KATHREIN SCALA DIVISION

Engineering Reference - Equations

Voltage Reflection Coefficient

$$\Gamma = \frac{Z_r - Z_o}{Z_r + Z_o}$$

where: Γ = reflection coefficient
Z_r = impedance at reflection
Z_o = characteristic impedance (typically 50Ω)

Impedance $Z = R \pm jX = \frac{1}{Y} = Z_0\left(\frac{1+\Gamma}{1-\Gamma}\right)$

Admittance $Y = G \pm jX = \frac{1}{Z} = Y_0\left(\frac{1-\Gamma}{1+\Gamma}\right)$

RSL_{dB} to VSWR

$$VSWR = \frac{\left(10^{\left(\frac{RSL_{dB}}{20}\right)} + 1\right)}{\left(10^{\left(\frac{RSL_{dB}}{20}\right)} - 1\right)}$$

VSWR to RSL_{dB}

$$RSL_{dB} = 20\text{Log}\left(\frac{VSWR-1}{VSWR+1}\right)$$

Voltage Standing Wave Ratio (VSWR)

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

$$\frac{P_r}{P_i} = |\Gamma|^2 = \left(\frac{r-1}{r+1}\right)^2$$

$$\frac{P_t}{P_i} = 1 - |\Gamma|^2 = \frac{4r}{(r+1)^2}$$

where: r = VSWR
Γ = reflection coefficient
P_r = reflected power
P_i = incident power
P_t = transmitted power

Material Parameters at 20°C Table 1.1

Nonmetals

Material	μ_r	ε_r, at frequency 60	10^6	10^{10}	$\frac{\varepsilon''}{\varepsilon'}$, at frequency 60	10^6	10^{10}	(V/inch)
Nylon	1	3.60	3.14	2.80	0.018	0.022	0.0110	400
Plexiglas	1	3.45	2.76	2.50	0.064	0.104	0.0050	990
Polyethylene	1	2.26	2.26	2.26	(<0.0002)		0.005	1200
Teflon (22°C)	1	2.10	2.10	2.10	(<0.005)		0.004	1500

Metals

Material	μ_r	ε_r	σ(℧/m)	Depth of penetration δ for plane waves (m)
Silver	1	1	6.17×10^7	$0.064/\sqrt{f}$
Copper	1	1	5.8×10^7	$0.066/\sqrt{f}$
Aluminum	1	1	3.72×10^7	$0.083/\sqrt{f}$
Brass	1	1	1.6×10^7	$0.013/\sqrt{f}$

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Engineering Reference - Equations

Characteristic Impedance of Free Space

$$\eta_o = \sqrt{\frac{\mu_o}{\varepsilon_o}} = 120\pi\Omega = 377\Omega$$

where: μ_o = free space permeability
$= 4.0\pi \times 10^{-7}$(H/m)
ε_o = free space permitivity
$= \left(\frac{10^{-9}}{36\pi}\right)$(F/m)

$$c = \frac{1}{\sqrt{\mu_o \varepsilon_o}} = \text{propagation velocity} = 2.997925 \times 10^8 \text{ m/s}$$
($\cong 3 \times 10^8$ m/s)

In free space the wavelength is:

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

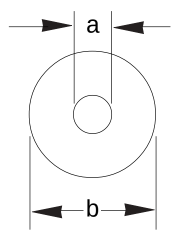
For a nonmagnetic dielectric:

$$\lambda_d = \frac{c}{f\sqrt{\varepsilon_r}} = \frac{\lambda_o}{\sqrt{\varepsilon_r}}$$

where: ε_r is relative dielectric from Table 1.1

Characteristic Impedance of Coaxial Line

$$Z_o = 138 \log_{10}\left(\frac{b}{a}\right)\sqrt{\frac{\mu_r}{\varepsilon_r}}$$



where: a = inner diameter
b = outer diameter
μ_r = relative permeability (usually = 1)
ε_r = permitivity (dielectric constant) as given in Table 1.1

