Optimal Audio and Video Reproduction at Home

Improving the Listening and Viewing Experience

Engineering Background

Vincent Verdult

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1 Introduction

This eBook is a companion to my book *Optimal Audio and Video Reproduction: Improving the Listening and Viewing Experience*. The book that will help you set up a modern audio-video system. My book contains practical advice for setting up an audio-video system to optimally reproduce audio and video with high quality in a small room, such as a home listening room, home theater, or studio control room. To understand the advice that I give in this book, you need to have some basic knowledge of physics and mathematics. Nothing fancy. Just the stuff you learned at high school. This eBook reviews some of this material for easy reference. It is not meant to be a tutorial. If you are looking for a tutorial or want to delve deeper into a particular subject, I recommend that you use the Internet as a resource; wikipedia.org is often a good place to start.

Find out more at: vincentverdult.nl **or** routledge.com

2 Notation

A physical quantity is specified by a number and a unit; for example: 2 m. Table 1 lists the physical quantities and their units of measurements that are used in the book. In mathematical formulas, symbols are used to refer to these physical quantities. Some symbols in table 1 are taken from the Greek alphabet. Table 2 shows the complete Greek alphabet, including the names of the symbols.

Table 1 follows the SI system, which is the accepted international metric system of measurement. It is used in most countries, but not for example in the United States. Table 3 contains conversion factors for some commonly used non-SI units of measurement.

Physical quantities can range from very small to very large. To effectively cope with such a large range of values, prefixes are used. The commonly used prefixes are shown in table 4.

Mathematical relations between physical quantities are expressed using the mathematical symbols from table 5.

Table 1: Physical quantities with their units of measurement.

Quantity	Symbol	Unit	Symbol
Length	ℓ	meter	m
Angle	α	radian	rad
Solid angle	Ω	steradian	sr
Time	t	second	s
Frequency	f	hertz	Hz
Mass	m	kilogram	kg
Force	F	newton	N
Pressure	p	pascal	Pa
Energy	E	joule	J
Power	P	watt	W
Temperature	T	kelvin	K
Electric charge	Q	coulomb	C
Current	I	ampere	A
Voltage	V	volt	V
Resistance	R	ohm	Ω
Capacitance	C	farad	F
Inductance	L	henry	H
Magnetic flux	Φ	weber	Wb
Magnetic flux density	B	tesla	T
Luminous intensity	I_v	candela	cd
Luminous flux	Φ_v	lumen	lm
Illuminance	E_v	lux	lx

Table 2: Greek alphabet.

Name	Upper case	Lower case
alpha	A	α
beta	B	β
gamma	Γ	γ
delta	Δ	δ
epsilon	E	ϵ
zeta	Z	ζ
eta	H	η
theta	Θ	θ
iota	I	ι
kappa	K	κ
lambda	Λ	λ
mu	M	μ
nu	N	ν
xi	Ξ	ξ
omicron	O	o
pi	Π	π
rho	P	ρ
sigma	Σ	σ
tau	T	τ
upsilon	Υ	υ
phi	Φ	ϕ
chi	X	χ
psi	Ψ	ψ
omega	Ω	ω

Table 3: Common conversion factors.

Quantity	Unit	Symbol	Multiplier	SI Unit
Length	inch	in	2.54×10^{-2}	m
	foot (= 12 in)	ft	0.3048	m
Area	circular mil	CM	5.067×10^{-10}	m^2
Volume	liter	L	10^{-3}	m^3
Mass	ounce	oz	28.3495×10^{-3}	kg
	pound (= 16 oz)	lb	$0.453\,592$	kg
Time	minute	min	60	s
	hour (= 60 min)	h	3600	s
Pressure	bar	bar	10^5	Pa
Angle	degrees	°	$\pi/180$	rad
Illuminance	foot candle	fc	$1/(0.3048^2)$	lx
Luminance	foot lambert	fL	$1/(\pi \cdot 0.3048^2)$	cd/m^2

Table 4: Multiple prefixes.

