Standard & Current Frequency Designations

STANDARD FREQUENCY DESIGNATIONS

HF	3 MHz - 30 MHz
VHF	30 MHz - 300 MHz
UHF	300 MHz - 1.0 GHz
L	1.0 GHz - 2.0 GHz
S	2.0 GHz - 4.0 GHZ
C	4.0 GHz - 8.0 GHZ
X	8.0 GHz - 12.0 GHz
Ku	12.0 GHz - 18.0 GHz
K	18.0 GHz - 27.0 GHz
Ka	27.0 GHz - 40.0 GHz

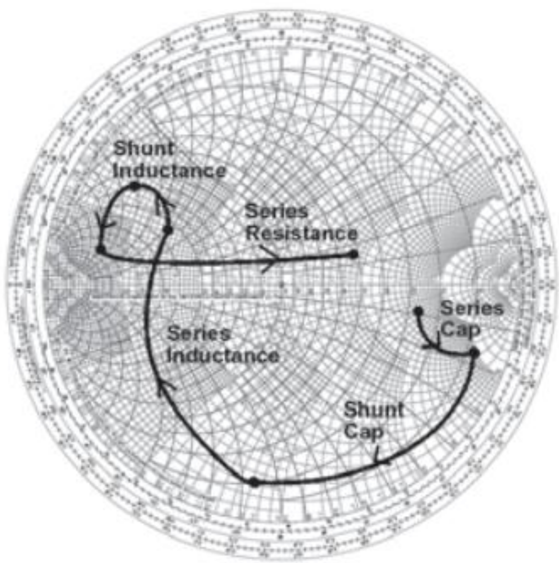
CURRENT FREQUENCY DESIGNATIONS

A	250 MHz - 500 MHz
B	500 MHz - 1.0 GHz
C	1.0 GHz - 2.0 GHz
E	2.0 GHz - 3.0 GHz
F	3.0 GHz - 4.0 GHz
G	4.0 GHz - 6.0 GHz
H	6.0 GHz - 8.0 GHZ
I	8.0 GHz - 10.0 GHz
J	10.0 GHz - 20.0 GHz
K	20.0 GHz - 40.0 GHz
L	40.0 GHz - 60.0 GHz
M	60.0 GHz - 100.0 GHz

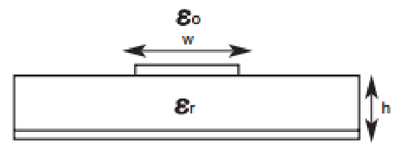
Electromagnetic Spectrum

FREQUENCY	WAVELENGTH (free space)	DESIGNATION	APPLICATIONS
< 3 Hz	> 100 Mm		Geophysical prospecting
3-30 Hz	10-100 Mm	ELF	Detection of buried metals
30-300 Hz	1-10 Mm	SLF	Power transmission, submarine communications
0.3-3 kHz	0.1-1 Mm	ULF	Telephone, audio
3-30 kHz	10-100 km	VLF	Navigation, positioning, naval communications
30-300 kHz	1-10 km	LF	Navigation, radio beacons
0.3-3 MHz	0.1-1 km	MF	AM broadcasting
3-30 MHz	10-100 m	HF	Short wave, citizens' band
30-300 MHz 54-72 76-88 88-108 174-216	1-10 m	VHF	TV, FM, police TV channels 2-4 TV channels 5-6 FM radio TV channels 7-13
0.3-3 GHz 470-890 MHz 915 MHz 800-2500 MHz 1-2 2.45 2-4	10-100 cm	UHF "money band"	Radar, TV, GPS, cellular phone TV channels 14-83 Microwave ovens (Europe) PCS cellular phones, analog at 900 MHz, GSM/CDMA at 1900 L-band, GPS system Microwave ovens (U.S.) S-band
3-30 GHz 4-8 8-12 12-18 18-27	1-10 cm	SHF	Radar, satellite communications C-band X-band (Police radar at 11 GHz) K_u-band (dBS Primestar at 14 GHz) K-band (Police radar at 22 GHz)
30-300 GHz 27-40 40-60 60-80 80-100	0.1-1 cm	EHF	Radar, remote sensing K_a-band (Police radar at 35 GHz) U-band V-band W-band
0.3-1 THz	0.3-1 mm	Millimeter	Astronomy, meteorology
10^{12}-10^{14} Hz	3-300 μm	Infrared	Heating, night vision, optical communications
3.95×10^{14}- 7.7×10^{14} Hz	390-760 nm 625-760 600-625 577-600 492-577 455-492 390-455	Visible light	Vision, astronomy, optical communications Red Orange Yellow Green Blue Violet
10^{15}-10^{18} Hz	0.3-300 nm	Ultraviolet	Sterilization
10^{16}-10^{21} Hz		X-rays	Medical diagnosis
10^{18}-10^{22} Hz		γ-rays	Cancer therapy, astrophysics
> 10^{22} Hz		Cosmic rays	Astrophysics

