

Technology Guide for Power Calculation for Coaxial Switching Products



Definitions

ZC: System's characteristic impedance (Ω)

P: Power in watts

PREF: Reference power in watts

U_{max}: Maximum voltage in V

CF (frequency correction): This takes into account the skin effect and the dissipation part in the dielectric that varies according to the frequency.

CT (temperature correction): This takes into account the external environment temperature and its impact on radiation and convection. This coefficient is calculated for infinitely long revolution symmetrical structures. Therefore, it does not apply to all components. However, in most case, it provides a conservative approach.

CR (VSWR correction): This takes into account any standing waves present in the power transmission line. It is the system's V.S.W.R. but not the switch's V.S.W.R. For instance, in the case of a line operating in open or short circuit, the worst case is the power present at each point of the switch is multiplied by 4.

CA (altitude correction): This takes into account the convection decrease when the pressure drops, in a non-pressurized area of a plane, for instance.

RF Power Rating of Coaxial Switches

The maximum power conveyed through a coaxial switch is limited by two factors: **heat** and **dielectric strength**.

I MAXIMUM PERMISSIBLE HEAT POWER

Part of the power conveyed through the switch turns into heat due to the dielectric and ohmic losses of the materials involved. The temperature becomes stable at about a value for which the heat generated by the power flow is equal to the heat dissipated by the switch through radiation, conduction and convection.

Such temperatures must remain lower than the acceptable limit for each material in the switch. This determines the **maximum permissible heat power**.

The maximum permissible heat power depends on several parameters:

1. Internal Heat Generation

Parameters:

- Base materials and plating resistivity
- Contact area resistivity
- Dissipation in dielectric materials
- Usage frequency
- Conveyed power and waveform
- Presence of standing waves

2. Heat Released in the Surrounding Environment

Parameters:

- Heat exchange on the surface with the outside
- Outside surface emissivity (gold plated, passivated surfaces)
- Quality of thermal bonds with surrounding parts
- Air flow (free or forced convection)
- Temperature and pressure of the surrounding environment

3. Permissible Temperature Limits

Parameters:

- Dielectric materials used in the connector and cable (Teflon, polypropylene, epoxy, etc.)
- Permissible surface temperature

To determine the maximum permissible heat power, it is necessary to know the precise internal components of the switches, as well as the actual product usage environment. It is therefore essential that customers and suppliers work together. Several approaches are possible:

A) SIMPLE APPROACH

This approach provides some permissible power values for most popular switches and their typical internal components. It is based on simple calculation models confirmed with some tests. The maximum conveyable power value is calculated as follows:

$$P = P_{REF} \times C_F \times C_T \times C_R \times C_A$$

P_{REF} is the reference power

C_F , C_T , C_R , C_A are correction factors

Refer to the calculation form in the following pages of this document to find the value of these parameters, or contact us for a specific product.

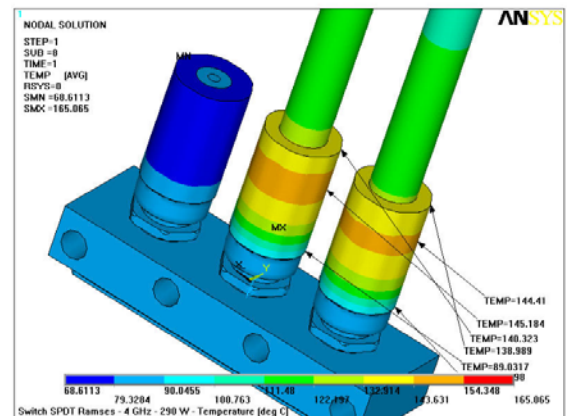
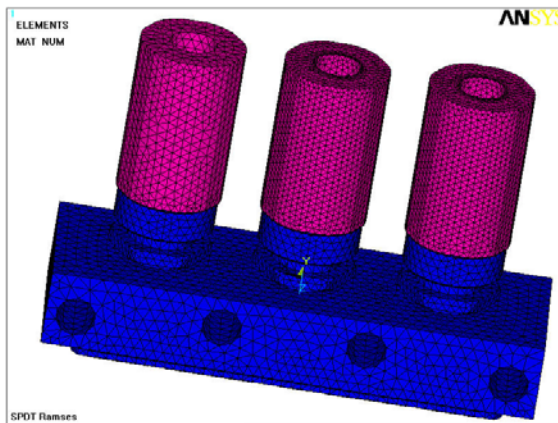
In the case of a repeated pulse signal, the power (P) calculated by the above formula is an average power. **In such a case, check that the peak voltage remains acceptable.**

Note: This is an indicative approach. It does not replace experimentation in the real environment of the switch.

B) REALISTIC THEORETICAL APPROACH

This approach uses developed models, such as finite element methods. It requires having an accurate knowledge of the switch environment and the material characteristics. This is a time consuming and costly approach. It can be used in difficult cases where experimentation is too complex. It also requires experimental adjustments but in conditions that are more accessible to experimentation.

Thermal calculations use the following methods and assumptions. The surface temperature is the controlling parameter. From this temperature and from conduction, convection and radiating emission, the temperature of each part of the switch is calculated knowing that the energy dissipated inside the switch must equal, at steady state, the energy lost outside the switch. A coaxial switch is defined as having layers of different materials (metal, air, polymers) which simulate the construction of the product. Heat dissipation is calculated using two dissipation modes: Joule effect in the conducting layers and dielectric losses in the insulator. The skin effect and the different surface plating and their thickness are considered.



The composite Insertion Loss of a transmission line is determined by the losses associated with the inner and outer conductors, the dielectric medium and characteristic impedance mismatches.

