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COAXIAL CONNECTORS

2008

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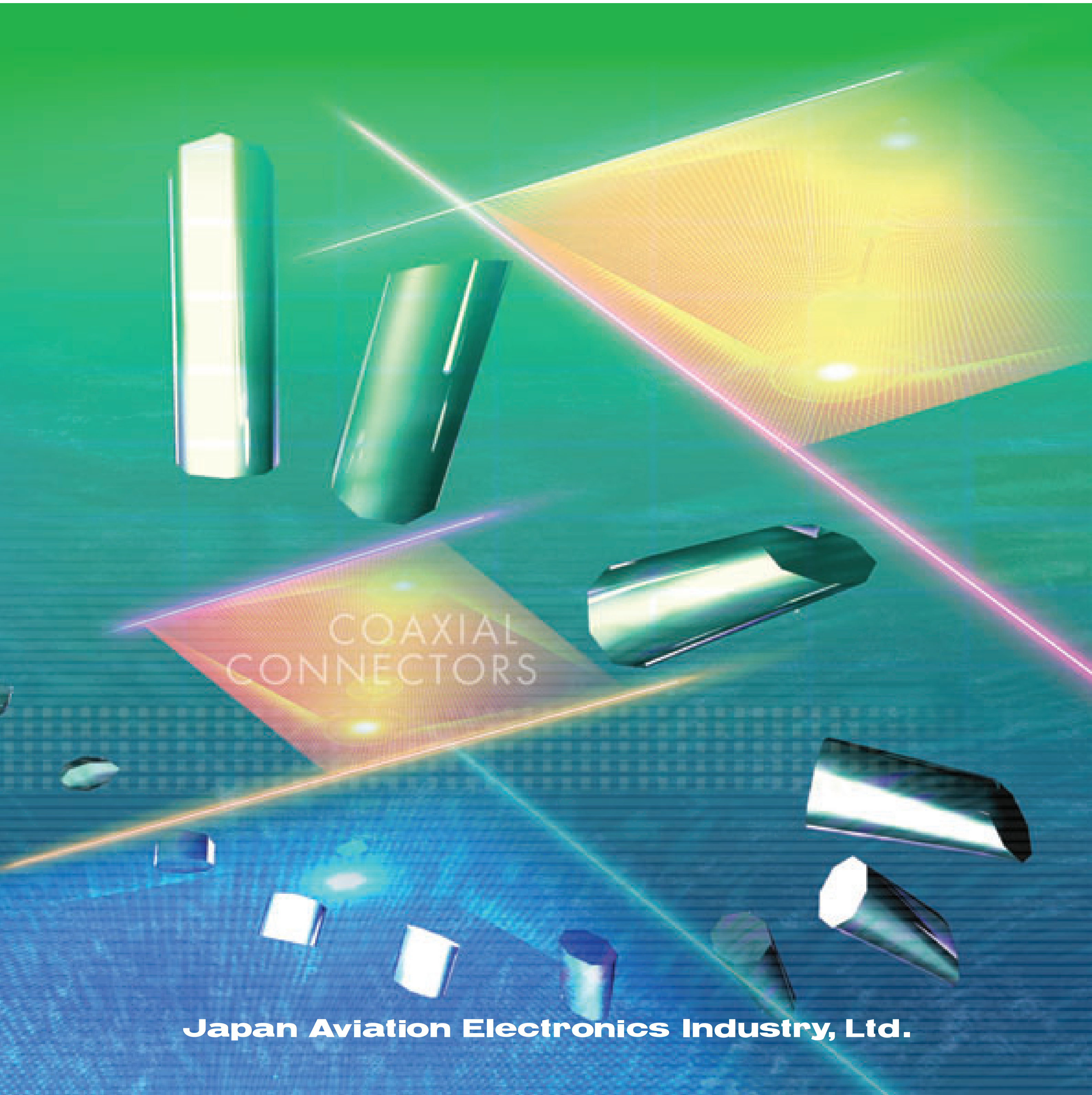


Japan Aviation Electronics Industry, Ltd.

