ROTARY JOINTS – GLOSSARY

1 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, and media transmission as well as radio frequency (RF) signals.

2 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. SPINNER does not guarantee these "typical values" however.

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	2*i*-1	2*i*

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.

3 Radio Frequency Characteristics

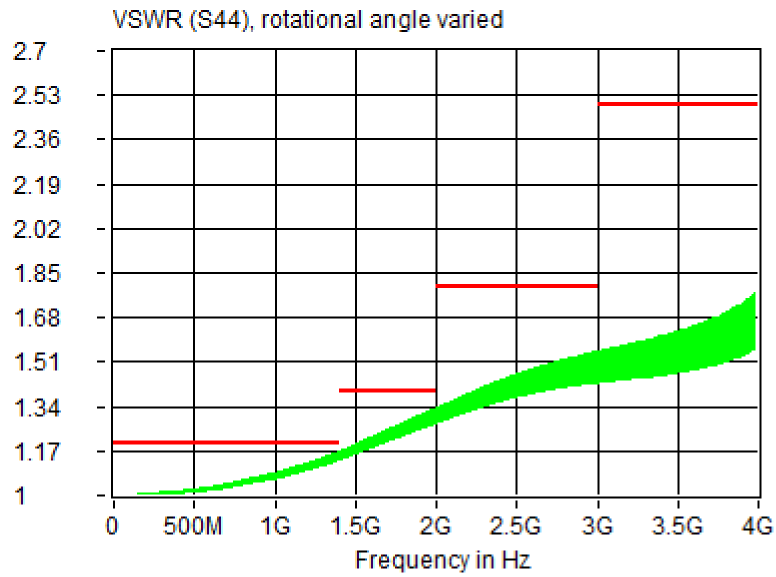
Interface type

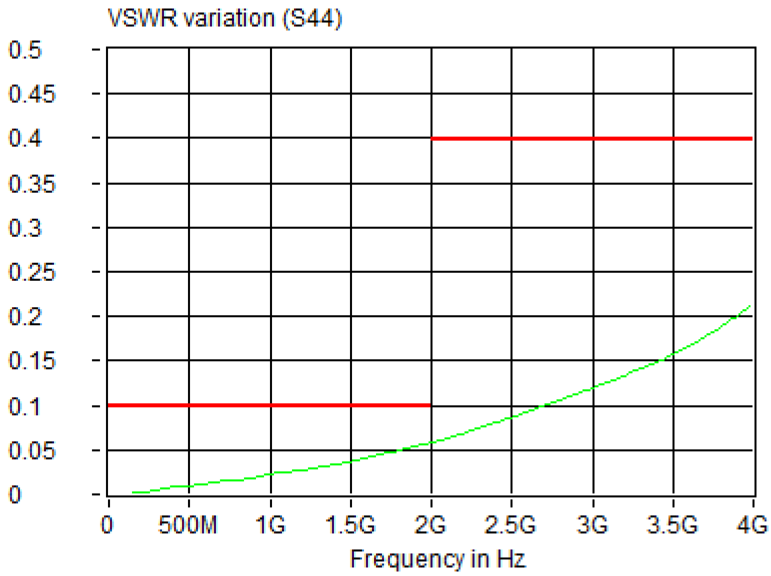
Generally, SPINNER RF rotary joints come with either waveguide or coaxial ports.

