Rotary Joints – Glossary

Purpose and Background

This document compiles the technical terms used by SPINNER in its product data sheets and other technical documents concerning rotary joints. Wherever possible we provided rigorous definitions of the terms.

The task of a rotary joint is to enable low-loss transmission of electrical and optical signals between a static and a rotating part. Electrical power and media can also be transmitted if necessary. Rotary joints may also be equipped with further subsystems like angular encoders and revolution counters.

SPINNER's design capabilities include systems for data, power, fiber optical and media transmission as well as radio frequency (RF) signals.

General Terms

Rotary Joint

A rotary transition featuring an unlimited angle of rotation.

Commonly a rotary joint is abbreviated as RJ or R/J, in case of fiber optical rotary joint as FORJ.

Swivel Joint

Any rotary transition featuring a limited angle of rotation.

Channel

Describes a physical transmission path having one port on the stator and one port on the rotor. Unlike in telecommunication engineering, this term does not describe a certain limited portion of the electro-magnetic spectrum when used in this context.

Module

A basic element of a rotary joint which often covers a single transmission channel. Multichannel designs are commonly comprised of several independent modules.

Hollow-shaft module

A module with a clear inner bore along its axis of rotation. Usually hollow-shaft modules are stackable to create multichannel rotary joints. In that case the inner transmission lines of all neighboring modules are fed through the center bore.

On-axis module (center module)

A module without a center bore. Commonly used as the final stacking element in multichannel units.

Stator

Static portion of a rotary joint. A stator is not necessarily characterized by the presence of a mounting flange.

Rotor

Rotating portion of a rotary joint. A rotor is not necessarily characterized by the absence of a mounting flange.

Rotational gap

Necessary mechanical gap which separates stator and rotor.

Rotational angle

Angle θ between rotor and stator.

Contacting rotary joint

A rotary joint utilizing galvanic sliding contacts. Typically, wide-band designs are based on contacting coupling structures. Furthermore, contacting designs allow for DC transmission and can handle low frequency signals at limited space. Operational life is limited however (usually to some 10^6 to 10^7 revolutions) because of contact wear.

Non-contacting rotary joint

A rotary joint based on non-contacting coupling mechanisms like capacitive, inductive, transmission line or transformer coupling.

Non-contacting rotary joints generally cover a limited bandwidth (typical relative bandwidth less than 40%; in most applications some 10 to 20%) because of frequency-dependent coupling mechanisms. Non-contacting rotary joints offer superior product lifetime over contacting designs since contact wear is eliminated. In the non-contacting case life figures are only limited by the bearing or sealing system and might be as high as several hundred million revolutions.

The transmission line coupling mechanism is usually limited to channels operating in the GHz frequency range because lower frequencies would result in large coupling structures.

Slip ring

A slip ring is a particular variant of a contacting low frequency rotary joint, mostly equipped with a large-diameter center bore.

Slip rings are based on ring and static brush systems and commonly used for power and signal transmission. Slip ring assemblies for big multichannel rotary joints may feature some 100 ways and are often used to accommodate the (smaller) RF subsystems which are nested inside the slip ring's center bore.

Fiber optic rotary joint

A fiber optic rotary joint (FORJ) is the optical equivalent of an RF rotary joint or an electrical slip ring. It allows the transmission of an optical signal while rotating.

Single channel and multichannel FORJs are available with both single- and multimode fiber types.

Maximum and minimum values

Maximum or minimum values represent guaranteed limit values for product characteristics which are not exceeded at any time or under any condition specified in the data sheet.

Usually there is a safety margin between these guaranteed maximum limits and the values measured at room temperature (20°C ± 5°C).

The general policy of SPINNER is to always state guaranteed values in data sheets.

Typical values

In many cases SPINNER specifies both guaranteed and typical values.

Typical values are given whenever useful for a more realistic description of the performance. These values are typically observed on the majority of a production batch when measured at room temperature. However, SPINNER does not guarantee these "typical values".

RF port numbering

In order to define the scattering matrix of a rotary joint a non-ambiguous designation of the RF ports is required. If not otherwise defined SPINNER uses the following RF port numbering convention for its documents (e.g. data sheets, interface control drawings, qualification test procedures and records, acceptance test procedures and records):

Channel number	Port number on labeled* part	Port number on unlabeled* part
1	1	2
2	3	4
…	…	…
i	$2i$-1	$2i$

Template Normal.dotm

Following this convention, the scattering matrix $[S]$ of a n-channel rotary joint can be written as

$$[S] = \begin{bmatrix} S_{1,1} & S_{1,2} & \cdots & S_{1,2n-1} & S_{1,2n} \\ S_{2,1} & S_{2,2} & & S_{2,2n-1} & S_{2,2n} \\ \vdots & & \ddots & \vdots & \\ S_{2n-1,1} & S_{2n-1,2} & \cdots & S_{2n-1,2n-1} & S_{2n-1,2n} \\ S_{2n,1} & S_{2n,2} & & S_{2n,2n-1} & S_{2n,2n} \end{bmatrix} \xrightarrow{ideal^{**}case} \begin{bmatrix} 0 & 1 & \cdots & 0 & 0 \\ 1 & 0 & & 0 & 0 \\ \vdots & & \ddots & & \vdots \\ 0 & 0 & \cdots & 0 & 1 \\ 0 & 0 & & 1 & 0 \end{bmatrix}$$

* Rotary joints consist of a stator and a rotor which are rotating relatively to each other. One of these two parts is marked with the product number BN XXXXXX, this is called the “labeled” part. The other part is called “unlabeled”.

** “Ideal” in this context means: impedance-matched, lossless, fully decoupled, electrical length negligible.

Dry air

Waveguide components, e.g. rotary joints, are sometimes pressurized either with “dry air” or other gases like N_2 or SF_6 to enhance their (peak) power handling figures.

Wherever possible, SPINNER preferably specifies pressurization with “dry air” due to availability, cost, safety and environmental reasons. “Dry air” describes air which has been dried to a dew point below the minimum specified operating temperature. It is mandatory to avoid any condensation inside the component. Additionally, the air must be free from particles and oil mist.

Typical dew point (rather, frost point) figures for nominally dry air are in the range of -40°C or better.

Radio Frequency Characteristics

Interface type

Generally, SPINNER RF rotary joints come with either waveguide or coaxial ports.

The appropriate choice depends on application, frequency range and power rating requirements. Most waveguide rotary joints feature standardized waveguide interfaces according to IEC-60154, MIL-DTL-3922 or EIA-RS 271, which may be either of the plain or choke type. Grooves on sealed flanges in combination with gaskets allow for pressurization and provide protection against ingress of dirt and moisture. Internal corners of rectangular waveguide interfaces are sometimes rounded for manufacturing reasons. These rounded corners have been designed carefully and thus are fully electrically compensated when mated to sharp-cornered standard waveguides. Consequently, RF performance will not be compromised by the rounding. Coaxial designs are usually equipped with precision coaxial connectors according to IEEE Std. 287.

Interface orientation

Describes the basic style of a rotary joint depending on the orientation of both interfaces (rotor and stator).

Several waveguide designs may actually only be realized as "U" styles and must be adapted to the desired style using external waveguides.