Appendices

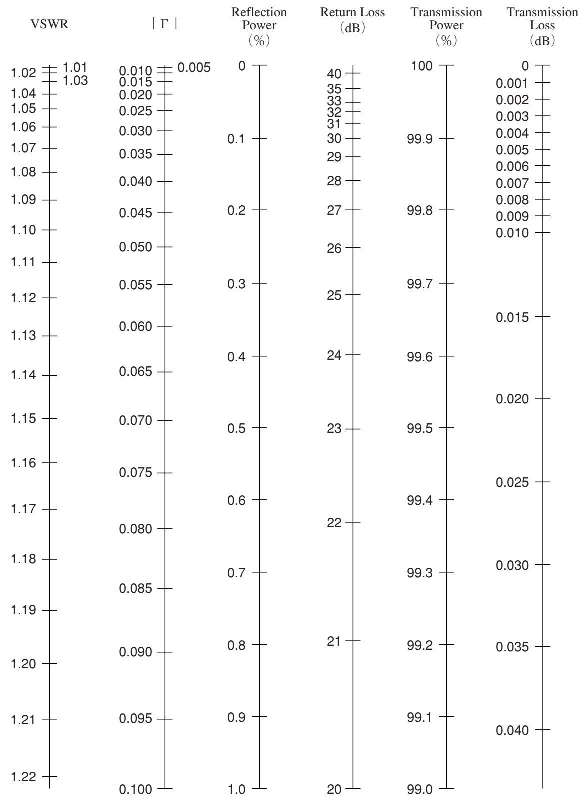
Appendices

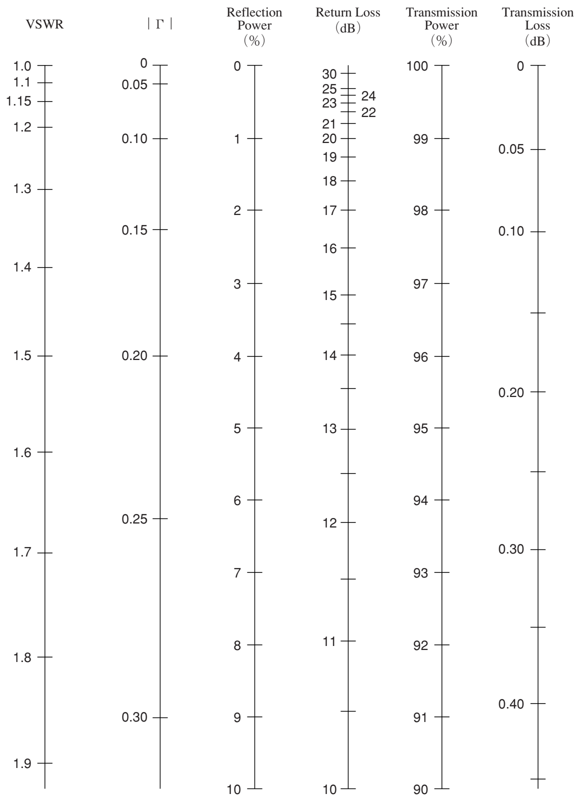
■VSWR Conversion

●VSWR Conversion Chart

	VSWR	Reflection Coefficient	Reflection Power (%)	Return Loss (dB)	Transmission Power (%)	Transmission Loss (dB)
VSWR S	S	$\frac{S-1}{S+1}$	$\left(\frac{S-1}{S+1}\right)^2\times100$	$-10\log\left(\frac{S-1}{S+1}\right)^2$	$\left\{1-\left(\frac{S-1}{S+1}\right)^2\right\}\times100$	$-10\log\left\{1-\left(\frac{S-1}{S+1}\right)^2\right\}$
Reflection Coefficient Γ	$\frac{1+\lvert\Gamma\rvert}{1-\lvert\Gamma\rvert}$	Γ	$\Gamma^2\times100$	$-10\log(\Gamma^2)$	$(1-\Gamma^2)\times100$	$-10\log(1-\Gamma^2)$
Reflection Power P_R	$\frac{10+\sqrt{P_R}}{10-\sqrt{P_R}}$	$\frac{\sqrt{P_R}}{10}$	P_R	$20-10\log(P_R)$	$100-P_R$	$20-10\log(100-P_R)$
Return Loss L_R	$\frac{1+10^{-\frac{L_R}{20}}}{1-10^{-\frac{L_R}{20}}}$	$10^{-\frac{L_R}{20}}$	$10^{\left(\frac{20-L_R}{10}\right)}$	L_R	$100-10^{\left(\frac{20-L_R}{10}\right)}$	$-10\log\left(1-10^{-\frac{L_R}{10}}\right)$
Transmission Power P_T	$\frac{10+\sqrt{100-P_T}}{10-\sqrt{100-P_T}}$	$\frac{\sqrt{100-P_T}}{10}$	$100-P_T$	$20-10\log(100-P_T)$	P_T	$20-10\log(P_T)$
Transmission Loss L_T	$\frac{1+\sqrt{1-10^{-\frac{L_T}{10}}}}{1-\sqrt{1-10^{-\frac{L_T}{10}}}}$	$\sqrt{1-10^{-\frac{L_T}{10}}}$	$100-10^{\left(\frac{20-L_T}{10}\right)}$	$-10\log\left(1-10^{-\frac{L_T}{10}}\right)$	$10^{\left(\frac{20-L_T}{10}\right)}$	L_T

