Chapter

3

Electromagnetic Spectrum

3.1 Introduction

The usable spectrum of electromagnetic-radiation frequencies extends over a range from below 100 Hz for power distribution to 1020 for the shortest X-rays. The lower frequencies are used primarily for terrestrial broadcasting and communications. The higher frequencies include visible and near-visible infrared and ultraviolet light, and X-rays.

3.1.1 Operating Frequency Bands

The standard frequency band designations are listed in Tables 3.1 and 3.2. Alternate and more detailed subdivision of the VHF, UHF, SHF, and EHF bands are given in Tables 3.3 and 3.4.

Low-End Spectrum Frequencies (1 to 1000 Hz)

Electric power is transmitted by wire but not by radiation at 50 and 60 Hz, and in some limited areas, at 25 Hz. Aircraft use 400-Hz power in order to reduce the weight of iron in generators and transformers. The restricted bandwidth that would be available for communication channels is generally inadequate for voice or data transmission, although some use has been made of communication over power distribution circuits using modulated carrier frequencies.

Low-End Radio Frequencies (1000 to 100 kHz)

These low frequencies are used for very long distance radio-telegraphic communication where extreme reliability is required and where high-power and long antennas can be erected. The primary bands of interest for radio communications are given in Table 3.5.

Table 3.1 Standardized Frequency Bands (*From* [1]. *Used with permission.*)

Extremely low-frequency (ELF) band:	30 Hz up to 300 Hz	(10 Mm down to 1 Mm)
Voice-frequency (VF) band:	300 Hz up to 3 kHz	(1 Mm down to 100 km)
Very low-frequency (VLF) band:	3 kHz up to 30 kHz	(100 km down to 10 km)
Low-frequency (LF) band:	30 kHz up to 300 kHz	(10 km down to 1 km)
Medium-frequency (MF) band:	300 kHz up to 3 MHz	(1 km down to 100 m)
High-frequency (HF) band:	3 MHz up to 30 MHz	(100 m down to 10 m)
Very high-frequency (VHF) band:	30 MHz up to 300 MHz	(10 m down to 1 m)
Ultra high-frequency (UHF) band:	300 MHz up to 3 GHz	(1 m down to 10 cm)
Super high-frequency (SHF) band:	3 GHz up to 30 GHz	(1 cm down to 1 cm)
Extremely high-frequency (EHF) band:	30 GHz up to 300 GHz	(1 cm down to 1 mm)

Table 3.2 Standardized Frequency Bands at 1GHz and Above (*From* [1]. *Used with permission.*)

L band:	1 GHz up to 2 GHz	(30 cm down to 15 cm)
S band:	2 GHz up to 4 GHz	(15 cm down to 7.5 cm)
C band:	4 GHz up to 8 GHz	(7.5 cm down to 3.75 cm)
X band:	8 GHz up to 12 GHz	(3.75 cm down to 2.5 cm)
Ku band:	12 GHz up to 18 GHz	(2.5 cm down to 1.67 cm)
K band:	18 GHz up to 26.5 GHz	(1.67 cm down to 1.13 cm)
Ka band:	26.5 GHz up to 40 GHz	(1.13 cm down to 7.5 mm)
Q band:	32 GHz up to 50 GHz	(9.38 mm down to 6 mm)
U band:	40 GHz up to 60 GHz	(7.5 mm down to 5 mm)
V band:	50 GHz up to 75 GHz	(6 mm down to 4 mm)
W band:	75 GHz up to 100 GHz	(4 mm down to 3.33 mm)

Medium-Frequency Radio (20 kHz to 2 MHz)

The low-frequency portion of the band is used for around-the-clock communication services over moderately long distances and where adequate power is available to overcome the high level of atmospheric noise. The upper portion is used for AM radio, although the strong and quite variable *sky wave* occurring during the night results in substandard quality and severe fading at times. The greatest use is for AM broadcasting, in addition to fixed and mobile service, LORAN ship and aircraft navigation, and amateur radio communication.

