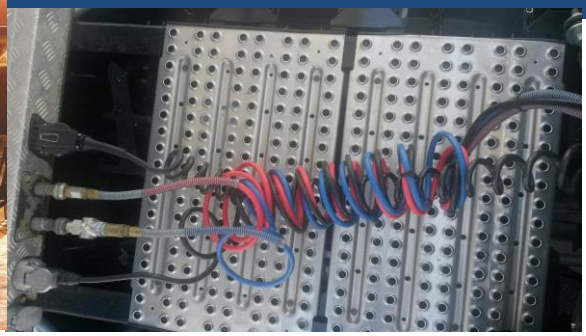
Heavy vehicle electrical wiring

Technical Advisory Procedure



Developed by the ATA Industry Technical Council
September 2015

About this Technical Advisory Procedure (TAP):

This Technical Advisory Procedure is published by the Australian Trucking Association Ltd (ATA) to promote good design and maintenance practices for electrical systems on heavy vehicles. It aims to do this by identifying important issues, design practices and by providing reliable electrical information. The TAP places particular emphasis on good practice for achieving adequate voltage levels on combination vehicles because lighting and other electrical loads on Australia's long combinations places significant stress on the electrical system. The Technical Advisory Procedure has been drafted to apply to a range of truck and trailer combinations. It is not, nor is it intended to be, complete or without exceptions.

The Technical Advisory Procedure is a guide only and its use is entirely voluntary. Recommendations or procedures may not be suitable for or applicable to all operators. Operators should consider their own circumstances, practices and procedures when using this Technical Advisory Procedure.

Operators must comply with the Australian Design Rules (ADRs), the Australian Vehicle Standards Regulations, roadworthiness guidelines and any specific information and instructions provided by manufacturers in relation to the vehicle systems and components.

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Introduction

This Technical Advisory Procedure (TAP) has been developed by the ATA Industry Technical Council (ITC) to provide operators with key information regarding the electrical wiring system of a heavy combination vehicle to set minimum wiring standards and awareness of issue around the wiring and connected components.

Reliability and satisfactory performance of truck and trailer electrical system performance mainly depends upon good design and maintenance practices being applied.

A satisfactory system will:

- provide adequate voltage at the loads
- carry the full load current with some reserve capacity
- be protected by fuses or circuit breakers so that short-circuit on wiring at any point will not result in burnt wiring
- operate reliably over the full range of practical temperatures
- have adequate moisture, corrosion and mechanical protection.

The prevalence of long combination vehicles on Australian roads causes significant challenges for electrical designs to meet these objectives. Such vehicles have long cable runs, substantial electrical current draw and multiple interconnection points. It is also common practice to use 12V electrical systems on trailers and to fit additional side and rear lights above statutory requirements.

This TAP covers truck and trailer wiring and connector practice to assist vehicle operators and designers assess the suitability of proposed designs.

The aspects that are considered are:

- electrical performance of truck charging systems
- voltage distribution on heavy combination vehicles
- current draw and load at connectors
- suitable choice of wiring gauge
- maintenance of connectors

Because 12V electrical systems have higher load currents than 24V systems when other factors are equal, the challenge to provide adequate voltage for trailer lighting on 12V trailer systems is greater. The guide is therefore focused on 12V electrical systems, unless otherwise noted.

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1. Towing motor vehicle voltage capability

The alternator on the towing motor vehicle is usually set to provide about 14V for charging. This allows for voltage losses through the truck wiring, allowing the batteries to usually experience 13.0-13.5V for charging. The alternator provides the load current when its voltage exceeds that of the batteries. Figure 1 is an illustration of a truck charging system with wire ground and chassis ground return.

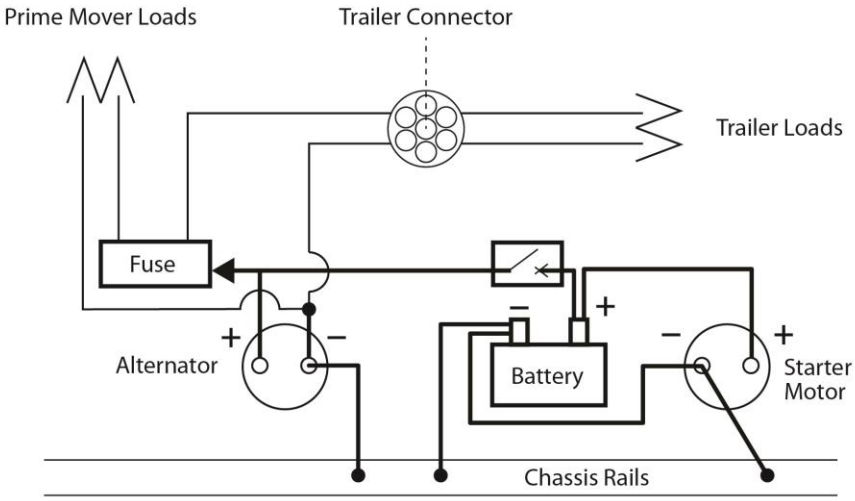


Figure 1: Basic truck wiring schematic

a.) Alternator regulation

The alternator regulator attempts to hold the alternator terminal voltage at the set level (typically 14.2V for vented lead acid batteries and 14.6V for maintenance free lead acid batteries). Under heavy load, the regulator may reach its limiting capability and voltage will fall substantially as current increases. Voltage will also vary with temperature depending on the regulator circuit design.

The open-circuit voltage curve of a fully charged vented lead-acid truck battery is shown in Figure 2, together with a typical alternator regulator characteristic. If battery charging is to occur, the alternator voltage must exceed the battery voltage. An adequately designed charging system will have the alternator providing the load current with a reserve that is available to trickle charge the battery. The design should achieve this when the engine is running at mid-range speed and at the usual working temperatures of the alternator and batteries.