●VSWR Nomograph





■dBm-W Conversion

●dBm-W Conversion

$A\,[\mathrm{dBm}] = 10\log_{10}(B\,[\mathrm{mW}])$

dBm	mW	dBm	mW	dBm	mW	dBm	mW	dBm	W	dBm	W	dBm	W
-10.0	0.100	0.0	1.00	10.0	10.0	20.0	100	30.0	1.00	40.0	10.0	50.0	100
-9.0	0.126	1.0	1.26	11.0	12.6	21.0	126	31.0	1.26	41.0	12.6	51.0	126
-8.0	0.158	2.0	1.58	12.0	15.8	22.0	158	32.0	1.58	42.0	15.8	52.0	158
-7.0	0.200	3.0	2.00	13.0	20.0	23.0	200	33.0	2.00	43.0	20.0	53.0	200
-6.0	0.251	4.0	2.51	14.0	25.1	24.0	251	34.0	2.51	44.0	25.1	54.0	251
-5.0	0.316	5.0	3.16	15.0	31.6	25.0	316	35.0	3.16	45.0	31.6	55.0	316
-4.0	0.398	6.0	3.98	16.0	39.8	26.0	398	36.0	3.98	46.0	39.8	56.0	398
-3.0	0.501	7.0	5.01	17.0	50.1	27.0	501	37.0	5.01	47.0	51.1	57.0	501
-2.0	0.631	8.0	6.31	18.0	63.1	28.0	631	38.0	6.31	48.0	63.1	58.0	631
-1.0	0.794	9.0	7.94	19.0	79.4	29.0	794	39.0	7.94	49.0	79.4	59.0	794

■Glossary

【dB(decibel)】

The transmission performance of a connector(insertion loss, return loss, isolation), for example, is expressed in decibels, in terms of a logarithm of the ratio between magnitudes of voltage, current and power.

Letting two different powers be P_1 and P_2 :

$$A[\mathrm{dB}]=10\log\frac{P_1}{P_2}\qquad\left(\frac{P_1}{P_2}=10^{\frac{A}{10}}\right)$$

With the voltage (with the current, I_1 and I_2 instead of V_1 and V_2) :

$$B[\mathrm{dB}]=20\log\frac{V_1}{V_2}\qquad\left(\frac{V_1}{V_2}=10^{\frac{B}{20}}\right)$$

【Characteristic Impedance】

Ratio of voltage to the flow of current allowed in an alternating current transmission line.

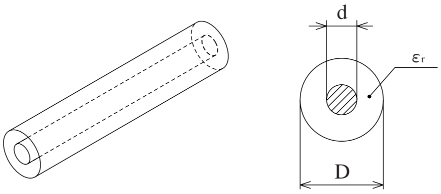
Impedance expressed in ohms is analogous to R in the equation of V=IR for a direct current circuit.With high frequencies, 50 ohms and 75 ohms are typical characteristic impedance values.

A good transmission characteristic is achieved by adjusting the input/output impedances of the device to 50 or 75 ohms. Also in the circuits inside the device, it is desirable to match the characteristic impedances in the whole region.

