Heat Transfer Study of the Scotchflex™ BRAND Cable/Connector System

By H.T. Mitchell
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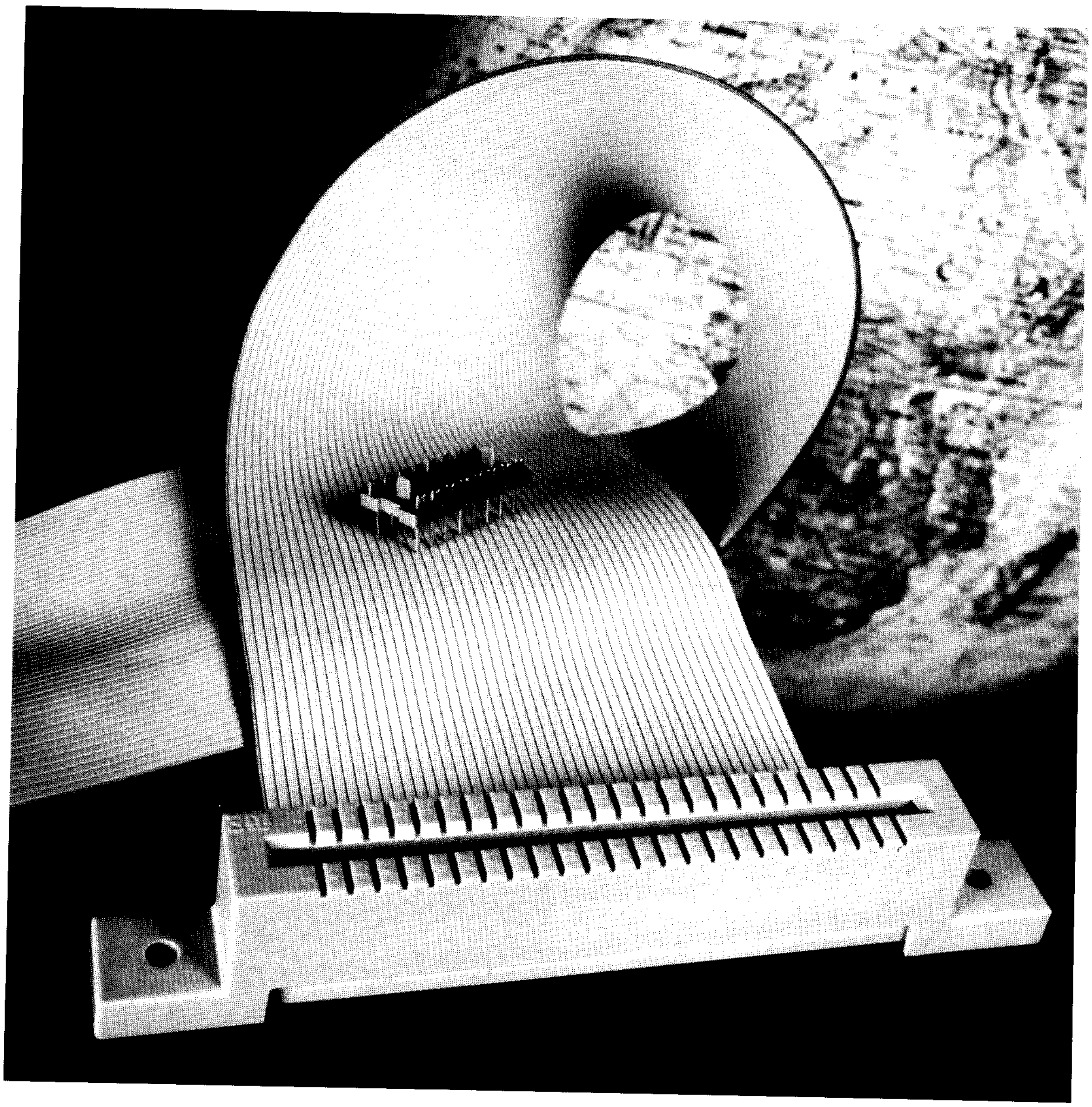

3M

This is a reprint of a paper
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About the Authors

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INTRODUCTION

This paper presents results of an experimental study defining heat limited current ratings of the 3M Brand Scotchflex* system. Various wire gages, cables, connectors, and current carrying configurations are evaluated. A standard test environment is developed and guidelines established for extension to a variety of industry applications. In addition to data curves, a table of recommended maximum current levels for the system is given for applications similar to the test environment.

