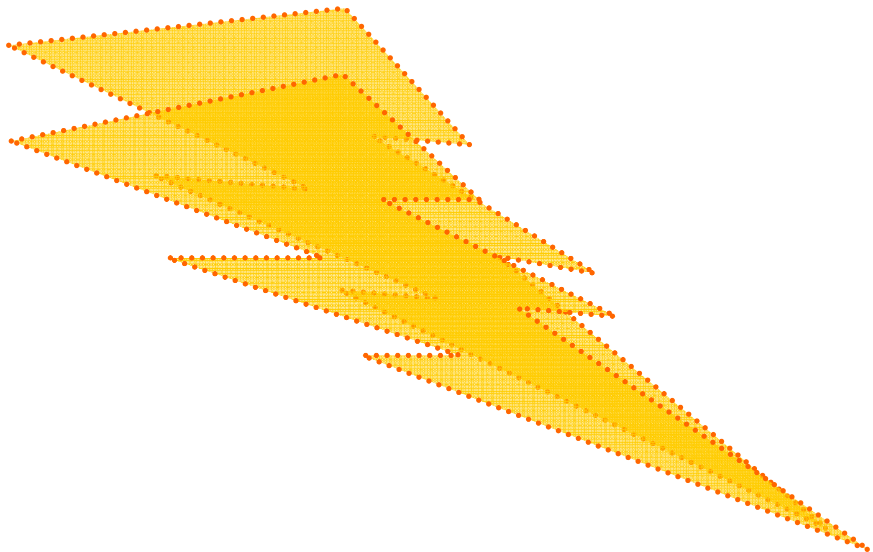
POWER AND VOLTAGE RATING



SCOPE:

The purpose of this document is to take the confusion out of power and voltage ratings in specifications and in product information publications.

This will be accomplished in three sections:

RMS (Root Mean Square) vs. RMS will discuss how this term is used in Power vs. Voltage

VOLTAGE RATINGS will discuss the differences between AC and DC volts as well as Peak vs. RMS voltage. Test standards and methods will also be reviewed and explained.

POWER/CURRENT RATINGS will provide test and measurement details as well as the basic theory surrounding current rating procedures and techniques. AC vs. DC and Peak vs. RMS will also be analyzed with regard to current.

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CONCLUSIONS

THE SIMPLE ANSWER

A BRIEF SUMMARY

Following is a brief summary of this document for those who may not need to read the theories and rationale.

VOLTAGE

Three voltage ratings are called out in the test reports:

1. Breakdown Voltage:	The failure voltage of the connector.
2. DWV (75% of breakdown):	The non-destructive voltage that the connector/cable should be tested at.
3. Working Voltage (1/3 of DWV):	The maximum continuous voltage that the product should be used at.

DC rating (compared to AC rating): VAC (RMS) * 1.414 = max DC

POWER/CURRENT

The current is limited by the ambient temperature and the number of contacts to be energized simultaneously.

Doubling the current creates four times the heat (temperature rise).

A connector with 50% of its contacts energized will carry approximately 75% as much current per contact as the single contact rating.

A connector with 100% of its contacts energized will carry approximately 60% as much current per contact as the single contact rating.

DEFINITIONS

THE POWER OF VOLTS

WHAT ARE VOLTS?

Volts are units of *Electro-motive Force*. Let's look more closely at that term Electro - Motive Force (also called EMF). Electro simply means electrical energy. Motive indicates propulsion or motion. Force is self-explanatory. This EMF is the potential difference that causes the electrical motion or current to flow. Think of it as electrical pressure.

Just like a fluid system, it is a difference in pressure that causes the fluid to flow from one point to another. Flow occurs from high to low pressure. The pressure inside the pipe is high, but the pressure on the other side of your kitchen faucet is low, so when you open the faucet valve, the pressure in the pipe pushes the water out into the low pressure of the room ambient (the kitchen sink). In the same way, electricity flows from high potential to low (+ of the power source to - of power supply).

CURRENT

The flow of electricity caused by the electrical pressure of the voltage is called current and is measured in Amperes (Amps).

The higher voltage that is applied to a given load, the higher the Amps that will flow through it will be.

RESISTANCE (LOAD)

Resistance is what limits the current flow for a given voltage. If you have a fixed voltage source, like a power supply, a wall outlet or a battery, varying the resistance of the load (including the entire circuit path) will vary the amount of current flowing through the load. The lower the resistance is, the more current will flow through the circuit.

That is why a high resistance connector is such a problem in a circuit. It will limit how much power is available to the load.

POWER

While the term Power is sometimes used interchangeably with the term current, they are *not* exactly the same.