Impedance Smith Chart



Microstrip Transmission Line Reference Table



Trace width for a 50Ω ± 1Ω microstrip, transmission line (in mils)

1 oz copper | @ 1 GHz | Data from MWO

Dielectric Thickness (h mils)

h	2.1	2.2	2.33	2.5	3	4.5	5.7	6	6.5	8	8.6	9.4	10
3	8.6	8.3	8	7.6	6.7	4.9	4	3.8	3.5	2.8			
4	11.7	11.3	10.9	10.4	9.1	6.7	5.5	5.2	4.8	3.9	3.7	3.3	3.1
5	14.8	14.3	13.8	13.1	11.6	8.5	7	6.7	6.2	5.1	4.7	4.3	4
10	30.4	29.5	28.4	27.1	23.9	17.7	14.6	14	13.1	10.8	10	9.2	8.6
15	46.2	44.8	43.1	41.2	36.4	27	22.4	21.4	20	16.5	15.4	14.1	13.3
20	61.9	60.1	57.9	55.3	48.9	36.4	30.1	28.8	26.9	22.3	20.9	19.1	18
25	77.7	75.4	72.7	69.4	61.4	45.7	37.9	36.3	33.9	28.2	26.3	24.1	22.7
31	96.7	93.9	90.4	86.4	76.4	56.9	47.2	45.2	42.3	35.1	32.8	30.1	28.3
40	125	122	117	112	98.9	73.8	61.2	58.7	54.8	45.6	42.6	39.1	36.8
50	157	152	147	140	124	92.5	76.8	73.6	68.8	57.3	53.6	49.2	46.3
62	195	189	182	174	154	115	95.5	91.6	85.6	71.3	66.7	61.2	57.6

Material Properties

Material	Conductivity, σ (Mho/meter) x 10^8
Tantalum Nitride	.000074
Carbon	.0006 - .0007
Nichrome *(80%Ni, 20%Cr)*	.0093
Lead	.047
Sn63 Solder	.0667
Tin	.087
Palladium	.0926
Indium	.1111
Nickel	.1449
Tungsten	.184
Rhodium	.1961
Beryllium	.2188
Brass *(66% Cu, 34% Zn)*	.2564
Aluminum	.3817
Gold	.4098
Copper	.5800
Silver	.6173

Dielectric Constant (ε_r) & Loss Tangent (tan δ) @ 3.0 GHz

Material	ε_r	*tan* δ
Air	1.000649	
Polystyrene Foam	1.03	.0001
PTFE	2.1	.0002
Vaseline	2.16	.00066
RT/Duroid® 5880	2.2	.0004
Polyethylene	2.3	.0003
Polystyrene	2.55	.00033
RO/Duroid® 3003	3.0	.0013
Quartz	3.78	.00006
Glass, Soda	4.82	.0054
Mica, Ruby	5.4	.0003
Diamond (CVD)	5.6	.0005
RT/Duroid® 6006	6.15	.0027
Beryllium Oxide (BeO)	6.5	.004
Aluminum Nitride (AlN)	8.9	.0005
Alumina (Al_2O_3) 99.6%	9.9	.0001
RT/Duroid® 6010	10.2	.0028

Reduction of SWR by a Matched Attenuator

$$\frac{1}{SWR_{input}} = \tanh\left[\frac{dB}{8.686} + \tanh^{-1}\frac{1}{SWR_{load}}\right]$$

Input Reflection Coefficient

$$\Gamma_{in} = S_{11} + \frac{S_{21}\,S_{12}}{1 - S_{22}\,\Gamma_l}$$

Reflection Coefficient (ρ) to SWR

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

Equivalent Parallel Capacitance

$$C_P = \frac{jB}{\omega}$$

SWR to Reflection Coefficient (ρ)

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

Reflection Coefficient (ρ) to Return Loss

$$R.L.(dB) = -20\log\rho$$

Return Loss to Reflection Coefficient (ρ)

$$\rho = \log^{-1}\left(\frac{R.L.}{-20}\right)$$

Reflected and Transmitted Power Due to SWR

$$P_{refl} = P_{in}\left(\frac{SWR - 1}{SWR + 1}\right)^2 = P_{in}\,\rho^2$$

$$P_{trans} = P_{in}\,\frac{4SWR}{(SWR + 1)^2} = P_{in}\,(1 - \rho^2)$$

Normalized Impedance to Reflection Coefficient

$$\Gamma = \frac{\bar{Z} - 1}{\bar{Z} + 1}$$

Electrical Length φ (degrees)