The purpose of this work has been to push the flat cable system to its logical power handling heat limits, recognizing that not all applications are signal circuits. The importance of proper installation of current carrying cables by the packaging engineer is emphasized, with criteria to be used for establishing an acceptable current level in the particular case.

THE PROBLEM

The electronics industry has recently been shifting at an extraordinary rate from discrete wire to flat cable systems. Numerous valid reasons have been given—the key ones being time and money, large amounts are to be saved by simultaneous termination of up to 64 conductors.

The smaller gage wires typically used (24 AWG to 30 AWG) are ideal for signal level circuits were small currents are involved. Occasionally, however, an engineer requires limited power handling capability in excess of the typical one ampere current rating found on manufacturer's specifications. To answer this current handling problem an analysis and testing program was developed.

THE ENVIRONMENT

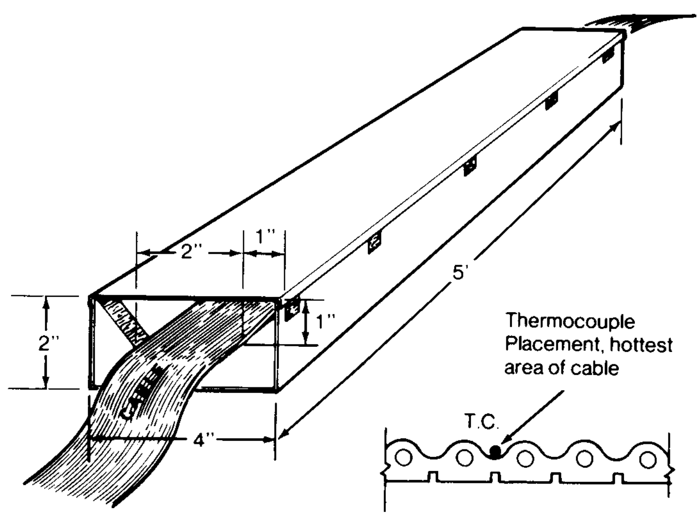
One of the most difficult areas to define in a heat transfer problem of any kind is the set of boundary value conditions. Placing this in perspective, one might consider for starters several questions:

1) What is the ambient air temperature?
2) How many ways are there to orient the cable?
3) How many layers of cable are there?
4) What air space is present?
5) What are the temperatures of all adjacent surfaces?
6) Is there forced air cooling?
7) Will the end product be used at sea level?

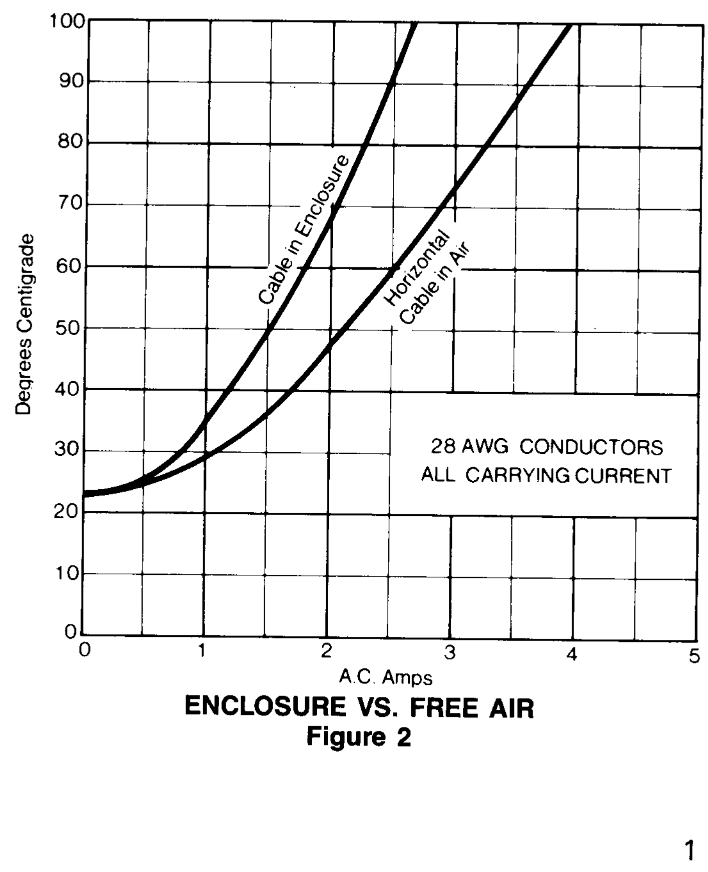
A computer program was employed to solve several idealized cases before a decision was made to avoid assumptions, define a standard room temperature environment and test sufficiently to characterize the current carrying flat cables in that environment. After this testing, an extension to higher ambients was planned.