High power connectors are actually high current connectors that deliver high amperage to high power loads, thus the interchangeability issue.

In reality, Power is measured in Watts, and Current is measured in Amps as previously discussed.

THE MATH BEHIND THE MAGIC

PAINFUL BUT NECESSARY

Term/Units:
I = Current/Amps
V = Voltage/Volts
R = Resistance/Ohms
P = Power/Watts

OHMS LAW

The basic relationship between voltage, current, and resistance can be expressed in three forms of the equation:

$I = V \div R$

$V = I * R$

$R = V \div I$

POWER

The most important thing to remember about power is the following formula:

POWER = HEAT

Well, it is not a real formula, but it *is* a real relationship.

The following formulas are based on DC or resistive AC circuits which are the majority of the applications. Large inductive or capacitive circuits require additional formula elements that we will not present at this time.

$P = V * I$

$P = I^2 * R$

$P = V^2 \div R$

RMS VS. RMS

There is so much confusion when it comes to Power or Current, AC or DC, Working Voltage, and DWV, etc. What does it all mean?

Well, it is confusing since we use some of the same terms for Power calculations as for voltage calculations, but they can actually be the exact opposite of what you think they are.

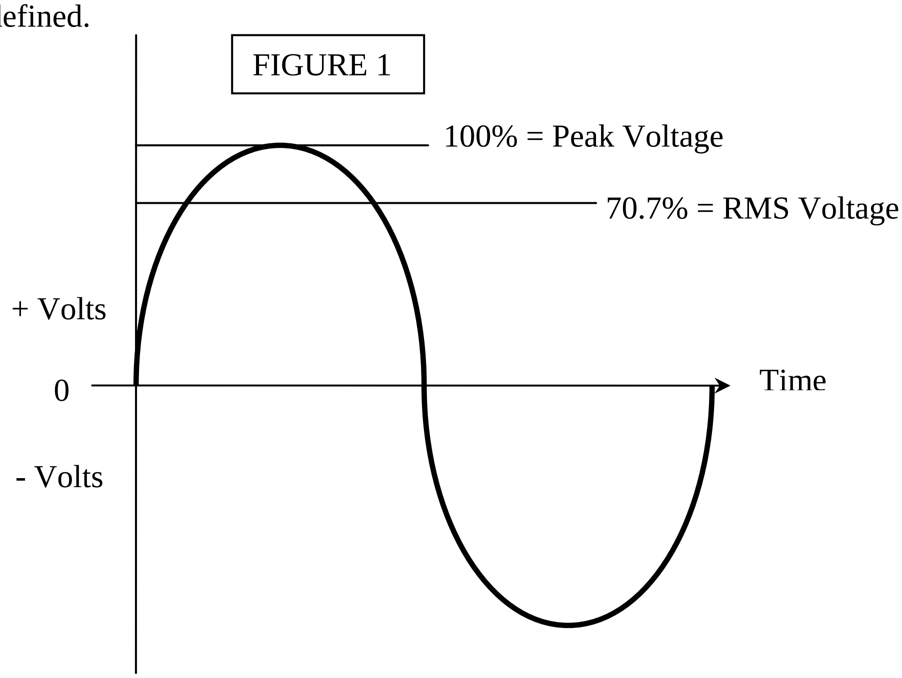
The main source of this problem is the RMS voltage “thing”. The following section will address how RMS affects the reporting and practical application of this mysterious term.

The RMS value is 70.7% of the peak voltage (See Figure 1.) and represents the amount of *heat* (Power) that an AC wave can produce as compared to the equivalent DC *voltage*.

The international convention for specifying AC voltage is to express the RMS value of the wave unless it is otherwise defined. Therefore, if you read a specified value that indicates 100 VAC, it means 100 VAC (RMS). If you wanted to report a voltage in peak value, you would record it as 141.4 VAC (PEAK).

You would have to include the word PEAK after the VAC designation, either in parenthesis or not. 141.4 VAC-Peak or 141.4 VAC Peak would also be acceptably defined.

FIGURE 1



This means that a 110 VAC (RMS) sine wave applied to a load will produce the same amount of heat/power (Watts) that a 110 VDC steady voltage will produce. The Peak value of said sine wave will actually be 155.5 VAC (PEAK) since the Alternating nature of the sine wave produces less power than the Direct Current. See Figure 1.

This does not mean that in regards to withstanding voltage that the RMS is the DC equivalent of the reported voltage; in fact, it is just the opposite. If you were to apply a DC voltage in the hopes of replicating the AC test, you would want to test at the peak voltage (1.414 x RMS). Therefore, when looking at a test report that specifies a test voltage of 500 VAC, which is the RMS value unless otherwise specified, the equivalent DC voltage would be 707 volts (1.414 x 500) since that is the actual maximum voltage that was applied.

