ABSTRACT

The power or current carrying capacity of a cable is commonly referred to as the **AMPACITY**. The term is simply a contraction of the two words **AMP**ere and cap**ACITY**.

The most recognized method of determining the ampacity of power cables is Article 310-15 (b) of the National Electrical Code (NEC). Currently, the NEC does not publish the ampacity of CATV cables.

The basis of the NEC ampacity formula is the IEEE (formerly AIEE) paper titled "The Calculation of the Temperature Rise and Load Capability of Cable Systems" published in 1957 by J.H. Neher and M.H. McGrath. Utilizing the concepts developed by Neher/McGrath this paper will detail ampacity formulas and, appended to this paper, the resulting calculated ampacity tables for the range of products offered by Times Fiber Communications.

INTRODUCTION

The Neher/McGrath paper considers thermal circuits applicable to cables. Those thermal circuits include sources of heat and the thermal paths through which the heat flows. Since any coaxial cable has physical characteristics that limit the amount of temperature it can be exposed to, the temperature of the conductor carrying current is limited so as not to exceed the maximum allowable insulation temperature. That is, the heat generated in the cable must be equal to or less than the heat dissipated by the cable.

THERMAL CIRCUITS

Thermal circuits are analogous to electrical circuits with the qualification that changes in thermal circuits always occur much more slowly than changes in electrical circuits. The results outlined herein, therefore, are given only for steady state. Other methods should be employed to evaluate cable temperature rise due to transient, or sudden application of, currents.

ELECTRICAL FORMULA (Ohms law)	THERMAL FORMULA
$E = I * R$	$\Delta T = W * R_{th}$

Where:

- E = Potential difference (voltage)
- ΔT = Temperature difference between t_a, the ambient temperature, and t_c, the conductor temperature or
- $\Delta T = t_c - t_a$
- I = Current (amperes)
- W = Heat (watts)
- R = Conductor resistance (ohms)
- R_{th} = Thermal resistance (°C-cm/watt)

SOURCES OF HEAT

The primary sources of heat that apply to CATV cables are the current carrying conductors (inner and outer conductor) and solar radiation.

The heat generated in the inner and outer conductor when current is flowing can be calculated as follows:

For the inner conductor

$$W_{IC} = I^2 * R_{IC}$$

and for the outer conductor

$$W_{OC} = I^2 * R_{OC}$$

Where:

- W_{IC} = Heat created in inner conductor due to current (I) flowing. (watts/ft)
- W_{OC} = Heat created in outer conductor due to current (I) flowing. (watts/ft)
- I = Current flowing in conductor. (amperes)
- R_{IC} = Resistance of inner conductor. (Ω/ft at operating temperature of conductor)
- R_{OC} = Resistance of outer conductor. (Ω/ft at operating temperature of conductor).

Heating due to exposure to solar radiation must be considered as an interfering heat source. In the development of formulas for outdoor (in air) ampacity a factor is introduced for added heating due to the solar radiation.

Other interfering heat sources, such as steam lines or other nearby cables operating at temperatures in excess of ambient temperature must be accounted for in a similar manner.

THERMAL RESISTANCE

In the thermal circuit, heat generated by current in the cable conductors will flow from the conductors through the insulation and jacket into the ambient air surrounding the cable. While the insulation and jacket are electrically insulating, they are also thermal insulators. That is, the insulation and jacket and any other thermal insulators (such as ducts, soil, etc.) will retain heat according to their thermal resistance.

Cable flooding compounds also introduce added thermal resistance to the cable. However, sensitivity studies have shown that the effect of cable flooding compound on cable ampacity is largely insignificant and can be safely disregarded.

A metallic object within the cable construction and in the thermal path, such as a cable armor, is considered to be an isotherm, or having an equal temperature on both sides of the armor. Certainly this assumption is not appropriate if there is air space in the thermal path, like the instance when cable is installed in metallic ducts.