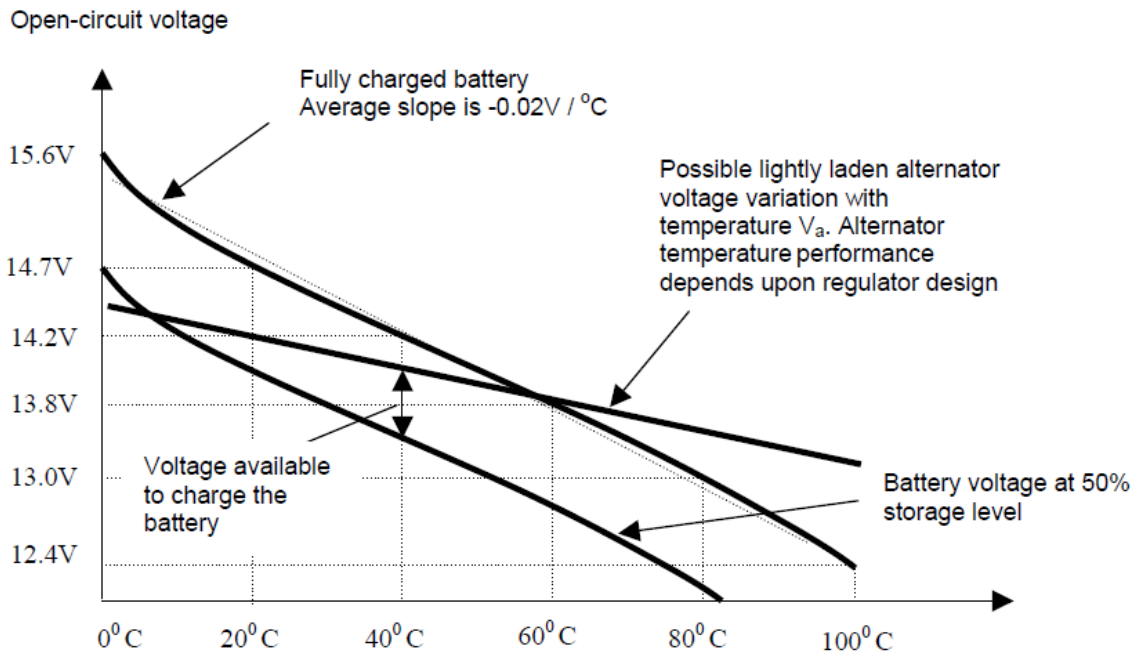


Figure 2: Temperature variation of fully charged vented lead acid battery (12V) and alternator voltage with temperature. Source:- Dr P. Hart, Hartwood Consulting Pty Ltd.

When the battery is not fully charged the battery voltage falls. As a guide, the open-circuit battery voltage drops by about 5 per cent between fully charged and half charged, so a battery with half energy density at 40°C will have a voltage of about 13.5V. This is shown in Figure 2. If the alternator voltage exceeds the battery voltage, battery charging will occur.

Figure 2 also shows that the battery and alternator have different thermal sensitivities. The alternator is invariably in the engine compartment. When delivering current, it typically runs at 50-70°C and higher temperatures can occur. The batteries are typically located in a detached box that experiences lower temperatures than the engine compartment. It is common for the battery temperature to be 40°C below that of the alternator. Such a temperature difference reduces the alternator's ability to adequately charge the batteries and provide the load current.

b.) Battery performance

Battery voltage and alternator voltage will also drop with current level. The battery has internal resistance with two components:

- plate resistance and
- electrolyte resistance from current flow through the electrolyte.

The electrolyte resistance dominates when the battery is discharged, and so the terminal voltage fall is greater for a given current when the battery is discharged than when fully charged. The battery resistance and the state of discharge determine the charge level for a given charging voltage. When the battery charge level falls off, the electrolyte resistance increases, which further limits the ability of the battery to deliver starter motor current.

When the battery is overcharged, the lead-acid charge storage action stops and the current flow goes into heating the electrolyte. The electrolyte resistance increases, as does the battery temperature.

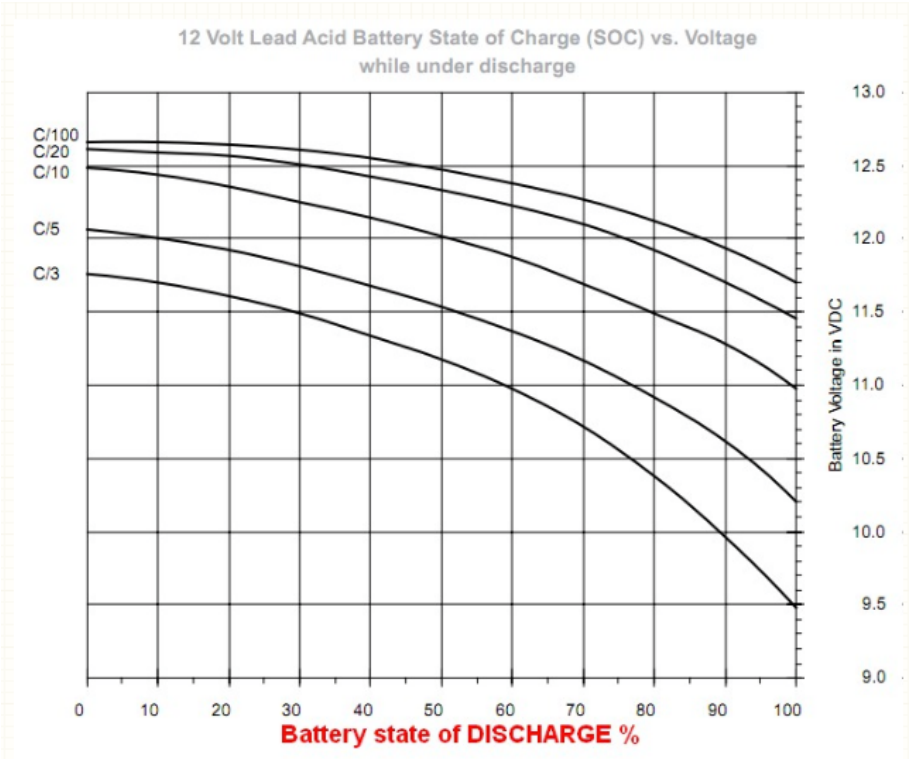


Figure 3: Battery condition as a function of discharge rate.[1]

Understanding figure 3, C/100 means it takes 100 h to discharge the battery. A higher current (e,g C/5) will discharge the battery faster. The faster the discharge, the more energy is wasted. With the battery 75% discharged, at low current draw (C/100), the available voltage is only 12.2V. This drops considerably for higher current draws, for example during starting when low voltage can be an issue for the ECU, preventing starting.

European manufactured alternators may require connection of an excitation wire to the D+ terminal. This requires an incandescent low-wattage globe to be connected between ignition and D+. The globe usually doubles as the alternator charge warning light. If the globe fails the alternator will not charge.

A new class of lead acid battery referred to as Absorbed Glass Mat (AGM) is being used by some OEM's for their benefits of superior starting power, high reserve capacity and long lasting life. They can be a direct replacement for flooded lead acid batteries, but cannot be mixed with other types and are sensitive to charging. The charging voltage should never exceed 14.8V.

c.) Starting performance

Recent practice has been to use 12V starter motors on high capacity engines. Previously, a series-parallel switch was used that fed 24V to the starter motor. Considering the continuing increase in engine power levels and the high compression ratios being used, reliable starting using 12V is challenging.

Some manufacturers use dual starter motor positive cables to reduce starting resistance. Take care to ensure that the cables do not rub on other metal features in the vicinity of the starter motor. Fires can result.

[1] The chart has been used with permission from Cadex Electronics Inc on behalf of **www.batteryuniversity.com**

Good practice is to:

- Use cables with generous copper cross-section. 90 mm^2 copper cross section or greater should be used on 12V start systems.
- Minimise the length of the cable run.
- Minimise the number of terminals and joins in the cable run.
- Run a return cable between the starter and the battery – wire ground return. Additionally, separate chassis connections at the battery and starter motor will lessen the return path voltage drop – frame or chassis ground return.
- Keep the terminal connections tight and protect them with an electrical grease to stop corrosion.

d.) Taking 12V loads off 24V battery systems

24V battery systems have two 12V batteries connected in series. When 12V loads are fitted it is tempting to take the 12V off one of the two batteries in series. This practice inevitably leads to battery failure even when the loads are small such as radio loads. If one battery in a 24V system is loaded more heavily than the second battery in the chain, the charging system causes the lightly laden battery to be over-charged and the more heavily laden battery to be undercharged. Eventually one or both batteries will fail.