The characteristic impedance in the coaxial line is given by

$$Z_0=\frac{60}{\sqrt{\varepsilon_r}}\ln\left(\frac{D}{d}\right)$$

where ε_r = dielectric constant of the insulator
d = outer diameter of the core conductor
D = inner diameter of the outer conductor



Coaxial line

【Reflection Coefficient】

Ratio between the reflected voltage wave V_2 and the incident voltage wave V_1.

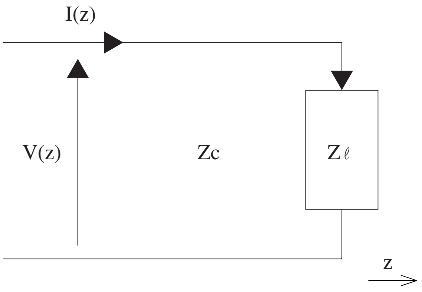
$$\Gamma=\frac{V_2}{V_1}$$

The value $|\Gamma|\leq 1$. With a higher degree of impedance matching, producing less reflection, the coefficient approaches zero.

If a load impedance Z_ℓ is connected to a transmission line with a characteristic impedance Z_c, reflection occurs.

The equation for the reflection coefficient at the connection point can be written as

$$\Gamma=\frac{Z_\ell-Z_c}{Z_\ell+Z_c}$$



Transmission line with end Zℓ

■Glossary

【Return Loss】

Logarithmic expression of the ratio between reflecting power P_2 and incident power P_1 to the circuit/connector.

$$RL = -10 \log \left(\frac{P_2}{P_1} \right) \text{ [dB]}$$

This can be rewritten in terms of the reflection coefficient Γ.

$$RL = -10 \log |\Gamma|^2 \text{ [dB]}$$

【V.S.W.R. (voltage standing wave ratio)】

A standing wave may be formed by interference between a wave transmitted into a transmission line and a reflected wave. V.S.W.R. is the ratio of the absolute value of maximum voltage and that of minimum voltage in the standing wave pattern. With a higher degree of impedance matching, the value of V.S.W.R. approaches 1.

$$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|}$$

Either return loss or V.S.W.R. is selected as a product specification.

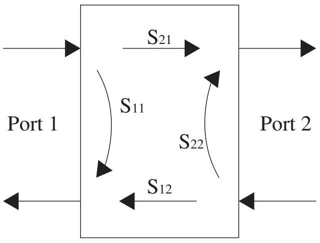
【Insertion Loss】

Logarithmic expression of the ratio of output power P_{out} to input power P_{in} of the circuit/connector.
It is sometimes simply referred to as "attenuation" or "loss."

$$IL = -10 \log \left(\frac{P_{out}}{P_{in}} \right) \text{ [dB]} \qquad \left(\frac{P_{out}}{P_{in}} = 10^{-\frac{IL}{10}} \right)$$

【S Parameter (Scattering Parameter)】

With high frequencies, it is difficult to directly measure the voltage and current in a transmission line.
The circuit characteristic can be expressed by the power measured instead of voltage or current.
The S parameter is an expression that is dependent on the amplitude and phase at each port (observation point).
V.S.W.R. and insertion loss described above can be obtained from the S parameter.



An example of S parameter with two ports

【Wave Length】

Distance the electric wave travels per cycle (1Hz). In a dielectric substance such as plastic insulator, the wavelength is reduced by its relative magnetic permeability.

$$\lambda = \frac{c}{f\sqrt{\varepsilon_r}}$$

where c= velocity of light　f= frequency　ε_r = relative permittivity of the insulator

The higher the frequency, the shorter the wavelength. As the wavelength approaches the circuit dimension, the wavelength increases in importance as a distribution constant.

Glossary

【Skin Effect】

Direct current is uniformly distributed in the conductor section.

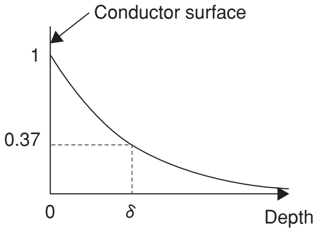
High-frequency currents, however, flow in a narrow skin of the conductor - hence the name "skin effect."