Insertion loss on SPDT coaxial switches fitted with SMA type connectors can be modeled using “conductor loss” β_1 and “dielectric losses” β_2 .

$$A = \beta_1 + \beta_2$$

$$\beta_1 \text{ (dB/cm)} = \text{Conductor Loss} = \frac{0,274}{Z_c} \left(\frac{\sqrt{\mu_1}}{a \sqrt{\sigma_1}} + \frac{\sqrt{\mu_2}}{b \sqrt{\sigma_2}} \right) \sqrt{F}$$

$$\beta_2 \text{ (dB/cm)} = \text{Dielectric Losses} = 0,91 \cdot \sqrt{\epsilon} \cdot \tan \delta \cdot K \cdot F \cdot 10^{-3}$$

Where:

Z_c : Characteristic impedance (Ohms)

a : Outer conductor inside diameter (cm)

b : Inner conductor diameter (cm)

F : Frequency (MHz)

σ_1 : Conductivity of inner conductor ($\Omega \cdot \text{cm}$)⁻¹

σ_2 : Conductivity of outer conductor ($\Omega \cdot \text{cm}$)⁻¹

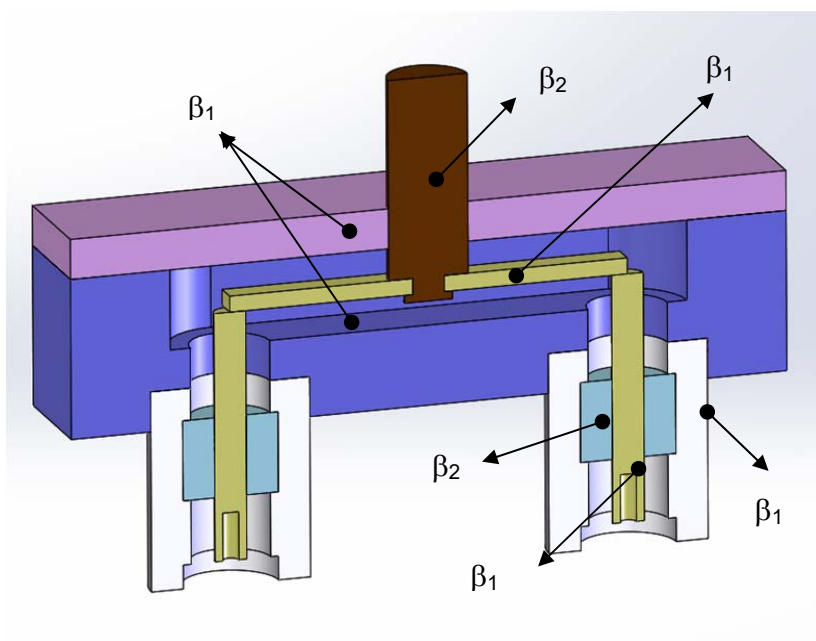
μ_1 : Magnetic permeability of inner conductor