High-Frequency Radio (2 to 30 MHz)

This band provides reliable medium-range coverage during daylight and, when the transmission path is in total darkness, worldwide long-distance service, although the

Table 3.3 Detailed Subdivision of the UHF, SHF, and EHF Bands (*From* [1]. *Used with permission.*)

L band:	1.12 GHz up to 1.7 GHz	(26.8 cm down to 17.6 cm)
LS band:	1.7 GHz up to 2.6 GHz	(17.6 cm down to 11.5 cm)
S band:	2.6 GHz up to 3.95 GHz	(11.5 cm down to 7.59 cm)
C(G) band:	3.95 GHz up to 5.85 GHz	(7.59 cm down to 5.13 cm)
XN(J, XC) band:	5.85 GHz up to 8.2 GHz	(5.13 cm down to 3.66 cm)
XB(H, BL) band:	7.05 GHz up to 10 GHz	(4.26 cm down to 3 cm)
X band:	8.2 GHz up to 12.4 GHz	(3.66 cm down to 2.42 cm)
Ku(P) band:	12.4 GHz up to 18 GHz	(2.42 cm down to 1.67 cm)
K band:	18 GHz up to 26.5 GHz	(1.67 cm down to 1.13 cm)
V(R, Ka) band:	26.5 GHz up to 40 GHz	(1.13 cm down to 7.5 mm)
Q(V) band:	33 GHz up to 50 GHz	(9.09 mm down to 6 mm)
M(W) band:	50 GHz up to 75 GHz	(6 mm down to 4 mm)
E(Y) band:	60 GHz up to 90 GHz	(5 mm down to 3.33 mm)
F(N) band:	90 GHz up to 140 GHz	(3.33 mm down to 2.14 mm)
G(A) band:	140 GHz up to 220 GHz	(2.14 mm down to 1.36 mm)
R band:	220 GHz up to 325 GHz	(1.36 mm down to 0.923 mm)

Table 3.4 Subdivision of the VHF, UHF, SHF Lower Part of the EHF Band (*From* [1]. *Used with permission.*)

A band:	100 MHz up to 250 MHz	(3 m down to 1.2 m)
B band:	250 MHz up to 500 MHz	(1.2 m down to 60 cm)
C band:	500 MHz up to 1 GHz	(60 cm down to 30 cm)
D band:	1 GHz up to 2 GHz	(30 cm down to 15 cm)
E band:	2 GHz up to 3 GHz	(15 cm down to 10 cm)
F band:	3 GHz up to 4 GHz	(10 cm down to 7.5 cm)
G band:	4 GHz up to 6 GHz	(7.5 cm down to 5 cm)
H band:	6 GHz up to 8 GHz	(5 cm down to 3.75 cm)
I band:	8 GHz up to 10 GHz	(3.75 cm down to 3 cm)
J band:	10 GHz up to 20 GHz	(3 cm down to 1.5 cm)
K band:	20 GHz up to 40 GHz	(1.5 cm down to 7.5 mm)
L band:	40 GHz up to 60 GHz	(7.5 mm down to 5 mm)
M band:	60 GHz up to 100 GHz	(5 mm down to 3 mm)

reliability and signal quality of the latter is dependent to a large degree upon ionospheric conditions and related long-term variations in sun-spot activity affecting sky-wave propagation. The primary applications include broadcasting, fixed and mobile services, telemetering, and amateur transmissions.

Table 3.5 Radio Frequency Bands (*From* [1]. *Used with permission*.)

