Chapter 3
Decibel

If you cannot measure it, you cannot improve it.

—Lord Kelvin

3.1 Gain and Loss [dB]

Let's have a look at the amplifier or attenuation network in Fig. 3.1. The power, voltage, and current gain of this network can be expressed in [dB] as [2]:

$$\text{Power gain in [dB]} = 10 \cdot \log_{10}\left(\frac{P_{out}}{P_{in}}\right) = 10 \cdot \log_{10}\left[\left(\frac{V_{out}}{V_{in}}\right)^2 \cdot \left(\frac{R_{in}}{R_{load}}\right)\right] \tag{3.1}$$

$$\text{Voltage gain in [dB]} = 20 \cdot \log_{10}\left(\frac{V_{out}}{V_{in}}\right) + 10 \cdot \log_{10}\left(\frac{R_{in}}{R_{load}}\right) \tag{3.2}$$

$$\text{Current gain in [dB]} = 20 \cdot \log_{10}\left(\frac{I_{out}}{I_{in}}\right) + 10 \cdot \log_{10}\left(\frac{R_{load}}{R_{in}}\right) \tag{3.3}$$

In case R_{in} and R_{load} are equal (typically 50 Ω), then the following term is equal to zero:

$$10 \cdot \log_{10}\left(\frac{R_{in}}{R_{load}}\right) = 10 \cdot \log_{10}\left(\frac{R_{load}}{R_{in}}\right) = 10 \cdot \log_{10}(1) = 0$$

Now we can write the following for power/voltage/current gain:

$$\textbf{Power gain in [dB]} = 10 \cdot \log_{10}\left(\frac{P_{out}}{P_{in}}\right) \tag{3.4}$$

R. B. Keller, *Design for Electromagnetic Compatibility–In a Nutshell*,
https://doi.org/10.1007/978-3-031-14186-7_3

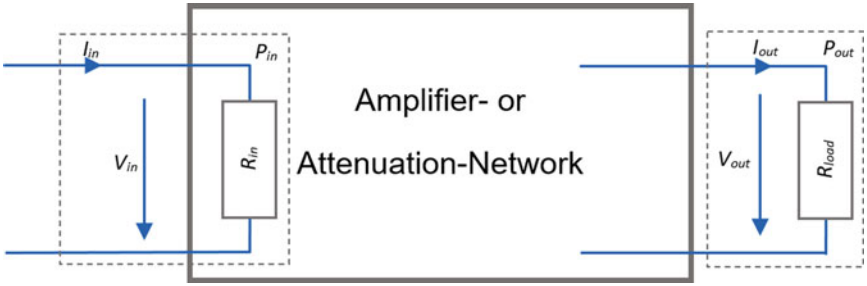

Fig. 3.1 An arbitrary amplifier or attenuation network

$$\textbf{Voltage gain in [dB]} = 20 \cdot \log_{10}\left(\frac{V_{out}}{V_{in}}\right) \tag{3.5}$$

$$\textbf{Current gain in [dB]} = 20 \cdot \log_{10}\left(\frac{I_{out}}{I_{in}}\right) \tag{3.6}$$

Points to remember when it comes to gain and loss calculations in *decibel*:

- **Absolute vs. relative**. Decibels are always ratios of numbers, never an absolute quantity, even if they are named *absolute levels*.
- **Amplification.** If P_{out} is bigger than P_{in}, the gain value in [dB] is positive. This means that in case of an amplification, the power gain in [dB] is positive.
- **Attenuation.** If P_{out} is smaller than P_{in}, the gain value in [dB] is negative. This means that in case of an attenuation (loss), the power gain in [dB] is negative.
- **Gain = −Loss.** Power loss is indicated by a negative decibel power gain. For example, if an interconnection shows a loss of 1 dB, the power gain of that interconnection is −1 dB.
- **Cutoff frequency f_c.** At the cutoff frequency, the output power (P_{out}) is half the input power (P_{in}), and the power/voltage/current gains are all −3 dB.

$$\text{Power gain in [dB] at } f_c = 10 \cdot \log_{10}\left(\frac{1}{2}\right) = -3\text{dB}$$

$$\text{Voltage gain in [dB] at } f_c = 20 \cdot \log_{10}\left(\frac{1}{\sqrt{2}}\right) = -3\text{dB}$$

$$\text{Current gain in [dB] at } f_c = 20 \cdot \log_{10}\left(\frac{1}{\sqrt{2}}\right) = -3\text{dB}$$

- **Ratio to [dB].** Table 3.2 presents some common ratio to [dB] value conversions. For example, if power increases by factor 2, the power/voltage/current gain increases by 3 dB.

