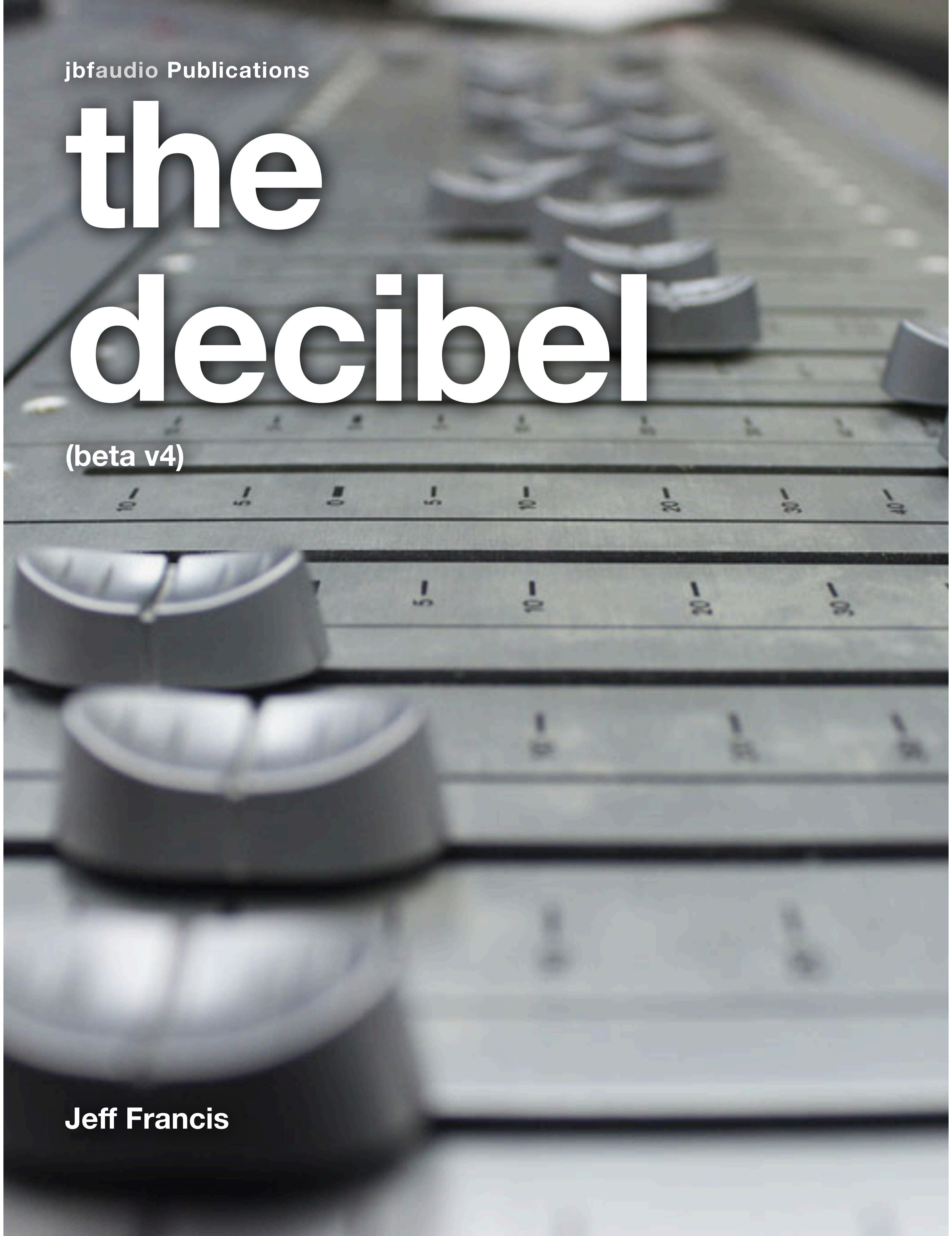
jbfaudio Publications

the decibel

(beta v4)

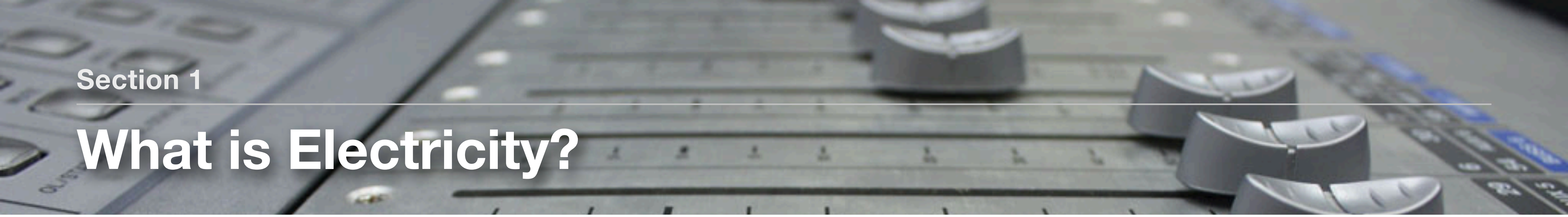


Jeff Francis

Chapter 1

Basic Electronics

An introduction to basic electronics used in audio engineering.



Section 1

What is Electricity?