So this is the question:

"It says in the report that the connector is rated at 300 VAC. What is the DC rating?"

What do you think the answer is?

1. 300 VDC
2. 424.2 VDC (300 x 1.414)
3. 212.1 VDC (300 x 0.707)

If you chose 424.2 VDC, you are right! The 300 VAC rating is a RMS value since it was not otherwise specified which means that the peak voltage (the highest voltage at the top of the sine wave) is 1.414 times that value.

Think of the rising sine wave as a DC voltage source like a DC power supply that is being turned up until the dielectric breaks down. This is the rational behind rating DC at the peak value of the AC wave used.

In reality, this is a slightly conservative number since the speed at which this wave rises actually would cause a failure at a slightly lower value then if it were a slow rising DC source. It is better to be safe in your estimation.

VOLTAGE RATING

Three voltage rating terms will be discussed:

Breakdown Voltage
Dielectric Withstanding Voltage
Working Voltage

Note: A brief discussion of voltage pulses will be included at the end of this section.

BREAKDOWN VOLTAGE

Breakdown Voltage tests slowly raise the voltage applied to the Device under Test (DUT) until an arc, corona (a high voltage charged field), or high leakage current occurs indicating a failure.

This test is performed in order to establish the minimum voltage level required to cause a failure in the laboratory.

Three quarters (3/4) of the breakdown voltage will be established as the Dielectric Withstanding Voltage (DWV) test voltage to allow an appropriate safety factor.

DIELECTRIC WITHSTANDING VOLTAGE

This is the attribute that defines the high voltage limit of the device under evaluation whether it be a connector, socket, cable, or cable assembly. Throughout this document, we will refer to the connector, socket, etc. as the DUT (Device under Test).

Dielectric Withstanding Voltage (DWV) in its simplest explanation using the terms of its name is just what it says; it is the *Voltage* that the *Dielectric* material in conjunction with the conductive material can *Withstand* while still functioning within the application.

What the above statement means is that at voltages not exceeding the DWV rating, there shall be no arcing, corona, leakage current, etc. that would be detrimental to the DUT or to the application in which it is being used.

DWV is a TEST voltage applied. It is not the same as the Working Voltage.

WORKING VOLTAGE

The Working Voltage of a connector is just that; it is the amount of voltage that a connector can withstand all the time.

The Working Voltage is rated at one third (1/3) of the DWV test voltage.

The reason this is apparently de-rated is to ensure that the connector will operate at the working voltage but still not fail when transient voltages (surges) occur at amplitudes of up to three times the working voltage.

"Crest factors" of three are common among other types of testing such as random vibration which runs at some defined average value (let's say 10 g), but has discreet vibration pulses up to three time higher (30 g pulses). Yet the vibration test is still defined by the average amplitude (it would be specified as a 10 g test).

VOLTAGE SURGES AND PULSES

Lightning strike and other high voltage surges such as inductive or capacitive spikes are special cases of voltage withstanding.

Voltage surges and pulses can not be allowed to exceed the normal DWV test voltage.

Very fast surges and pulses will actually cause arcing at lower voltages than our test signal of 60 Hz "wall outlet frequency".

Fast changing voltage signals will have to be dealt with on a case by case basis. In most instances, this will require independent tests that typically cost in the $5K – 10K range.

CURRENT

~~POWER~~ RATING

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PREFACE

Note: Some of the information in this section is repeated from the Voltage Rating section.

For this discussion, we will assume all loads will be resistive in nature (such as computer and most telecom applications). Inductive and capacitive loads are beyond the scope of this paper.

The international convention for specifying AC voltage is to express the RMS value of the wave, and that is how current will be addressed in this section.

From a power standpoint, a 100 VAC source will provide the same amount of power as a 100 VDC supply since the VAC value is RMS.

This means that power ratings are the same for AC and DC as long as the VAC is an RMS value.

POWER LOAD

Let us clarify right in the beginning: connectors do not supply Power; they supply Current.

Loads (the working parts of the circuit) require current to power the work they do.

The receptacle in the wall is not a 100 watt receptacle, but the bulb you plug into it dissipates 100 watts (of heat). The light coming from the bulb is a result of the heat.

So in the above case, we have a 110 VAC wall outlet lighting up a 100 watt light bulb. By manipulating the formula $P = V * I$ ($I = P \div V$), we can calculate the current to be 0.909 A. That same wall outlet can supply the same current from a 220 VAC source and power a 200 watt bulb. That does not mean that the outlet is suddenly more capable than it was, it just means that the source and load have changed.