Friis Transmission Equation

$$\frac{P_r}{P_t} = \left(\frac{\lambda}{4\pi R}\right)^2 G_t G_r$$

where: P_r = received power
P_t = transmitted power
R = separation distance

$$\left(\frac{\lambda}{4\pi R}\right)^2 = \text{free space loss}$$

Using effective areas

$$\frac{P_r}{P_t} = \frac{A_{et}A_{er}}{\lambda^2 R}$$

Effective Aperature Related to Gain of Antenna

$$A_{em} = \frac{\lambda^2}{4\pi} G$$

$$G = \frac{4\pi A_{em}}{\lambda^2}$$

Watts to dBm

$$\text{dBw} = 10 \log_{10}(\text{Power Watts})$$

$$\text{dBm} = (10 \log_{10}(\text{Power Watts})) + 30$$

dBw to Watts

$$\text{Watts} = 10^{\left(\frac{\text{dBw}}{10}\right)}$$

$$\text{Milliwatts} = 10^{\left(\frac{\text{dBw}+30}{10}\right)}$$

dBm to Watts

$$\text{Watts} = 10^{\left(\frac{\text{dBm}-30}{10}\right)}$$

$$\text{Milliwatts} = 10^{\left(\frac{\text{dBm}}{10}\right)}$$

Voltage Gain/Loss to dB

$$\text{dB}_{(\text{gain/loss})} = 20\text{Log}_{10}(\text{Gain or Loss})$$

dBm to Volts/μVolts

$$\text{Volts} = \text{Log}_{10}^{-1}\left(\frac{\text{dBm}-13}{20}\right)$$

$$\mu\text{Volts} = \text{Log}_{10}^{-1}\left(\frac{\text{dBm}-107}{20}\right)$$

dBw to Volts/μVolts

$$\text{Volts} = \text{Log}_{10}^{-1}\left(\frac{\text{dBw}-17}{20}\right)$$

$$\mu\text{Volts} = \text{Log}_{10}^{-1}\left(\frac{\text{dBw}-137}{20}\right)$$

Quarter Wave Matching

$$Z = \sqrt{Z_o Z_L}$$

where: Z = line impedance
Z_o = desired input impedance
Z_L = given load impedance

Noise Factor

$$F = \frac{P_{no}}{G_A P_{ni}} = \frac{SNR_{IN}}{SNR_{OUT}} = \left(\frac{T_e}{T_o}\right) - 1$$

Noise Figure

$$NF = 10 \text{Log} F$$

Cascade Noise Factor

$$F = F_1 + \frac{F_2 - 1}{G_{A1}} + \frac{F_3 - 1}{G_{A1} G_{A1}} + \ldots$$

Freespace Path Loss

$$L = 96.6 + 20 \log(d) + 20 \log(f)$$

where: L = freespace path loss
d = distance in miles
f = frequency in GHz

Directive Antenna Gain

$$G = \frac{41253}{\theta \cdot \phi}$$

theoretical

$$G = \frac{32400}{\theta \cdot \phi}$$

corrected for efficiencies

where: G = directive antenna gain
θ = horizontal beamwidth
ϕ = vertical beamwidth

Radio Horizon (in miles)

$$H = \sqrt{2}\,(Tx)^{½}(Rx)^{½}$$

where: H = horizon
Tx = transmit height in feet
Rx = receive height in feet

Gain of Parabolic Antenna

$$G = 10 \log K \left(\frac{\pi D}{\lambda}\right)^2$$

where: G = parabolic antenna gain
K = eff L 55%
D = diameter in feet
λ = wavelength in feet

Beamwidth of Parabolic Antenna

$$\Psi = \frac{70\lambda}{D}$$

where: Ψ = beamwidth
D = diameter in feet
λ = feet

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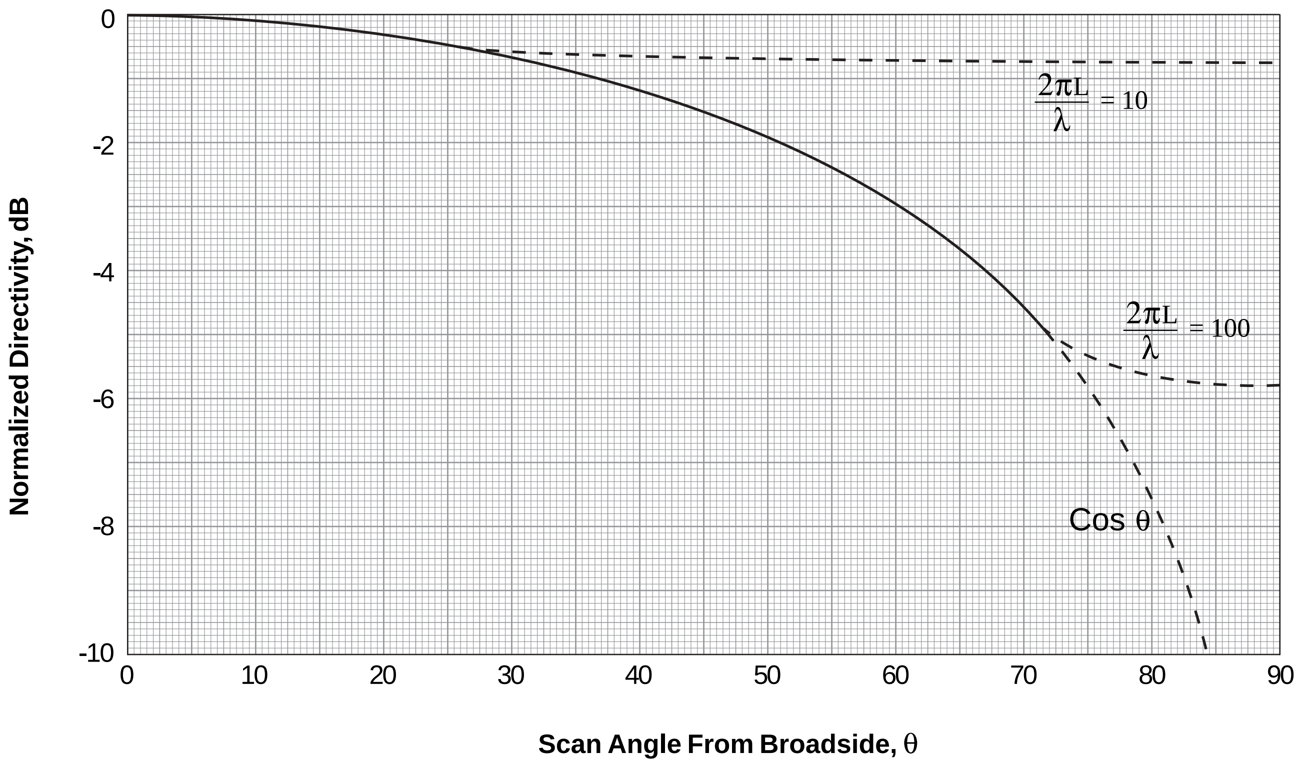