μ_2 : Magnetic permeability of outer conductor

ε : Dielectric constant

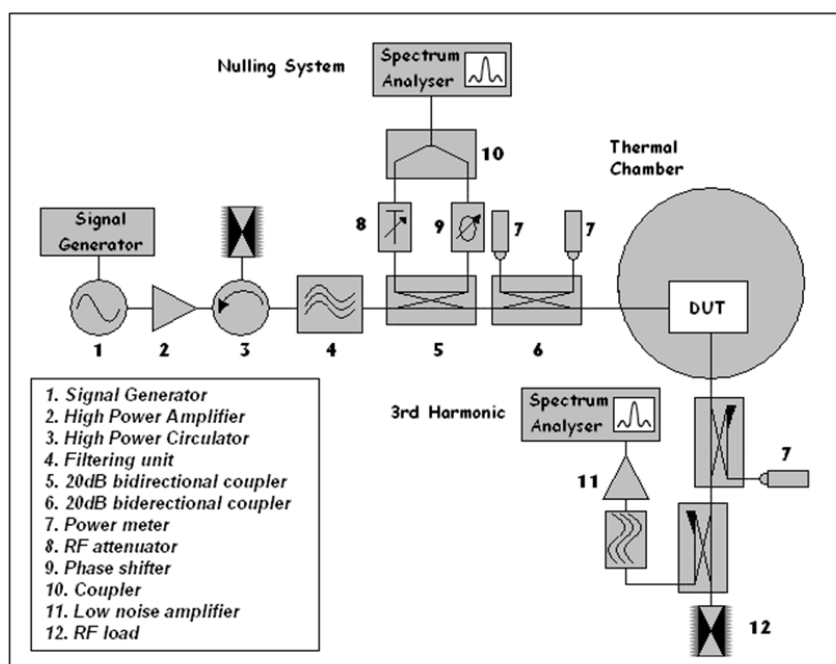
$\tan \delta$: Loss tangent

K = Ratio between the two conductors b/a



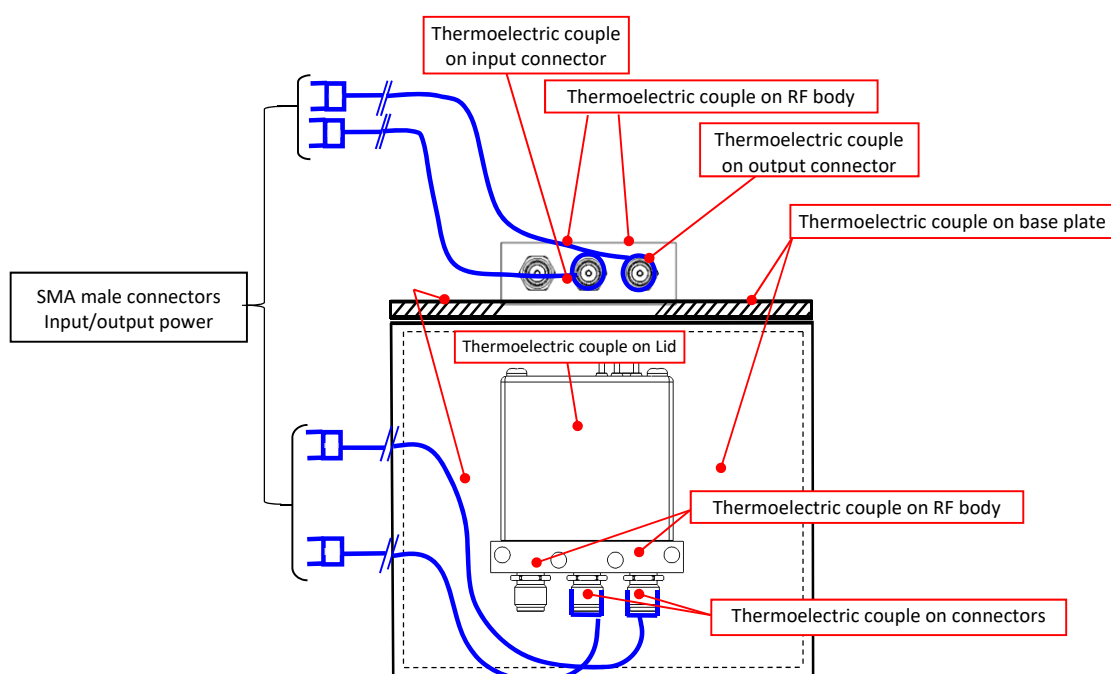
C) EXPERIMENTAL APPROACH

An experimental approach is usually carried out by the final user. The actual switch arrangement or DUT (Device Under Test) is fixed on a base plate in a thermal chamber. Thermoelectric couples are set out according to internal procedure (usually, placed on the base plate, RF test cables and the RF body). We recommend to use our TestPro or SHF ultra low loss cable assemblies for the RF connections from the switch RF paths to RF components or equipment.



Test Set Up

Example of RF Cable Connection and Thermoelectric Couple Location



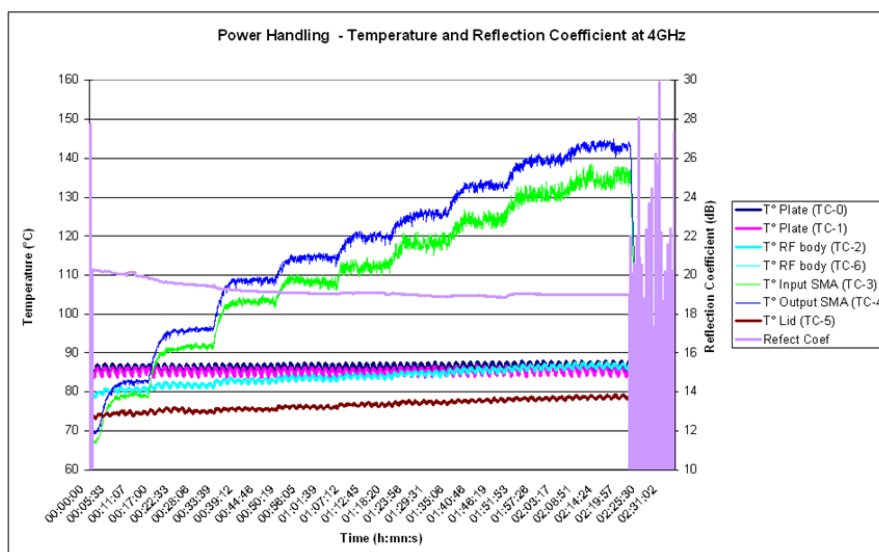
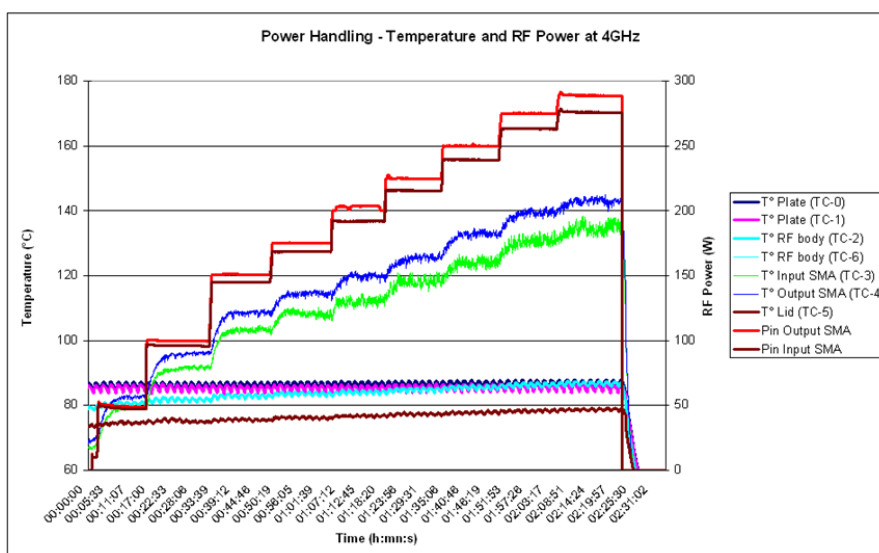
The RF switch arrangement is placed and fixed on a base plate. TestPro or SHF cable assemblies for input/output power are connected to the switch RF ports using adequate coupling torque. The thermoelectric couples are set on the product as described into internal procedure and connected to the automatic test benches interfaces. Reflection coefficient and insertion loss measurements are performed at ambient temperature and pressure in order to check any anomaly.

The RF power is injected on the RF path and then transferred to a matched load. The applied power is increased in steps up to desired RF power.

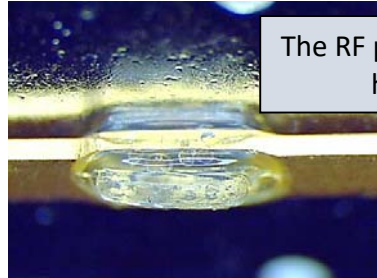
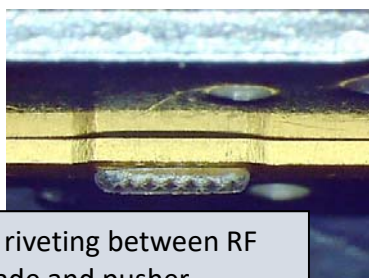
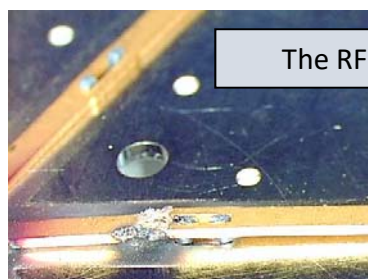
The following parameters are continuously monitored during the test:

- Reflection coefficient through reflected power
- Input power on input RF connector and output power on output RF connector
- Temperature changes through each thermoelectric couples