Alternatively, using a charge equaliser is another approach to power 12V loads off a 24V battery system. A charge equaliser allows for a 12V supply to be provided while maintaining an equal voltage and therefore charge across the two 12V batteries.

e.) Prime mover voltage performance

Voltage at points away from the alternator fall off under load due to:

- wiring resistances.
- internal battery voltage drops.
- contact voltage losses through relays and switches.
- alternator and battery voltage drop as temperature increases.

Truck alternators are typically driven at three to four times the engine speed. Alternators do not charge until a sufficient engine speed is reached. This speed may be greater than idle speed. Once this is achieved the alternator may continue to charge when the engine speed falls back to idle. For applications involving long idling periods, the alternator charging speed should be met at idle by suitable choice of drive ratio.

It is good practice to relay the trailer lighting circuit so that the load currents flow directly from the battery box to the trailer connector and not go via the cabin. The cabin wiring need only provide the control for the lighting relays. Use of generous wire gauge will also help. 5 mm^2 copper stranded cable will give adequate performance.

The voltage available at the trailer coupling when the alternator is charging the batteries and the electrical load should be in the range 13-13.5V. When the electrical load is higher such as at night with the heater fan motors running and lighting, the available voltage is likely to be in the range 12-12.5V.

All load current on trailers returns via the return pole on the truck-trailer connector. In contrast the towing-vehicle load return currents usually return via both wire and chassis metal paths.

f.) Short-circuit protection of power cables

Usual practice is that the starter motor cables have no circuit breaker protection. That is, the heavy power cables run between the battery positive terminal and starter motor power terminal without circuit breaker protection. Because the starter motor current draw can be thousands of amperes, it is impractical to provide circuit breaker protection.

Starter motor cables should be double insulated and the terminals should be insulated to provide protection against a short-circuit.

Power cables that provide supply for the electrical loads other than starter motor should be protected by circuit breakers. The current load for a multiple trailer combination might be 100 to 150A. Circuit breakers capable of supplying this level are readily available.

It is preferable that a circuit breaker is provided in the battery box to protect the power cables that run to the cabin and other electrical distribution points.

g.) Summary

- The no-load alternator voltage of a truck is usually set to about 14.2V. For maintenance free batteries the setting may be higher at 14.6V.
- For battery charging to occur the alternator voltage must exceed the battery voltage.
- Alternators may not generate sufficient charging voltage until alternator speed is greater than about 2,000 rpm.
- Truck batteries are usually located away from the engine compartment where they experience lower temperatures than the alternator. A loss of charging voltage arises because of the different temperature sensitivities of batteries and alternator.
- Voltage drops along the wiring between the batteries and the trailer connector can be significant. To minimise these it is sensible to have relay controls near the trailer connector and not to run the heavy trailer currents via the cabin. The cabin wiring provides relay control only.
- Generous wire gauge running to the trailer connector will lessen voltage drops.
- Never connect 12V loads to one battery of a 24V system that has two 12V batteries connected in series. Use a voltage reducer or charge equaliser instead.
- A well-designed system should achieve 12V measured at the trailer connector on the lighting circuit with lights on and with the truck at operating temperature.

2. Light characteristics

a.) Incandescent light bulbs

Usual practice is to use incandescent bulbs (12V) in trailer lights. The percentage light output from a 21W incandescent auto globe varies with voltage as shown in Figure 3. The nominal globe resistance at 12V is 6.9Ω. As the voltage rises the globe resistance also rises so that percentage current drawn by the globe varies as shown in Figure 3.

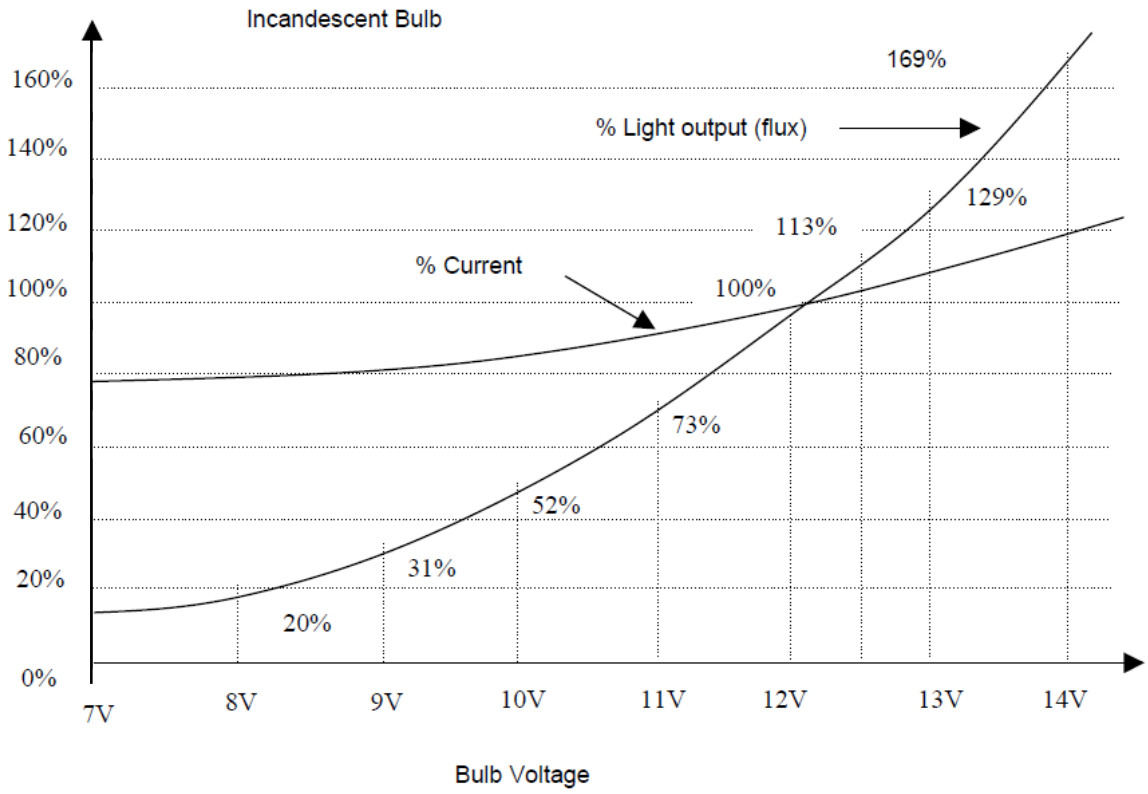


Figure 3: Variation of light output from a 21W incandescent globe as voltage varies. Assumed ambient temperature is 20°C. Source: Dr P. Hart, Hartwood Consulting Pty Ltd.

b.) Light Emitting Diodes (LEDs)

The application of LED lamps has grown and they are now available for all positions on the trailer. They offer many benefits – reliability, durability with typically reduced current draw, and for recently released lamps, flexibility of voltage from 9V to 33V.

Other less well known benefits include fast illumination of LEDs at 0.159 of a second quicker than incandescent lamps. This is equivalent of 4.4 metres at 100 km/h, and may mean the difference between a rear-end crash and a near miss.

As a guide an LED lamp of the same brightness of an incandescent lamp is likely to draw less than 10% of the total current. Table 1 provides examples.