Longwave broadcasting band:	150–290 kHz
AM broadcasting band:	550–1640 kHz (1.640 MHz) (107 Channels, 10-kHz separation)
International broadcasting band:	3–30 MHz
Shortwave broadcasting band:	5.95–26.1 MHz (8 bands)
VHF television (channels 2–4):	54–72 MHz
VHF television (channels 5–6):	76–88 MHz
FM broadcasting band:	88–108 MHz
VHF television (channels 7–13):	174–216 MHz
UHF television (channels 14–83):	470–890 MHz

Very High and Ultrahigh Frequencies (30 MHz to 3 GHz)

VHF and UHF bands, because of the greater channel bandwidth possible, can provide transmission of a large amount of information, either as television detail or data communication. Furthermore, the shorter wavelengths permit the use of highly directional parabolic or multielement antennas. Reliable long-distance communication is provided using high-power *tropospheric scatter* techniques. The multitude of uses include, in addition to television, fixed and mobile communication services, amateur radio, radio astronomy, satellite communication, telemetering, and radar.

Microwaves (3 to 300 GHz)

At these frequencies, many transmission characteristics are similar to those used for shorter optical waves, which limit the distances covered to line of sight. Typical uses include television relay, satellite, radar, and wide-band information services. (See Tables 3.6 and 3.7.)

Infrared, Visible, and Ultraviolet Light

The portion of the spectrum visible to the eye covers the gamut of transmitted colors ranging from red, through yellow, green, cyan, and blue. It is bracketed by infrared on the low-frequency side and ultraviolet (UV) on the high side. Infrared signals are used in a variety of consumer and industrial equipments for remote controls and sensor circuits in security systems. The most common use of UV waves is for excitation of phosphors to produce visible illumination.

X-Rays

Medical and biological examination techniques and industrial and security inspection systems are the best-known applications of X-rays. X-rays in the higher-frequency range are classified as *hard X-rays* or *gamma rays*. Exposure to X-rays for long periods can result in serious irreversible damage to living cells or organisms.

Table 3.6 Applications in the Microwave Bands (*From* [1]. *Used with permission.*)

Aeronavigation:	0.96–1.215 GHz
Global positioning system (GPS) down link:	1.2276 GHz
Military communications (COM)/radar:	1.35–1.40 GHz
Miscellaneous COM/radar:	1.40–1.71 GHz
L-band telemetry:	1.435–1.535 GHz
GPS downlink:	1.57 GHz
Military COM (troposcatter/telemetry):	1.71–1.85 GHz
Commercial COM and private line of sight (LOS):	1.85–2.20 GHz
Microwave ovens:	2.45 GHz
Commercial COM/radar:	2.45–2.69 GHz
Instructional television:	2.50–2.69 GHz
Military radar (airport surveillance):	2.70–2.90 GHz
Maritime navigation radar:	2.90–3.10 GHz
Miscellaneous radars:	2.90–3.70 GHz
Commercial C-band satellite (SAT) COM downlink:	3.70–4.20 GHz
Radar altimeter:	4.20–4.40 GHz
Military COM (troposcatter):	4.40–4.99 GHz
Commercial microwave landing system:	5.00–5.25 GHz
Miscellaneous radars:	5.25–5.925 GHz
C-band weather radar:	5.35–5.47 GHz
Commercial C-band SAT COM uplink:	5.925–6.425 GHz
Commercial COM:	6.425–7.125 GHz
Mobile television links:	6.875–7.125 GHz
Military LOS COM:	7.125–7.25 GHz
Military SAT COM downlink:	7.25–7.75 GHz
Military LOS COM:	7.75–7.9 GHz
Military SAT COM uplink:	7.90–8.40 GHz
Miscellaneous radars:	8.50–10.55 GHz
Precision approach radar:	9.00–9.20 GHz
X-band weather radar (and maritime navigation radar):	9.30–9.50 GHz
Police radar:	10.525 GHz
Commercial mobile COM [LOS and electronic news gathering (ENG)]:	10.55–10.68 GHz
Common carrier LOS COM:	10.70–11.70 GHz
Commercial COM:	10.70–13.25 GHz
Commercial Ku-band SAT COM downlink:	11.70–12.20 GHz
Direct broadcast satellite (DBS) downlink and private LOS COM:	12.20–12.70 GHz
ENG and LOS COM:	12.75–13.25 GHz
Miscellaneous radars and SAT COM:	13.25–14.00 GHz
Commercial Ku-band SAT COM uplink:	14.00–14.50 GHz
Military COM (LOS, mobile, and Tactical):	14.50–15.35 GHz
Aeronavigation:	15.40–15.70 GHz
Miscellaneous radars:	15.70–17.70 GHz
DBS uplink:	17.30–17.80 GHz