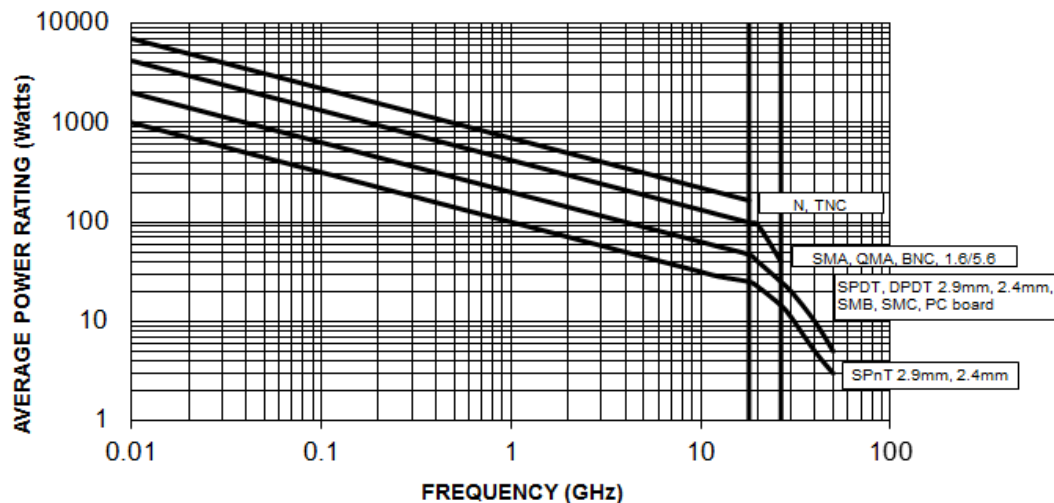
Example of Test History



If RF input power is higher than the power handling capability of the switch, some discharges and breakdown may occur and damage the RF connectors or RF line of the switch. See pictures below for illustrations of permanent damages to the device.



RF Power Chart



II DIELECTRIC STRENGTH

Beyond a power threshold, the electrical field inside the RF switch causes the materials to wear out or fail early. This phenomenon defines the **maximum permissible withstand voltage**.

1. The dielectric strength is based on several parameters

The insulation breakdown and the corona effect depend on the electric field inside the RF line. The type and consequences of the breakdown may vary according to the dielectric materials. In the case of a solid insulator, the breakdown will destroy the dielectric, which causes a conductive path to occur along the carbonized walls of the arc track. If the breakdown threshold is not reached, vacuum in the dielectric may cause local field reinforcement. This may lead to partial discharges. Over time, such discharges will erode the dielectric and cause early aging. In the case of an air insulator, the breakdown is not necessarily destructive. Such breakdown will occur depending on ambient pressure, type of gas, opposite surface cleanliness and line geometry. All of these phenomena have a complex dependency upon frequency.

2. Dielectric strength and pressure effect (air dielectric)

This is a well-known phenomenon. As pressure drops, disruptive voltage falls. It dips to a minimum for a critical value of the pressure multiplied by the distance between the electrodes. It then increases for very low pressure. The variation of the disruptive voltage according to the pressure follows the Paschen law. It provides that for a breakdown to occur, shocks between gas molecules and electrons must cause the electrons to multiply (the avalanche effect). The disruptive voltage is then directly related to the number of gas molecules between both electrodes. This number is proportional to the product of the pressure by the distance between both electrodes.

In the case of coax connectors, the field is not homogeneous and the Paschen law does not apply directly. However, it provides a qualitative assessment of the disruptive voltage according to the pressure.

3. Dielectric strength and frequency effect (air dielectric)

In microwave, breakdown will occur according to much more complex rules. Electrons present between both conductors are driven by the alternating electromagnetic field.

The breakdown comes from the simultaneous occurrence of the electron loss phenomenon. The electron production is the result of free electrons colliding with gas molecules or conductors. It requires minimum kinetic energy. The electron loss is the result of electrons being spread and drained through conductors. It requires minimum kinetic energy. The electron loss is the result of electrons being spread and drained through conductors. The breakdown occurs when more electrons are produced than used. This expressed by the Townsend criteria.

At ambient pressure, the average free travel of electrons is very small, and there are many shocks but they are not effective for electron production. The breakdown occurs at a high voltage that is practically independent from the frequency.

At low pressure, the average free travel of electrons increases. Electrons gain kinetic energy and ionize gas molecules more effectively. The breakdown voltage then falls to a minimum. At this minimum, there are two phenomena regarding the influence of frequency. First, if frequency is low and rising, the breakdown will occur at increasingly lower voltage levels (less electron drainage by the conductors). Then, if frequency keeps rising, the breakdown will occur at a higher voltage (because the electron oscillation magnitude becomes too low to ionize the gas molecules effectively).

For the range of distance between conductors in RF switch, note that a frequency increase does not have any influence at high pressure and it actually improves the dielectric strength at low pressure. This latest effect cannot be quantified in a simple way.

The maximum voltage limits of a switch are determined by the length of the air gap between the internal parts in the transmission path and the body of the switch, and by the voltage breakdown ratings of the RF connectors. The air gap distance in Radiall electromechanical coaxial switches varies with each model, and voltage. See table below:

Connector Series	Voltage Rating (RMS)	Peak Power
SMA	300 V	1.80 kW
2.92 mm	250 V	1.25 kW
2.40 mm	200 V	0.80 kW
1.85 mm	200 V	0.80 kW
TNC	400 V	3.00 kW
N	400 V	3.00 kW

4. Dielectric strength and V.S.W.R.

The presence of mismatches at various points in a line leads to the occurrence of standing waves that increase the electrical field locally. The maximum voltage at any point will therefore be:

$$U_{\max} = U_{\text{inci}} \cdot \frac{2 \text{ VSWR}}{\text{VSWR} + 1}$$

Where V.S.W.R. is the V.S.W.R. of the system and U_{inci} is the incident voltage. U_{\max} will have to be compared to the maximum permissible voltage for the switch