What is Electricity?

Introduction

Decibels are used throughout audio to measure the intensity (or loudness) of sound in the air and audio in various forms. To understand the decibel and use it properly, it is important to have a general understanding of electricity and basic electronics. This chapter is not a substitute for a good course on electronics, but will serve to outline some fundamentals.

Electricity

Electricity is the flow of electrons thru a conductor.

A conductor is a material that permits the flow of electrons. Typical materials that make good conductors are metals such as copper, gold, and aluminum. Materials that do not permit the flow of electricity are called insulators. Rubber, air, and ceramics are good insulators.

Current (I)

The flow of electrons is called current. Current is given the symbol I and is is measured in amperes or (amps). The unit was named for French mathematician and physicist, André-Marie Ampère.

Direct current (DC)

Electricity that flows steadily in one direction is called direct current, abbreviated DC. Common household batteries can supply DC.

Alternating current (AC)

Current can also flow back and forth, changing direction periodically. This is termed alternating current, which is abbreviated AC. Alternating current also has a frequency, which describes how often it changes direction. The electricity supplied by the wall outlets in the U.S. is alternating current and changes direction 60 times a second, or 60 Hertz (Hz).

Voltage (V or E)

Voltage, which is given the symbol V or E, is the electromotive force (EMF), or the *push* that causes current to flow in a conductor. Voltage is often called potential, because the presence of a voltage creates the *potential* for electron flow. However, no flow occurs unless there is a suitable conductor.

Voltage is measured in Volts (named for Alessandro Volta, and Italian physicist).

DC voltage

Voltage that does not change, which will give rise to direct current (if there is a suitable conductor).

AC voltage

Voltage that changes, which will gives rise to alternating current (if there is a suitable conductor). Like alternating current, AC Voltage has a frequency, measured in Hertz (Hz).

Audio is AC

Human can hear sounds that range in frequency from 20Hz to 20,000Hz. Typical sounds and music contain many of these frequencies all at the same time. Because of this, audio is considered to be an alternating signal

Resistance (R)

Resistance (symbol R) is opposition to the flow of direct current. It is measured in ohms, named for German physicist Georg Ohm.

Conductors, such as copper wire, allow electrons to flow easily. They have low resistance. Insulators, such as rubber, resist the flow of electricity. They have high resistance.

Impedance (Z)

The opposition to the flow of alternating current is called impedance; it uses the symbol Z. Alternating signals (especially audio) can consist of many frequencies. A single element may have a different impedance at each of these frequencies, so impedance is often represented using complex numbers, which is beyond the scope of this text.

Load

A circuit’s impedance determines the amount of load it places on the source. If load impedance is high, there is little current flow, therefore little demand on the source.

If load impedance is low, there is much current flow, therefore the source must supply many electrons.

Measuring Amplitude

Alternating signals (currents and voltages) are typically bipolar - they spend some of the time above zero (positive) and some of the time below zero (negative). A simple average will always equal zero, no matter how large the signal is. Because of this, measuring the amplitude of a bipolar signal is slightly complicated.

There are several common ways used to measure the amplitude of alternating signals:

Peak

The difference between the maximum amplitude and zero.

Peak - to - Peak

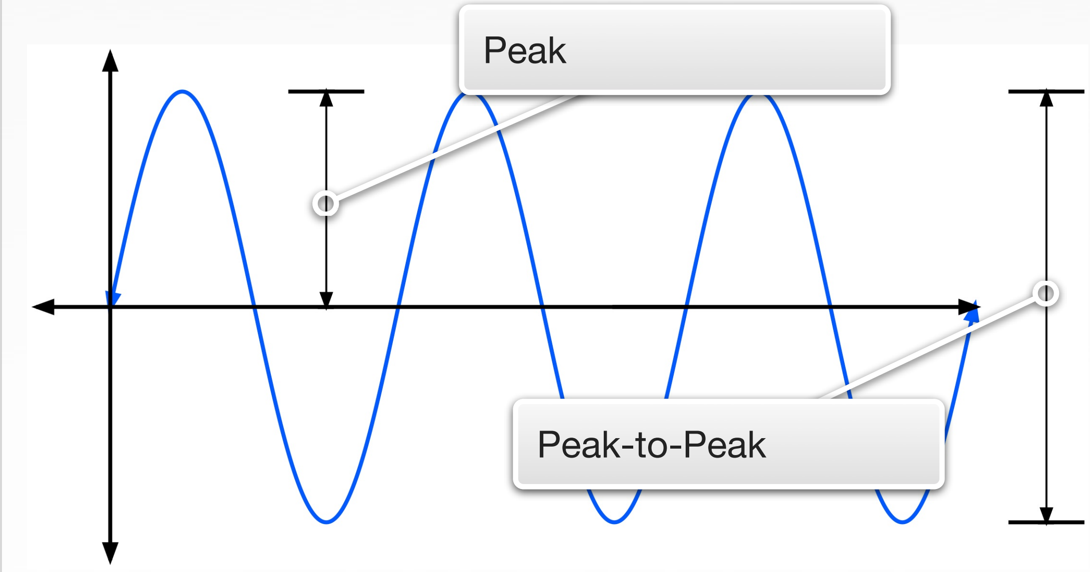
The difference between the maximum positive and maximum negative amplitudes.