The distance below the conductor surface where the intensity of the magnetic field falls to $\frac{1}{e}$ or about 37% of its value at the conductor surface, is defined as skin depth, and is given by

$$\delta = \sqrt{\frac{\rho}{\pi f \mu_0 \mu_s}}$$

where ρ = resistivity of the conductor   f = frequency

μ_0 = magnetic permeability of vacuum μ_s = relative magnetic permeability of the conductor



Skin depth

Since signals exceeding the GHz band flows in a very narrow skin of several micrometers, the conductor loss increases.

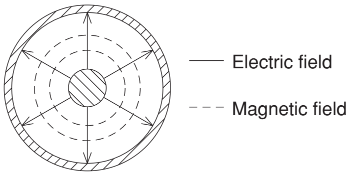
【TEM Mode (Transverse Electromagnetic Mode)】

Dominant mode of electromagnetic wave transmitted in a coaxial line.

Electric field in a section in a coaxial line is distributed radially from the core conductor to the outer conductor, whereas magnetic field forms concentric circles.

The direction of the electric and magnetic fields is orthogonal, i.e., transverse, to the direction the wave is moving.

Hence the abbreviated name, TEM.



Direction of electromagnetic field in a coaxial line

【Cutoff Frequency】

In the electromagnetic field distribution in a coaxial line, a higher mode may occur depending upon the relationship between wavelength and line diameter, resulting in poorer propagation characteristics. The frequency at which the higher mode theoretically occurs is called the cutoff frequency, which is given by

$$f_C = \frac{2c}{\pi (d + D)\sqrt{\varepsilon_r}}$$

where c = velocity of light   d = outer diameter of the core conductor

D = inner diameter of the outer conductor ε_r = relative permittivity of the insulator

The frequency in the coaxial line should be lower than the cutoff frequency.

【dBm】

A measure of absolute power value in decibels. Zero dBm equals to one milliwatt.

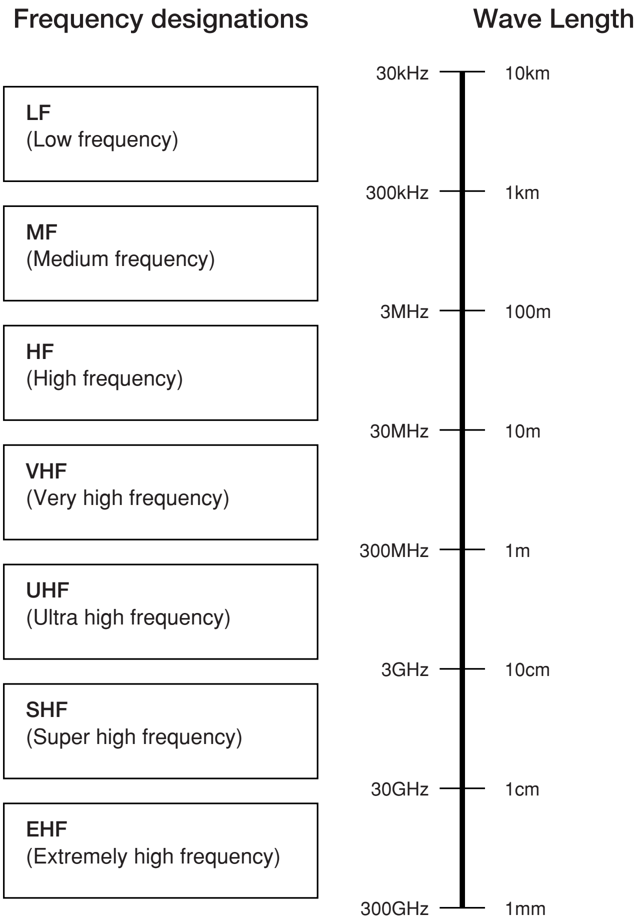
【Hz】

Number of signal cycles repeating per second.

【bps (bits per second)】

Number of bits transmitted per second.

■Frequency designations



■Calculation of the VSWR of connection in cascade connection

You cannot obtain the VSWR of the circuits of connectors, cables or components in cascade connection (mating), even when the VSWR of each circuit is known, unless the S-parameter of each circuit is obtainable.
The VSWR shall be calculated at each frequency.