5. How to calculate a maximum withstand voltage

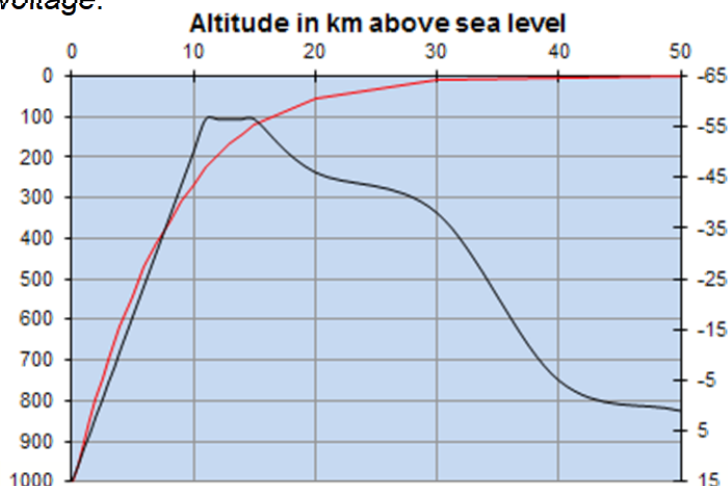
a) At ambient pressure

Just check that the maximum voltage does not exceed the permissible value for the series by following this formula:

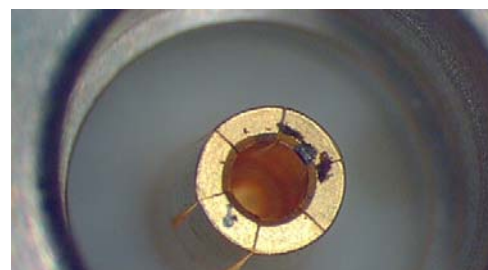
$$U_{\max} = \frac{2 \text{ VSWR}}{\text{VSWR} + 1} \cdot \sqrt{P \times Z_C}$$

b) At any other pressure

The derating coefficient from the following table must be applied to the maximum permissible voltage.



Pressure (mBar)	Derating	Altitude (feet)	Altitude (km)
1,000	1.00	0	0
480	0.50	20,000	6
200	0.25	40,000	12
80	0.12	60,000	18
59	0.10	70,000	21



Example of voltage breakdown damage

III CALCULATION FORMULA

$$P = P_{REF} \times \underbrace{C_F \times C_T \times C_R \times C_A}_{\text{CORRECTION FACTORS}}$$

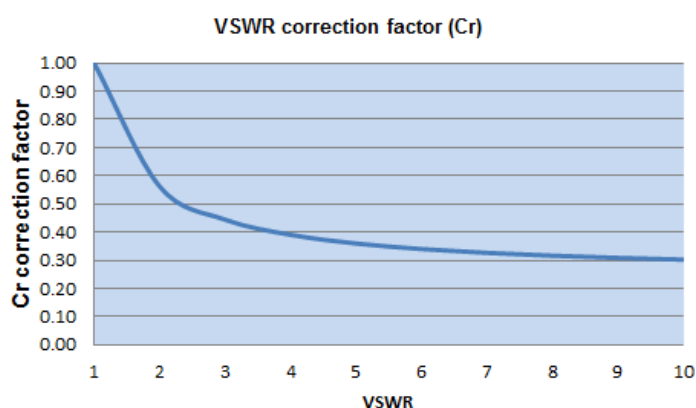
REFERENCE POWER

		P_{REF} (Watt)	F_{REF} (MHz)
SMA	SPDT – DPDT – DP3T– SPnT	4,200	10
2.92 mm	SPDT – DPDT – DP3T	2,000	10
	SPnT	1,000	
2.4 mm	SPDT – DPDT	2,000	10
	SPnT	1,000	
1.85 mm	SPDT	2,000	10
TNC	SPDT – DPDT – SPnT	7,000	10
N	SPDT – DPDT – SPnT	7,000	10

CORRECTION FACTORS

VSWR

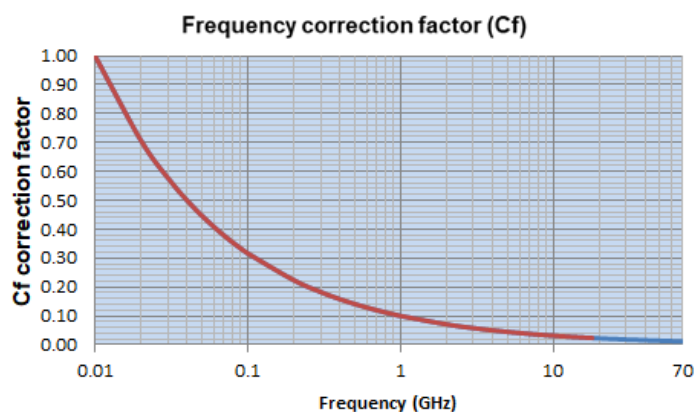
The incident signal will, along the line, combine with the reflected signal. The VSWR of the system seen from the connector is the driving factor. The worst case will be the combination of incident and reflected signals in phase.



Frequency

The signal traveling in the RF switch loses energy through the Joule effect in the conducting layers and dielectric losses. The Joule effect depends on material characteristics and skin depth, which is linked to the frequency. A rough calculation gives an attenuation having a SQRT (frequency) behavior. When the surface plating thickness is taken into consideration, formulas are more complicated but can still be calculated the same way.

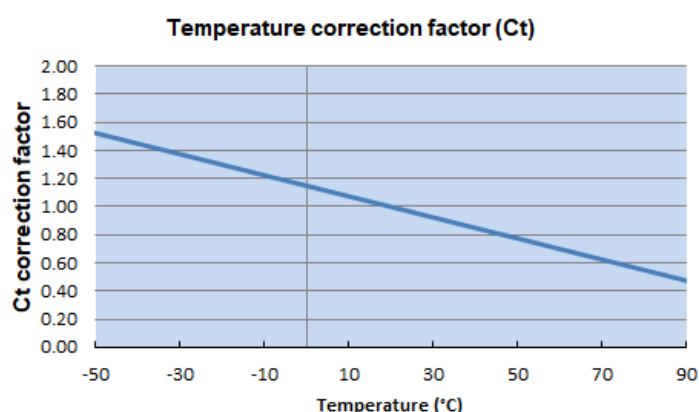
The driving parameters of the dielectric losses are the loss angle and the frequency. A rough calculation gives an attenuation having a linear behavior versus frequency. Resulting from those two dissipation modes and depending on the amount of dielectric in each series of connectors, an overall derating factor versus frequency can be given for SMA, 2.92 mm, 2.40 mm or N connectors.