Both peak and peak-to-peak only look at the maximum value. They do not give a value that represents the true average value of the signal.

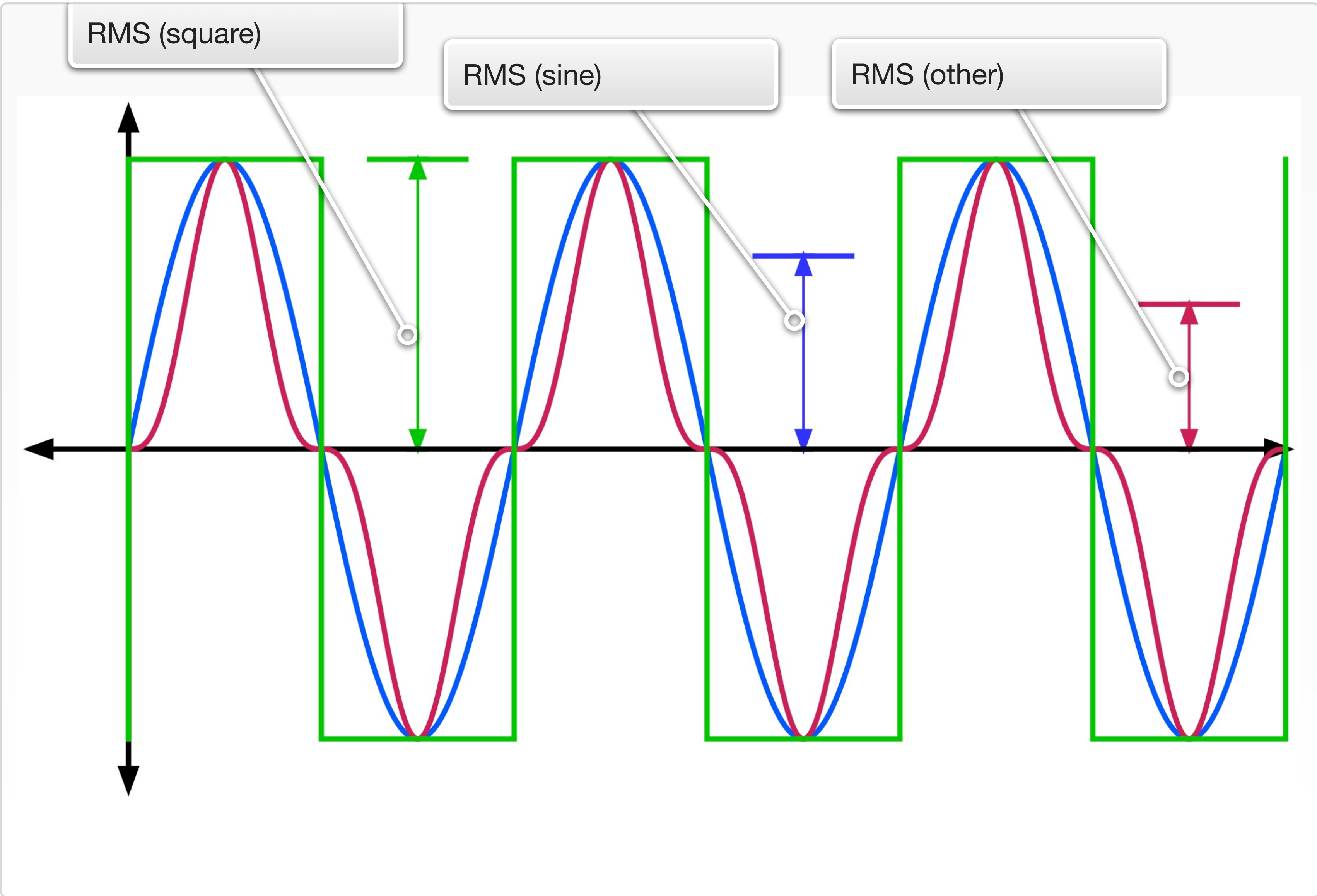
RMS (Root-Mean-Square)

The square root of the average of the square of the amplitude at each instant. RMS is the best and most common way to measure the average value of an alternating signal such as audio.

