

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

SAE J163 Low Tension Wiring and Cable Terminals and Splice Clip

SAE J378 Marine Wiring

SAE J1116 Categories of Off-Road Self-Propelled Work Machines

SAE J1127 Battery Cable

SAE J1128 Low Tension Primary Cable

SAE J1493 Shielding of Starter System Energization

SAE J1908 Electrical Grounding Practice

2.1.2 IEC Publication

Available from International Electrotechnical Commission, 3, rue de Verambe, P.O. Box 131, 1211 Geneva 20, Switzerland, Tel: +41-22-919-02-11, www.iec.ch.

IEC 617 Graphical Symbols for Diagrams

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this document.

2.2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

SAE J562 Loom, Asphalt Impregnated

SAE J821 Electrical Systems for Construction and Industrial Machines

3. DEFINITIONS

3.1 Electrical Circuits

An electrical circuit includes all the components and connecting cables, starting from the electrical energy source, going to the functional component(s) and the return route to the energy source.

3.2 Electrical Component

An electrical component is normally a combination of parts, sub-assemblies, or assemblies and is a self-contained element intended to store, generate, distribute, alter, or consume electrical energy.

3.3 Conductor(s)

The current carrying element(s) in a cable.

3.4 Electrical Cable

Insulated stranded electrical conductor used to establish a single current path.

3.5 Harness

A group of two or more cables bundled together.

3.6 Terminal

An electrically conductive device attached to a cable to facilitate connection to an electrical component, cable, or termination.

3.7 Connector

A coupling device which provides an electrical and/or mechanical junction between two cables or between a cable(s) and an electrical component.

3.8 Wiring

Collectively, the cables, harnesses, connectors, terminations, and supporting components used in the electrical wiring distribution system.

4. WIRING DESIGN

4.1 Cable Selection

The preferred cable shall meet the requirements of SAE J1127 and SAE J1128 type SXL. Other cable types may be required for specific applications.

4.2 Cable Size Determination

Cable size is determined by consideration of the following factors:

- a. Cable mechanical strength
- b. Maximum temperature rise
- c. System voltage drops
- d. Selected connectors

4.2.1 Apply the procedure in Figure 1, Cable Sizing Flowchart, for determining cable sizes.

These factors vary in importance depending upon the application. Details specific to each are found in the following paragraphs.

4.2.1.1 Configure the electrical circuit including grounds and connectors.

4.2.1.2 Determine current requirements and cable lengths.

4.2.1.3 Determine fuse, circuit breaker, or other requirements applying appropriate de-rating factors.

4.2.1.4 A minimum size cable, or larger, shall be selected which meets all the previous requirements.

TABLE 1 - CABLE SIZED FOR THERMAL CIRCUIT BREAKERS

70% Load Operating Current (A)	Circuit Breaker Rating (Thermal type) (A)	Smallest Cable Size Acceptable (mm ²) Calculations for this column are found in Appendix A.
5.2	7.5	0.8
7.0	10	1
10.5	15	2
14	20	3
21	30	5
28	40	8
42	60	13
56	80	19

- 4.2.5 For Steady-State Thermal Capacity, the selected cable size should be verified by load testing. Table 2 gives the values of currents permissible based on the assumptions of 30 °C rise for cables bundled in a harness and 10 °C rise of a single cable in free air due to steady-state current heating. Circuit protection should be sized for the smaller size wire within the circuit.

TABLE 2 - STEADY-STATE THERMAL CAPACITY⁽¹⁾

Cable Size (mm ²)	Ratings (A)
0.8	7.5
1	10
2	14
3	20
5	29
8	41
13	60
19	82

1. Dimensions used in calculating this table are typical industry values. Values found in this table are based on the calculations found in Appendix A.

4.2.6 Intermittent Load Cycles

For circuits where the electrical load is of a short duration, a 90-s rating can be used. As an example, a cable which is at a 40 °C ambient and is allowed to thermally rise to 150 °C. A short-term rating can be calculated based on its thermal mass. Based on the formula $\frac{\text{Current}}{\text{Area}} = 13.82$, the following ratings and sizings would be established. Please see Appendix A for the derivation of the constant.