In order to simulate a stagnated air condition, where test data would lead to conservative rating of the current carrying capability of the system, a horizontal aluminum channel with limited air space was chosen, **Figure 1.** Thermocouples were mounted on the top center of the cable and above the cable on the underside of the channel cover. Room ambient temperatures were maintained by blowing the outside of the box, wrapped with water soaked paper towels as necessary.

Checking cable in the stagnated air test environment versus heat transfer of a horizontally suspended cable outside the enclosure, the data in **Figure 2** were obtained. All 40 conductors in the standard 3365 cable were carrying the identical current in each case. As was desired, higher cable temperatures and poorer heat transfer were found in the test enclosure. For this, and all subsequent data, temperatures were allowed to stablize before reading.



TEST ENCLOSURE
Figure 1

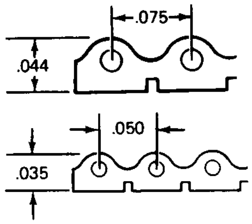


ENCLOSURE VS. FREE AIR
Figure 2

*Scotchflex is a registered trademark of the 3M Company.

THE CABLE

Four cables were tested extensively. In all likelihood they represent the majority of flat cable types used by the industry in an insulation piercing system.



COPPER CONDUCTORS	INSULATION	WIRES	TOTAL WIDTH	3M PART NO.
24 AWG 7/32 Stranded	PVC	28	2.10	3405/28
26 AWG Solid	PVC	40	2.00	3306/40
28 AWG 7/36 Stranded	PVC	40	2.00	3365/40
30 AWG Solid	PVC	40	2.00	3350/40

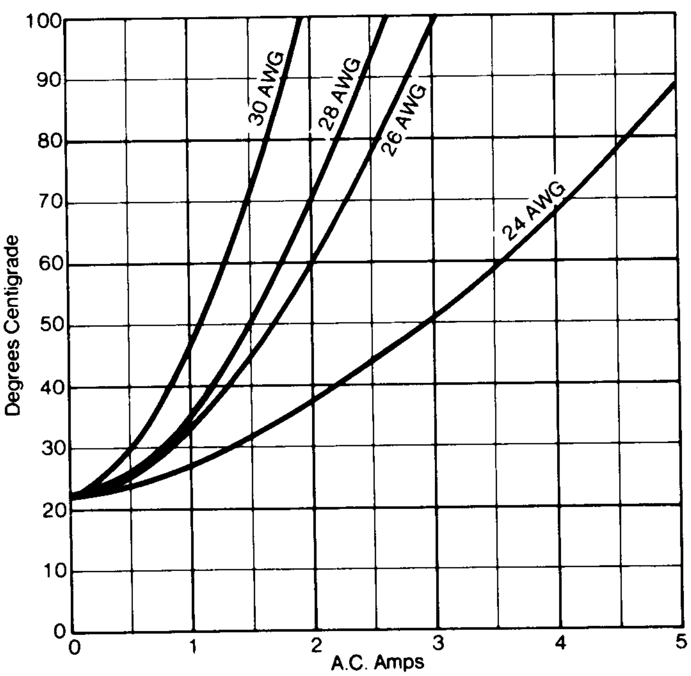
Based on reference 1, the ohmic resistance and corresponding voltage drop per amp for an extended range of wire sizes are given. Both room and 75°C temperatures are listed in order to indicate increases of resistance and voltage drop to be expected with increasing temperature.