Interactive 1.1 Measuring Amplitude: Peak vs. Peak-to-Peak



Interactive 1.2 Measuring Amplitude: RMS



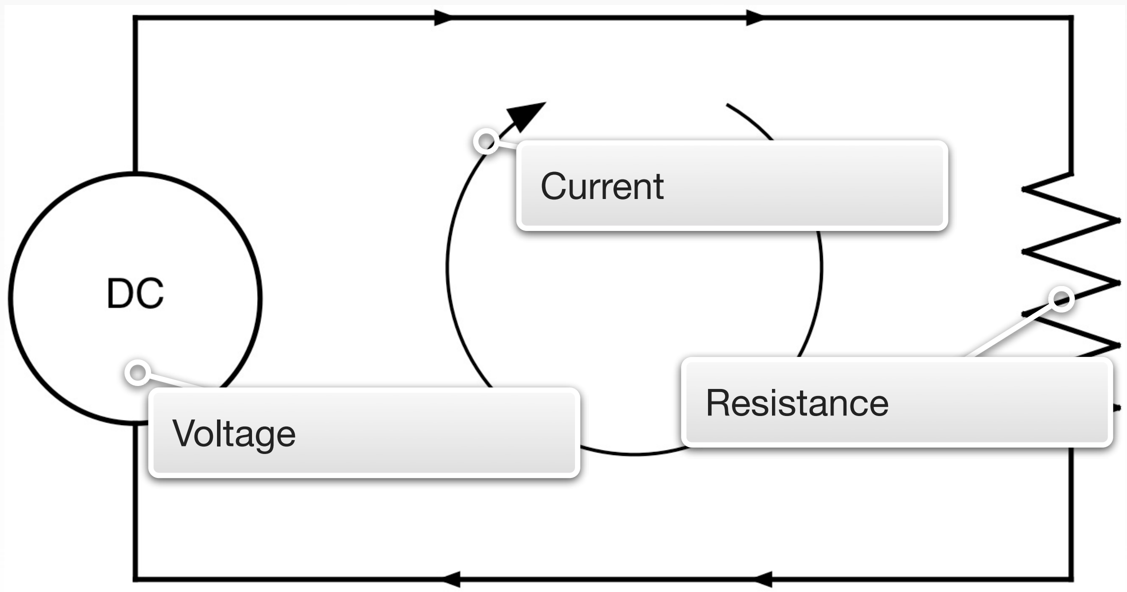
Simple Circuits

Simple Circuits

Simple Circuits

Interactive 1.3 shows a simple direct current circuit.

Interactive 1.3 Simple DC Circuit



On the left is a DC voltage source, which could be a battery, or a microphone. This voltage provides the potential to push electrons thru the conductor.

The greater the voltage, the greater the push.

On the right is a resistor, which represents resistance to the flow of electrons. This is the load of the circuit. It may be an electrical component called a resistor, a light bulb filament, or a speaker.

The higher the resistance, the greater the opposition to the flow of current.

If there is a closed circuit from the voltage source through the resistor and back to the voltage source, current will flow thru the resistor, based on Ohm's law.

Ohm's Law

Ohm's Law outlines the relationship between voltage, current and resistance. Current is voltage divided by resistance, as shown by the simple equation:

$$I = {}^{V}/_{R}$$

Where I is current in amperes (amps), V is voltage in volts, and R is resistance in ohms.

By using simple algebra, we can re-write Ohm's law in it's alternate forms:

$$V = I \cdot R \qquad \text{and } R = {}^{V}/_{I}$$

Notice that as the voltage increases, so does the current. More push yields more flow. Conversely, if the resistance increases, the flow decreases.

Power (P)

Power is the rate at which energy is transferred, used, or transformed or the amount of work performed per unit of time. Electrical power is used to light lightbulbs, run motors, and turn on televisions. The unit for electrical power is the Watt, named for Scottish engineer James Watt.

Once a voltage potential has caused a current to flow in a resistive load, power is expended. The amount of power expended is given by Watt's Law.

Watt's Law

Watt's Law describes the relationship between voltage, current and power. Power is simply current times voltage, as shown by:

$$P = I \cdot V$$

Where P is power in watts, I is current in amperes (amps), and V is voltage in volts.

By using simple algebra and substituting variables from Ohm's law, we can re-write Watt's law in it's alternate forms:

$$P = V^2/R \quad \text{and } R = I^2 \cdot R$$

Review 1.1 Electricity

Question 1 of 2

A regularly changing potential is called...

- **A.** DC current
- **B.** AC current
- **C.** DC voltage
- **D.** AC voltage ✓