$$\phi = -360\sqrt{\varepsilon_r}$$

Lf

$$\frac{\sqrt{\varepsilon_r}\,L}{c} = T_D = \text{Time Delay (seconds)}$$

$$\phi = -360\,T_d f$$

$$\phi = \frac{\Delta\phi}{\Delta f}\,f$$

Total Power Dissipated in Attenuator

$$P_d = P_{in}\left(1 - \log^{-1}\frac{dB}{-10}\right)$$

Parallel Plate Capacitance

$$Cpp = \frac{A\varepsilon_r\varepsilon_o}{h}$$

Reactance: $X_L = 6.28 f_{GHz} L_{nH}$ and $X_c = \frac{159}{f_{GHz} C_{pF}}$

Conductance: $G = \frac{1}{R}$ and $g = \frac{1}{r}$

Susceptance: $B = \frac{1}{X}$ and $b = \frac{1}{x}$

Impedance (Z_o is the Characteristic Impedance)

$$Z = R \pm jX = \frac{1}{Y} = Z_o\left(\frac{1-\Gamma}{1+\Gamma}\right) \text{ and } z = \frac{Z}{C}$$

Admittance (Y_o is the Characteristic Admittance)

$$Y = G \pm jB = \frac{1}{Z} = Y_o\left(\frac{1-\Gamma}{1+\Gamma}\right) \text{ and } Y = \frac{Y}{Y_o}$$

Reflection Coefficient: $\Gamma = \frac{Z - Z_o}{Z + Z_o} = \frac{Y_o - Y}{Y_o + Y} = \frac{VSWR - 1}{VSWR + 1} = \frac{z - 1}{z + 1}$

Voltage Standing Wave Ratio: $VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|} = \frac{R_{LARGER}}{R_{SMALLER}}$

Return Loss: $RL = 20\log|\Gamma| = -20\log\left|\frac{Z - Z_o}{Z + Z_o}\right|$

Mismatch Loss ($\Gamma_s = 0$, $\Gamma_L \neq 0$)

$$ML = -10\log(1 - |\Gamma_L|^2) = -10\log\left(1 - \left|\frac{Z_L - Z_o}{Z_L + Z_o}\right|^2\right) = -10\log\left[1 - \left(\frac{VSWR-1}{VSWR+1}\right)^2\right]$$

Mismatch Loss ($\Gamma_s \neq 0$, $\Gamma_L \neq 0$)

$$ML = -10\log\left[\frac{(1 - |\Gamma_s|^2)(1 - |\Gamma_L|^2)}{|1 - \Gamma_L\Gamma_s|}\right]$$

Wavelength

$$\lambda = \frac{c}{f\sqrt{\varepsilon_r\mu_r}} = \frac{3 \cdot 10^8 m}{f_{Hz}\sqrt{\varepsilon_r\mu_r}} = \frac{30cm}{f_{GHz}\sqrt{\varepsilon_r\mu_r}}$$

Conversion to dB

$$dB = 20\log\frac{V_2}{V_1} = 20\log\frac{i_2}{i_1} = 10\log\frac{P_2}{P_1}$$

Equations for Coaxial Transmission Lines

Characteristic Impedance	(eq 1)	$Z_o = \frac{59.959}{\sqrt{\varepsilon_r}} \cdot \ln \frac{b}{a}$
Velocity of Propagation	(eq 2)	$V_P = \frac{c}{\sqrt{\varepsilon_r}}$
Free Space Wavelength	(eq 3)	$\lambda = \frac{c}{f}$
Electrical Length	(eq 4)	$\phi = \frac{-360\sqrt{\varepsilon_r} \cdot Lf}{c}$
Time Delay	(eq 5)	$T_D = \frac{\sqrt{\varepsilon_r} \cdot L}{c}$
Cutoff Frequency	(eq 6)	$f_c = \frac{c}{\pi(a+b)\sqrt{\mu_r \varepsilon_r}}$
Capacitance	(eq 7)	$C' = \frac{2\pi\varepsilon_o\varepsilon_r}{\ln \frac{b}{a}}$
Inductance	(eq 8)	$L' = \frac{\mu_o\mu_r}{2\pi} \cdot \ln \frac{b}{a}$
Skin Depth	(eq 9)	$\delta_S = \frac{1}{\sqrt{\pi f \mu_o \mu_r \sigma}}$
Conductor Loss	(eq 10)	$\alpha_c = 13.6 \frac{\delta_S \sqrt{\varepsilon_r} \cdot 1 + \frac{b}{a}}{\lambda b \cdot \ln \frac{b}{a}}$
Dielectric Loss	(eq 11)	$\alpha_\alpha = 27.3 \frac{\sqrt{\varepsilon_r}}{\lambda} \cdot \tan(\delta)$
Coaxial Line Loss	(eq 12)	$\alpha_T = \alpha_c + \alpha_\alpha$