Lamp type	Current draw for incandescent at rated voltage (amps)	Current draw for LEDs (amps)
Clearance	1.3	0.1
Stop	4.2	1.0
Tail	1.2	0.2
Turn	4.2	1.0

Table 1: Comparison of current for incandescent lamps versus LEDs

LED lamps can vary between suppliers and models. A true regulated multi-volt LED product can seamlessly handle 9 to 33V with stable light output, meeting the ADR candela requirements without dimming.

The market is, however, faced with unregulated LED products that claim multi-volt capability but do not meet the required light output under ADR when voltage drops. The light output of these can perform similarly to the incandescent bulbs.

Although not all LED products are equal, they will all typically offer improvements in reliability over incandescent bulbs. ADR compliance of a partially failed LED lamp is an issue; it is generally not defined as to when an LED lamp becomes non-complying to the ADR when individual elements or segments are non-functioning.

From a current draw point of view, the truck voltage drop figures in section 6 should be applied to LEDs as a conservative approach to wire sizing. The voltage drops / current draw are still relevant for unregulated LEDs, while for incandescent lamps they are significantly more consistent across brands and models. Therefore, the wiring guide can assumed to be appropriate for both LEDs and incandescent lamps.

c.) Summary

- The light output of an incandescent globe falls off rapidly with reducing voltage. With 10V at the globe terminals the light level is about 50 percent of that with 12V.
- In contrast to incandescent lighting, regulated LED lighting can maintain light output levels irrespective of voltage over the design voltage range of the lamp.
- Despite this, follow the wiring guide recommendation for incandescent lamps at all times, in case unregulated LEDs are fitted. These can have higher current demands than regulated LEDs.

3. Automotive electrical cable characteristics

The electrical resistance and stranding characteristics of heavy truck wiring are detailed in Table 2. The data is cable manufacturers' data for commonly used cabling on original equipment manufacturer installations. Replacement market or after-market cables having the same common description as those described below may have a smaller copper cross-section. To avoid issues, compare the wire's cross sectional area in mm^2 to ensure they are like for like.

Nominal cable copper cross sectional area (mm^2)	Common electrician terminology (nominal OD in mm)	Stranding	Resistance per metre (Ω/m)	Maximum current V105 cable (Amps)	De-rated current (de-rating 143%) (Amps)
1.25 mm^2	3 mm	16 x 0.32	0.0140	10	7.0
2.0 mm^2	4 mm	26 x 0.32	0.0087	15	11.0
3.0 mm^2	5 mm	41 x 0.32	0.0054	25	17.5
5.0 mm^2	6 mm	65 x 0.32	0.0034	38	27.0
8.0 mm^2	8 mm	112 x 0.32	0.0024	80	56.0

Table 2. Electrical details of common auto wire sizes

a.) CAN bus and ABS/EBS wire sizing

Controller Area Network (CAN bus) in a truck is similar to the blue ethernet cable connecting computers together in the office or home. Modern trucks have multiple computers or Electronic Control Units (ECUs) – engine, transmissions, body computers, doors, instrument panel are all linked together via the CAN bus to manage the function and controls of the vehicle.

CAN bus wiring stands out by usually being a white/green with a white/brown as a twisted pair cable set, to protect the signal from radio interference, of only 1 mm^2 cross section.

CAN bus wiring should never be cut or spliced, as this will cause system issues. The CAN harness will provide legs with resistor plugs insert into the terminal pack to allow for additional equipment to interface with the network.

Voltage drop across CAN bus wiring is an issue in longer vehicle combinations often requiring CAN bus repeaters to be used to support second and subsequent trailers in a combination.

b.) Summary

- Stranded copper cable is usually used on truck electrical systems.
- 1 mm^2 cross-sections are often used for CAN bus communications.
- 0.85 and 1.25 mm^2 cross-sections are often used for control functions.
- 1.25, 2.0 and 3.0 mm^2 cross-sections are often used for light loads.
- 5.0 and 8.0 mm^2 cables may be used for heavy loads.

4. Descriptions of common trailer wiring gauges

Table 3 show common trailer cabling configurations. The use of a heavier gauge return wire accounts for the common return of the load circuits in this conductor. Some poor quality trailer cables (and connectors) have the return circuit of the same gauge as the load circuits. The loop resistance is the sum of the resistances of one delivery core and the return core per metre length.

Description	**Cores** (with copper cross sectional area)	**Loop resistance per m** (from Table 1)	**Trailer cable loop resistance** (assume 5 mΩ contact resistance [1])
Light duty wiring	1 x 3 mm^2 & 6 x 2 mm^2	14.1 mΩ	90.5 mΩ
Medium duty wiring	1 x 5 mm^2 & 6 x 3 mm^2	8.8 mΩ	64.0 mΩ
Heavy duty wiring	1 x 8 mm^2 & 6 x 5 mm^2	5.8 mΩ	49.0 mΩ

Table 3: Details of the wiring used in the calculation of truck voltages

Note
[1] The trailer cable resistances are based upon a cable length of 5 m and 5 mΩ per contact.

ADR63/00 - Trailers designed for use in road trains dictates that:

- Main line supply cables, other than feeder wires to the lamps, must have a DC resistance of not more than 4 mΩ/metre or in the case of copper cables must have a cross-sectional area not less than 5 mm^2.
- Every trailer must be equipped with a return electrical conductor have a minimum cross-sectional area of 5 mm^2, independent of the mechanical metal coupling components.

ADR64/00 - Heavy goods vehicles designed for use in road trains and B-doubles, dictates that:

- Be fitted with a lighting supply system having a minimum capacity available for connection to the trailers of 30 amps for a nominal 12V system or 15 amps for a nominal 24V system.
- The interconnection between the vehicle parts must be through a “single connector for trailer lighting and signalling circuits”.
- Be fitted with resettable circuit breakers for all lighting and signalling equipment circuits.
- Be equipped with a generator having a minimum rated power output capacity of 100 amps for a nominal 12V electrical systems or 50 amps for a 24V electrical systems.

Within the ADRs, road trains are defined as covering all multi trailer combinations (having more than 1 trailer) other than B-Doubles which are treated as a special case.

ADR63/00 dictates the minimum at 5 mm^2, which is often necessary to counter the impact of the long loops used on multi trailer combination such as road trains. The minimum recommended wiring gauge for a road train or multi trailer combination is heavy duty.

Note: ADRs are amended from time to time and the most up to date information can be found https://infrastructure.gov.au/roads/motor/design/index.aspx

c.) Summary

- The circuit length on the trailer is much greater than on the prime mover, the choice of wiring gauge for trailer circuits is very important. Substantial voltage losses may occur on the trailer.
- Trailer cable gauge is often too light for the current level and excess voltage drops often occur across the trailer cable.
- Minimum trailer wiring gauge that meets ADR63/00 requirements for road train service is 5 mm^2.
- Heavy duty wire gauge is recommended for all multi trailer applications.

5. Truck/trailer wiring plugs

a) Heavy duty 7-pin trailer connector, Australia Standard AS4735 for lights and power.