The thermal resistivities (ρ) of materials in CATV cable are as follows:

Foamed polyethylene insulation

$\rho_i = 1300$ (°C-cm/watt)

Polyethylene (PE) jacket

$\rho_j = 400$ (°C-cm/watt)

Polyvinylchloride (PVC) jacket

$\rho_j = 350$ (°C-cm/watt)

The resulting thermal resistance, in °C/watt/ft, can be calculated as follows:

For the insulation

$$R_i = 0.00522 * \rho_i * \ln \frac{C}{d}$$

and for jackets,

$$R_j = 0.00522 * \rho_j * \ln \frac{D}{D_s}$$

The total thermal resistance of the circuit is:

$$R_{th} = R_i + R_j$$

Where:

ρ_i = Thermal resistivity of the insulation material

ρ_j = Thermal resistivity of the jacket material

R_i = Thermal resistance of insulation

R_j = Thermal resistance of jacket

R_{th} = Total thermal resistance of thermal circuit

ln = Natural logarithm

C = Insulation diameter (inches)

d = Center conductor diameter (inches)

D_s = Outer condutor diameter (inches)

D = Jacket diameter

GENERAL AMPACITY EQUATION

Using the thermal equation $\Delta T = W_{OC} * R_{th}$, assuming only the outer conductor is carrying current, and replacing

ΔT with $t_c - t_a$ (see ΔT definition) and

W_{OC} with $I^2 * R_{OC}$

results in

$$t_c - t_a = I^2 * R_{OC} * R_{th}$$

Before solving the equation for (I) it may be useful to solve first for the conductor temperature, t_c, which will allow illustration of those factors which *control* maximum conductor temperature.

$$t_c = I^2 * R_{OC} R_{th} + t_a$$

It is now apparent that the toal watts ($I^2 * R_{OC}$), the thermal resistance (R_{th}), and the ambient temperature (t_a) determine the conductor operating temperature. Since the ambient temperature and the thermal resistance are determined by given cable installation conditions, it can be seen that the conductor temperature must be controlled by the total watts ($I^2 * R_{OC}$). Since the conductor temperature must not exceed the rated insulation or jacket temperature it is necessary to limit the total watts ($I^2 * R_{OC}$) by limiting the current (I) or the ampacity.

Returning to the thermal equation and solving for (I), in amperes, yields:

$$I = \sqrt{\frac{t_c - t_a}{R_{OC} * R_{th}}}$$

It should be noted that this equation is nearly identical that defined in NEC 310-15(b) and is used as a general formula for calculating cable ampacity.

INDOOR CABLE AMPACITY

The ampacity of indoor cables are the assumed worst case conditions for CATV installations since cables typically run from outdoors (where wind helps to cool the cable) to indoor or enclosed installations.

Like in the general equation, indoor cable ampacity is based on an assumed maximum allowable conductor temperature. The heat for cables installed indoors will flow from the conductor through the cable insulation (for inner conductor) and jacket to the cable surface where it is radiated away from the cable.

The indoor cable ampacity with the *outer conductor carrying current* is found by solving the following **simultaneous equations:**

$$I=\sqrt{\frac{t_c-t_s}{R_{oc}*(R_{th}-R_i)}}$$

and

$$I=\sqrt{\frac{0.182*\epsilon*D*(t_s-t_a)+0.0714*D^{0.75}*(t_s-t_a)^{1.25}}{n*R_{oc}}}$$

For indoor cable ampacity with *both outer and inner conductors carrying current* the **simultaneous equations** are modified as follows:

$$I=\sqrt{\frac{t_c-t_s}{(R_{ic}+R_{eoc})*R_{th}}}$$

and

$$I=\sqrt{\frac{0.182*\epsilon*D*(t_s-t_a)+0.0714*D^{0.75}*(t_s-t_a)^{1.25}}{n*(R_{ic}+R_{eoc})}}$$

R_{eoc} is the effective increase in the center conductor resistance due to the effects of the outer conductor and is calculated as follows:

$$R_{eoc}=\frac{R_{th}-R_i}{R_{th}}*R_{oc}$$

Where:

I	=	Ampacity (amperes)
t_c	=	Conductor operating temperature (°C)
t_a	=	Ambient temperature (°C)
t_s	=	Cable surface temperature (°C)
R_{ic}	=	Inner conductor resistance (Ω/ft at t_c)
R_{oc}	=	Outer conductor resistance (Ω/ft at t_c)
R_{eoc}	=	Increase in R_{ie} due to outer conductor
R_{th}	=	Thermal resistance of circuit (°C/watt/ft)
R_i	=	Thermal resistance of insulation (°C/watt/ft)
ϵ	=	Emissivity of cable surface
		Jacketed = 0.95
		Bare = 0.35
n	=	Number of cables
D	=	Cable Diameter (in.)