Check Answer

Section 3

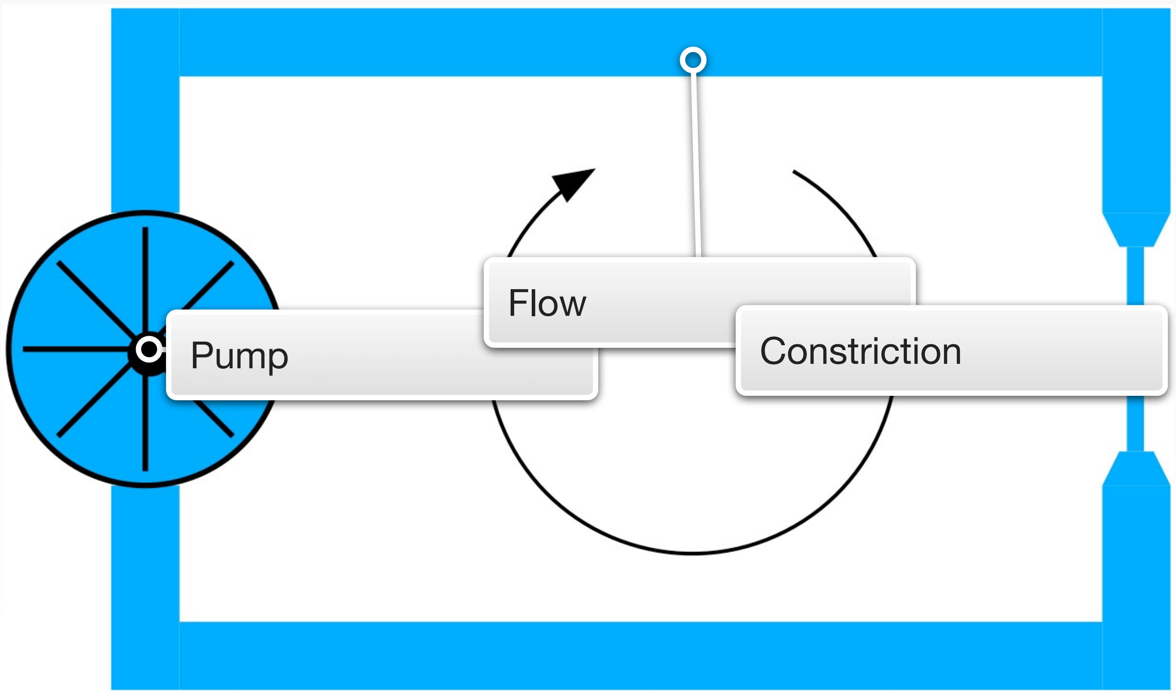
Analogy

Water Pump Analogy

Water Pump Analogy

Because we cannot see it, the flow of electricity and the relationship between voltage, current and resistance can be difficult to understand at first. The water pump analogy (also

Interactive 1.4 Simple Circuit - Water Analogy



called the electronic–hydraulic analogy) is commonly used to explain simple circuits and electrical components by relating them to their equivalent function in the flow of liquids.

Equivalents

Each element in electricity has a corresponding element in hydraulics. The flow of water symbolizes the flow of electrons and conductors (wires) are represented by very large pipes. To model voltage, which is the push that causes electrons to flow, we substitute a device which gives a push to water - a hydraulic pump. Constrictions in a pipe (narrow gauge bores) embody resistance to the flow.

	Electricity	Water
material that flows	electrons	water
amount of flow	current (amperes)	flow rate (gallons per minute)
conduit	conductor	pipes
obstruction	resistance (ohms)	narrow bore pipe (gauge)
push	voltage (volts)	pressure difference (psi)
thing that creates the push	voltage source	pump

"Ohm's Law"

Ohm's law establishes a relationship between voltage, current, and resistance. For the same voltage (push), as resistance increases, current decreases:

$$I = {}^{V}/_{R}$$

In the same way, there is an intuitive relationship between the pressure created by the pump (voltage), the restriction in the pipe (resistance) and the flow rate (current).

As the pump increases pressure, the flow increases. As the pump pressure decreases, the flow decreases.

If the restriction becomes narrower (thus causing a greater resistance to the flow), less water flows. Conversely, if the restriction opens (and there is less resistance), flow increases.

Note: There is an equivalent law in fluid dynamics, the Hagen–Poiseuille law, but it is beyond the scope of this textbook.

"Watt's Law"

Carrying the analogy further, we can make a natural extension to Watt's law, which states that electrical power is proportional to the product of voltage and current:

$$P = I \cdot V$$

Imagine that the load of our water 'circuit' is a waterwheel. In order to get more power from the waterwheel, there must be both *push* in the form of water pressure (voltage) and *flow* (current). If the pipe is constricted (high resistance), there will be little flow (current) and therefore, little power.

Limitations

Obviously we can only take this analogy so far. Electricity and water are vastly different when we consider their speed of propagation or their mass.

While this analogy does have its limitations, it is useful as a conceptual model. If you are new to electricity and electrical circuits, use the water pump analogy to think about the flow of electrons thru conductors and resistors.

Just don’t mix electricity and water!

Chapter 2

The decibel

The decibel, the decibel equation, and referenced forms.

Section 1

What is a decibel?

Decibel (dB)

Not a measurement

The most common misunderstanding about the decibel is that it is not a measurement.. Decibels by themselves do not provide any concrete information - they are merely a convenient way of expressing a comparison.

For example, if I tell you that I drove to work twice as fast today as I did yesterday, can you tell me how fast I drove today? One cannot tell from the information that is provided. All you know is the ratio of the two speeds - twice as fast today as yesterday.

Decibels work the same way - they are a comparison.

A comparison

A decibel expresses the ratio of two levels. The comparison may be:

- comparing input to output
- comparing before to after

Why decibels?

Decibels provide several benefits. Since they are always a comparison, decibels display the same information and have the same meaning no matter what the medium or measurement.

A 10 decibel increase is the same amount whether it refers to sound in the air, electricity in a wire, or a digital representation of audio.

Human hearing

In audio decibels are used to express loudness, amplitude, power, and gain. Human hearing is sensitive to an incredible range of volumes, from very soft to very loud. In fact, the loudest sounds we can hear are some 10,000,000 times bigger than the quietest. This huge range is very difficult to deal with. Decibels condense the huge range and simplifies calculations.

Human perceive a change in intensity (loudness) based on the ratio of change, not on the actual values. In other words, a doubling of sound pressure is perceived as the same level change, regardless of whether the sound is quiet or loud. Because of our perception of loudness is geometric in nature it is helpful to have a unit (the decibel) that is also geometric.