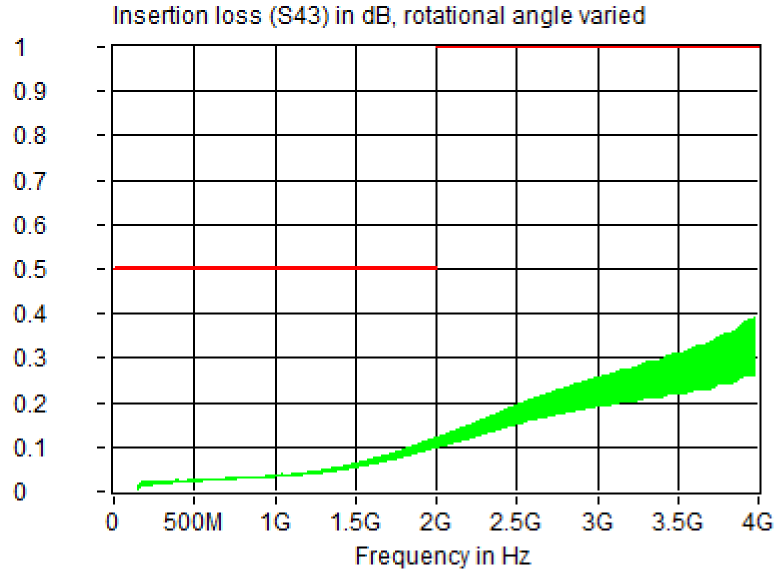
The appropriate choice depends on application, frequency range and power rating requirements. Most waveguide rotary joints feature standardized waveguide interfaces according to IEC-60154, MIL-DTL-3922 or EIA-RS 271, which may be either of the plain or choke type. Grooves on sealed flanges in combination 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.

<table>
<tr><td>Interface orientation</td><td>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, the other interface is in line with the rotating axis.</td></tr>
<tr><td>Frequency range</td><td>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.</td></tr>
<tr><td>Peak power rating</td><td>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.</td></tr>
<tr><td>Average power rating</td><td>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.</td></tr>
</table>

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. $$VSWR_{max} = \max_{f \in FR} \left\{ \max_{0° \leq \theta < 360°} \{VSWR(f,\theta)\} \right\}$$ <u>Example:</u> 
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.

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: $$\Delta VSWR(f) = \max_{0°\leq\theta<360°}\{VSWR(f,\theta)\} - \min_{0°\leq\theta<360°}\{VSWR(f,\theta)\}$$ $$\Delta VSWR_{max} = \Delta VSWR(f_{VSWRv}) = \max_{f\in FR}\{\Delta VSWR(f)\}$$ 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: 
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 $$VSWR_{ratio}(f) = \frac{\max_{0°\leq\theta<360°}\{VSWR(f,\theta)\}}{\min_{0°\leq\theta<360°}\{VSWR(f,\theta)\}}$$ $$VSWR_{ratio,max} = VSWR_{ratio}(f_{VSWRv}) = \max_{f\in FR}\{VSWR_{ratio}(f)\}$$ 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. Generally speaking: Long designs 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> 

