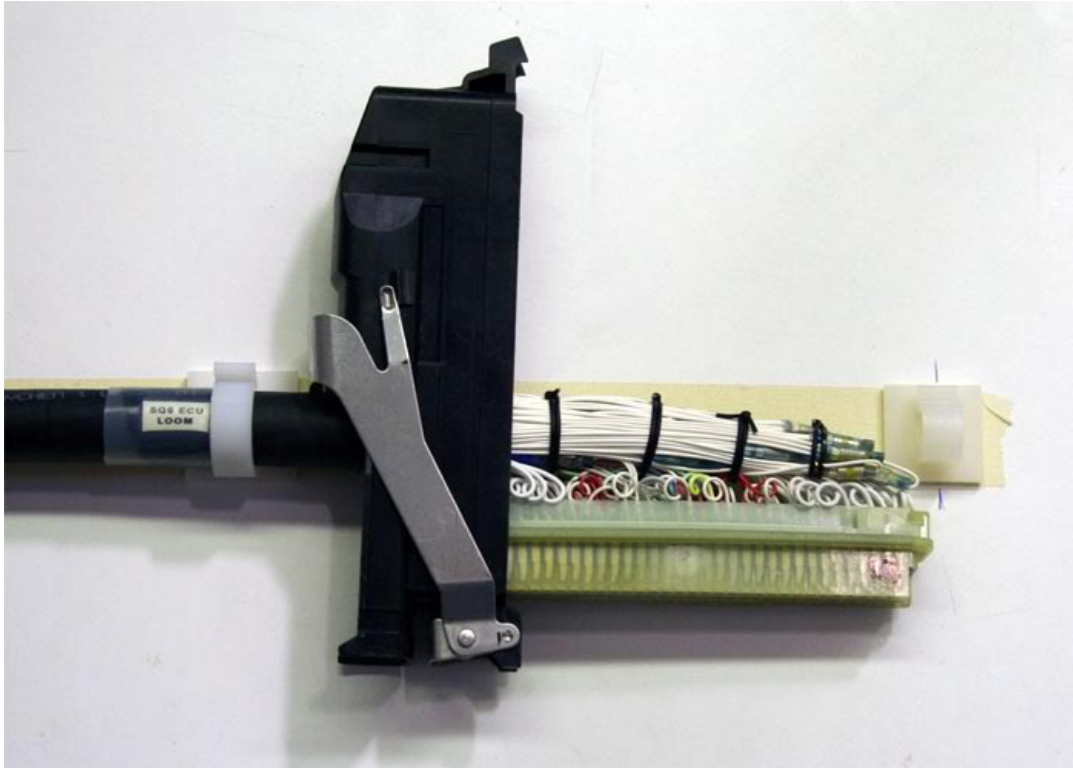
Women did much of the WWII aero wiring. These days you see men or "blokes" doing the motorsport wiring (See video below). We have no doubt women are better at it.

## F1 Wiring



[Renvale Ltd.](#) (Formerly Tony James Wiring) in the United Kingdom is a specialist in high end motorsports wiring. [This is a video](#) of their work for the now defunct USA F1 Team. Let's hope they got paid.

## Motorsports Wiring Example



Here we have an 88-way Cosworth Pectel SQ6 connector with service loops twisted just before the connector sockets. Follow the construction of a [Cosworth Pectel SQ6 Wiring Harness](#)

It requires a lot of money, time and supplies. In this case all the wires are all white in color...This makes servicing things down the road as well as construction much more difficult.

An excellent source for your wiring supplies for you go it alone types is [Prowire](#) as they stock about everything you need and sell in small quantities. It a good place to pick up your MIL-W-22759/16 wire and supplies. They have 140 Mil-Spec wire color combinations in stock. Quick service and excellent prices.

## Costs: A Reality Check



The simple fact is that a professional motorsports wiring harness costs a lot of money. Unless it is some kind of production item, which it never is, these are going to be expensive whether you like it or not and a rule of thumb is that it is going to cost as much as your engine controller of choice and most likely more. One of the people we know typically spends about 200 man hours designing and fabricating a custom wiring harness. Another person we know used to wire high end off the road racing vehicles where the total wiring bill was often North of \$25,000.00 for parts and labor and he did not want to do it anymore as it was tough getting paid for the work, not to mention all the travel and fighting clients.

It's the old adage "Time is Money". Add up all the hours in planning, ordering and stocking parts, buying tooling, plus the actual fabrication and write yourself a fat check...Or let someone else do it. Letting someone else do it implies there is a solid design template or that person is going to have access to the project where it can be planned and executed in place. Sometimes it's best to pay and get on with your life.

We do our own harnesses as we have our projects in-house and don't like running around. Definitely not cost effective though.

wire harness design - prototyping & production - hi-pot testing services - complete vehicle wiring

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[Sakata Motorsport](#) has been making Mil-Spec Motorsports wiring harnesses on a contract basis for a long time. There are many others but you can research these out.

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