Unit	Type Unit	Reference Value	Typical Usage
dBm	Power	1 mW	Wireless and RF applications
dBw	Power	1 W	Wireless and RF applications
dBμV	Voltage	1 μV	Conducted emission
dBμA	Current	1 μA	Conducted emission
dBμV/m	Electric Field Strength	1 μV/m	Radiated emission
dBμA/m	Magnetic Field Strength	1 μA/m	Radiated emission

Fig. 3.2 Commonly used absolute decibel levels in EMC

3.2 Absolute Levels [dBm, dBμV, dBμA]

The most common absolute power, voltage, and current levels in EMC are [dBm], [dBμV], and [dBμA] (Fig. 3.2). They are calculated like this [2]:

$$\textbf{Absolute power level in } [\textbf{dBm}] = 10 \cdot \log_{10}\left(\frac{P}{1\,\text{mW}}\right) \tag{3.7}$$

$$\textbf{Absolute voltage level in } [\textbf{dB}\mu\textbf{V}] = 20 \cdot \log_{10}\left(\frac{V}{1\,\mu\text{V}}\right) \tag{3.8}$$

$$\textbf{Absolute current level in } [\textbf{dB}\mu\textbf{A}] = 20 \cdot \log_{10}\left(\frac{I}{1\,\mu\text{A}}\right) \tag{3.9}$$

More information about physical quantities and their units (also in decibel) can be found in the Appendix D. The same concept of absolute levels can also be applied to electrical fields E [V/m], magnetic fields H [A/m], or radiated power density S [W/m^2]:

$$\textbf{Electric field strengnth in } [\textbf{dB}\mu\textbf{V/m}] = 20 \cdot \log_{10}\left(\frac{E}{1\,\mu\text{V/m}}\right) \tag{3.10}$$

$$\textbf{Magnetic field strength in } [\textbf{dB}\mu\textbf{A/m}] = 20 \cdot \log_{10}\left(\frac{H}{1\,\mu\text{A/m}}\right) \tag{3.11}$$

$$\textbf{Radiated power density in } [\textbf{dBmW/m}^2] = 10 \cdot \log_{10}\left(\frac{S}{1\,\text{mW/m}^2}\right) \tag{3.12}$$

Points to remember when it comes to calculations with absolute power levels in decibel:

- **Zero values.**
  - $0\,\text{dBm} \stackrel{\text{def}}{=} 1\,\text{mW}$
  - $0\,\text{dB}\mu\text{V} \stackrel{\text{def}}{=} 1\,\mu\text{V}$
  - $0\,\text{dB}\mu\text{A} \stackrel{\text{def}}{=} 1\,\mu\text{A}$
  - $0\,\text{dB}\mu\text{V/m} \stackrel{\text{def}}{=} 1\,\mu\text{V/m}$
  - $0\,\text{dB}\mu\text{A/m} \stackrel{\text{def}}{=} 1\,\mu\text{A/m}$
- **Negative values.** A negative [dBm]-value means that the power is smaller than 1 mW. A negative [dBμV]-value means that the voltage is smaller than 1 μV. A negative [dBμA]-value means that the current is smaller than 1 μA.
- **Positive values.** A [dBm]-value bigger than 0 means that the power is higher than 1 mW. A [dBμV]-value bigger than 0 means that the voltage is higher than 1 μV. A [dBμA]-value bigger than 0 means that the current is higher than 1 μA.
- **Gain and loss.** Gain values in [dB] G_{dB} can just be added to the absolute power levels in order to get the output power. The linear calculation with input power P_{in}, linear gain G, and output power P_{out} can be written as:

  $$P_{out} = P_{in} \cdot G$$

  In decibel, the output power $P_{out,dB}$ is the sum of the input power $P_{in,dB}$ and the gain G_{dB}:

  $$P_{out,dB} = 10 \cdot \log_{10}(P_{out}) = 10 \cdot \log_{10}(P_{in}) + 10 \cdot \log_{10}(G) = P_{in,dB} + G_{dB}$$