■Calculation of VSWR

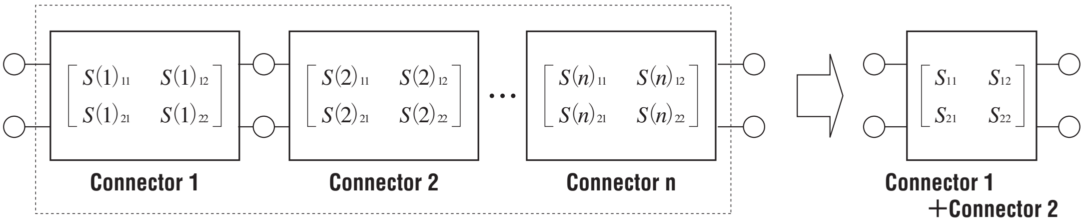
You can calculate VSWR by using S_{nn} of S-parameters

$(a+jb)$ or $(r\angle\theta)$

$$\text{From}\quad r\angle\theta = r(\cos\theta + j\sin\theta)\qquad \begin{cases} a = r\cos\theta \\ b = r\sin\theta \end{cases}$$

$$|\Gamma| = |S_{nn}| = \sqrt{a^2+b^2}、\ VSWR = \frac{1+|\Gamma|}{1-|\Gamma|}$$

■S-parameters of connectors in cascade connection



Transform the S-parameter of each connector into a T-parameter.

$$\begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} = \frac{1}{S_{21}} \begin{bmatrix} -S_{11}S_{22}+S_{12}S_{21} & S_{11} \\ -S_{22} & 1 \end{bmatrix}$$

Calculate the product of the matrices of T-parameters.

$$\begin{bmatrix} T(All)_{11} & T(All)_{12} \\ T(All)_{21} & T(All)_{22} \end{bmatrix} = \begin{bmatrix} T(1)_{11} & T(1)_{12} \\ T(1)_{21} & T(1)_{22} \end{bmatrix} \begin{bmatrix} T(2)_{11} & T(2)_{12} \\ T(2)_{21} & T(2)_{22} \end{bmatrix} \cdots \begin{bmatrix} T(n)_{11} & T(n)_{12} \\ T(n)_{21} & T(n)_{22} \end{bmatrix}$$

Inversely transform T-parameters into S-parameters.

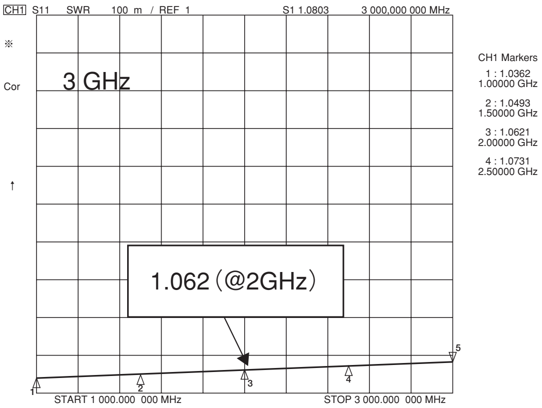
$$\begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} = \frac{1}{T_{22}} \begin{bmatrix} T_{12} & T_{11}T_{22}-T_{12}T_{21} \\ 1 & -T_{21} \end{bmatrix}$$

The S-parameter thus obtained gives the S-parameter of the coaxial connectors in cascade connection.

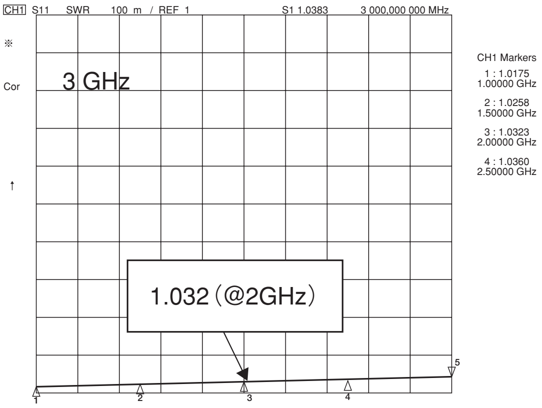
By this method, you can calculate the S-parameter of the entire circuit (including VSWR) based on the S-parameter of each connector in cascade connection.