Uses logarithms

To achieve this geometric progression, the decibel expresses the comparison as the *logarithm* of the ratio. The logarithm of a number is the exponent to which you raise 10 to get that number.

That is, if:

$$10^3 = 1{,}000$$

then:

$$\log 1000 = 3$$

The easiest way to think about logarithms is with the phrase,

“10 to the what power equals...”

(Note: The decibel uses base-10 logarithms, also called common logarithms. See Appendix A for more information on logarithms.)

What’s the big deal?

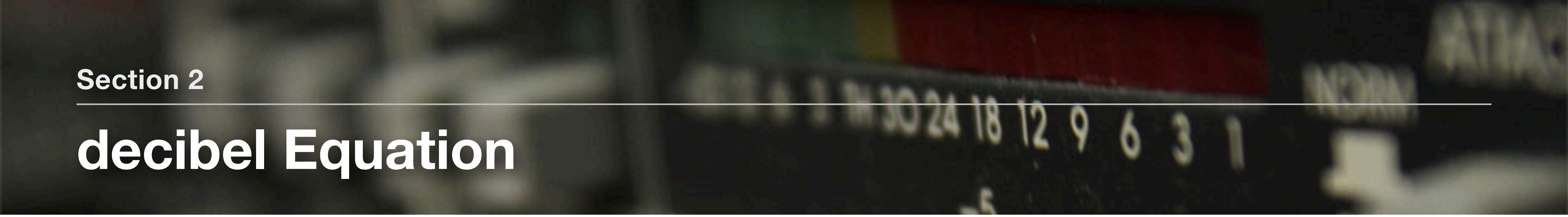
Using logarithms provides several benefits. The logarithm, since it is the inverse function of an exponent, *condenses huge ranges* in much the same way that exponents can create large ranges.

Logarithms *simplify calculations*. The log function turns multiplication into addition and division into subtraction. I don’t know about you, but I would *much* rather add and subtract!

Often a complex signal chain will involve many gain components, each of which can provide another factor which must be multiplied to find the total gain factor of the system. By converting all the gain factors to decibels, they can simply be added together to get the total gain in decibels.

So, what exactly is a decibel?

A decibel is the *comparison* of two quantities (power or amplitude) which uses the common logarithm function to simplify very large or small ratios.



Section 2

decibel Equation

Decibel Equation

Decibel (dB) Equation

Power:

A decibel is defined as 10 times the base-10 (common) log of a ratio of two powers.

$$dB = 10log(\frac{Power_1}{Power_2})$$

This equation can be used anytime the quantities in question are expressions of power or intensity. In audio, these are typically sound power or electrical power.

Amplitude:

However, very often we are faced with other amplitude measurements, such as sound pressure, electrical voltage and current, or numerical amplitude in digital audio. Since power is proportional to the square of amplitude measurements, all of these have a squared relation to power.

Proof:

To demonstrate this fact, follow thru substituting Watt’s law into the decibel equation (or how to find dBs of a voltage ratio):

Start with the decibel equation:

$$dB = 10 * \log \left({}^{Power1} / {}_{Power2} \right)$$

and one of the alternate forms of Watt's Law:

$$P = V^2 / {}_R$$

Substituting P in the decibel equation gives:

$$dB = 10 \log [(V_1^2 / R_1) / (V_2^2 / R_2)]$$

Since we are comparing two different voltages of the same system, we can assume $R_1 = R_2$. The R's cancel, giving:

$$dB = 10 \log [(V_1^2) / (V_2^2)]$$

A fraction with a squared quantity over a squared quantity is the same as the square of the fraction, so the equation simplifies to:

$$dB = 10 \log (V_1 / V_2)^2$$

The power logarithmic identity shows that the exponent can come out of the logarithm as product [$\log(A^2) = 2 * \log A$], so:

$$dB = 2 \cdot 10 \log (V_1 / V_2)$$

which simplifies to:

$$dB = 20 \log (V_1 / V_2)$$

The same holds true for other amplitude measurements such as sound pressure, electrical current, and numeric (digital) amplitude.

Decibel Forms

10 log (power):

For Power (acoustic or electrical), use 10 log form:

$$dB = 10 \log \left({}^{Power1} / {}_{Power2} \right)$$

20 log (amplitude):

For anything that has a squared relationship to power (voltage, current, pressure, or digital amplitude), use the 20 log form:

Review 2.1 Decibel equation

Question 1 of 2

To calculate the decibels of a sound pressure change, which form of the decibel equation should you use.

- **A.** 10 log form
- **B.** 20 log form ✓
- **C.** Either, it doesn't matter.
- **D.** Not enough information given.

Check Answer

$$dB = 20 \log \left(\frac{Voltage1}{Voltage2} \right)$$

$$dB = 20 \log \left(\frac{Current1}{Current2} \right)$$

$$dB = 20 \log \left(\frac{Pressure1}{Pressure2} \right)$$

$$dB = 20 \log \left(\frac{Amplitude1}{Amplitude2} \right)$$

History of the decibel

In the 1920s, Engineers at Bell Telephone Laboratories developed the transmission unit to measure losses in telephone lines. In 1928, they renamed it the decibel and also defined the bel. The bel is the ratio of powers expressed as common log (base 10) of ratio, hence it there are 10 decibels in a bel. The bel was named for the founder of Bell Labs and inventor of the telephone, Alexander Graham Bell.