Symbols for Coaxial Transmission Lines

Symbol	Description	Units
b	Inside radius of outer conductor	meter
a	Outside radius of center conductor	meter
ε_r	Relative permittivity (dielectric constant)	1
ε_o	Permittivity of free space (8.854×10^{-12})	Farad/meter
c	Velocity of light in free space (299.7925×10^6)	meter/second
μ_r	Relative permeability	1
μ_o	Permeability of free space ($4\pi \times 10^{-7}$)	Henry/meter
f	Frequency	Hertz
f_c	Cutoff frequency	Hertz
ϕ	Phase length	degree
T_D	Time delay	second
V_P	Velocity of propagation	meter/second

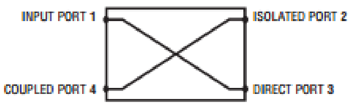
Symbols for Coaxial Transmission Lines

Symbol	Description	Units
Z_o	Characteristic impedance	ohm
C	Capacitance per unit length	Farad/meter
L	Inductance per unit length	Henry/meter
δ_s	Skin depth	meter
σ	Conductivity	Mho/meter
α_c	Attenuation constant, conductors	dB/meter
α_d	Attenuation constant, dielectric	dB/meter
α_T	Attenuation constant, total	dB/meter
λ	Wavelength in free space	meter
tan δ	Loss tangent	meter

INTERNATIONAL SYSTEM OF UNITS			
Quantity	**Unit**	**Symbol**	**Dimensions**
Capacitance	farad	F	C/V
Conductance	siemens	S	A/V
Current	ampere	A	A
Electric charge	coulomb	C	A-s
Energy	joule	J	N-m
Force	newton	N	kg-m/s^2
Frequency	hertz	Hz	1/s
Inductance	henry	H	Wb/A
Length	meter	m	m
Magnetic flux	weber	Wb	V-s
Magnetic induction	tesla	T	Wb/m^2
Mass	kilogram	kg	kg
Potential	volt	V	J/C
Power	watt	W	J/s
Pressure	pascal	Pa	N/m^2
Resistance	ohm	Ω	V/A
Temperature	kelvin	K	K
Time	second	s	s

90˚ Hybrid Couplers Performance Parameters

90˚ Hybrid Couplers



90˚ Crossover Hybrid

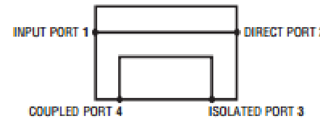
PORT	1	2	3	4
1	IN	ISO	-90˚	0˚
2	ISO	IN	0˚	-90˚
3	-90˚	0˚	IN	ISO
4	0˚	-90˚	ISO	IN

Performance Parameters

VSWR	$\text{VSWR} = \dfrac{V_{max}}{V_{min}}$
Return Loss	$\text{Return Loss (dB)} = 20 \bullet \text{Log}\left(\dfrac{VSWR+1}{VSWR-1}\right)$
Insertion Loss	$\text{Insertion Loss (dB)} = 10 \bullet \text{Log}\left(\dfrac{P_{in}}{P_{coupled} + P_{direct}}\right)$
Isolation	$\text{Isolation (dB)} = 10 \bullet \text{Log}\left(\dfrac{P_{in}}{P_{isolated}}\right)$
Phase Balance	$\text{Phase Balance (°)} = \pm\dfrac{\lvert Phase_{coupled} - Phase_{direct}\rvert}{2}$
Amplitude Balance	$\text{Amplitude Balance (dB)} = 10 \bullet \text{Log}\dfrac{P_{coupled}}{\left(\dfrac{P_{coupled} + P_{direct}}{2}\right)}$ $\text{Amplitude Balance (dB)} = 10 \bullet \text{Log}\dfrac{P_{direct}}{\left(\dfrac{P_{direct} + P_{coupled}}{2}\right)}$

Directional Couplers Performance Parameters

Directional Couplers



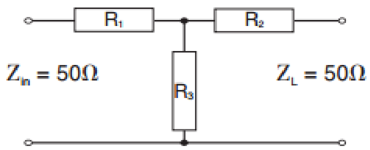
Directional Coupler

Performance Parameters

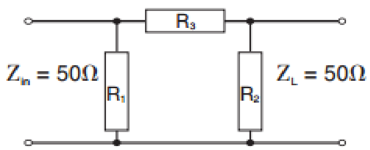
Coupling Ratio	$\text{Coupling Ratio (dB)} = 10 \bullet \text{Log}\left(\dfrac{P_{coupled}}{P_{in}}\right)$
VSWR	$\text{VSWR} = \dfrac{V_{max}}{V_{min}}$
Return Loss	$\text{Return Loss (dB)} = 20 \bullet \text{Log}\left(\dfrac{VSWR+1}{VSWR-1}\right)$
Insertion Loss	$\text{Insertion Loss (dB)} = 10 \bullet \text{Log}\left(\dfrac{P_{in}}{P_{coupled} + P_{direct}}\right)$
Transmission Loss	$\text{Transmission Loss (dB)} = 10 \bullet \text{Log}\left(\dfrac{P_{in}}{P_{direct}}\right)$
Directivity	$\text{Directivity (dB)} = 10 \bullet \text{Log}\left(\dfrac{P_{coupled}}{P_{isolated}}\right)$
Frequency Sensitivity	$[C_{max}(dB) - C_{mean}(dB)]$ $[C_{min}(dB) - C_{mean}(dB)]$