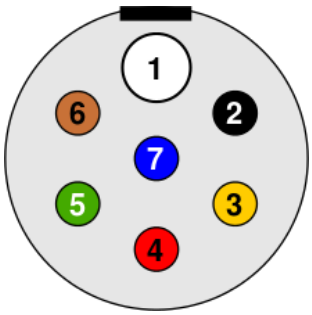


Figure 4: Plug viewed from the towing vehicle side

This connector is based on both SAE J560 and ISO 1185 and is providing either 12V with 7 x 40A or 24V with 7 x 20A.

The voltage varies from vehicle to vehicle.

Pin No:	Wire Function	Wire Specification	Wire Colour
1	Ground (-)V	8 mm^2	White
2	Clearance lamps/outline marker lamps, side marker lamps, identification lamps	3 mm^2	Black
3	Left turn signal	3 mm^2	Yellow
4	Stop lamps	5 mm^2	Red
5	Right turn signal	3 mm^2	Green
6	Tail lamps, registration plate lamp	3 mm^2	Brown
7	Reversing lamps or (+)V via ignition lock	5 mm^2	Blue

Table 4: Wiring guide for HD trailer connector

Note: The ISO plug is also available with a ground receptacle rather than a pin. This can be used as an accessories plug with no risk of incorrect interconnection.

Do not use ‘Anderson plugs’ for truck-trailer power connections. These plugs are intended for fork-lift charging and do not have suitable mechanical protection for wiring on moving vehicles.

b) Heavy duty 7-pin Australian trailer connector for lights and power.

Figure 5: Plug viewed from the towing vehicle side

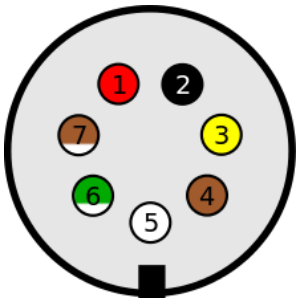
Australia uses basically the same wiring as the ISO standard with the exception for pin 5 and pin 2. The problematic part here is that pin 5 is used for trailer brakes, which means that if you for some reason connect an Australian trailer to a towing vehicle with ISO wiring you will get into trouble with the trailer brakes being applied as soon as you turn on the lights.

Pin No:	Wire Function	Wire Specification	Wire Colour
1	Left turn signal	2 mm^2	Yellow
2	Reversing signal	2 mm^2	Black
3	(-)V ground connected to chassis	3 mm^2	White
4	Right turn signal	2 mm^2	Green
5	Service brake	2 mm^2	Blue
6	Stop lamps	2 mm^2	Red
7	Tail , clearance, outline marker and registration plate lamps	2 mm^2	Brown

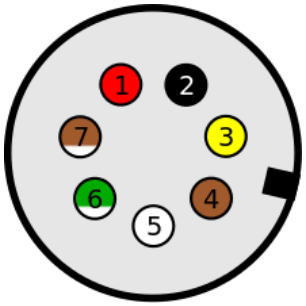
Table 5: Wiring guide for HD Australian trailer connector

Note:
The light-duty seven-pin trailer connector is not recommended. Use the heavy-duty connector instead.

a.) ABS and EBS trailer plug/wiring



24V plug, key at 6 o'clock position



12V plug, key at 3 o'clock

Figure 6: Plug viewed from the towing vehicle side

Note with the ABS plug, pins 6 and 7 are usually not included and certainly not active.

Pin No:	Wire Function	Wire Specification	Wire Colour
1	Battery (+)V	4 mm^2 (preferably 6 mm^2)	Red
2	Ignition (+)V	1.5 mm^2	Black
3	Earth (-)V	1.5 mm^2	Yellow
4	Earth (-)V	4 mm^2 (preferably 6 mm^2)	Brown
5	Warn Lamp	1.5 mm^2	White
6	CAN Hi Communications	1.0 mm^2	White and Green, twisted pair
7	CAN Low Communications	1.0 mm^2	White and Brown, twisted pair

Table 6: Wiring guide for ABS/TEBS trailer connectors

Note: There are multi volt trailer ABS/EBS cables available. These are not recommended! In preference, trailers should be equipped with both 12V and 24V sockets, which would then enable them to support the use of either pure 12V or pure 24V cables.
The issue is that multi-volt Trailers Electronic Brake System (TEBS) units, for trailer stability control, support multi-volt CAN sign and power supply, but not mixed 12V / 24V sources. For further information on smart braking systems, refer to the RSC and ESC systems TAP.

For multi volt TEBS units	EBS Communications	ABS / load sensing functionality	RSC functionality
12V power / 12V CAN signal	YES	YES	YES
24V power / 24V CAN signal	YES	YES	YES
12V power / 24V CAN signal	NO	YES	NO
24V power / 12V CAN signal	NO	YES	NO
12V or 24V power / no CAN signal	NO	YES	YES

Table 7: Impact of mix and matching power and CAN signal format

6. Trailer voltage and current distributions

Based on the relationship between voltage and light output given in figure 3, the light output at the rear of the last trailer for each considered vehicle configuration has been calculated and is given in table 14. The voltage distribution on the side marker/rear position lights circuit has been calculated using the cable resistance values in tables 1 and 2 and the lamp current levels indicated in figure 7.

It has been assumed that the towing vehicle can provide 12.5V at the trailer coupling for a single trailer, 12.25V for a double trailer vehicle and 12.0V for a triple trailer vehicle.

For each of the following examples, incandescent lamps are used.

a.) Semi-trailer voltage distribution

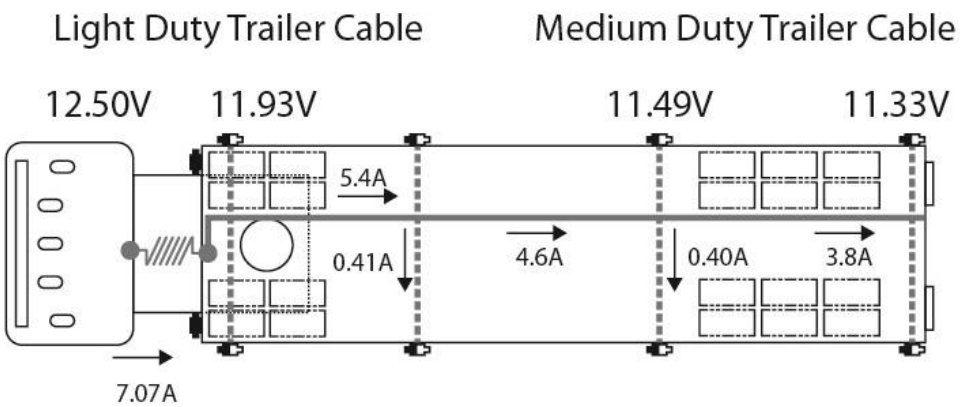


Figure 7: Semi-trailer voltage distribution – acceptable installation.