Section 3

Referenced decibels

Decibels as Measurement

As stated in Section 1, a decibel is a *comparison*, not a measurement. As such, the decibel describes relationships, not concrete information. Recall the example of how fast I drove to work:

If I tell you that I drove to work twice as fast today as I did yesterday, all you know is the ratio of the two speeds - twice as fast today as yesterday.

But often times, a quantity in question is compared to a known reference quantity, which makes the decibel function as a measurement. In the driving example, we might use a known reference of miles per hour (MPH). Now if I tell you I drove 35 times as fast as 1 MPH, you know *exactly* how fast I drove.

Decibels can work the same way, by referencing a known quantity. These are called referenced forms. Each has a unique subscript and unique reference.

It is important to remember that for each reference form, the 0dB point is the referenced value. Positive decibels are larger and negative decibels are smaller in magnitude.

Referenced forms

Sound Pressure Level (dB_{SPL})

dB_{SPL} is used for expressing the pressure levels of sound in decibels. If someone or something is referring to how ‘loud’ a sound is, they are most likely using dB_{SPL}. See Gallery

2.1 for the sound pressure level of some common sounds. dB_{SPL} is the most commonly used form of the decibel, and is often confused with the decibel itself.

Gallery 2.1 Common Sound Pressure Levels

Rustling Leaves - approximately 20 dB SPL

Pressure can be measured in many units. Most of us are familiar with PSI (pounds per square inch), which is used to measure the pressure in car tires. Meteorologist use a different unit of air pressure, the millibar, to predict the weather. When dealing with sound, pressure is often measured in Pascals (PA).

The reference for dB_{SPL} is 20μPA (micro – Pascals). This is an extremely quiet sound, about the quietest sound that humans can hear. Because of this, 0 dB_{SPL} is often referred to as the *Threshold of Hearing*. Very loud sounds - above 130 or 140 dB_{SPL} - approach the *Threshold of Pain*, where the sound becomes physically uncomfortable or painful. It is important to note that hearing damage can occur well before sound becomes painful, damage is based not only on how loud a sound it, but also on the length of exposure to that sound.

Note that since we are measuring pressure, this uses 20 log (amplitude) form of the decibel equation:

$$dB_{SPL} = 20 \log \left[{}^{\text{Pressure (PA)}} / {}_{0.00002} \right]$$

subscript: SPL

reference: 20μPA

The subscript ($_{SPL}$) shows that we are comparing a measured sound pressure to a known reference of 20μPA.

When used in a Sound Pressure Level meter, the dB_{SPL} pressure input can be weighted to mimic the ear's response. See the sidebar for more details.

dB_{SPL} weighting

Since humans do not hear all frequencies equally well, the dB_{SPL} unit by itself does not given an accurate picture of how loud a sound is. A large pressure (and therefore a high dB_{SPL} number) at a frequency we don't hear well (such as low frequencies) would not be as loud as the dB_{SPL} number might suggest.

To make a sound pressure level (SPL) meter display something closer to how people hear, several weighting curves were developed, based on average human hearing.

Two commonly used weighting curves are A-weighting, designed for quiet sounds, and C-weighting, designed for louder sounds.

Electrical Power (dBm)

The decibel began as a way to compare electrical power, so it is natural that a referenced form (dBm) developed. This compares electrical power (measured in watts) to the reference of 1milliwatt (mW).

$$dBm = 10 \log [\ ^{Power} / _{0.001}\ ]$$

subscript: m

reference: 1mWatt

Electrical Voltage

There are actually two different referenced decibel forms for electrical voltage. Both use the 20 log form of the decibel equation, since voltage is an amplitude that has a squared relationship to power.

dBV

dBV (often called "dee-bee big-vee") compares a voltage (measured in volts) to a reference of 1 Volt.

$$dBV = 20 \log [\ ^{Voltage} / _{1\ V}\ ]$$

subscript: V

reference: 1Volt

dBu

dBu ("dee-bee you") is very similar to dBV with a slightly different reference. It compares a voltage (measured in volts) to a reference of 0.775 Volt.

$$dBu = 20 \log [\ ^{Voltage} / _{0.775\ V}\ ]$$

subscript: u

reference: 0.775 Volt

Why 0.775?

For more about dBu and where 0.775 volts comes from, see the sidebar.

Digital Audio

Digital audio is audio (and sound) represented as numbers. The audio is periodically sampled at a very fast rate (44.1kHz or greater) and the amplitude at that instant is encoded as a binary number. Since digital audio represents the amplitude (not the power) of the audio signal, the 20 log form of the decibel equation is used.

dBFS

A number system with a fixed number of bits (or digits) has a maximum possible number. Thing about the biggest three digit number you can think of. I'll bet you thought of 999, didn't you? There is no larger three digit number. In the same way, digital audio has a maximum amplitude built into the system. This is called Full Scale (largest possible signal) and acts as the reference for dBFS.

$$dBFS = 20 \log [\ ^{digital\ amplitude} / _{full\ scale\ amplitude}\ ]$$

subscript: FS

reference: Full Scale

dBu: why 0.775 volts?

dBu was designed to be the voltage equivalent of dBm. Audio gear had been developed from telephone equipment, which all an impedance of 600 ohms.

