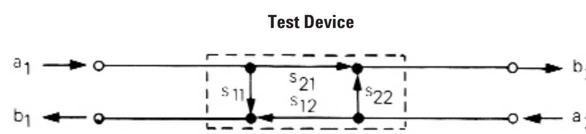
RF & Microwave References *1of 4*

S-Parameters/Return Loss/Smith Chart

S-parameters (scattering parameters) are a convention for characterizing RF & microwave devices, consisting of reflection and transmission coefficients–familiar concepts to designers. Transmission coefficients are commonly referred to as gains or attenuations, reflection coefficients relate to return losses and VSWRs (voltage standing wave ratios).

Conceptually, “s” parameters are like “h”, “y”, or “z” parameters because they describe the inputs and outputs of a black box. The inputs and outputs are in terms of power for “s” parameters; for “h”, “y”, and “z” parameters, they are voltages and currents. Using the convention that “a” is a signal into a part and “b” is a signal out, the figure below helps to explain “s” parameters.



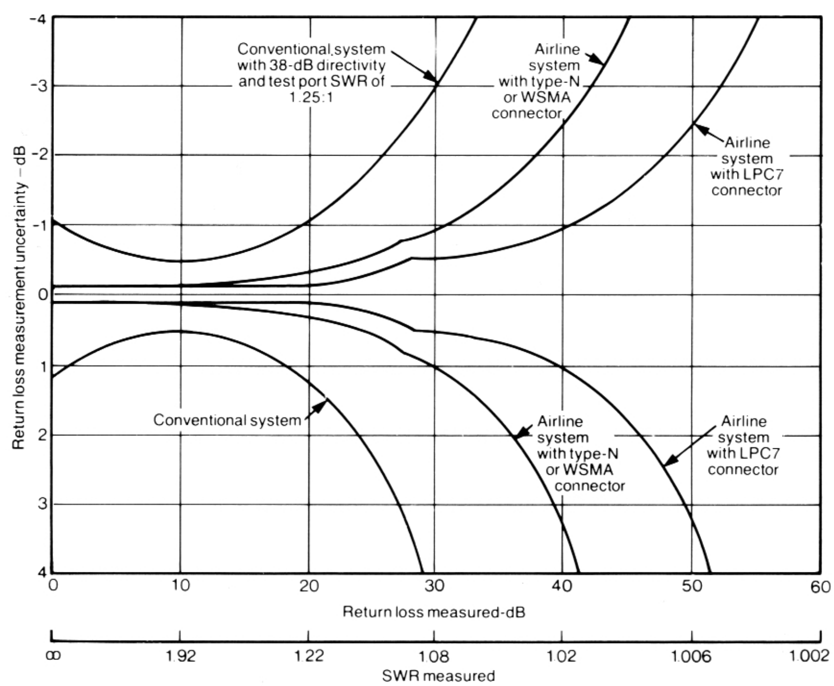
In this figure, “a” and “b” are the square roots of power; $(a_1)^2$ is the power incident are port 1 and $(b_2)^2$ is the power leaving port 2. The diagram shows the relationship between the “s” parameters and the “a’s” and “b’s”. For example, a signal, a_1, is partially reflected at port 1; the rest of the signal is transmitted through the device and out of port 2. The fraction of a_1 that is reflected at port 1 is s_{11}; the fraction of a1 that is transmitted is s_{21}. Similarly, the fraction of a_2 that is reflected at port 2 is s_{22}, and the fraction s_{12} is transmitted. The signal, b_1, leaving port 1 is the sum of the fraction of a_1 that is reflected at port 1 and the fraction of a_2 that is transmitted from port 2. Thus, the outputs can be related the the inputs by the equations:

$b_1=s_{11}a_1+s_{12}a_2$

$b_2=s_{21}a_1+s_{22}a_2$

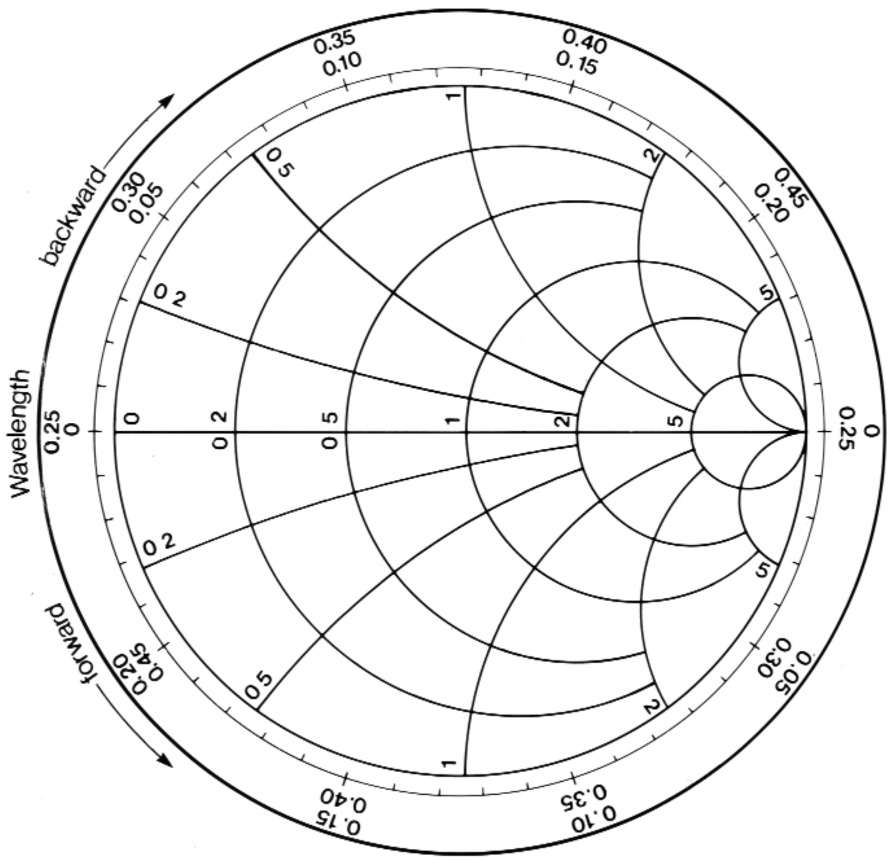
when $a_2= 0$ and when $a_1= 0$

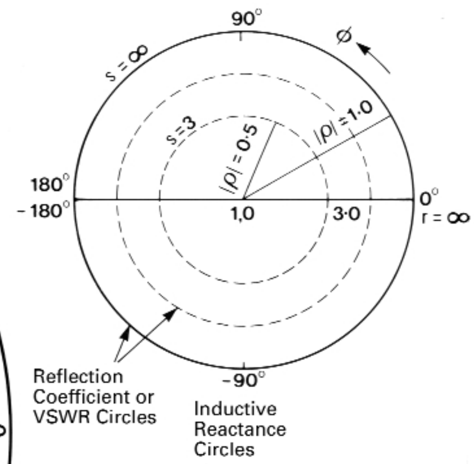
$s_{11}=\frac{b_1}{a_1}$ $s_{21}=\frac{b_2}{a_1}$ $s_{12}=\frac{b_1}{a_2}$ $s_{22}=\frac{b_2}{a_2}$

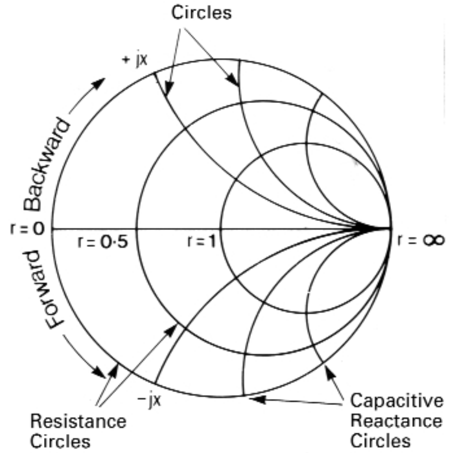


Continued page 2

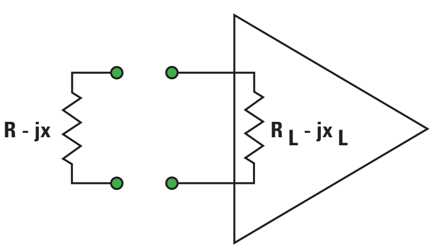
S-Parameters/Return Loss/Smith Chart, continued







Noise Power at Standard Temperature



k = 1.38 x 10^{-23} joule /k
T = Temperature (K)
B = Bandwidth (Hz)

Available Noise Power*

P_{av} = kTB
At 290KP_{av} = 4 x 10^{-21} W/Hz = -174dBm/Hz
In deep space kT = -198dBm/Hz