"I"- style:	Both interfaces in line with the rotational axis.
"U"- style:	Both interfaces perpendicular to the rotational axis.
“L”-style:	One interface is perpendicular to the rotational axis and the other interface is in line with the rotating axis.

Frequency range

Portion of the electromagnetic spectrum which a component has been designed for and within which the respective specification is valid.

SPINNER offers designs for the entire frequency range between DC and the millimeter wave range.

In the following the frequency range will be referred to as FR.

Peak power rating

Maximum permissible short-term power which a component can handle safely without internal arcing or breakdown.

In contrast to "instantaneous values", this term refers to short-term RMS values within the pulse duration. Usual pulse durations are in the µs range. It should be pointed out that the actual peak power rating depends considerably on parameters such as absolute air pressure inside the component, load VSWR, temperature, pulse duration and pulse repetition frequency. Specifying the required operating pressure for a given peak power is of paramount importance. While low ambient air pressure will degrade the peak power rating, it can be massively enhanced by a pressurization of all electrically stressed components with dry compressed air or particular insulation gases like SF_6. If space use is intended, a different vacuum discharge mechanism called "multipactor discharge" becomes crucial. SPINNER datasheets provide all necessary information about these limiting conditions.

Depending on the connector size, coaxial rotary joints usually feature peak power figures in the 1 to 10 kW range while typical values for unpressurized waveguide rotary joints might be as high as 10 kW to 1 MW (also depending on waveguide size).

Peak power rating is limited to the air pressure at sea level unless otherwise noted.

Average power rating

Maximum permissible long term ("continuous wave" or CW) power which a component can handle safely without internal overheating.

During operation Ohmic and dielectric losses generate heat inside the rotary joint. Hence, the maximum permissible average power is frequency dependent.

The relation between heat generation and heat dissipation (by metallic feeder waveguides, casing, mounting flanges and air convection) determines the actual CW power that may be applied over a long period of time while still ensuring safe internal operating temperatures for all critical parts. Average power handling may be increased by additional forced cooling (air or water) and use of advanced materials or designs. Excessive ambient temperatures will degrade the average power rating, respectively.

VSWR

The "Voltage Standing Wave Ratio (VSWR)" is an expression for the degree of wave reflection from a component due to impedance mismatch.

Ideally, in the perfectly matched case there is no reflected wave and VSWR is equal to 1. It is infinite in the case of total reflection.

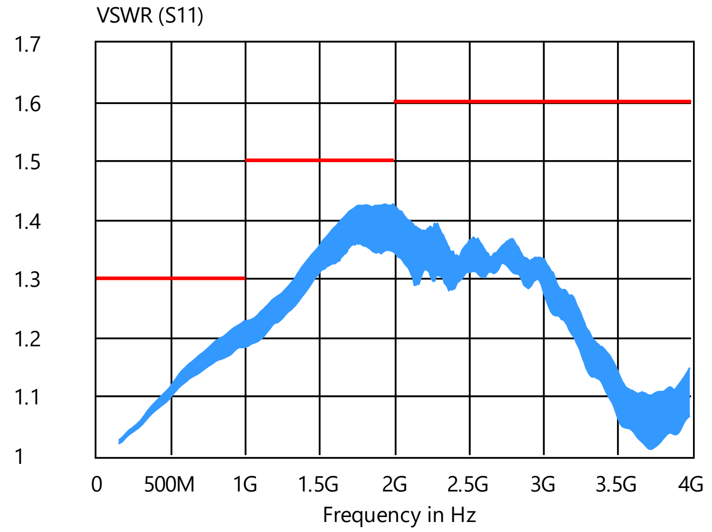
High VSWR values are not desirable because they indicate a high percentage of reflected power and contribute to insertion loss. A high VSWR will also cause locally raised voltages due to standing waves and therefore compromise power handling.

Often a tradeoff between VSWR and bandwidth must be found. Usual VSWR values would range from 1.10 to 1.70. Specialized big center bore designs which must cover a very wide bandwidth cannot reach these values, however.

"VSWR, max.", as given in SPINNER data sheets, represents worst-case values that besides frequency response also include thermal and rotational effects.

$$VSWR_{max} = \max_{f \in FR}\left\{\max_{0° \leq \theta < 360°}\{VSWR(f,\theta)\}\right\}$$

Example:



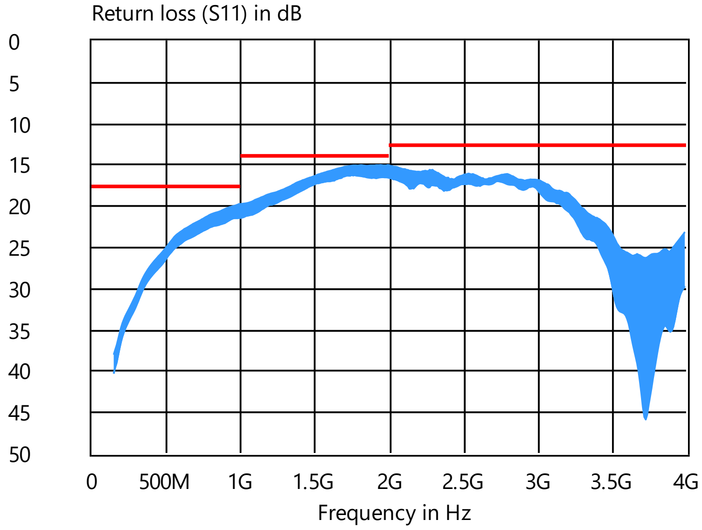
Return loss

Alternative representation of VSWR, describes the logarithmic ratio (in dB) between incident power P_{in} and reflected power P_r at a component's port:

$$a_r = 10\text{ dB} \cdot \lg \frac{P_{in}}{P_r}$$

The return loss a_r is infinite in the perfectly matched case and zero at total reflection. A high return loss figure is desirable and indicates a well-matched component. Return loss values usually range from 10 dB to 40 dB.

Example:



VSWR variation with rotation

The most popular way of describing how much the VSWR changes over a full rotation at the "worst" frequency within the specified frequency range is the difference definition $\Delta VSWR$. SPINNER generally adheres to this definition.

"VSWR variation with rotation, max." ($\Delta VSWR_{max}$) expresses the difference between the maximum and minimum VSWR values measured at the frequency point f_{VSWRv} which features the highest VSWR variation over the rotational angle θ:

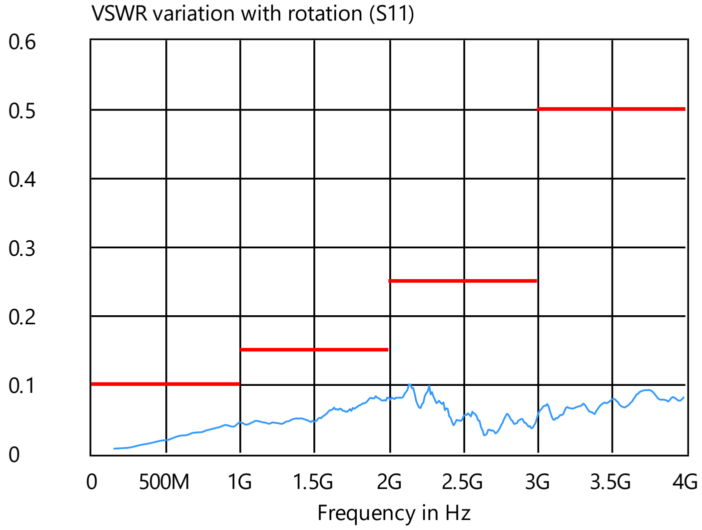
$$\Delta VSWR(f) = \max_{0^\circ \le \theta < 360^\circ}\{VSWR(f,\theta)\} - \min_{0^\circ \le \theta < 360^\circ}\{VSWR(f,\theta)\}$$

$$\Delta VSWR_{max} = \Delta VSWR(f_{VSWRv}) = \max_{f \in FR}\{\Delta VSWR(f)\}$$

For practical measurements the definition above is often approximated by the maximum distance between the two VSWR frequency response curves taken at the "worst" and the "best" rotational angle. Common values are between 0.02 and 0.2.