Wire	20°C		75°C	
Gage	Ω/ft.	mV/ft-A	Ω/ft.	mV/ft-A
18	.00639	6.39	.00777	7.77
20	.0101	10.1	.0123	12.3
22	.0162	16.2	.0197	19.7
24	.0257	25.7	.0312	31.2
26	.0410	41.0	.0499	49.9
28	.0653	65.3	.0794	79.4
30	.104	104	.126	126

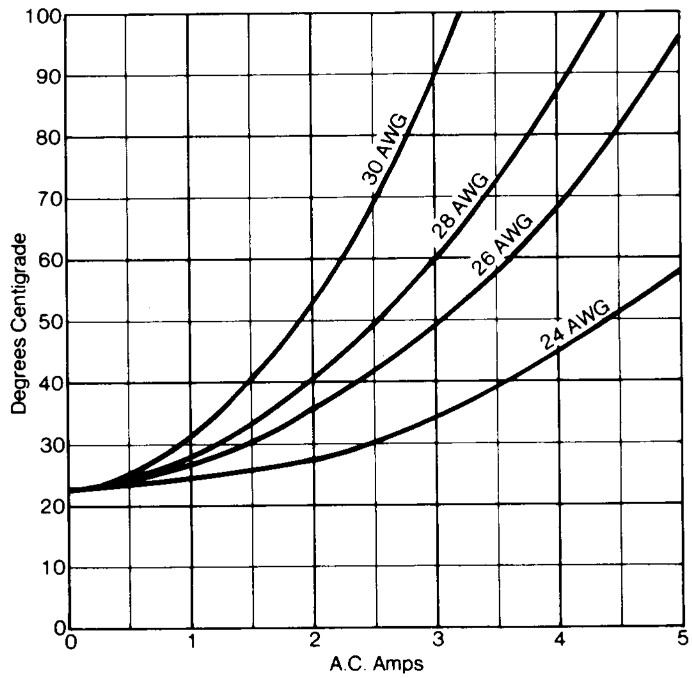
Note that two wires are present in a circuit. It is necessary to multiply cable length by a factor of 2 in order to determine circuit resistance and voltage drop. (See "Design Example" on inside back cover)

CABLE TEMPERATURE RISE

One set of tests utilized all conductors in series carrying the same continuous current, **Figure 3.** Recognizing that



ALL CONDUCTORS CARRYING CURRENT
Figure 3



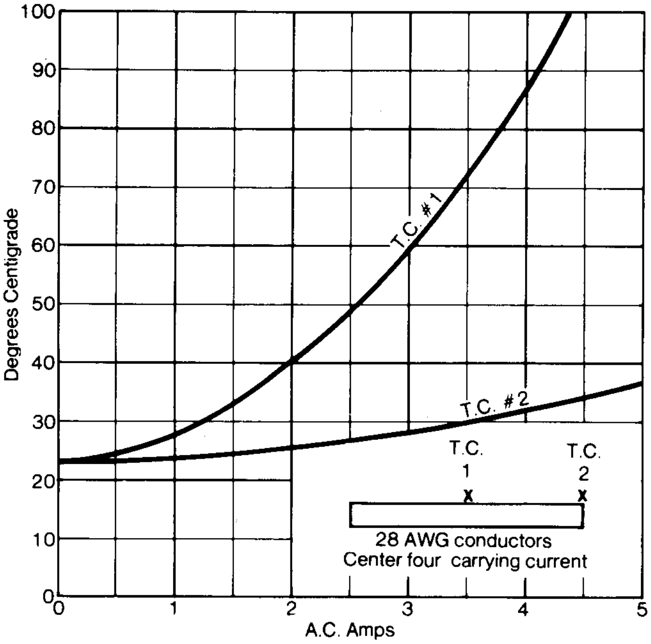
CENTER FOUR CONDUCTORS CARRYING CURRENT
Figure 4

in most applications the majority of wires would be used for small signal level currents, a second set of tests involved current in just four adjacent center conductors, **Figure 4.** The 24 AWG cable temperatures appear to be inconsistent with the trends indicated by the other gage cables. The 24 AWG cable, however, has wider spacing and fewer total wires.