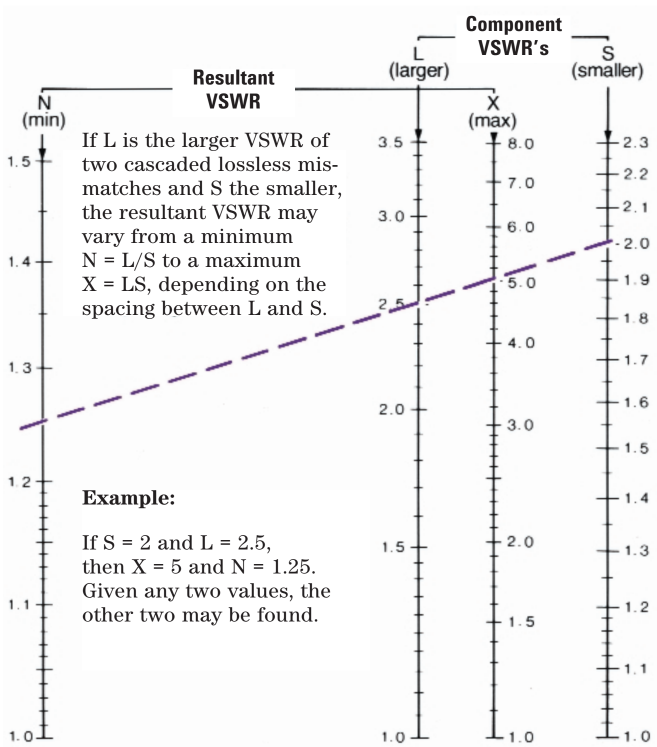
* Noise figure is defined when input is terminated at 290 Kelvins.

Noise Figure (NF_{dB})

$$NF_{dB} = 10 \log_{10} \frac{S_i/N_i}{S_o/N_o}$$

Where NF_{dB} = noise figure (dB)
S_i/N_i = input signal-to-noise ratio
S_o/N_o = output signal-to-noise ratio

Maximum and Minimum Resultant VSWR from Two Mismatches

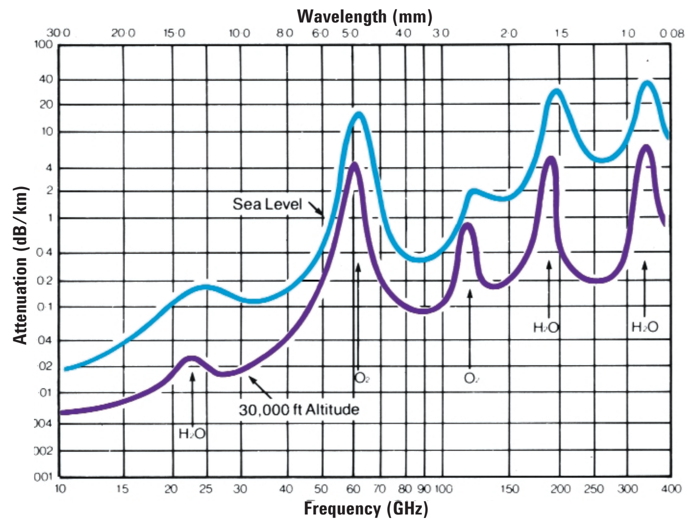


If L is the larger VSWR of two cascaded lossless mismatches and S the smaller, the resultant VSWR may vary from a minimum N = L/S to a maximum X = LS, depending on the spacing between L and S.

Example:

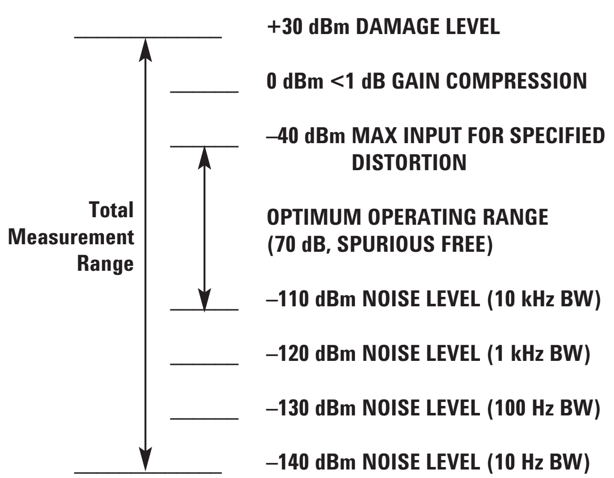
If S = 2 and L = 2.5, then X = 5 and N = 1.25. Given any two values, the other two may be found.