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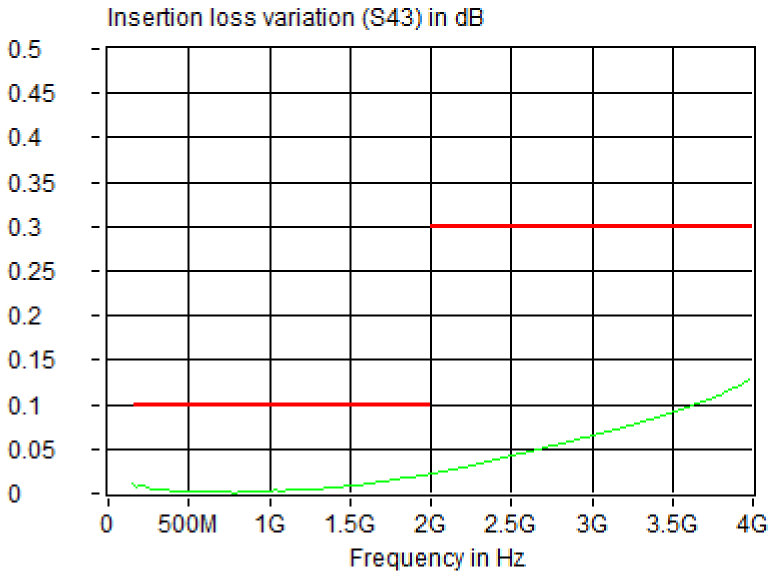
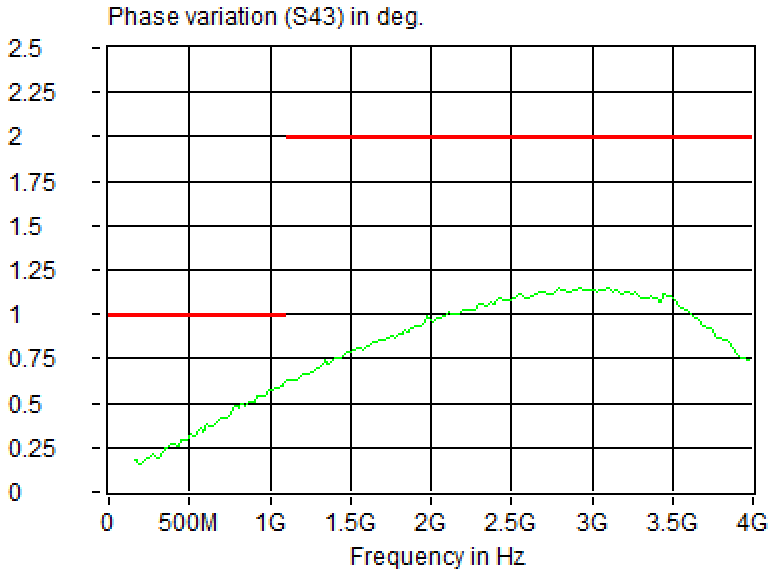
Insertion loss variation with rotation	This quantity describes how much insertion loss changes over a full rotation at the "worst" frequency within the specified frequency range. For most technical applications, this parameter is of higher relevance than VSWR variation with rotation. "Insertion loss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

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: $$\Delta\varphi_i(f) = \max_{0°\le\theta<360°}\{\varphi_i(f,\theta)\} - \min_{0°\le\theta<360°}\{\varphi_i(f,\theta)\}$$ $$\Delta\varphi_{i,max} = \Delta\varphi_i(f_{Pv}) = \max_{f\in FR}\{\Delta\varphi_i(f)\}$$ 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: 

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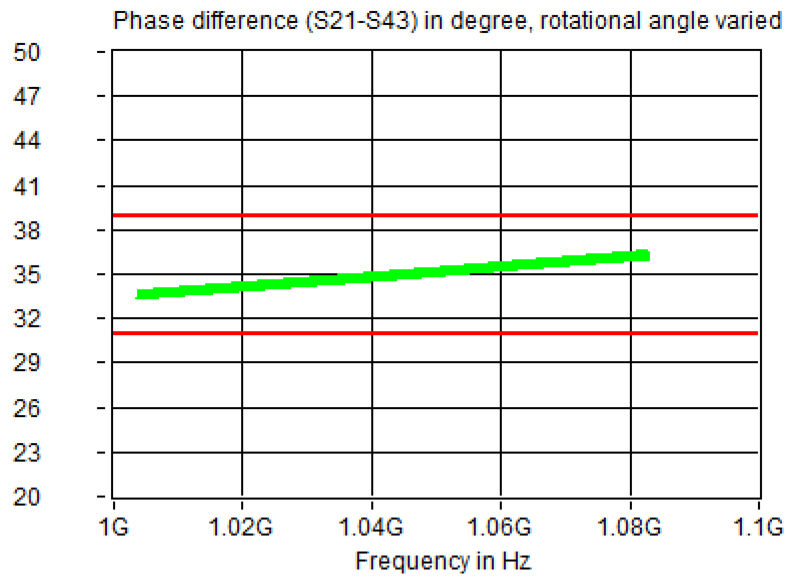
Insertion loss difference	This parameter is only defined for two channels operating in the same frequency range. It describes the difference between their insertion loss figures at a certain frequency and rotational angle *θ*. "Insertion loss difference, max." ILD_{max}, as given in SPINNER datasheets, describes the worst-case insertion loss difference value over the rotational angle *θ* within the operating frequency band: $$ILD(f,\theta) = a_{i,CH1}(f,\theta) - a_{i,CH2}(f,\theta)$$ $$ILD_{max} = \max_{f \in FR}\left\{\max_{0° \leq \theta < 360°} \lvert ILD(f,\theta)\rvert\right\}$$ 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: $$PD(f,\theta) = \varphi_{i,CH1}(f,\theta) - \varphi_{i,CH2}(f,\theta)$$ $$PD_{max} = \max_{f \in FR}\left\{\max_{0° \leq \theta < 360°} \lvert PD(f,\theta)\rvert\right\}$$ 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.