Connector types:
SMA – 2.92 mm
2.40 mm – 1.85 mm
N-TNC

Temperature

The effect of the ambient temperature increase is to lower the amount of energy that can be dissipated by radiation or convection or conduction from the switch to the environment. Another effect is to change material dissipation characteristics such as conductivity, emissivity, loss angle, and resistivity. Those complex effects lead to temperature dependency of the switch.

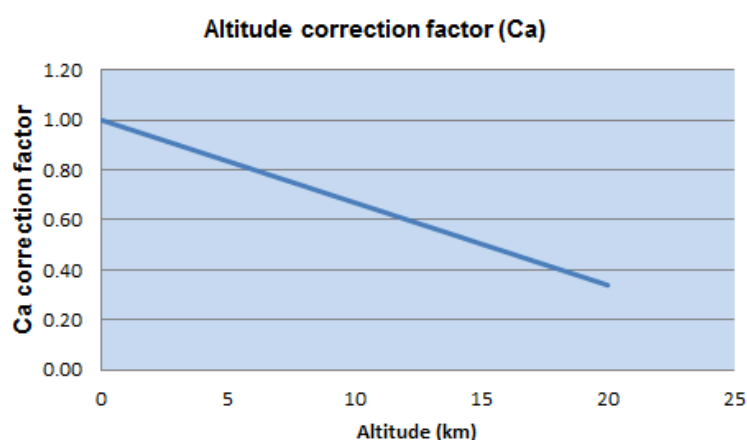


Connector types:
SMA – 2.92 mm
2.40 mm – 1.85 mm
N-TNC

Altitude/Pressure

The effect of the pressure decrease is to lower the amount of energy that can be dissipated by convection from the switch to the environment. This assumes that no forced air convection, but only natural convection is involved in the energy transfer. The energy transfer at the interface between the switch and the environment is driven by different quantities (Prandtl, Grashof, Rayleigh and Nusselt) which involve dynamic viscosity, conductivity, specific heat, cinematic viscosity, cubic expansion coefficient and volume mass of the air. Air pressure can easily be linked to the altitude, as shown in the table below.

Altitude (Km)	0	6	12	18
Altitude (feet)	0	20,000	40,000	60,000
Pressure (mbar)	1,000	480	200	80



The approximation formulas for the corrective factors are given below for the relevant connector series used in coaxial switches.

	C_F Frequency (GHz)	C_T Temperature (°C)	C_R <i>max V.S.W.R. view from connector</i>	C_A Altitude (<i>h</i> in Km)
SMA	$C_F = \frac{1}{\sqrt{F}} \times 0.1$	$C_T = 1 - \frac{7.5(T - 20)}{1000}$	$C_R = \frac{(VSWR + 1)^2}{4(VSWR)^2}$	$C_A = 1 - 0.033 \times h$
2.92 mm				
2.4 mm				
1.85 mm				
TNC				
N				

IV EXAMPLE

To determine the maximum permissible heat power, it is necessary to know the precise tests conditions. In this example, a simple approach was used.

Type	SPDT fitted with SMA type connectors	-
VSWR	1.20	-
Frequency	18	GHz
Altitude	1	km
Temperature	+55	°C

The maximum conveyable power value is calculated as follows:

$$P = P_{REF} \times \underbrace{C_F \times C_T \times C_R \times C_A}_{\text{CORRECTION FACTORS}}$$

P_{REF} is the reference power.

REFERENCE POWER

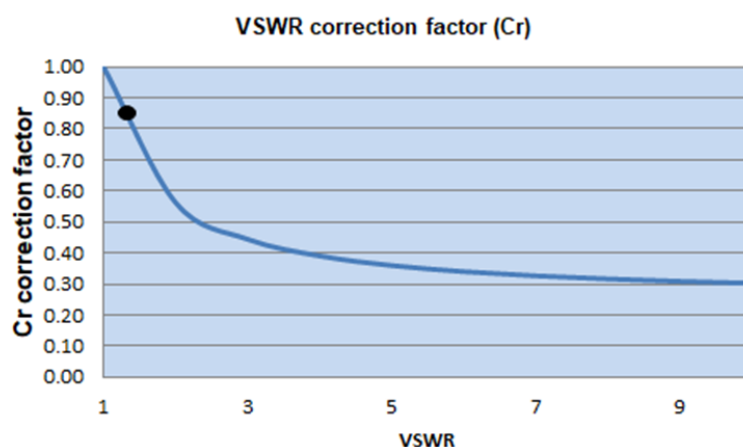
		P_{REF} (Watt)	F_{REF} (MHz)
SMA	SPDT – DPDT - DP3T- SPnT	4200	10

CORRECTION FACTORS

C_R

In this example, VSWR view from the connector of the switch is 1.20.

	C_R max V.S.W.R. view from connector
SMA	$C_R = \frac{(VSWR + 1)^2}{4(VSWR)^2}$

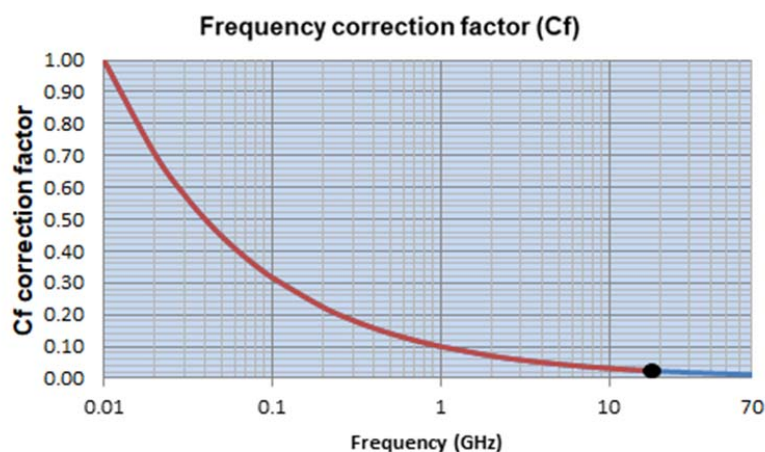


A derating factor of **0.84** must be applied.