■Calculation of the VSWR of connection in cascade connection

■An example (connectors 1 and 2 in cascade connection)



Connector 1 · VSWR (measured)



Connector 2 · VSWR (measured)

Let's calculate VSWR at 2GHz here as an example.

The S-parameter of each connector at 2GHz is measured as:

$$\begin{bmatrix} S(1)_{11} & S(1)_{12} \\ S(1)_{21} & S(1)_{22} \end{bmatrix} = \begin{bmatrix} 0.029988-0.002592j & 0.408634-0.90502j \\ 0.409045-0.90593j & 0.023405+0.01555j \end{bmatrix}$$

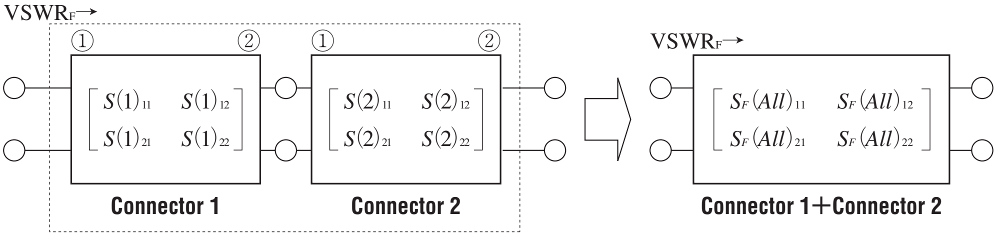
$$\begin{bmatrix} S(2)_{11} & S(2)_{12} \\ S(2)_{21} & S(2)_{22} \end{bmatrix} = \begin{bmatrix} -0.007512-0.01413j & 0.642835-0.76339j \\ 0.642835-0.76339j & -0.01136-0.007661j \end{bmatrix}$$

The above S-parameters can be transformed into the following T-parameters

$$\begin{bmatrix} T(1)_{11} & T(1)_{12} \\ T(1)_{21} & T(1)_{22} \end{bmatrix} = \begin{bmatrix} 0.968064-68.226j & 0.07518-0.0006793j \\ 0.511292-0.008163j & 0.0002302+0.01522j \end{bmatrix}$$

$$\begin{bmatrix} T(2)_{11} & T(2)_{12} \\ T(2)_{21} & T(2)_{22} \end{bmatrix} = \begin{bmatrix} 7.8211+295.214j & 2.36379-0.04696j \\ -2.9247+0.05822j & 0.0004006+0.02003j \end{bmatrix}$$

(1) VSWR_F viewed from the connector 1 when connectors 1 and 2 are connected in this order (connector 1 + connector 2)



Transform S-parameters into T-parameters and calculate the product of the matrices of T-parameters.

$$\begin{bmatrix} T_F(All)_{11} & T_F(All)_{12} \\ T_F(All)_{21} & T_F(All)_{22} \end{bmatrix} = \begin{bmatrix} T(1)_{11} & T(1)_{12} \\ T(1)_{21} & T(1)_{22} \end{bmatrix} \begin{bmatrix} T(2)_{11} & T(2)_{12} \\ T(2)_{21} & T(2)_{22} \end{bmatrix} = \begin{bmatrix} -0.42919-0.8943j & -0.02174+0.01689j \\ -0.03027-0.01444j & -0.43595+0.90886j \end{bmatrix}$$

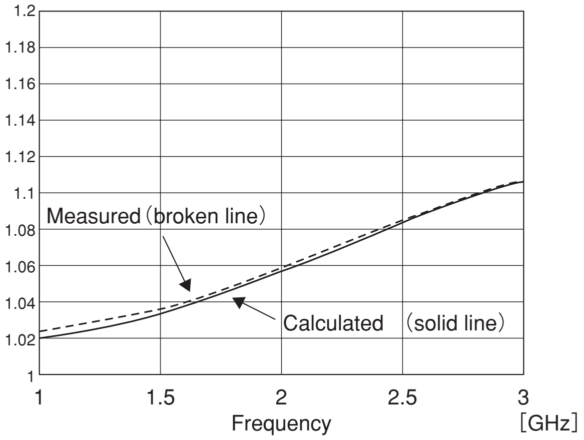
Inversely transform T-parameters thus obtained into S-parameters.