8 mm² is rated 90 A
 13 mm² is rated 160 A
 19 mm² is rated 250 A

- 4.2.7 The procedure used to determine voltage drop with respect to cable size begins with establishing maximum allowable voltage drop VD (volts), length of cable l (mm), and maximum operating current in circuit i (A).

4.2.7.1 Calculate cable resistance in micro-ohms/mm (r) as shown in Equation 1:

$$r = \frac{VD}{li} \times 10^6 \quad (\text{Eq. 1})$$

4.2.7.2 After finding the calculated resistance, select the cable size from Table 3.

TABLE 3 - VOLTAGE DROP RESISTANCE

Cable Size (mm ²)	Resistance (μΩ/mm)
19	0.814
13	1.388
8	2.254
5	3.576
3	5.676
2	9.088
1	14.370
0.8	21.496

4.2.7.3 Examples of typically acceptable run lengths with a 1 V drop in a 12 V system are given on Table 4. Please note certain systems require voltage drops as small as 0.1 V. Calculation of the full system voltage drop is always recommended. (Note: run length is ½ of loop length.)

Maximum voltage drop shall be established to provide optimum performance and reliability of the components, e.g., voltage sensitive devices.

TABLE 4 - TYPICAL 1 V DROPS RUN LENGTHS

	0.8	1	2	3	5	8	13	19	Cable Size (mm ²)
Amperage (amps)									
2.5	9.0	13	22	34	54	84	135	182	
5	4.5	6.6	11	17	27	42	68	91	
7.5	3.0	4.4	7.3	11	18	28	45	61	
10	2.3	3.3	5.4	8.5	14	21	34	45	
12.5		2.6	4.4	6.8	11	17	27	36	
15			3.6	5.7	9.0	14	23	30	
20			2.7	4.3	6.8	11	17	23	
25				3.4	5.4	8.4	14	18	
30				2.8	4.5	7.0	11	15	
					Marginal				Acceptable

4.2.8 Procedure for Resistance Budget

- Determine entire voltage drop that is acceptable from the positive terminal of the battery to the negative terminal of the battery.
- Divide the voltage drop by the anticipated current draw of the load to calculate the entire resistance that is tolerable ("Resistance Budget").

- c. Subtract known resistance values from the budget amount. Suppliers of components should be able to provide component specifications. If not, they can be measured or estimated by considering electrical contact junctions equal to 1 milli-ohms per contact and internal switch contacts equal to 8 milli-ohms each.
- d. Divide the remaining resistance by the distance to and from the load. This is the "Maximum Allowable Resistance".
- e. Use Table 3 to determine the wire size needed based on resistance.
- f. If an iron casting or steel frame is used for ground return, that resistance will have to be calculated and subtracted from the resistance budget before calculating the power source wire size.

4.2.9 Consideration must be given to the connectors that have been chosen when determining cable size. In the case where the wire is too large for the connector, there is an acceptable alternative. Here, a smaller diameter wire can be used and the electrical load split between two cables with 2 separate connections. Circuit protection for the smaller wire diameters of such split loads must be reconsidered.

4.3 Terminals

4.3.1 A corrosion-resistant conductive plating is recommended.

4.3.2 Terminal materials and platings shall be chosen to reduce galvanic corrosion when mated. Low-energy circuits may require terminal materials which prevent degradation due to vibration, fretting, corrosion, and oxidation.

4.3.3 All terminations shall conform to the physical and electrical performance requirements of SAE J163, except that the voltage drop test is to be modified as follows:

- a. 200 off/on cycles at $125\text{ }^{\circ}\text{C} \pm 3\text{ }^{\circ}\text{C}$, 60 min off at $21\text{ }^{\circ}\text{C} \pm 2\text{ }^{\circ}\text{C}$.
- b. Transition between temperature states to occur at $3\text{ }^{\circ}\text{C}$ $\frac{+3\text{ }^{\circ}\text{C}}{-0\text{ }^{\circ}\text{C}}$ per min with the power off during the transition.