Normalized Dissipated Power

"T" Attenuator Network Design



π Attenuator Network Design



EXAMPLE:

- Input Power = 75 Watts
- Attenuation = 3.75 dB
- Power Dissipated in R_1 = .213 (75)
  = 15.975 Watts

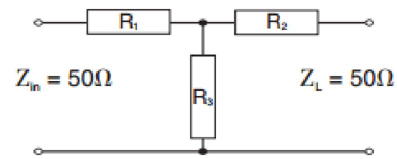
Normalized Dissipated Power in "T" & π Attenuator Elements

Attenuation (dB)	Power Dissipation (watts)		
	R_1	R_2	R_3
0.25	.014	.014	.028
0.50	.029	.026	.054
0.75	.043	.037	.079
1.00	.058	.046	.103
1.25	.072	.054	.124
1.50	.086	.061	.145
1.75	.100	.068	.164
2.00	.115	.073	.182
2.25	.129	.076	.199
2.50	.143	.081	.214
2.75	.157	.083	.229
3.00	.171	.086	.242
3.25	.185	.088	.254
3.50	.199	.088	.266
3.75	.213	.089	.276
4.00	.226	.091	.285
4.25	.240	.090	.294

Normalized Dissipated Power in "T" & π Attenuator Elements
(continued)

Attenuation (dB)	Power Dissipation (watts)		
	R_1	R_2	R_3
4.50	.253	.090	.302
4.75	.267	.089	.309
5.00	.280	.089	.315
5.25	.293	.087	.321
5.50	.306	.087	.325
5.75	.319	.085	.330
6.00	.332	.084	.333
7.00	.382	.076	.342
8.00	.431	.068	.342
9.00	.476	.060	.338
10.00	.519	.052	.329
12.00	.598	.038	.301
14.00	.667	.027	.266
16.00	.726	.018	.230
18.00	.776	.013	.195
20.00	.818	.008	.164
30.00	.939	.001	.059

"T" Attenuator Network Design



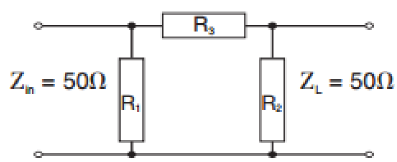
$N = \log^{-1}\left(\frac{db}{10}\right)$

$R_1 = R_2$

$$R_1 = \frac{Z(\sqrt{N} - 1)}{(\sqrt{N} + 1)}$$

$$R_3 = \frac{2Z\sqrt{N}}{N - 1}$$

π Attenuator Network Design



$N = \log^{-1}\left(\frac{db}{10}\right)$

$R_1 = R_2$

$$R_1 = \frac{Z(\sqrt{N} + 1)}{(\sqrt{N} - 1)}$$

$$R_3 = \frac{Z(N - 1)}{2\sqrt{N}}$$

The Effect of VSWR on Transmitted Power

VSWR	Return Loss (dB)	Trans. Loss (dB)	Volt. Refl. Coeff.	Power Trans. (%)	Power Refl. (%)
1.00	∞	.000	.00	100.0	.0
1.01	46.1	.000	.00	100.0	.0
1.02	40.1	.000	.01	100.0	.0
1.03	36.6	.001	.01	100.0	.0
1.04	34.2	.002	.02	100.0	.0
1.05	32.3	.003	.02	99.9	.1
1.06	30.4	.004	.03	99.9	.1
1.07	29.4	.005	.03	99.9	.1
1.08	28.3	.006	.04	99.9	.1
1.09	27.3	.008	.04	99.8	.2
1.10	26.4	.010	.05	99.8	.2
1.11	25.7	.012	.05	99.7	.3
1.12	24.9	.014	.06	99.7	.3
1.13	24.3	.016	.06	99.6	.4
1.14	23.7	.019	.07	99.6	.4
1.15	23.1	.021	.07	99.5	.5
1.16	22.6	.024	.07	99.5	.5
1.17	22.1	.027	.08	99.4	.6
1.18	21.7	.030	.08	99.3	.7
1.19	21.2	.033	.09	99.2	.8
1.20	20.8	.036	.09	99.2	.8
1.21	20.4	.039	.10	99.1	.9
1.22	20.1	.043	.10	99.0	1.0
1.23	19.7	.046	.10	98.9	1.1
1.24	19.4	.050	.11	98.9	1.1
1.25	19.1	.054	.11	98.8	1.2
1.26	18.8	.058	.12	98.7	1.3
1.27	18.5	.062	.12	98.6	1.4
1.28	18.2	.065	.12	98.5	1.5
1.29	17.9	.070	.13	98.4	1.6
1.30	17.7	.075	.13	98.3	1.7