Table 3.6 Applications in the Microwave Bands (continued)

Common carrier LOS COM:	17.70–19.70 GHz
Commercial COM (SAT COM and LOS):	17.70–20.20 GHz
Private LOS COM:	18.36–19.04 GHz
Military SAT COM:	20.20–21.20 GHz
Miscellaneous COM:	21.20–24.00 GHz
Police radar:	24.15 GHz
Navigation radar:	24.25–25.25 GHz
Military COM:	25.25–27.50 GHz
Commercial COM:	27.50–30.00 GHz
Military SAT COM:	30.00–31.00 GHz
Commercial COM:	31.00–31.20 GHz
Navigation radar:	31.80–33.40 GHz
Miscellaneous radars:	33.40–36.00 GHz
Military COM:	36.00–38.60 GHz
Commercial COM:	38.60–40.00 GHz

3.2 Radio Wave Propagation

To visualize a radio wave, consider the image of a sine wave being traced across the screen of an oscilloscope [2]. As the image is traced, it sweeps across the screen at a specified rate, constantly changing amplitude and phase with relation to its starting point at the left side of the screen. Consider the left side of the screen to be the antenna, the horizontal axis to be distance instead of time, and the sweep speed to be the speed of light, or at least very close to the speed of light, and the propagation of the radio wave is visualized. To be correct, the traveling, or propagating, radio wave is really a wavefront, as it comprises an electric field component and an orthogonal magnetic field component. The distance between wave crests is defined as the *wavelength* and is calculated by,

$$\lambda = \frac{c}{f} \tag{3.1}$$

where:
λ = wavelength, m
c = the speed of light, approximately 2.998×10^8 m/s
f = frequency, Hz

At any point in space far away from the antenna, on the order of 10 wavelengths or 10 times the aperture of the antenna to avoid *near-field effects*, the electric and magnetic fields will be orthogonal and remain constant in amplitude and phase in relation to any other point in space. The polarization of the radio wave is defined by the polarization of the electric field, horizontal if parallel to the Earth's surface and vertical if perpendicu-

Table 3.7 Satellite Frequency Allocations (*From* [1]. *Used with permission.*)

Band	Uplink	Downlink	Satellite Service
VHF		0.137–0.138	Mobile
VHF	0.3120–0.315	0.387–0.390	Mobile
L-Band		1.492–1.525	Mobile
	1.610–1.6138		Mobile, Radio Astronomy
	1.613.8–1.6265	1.6138–1.6265	Mobile LEO
	1.6265–1.6605	1.525–1.545	Mobile
		1.575	Global Positioning System
		1.227	GPS
S-Band	1.980–2.010	2.170–2.200	MSS. Available Jan. 1, 2000
	(1.980–1.990)		(Available in U.S. in 2005)
	2.110–2.120	2.290–2.300	Deep-space research
		2.4835–2.500	Mobile
C-Band	5.85–7.075	3.4–4.2	Fixed (FSS)
	7.250–7.300	4.5–4.8	FSS
X-Band	7.9–8.4	7.25–7.75	FSS
Ku-Band	12.75–13.25	10.7–12.2	FSS
	14.0–14.8	12.2–12.7	Direct Broadcast (BSS) (U.S.)
Ka-Band		17.3–17.7	FSS (BSS in U.S.)
			22.55–23.55 Intersatellite
			24.45–24.75 Intersatellite
			25.25–27.5 Intersatellite
	27–31	17–21	FSS
Q	42.5–43.5, 47.2–50.2	37.5–40.5	FSS, MSS
	50.4–51.4		Fixed
		40.5–42.5	Broadcast Satellite
V	54.24–58.2		Intersatellite
	59–64		Intersatellite