This is the end of the power discussion! The rest of this section will deal with Current Carrying Capacity (CCC).

CURRENT CARRYING CAPACITY

STANDARD DEFINITION

The standard industry definition for Current Carrying Capacity of a conductor is:

The maximum amount of current that a conductor (in our case it's a contact) or its insulator (connector body) can carry without melting.

CONNECTOR SPECIFIC DEFINITION

The maximum amount of current that a connector can carry without exceeding the maximum temperature rating of any of the connector component materials is the Current Carrying Capacity of the connector or cable assembly.

This maximum temperature rating includes the temperature rise plus the ambient (operating) temperature.

As in any other system, it is only as good as the weakest link meaning the lowest rated material in the system which is usually the wire

LIMITING FACTORS

1. The conductivity of the contact material.

2. Contact cross-sectional area and the contact length (total geometry).

3. Many times the contact interface is the "hot spot" in a connector.

   Note: in a system where the contact interface is the source of heat generation, longer contacts will actually provide more cooling.

4. The number of current carrying contacts in close proximity.

5. Ambient temperature.

6. Housing material and construction.

AMBIENT TEMPERATURE

The most common limit that you will be working with is the ambient temperature.

The capacity of the system is directly limited by the ambient temperature in which the DUT will operate.

The current passing through the contact (s) will create a certain amount of temperature rise. That is, the increase in temperature due to current.

This means that at each given current, the temperature will rise a specific amount unrelated to the ambient temperature (within the operating limits).

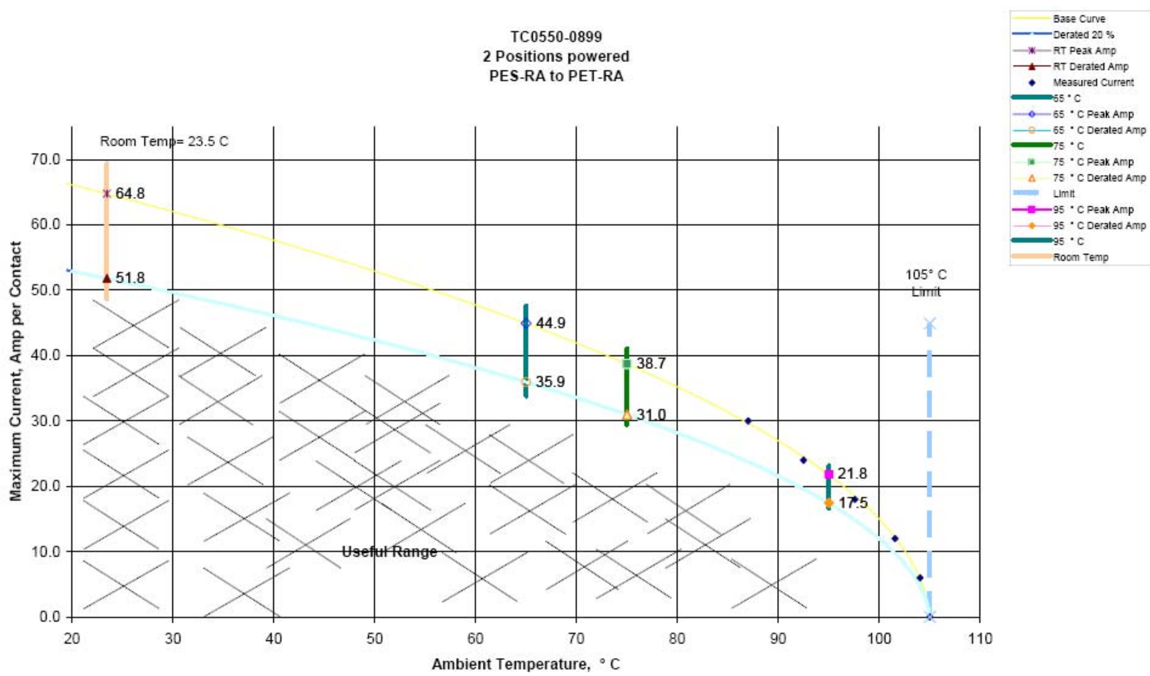
Ambient + temp rise = connector temperature

Since there is a defined temperature limit for the material systems, then at higher ambient temperatures, it takes less current to reach said limits.

AMBIENT TEMPERATURE VS. CCC

The following chart represents the relationship of the capacity of the system as limited by the ambient temperature in which the DUT will operate.