Symbol	Prefix	Name	Number	Exponential form
T	Tera	Trillion	1 000 000 000 000	10^{12}
G	Giga	Billion	1 000 000 000	10^9
M	Mega	Million	1 000 000	10^6
k	Kilo	Thousand	1000	10^3
h	Hecto	Hundred	100	10^2
da	Deka	Ten	10	10^1
–	–	One	1	10^0
d	Deci	Tenth	0.1	10^{-1}
c	Centi	Hunderdth	0.01	10^{-2}
m	Milli	Thousandth	0.001	10^{-3}
μ	Micro	Millionth	0.000 001	10^{-6}
n	Nano	Billionth	0.000 000 001	10^{-9}
p	Pico	Trillionth	0.000 000 000 001	10^{-12}

Table 5: Mathematical symbols.

Symbol	Meaning	Application
$=$	equal to	$a = b$
$\neq$	not equal to	$a \neq b$
$\approx$	approximately equal to	$a \approx b$
$<$	less than	$a < b$
$>$	greater than	$a > b$
$\leq$	less than or equal to	$a \leq b$
$\geq$	greater than or equal to	$a \geq b$
$+$	addition, sum	$a + b$
$-$	subtraction, difference	$a - b$
$\times$	multiply	$a \times b$ or $a \cdot b$ or ab
$:$	division	$a : b$ or a/b or $\frac{a}{b}$
$\sqrt{}$	square root	$\sqrt{a}$

3 The Circle and the Sine

The *sine* is a mathematical function that is related to movement around the circumference of a circle. Figure 1 shows a circle with a radius of one. The radius equals the distance between the center point and the points on the circumference. Also shown in the figure are the x-axis and y-axis that can be used to define any point by its (x, y)-coordinates. To obtain a sine, you move with a constant speed along the circumference of the circle. Start at the top of the circle at the point $(x, y) = (0, 1)$ and move in a clockwise fashion to the point $(1, 0)$ and onto $(0, -1)$, $(-1, 0)$, and finally to $(0, 1)$ again. The sine is obtained by plotting for each time instant the x-coordinate of the point moving along the circle. If you travel around the complete circle in one second, you obtain a sine with a frequency of 1 Hz. Such a sine is shown in figure 2. If you go around the circle f times in a second, you obtain a sine with a frequency of f Hz. The amplitude of the sine is defined as the maximum value that the sine attains. The amplitude of the sine is always equal to the radius of the circle.

A more common way to look at the sine function is in relation to angles. Every position on the circumference of the circle can be expressed as an angle with respect to the y-axis. Figure 3 shows this angle α. Angles are often measured in degrees with a full circle corresponding to 360°. Figure 4 contains some examples of angles. The sine function can now be obtained by plotting for each angle α the x-coordinate of the point P. Figure 5 shows such a plot. It is essentially the same as figure 2; the only difference is that time has been replaced by angle. It is also possible to plot the y-coordinate of the point P for each angle α. Figure 6 shows what happens. The function that you obtain in this way is called the *cosine* function.

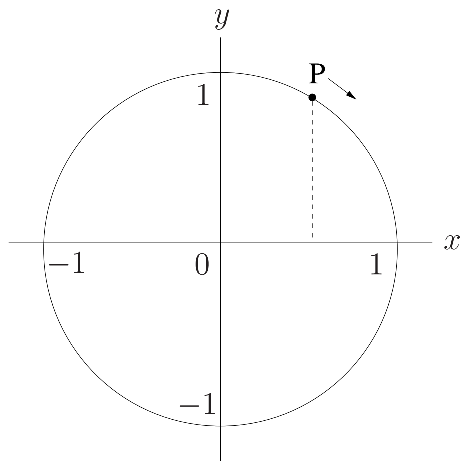

Figure 1: Circle with x-axis and y-axis. If you move the point P along the circle and plot for each time instant its x-coordinate, you obtain a sine function.

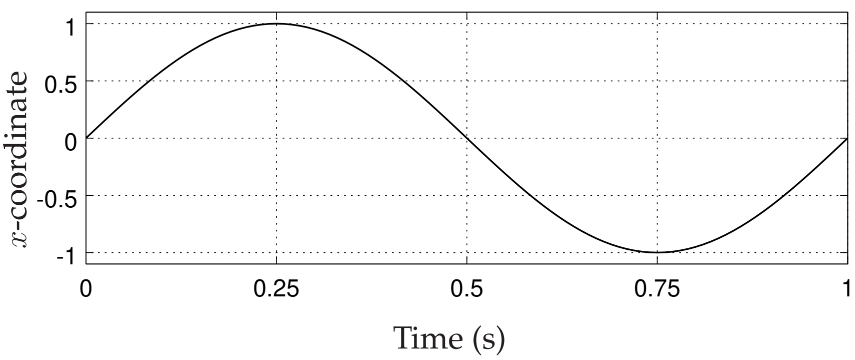

Figure 2: Sine with a frequency of 1 Hz.