The Effect of VSWR on Transmitted Power *(continued)*

VSWR	Return Loss (dB)	Trans. Loss (dB)	Volt. Refl. Coeff.	Power Trans. (%)	Power Refl. (%)
1.32	17.2	.083	.14	98.1	1.9
1.34	16.8	.093	.15	97.9	2.1
1.36	16.3	.102	.15	97.7	2.3
1.38	15.9	.112	.16	97.5	2.5
1.40	15.6	.122	.17	97.2	2.8
1.42	15.2	.133	.17	97.0	3.0
1.44	14.9	.144	.18	96.7	3.3
1.46	14.6	.155	.19	96.5	3.5
1.48	14.3	.166	.19	96.3	3.7
1.50	14.0	.177	.20	96.0	4.0
1.52	13.7	.189	.21	95.7	4.3
1.54	13.4	.201	.21	95.5	4.5
1.56	13.2	.213	.22	95.2	4.8
1.58	13.0	.225	.22	94.9	5.1
1.60	12.7	.238	.23	94.7	5.3
1.62	12.5	.250	.24	94.4	5.6
1.64	12.3	.263	.24	94.1	5.9
1.66	12.1	.276	.25	93.8	6.2
1.68	11.9	.289	.25	93.6	6.4
1.70	11.7	.302	.26	93.3	6.7
1.72	11.5	.315	.26	93.0	7.0
1.74	11.4	.329	.27	92.7	7.3
1.76	11.2	.342	.28	92.4	7.6
1.78	11.0	.356	.28	92.1	7.9
1.80	10.9	.370	.29	91.8	8.2
1.82	10.7	.384	.29	91.5	8.5
1.84	10.6	.398	.30	91.3	8.7
1.86	10.4	.412	.30	91.0	9.0
1.88	10.3	.426	.31	90.7	9.3
1.90	10.2	.440	.31	90.4	9.6
1.92	10.0	.454	.32	90.1	9.9

Power Conversion Table

dBm	Watts	dBm	Watts	dBm	Watts
30.0	1.00	36.8	4.79	43.6	22.91
30.2	1.05	37.0	5.01	43.8	23.99
30.4	1.10	37.2	5.25	44.0	25.12
30.6	1.15	37.4	5.50	44.2	26.30
30.8	1.20	37.6	5.75	44.4	27.54
31.0	1.26	37.8	6.03	44.6	28.84
31.2	1.32	38.0	6.31	44.8	30.20
31.4	1.38	38.2	6.61	45.0	31.62
31.6	1.45	38.4	6.92	45.2	33.11
31.8	1.51	38.6	7.24	45.4	34.67
32.0	1.58	38.8	7.59	45.6	36.31
32.2	1.66	39.0	7.94	45.8	38.02
32.4	1.74	39.2	8.32	46.0	39.81
32.6	1.82	39.4	8.71	46.2	41.69
32.8	1.91	39.6	9.12	46.4	43.65
33.0	2.00	39.8	9.55	46.6	45.71
33.2	2.09	40.0	10.00	46.8	47.86
33.4	2.19	40.2	10.47	47.0	50.12
33.6	2.29	40.4	10.96	47.2	52.48
33.8	2.40	40.6	11.48	47.4	54.95
34.0	2.51	40.8	12.02	47.6	57.54
34.2	2.63	41.0	12.59	47.8	60.26
34.4	2.75	41.2	13.18	48.0	63.10
34.6	2.88	41.4	13.80	48.2	66.07
34.8	3.02	41.6	14.45	48.4	69.18
35.0	3.16	41.8	15.14	48.6	72.44
35.2	3.31	42.0	15.85	48.8	75.86
35.4	3.47	42.2	16.60	49.0	79.43
35.6	3.63	42.4	17.38	49.2	83.18
35.8	3.80	42.6	18.20	49.4	87.10
36.0	3.98	42.8	19.05	49.6	91.20
36.2	4.17	43.0	19.95	49.8	95.50
36.4	4.37	43.2	20.89	50.0	100.00
36.6	4.57	43.4	21.88	50.2	105.00