Sources: Final Acts of the World Administrative Radio Conference (WARC-92), Malaga–Torremolinos, 1992; 1995 World Radiocommunication Conference (WRC-95). Also, see Gagliardi, R.M. 1991. *Satellite Communications,* van Nostrand Reinhold, New York. Note that allocations are not always global and may differ from region to region in all or subsets of the allocated bands.

lar to it. Typically, polarization can be determined by the orientation of the antenna radiating elements.

An *isotropic antenna* is one that radiates equally in all directions. To state this another way, it has a gain of unity.

If this isotropic antenna is located in an absolute vacuum and excited with a given amount of power at some frequency, as time progresses the radiated power must be equally distributed along the surface of an ever expanding sphere surrounding the isotropic antenna. The power density at any given point on the surface of this imaginary sphere is simply the radiated power divided by the surface area of the sphere, that is:

$$P_d = \frac{P_t}{4\pi D^2} \tag{3.2}$$

where:
P_d = power density, W/m^2
D = distance from antenna, m
P_t = radiated power, W

Because power and voltage, in this case power density and electric field strength, are related by impedance, it is possible to determine the electric field strength as a function of distance given that the impedance of free space is taken to be approximately 377 Ω,

$$E = \sqrt{Z P_d} = 5.48 \frac{\sqrt{P_t}}{D} \tag{3.3}$$

where E is the electric field strength in volts per meter.

Converting to units of kilowatts for power, the equation becomes

$$E = 173 \frac{\sqrt{P_{t(kW)}}}{D} \text{ V/m} \tag{3.4}$$

which is the form in which the equation is usually seen. Because a half-wave dipole has a gain of 2.15 dB over that of an isotropic radiator (dBi), the equation for the electric field strength from a half-wave dipole is

$$E = 222 \frac{\sqrt{P_{t(kW)}}}{D} \text{ V/m} \tag{3.5}$$

From these equations it is evident that, for a given radiated power, the electric field strength decreases linearly with the distance from the antenna, and power density decreases as the square of the distance from the antenna.

3.2.1 Free Space Path Loss

A typical problem in the design of a radio frequency communications system requires the calculation of the power available at the output terminals of the receive antenna [2]. Although the gain or loss characteristics of the equipment at the receiver and transmitter sites can be ascertained from manufacturer's data, the effective loss between the two antennas must be stated in a way that allows for the characterization of the transmission path between the antennas. The ratio of the power radiated by the transmit antenna to the power available at the receive antenna is known as the *path loss* and is usually expressed in decibels. The minimum loss on any given path occurs between two antennas when there are no intervening obstructions and no ground losses. In such a case when the receive and transmit antennas are *isotropic*, the path loss is known as *free space path loss*.

If the transmission path is between isotropic antennas, then the power received by the receive antenna is the power density at the receive antenna multiplied by the effective area of the antenna and is expressed as

$$P_r = \frac{P_t A}{4\pi D^2} \tag{3.6}$$

where A is the effective area of the receive antenna in square meters.

The effective area of an isotropic antenna is defined as $\lambda^2/4\pi$. Note that an isotropic antenna is not a point source, but has a defined area; this is often a misunderstood concept. As a result, the received power is

$$P_r = \frac{P_t}{4\pi D^2} \cdot \frac{\lambda^2}{4\pi} = P_t \left(\frac{\lambda}{4\pi D} \right)^2 \tag{3.7}$$