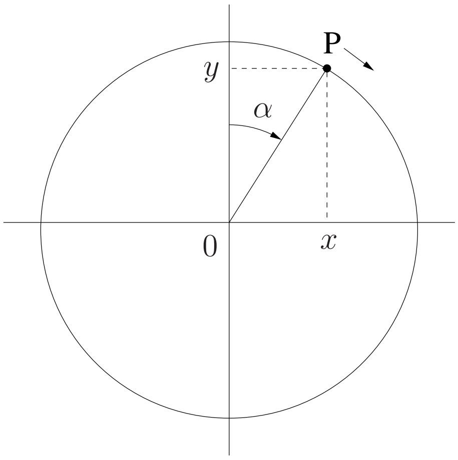

Figure 3: The position of the point P on the circle can be described by the angle α.

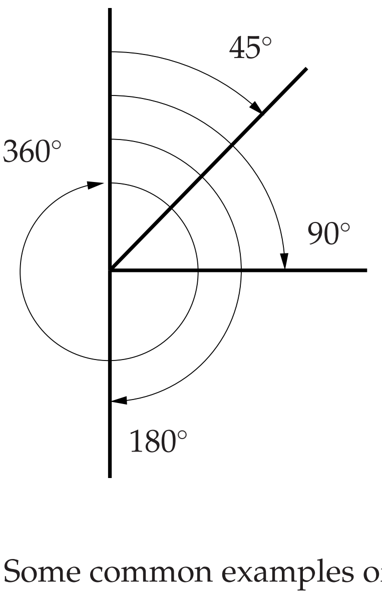

Figure 4: Some common examples of angles.

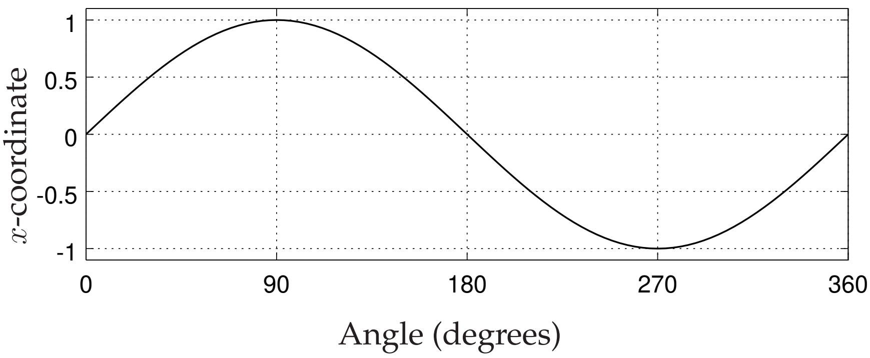

Figure 5: Sine function.

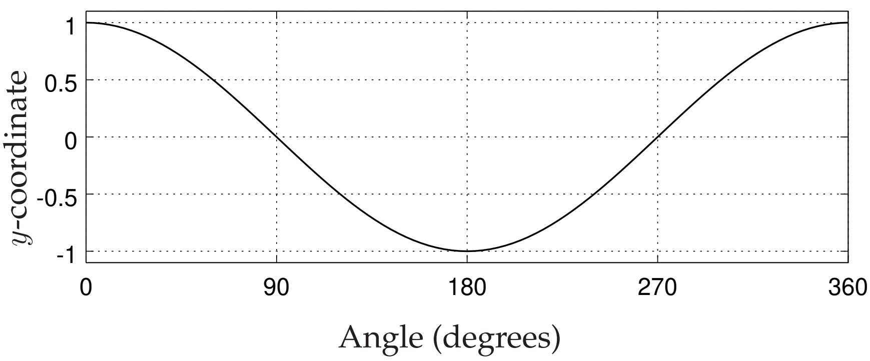

Figure 6: Cosine function.