Power Conversion Table

dBm	Watts	dBm	Watts	dBm	Watts
50.4	110	57.0	501	63.6	2291
50.6	115	57.2	525	63.8	2399
50.8	120	57.4	550	64.0	2512
51.0	126	57.6	575	64.2	2630
51.2	132	57.8	603	64.4	2754
51.4	138	58.0	631	64.6	2884
51.6	145	58.2	661	64.8	3020
51.8	151	58.4	692	65.0	3162
52.0	158	58.6	724	65.2	3311
52.2	166	58.8	759	65.4	3467
52.4	174	59.0	794	65.6	3631
52.6	182	59.2	832	65.8	3802
52.8	191	59.4	871	66.0	3981
53.0	200	59.6	912	66.2	4169
53.2	209	59.8	955	66.4	4365
53.4	219	60.0	1000	66.6	4571
53.6	229	60.2	1047	66.8	4786
53.8	240	60.4	1096	67.0	5012
54.0	251	60.6	1148	67.2	5248
54.2	263	60.8	1202	67.4	5495
54.4	275	61.0	1259	67.6	5754
54.6	288	61.2	1318	67.8	6026
54.8	302	61.4	1380	68.0	6310
55.0	316	61.6	1445	68.2	6607
55.2	331	61.8	1514	68.4	6918
55.4	347	62.0	1585	68.6	7244
55.6	363	62.2	1660	68.8	7586
55.8	380	62.4	1738	69.0	7943
56.0	398	62.6	1820	69.2	8318
56.2	417	62.8	1905	69.4	8710
56.4	437	63.0	1995	69.6	9120
56.6	457	63.2	2089	69.8	9550
56.8	479	63.4	2188	70.0	10000

Thermal Conductivity $\left(\frac{Watts}{cm \cdot °C}\right)$

METALS

Silver	(Ag)	4.08
Copper	(Cu)	3.94
Gold	(Au)	2.96
Aluminum	(Al)	2.18
Beryllium	(Be)	2.00
Tungsten	(W)	1.74
Rhodium	(Rh)	1.50
Molybdenum	(Mo)	1.46
Brass	(66% Cu, 34% Zn)	1.110
Chromium	(Cr)	0.937
Nickel	(Ni)	0.920
Platinum	(Pt)	0.716
Tin	(Sn)	0.666
Tantalum	(Ta)	0.575
Lead	(Pb)	0.353
Titanium	(Ti)	0.219
Manganese	(Mn)	0.078

PC BOARD MATERIAL

RT/Duroid® 5880	.0026
G10/FR4	.0027
RT/Duroid® 60 (XX)	.0041 - .0048
TMM® (X)	.0068 - .0075

Thermal Conductivity $\left(\frac{Watts}{cm \cdot °C}\right)$

(continued)

INSULATORS

Diamond	(CVD)	10.0 - 16.0
Beryllium Oxide 99.5%	(BeO)	2.61
Aluminum Nitride	(AlN)	1.70
Boron Nitride	(HBN 500°)	0.59
Sapphire		0.46
Alumina Oxide 99.6%	(Al_2O_3)	0.36
Alumina Oxide 96%	(Al_2O_3)	0.26
Alumina Oxide 91%	(Al_2O_3)	0.13
Glass		0.015
Mica		0.0043 - 0.0062
Air		0.00026

BONDING

Gold Germanium 88/12		.8834
Gold Tin 80/20		.6824
Tin Lead Solder	(Sn62)	.4921
Indium 100%		.2386
Silver Filled Epoxy		.0156
Epoxy		.0099

MISC.

Thermal Grease	.0042 - .0049

Thermal Conductivity Conversion Factors

Thermal Conductivity

To Convert	To	Multiply By
$\frac{Watt}{m \cdot {}^{\circ}K}$	$\frac{Watt}{cm \cdot {}^{\circ}C}$	0.01
$\frac{cal \cdot cm}{sec \cdot cm^2 \cdot {}^{\circ}C}$	$\frac{Watt}{cm \cdot {}^{\circ}C}$	4.1868
$\frac{BTU \cdot ft}{hr \cdot ft^2 \cdot {}^{\circ}F}$	$\frac{Watt}{cm \cdot {}^{\circ}C}$	.01731
$\frac{BTU \cdot ft}{hr \cdot ft^2 \cdot {}^{\circ}F}$	$\frac{cal \cdot cm}{sec \cdot cm^2 \cdot {}^{\circ}C}$	.004134
$\frac{Watt}{m \cdot {}^{\circ}K}$	$\frac{cal \cdot cm}{sec \cdot cm^2 \cdot {}^{\circ}C}$	.002397
$\frac{Watt}{cm \cdot {}^{\circ}C}$	$\frac{Watt}{inch \cdot {}^{\circ}C}$	2.54
$\frac{BTU \cdot in}{ft^2 \cdot h \cdot {}^{\circ}F}$	$\frac{Watt}{cm \cdot {}^{\circ}C}$	1.422^{-3}

(AT 20°C)