The term $(\lambda^2/4\pi D)^2$ is the free space path loss. Expressed in decibels with appropriate constants included for consistency of units, the resulting equation for free space path loss, written in terms of frequency, becomes

$$L_{fs} = 32.5 + 20 \log D + 20 \log f \tag{3.8}$$

where:
D = distance, km
f = frequency, MHz

The equation for the received power along a path with no obstacles and long enough to be free from any near-field antenna effects, such as that in Figure 3.1, then becomes

$$P_r = P_t - L_t + G_t - L_{fs} + G_r - L_r \tag{3.9}$$

where:
P_r = received power, dB
P_t = transmitted power, dB
L_t = transmission line loss, dB
G_t = gain of transmit antenna referenced to an isotropic antenna, dBi
L_{fs} = free space path loss, dB
G_r = gain of receive antenna, dBi
L_r = line loss of receiver downlead, dB

It should be pointed out that the only frequency-dependent term in the equation for free space path loss occurs in the expression for the power received by an isotropic antenna. This is a function of the antenna area and, as stated previously, the area of an isotropic radiator is defined in terms of wavelength. As a result, the calculated field

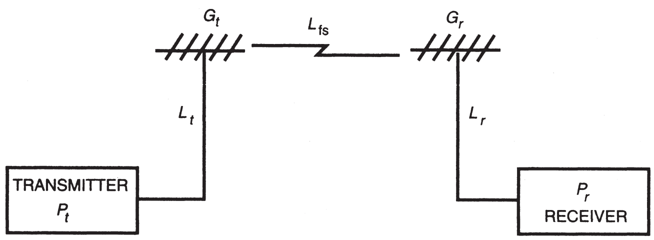

Figure 3.1 Path loss variables. (*From* [2]. *Used with permission*.)

strength at a given distance from sources with equal radiated powers but on frequencies separated by one octave will be identical, but the free space path loss equation will show 6-dB additional loss for the higher frequency path. To view this another way, for the two paths to have the same calculated loss, the antennas for both paths must have equal effective areas. An antenna with a constant area has higher gain at higher frequencies. As a result, to achieve the same total path loss over these two paths, the higher frequency path requires a higher gain antenna, but the required effective areas of the antennas for the two paths are equal. The most important concept to remember is that the resultant field strength and power density at a given distance for a given radiated power are the same regardless of frequency, as long as the path approximates a free space path, but that the free space path loss increases by 6 dB for a doubling of frequency or distance.

The representation of the radio wave path in Figure 3.1 and the previous discussion have only considered a direct path between the receiver and transmitter. In reality, there are two major modes of propagation: the *skywave* and the *groundwave*.

The skywave refers to propagation via the ionosphere, which consists of several layers of ionized particles in the Earth's atmosphere from approximately 50 to several hundred kilometers in altitude. Some frequencies will be reflected by the ionosphere resulting in potentially long-distance propagation.

Groundwave propagation consists of two components, the space wave and the surface wave. The space wave also has two components known as the *direct path* and the *reflected path*. The direct path is the commonly depicted line-of-sight path that has been previously discussed. The reflected path is that path which ends at the receiver by way of reflection from the ground or some other object. Note that there may be multiple reflected paths. The surface wave is that portion of the wavefront that interacts with and travels along the surface of the Earth. The surface wave is commonly incorrectly called the *groundwave*.

3.3 References

1. Whitaker, Jerry C. (ed.), *The Electronics Handbook*, CRC Press, Boca Raton, FL, 1996.

2. Straub, Gerhard J., "Radio Wave Propagation," in *The Electronics Handbook*, Jerry C. Whitaker (ed.), CRC Press, Boca Raton, FL, pp. 131–1332, 1996.

3.4 Bibliography

Whitaker, Jerry C., and K. Blair Benson (eds.), *Standard Handbook of Video and Television Engineering*, McGraw-Hill, New York, NY, 2000.