Terminals shall meet the contact resistance test after cycling.

4.3.4 Contact resistance measurement of connection resistance as illustrated in Figure 2. The resistance of the cables shall be subtracted from measured values.

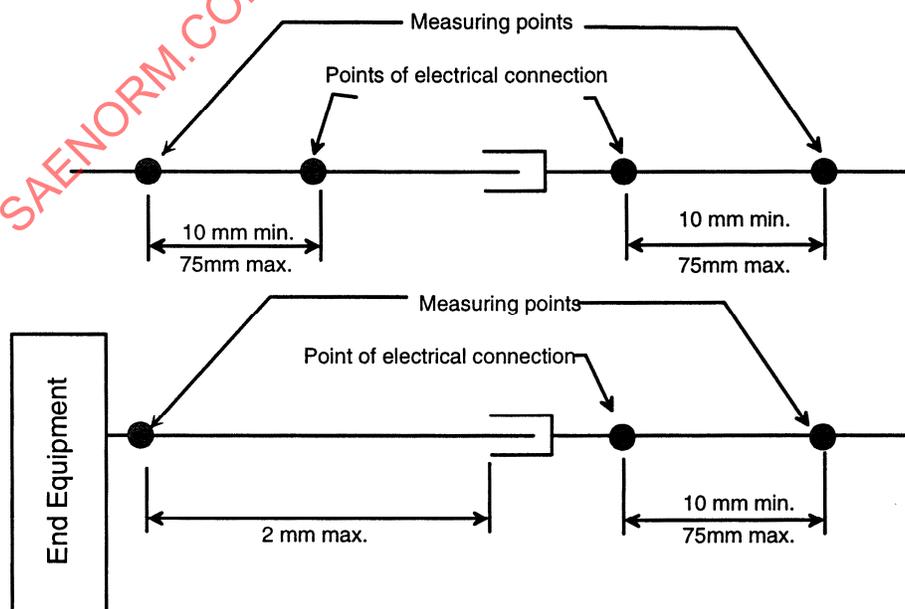


FIGURE 2 - CONTACT RESISTANCE TEST POINTS

4.3.5 Measurements at specified test current shall be taken after thermal equilibrium at current levels shown in Table 5.

TABLE 5 - CONTACT RESISTANCE TEST CURRENTS

Cable Size (Ref. J163) (mm ²)	Test Current (A)
0.8	10
1	15
2	20
3	30
5	40
8	50
13	60
19	70

4.3.6 Acceptance criteria of connection resistance is:

10 milli-ohms maximum initially.
20 milli-ohms maximum after endurance testing.

4.3.7 Maximum allowable voltage drop across a terminal as depicted in Figure 2 shall be 100 mV.

4.3.8 Terminals shall be used and applied according to manufacturers' specifications. Special consideration shall be given to terminals carrying low-voltage signals.

4.3.9 Terminals shall have cable insulation support or the connector body/device shall provide support for the cable.

4.4 Connector Selection

4.4.1 Single connections shall be used in close proximity to each other only where there is no possibility of mis-connection in assembly or service.

4.4.2 Connector bodies shall be used at all points where two or more cables terminate, and where there is a possibility of mis-connection in fabrication, assembly or service.

4.4.3 Cable-to-cable connectors shall have positive locking devices. The locking device shall withstand a pulling force defined by 111 N times the number of contacts or a maximum of 444 N. The load shall be applied for 30 s.

4.4.4 Connectors shall be polarized.

4.4.5 Minimum terminal retention, within the connector, shall be 111 N.

4.4.6 Secondary locks for the terminal and/or connector are highly recommended.

4.4.7 Connectors exposed to the outside environment require adequate protection from hazards (brush snags, rock impact, splash proof, etc.) associated with that environment.