Light positions	Semi-trailer bulb quantity & wattage
Rear position	4 * 5W
Stop	4 * 21W
Directional indicator	4 * 21W
Number plate	4 * 5W

Table 8: Light bulb position and wattage

b.) B-Double voltage distribution

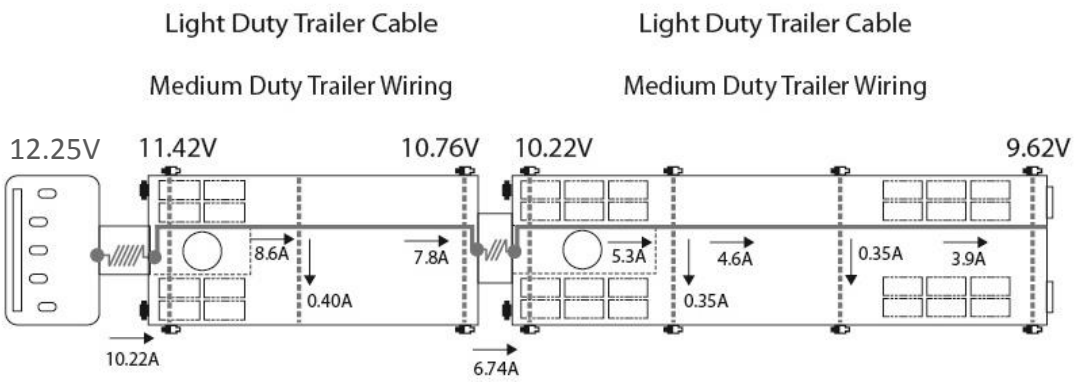


Figure 8a: Light duty trailer cables and medium duty wiring on both trailers - Not an acceptable installation.

Light positions	A-trailer, single tail lamp setup bulb quantity & wattage	B-trailer, dual tail lamp setup bulb quantity & wattage
Rear position	2 * 5W	4 * 5W
Stop	2 * 21W	4 * 21W
Directional indicator	2 * 21W	4 * 21W
Number plate	1 * 5W	1 * 5W

Table 10: Light bulb position and wattage

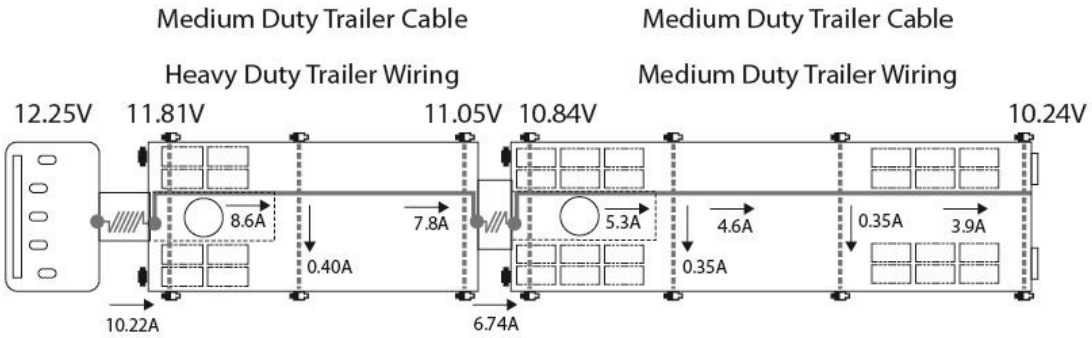


Figure 8b: Medium duty trailer cables and heavy duty wiring on the A-trailer - Marginally acceptable installation, consider upgrading the B-trailer wiring to heavy duty!

Light positions	A-trailer, Single tail lamp setup Bulb quantity & wattage	B-trailer, Dual tail lamp setup Bulb quantity & wattage
Rear position	2 * 5W	4 * 5W
Stop	2 * 21W	4 * 21W
Directional indicator	2 * 21W	4 * 21W
Number plate	1 * 5W	1 * 5W

Table 9: Light bulb position and wattage

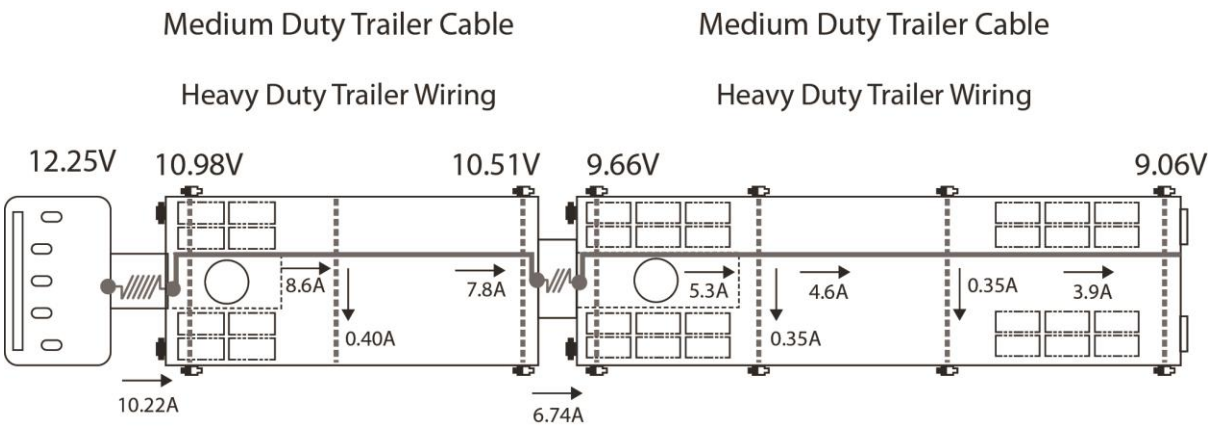


Figure 8c: As for figure 8a) but with connector pole resistance of 20 mΩ -
Not acceptable installation.

Light positions	A-trailer, single tail lamp setup bulb quantity & wattage	B-trailer, dual tail lamp setup bulb quantity & wattage
Rear position	2 * 5W	4 * 5W
Stop	2 * 21W	4 * 21W
Directional indicator	2 * 21W	4 * 21W
Number plate	1 * 5W	1 * 5W

Table 11: Light bulb position and wattage

c.) Voltage distributions for two and three road train configurations

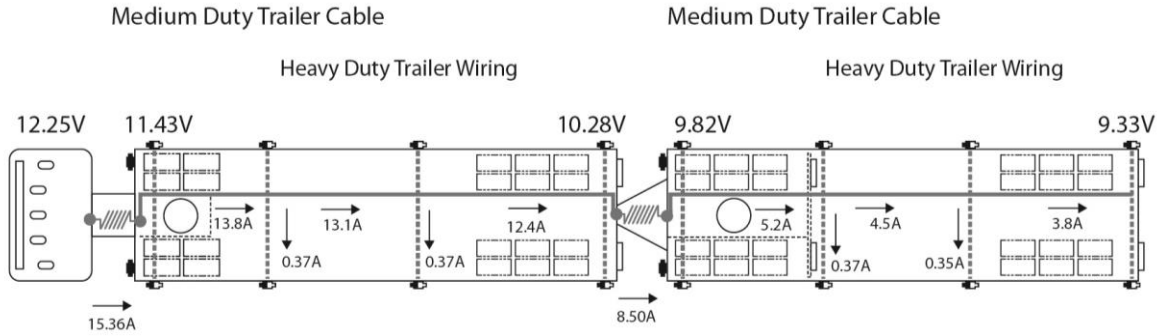


Figure 9a: Double road train with heavy-duty cables -
Marginally acceptable installation, lamps should upgrade to regulated LEDs.