$$\begin{bmatrix} S_F(All)_{11} & S_F(All)_{12} \\ S_F(All)_{21} & S_F(All)_{22} \end{bmatrix} = \begin{bmatrix} 0.02444+0.01219j & -0.42862-0.89358j \\ -0.42905-0.89448j & -0.00007447-0.03327j \end{bmatrix}$$

Calculation of the VSWR of connection in cascade connection

When the connector 1 and connector 2 are connected in this order, the VSWR of this combination viewed from the connector 1 is calculated as 1.056 (at 2GHz) from $S_F(All)_{11}$, which is measured as 1.059

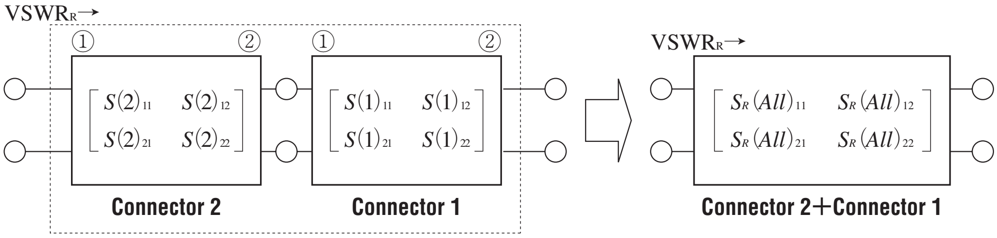
《Reference》
VSWR at 2GHz (measured)
Connector 1 (unit): 1.062
Connector 2 (unit): 1.032



VSWR of the combined connectors viewed from the connector 1

(2) VSWR$_R$ viewed from the connector 2 when connectors 2 and 1 are connected in this order (connector 2 + connector 1)

※Pay attention to the directions of connectors ① and ②.



Similarly, calculate the product of the matrices of the transformed T-parameters.

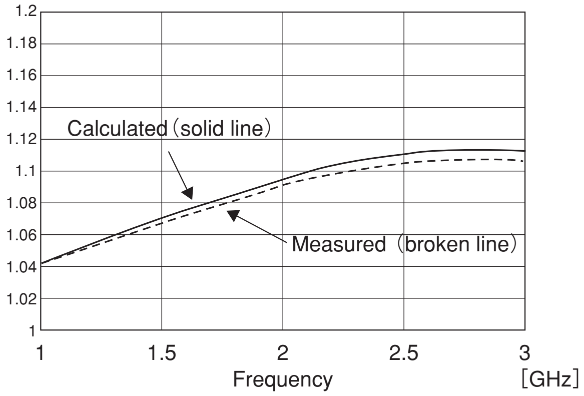
$$\begin{bmatrix} T_R(All)_{11} & T_R(All)_{12} \\ T_R(All)_{21} & T_R(All)_{22} \end{bmatrix} = \begin{bmatrix} T(2)_{11} & T(2)_{12} \\ T(2)_{21} & T(2)_{22} \end{bmatrix} \begin{bmatrix} T(1)_{11} & T(1)_{12} \\ T(1)_{21} & T(1)_{22} \end{bmatrix} = \begin{bmatrix} -0.42923-0.89477j & 0.0458+0.005022j \\ 0.03729-0.01025j & -0.4359+0.90933j \end{bmatrix}$$

Inversely transform T-parameters thus obtained into S-parameters

$$\begin{bmatrix} S_R(All)_{11} & S_R(All)_{12} \\ S_R(All)_{21} & S_R(All)_{22} \end{bmatrix} = \begin{bmatrix} -0.01514-0.04311j & -0.42823-0.89332j \\ -0.42866-0.89422j & 0.02514+0.02896j \end{bmatrix}$$

When the connector 2 and connector 1 are connected in this order, the VSWR of this combination viewed from the connector 2 is calculated as 1.096 (at 2GHz) from $S_R(All)_{11}$, which is measured as 1.091.

《Reference》
VSWR at 2GHz (measured)
Connector 1 (unit): 1.062
Connector 2 (unit): 1.032



VSWR of the combined connectors viewed from the connector 2

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