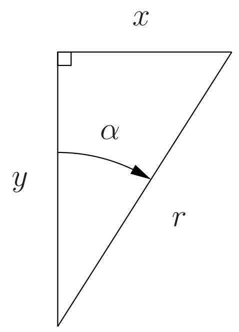

Figure 7: A triangle with angle α, opposite side x, adjacent side y, and hypotenuse r.

The sine and the cosine functions are trigonometric functions. They can be used to relate angles of a triangle to the lengths of its sides. Figure 7 provides another view of the triangle from figure 3. There are three sides in this triangle: the opposite side x, the adjacent side y, and the hypotenuse r. Note that the terms *opposite* and *adjacent* are used with respect to the angle α. For the magic to work, the angle between the opposite side and the adjacent side needs to be 90°. Such an angle is called a *right angle* and indicated by a small square. The hypotenuse r is opposite of the right angle and is the longest side of the triangle. The length of the hypotenuse equals in fact the radius of the circle in figure 3. The following two relations hold:

$$\begin{aligned} x &= r \cdot \sin(\alpha), \\ y &= r \cdot \cos(\alpha). \end{aligned}$$

Most pocket calculators and calculator apps have the $\sin$ and $\cos$ functions built in. They also have the inverse functions, $\sin^{-1}$ and $\cos^{-1}$, so that you can calculate angles from

$$\begin{aligned} \alpha &= \sin^{-1}\left(\frac{x}{r}\right), \\ \alpha &= \cos^{-1}\left(\frac{y}{r}\right). \end{aligned}$$

The *tangent* is another trigonometric function that is often used. It is defined as

$$\tan(\alpha) = \frac{\sin(\alpha)}{\cos(\alpha)}$$

and thus,

$$\alpha = \tan^{-1}\left(\frac{x}{y}\right).$$

When you use the trigonometric functions of your calculator, you should make sure that the calculator is set to *degrees* and not to *radians*. In this book, angles are always specified in degrees. In mathematics, angles are often specified in radians instead of degrees. One full circle has 2π radians. Thus, 1 rad $= 180/\pi\,^\circ$. The number π is an interesting number; it is the length of the circumference of a circle divided by the diameter ($2r$) of this circle. The number π is approximately equal to 3.141 592 654.

4 The Logarithm

In calculations with decibels, the logarithm plays an important role. The logarithm can be considered to be the inverse operation to exponentiation. In exponentiation, a number is repeatedly multiplied by itself. The number of multiplications is indicated by the exponent, which is stuck to the top right-hand corner of the number. For example, 2^3 means $2 \times 2 \times 2 = 8$. In general,

$$y = b^x$$

where b is the base and x is the exponent. The logarithm inverses this operation as follows:

$$x = \log_b(y)$$

In other words, the logarithm calculates the number of times x that the base b needs to be multiplied by itself to obtain the number y. You typically need a calculator to compute logarithms. The following relations are useful to understand some of the formulas in the book:

$$\begin{aligned}
\log_b(x^p) &= p \cdot \log_b(x) \\
\log_b(x \cdot y) &= \log_b(x) + \log_b(y) \\
\log_b(x/y) &= \log_b(x) - \log_b(y) \\
\log_b(x) &= \frac{\log_c(x)}{\log_c(b)}
\end{aligned}$$

where c can be any number.

5 Electrical Circuits

An electrical circuit is an interconnection of basic electrical components, such as resistance, inductance, and capacitance. Loudspeakers, power amplifiers, and other audio components can all be represented as an electrical circuit.

In an electrical circuit a *voltage* difference between two points exists when one point has an excess of electrons in relation to the other. This voltage difference is also called a potential difference. The *volt* (V) is the unit of measurement that is used to express the magnitude of a voltage difference.

In an electrical circuit a voltage difference between two points causes electrons to flow to the point of lower voltage. The rate of electron flow is called *current*. The *ampere* (A) is the unit of measurement that is used to express the magnitude of current flow.

Power is the rate of doing work. Electrical power P equals the product of voltage and current, that is:

$$P = V \cdot I$$

where V is the voltage and I the current.