Light positions	A-trailer, single TL setup bulb quantity & wattage	Dolly trailer, dual TL setup bulb quantity & wattage	B-trailer, dual TL setup bulb quantity & wattage
Rear position	8 * 5W	4 * 5W	4 * 5W
Stop	4 * 21W	2 * 21W	4 * 21W
Directional indicator	4 * 21W	2 * 21W	4 * 21W
Number plate	1 * 5W	1 * 5W	1 * 5W
End Outline Marker	2 * 5W		

Table 12: Light bulb position and wattage

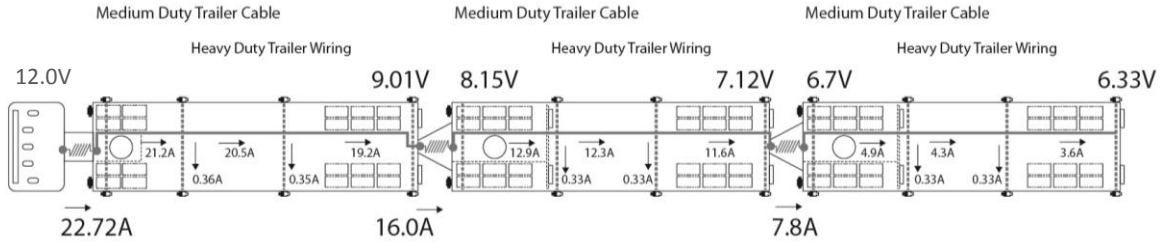


Figure 9b: Triple road train with medium duty cables and heavy duty trailer wiring
Not an acceptable installation, lamps must upgrade to regulated LEDs.

Light positions	Semi trailer, dual TL setup bulb quantity & wattage	Semi trailer, dual TL setup bulb quantity & wattage	Semi trailer, dual TL setup bulb quantity & wattage
Rear position	8 * 5W	4 * 5W	4 * 5W
Stop	4 * 21W	2 * 21W	4 * 21W
Directional indicator	4 * 21W	2 * 21W	4 * 21W
Number plate	1 * 5W	1 * 5W	1 * 5W
End Outline Marker	2 * 5W		

Light positions	Dolly trailer, single TL setup bulb quantity & wattage	Dolly trailer, dual TL setup bulb quantity & wattage
Rear position	4 * 5W	4 * 5W
Stop	2 * 21W	2 * 21W
Directional indicator	2 * 21W	2 * 21W
Number plate	1 * 5W	1 * 5W

Table 13: Light bulb position and wattage

d.) Summary

The following figures show the calculated voltage distribution on the marker and rear position light circuit for various truck configurations. No other loads, such as stop lights or direction indicator lights are active.

The assumed loads are identified on each diagram. The loads reflect common practice; however, other configurations may also be encountered.

Combination (with figure reference)	Light intensity (100% at 12V)	Voltage at rear of the last trailer	Configuration	Status
7) Single Trailer	75%	11.3V	Light duty truck-trailer cable[1]. Medium duty wiring.	**Acceptable**.
8a) B-Double	41%	9.62V	Medium duty wiring. Light duty truck-trailer cables[1].	**Not acceptable**
8b) B-Double	50%	10.42V	Medium duty wiring for the B-trailer Heavy duty wiring for the A-trailer. Medium duty trailer-trailer Cables[1].	**Marginal, consider upgrading the B-trailer wiring to heavy duty.**
8c) B-Double with high contact resisitance	31%	9.06V	Configuration as for 8a). Connector contact resistance is 20 mΩ per pole.	**Not acceptable**
9a) Double Road Train	38%	9.32V	Heavy-duty wiring. Medium duty truck-trailer cables[1].	**Marginal[2], should upgrade to regulated LEDs**
9b) Triple Road Train	<25%	6.33V	Heavy-duty wiring. Medium duty truck-trailer cables[1].	**Not acceptable[2], must upgrade to regulated LEDs**

Table 14: Summary

Note:

[1] Contact resistance at the truck-trailer connectors is assumed to be 5 mΩ per pole. Approximate light output from tail-lights at the rear of the last trailer 100% light output is defined as that achieved at 12V.

[2] As road trains operate in and through remote areas, where the ambient light levels are significantly lower than in the populated cities, the poor light performance noted above, should not the issue expected.

These results illustrate how difficult it is to achieve adequate voltage level at the rear of the last trailer in a multiple combination. It can be seen that:

- Voltage levels and thereby incandescent light output is unsatisfactory for many combinations. Choice of cables, connectors and minimal application of lighting is important for achieving acceptable performance.
- Voltage drops of 1V or more occur across the trailer-truck connections when light-duty trailer cables are used or when the connector contact resistance is high.
- Voltage levels of about 6V can occur at the rear of road-trains. This voltage level is inadequate for night lighting levels. Design action to reduce the load and/or increase the system capacity is recommended.
- The use of regulated LED lamps is highly recommended due to lower current draw and improved durability in longer combinations.

Some manufacturers and operators install a heavy power and return cable so that the lights on the rear trailer(s) are supplied using a relay connection fed from the heavy power supply. A suitable heavy-duty connector for road train service is identified in the Australian Standard AS4735-2003 Heavy Road Vehicles – electrical connectors for articulated vehicles.

Measurement of the voltage at the rear of the vehicle with night lighting on provides the best guide to the adequacy of the electrical system. A voltage level of 10V or more is recommended.

7. Connector choice and maintenance

Degraded connector terminals will have increased contact resistance. This can lead to further temperature-related degradation. Experience is that new connectors have contact resistance per pole of 3-5 mΩ. For a modest increase in pole contact resistance from 5 mΩ to 20 mΩ, the voltage available at the rear of B-Double configuration 3 falls from 10.42V to 9.06V (Figures 8b) and 8c)). The light output falls from 50% to about 30%.

Appropriate maintenance of connector terminals is important to keep the contact resistance low and thereby minimise voltage loss.

Poor terminal condition also causes terminal heating under heavy load. If the first connector (configuration 9b), is carrying 22.7A and has high contact resistance (20 mΩ), the power loss at each pole is 10W. Over a long journey with high ambient temperatures, such heating may cause further terminal degradation. Heavy gauge cable helps to transmit terminal heat away.

Heavy gauge cable plays an important role in removing heat from connector terminals. Often wire gauge is selected to provide good mechanical strength and ‘heat sink’ ability. Use of light gauge wire causes not only unacceptable voltage loss but contributes to connector terminal degradation, which exacerbates voltage drop. Designers should be careful to select connectors that have robust connector terminals that are designed to take heavy-duty wiring.

The computations have not considered the effect of occasional operation of the stop and direction indicator lights. These lights often use 21W 12V bulbs that draw substantially more current that the 5W, 12V bulbs in the park light circuit. Whilst fewer 21W bulbs are used, their greater current consumption results in current levels that are comparable with the marker/rear position light loads. As all trailer load current returns via the connector return poles, the return current level may be at the rating of the connector.

For example, all lights are active at night; the return pole connector current at the towing-vehicle to trailer connector of the triple road-train will instantaneously carry about 45A. If the connector has a contact resistance of 20 mΩ the power loss at this pole has a peak of 40W, which is unacceptably high.