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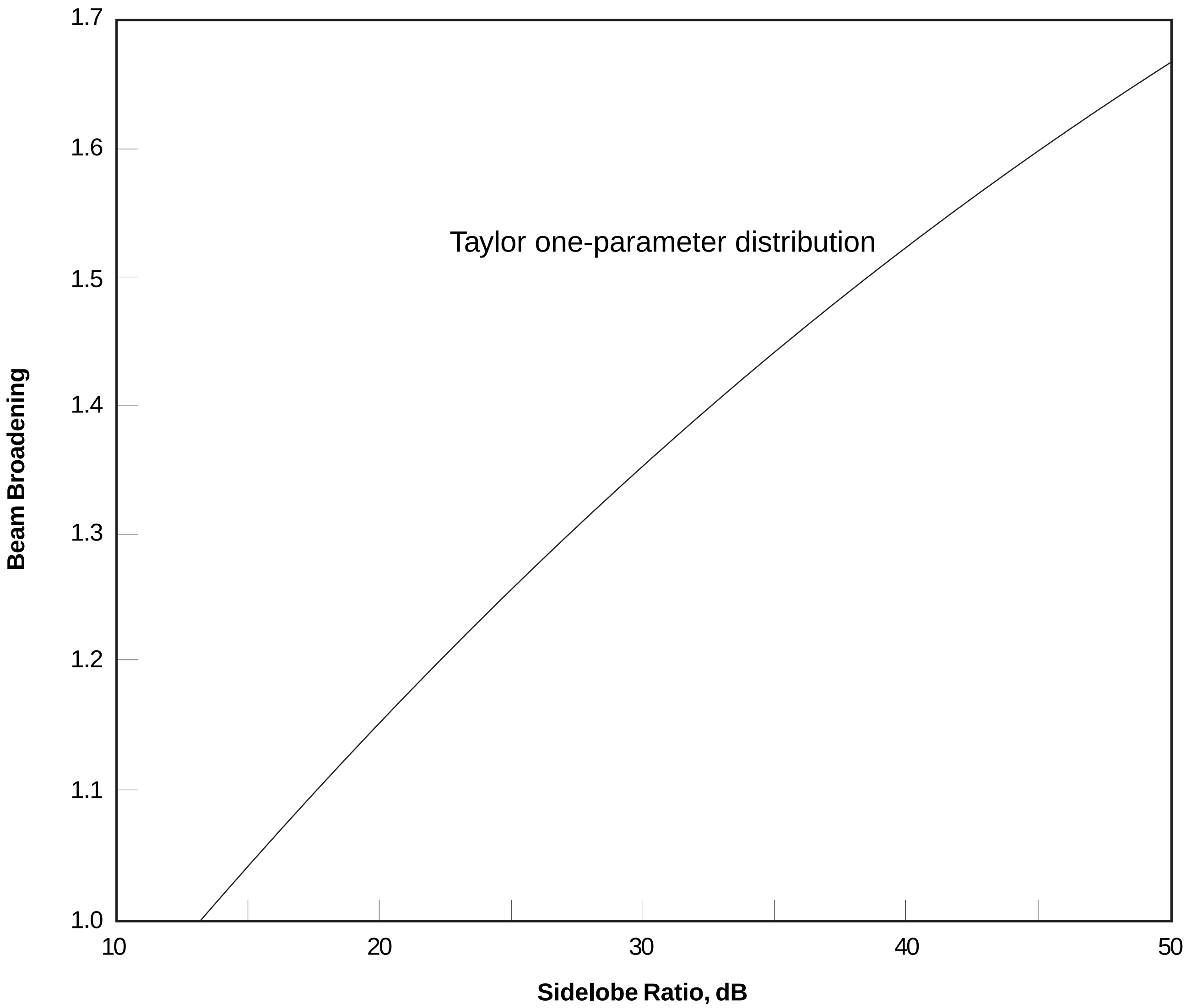
Beam Broadening Versus Sidelobe Ratio



Courtesy of Dr. R. C. Hansen