C_F

In this example, the test frequency view from the connector of the switch is 18 GHz.

	C_F Frequency (GHz)
SMA	$C_F = \frac{1}{\sqrt{F}} \times 0.1$

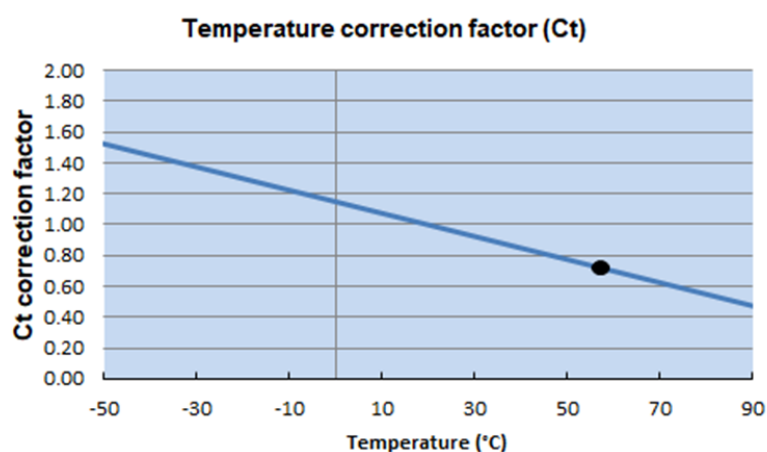


A derating factor of **0.02** must be applied.

C_T

In this example, the temperature view from the switch is +55 °C.

	C_T Temperature (°C)
SMA	$C_T = 1 - \frac{7.5(T - 20)}{1000}$

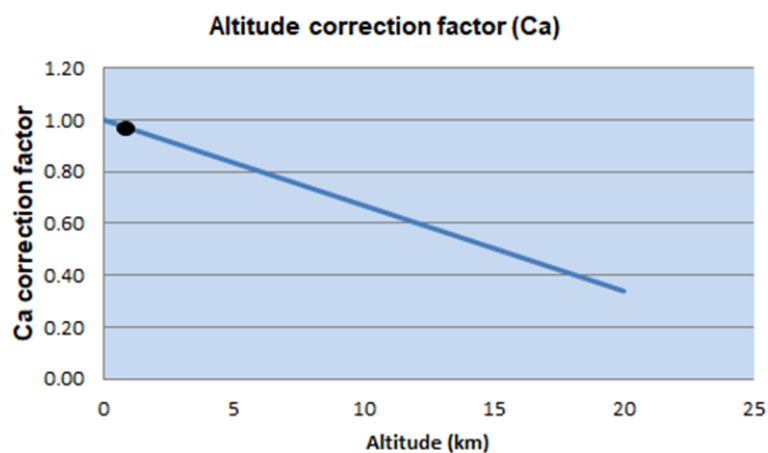


A derating factor of **0.74** must be applied.

C_A

In this example altitude view from the switch is 1 km.

	C_A Altitude (h in Km)
SMA	$C_A = 1 - 0.033 \times h$



A derating factor of **0.97** must be applied.

The maximum conveyable power value is calculated as follows:

$$P = P_{REF} \times C_F \times C_T \times C_R \times C_A$$

$$P = 4200 \times 0.023 \times 0.737 \times 0.840 \times 0.967$$

$$P = 60 \text{ Wcw}$$

Power handling capability of SPDT fitted with SMA type connectors is **60 Wcw** at 18 GHz, +55 °C (base plate), 1.20 of VSWR at 1 km.

To determine the maximum withstand voltage, it is necessary to use the same electrical and environmental conditions. The following formula must be used to calculate maximum withstand voltage.

$$P_{inci} = P_{REF} \times C_F \qquad P_{inci} = 4200 \times 0.023 \qquad P_{inci} = 97 \text{ W}$$

$$U_{inci} = \sqrt{P_{inci} \times Z_C} \qquad U_{inci} = 70 \text{ V}$$

$$U_{max} = U_{inci} \cdot \frac{2 \text{ VSWR}}{\text{VSWR} + 1}$$

$$U_{max} = 70 \times \frac{2.40}{2.20}$$

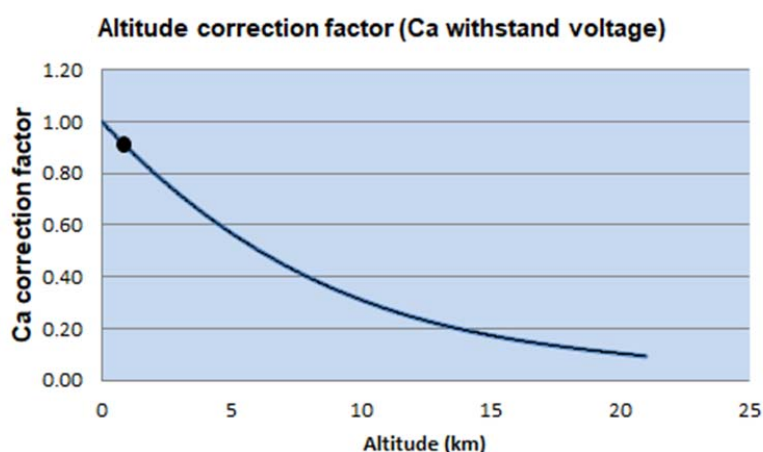
$$U_{max} = 76 \text{ V}$$

U_{max} reach 76 V.

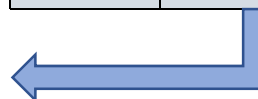
Maximum withstand voltage permissible on SMA type switches is 300 V at sea level.