Another expression for "VSWR variation with rotation" which is sometimes used outside SPINNER is **"VSWR WOW"**.

Example:



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VSWR ratio with rotation

An alternative way of describing how much the VSWR changes over a full rotation is the ratio definition. It is given by

$$VSWR_{ratio}(f) = \frac{\max\limits_{0° \leq \theta < 360°}\{VSWR(f,\theta)\}}{\min\limits_{0° \leq \theta < 360°}\{VSWR(f,\theta)\}}$$

$$VSWR_{ratio,max} = VSWR_{ratio}(f_{VSWRv}) = \max_{f \in FR}\{VSWR_{ratio}(f)\}$$

The ratio definition leads to values greater than one. SPINNER uses this definition only when it is explicitly required by a customer.

Another expression for "VSWR ratio with rotation" which is sometimes used outside SPINNER is **"VSWR WOW"**.

Insertion loss

The insertion loss (often abbreviated as IL) is the attenuation of a signal being passed through a device within the signal path. Insertion loss a_i is usually expressed as the logarithmic ratio (in dB) between incident power P_{in} and output power P_{out}:

$$a_i = 10\ \mathrm{dB} \cdot \lg \frac{P_{in}}{P_{out}}$$

Internal transmission line structures, feeder waveguides or cables cause Ohmic, dielectric and reflection losses. The dissipated energy results in heat generation and limits the maximum permissible long-term power rating.

Long designs generally suffer from higher insertion loss than shorter ones and waveguide designs are usually superior to coaxial designs. Whenever there is a choice, the system waveguide size should be chosen as big as possible because of increased waveguide losses in the lower portion of their operating band.

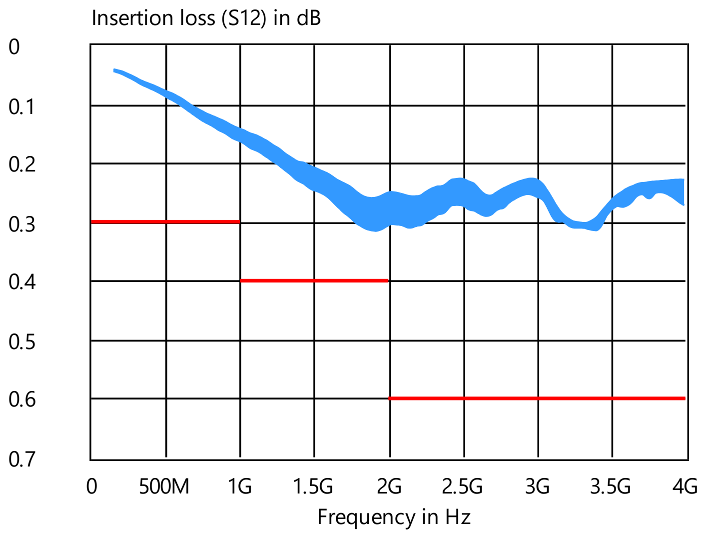
Insertion loss is somewhat temperature dependent. SPINNER likes to point out that any insertion loss figures stated in SPINNER data sheets hold true for the entire specified range of operating temperatures and the nominal operating power.

Most waveguide rotary joints feature insertion loss values in the 0.1 dB to 0.5 dB range, and so do usual coaxial designs without cables. Large multichannel rotary joints contain additional internal cables which may cause significant additional losses.

"Insertion loss, max.", as given in SPINNER data sheets, represents worst-case values that besides frequency response also include thermal and rotational effects.

$$a_{i,max} = \max_{f \in FR}\left\{\max_{0° \leq \theta < 360°}\{a_i(f,\theta)\}\right\}$$

<u>Example:</u>



Insertion loss variation with rotation

This quantity describes how much insertion loss changes over a full rotation at the "worst" frequency within the specified frequency range. For most technical applications, this parameter is of higher relevance than VSWR variation with rotation.

"Insertion loss variation with rotation, max." $\Delta a_{i,max}$ is defined as the difference between the maximum and minimum insertion loss values measured at the frequency point f_{ILv} which features the highest insertion loss variation over the rotational angle θ:

$$\Delta a_i(f) = \max_{0° \leq \theta < 360°}\{a_i(f,\theta)\} - \min_{0° \leq \theta < 360°}\{a_i(f,\theta)\}$$

$$\Delta a_{i,max} = \Delta a_i(f_{ILv}) = \max_{f \in FR}\{\Delta a_i(f)\}$$

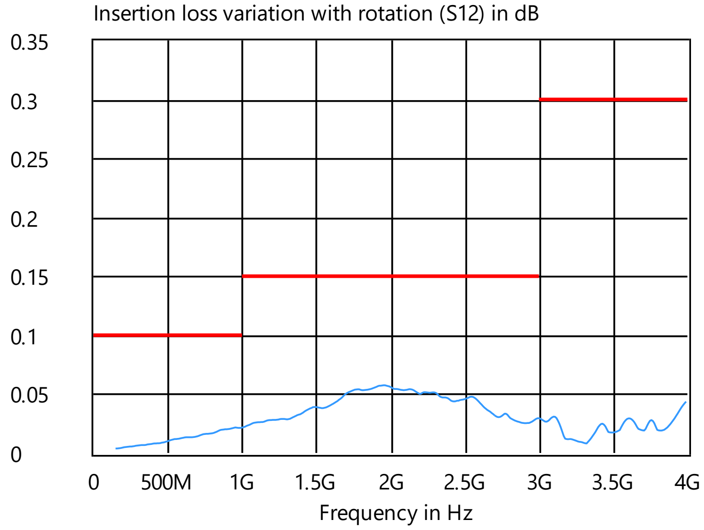
Another expression for "Insertion loss variation with rotation" which is sometimes used outside SPINNER is **"Insertion loss WOW"** or simply **"WOW"**.

For practical measurements the definition above is often approximated by the maximum distance between the two insertion loss frequency response curves taken at the "worst" and the "best" rotational angle.

Insertion loss variation is mostly a footprint of VSWR variation which in turn causes varying reflection losses.

Any "insertion loss variation with rotation, max." figures given in SPINNER data sheets are worst-case values (usually between 0.05 dB and 0.2 dB) and do already include a safety margin to consider measurement instabilities and drift.

Example:



Insertion loss variation with frequency

This quantity describes how much insertion loss changes in the operating frequency range. As insertion loss describes the propagation losses of the different frequency components of the signal through the device, insertion loss variation with frequency characterizes the signal distortion as it passes through the device.