4.5 Splicing

4.5.1 When splices are required, they shall be located dimensionally on drawings to preclude being located:

- a. In areas of harness flexing
- b. Within 50 mm of a clamp
- c. Within 50 mm of a branch of the harness

- d. Within 25 mm of any other adjacent splice
- e. Within 100 mm of any connector or termination
- f. Within 150 mm between connected/consecutive splices

4.5.2 Configure splice so that

- a. Cables are not doubled back within the harness bundle.
- b. Splices are within the covered or bundled section of the harness.
- c. The cross sectional area of the cables on either side of the splice are approximately equal.

4.5.3 Splice Construction

The cable conductors shall be reliably terminated. All splices shall conform with the electrical specifications for splices per SAE J163. Additionally, the splices must meet or exceed the minimum pull test as shown in Table 6 (Extracted from SAE J378). Value to be based upon smallest cable in splice.

TABLE 6 - SPLICE PULL OUT REQUIREMENTS

Cable Size (mm ²)	1-s Pull Value (Newtons)
0.8	80
1	124
2	155
3	177
5	200
8	222
13	355
19	440

4.6 Harness Assembly Construction

4.6.1 Cables shall be grouped, where practical, into harnesses.

4.6.2 Harness covering shall be selected in accordance with the application. Examples of typical harness coverings are as follows: polyvinyl chloride tape, extruded plastic (PVC) tubing, flexible thermoplastic conduit (typically slit lengthwise), metal conduit, braid (vinyl/nylon or vinyl/polypropylene).

4.6.3 The wiring harness covering shall be adequate to protect the harness in the expected environment and shall furnish protection during machine assembly and operation.

4.7 Cable Circuit Identification

4.7.1 Circuits shall be identified with either color, numbers, letters, symbols, or a combination thereof.

Identification shall change when passing through an electrical component, but not when passing through a terminal block, connector, splice, or common junction.

4.7.2 Identification Durability Requirements

4.7.2.1 Abrasion Resistance Test

Place the cable on a firm surface with the circuit identification markings face up. Secure the cable in place. With a force of 30 N, wipe a "Pink Pearl" or equivalent eraser across the cable and markings parallel to the centerline ten times.

4.7.2.2 Fluid Resistance Test

Immerse a 200 mm length of cable in $25\text{ }^{\circ}\text{C} \pm 5\text{ }^{\circ}\text{C}$ fluid for 10 min. Remove and wipe the insulation two times with slight pressure using a paper towel. The fluids required for this test are: diesel fuel, gear and engine oil, antifreeze fluid, hydraulic fluid, and gasoline. Other fluids may be added to this test at the manufacturer's discretion.

4.7.2.3 Acceptance Criteria

The characters on the cable insulation shall be legible in low lighting after each test.

4.8 Assembly Routing and Protection

4.8.1 Harness design should prevent misconnection during assembly or service.

4.8.2 Harness routing shall be such that maximum protection is provided by the machine covering and structure.

4.8.3 Devices such as grommets and/or insulated clamps, are required to provide adequate protection from sharp edges and vibration.

4.8.4 Wiring shall be located to afford protection from exposure to the following: moving mechanisms, stones, abrasives, grease, oil, water, and fuel.

4.8.5 Wiring shall be routed to avoid excessive heat areas.

4.8.6 Strain relief may be necessary for some connector applications and can be addressed by connector design or by clamping, routing, and harness support.

4.8.7 Protection (i.e., boots or shields) against accidental shorting shall be provided for terminals which always have voltage present. This protection shall conform to SAE J1493. Some examples of continually live electrical terminals include:

Battery terminals

Alternator output terminals

Accessory relay terminals

4.8.8 Fluid conduits/lines shall not be used as support for wiring harnesses.

4.9 Electrical Grounding Practice

4.9.1 Grounding connections shall conform to SAE J1908.

5. NOTES

5.1 Marginal Indicia

The change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions have been made to the previous issue of the report. An (R) symbol to the left of the document title indicates a complete revision of the report.

PREPARED BY THE SAE COMMON TESTS TECHNICAL COMMITTEE SC2—
ELECTRICAL COMPONENTS AND SYSTEMS

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APPENDIX A

A.1 This appendix is provided for informational purposes and is not to be considered as part of the document.