3.5 Tabular Data

Table 3.8 Power Conversion Factors (decibels to watts)

dBm	dBw	Watts	Multiple	Prefix
+150	+120	1,000,000,000,000	10^{12}	1 Terawatt
+140	+110	100,000,000,000	10^{11}	100 Gigawatts
+130	+100	10,000,000,000	10^{10}	10 Gigawatts
+120	+90	1,000,000,000	10^{9}	1 Gigawatt
+110	+80	100,000,000	10^{8}	100 Megawatts
+100	+70	10,000,000	10^{7}	10 Megawatts
+90	+60	1,000,000	10^{6}	1 Megawatt
+80	+50	100,000	10^{5}	100 Kilowatts
+70	+40	10,000	10^{4}	10 Kilowatts
+60	+30	1,000	10^{3}	1 Kilowatt
+50	+20	100	10^{2}	1 Hectrowatt
+40	+10	10	10	1 Decawatt
+30	0	1	1	1 Watt
+20	–10	0.1	10^{-1}	1 Deciwatt
+10	–20	0.01	10^{-2}	1 Centiwatt
0	–30	0.001	10^{-3}	1 Milliwatt
–10	–40	0.0001	10^{-4}	100 Microwatts
–20	–50	0.00001	10^{-5}	10 Microwatts
–30	–60	0.000,001	10^{-6}	1 Microwatt
–40	–70	0.0,000,001	10^{-7}	100 Nanowatts
–50	–80	0.00,000,001	10^{-8}	10 Nanowatts
–60	–90	0.000,000,001	10^{-9}	1 Nanowatt
–70	–100	0.0,000,000,001	10^{-10}	100 Picowatts
–80	–110	0.00,000,000,001	10^{-11}	10 Picowatts
–90	–120	0.000,000,000,001	10^{-12}	1 Picowatt

Table 3.9 Relationships of Voltage Standing Wave Ratio and Key Operating Parameters

SWR	Reflection Coefficient	Return Loss	Power Ratio	Percent Reflected
1.01:1	0.0050	46.1 dB	0.00002	0.002
1.02:1	0.0099	40.1 dB	0.00010	0.010
1.04:1	0.0196	34.2 dB	0.00038	0.038
1.06:1	0.0291	30.7 dB	0.00085	0.085
1.08:1	0.0385	28.3 dB	0.00148	0.148
1.10:1	0.0476	26.4 dB	0.00227	0.227
1.20:1	0.0909	20.8 dB	0.00826	0.826
1.30:1	0.1304	17.7 dB	0.01701	1.7
1.40:1	0.1667	15.6 dB	0.02778	2.8
1.50:1	0.2000	14.0 dB	0.04000	4.0
1.60:1	0.2308	12.7 dB	0.05325	5.3
1.70:1	0.2593	11.7 dB	0.06722	6.7
1.80:1	0.2857	10.9 dB	0.08163	8.2
1.90:1	0.3103	10.2 dB	0.09631	9.6
2.00:1	0.3333	9.5 dB	0.11111	11.1
2.20:1	0.3750	8.5 dB	0.14063	14.1
2.40:1	0.4118	7.7 dB	0.16955	17.0
2.60:1	0.4444	7.0 dB	0.19753	19.8
2.80:1	0.4737	6.5 dB	0.22438	22.4
3.00:1	0.5000	6.0 dB	0.25000	25.0
3.50:1	0.5556	5.1 dB	0.30864	30.9
4.00:1	0.6000	4.4 dB	0.36000	36.0
4.50:1	0.6364	3.9 dB	0.40496	40.5
5.00:1	0.6667	3.5 dB	0.44444	44.4
6.00:1	0.7143	2.9 dB	0.51020	51.0
7.00:1	0.7500	2.5 dB	0.56250	56.3
8.00:1	0.7778	2.2 dB	0.60494	60.5
9.00:1	0.8000	1.9 dB	0.64000	64.0
10.00:1	0.8182	1.7 dB	0.66942	66.9
15.00:1	0.8750	1.2 dB	0.76563	76.6
20.00:1	0.9048	0.9 dB	0.81859	81.9
30.00:1	0.9355	0.6 dB	0.87513	97.5
40.00:1	0.9512	0.4 dB	0.90482	90.5
50.00:1	0.9608	0.3 dB	0.92311	92.3