“Insertion loss variation with frequency, max.” $\Delta_f a_{i,max}$, as given in SPINNER data sheets, is defined as the difference between the maximum and minimum insertion loss values in any given frequency window $FW \leq FR$ measured at the rotational angle θ_{ILvf}, that features the highest insertion loss variation.

$$\Delta_f a_i(f,\theta) = \max_{f_{ev} \in \left[f-\frac{FW}{2};f+\frac{FW}{2}\right]}\{a_i(f_{ev},\theta)\} - \min_{f_{ev} \in \left[f-\frac{FW}{2};f+\frac{FW}{2}\right]}\{a_i(f_{ev},\theta)\}$$

$$\Delta_f a_i(\theta) = \max_{f \in FR}\{\Delta_f a_i(f,\theta)\}$$

$$\Delta_f a_{i,max} = \Delta_f a_i(\theta_{ILvf}) = \max_{0° \leq \theta < 360°}\{\Delta_f a_i(\theta)\}$$

The frequency window FW often corresponds to the signal bandwidth.

Without a specified frequency window for evaluation, insertion loss variation with frequency is defined as the difference between the maximum and minimum insertion loss values in the **complete frequency range** measured at the rotational angle θ_{ILvf}, that features the highest insertion loss variation. The above equations can be reduced to

$$\Delta_f a_i(\theta) = \max_{f \in FR}\{a_i(f,\theta)\} - \min_{f \in FR}\{a_i(f,\theta)\}$$

$$\Delta_f a_{i,max} = \Delta_f a_i(\theta_{ILvf}) = \max_{0° \leq \theta < 360°}\{\Delta_f a_i(\theta)\}$$

Further expressions for “insertion loss variation with frequency”, that are sometimes used outside SPINNER, are “insertion loss variation”, “**insertion loss flatness**”, and “**insertion loss ripple**”.

Transmission phase

The transmission phase is the phase shift experienced by a signal being passed through a device within the signal path. Transmission phase φ_i is defined as the argument of the complex transfer function $H(j\omega)$ of a linear time-invariant system. This transfer function is usually a transmission coefficient S-Parameter S_{mn} , $m \neq n$ for high-frequency devices, so that the transmission phase is calculated as

$$\varphi_i(f,\theta) = arg\big(S_{mn}(f,\theta)\big), m \neq n$$

for the channel i from port n to port m.

This parameter can be utilized as a measure for the effective electrical length of the device. It is useful to express transmission phase as **unwrapped phase** to avoid discontinuities and ambiguities in further calculations of phase variation and difference quantities (e.g. “transmission phase variation with rotation”, “transmission phase difference”).

“Transmission phase, max.” $\varphi_{i,max}$, as given in SPINNER data sheets, is defined as the maximum absolute transmission phase value in the entire frequency range, also including rotational effects, expressed in degrees.

$$\varphi_{i,max} = \max_{f \in FR}\left\{\max_{0° \leq \theta < 360°}\{|\varphi_i(f,\theta)|\}\right\}$$

Transmission phase variation with rotation

This quantity describes how much the transmission phase of a rotary joint changes over a full rotation at the "worst" frequency within the specified frequency range.

This parameter indicates a variation of the effective electric length. Along with insertion loss variation with rotation it is of higher relevance for most technical applications than VSWR variation.

"Transmission phase variation with rotation, max." $\Delta\varphi_{i,max}$ is defined as the difference between the maximum and minimum transmission phase values measured at the frequency point f_{Pv} which features the highest transmission phase variation over the rotational angle θ:

$$\Delta\varphi_i(f) = \max_{0° \leq \theta < 360°}\{\varphi_i(f,\theta)\} - \min_{0° \leq \theta < 360°}\{\varphi_i(f,\theta)\}$$

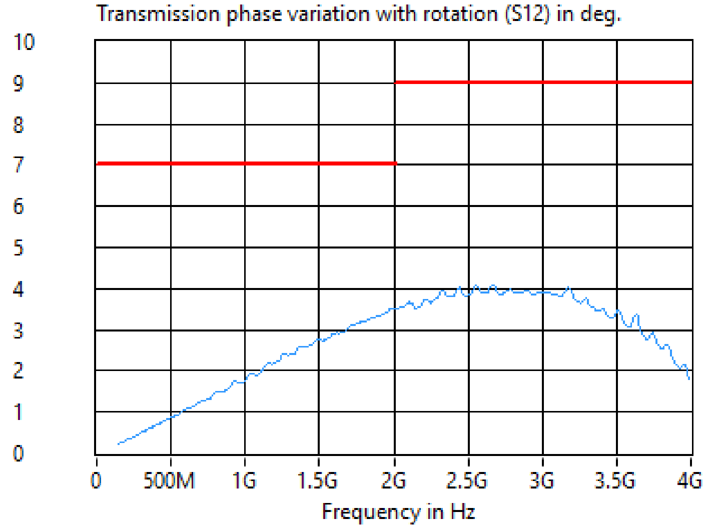
$$\Delta\varphi_{i,max} = \Delta\varphi_i(f_{Pv}) = \max_{f \in FR}\{\Delta\varphi_i(f)\}$$

Another expression for "Transmission phase variation with rotation" which is sometimes used outside SPINNER is **"Phase WOW"**.

For practical measurements the definition above is often approximated by the maximum distance between the two transmission phase frequency response curves taken at the "worst" and the "best" rotational angle.

Any "transmission phase variation with rotation, max." figures given in SPINNER data sheets are worst-case values (usually of the order of 0.5 to 5 degrees) and do already include a safety margin to consider measurement instabilities and drift.

Example:



Insertion loss difference

This parameter is only defined for two channels operating in the same frequency range. It describes the difference between their insertion loss figures at a certain frequency and rotational angle θ.

"Insertion loss difference, max." ILD_{max}, as given in SPINNER datasheets, describes the worst-case insertion loss difference value over the rotational angle θ within the operating frequency band:

$$ILD(f,\theta) = a_{i,CH1}(f,\theta) - a_{i,CH2}(f,\theta)$$

$$ILD_{max} = \max_{f \in FR}\left\{\max_{0° \leq \theta < 360°} |ILD(f,\theta)|\right\}$$

If required, careful tuning of the internal cable lengths enables insertion loss matching of channels within 0.1 to 0.2 dB (for coaxial multichannel rotary joints).

Transmission phase difference

Like insertion loss difference, this parameter is only defined for two channels operating in the same frequency range. It describes the difference between their transmission phases at a certain frequency and rotational angle θ.