Millimeter–Wave Transmission Attenuation Curves



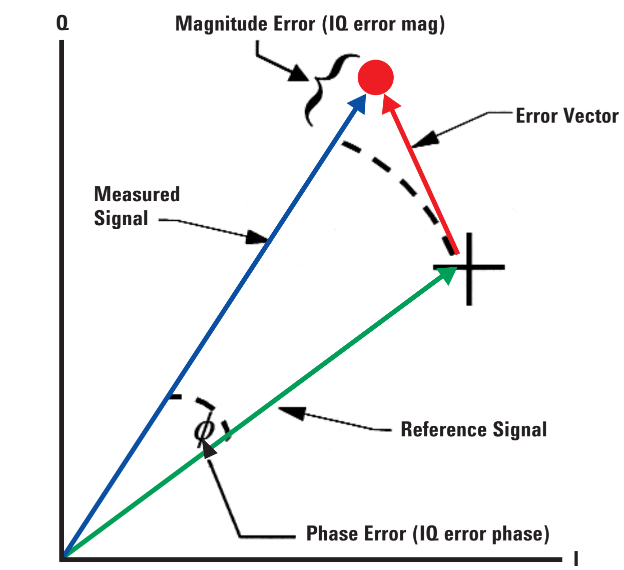
The atmospheric attenuation of mm-wave signals varies greatly, allowing for long-range exploitation by operating in the windows at 35, 94, 140, and 220 GHz, or for short-range, intercept resistant communications at 44 to 65 GHz.

Spectrum Analyzer Display Range



Typical Values

Modulation Quality: Error Vector Magnitude



RF & Microwave References

Microwave Formulae

Wavelength (λ)

$$\lambda(\text{centimeters}) = \frac{3 \times 10^{10}}{f}$$

$$\lambda(\text{meters}) = \frac{3 \times 10^{10}}{f}$$

where f = frequency (hertz)

dB (Power and Voltage)

$$dB_{(power)} = 10 \log_{10} \frac{P1}{P2}$$

$$dB_{(power)} = 20 \log_{10} \frac{E1}{E2}$$

where P1 & P2 = system powers
E1 & E2 = system voltages

Characteristic Impedance (Z_0) of RF Cable

$$Z_0 = \frac{138}{\sqrt{\varepsilon_r}} \log_{10} \frac{D}{d}$$

where ε_r = relative dielectric constant

D = inside diameter of outer conductor

d = outside diameter of inner conductor

Velocity Factor

$$v = \frac{1}{\sqrt{\varepsilon_r}} \times 100$$

where ε_r = relative dielectric constant

Noise Figure (NF_{dB})

$$NF_{dB} = 10 \log_{10} \frac{S_i/N_i}{S_o/N_o}$$

Where NF_{dB} = noise figure (dB)
S_i/N_i = input signal-to-noise ratio
S_o/N_o = output signal-to-noise ratio

Reflection Coefficient ρ

$$\rho = \frac{VSWR - 1}{VSWR + 1}$$

where VSWR = Voltage Standing Wave Ratio

Return Loss in dB

$$dB = 20 \log_{10} |\rho|$$

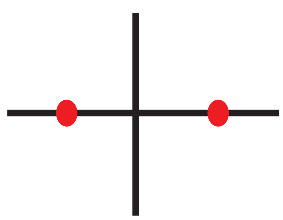
where ρ = reflection coefficient

VSWR

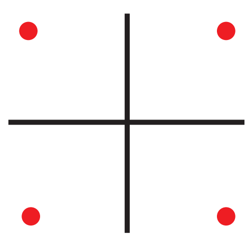
$$VSWR = \frac{1 + \rho}{1 - \rho}$$

where ρ = reflection coefficient

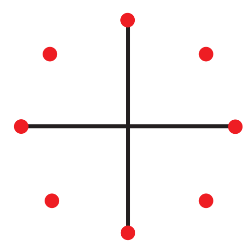
Digital Modulation Type and Constellation



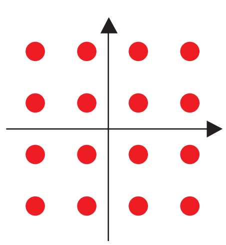
BPSK
One Bit Per Symbol
Symbol Rate = Bit Rate



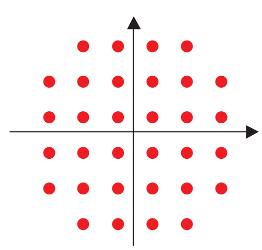
QPSK
Two Bits Per Symbol
Symbol Rate = 1/2 Bit Rate



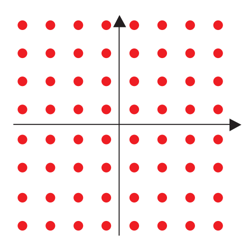
Pi/4DQPSK: Two Bits Per Symbol
Symbol Rate = 1/2 Bit Rate
or 8PSK: Three Bits Per Symbol
Symbol Rate = 1/3 Bit Rate



16 QAM
Four Bits Per Symbol
Symbol Rate = 1/4 Bit Rate



32 QAM
Five Bits Per Symbol
Symbol Rate = 1/5 Bit Rate



64 QAM
Six Bits Per Symbol
Symbol Rate = 1/6 Bit Rate