Temperature Conversion Table

TEMPERATURE CONVERSION TABLE

°C	°F	°C	°F	°C	°F	°C	°F
-100	-148	+60	+140	+220	+428	+380	+716
-95	-139	+65	+149	+225	+437	+385	+725
-90	-130	+70	+158	+230	+446	+390	+734
-85	-121	+75	+167	+235	+455	+395	+743
-80	-112	+80	+176	+240	+464	+400	+752
-75	-103	+85	+185	+245	+473	+405	+761
-70	-94	+90	+194	+250	+482	+410	+770
-65	-85	+95	+203	+255	+491	+415	+779
-60	-76	+100	+212	+260	+500	+420	+788
-55	-67	+105	+221	+265	+509	+425	+797
-50	-58	+110	+230	+270	+518	+430	+806
-45	-49	+115	+239	+275	+527	+435	+815
-40	-40	+120	+248	+280	+536	+440	+824
-35	-31	+125	+257	+285	+545	+445	+833
-30	-22	+130	+266	+290	+554	+450	+842
-25	-13	+135	+275	+295	+563	+455	+851
-20	-4	+140	+284	+300	+572	+460	+860
-15	+5	+145	+293	+305	+581	+465	+869
-10	+14	+150	+302	+310	+590	+470	+878
-5	+23	+155	+311	+315	+599	+475	+887
0	+32	+160	+320	+320	+608	+480	+896
+5	+41	+165	+329	+325	+617	+485	+905
+10	+50	+170	+338	+330	+626	+490	+914
+15	+59	+175	+347	+335	+635	+495	+923
+20	+68	+180	+356	+340	+644	+500	+932
+25	+77	+185	+365	+345	+653	+505	+941
+30	+86	+190	+374	+350	+662	+510	+950
+35	+95	+195	+383	+355	+671	+515	+959
+40	+104	+200	+392	+360	+680	+520	+968
+45	+113	+205	+401	+365	+689	+525	+977
+50	+122	+210	+410	+370	+698	+530	+986
+55	+131	+215	+419	+375	+707	+535	+995

Conversion of Temperatures:

Celsius to Fahrenheit $T_F = 1.8\,T_C + 32$

Celsius to Kelvin $T_K = T_C + 273.15$

Fahrenheit to Celsius $T_C = \frac{T_F - 32}{1.8} = .5556\,(T_F - 32)$

Kelvin to Celsius $T_C = T_K - 273.15$

Decimal Equivalents Table

STANDARD DECIMAL PREFIXES

MULTIPLIER	PREFIX	ABBREVIATION	MULTIPLIER	PREFIX	ABBREVIATION
10^{18}	exa	E	10^{-2}	centi	c
10^{15}	peta	P	10^{-3}	milli	m
10^{12}	tera	T	10^{-6}	micro	µ
10^{9}	giga	G	10^{-9}	nano	n
10^{6}	mega	M	10^{-12}	pico	p
10^{3}	kilo	k	10^{-15}	femto	f
10^{-1}	deci	d	10^{-18}	atto	a

Fraction	Decimal	Fraction	Decimal
1/64	.015625	33/64	.515625
1/32	.03125	17/32	.53125
3/64	.046875	35/64	.546875
1/16	.0625	9/16	.5625
5/64	.078125	37/64	.578125
3/32	.09375	19/32	.59375
7/64	.109375	39/64	.609375
1/8	.125	5/8	.625
9/64	.140625	41/64	.640625
5/32	.15625	21/32	.65625
11/64	.171875	43/64	.671875
3/16	.1875	11/16	.6875
13/64	.203125	45/64	.703125
7/32	.21875	23/32	.71875
15/64	.234375	47/64	.734375
1/4	.25	3/4	.75
17/64	.265625	49/64	.765625
9/32	.28125	25/32	.78125
19/64	.296875	51/64	.796875
5/16	.3125	13/16	.8125
21/64	.328125	53/64	.828125
11/32	.34375	27/32	.84375
23/64	.359375	55/64	.859375
3/8	.375	7/8	.875
25/64	.390625	57/64	.890625
13/32	.40625	29/32	.90625
27/64	.421875	59/64	.921875
7/16	.4375	15/16	.9375
29/64	.453125	61/64	.953125
15/32	.46875	31/32	.96875
31/64	.484375	63/64	.984375
1/2	.50	1	1.00

Solders Per QQ-S-571

Composition	Melting Range	
	Solidus	Liquidus
Sn96	221˚C	221˚C
Sn70	183˚C	193˚C
Sn63	183˚C	183˚C
Sn62	179˚C	179˚C
Sn60	183˚C	191˚C
Sn50	183˚C	216˚C
Sn40	183˚C	238˚C
Sn35	185˚C	243˚C
Sn30	185˚C	250˚C
Sn20	184˚C	270˚C
Sn10	268˚C	290˚C
Sn5	308˚C	312˚C
Sb5	235˚C	240˚C
Pb80	183˚C	277˚C
Pb70	183˚C	254˚C
Pb65	183˚C	246˚C
Ag1.5	309˚C	309˚C
Ag2.5	304˚C	304˚C
Ag5.5	304˚C	380˚C
Other Commonly Used Solders		
Gold Germanium 88/12	356˚C	356˚C
Gold Tin 80/20	280˚C	280˚C
Indium 100%	157˚C	157˚C