Resistance is the opposition to current flow. The higher the resistance, the less current flows. The magnitude of resistance is expressed in *Ohm* (Ω). Ohm's law states that resistance R equals the ratio between voltage and current, that is:

$$R = \frac{V}{I}$$

where V is the voltage across the resistance and I the current that flows through the resistance.

Inductance is the opposition to changes in current flow. Electrons that flow through a conductor create a magnetic field surrounding that conductor. Similarly, a changing magnetic field around a conductor causes electrons to flow through this conductor. This principle is called *Faraday's law of induction*. Coiling the conductor concentrates the magnetic field and increases the inductance of the conductor. The magnitude of inductance is expressed in *henry* (H). The higher the frequency of current change, the larger the inductance. Therefore, inductance can be thought of as a frequency-dependent resistance. The inductive reactance Z_L in Ohm (Ω) is given by:

$$Z_L = 2\pi \cdot f \cdot L$$

where f is the frequency and L is the inductance.

Capacitance is the opposition to any change in the strength of the charge of an electric field. An electric field exists between any two conductors having a voltage difference between them. The magnitude of capacitance is expressed in *farad* (F). The higher the frequency of current change, the smaller the capacitance. Therefore, capacitance can be thought of as a frequency-dependent resistance. The capacitive reactance Z_C in Ohm (Ω) is given by:

$$Z_C = \frac{1}{2\pi \cdot f \cdot C}$$

where f is the frequency and C is the capacitance.

Impedance is the opposition to current flow in an electrical circuit where voltages and currents change over time. When the voltages and currents remain constant over time impedance and resistance are the same, but if they vary there is a difference. Impedance can be thought of as the combined resistance, inductance, and capacitance of a circuit.

Kirchhoff's laws dictate how currents and voltages in an electrical circuit are related to each other. Kirchhoff's current law states that at each node the sum of the incoming currents equals the sum of the outgoing currents. For example, in the circuit shown in figure 8 the supply current I equals the sum of the currents I_1 and I_2 in the two impedances Z_1 and Z_2:

$$I = I_1 + I_2$$

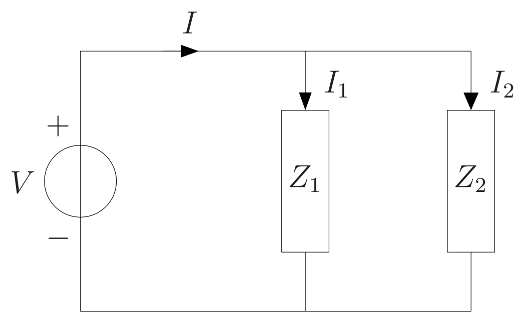

Figure 8: In this parallel connection of two impedances Z_1 and Z_2 the sum of the currents I_1 and I_2 equals the supply current I.

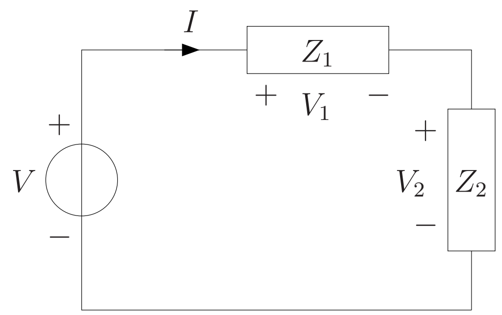

Figure 9: In this series connection of two impedances Z_1 and Z_2 the sum of the voltages V_1 and V_2 equals the supply voltage V.

Kirchhoff's voltage law states that in each closed loop the sum of the voltages equals zero. For example, in the circuit shown in figure 9 the total sum of the supply voltage V and the voltages V_1 and V_2 across the two impedances Z_1 and Z_2 equals zero. Note that the polarity of the voltages corresponds to the direction of current flow, therefore: $V_1 + V_2 - V = 0$ or equivalently:

$$V = V_1 + V_2$$

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Optimal Audio and Video Reproduction at Home is a comprehensive guide that will help you set up a modern audio-video system in a small room such as a home theatre or studio control room.

This book covers everything you need to know to optimize the reproduction of multichannel audio and high-resolution video. It provides concrete advice on equipment set up, display calibration, loudspeaker positioning, room acoustics, and much more.

Detailed, easy-to-grasp explanations of the underlying principles ensure you will make the right choices, find alternatives, and separate the rigid from the more flexible requirements to achieve the best possible results.

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