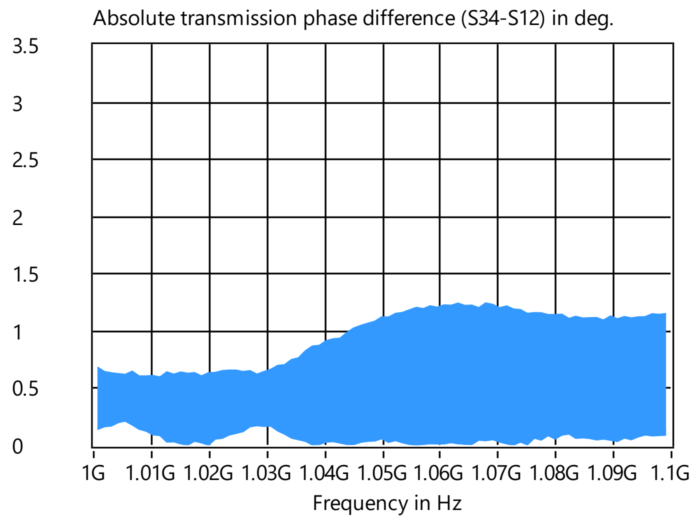
"Transmission phase difference, max." PD_{max}, as given in SPINNER datasheets, describes the worst-case transmission phase difference value over the rotational angle θ within the operating frequency band:

$$PD(f,\theta) = \varphi_{i,CH1}(f,\theta) - \varphi_{i,CH2}(f,\theta)$$

$$PD_{max} = \max_{f \in FR}\left\{\max_{0° \leq \theta < 360°} |PD(f,\theta)|\right\}$$

If required, careful tuning of the internal cable lengths enables transmission phase matching of channels within a few degrees (for coaxial multichannel designs, depending on wavelength).

Example:



Insertion loss difference variation with rotation

This quantity is only defined for two channels operating in the same frequency range. It describes their insertion loss synchronism with rotation.

Two modules, each suffering from high insertion loss variation with rotation, can still result in a dual channel rotary joint with good insertion loss synchronism since the two individual variations may be similar and therefore cancel out if combined properly.

"Insertion loss difference variation with rotation, max." ILT_{max} is defined as the difference between the maximum and minimum insertion loss difference values over the rotational angle θ within the operating frequency band:

$$ILT(f) = \max_{0°\leq\theta<360°}\{ILD(f,\theta)\} - \min_{0°\leq\theta<360°}\{ILD(f,\theta)\}$$

$$ILT_{max} = ILT(f_{ILT}) = \max_{f\in FR}\{ILT(f)\}$$

Another expression for "Insertion loss difference variation with rotation" which is sometimes used outside SPINNER is **"Insertion loss tracking with rotation"**.

Transmission phase difference variation with rotation

This quantity is only defined for two channels operating in the same frequency range. It describes their transmission phase synchronism with rotation.

Two modules, each suffering from high transmission phase variation with rotation, can still result in a dual channel rotary joint with good transmission phase synchronism since the two individual variations may be similar and therefore cancel out if combined properly.

"Transmission phase difference variation with rotation, max." PT_{max} is defined as the difference between the maximum and minimum transmission phase difference values over the rotational angle θ within the operating frequency band:

$$PT(f) = \max_{0°\leq\theta<360°}\{PD(f,\theta)\} - \min_{0°\leq\theta<360°}\{PD(f,\theta)\}$$

$$PT_{max} = PT(f_{PT}) = \max_{f\in FR}\{PT(f)\}$$

Another expression for "Transmission phase difference variation with rotation" which is sometimes used outside SPINNER is **"Phase tracking with rotation"**.

Some applications, for example secondary surveillance radar (SSR), require well matched rotary joint channels (both insertion loss and transmission phase) along with tracking requirements.

Group delay

Group delay characterizes the propagation time of a signal being passed through a device within the signal path. Group delay τ_{gr} is generally frequency dependent and can be calculated as the (negative) derivative of the transmission phase $\varphi_i(f)$ with respect to frequency f.

$$\tau_{gr}(f) = -\frac{1}{2\pi} \cdot \frac{d\varphi_i(f)}{df}$$

"Group delay, max." $\tau_{gr,max}$, as given in SPINNER data sheets, represents the worst-case group delay value over the rotational angle θ within the operating frequency band.

$$\tau_{gr,max} = \max_{f \in FR} \left\{ \max_{0° \leq \theta < 360°} \{\tau_{gr}(f, \theta)\} \right\}$$

As transmission phase measurements on a VNA suffer from noise due to frequency jitter, it is sometimes necessary to apply smoothing to measurements in order to obtain meaningful group delay values. The degree of smoothing will be agreed with customers.

Group delay variation with frequency

This quantity describes how much group delay changes in the operating frequency range. As group delay describes the propagation time of the different frequency components of the signal through the device, group delay variation with frequency characterizes the signal distortion as it passes through the device. Devices that show high group delay variation with frequency, also referred to as high dispersion, contribute more towards signal distortion.

"Group delay variation with frequency, max." $\Delta_f \tau_{gr,max}$, as given in SPINNER data sheets, is defined as the difference between the maximum and minimum group delay values in any given frequency window $FW \leq FR$ measured at the rotational angle θ_{grvf}, that features the highest group delay variation.

$$\Delta_f \tau_{gr}(f, \theta) = \max_{f_{ev} \in \left[f - \frac{FW}{2}; f + \frac{FW}{2}\right]} \{\tau_{gr}(f_{ev}, \theta)\} - \min_{f_{ev} \in \left[f - \frac{FW}{2}; f + \frac{FW}{2}\right]} \{\tau_{gr}(f_{ev}, \theta)\}$$

$$\Delta_f \tau_{gr}(\theta) = \max_{f \in FR} \{\Delta_f \tau_{gr}(f, \theta)\}$$

$$\Delta_f \tau_{gr,max} = \Delta_f \tau_{gr}(\theta_{grvf}) = \max_{0° \leq \theta < 360°} \{\Delta_f \tau_{gr}(\theta)\}$$

The frequency window FW often corresponds to the signal bandwidth.

Without a specified frequency window for evaluation, group delay variation with frequency is defined as the difference between the maximum and minimum group delay values in the **complete frequency range** measured at the rotational angle θ_{grvf}, that features the highest group delay variation. The above equations can be reduced to

$$\Delta_f \tau_{gr}(\theta) = \max_{f \in FR} \{\tau_{gr}(f, \theta)\} - \min_{f \in FR} \{\tau_{gr}(f, \theta)\}$$

$$\Delta_f \tau_{gr,max} = \Delta_f \tau_{gr}(\theta_{grvf}) = \max_{0° \leq \theta < 360°} \{\Delta_f \tau_{gr}(\theta)\}$$

Further expressions for "group delay variation with frequency", that are sometimes used outside SPINNER, are "group delay variation", "**group delay flatness**", and "**group delay ripple**".

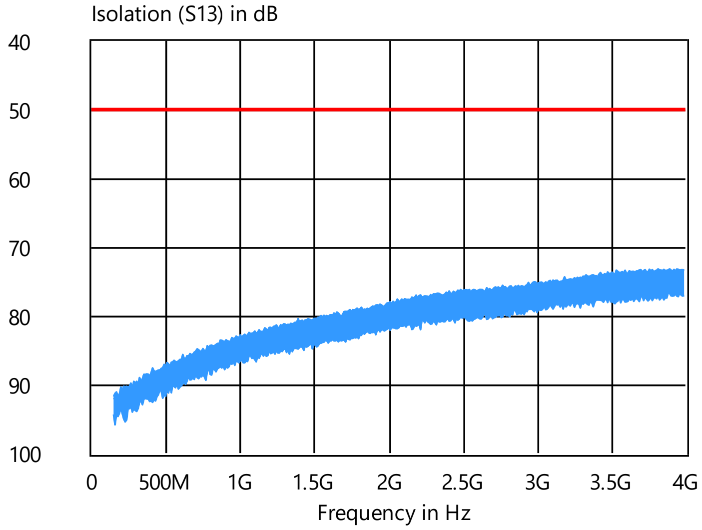
Isolation

This quantity describes the **crosstalk** between two channels.