  Let's assume a signal with $P_{in,dBm} = 0\,\text{dBm}$ at the input of an amplifier with gain $G_{dB} = 20\,\text{dB}$. The output power is:

  $$P_{out,dBm} = P_{in,dBm} + G_{dB} = 0\,\text{dBm} + 20\,\text{dB} = 20\,\text{dBm}$$

- **Never sum up absolute levels.** Do never sum up absolute decibel levels, because adding decibels means multiplying the linear values and therefore:

  $$0\,\text{dBm} + 0\,\text{dBm} \stackrel{\text{def}}{=} 1\,\text{mW} \cdot 1\,\text{mW} = 1\,\text{mW}^2 = ?$$

  What does power squared mean? Thus, never add up absolute decibel levels.
- **Sum of absolute levels and decibel.** It is allowed and useful to sum up [dBm]-, [dBμV]-, or [dBμA]-values with gain G values in [dB]:

  $$P_{out,lin} = P_{in,lin} \cdot G_{lin} \stackrel{\text{def}}{=} P_{out,dBm} = P_{in,dBm} + G_{dB} = -3\,\text{dBm} + 20\,\text{dB} = 17\,\text{dBm}$$

  $$V_{out,lin} = V_{in,lin} \cdot V_{lin} \stackrel{\text{def}}{=} V_{out,dBV} = V_{in,dBV} + G_{dB} = -3\,\text{dBV} + 20\,\text{dB} = 17\,\text{dBV}$$

- **Subtraction of two absolute levels.** Subtracting two absolute [dBm]-, [dBμV]-, or [dBμA]-values is equivalent to computing the ratio of their linear values:

$$\frac{P_{out,lin}}{P_{in,lin}} = \frac{100\,\mathrm{mW}}{1\,\mathrm{mW}} = 100 \stackrel{\text{def}}{=} P_{out,dBm} - P_{in,dBm} = 20\,\mathrm{dBm} - 0\,\mathrm{dBm} = 20\,\mathrm{dB}$$

$$\frac{V_{out,lin}}{V_{in,lin}} = \frac{10\,\mathrm{V}}{1\,\mathrm{V}} = 10 \stackrel{\text{def}}{=} V_{out,dBV} - V_{in,dBV} = 20\,\mathrm{dBV} - 0\,\mathrm{dBV} = 20\,\mathrm{dB}$$

3.3 Summary

The Tables 3.1, 3.2, 3.3 and 3.4 present conversions between different absolute decibel levels, linear rations to relative decibel values and vice versa.

Table 3.1 Conversion between [dBμV], [dBμA], and [dBm] for systems with system impedance $Z_0 = 50\,\Omega$[1]

[dB] Unit Conversion for 50Ω-Systems - [dBm] to [dBμV] to [dBμV]		
dBm [dBm=dBμV-107] [dBm=dBμA-73]	dBμV [dBμV=dBm+107] [dBμV=dB A+34]	dBμA [dBμA=dBm+73] [dBμA=dB V-34]
50	157	123
40	147	113
30	137	103
20	127	93
10	117	83
0	107	73
10	97	63
20	87	53
30	77	43
40	67	33
50	57	23
60	47	13
70	37	3
80	27	7
90	17	17
100	7	27