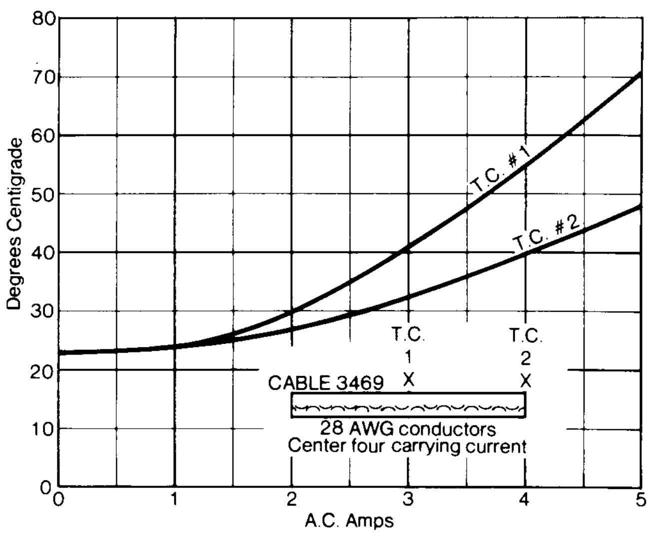
Establishing the cross-cable temperature gradient for the 28 AWG four center conductor case, **Figure 5** resulted. A separate test determined that when the four adjacent current carrying conductors are on one edge of the cable, the maximum temperature is increased only 3°C.

One special test of similar 28 AWG cable with a ground plane (3M Part Number 3469) indicated its ability to spread and dissipate heat, **Figure 6.** The maximum temperature is significantly lower. In the test four conductors carried current; if all conductors carried current the ground plane heat flow benefit would not occur.

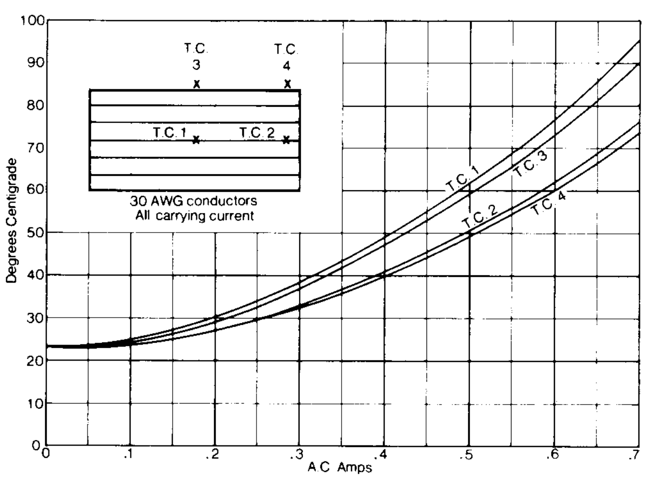
To determine worse case heat loading effects, six layers of 30 AWG were stacked. All 240 conductors carried the



TEMPERATURE GRADIENT ACROSS CABLE
Figure 5



GROUND PLANE CABLE TEMPERATURE GRADIENT
Figure 6



SIX LAY STACK HEATING
Figure 7

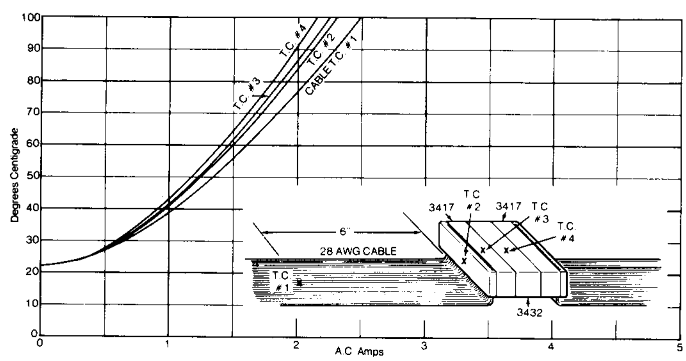
same current, **Figure 7**. As expected, relatively low currents produced severe heating. This test may appear of questionable value at first glance, but it does print up that a packaging engineer can inadvertently produce high temperatures in a device by failing to allow for proper exposure and cooling of heat sources.