The amount of RF energy leaking from one channel to a second one is usually expressed as insertion loss (in dB) between one port of the first channel and another port of the second channel while all remaining ports are properly terminated. Depending on the choice of ports two different crosstalk types must be considered: Far-end and near-end crosstalk. All isolation values given by SPINNER represent worst-case values including both far-end and near-end consideration.

Usual values are around 50 to 70 dB, whereas certain designs, e.g. waveguide rotary joints, which are designed for exceptionally high power levels, achieve isolation values well above 70 dB.

Example:



Shielding effectiveness

Shielding effectiveness describes the amount of RF energy leaking from a channel out of the rotary joint into the surrounding space. It is often confirmed by analysis and expressed in decibels.

DC current rating

Naturally, this parameter is only specified for contacting rotary joints. It describes the maximum DC current that can be safely transmitted through a rotary joint. This may be of relevance for applications where biased electronic assemblies are located close to the antenna. If high direct (or low frequency) current transfer is demanded, the RF power rating is usually compromised.

Because of the delicate nature of several contact parts inside most RF rotary joints the DC current rating is commonly limited to currents of a few amperes and to low voltages.

If higher DC or low frequency AC power transmission capabilities are desired, SPINNER encourages the use of a slip ring assembly or a non-contacting power transmission system.

Additive phase noise

Additive phase noise, also referred to as **"Residual phase noise"**, is the self-phase noise that adds to an existing signal as it passes through a component. In rotary joints additive phase noise is caused by small variations in insertion loss and electrical phase during rotation.

Typical values in the gigahertz range are in the order of -110 dBc/Hz for contacting and 150 dBc/Hz for non-contacting channels (both for a carrier offset of 100 Hz).

Fiber Optic Characteristics

Interface type

Most SPINNER FORJs are equipped with fiber pigtails having standardized or custom FO connectors. In rare cases direct FO receptacles or open fiber ends serve as FO interfaces.

Endface geometry of the connectors is compliant to IEC / GR-326-CORE and endface quality is compliant to IEC 61300-3-35.

Fiber type

SPINNER FORJs are available with many different fiber types. The following types are most common:

- 50/125 GI (gradient index, multimode)
- 62.5/125 GI (gradient index, multimode)
- 9/125 SM (step index, singlemode)

In addition, large core fibers with different numerical apertures and core diameters larger than 100 µm, also plastic optical fibers, are available.

Wavelength range

Portion of the electromagnetic spectrum which a component has been designed for and within which the respective specification is valid.

For data transmission SPINNER offers designs for the standard optical windows at 850 nm, 1310 nm or 1550 nm. FORJs for broadband applications are also available. Additionally, SPINNER supplies FORJs for the whole visual range starting from 400 nm.

In the following the wavelength range will be referred to as WR Λ.

Average power rating

Maximum permissible long term (“continuous wave” or CW) power which a component can handle safely without internal damage.

Periodicity with rotation

Due to their inherent design FORJs show a periodic behavior of the optical performance with the rotational period θ_s, i.e. a full rotation of a FORJ. The rotational period θ_s depends on the type of rotary joint:

Single channel rotary joints: $\theta_s = 360°$

Multichannel rotary joints: $\theta_s = 720°$

Measurement direction

Generally, all SPINNER FORJs allow a bidirectional propagation of light, i.e. the light source can be attached on either side of the rotary joint. For the test records SPINNER defines the direction of propagation of light as Stator → Rotor (SR) and Rotor → Stator (RS), according to the technical drawings.

Typically, tiny effects, e.g. due to the connectors, cause insertion loss differences of some 0.1 dB between the measurement directions. FORJs are only tested in one measurement direction. On a customer’s wish, both directions can be tested.

Return loss

Describes the logarithmic ratio (in dB) between incident power P_{in} and reflected power P_r at a component's port:

$$a_r = 10\ \text{dB} \cdot \lg \frac{P_{in}}{P_r}$$

The return loss of a FORJ is determined in accordance with IEC 61300-3-6 method 1.

Any "return loss, min." figures given in SPINNER data sheets are worst-case values.

Insertion loss

Attenuation of a signal being passed through a device within the signal path.

Insertion loss a_i is usually expressed as the logarithmic ratio (in dB) between incident power P_{in} and output power P_{out}:

$$a_i = 10\ \mathrm{dB} \cdot \lg \frac{P_{in}}{P_{out}}$$

The insertion loss a_i depends on the wavelength λ and the rotational angle θ: $a_i = a_i(\lambda, \theta)$.

The "Insertion loss, max." $a_{i,max}(\lambda)$, as given in SPINNER data sheets, represents the worst-case value for the given wavelength that includes rotational effects.

$$a_{i,max}(\lambda) = \max_{0° \leq \theta < \theta_s} \{a_i(\lambda, \theta)\}$$

The insertion loss of a FORJ is determined in accordance with IEC 61300-3-4 insertion method (C).

Insertion loss variation with rotation

This quantity describes how much insertion loss changes over a full rotation θ_s at the defined wavelengths.

"Insertion loss variation with rotation, max." $\Delta a_{i,max}$ is defined as the difference between the maximum and minimum insertion loss values measured over a full rotation θ_s:

$$\Delta a_i(\lambda) = \max_{0° \leq \theta < \theta_s} \{a_i(\lambda, \theta)\} - \min_{0° \leq \theta < \theta_s} \{a_i(\lambda, \theta)\}$$

$$\Delta a_{i,max} = \max_{\lambda \in \Lambda} \{\Delta a_i(\lambda)\}$$

This value Δa_i depends on the wavelength λ.

Another expression for "Insertion loss variation with rotation" which is sometimes used outside SPINNER is **"Insertion loss WOW"** or simply **"WOW"**.

Insertion loss variation with wavelength and rotation

The parameter Δa_{WR} is defined for a 1CH FORJ or one channel n of a multichannel FORJ having a WR Λ as

$$\Delta a_{WR}(n) = \max_{0° \leq \theta < \theta_s; \lambda \in \Lambda} \{a_i(\theta, \lambda, n)\} - \min_{0° \leq \theta < \theta_s; \lambda \in \Lambda} \{a_i(\theta, \lambda, n)\}$$

where θ is the rotational position and there are several test wavelengths λ in the WR Λ.

Insertion loss maximum variation with wavelength

This quantity describes how much the insertion loss maximum over a full rotation θ_s changes between the defined wavelengths in the WR Λ.

The parameter $\Delta_\lambda a_{i,max}$ is defined for a 1CH FORJ or for one channel n of a multichannel FORJ as

$$a_{i,max}(\lambda, n) = \max_{0° \leq \theta < \theta_s} a_i(\theta, \lambda, n)$$

$$\Delta_\lambda a_{i,max}(n) = \max_{\lambda \in \Lambda} \{a_{i,max}(\lambda, n)\} - \min_{\lambda \in \Lambda} \{a_{i,max}(\lambda, n)\}$$

where θ is the rotational position and there are several test wavelengths λ in the WR Λ.