Table 3.2 Conversion from (linear) ratios to [dB] values and vice versa

Unit Convertion - Voltage/Current/Power Ratio [1] to [dB]					
Voltage Ratio Current Ratio	Power Ratio	[dB]	Voltage Ratio Current Ratio	Power Ratio	[dB]
1	1	0	1	1	0
1.02	1.04	0.17	0.98	0.96	−0.17
1.04	1.08	0.34	0.96	0.92	−0.34
1.07	1.14	0.59	0.93	0.87	−0.59
1.10	1.21	0.83	0.91	0.83	−0.83
1.15	1.32	1.21	0.87	0.76	−1.21
1.20	1.44	1.58	0.83	0.69	−1.58
1.30	1.69	2.28	0.77	0.59	−2.28
1.41	2	3.01	0.71	0.50	−3.01
1.50	2.25	3.52	0.67	0.44	−3.52
1.60	2.56	4.08	0.63	0.39	−4.08
1.73	3	4.77	0.58	0.33	−4.77
1.80	3.24	5.11	0.56	0.31	−5.11
1.90	3.61	5.58	0.53	0.28	−5.58
2	4	6.02	0.50	0.25	−6.02
2.20	4.84	6.85	0.45	0.21	−6.85
2.40	5.76	7.60	0.42	0.17	−7.60
2.50	6.25	7.96	0.40	0.16	−7.96
2.60	6.76	8.30	0.38	0.15	−8.30
2.80	7.84	8.94	0.36	0.13	−8.94
3	9	9.54	0.33	0.11	−9.54
3.25	10.6	10.2	0.31	0.095	−10.2
3.50	12.3	10.9	0.29	0.082	−10.9
3.75	14.1	11.5	0.27	0.071	−11.5
4	16	12.0	0.25	0.063	−12.0
4.50	20.3	13.1	0.22	0.049	−13.1
5	25	14.0	0.20	0.040	−14.0
5.50	30.3	14.8	0.18	0.033	−14.8
6	36	15.6	0.17	0.028	−15.6
6.50	42.3	16.3	0.15	0.024	−16.3
7	49	16.9	0.14	0.020	−16.9
7.50	56.3	17.5	0.13	0.018	−17.5
8	64	18.1	0.13	0.016	−18.1
9	81	19.1	0.11	0.012	−19.1
10	100	20	0.10	0.010	−20
30	900	29.5	0.03	1.11E-03	−29.5
100	1.00E+04	40	0.01	1.00E-04	−40
300	9.00E+04	49.5	0.003	1.11E-05	−49.5
1000	1.00E+06	60	0.001	1.00E-06	−60
3000	9.00E+06	69.5	0.0003	1.11E-07	−69.5
1.00.E+04	1.00E+08	80	1.00E-04	1.00E-08	−80
3.00.E+04	9.00E+08	89.5	3.33E-05	1.11E-09	−89.5
1.00.E+05	1.00E+10	100	1.00E-05	1.00E-10	−100
1.00.E+06	1.00E+12	120	1.00E-06	1.00E-12	−120
1.00.E+07	1.00E+14	140	1.00E-07	1.00E-14	−140
1.00.E+08	1.00E+16	160	1.00E-08	1.00E-16	−160
1.00.E+09	1.00E+18	180	1.00E-09	1.00E-18	−180
1.00.E+10	1.00E+20	200	1.00E-10	1.00E-20	−200

Table 3.3 Conversion between voltages in [V] and [dBμV], between currents in [A] and [dBμA], and between power in [dBm] and [mW] for different system impedances Z_0 [1]

[dB] Unit Conversion - [V], [dBV], [dBμV], [A], [dBA], [dBμA], [dBm]		
To	**Calculation**	**Remark**
V	$[\mathbf{V}] = 10^{\left(\frac{[\mathbf{dBV}]}{20}\right)}$	
V	$[\mathbf{V}] = 10^{\left(\frac{([\mathbf{dB\mu V}]-120)}{20}\right)}$	
dBV	$[\mathbf{dBV}] = 20\log_{10}(\mathbf{V})$	
dBV	$[\mathbf{dBV}] = [\mathbf{dB\mu V}] - 120$	
dBμV	$[\mathbf{dB\mu V}] = 20\log_{10}(\mathbf{V}) + 120$	
dBμV	$[\mathbf{dB\mu V}] = [\mathbf{dBm}] + 10\log_{10}(Z) + 90$	Z = system impedance
dBμV	$[\mathbf{dB\mu V}] = [\mathbf{dBm}] + 107$	50Ω system impedance
dBμV	$[\mathbf{dB\mu V}] = [\mathbf{dB\mu A}] + 20\log_{10}(Z)$	Z = system impedance
dBμV	$[\mathbf{dB\mu V}] = [\mathbf{dB\mu A}] + 34$	50Ω system impedance
A	$[\mathbf{A}] = 10^{\left(\frac{[\mathbf{dBA}]}{20}\right)}$	
A	$[\mathbf{A}] = 10^{\left(\frac{([\mathbf{dB\mu A}]-120)}{20}\right)}$	
dBA	$[\mathbf{dBA}] = 20\log_{10}(\mathbf{A})$	
dBA	$[\mathbf{dBA}] = [\mathbf{dB\mu A}] - 120$	
dBμA	$[\mathbf{dB\mu A}] = 20\log_{10}(\mathbf{A}) + 120$	
dBμA	$[\mathbf{dB\mu A}] = [\mathbf{dBm}] - 10\log_{10}(Z) + 90$	Z = system impedance
dBμA	$[\mathbf{dB\mu A}] = [\mathbf{dBm}] + 73$	50Ω system impedance
dBμA	$[\mathbf{dB\mu A}] = [\mathbf{dB\mu V}] - 20\log_{10}(Z)$	Z = system impedance
dBμA	$[\mathbf{dB\mu A}] = [\mathbf{dB\mu V}] - 34$	50Ω system impedance
dBm	$[\mathbf{dBm}] = [\mathbf{dB\mu V}] - 10\log_{10}(Z) - 90$	Z = system impedance
dBm	$[\mathbf{dBm}] = [\mathbf{dB\mu V}] - 107$	50Ω system impedance
dBm	$[\mathbf{dBm}] = [\mathbf{dB\mu A}] + 10\log_{10}(Z) - 90$	Z = system impedance
dBm	$[\mathbf{dBm}] = [\mathbf{dB\mu A}] - 73$	50Ω system impedance
W	$[\mathbf{W}] = 10^{\left(\frac{[\mathbf{dBW}]}{10}\right)}$	
mW	$[\mathbf{mW}] = 10^{\left(\frac{([\mathbf{dBm}])}{10}\right)}$	