FIGURE 2



NUMBER OF CONTACTS POWERED

The second most common limit that you will be working with is the number of contacts within a connector that will be powered-on simultaneously.

The capacity of the system is directly limited by the number of contacts in the DUT that will operate and the proximity of said contacts.

Right now, the standard test at Samtec is performed with six contacts grouped together. This provides a moderate degree of mutual heating and will cover most applications.

Below is an example of how current-contact density effects Current Carrying Capacity in one connector series tested:

FIGURE 3

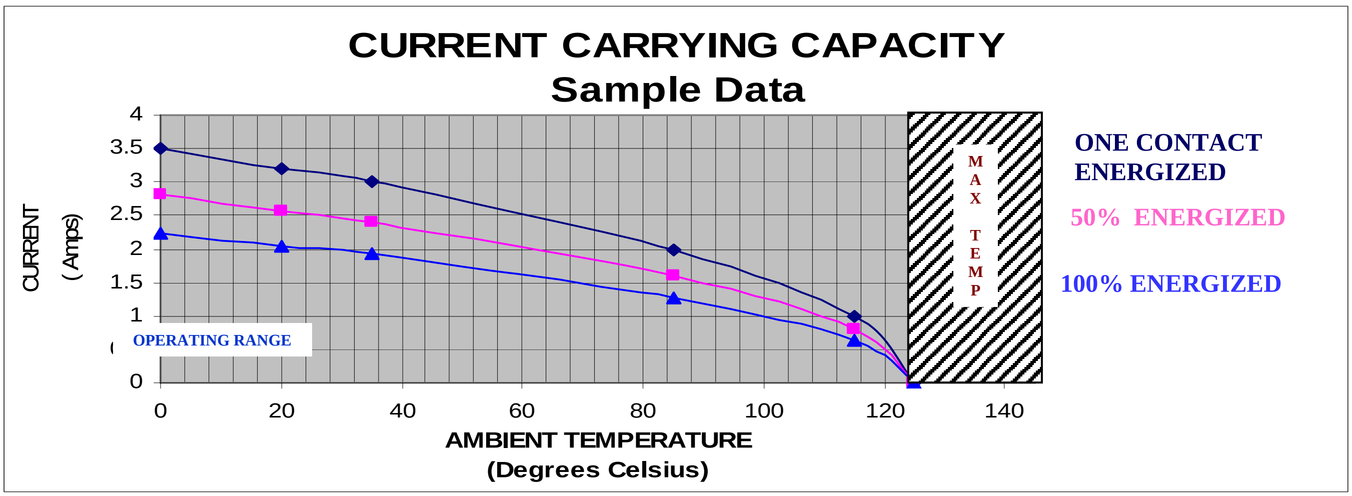


TABLE 1

Ambient Temperature (Degrees C)	Max Current One Contact	Max Current 50% Energized	Max Current 100% Energized
125	0	0	0
115	1	0.8	0.64
85	2	1.6	1.28
35	3	2.4	1.92
20	3.2	2.56	2.048
0	3.5	2.8	2.24

Do not be confused into using the above relationship for every device you encounter. This is how one particular device performs. It is just presented to illustrate the effects of multiple contacts being powered.

A general approximation for connector loading is that if the connector is evenly loaded, that is, energized contacts are evenly distributed throughout the connector, then 50% loading can provide about 75% the Current Carrying Capacity as compared to a single contact rating. A connector 100% energized will be able to carry about 60% the current as compared to a single contact rating.

CHANGING CURRENT VS. CHANGING CAPACITY

If you look closely at Figures 2 or 3, you will notice that the data lines on the graphs are not straight.

This is because the current-power relationship is not linear. That is also evident in the formula $P = I^2 * R$.

What this means is that if you take current and load as follows:

$P = (2\ \text{Amps})^2 * 10\ \Omega$

The power dissipated by the load is 40 watts.

If we now want to double that current, we get the following result:

$P = (4\ \text{Amps})^2 * 10\ \Omega$

The power dissipated now for the same load and doubled current is 160 watts.

This means that the DUT will get four times hotter for an Amperage increase of double.

CURRENT PULSES AND SURGES

As with voltage, transient currents must be dealt with on a case by case basis.

The amount of energy being delivered must be understood before a determination can be made regarding the ability of a DUT to carry the pulse in question.

The data required to understand the pulse/surge are:

1. Ambient Temperature (as always).

2. Steady state current, if any (the normal 100% of the time amperage).

3. Pulse shape characteristics (timing, amplitude, repetition rate).

Contact Us

For questions about the information contained in this document, contact our Power Integrity Support Group at pi@samtec.com