The current rating of the light-duty connector (AS2513-1982 – Reference ADR 42/03 *General Safety Requirements*) that has been commonly used on heavy vehicles is usually 15A. Consequently it can be concluded that road train vehicles cannot satisfy the requirements in ADR 64 using a light duty connector because the service current exceeds 15A. Furthermore, considering that the return pole current is the sum of all active circuit currents, the return current level on a B-double will often exceed the rating of the light-duty connector.

Connectors should be regularly inspected for signs of terminal heating and corrosion. Corrosion can be prevented by routine use of lithium or lanoline based grease. Such greases have minimal conductivity. Their function is to prevent moisture ingress into the connector and to lubricate the poles. Good connector design should also provide moisture protection to the cable side of each connector part. Poor contact between the pole and the incoming cable is a common cause of terminal heating and degradation.

Summary

- Both the supply and return current flows via the connectors. In particular, the total return current flows through the earth pole.
- Voltage losses occur at the connector poles arising from both contact resistance and the connection resistances between the cables and the terminals.
- Heavy gauge poles and wire terminations help minimise voltage drops.
- Heavy gauge wiring helps transfer heat away from the connector poles.
- Preventative maintenance at the connector that prevents corrosion and keeps wiring tightly in place is important.
- Wiring should be supported near the connector so the terminals are not loaded by the weight of the wiring.

8. Truck-trailer cable choice

As is illustrated in Section 4, significant voltage loss occurs across the trailer cable when light duty cables are used on multiple combination vehicles. Light duty trailer cables have been used in the past to reduce the weight on poor quality connectors. The greatly improved connectors specified in this TAP are able to withstand the loads imposed by the weight of medium- and heavy- duty trailer cables.

Summary

- The use of heavy-duty truck-trailer cables are preferable, because they lessen voltage losses in multi combination vehicles.

9. Electrical fires and typical causes

The 2015 NTI / NTARC report, covering its 2013 insurance claims, found “truck fires continue to account for 10.7 percent of large loss incidents with electrical failures accounting for 68.5 percent of cabin / engine compartment fires”.

Trucks and trailers take a pounding in their life, travelling the roads of Australia. There is a lot of relative movement between the cab, chassis and powertrain components plus multiple electrical cable plugs and connection points.

There are 3 main areas of concern that could result in fires or electrical reliability issues:-

- Electrical insulation failure
- Excessive current flow
- Excessive resistance

Road vibration combined with gritty moist road grit creates an abrasive mix, which is often hidden, wearing away at insulation resulting in electrical short circuits.

- Cable routing and strapping is critical for harnesses. They should be supported every 200 mm and be protected from any potential contact points during the full movement of surrounding components with a minimum clearance of 25 mm.
- The electrical harness should never sag.
- Split conduit is not recommended as wires can drop out and it can trap grit around the cable.

There are key positive cables (battery to starter motor and alternator) which due to their nature may not be provided with a circuit breaker (refer to figure 1). The terminals on the starter and alternator are often also exposed and any metal object item landing on them could create a short circuit produce extreme current flow, resulting in a fire.

- Always disconnect batteries when working on a vehicle.
- Regularly inspect the unfused cables for wear and contact or rub points.

Terminals and plugs (lighting and ABS/EBS) are often a source of intermittent reliability issues. Heat is a great tell-tale for either excessive resistance or current travelling through a cable or excessive resistance at a joint. In extreme cases plugs will melt and cables will sag often resulting in contacting a wear point.

- Plugs should never be under strain and stretch the terminals. This reduces the contact pressure and increases their resistance.

10. Good practice guide

a.) Wiring

- Use medium- or heavy-duty truck-trailer cables on multiple combination trucks. Heavy-duty wiring is preferred on road trains: ADR63/00 specifies a minimum cross section of 5 mm^2.
- Wiring gauge should be chosen to safely carry the maximum load current and to provide acceptable voltage drops. Often voltage drop considerations determine the choice of wire gauge.
- Particular attention should be taken of trailer-cable choice because significant voltage drops often occur across the interconnections.
- Road train voltage levels are improved by using a relay scheme on trailers whereby the loads are fed from a main power and return cable. The supply currents flow through a heavy-duty two-pole connector and the seven-pole connector only carries control circuits.

b.) Lighting

- Incandescent bulbs have light outputs that are very sensitive to voltage level.
- Added lights will increase current flow and reduced voltage. If additional lights are desired for night-time safety, use them only where they are seen.
- In some jurisdictions dolly trailer lighting can be disabled when the dolly trailer is under a semi-trailer.
- LED based lighting will provide more reliable lighting levels on multiple combination trailers because this lighting has lower current draw. Voltage regulated LED lighting will provide reliable lighting levels over a wide voltage range. Due to variability in current draw of LED lamps, use the same wire gauge that would be used with incandescent lamps.

c.) Voltage level

- 24V (nominal) lighting systems will produce higher light levels on trailers than 12V (nominal) systems, other factors being equal.
- A minimum voltage of 10V is recommended at the rear of a multiple combination, with night lighting on.

d.) Towing vehicle electrical performance

- The prime mover should be designed to provide at least 12V (for a nominal 12V system) at the trailer connector when the continuously operating night-time lighting is on. On a single trailer vehicle this voltage should be at least 12.5V.
- Higher trailer voltage levels are achieved when the main current path of lighting circuits to the trailer(s) does not go via the cabin. That is, when the lighting circuits are relayed outside the cabin.
- Generous wire gauge should be provided on the circuits that run to the trailer connector.

e.) Alternator and battery considerations

- Alternator voltage should be set considering the battery type and temperature environment.
- An alternator voltage setting of 14.2V (lightly laden on a nominal 12V system) or 28.4V on a lightly laden nominal 24V system are usual. Slightly higher voltages are required with low maintenance or sealed lead-acid batteries.
- The battery charging ability of the electrical system is reduced if the alternator is at a substantially higher operating temperature than the batteries.

f.) Connector choice

- Light-duty seven-pole connectors (per AS 2513-1982 and ADR 42/03 Cl 10.2) are inadequate for road-train or B-double combination vehicles and not recommended for use with any heavy trailers.
- Use of heavy gauge wiring to the connector will help to remove heat from the connector poles.
- High temperatures at connector poles lead to degradation and dust ingress.
- Connectors should have robust terminations suitable for heavy-duty wiring.
- Regular maintenance, involving application of electrical grease to the poles of the connector, will minimise contact resistances.
- Connectors should seal tightly to reduce dust ingress.
- The connector body should support and clamp the wiring to reduce stress on the terminals.

INDUSTRY TECHNICAL COUNCIL

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The Industry Technical Council (ITC) is a standing committee of the Australian Trucking Association (ATA). The ITC's mission is to improve trucking equipment, its maintenance and maintenance management. The ITC was established in 1995.

As a group, the ITC provides the ATA with robust professional advice on technical matters to help underpin the ATA's evidence based policymaking. It is concerned with lifting technical and maintenance standards, improving the operational safety of the heavy vehicle sector, and the development of guidelines and standards for technical matters.

ITC performs a unique service in the Australian trucking industry by bringing operators, suppliers, engineers and other specialists together in a long-term discussion forum. Its members provide expert and independent advice in the field to inform the work of the ITC. The outcomes from ITC benefit all ITC stakeholders and the heavy vehicle industry at large.

The ITC operates under the Australian Trucking Association's Council, which formulates industry policy for implementation by the organisation.

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