Placing the test enclosure in an oven the ambient temperature was raised and sufficient testing accomplished to verify that the previous curves are merely shifted vertically. The higher ambient temperature did not significantly affect the heat radiation factor. It was logical that conduction and convection should remain essentially the same.

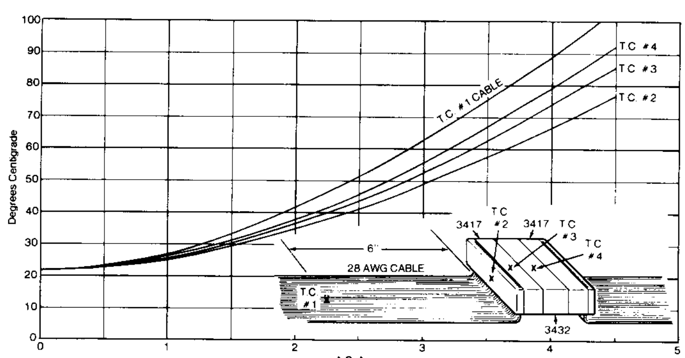
THE CONNECTOR

Any cable current carrying capacity is worthless unless the terminating connectors are equal to the task. Basic connector sets were current cycled in an 8 week test up to and including 6.5 amps and found to have stable resistance with no sign of connector degradation.

A "worse case" connector set was also fabricated from two socket connectors (P/N 3417) and a wire wrap post straight header (P/N 3432) by shortening the wire wrap tails to permit mating to the second socket. From the **Figure 8** data one can see that for all conductors carrying the same current the connector is slightly hotter than the cable 6 inches away. For the case where four wires carry current, **Figure 9**, the connector set is cooler and acts as a heat sink. Notice that this worse case connector set includes unusual I^2R heating from the bulk resistance of three pins, the constriction resistance of two U contacts, and two wiping tab interfaces.



THREE CONNECTORS WITH ALL CONDUCTORS CARRYING CURRENT
Figure 8



THREE CONNECTORS WITH CENTER FOUR CONDUCTORS CARRYING CURRENT
Figure 9

GOLD CONTACTS

In addition to the well known advantages of gold contacts, Reference 2 lists its softening temperature as 100°C and the corresponding softening interface voltage as .07V, calculated, and .08V experimental. Even though the connectors under consideration do not switch current it is desirable to stay below the gold softening temperature of 100°C to avoid possible sticking.

Gold contacts also must be reviewed for ability to handle the many pulse current applications that are emerging. Reference 3 gives the I^2/F parameter for the softening point of gold as 33,300 $Amp^2/Newton$. The lowest normal force to be expected in a Scotchflex connector being 150 grams this would permit a surge current of 221 amperes.

ENGINEERING JUDGMENT

Engineering judgment must now be applied to develop recommendations for acceptable current handling levels in the round conductor flat cable/connector system.

Although the cable tested has an Underwriters Laboratories rating of 105°C and 300 VAC, a recommended maximum temperature of 85°C has been chosen to provide a margin for the designer when he uses the cable and connectors for carrying power level currents. A current produced temperature increase of 30°C over ambient is the maximum recommended with 85°C as the upper limit.

A Bell System standard, given in **Reference 4**, requires the connector contact interface temperature to be within 6°C of the bulk temperature. For the connector discussed there, "Long term operation at 8 amperes, 70°C bulk, and 76°C interface require 2.5 milliohms or less". This is the order of magnitude of our wiping contact interface resistance. The 30°C temperature guideline we have chosen is approximately contact bulk temperature plus interface temperature.

A pulse limit of 20 amperes has been chosen for connectors in the system. A corresponding duty cycle limit must be calculated from the parameter $(I_{pulse})^2$(%duty cycle) listed in the summary.

Example: 28 AWG cable, (I^2) (%) = 700 maximum
If I_{pulse} = 12 amp
$$\text{Duty Cycle} = \frac{700}{12^2} = 4.9\% \text{ maximum}$$

This section on engineering judgment points out the need for an engineer to review personal or company design standards. The purpose of this paper has been to present the data and recommend maximums. For some, those maximums may be overly aggressive. From a pratical standpoint in a given piece of equipment, cable length and voltage drop may preclude operation at the higher current levels in individual conductors and paralleling may be required.