A.2 CABLE THERMAL RISE

From thermodynamics a first order equation that is often used is:

$$\text{Heat}(H) = \text{Constant}(C) \times \text{Surface Area}(A) \times \text{Temperature Rise } (\Delta\theta) \quad (\text{Eq. A1})$$

This can be written:

$$H = CA \Delta\theta \quad (\text{Eq. A2})$$

For a cable with current (I) and resistance (R) in steady-state:

$$I^2 R = CA \Delta\theta \quad (\text{Eq. A3})$$

The resistance can be written as Equation A4. Also see Figure A1.

$$R = \rho \frac{\Delta l}{\pi / 4 D^2} \quad (\text{Eq. A4})$$

where:

D = diameter
 Δl = length
 ρ = resistivity

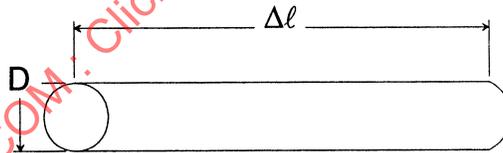


FIGURE A1 - WIRE DIMENSIONS

The area of the surface is:

$$A = \pi D \times \Delta l \quad (\text{Eq. A5})$$

At the fusing condition copper melts, and

$$\begin{aligned} \text{F.C.} &= I, \quad \Delta\theta = \theta_M - \theta_A \\ \theta_M &= 1083^\circ\text{C} \\ \theta_A &= 20^\circ\text{C} \end{aligned} \quad (\text{Eq. A6})$$

where:

F.C. = Fusing Current
 θ_m = Melting Point Temperature
 θ_A = Ambient Temperature

then

$$I = \sqrt{\frac{C}{4\rho} \pi^2 (\theta_M - \theta_A) D^2} \quad (\text{Eq. A7})$$

The W. H. Preece Equation at fusing is F.C. = 10 244 D^{3/2} (where D is in inches).

For a thermal rise of 10 °C at 20 °C ambient, we can write a similar equation.

$$I = \sqrt{\frac{C}{4\rho} \pi^2 (\theta_{M1} - \theta_A) D^2} \quad (\text{Eq. A8})$$

Dividing one equation by the other we obtain

$$\frac{I}{\text{F.C.}_{\theta_A}} = \sqrt{\frac{\theta_{M1} - \theta_A}{\theta_M - \theta_A}} = \sqrt{\frac{\Delta\theta_1}{\Delta\theta_{\text{F.C.}}}} \quad (\text{Eq. A9})$$

at $\theta_M=1083$ °C, $\theta_A=20$ °C, $\theta_{M1}=30$ °C

$$\frac{I}{\text{F.C.}_{20^\circ\text{C}}} = \sqrt{\frac{10^\circ\text{C}}{1063^\circ\text{C}}} \quad (\text{Eq. A10})$$

NOTE: These equations are approximations. They neglect other heating effects such as resistivity, radiation, conduction, and convection. Adding insulation to the cable may cause a higher temperature rise.

Table A1 represents the preceding equations applied to typical industry values.

TABLE A1 - THERMAL RISE IN STEADY-STATE CONDITIONS

Cable Size (mm ²)	SAE Area	Fusing Current (F.C.)	Ratings (A)
0.8	0.760	78.1	7.5
1	1.13	105.1	10
2	1.85	152.1	14
3	2.91	213.7	20
5	4.65	303.7	29
8	7.23	422.9	41
13	12.1	622.3	60
19	18.3	848.7	82

A.3 FAULT CONDITIONS

In a fault condition, the wire must be sized for the circuit protection provided. It is important that the wire and breaker are sized in such a way that the thermal circuit breaker "heats" at a rate higher than the wire if we are to protect the wire from any damage. Table 1 in SAE J1614 lists the minimum wire sizes for a given thermal circuit breaker.

In a fault condition, it is typical that all the heat generated (I^2R loss) is put into increasing the temperature of the wire. This is usually a good assumption since the fault occurs very fast.

$$\text{power} \times \text{delta time} = \text{mass} \times \text{specific heat} \times \text{delta temperature} \quad (\text{Eq. A11})$$