Insertion loss span of all channels

The insertion loss span of all channels Δa_{span} is defined as

$$\Delta a_{span}(\lambda_i) = \max_{0° \leq \theta < \theta_s; n \in N} \{a_i(\theta, n, \lambda_i)\} - \min_{0° \leq \theta < \theta_s; n \in N} \{a_i(\theta, n, \lambda_i)\}$$

where θ is the rotational position, N is the total number of channels, and n is the channel number. The insertion loss bandwidth of all channels is defined at one wavelength λ_i.

Insertion loss variation within rotational sector

This parameter is defined for one channel and a fixed wavelength λ. The insertion loss variation Δa_γwithin a defined rotational sector γ is evaluated. This procedure is repeated until a full rotation θ_s is completed. Finally, the overall maximum insertion loss variation over all these rotational sectors $\Delta a_{\gamma,max}$ is determined.

$$\Delta a_\gamma(\theta_k) = \max_{\theta_k \leq \theta < \theta_k + \gamma} \{a_i(\theta)\} - \min_{\theta_k \leq \theta < \theta_k + \gamma} \{a_i(\theta)\}$$

$$\Delta a_{\gamma,max} = \max_{\theta_k \in [0; \theta_s]} \{\Delta a_\gamma(\theta_k)\}$$

Common values for the rotational sector γ are for example 5 or 15 degrees.

Isolation

Describes the crosstalk between two channels.

Depending on the choice of ports two different crosstalk types must be considered: Far-end and near-end crosstalk. All isolation values given by SPINNER represent worst-case values including both far-end and near-end consideration.

Mechanical Characteristics

Differential operating pressure

Differential pressure between pressurized area within the RF part and environment indicated in MPa (10^6 Pa) and in bar.

“Differential operating pressure, max.”, as given in SPINNER datasheets, is valid for the complete operating ambient temperature range. The term “Differential operating pressure, nominal” describes the recommended operating condition.

Absolute operating pressure

Absolute pressure within the RF part of the rotary joint indicated in MPa and in bar.

“Absolute operating pressure, min.”, as given in SPINNER datasheets, describes the minimum pressure to be maintained in all operating conditions to ensure the peak power rating of the rotary joint. Depending on the type of insulating gas, different minimum pressures need to be maintained.

Leakage rate

Leakage rate for pressurized wave guides valid for the indicated operating ambient temperature range. Usually indicated as maximum value valid at the indicated nominal differential pressure

Rotational speed

The rotational speed ω (in rpm) is usually indicated as nominal and maximum speed.

Lifetime

The lifetime, usually indicated in number of revolutions, is limited by the transmission type (contacting) as well as by bearings and dynamic seals. The lifetime can be extended by dedicated maintenance tasks, available for some products.

Torque

The torque of a rotary joint describes the mechanical resistance during start up or turning at nominal speed. Usually, these two values are indicated in Nm, for room temperature (20°C ± 5°C) and for the minimum specified operating ambient temperature.

If no temperature is indicated, the torque is defined at room temperature. Torque values for other temperatures can be given upon request.

Interface loads

The interface loads coming from the installation of the rotary joint will have an effect on the bearing design. SPINNER rotary joints usually are not designed to withstand external forces, which means that no or no significant loads are allowed.

In some cases, safe interface loads are specified. These loads are expressed as forces in axial and radial direction as well as the bending moment on the interface axis.

Housing material

The housing material is the material of the body and main flanges. For the internal design other materials are used also. Typical materials are aluminum alloys, copper alloys or stainless steel.

Housing surface coating

The housing surface coating is the coating of the body and main flanges. For interior parts also other coatings may be used. Some joints do not have any surface coating, other typical coatings are chromate conversion coat per MIL-DTL-5541 (e.g. Surtech 650), silver plating or painting (e.g. two-component paints, PU-based, color according to RAL or other specifications).

Degree of protection

The degree of protection is given as an IP class according to IEC 60529. Typical IP classes for rotary joints are:

IP 40:	Protection against wires and screws; no protection against liquids
IP 54:	Protection against dust & splashing water
IP 65:	Dust tight & protected against water jets

The given IP classes are valid for all installation directions unless otherwise noted. To achieve the given degree of protection, the rotary joint must be installed and connected correctly as well as mounted with the appropriate gaskets.

Weight

Weight of rotary joint assembly without mounting screws and protective packing.

Marking

Marking or labeling of the rotary joint. Typical solutions are adhesive label, riveted label, laser engraving, engraving, or stamping.

Environmental Conditions

Application

The application indicates the general environment of the installed rotary joint. The application is typically defined as airborne plane, airborne helicopter, ground fixed, ground mobile, shipboard, submarine, or satellite according to MIL-HDBK-217.

Ambient temperature range

Temperature range of the environment in °C. Typically indicated for operating and for storage condition.

If not otherwise indicated SPINNER assumes that no heat from external sources is introduced into the rotary joint.

Relative humidity

This is the ratio of the actual vapor pressure of the air to the saturation vapor pressure in %. It is typically indicated as a maximum value, valid for the complete temperature range (ambient or storage).

Shock

Information for the compliance demonstration according to MIL, RTCA, or any other applicable standard.

Vibration

Information for the compliance demonstration according to MIL, RTCA, or any other applicable standard.

Salt fog

Information for the compliance demonstration according to MIL, RTCA, or any other applicable standard.

Icing/Freezing Rain

Information for the compliance demonstration according to MIL, RTCA, or any other applicable standard.

Fungus

Information for the compliance demonstration according to MIL, RTCA, or any other applicable standard.

Rain

Information for the compliance demonstration according to MIL, RTCA, or any other applicable standard.

Sand and Dust

Information for the compliance demonstration according to MIL, RTCA, or any other applicable standard.

Slip Ring Characteristics

Ring

A ring is defined as single electrical sliding contact inside a slip ring, that represents the basic functional element of a slip ring.

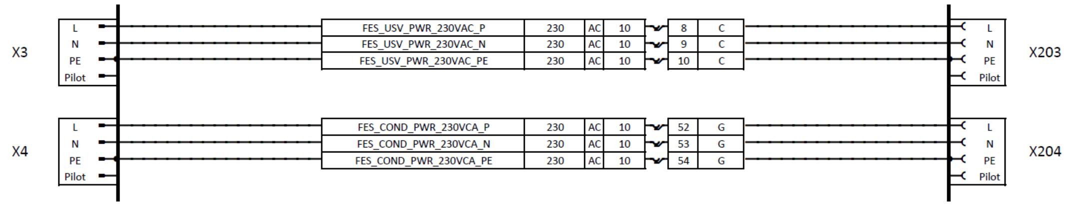
Track

A track is defined as an individual sliding contact system inside a slip ring. It is composed of a single or multiple rings.