OUTDOOR CABLE AMPACITY

Ampacities for cables installed outdoors are calculated using simultaneous equations very similar to the those for indoor cables. Outdoor equations, however, include a term to account for heating due to solar radiation and additional cooling from forced convection (wind) rather than natural convection.

The ampacity of outdoor cable with the *outer conductor carrying current* is found by solving the following **simultaneous equations**:

$$I=\sqrt{\frac{t_c-t_s}{R_{oc}*(R_{th}-R_i)}}$$

and

$$I=\sqrt{\frac{0.182*\epsilon*D*+(0.237*(p*v)^{0.7}*D^{0.5})*(t_s-t_a)-8.77*\epsilon_{cs}*D}{n*R_{oc}}}$$

For outdoor cable ampacity with both *outer and inner conductors carrying current* the **simultaneous equations** are modified as follows:

$$I=\sqrt{\frac{t_c-t_s}{(R_{ic}+R_{eoc})*R_{th}}}$$

and

$$I=\sqrt{\frac{0.182*\epsilon*D+(0.237*(p*v)^{0.7}*D^{0.5}(t_s-t_a)-8.77*\epsilon_{cs}*D}{n*(R_{ic}+R_{eoc})}}$$

The nomenclature used for the variables in this section are the same as those used for indoor cables with the following additions:

ϵ_{cs}	=	Absorptivity of the jacket surface = 0.33
p	=	Atmospheric pressure (atmospheres)
v	=	wind speed (feet/second)

SUMMARY

It is not the intent of this paper to instruct on the use of techniques developed in the Neher/McGrath paper, or to derive the formulas and constants that resulted from that paper.

In summary, this paper is intended to introduce to the CATV industry ampacity tables, similar to those in the NEC for power cables, utilizing a well known and proven method for determining the current carrying capability of cables.

REFERENCES

The Calculation of the Temperature Rise and Load Capability of Cable Systems", J.H. Neher and M.H. McGrath, AIEE, March 1957

The Current-Carrying Capacity of Rubber Insulated Conductors, S.J. Rosch, AIEE, April 1938

The National Electrical Code Handbook, 1993 National Fire Protection Association, Sixth Edition, 1993

CRC Handbook of Chemistry and Physics, CRC Press, Inc., 62nd Edition, 1981

The Cable Book, Times Fiber Communications Inc., December 1993

APPENDIX I.

AMPACITY CALCULATIONS FOR 500 SERIES TFC CABLE WITH BOTH INNER & OUTER CONDUCTORS CARRYING CURRENT.

d	=	0.109"	C	=	0.450"
D_s	=	0.500"	D	=	0.560"
t_a	=	20°C	t_c	=	65°C

R_{oc} = $0.3581 \times 10^{-3}\ \Omega$/ft@20°C

R_{IC} = $1.3456 \times 10^{-3}\ \Omega$/ft@20°C

ϵ = 0.95

n = 1

ρ_i = 1300 °C-cm/watt

ρ_j = 400 °C-cm/watt

Since the conductors will be operating at 65°C, the resistances, R_{ic} and R_{oc} must be corrected from 20°C to 65°C. The correction factor is calculated to be 1.181 and the resulting resistances at 65°C are:

R_{oc} = $0.4229 \times 10^{-3}\ \Omega$/ft @ 65°C

R_{IC} = $1.589 \times 10^{-3}\ \Omega$/ft @ 65°C

$$R_i = 0.00522 * 1300 * \ln\frac{0.450}{0.109} = 9.622$$

$$R_j = 0.00522 * 400 * \ln\frac{0.560}{0.500} = 0.237$$

$$R_{th} = 9.622 + 0.237 = 9.859$$

$$R_{eoc} = \frac{9.859 - 9.622}{9.859} * 4.229 * 10^{-3} = 0.1017 * 10^{-3}$$

Substituting these values into the simultaneous equations for indoor cables yields:

$$I = \sqrt{\frac{65 - t_s}{(0.4229 * 10^{-3} + 0.1017 * 10^{-3}) * 9.859}}$$

and

$$I = \sqrt{\frac{0.182 * 0.95 * 0.560 * (t_s - 20) + 0.0714 * 0.560^{0.75} * (t_s - 20)^{1.25}}{I * (0.4229 * 10^{-3} + 0.1017 * 10^{-3})}}$$

which, when solved simultaneously results in:

I = 43.084 or 43 amperes

APPENDIX II.

DERATING FACTORS FOR TWO SINGLE, CURRENT CARRYING CABLES JOINED BY AN OVERALL JACKET (SIAMESE)

If the number of cables (n) in Appendix I is changed from n=1 to n=2 the resulting ampacity would be 38 amperes. This equals a derating factor of 88.3% to account for the mutual heating of another cable in the proximity of the original single cable. Sensitivity studies have shown that a derating factor of 85% can be safety used for Siamese drop cables with current in both the inner and outer condutors and 70% can be used for Siamese drop cables with current in the outer conductor only.

Alan J. Amato, Senior Application Engineer
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Appendix III
TFC Semiflexible Cable Ampacity

TFC Semiflexible Cable Ampacity (Amperes)				
Cable Type	Current in Both Conductors		Current in Outer Conductors	
	20°C (68°F) Ambient	40°C (104°F) Ambient	20°C (68°F) Ambient	40°C (104°F) Ambient
T10 Series Semiflex Cable				
T10412	33	25	125	90
T10500	43	32	148	107
T10625	54	40	201	145
T10750	67	50	254	184
T10875	81	60	304	220
T101000	94	71	404	293
TX10 Series Semiflex Cable				
TX10565	50	38	158	115
TX10700	66	49	201	146
TX10840	79	59	257	187
TX101160	117	87	436	317

Notes:

1) Conductor operating temperature = 65°C (149°F)
2) Center conductor material - Copper clad aluminum
3) Outer conductor material - Aluminum

Drop Cable Ampacity

TFC Drop Cable Ampacity (Amperes)				
Cable Type	**Current in Both Conductors**		**Current in Outer Conductors**	
	20°C (68°F) Ambient	**40°C (104°F) Ambient**	**20°C (68°F) Ambient**	**40°C (104°F) Ambient**
59 Series Drop Cable				
Standard Shield (53%)	6	4	18	13
Standard Shield (67%)	6	4	20	14
Premium Shield (95%)	6	4	24	17
Trishield (53%)	6	4	22	15
Trishield (80%)	6	4	24	17
Quadshield (53%-34%)	6	5	25	18
6 Series Drop Cable				
Standard Shield (60%)	8	6	21	15
Premium Shield (90%)	8	6	27	19
Trishield (60%)	8	6	26	18
Trishield (80%)	8	6	28	20
Quadshield (60%-40%)	8	6	30	22
7 Series Drop Cable				
Standard Shield (53%)	10	7	24	18
Trishield (80%)	10	8	32	23
Quadshield (60%-36%)	10	8	34	25
11 Series Drop Cable				
Standard Shield (53%)	13	10	28	20
Premium Shield (60%)	13	10	29	21
Trishield (60%)	13	10	35	25
Quadshield (53%-32%)	13	10	38	28
Quadshield (60%-40%)	13	10	41	29
TX Flexible Feeder				
Standard Shield (60%)	41	30	42	30
Trishield (60%)	42	31	50	36
Quadshield (60%-40%)	42	31	58	42

Notes:

1) Conductor operating temperature = 65°C (149°F)
2) Derating factors (multiply derating factor by value selected above):
   Siamese, outer conductor of both components carrying current = 0.85
   Siamese, both conductors of both components carrying current = 0.70
3) Center conductor material - Copper clad steel
4) Outer conductor material - Combination of aluminum/polypropylene/aluminum tape(s) and aluminum alloy wire braid(s) as applicable.