SUMMARY

Recommended maximum current levels are listed for the four wire gages tested. The final current levels must be determined by the system designer, taking into account the heat generated and configuration of his system. Prototype testing with thermocouple sampling of the hottest flat cable locations should be a part of the design process.

This study was performed to give basic current/temperature relationships to serve as guidelines for the systems designer and packaging engineer.

MAXIMUM SYSTEM CURRENTS*

	All Conductors Carrying Current	1-4 Conductors Carrying Current	Maximum Pulse	Maximum (I^2)(%Duty Cycle)
24 AWG	3.0 Amp	4.6 Amp	20 Amp	2100 Amp^2%
26	1.8	3.2	20	990
28	1.5	2.6	20	700
30	1.1	2.0	20	400

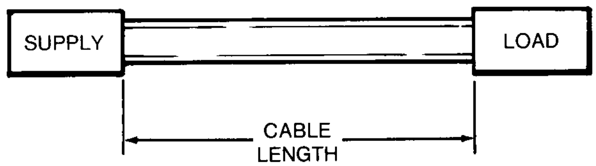
*Single horizontal cable in dead air space
30°C maximum rise recommended
85°C maximum temperature recommended

U.L. Style 2651 and 2682 cables are actually rated at 300 VAC and 105°C

REFERENCES

1. National Bureau of Standards, Handbook 100, "Copper Wire Tables"
2. H.N. Wagar, "Principles of Conduction through Electrical Contacts", **Physical Design of Electronic Systems,** Vol. III, Prentice Hall, New Jersey, 1971, page 456
3. H.N. Wagar, page 461
4. R.W. Rollings, "Design of a Reliable Separable Power Connector . . . ", 1974 Holm Seminar Proceedings, Illinois Institute of Technology, Chicago, page 53

DESIGN EXAMPLE



GIVEN:

Cable length 2 feet
Conductors 28 AWG
Load Resistance 1.25 Ω
Enclosed Cabinet With No Fan
Cable Isolated, Not Stacked
Power Supply 5 Volt

SOLUTION To select parallel wires, if necessary, the approximate

$$I = \frac{5V}{1.25\Omega} = 4 \text{ Amp}$$

From the maximum current table, 28 AWG cable can handle 2.6 amp if 1 to 4 close wires in a cable are all that carry high current. In this problem use two circuits (4 wires) to share the 4 amp load.

To find actual resistance, from the wire table, assuming 75°C wire temperature,

28 AWG; .0794 Ω/ft.

Cable Resistance Formula,

$$R_{Cable} = \left(\text{Table} \frac{\Omega}{\text{ft.}}\right)\left(\text{Circuit Length}\right)\left(\frac{1}{\text{Number of Parallel Circuits}}\right)$$

$$\boxed{R_{Cable} = \left(\text{Table} \frac{\Omega}{\text{ft.}}\right)\left(\text{2 X Cable Length}\right)\left(\frac{1}{\text{Number of Parallel Circuits}}\right)}$$

$$R_{Cable} = \left(.0794 \ \frac{\Omega}{\text{ft.}}\right)\left(2 \text{ X } 2 \text{ Feet}\right)\left(\frac{1}{2}\right) = .159 \ \Omega$$

$$I_{Actual} = \frac{5V}{1.25\Omega + .16\Omega} = 3.55 \text{ Amp}$$

To determine cable loss, the cable voltage drop formula is

$$\boxed{V_{Cable} = \left(\text{Table} \frac{\text{mV}}{\text{ft.-A}}\right)\left(2 \text{ X } \frac{\text{Cable}}{\text{Length}}\right)\left(\frac{1}{\text{Number of Parallel Circuits}}\right)\left(I_{Actual}\right)}$$

$$V_{Cable} = \left(79.4 \frac{\text{mV}}{\text{ft.-A}}\right)\left(2 \text{ X } 2 \text{ ft.}\right)\left(\frac{1}{2}\right)\left(3.55 \text{ A}\right) = 564 \text{ mV}$$

This cable voltage drop gives

$$V_{Load} = V_{Supply} - V_{Cable} = 5V - .564V = 4.44V$$

For a 5 Volt component, this load voltage may be too low. Other parallel wires could be added, the cable made shorter or a larger wire gage used.

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