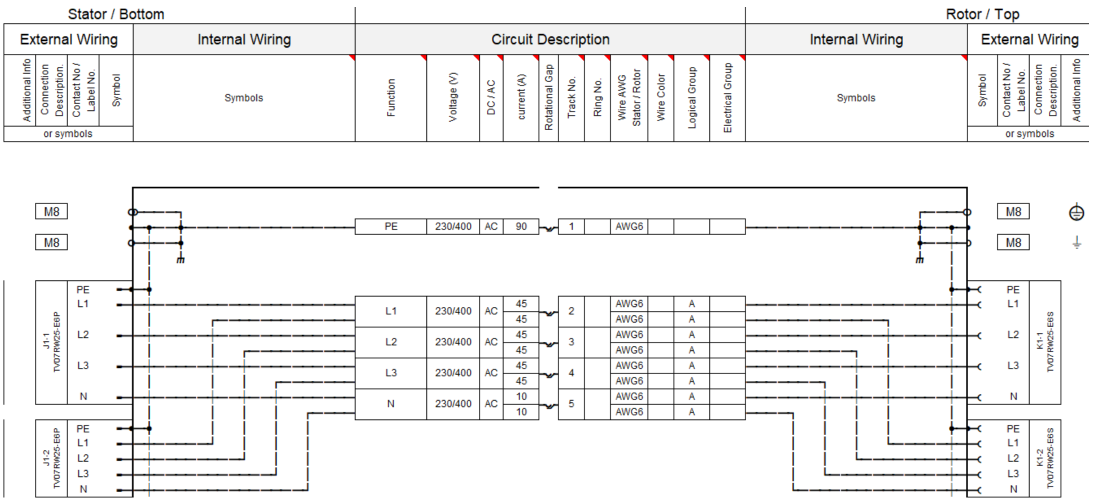
Path

A single route along which electrical current flows, when a signal is being transferred between different contact interfaces through the slip ring, is defined as a path.

Example: Connector X3, contact L → wire → track 8 → wire → Connector X203, contact L (according to circuit diagram below). **Designation: X3.L → Track 8 → X203.L**



Example: Different paths routed through one track.
Connector J1-1, contact L1 and connector J1-2 ,contact L1 → wires → track 2 → wires → connector K1-1, contact L1 and connector K1-2 ,contact L1.



PE or shield paths of different groups may be interconnected through connections to the common housing of the slip ring.

Channel

A channel is defined on slip ring products as a group of tracks that are operated in common to transfer a single specified electrical signal between stator and rotor. The number of tracks required for a channel is dependent on the type and characteristics of the signal.

Group

A grouping of channels or tracks, usually with similar or identical electrical properties. It is possible to have more than one group of the same signal type.

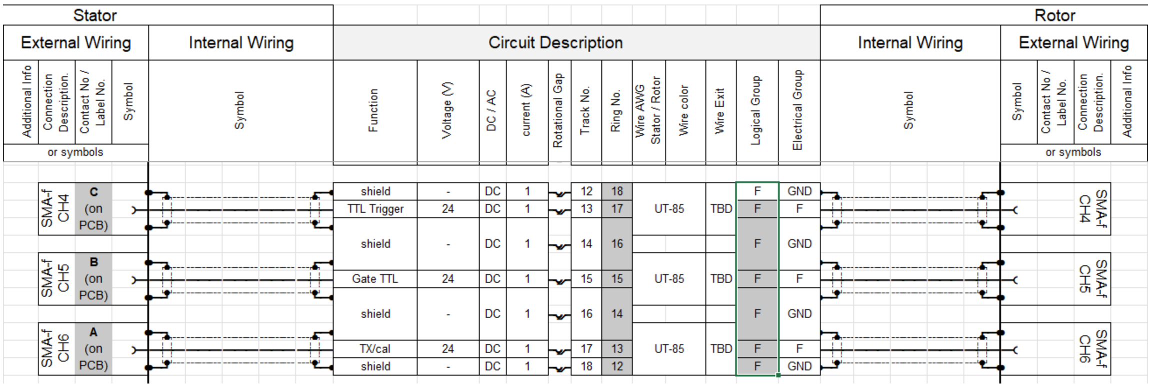
Example: 2x Fast Ethernet channels used for different purposes are grouped together as Group A.

SPINNER differentiates between two types of groups:

- *Logical group*: channel grouping according to the signal type. Usually found on data sheets.
  Example: logical group F unites channels that are used to transmit the TTL signal.

- *Electrical group*: channel grouping according to the internal interconnections. Needed for test definition.
  Example: electrical group F combines the signal tracks for the TTL signal. The shield tracks are in the electrical group GND.

Physically interconnected tracks cannot be assigned to different electrical groups but can belong to different logical groups.



Wiring

Describes the physical embodiment of paths of a slip ring according to a circuit diagram.

Low voltage tests (wiring test and insulation test) are usually performed to verify correct wiring.

Peak voltage rating

Peak voltage rating is the maximum voltage, that can be applied to a channel of a slip ring permanently. The slip ring is designed accordingly, so that this voltage can be applied without undergoing electrical breakdown.

Peak voltage rating is verified by a high voltage AC or DC test.

Insulation resistance

Insulation resistance is the minimum resistance between two or more tracks.

Insulation resistance is verified by a high voltage DC test.

Typical values for electrical insulation resistance between slip ring tracks are 100 MΩ or higher when measured at 500 V DC. In high humidity environments the insulation resistance value can be significantly lower.

A further expression for “insulation resistance”, that is sometimes used outside SPINNER, is “isolation resistance”.

End-to-end resistance

End-to-end resistance R_E, is defined as the resistance measured on a **slip ring path** from the stator terminal through the slip ring to the rotor terminal.

"End-to-end resistance, max.", as given in SPINNER data sheets, represents the worst-case value over a full revolution excluding contact noise.

$$R_{E,max} = \max_{0° \le \theta < 360°} \{R_E(\theta)\}$$

Typical values are in the range of 10 mΩ < R_E < 1000 mΩ depending on the design.

End-to-end resistance variation with rotation

End-to-end resistance variation with rotation describes how much the end-to-end resistance changes over a full rotation. It is typically low frequency (typ. < 10 Hz) and caused by the circuit length that changes periodically while the slip ring is rotated and is directly related to the angular position of the slip ring.

"End-to-end resistance variation with rotation, max." $\Delta R_{E,max}$ is defined as the difference between the maximum and minimum end-to-end resistance values measured over the rotational angle θ:

$$\Delta R_{E,max} = \max_{0° \leq \theta < 360°}\{R_E(\theta)\} - \min_{0° \leq \theta < 360°}\{R_E(\theta)\}$$

Contact noise

Contact noise, i.e. contact resistance variation with rotation, is defined as the resistance variation caused by the microscopic change in contact surface area between the surface of the ring and the sliding contact while the slip ring is rotated. It is typically high frequency (typ. > 10 Hz).

Contact noise is derived from the resistance measured while rotating the slip ring at the nominal rotational speed ω_{nom} by band pass filtering (typ. 10 Hz to 1 kHz).

The measured value is influenced by various factors such as test current, test setup, filtering, sample rate and rotational speed but may also depend on storage duration and run-in condition of the unit.

$$R_{N,max} = \max_{\substack{0° \leq \theta < 360° \\ \omega = \omega_{nom}}}\{R_N(\theta, \omega)\}$$

Typical values: 5 mΩ < $R_{N,max}$ < 50 mΩ depending on design.

Further expressions for “contact noise”, that are sometimes used outside SPINNER, are “resistance noise”, “noise resistance”, and “Ohmic noise”.

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