Connector Series	Voltage Rating (RMS)	Peak Power
SMA	300 V	1.80 kW

A derating factor to the maximum withstand voltage due to altitude/pressure must be applied according to the following table.



Pressure (mBar)	Derating	Altitude (feet)	Altitude (km)
1,000	1.00	0	0
480	0.50	20,000	6
200	0.25	40,000	12
80	0.12	60,000	18
59	0.10	70,000	21



A derating factor of **0.90** must be applied to the maximum withstand voltage. Maximum withstand voltage permissible on SMA type switches at 1 km altitude is **270 V**.

SPDT fitted with SMA type connectors can handle without problem U_{max} of 76 V.

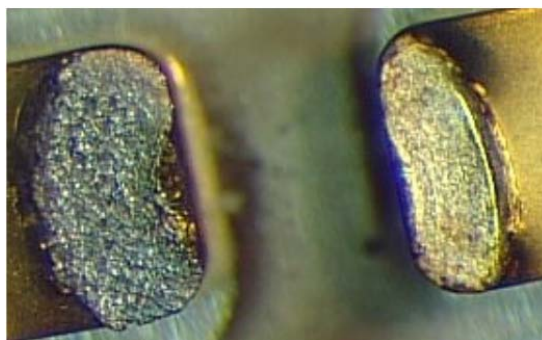
V HOT SWITCHING

Hot switching occurs when RF microwave power is present at the ports of the switch at the time of the switching. During hot switching, spark voltage and current occurs. It's similar to an electrical arc. This arcing causes degradation of the switch contacts by leaving deposits on the contact extremity and burning them. It causes significant stress on internal contacts, which can lead to premature failure.

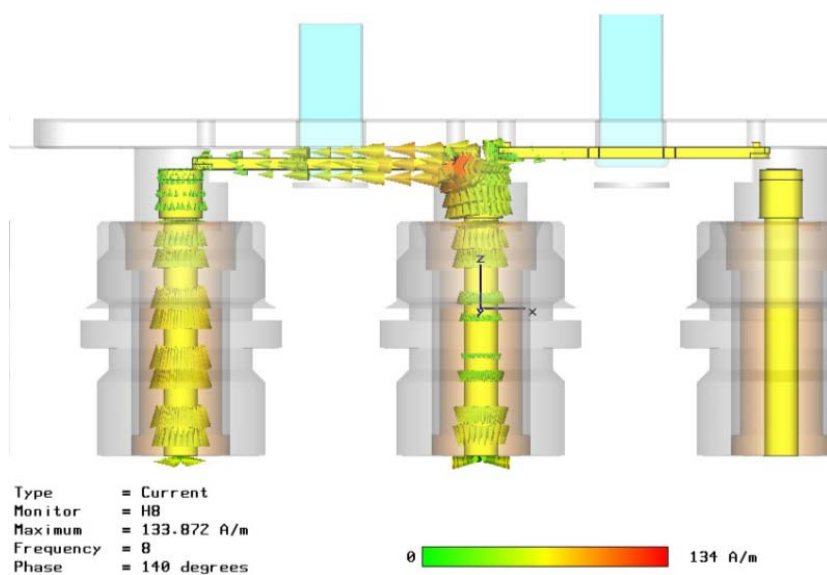
The worst case for arcing is at DC voltages where the voltage is constant and will sustain an arc for a longer period of time. At AC voltages, the voltage passes through zero twice each cycle, this quick cycling is not constant so the arc will often extinguish.

Radiall switches can perform hot switching at 1W cw without any degradation on RF contacts. 1W cw causes minimal arcing effect for hot switching. When the power level goes higher, the stronger electromagnetic field will cause more arcing and lead to premature failure of the switch contacts.

Contact Area After 90,000 Switching Cycles 20 W cw 9 GHz



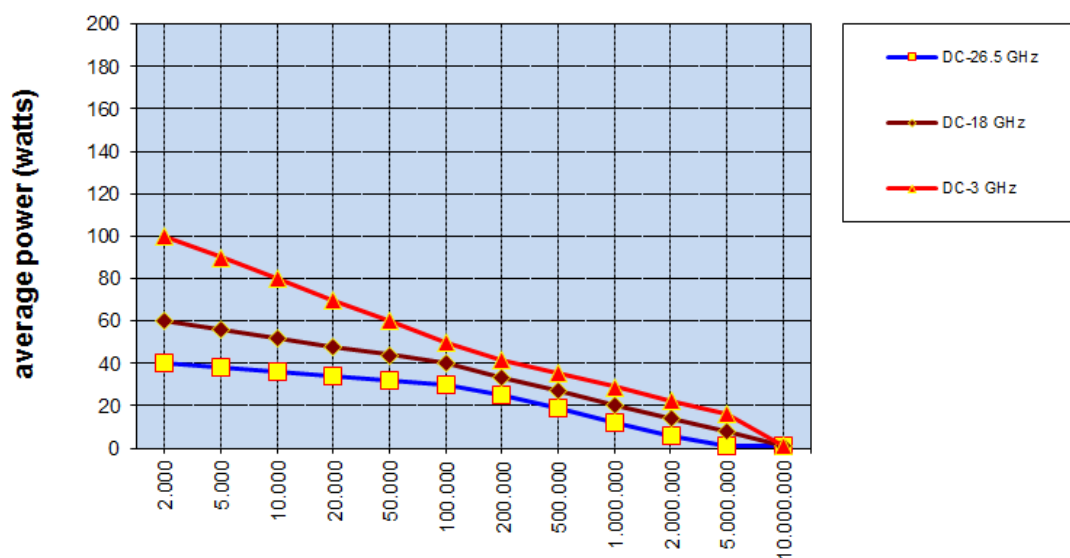
Current Flow Near Contact Area on SPDT



Switching with RF power applied to the contacts during the switching period can be performed with Radiall switches at power levels significantly below the maximum power handling rating.

Life derating curve for hot switching use on SMA switches

Impedance 50Ω.
V.S.W.R. <1.25.
Max switching
frequency:
30 cycles per mn.



Life derating curve for hot switching use on N-TNC switches

Impedance 50Ω.
V.S.W.R. <1.25.
Max switching
frequency:
30 cycles per mn.