Table 3.4 Conversion between field strengths [V/m], [A/m], [dBμV/m], [dBμA/m], [dBpT], and [μT] for free-space (far-field) where $Z_0 = 377\ \Omega$ [1]

[dB] Unit Conversion - Field Strength (free-space, 377Ω)		
To	Calculation	Remark
V/m	$[\mathbf{V/m}] = 10^{\left(\frac{([\mathbf{dB\mu V/m}]-120)}{20}\right)}$	
V/m	$[\mathbf{V/m}] = \sqrt{[\mathbf{W/m^2}] \cdot 377}$	Free space, Z = 377Ω
A/m	$[\mathbf{A/m}] = \frac{[\mathbf{\mu T}]}{1{,}25}$	Free space, Z = 377Ω
dBμV/m	$[\mathbf{dB\mu V/m}] = 20\log_{10}([\mathbf{V/m}]) + 120$	
dBμV/m	$[\mathbf{dB\mu V/m}] = [\mathbf{dBm/m^2}] + 10\log_{10}(Z) + 90$	Z = system impedance
dBμV/m	$[\mathbf{dB\mu V/m}] = [\mathbf{dBm/m^2}] + 115{,}8$	Free space, Z = 377Ω
dBμV/m	$[\mathbf{dB\mu V/m}] = [\mathbf{dB\mu A/m}] + 20\log_{10}(Z)$	Z = system impedance
dBμV/m	$[\mathbf{dB\mu V/m}] = [\mathbf{dB\mu A/m}] + 51{,}5$	Free space, Z = 377Ω
dBμA/m	$[\mathbf{dB\mu A/m}] = [\mathbf{dB\mu V/m}] - 20\log_{10}(Z)$	Z = system impedance
dBμA/m	$[\mathbf{dB\mu A/m}] = [\mathbf{dB\mu V/m}] - 51{,}5$	Free space, Z = 377Ω
dBμA/m	$[\mathbf{dB\mu A/m}] = [\mathbf{dBpT}] - 2$	Free space, Z = 377Ω
dBmW/m²	$[\mathbf{dBm/m^2}] = [\mathbf{dB\mu V/m}] - 10\log_{10}(Z) - 90$	Z = system impedance
dBmW/m²	$[\mathbf{dBm/m^2}] = [\mathbf{dB\mu V/m}] - 115{,}8$	Free space, Z = 377Ω
dBpT	$[\mathbf{dBpT}] = [\mathbf{dB\mu A/m}] + 2$	Free space, Z = 377Ω
μT	$[\mathbf{\mu T}] = [\mathbf{A/m}] \cdot 1{,}25$	Free space, Z = 377Ω

References

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2. Henry W. Ott. *Electromagnetic Compatibility Engineering*. John Wiley & Sons Inc., Sept. 11, 2009.