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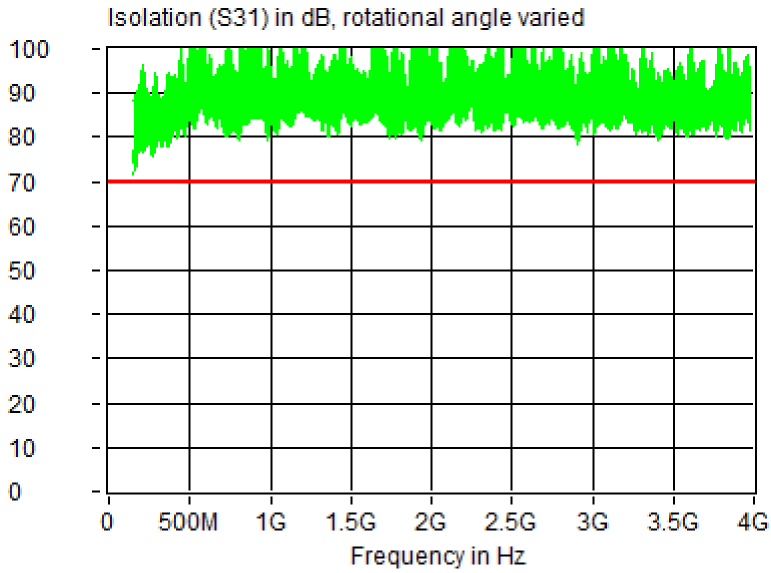
<table>
<tr><td>Isolation</td><td>This quantity describes the crosstalk between two channels.

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.

<u>Example:</u>


</td></tr>
<tr><td>Shielding effectiveness</td><td>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.</td></tr>
<tr><td>DC current rating</td><td>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.</td></tr>
<tr><td>Additive phase noise</td><td>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).</td></tr>
</table>

4 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: $\theta_s = 360°$ Multi channel 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 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.

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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}: $$a_i = 10\ \text{dB} \cdot \lg \frac{P_{in}}{P_{out}}$$ 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 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_γ within 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. $$\Delta a_\gamma(\theta_k) = \max_{\theta_k \le \theta < \theta_k+\gamma}\{a_i(\theta)\} - \min_{\theta_k \le \theta < \theta_k+\gamma}\{a_i(\theta)\}$$ $$\Delta a_{\gamma,max} = \max_{\theta_k \in [0;\theta_s]}\{\Delta a_\gamma(\theta_k)\}$$ 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.

5 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
Rotating speed	The rotating speed (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 gives 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 case also some loads are indicated which can be introduced into the system. In that cases the loads are expressed as forces in axial and radial direction as well as the bending moment on the interface axis.
Case material	The case material is the material of the housings and main flanges. For the internal design other materials are used also. Typical materials are aluminum alloys, copper alloys or stainless steel.
Case surface coating	The case surface coating is the coating of the housings 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).
IP protection level	All IP protection levels are given 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 IP class 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.

6 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.