0.775 volts across 600 ohms yields 1mW

From one of the forms of Watt's law:

$$P = V^2 / R$$

$$1mW = (V)^2 / 600$$

$$0.001 = (V)^2 / 600$$

Solving for the voltage (V) gives:

$$(V)^2 = 0.001 \bullet 600$$

$$(V)^2 = 0.6$$

$$V = 0.775 \text{ volts}$$

Chapter 3

Appendix A: Math Review

A basic overview of exponents and logarithms.

Section 1

Math Review

Math Review

Exponents

Exponents are a shorthand method to represent multiplying the same number many times.

$$A \cdot A \cdot A \cdot A = A^4 \qquad \text{or} \qquad 3 \cdot 3 \cdot 3 \cdot 3 = 3^4$$

Using exponents can create extremely large (or small) numbers, such as in scientific notation:

$$1{,}230{,}000{,}000 = 1.23 \cdot 10^9$$

Logarithms

The logarithm is the inverse function of the exponent. If:

$$B^X = C$$

then:

$$X = \log_B (C)$$

Where B is the Base, and X is the exponent.

Common (Base-10) Logarithm

If the Base (B) is 10, it is called a Common Logarithm.

$$10^X = C$$

$$X = \log_{10}(C)$$

Typically, when common logs are written, the 10 is left out:

$$X = \log_{10}(C)$$

Using Common Logarithms

The common logarithm of a number is the power to which you raise 10 to get the number. That is, if:

$$10^3 = 1{,}000$$

then:

$$\log 1000 = 3$$

In use, it is often easiest to logarithms using the phrase:

"10 to the what power equals..."

When you see:

$$\log 100$$

read "10 to the *what* power equals 100?" The answer, 2 is the common log of 10.

x	log x
1,000,000	6
1,000	3
100	2
10	1
1	0
0.1	-1
0.01	-2
0.001	-3
10^{-6}	-6
0	- infinity

Logarithmic Identities

There are several useful identities or laws that can be helpful when using logarithms:

Product

The log of a product is equal to as the sum of the logs of the individual factors:

$$\log(A \cdot B \cdot C \cdot \ldots) = \log(A) + \log(B) + \log(C) + \ldots$$

Quotient

The log of a quotient is equal to as the log of the dividend minus the log of the divisor:

$$\log(^{A} / {}_{B}) = \log(A) - \log(B)$$

Power

The log of a exponent is equal to the power times the log of the base:

$$\log(A^{B}) = B \cdot \log(A)$$

The Decibel

All content and diagrams by Jeff Francis

Photographs by Matt Francis, courtesy of Matt Francis Photography

Alternating Current

Current that changes direction at some frequency.

Related Glossary Terms

Current, Direct Current

Index Find Term

Current

The flow of electrons through a conductor.

Related Glossary Terms

Alternating Current, Direct Current

Index

Find Term

Chapter 1 - What is Electricity?

Decibel

The comparison of two quantities (power or amplitude) which uses the common logarithm function to simplify very large or small ratios.

A decibel is defined as 10 times the log of a ratio of two powers.

$$dB = 10 * \log \left({}^{Power1} / {}_{Power2} \right)$$

Related Glossary Terms

Drag related terms here

Index Find Term

Direct Current

Current that flows in the same direction.

Related Glossary Terms

Alternating Current, Current

Index Find Term

Electricity

Electricity is the presence and flow of electric charges.

Related Glossary Terms

Current, Resistance, Voltage

Index Find Term

Exponents

Represents multiplying the same number many times.

The exponent (which is written as a superscripted number following the base). In the example A^4, A is the base and 4 is the exponent.

$$A^4 = A \cdot A \cdot A \cdot A$$

Related Glossary Terms

Logarithms

Index Find Term

Chapter 3 - Math Review

Impedance

The opposition to the flow of alternating current.

Related Glossary Terms

Resistance

Logarithms

The logarithm is the inverse function of the exponent. If:

$$B^X = C$$

then:

$$X = \log_B (C)$$

Where B is the Base, and X is the exponent.

Related Glossary Terms

Exponents

Ohm’s Law

Ohm’s Law outlines the relationship between voltage, current and resistance. Current is voltage divided by resistance, as shown by the simple equation:

$$I = {}^{V}/_{R}$$

Related Glossary Terms

Current, Resistance, Voltage

Potential

Another term for voltage.

Related Glossary Terms

Voltage

Power

Power is the rate at which energy is transferred, used, or transformed or the amount of work performed per unit of time.

Related Glossary Terms

Watt's Law

Resistance

Resistance is opposition to the flow of direct current.

Related Glossary Terms

Impedance

Voltage

Also called potential, this is the is the electromotive force (EMF), or the *push* that causes current to flow in a conductor.

Related Glossary Terms

Potential

Index Find Term

Water Pump Analogy

A conceptual model for understanding the basics of electricity by relating the flow of electrons to the flow of water.

Related Glossary Terms

Ohm's Law

Index Find Term

Watt’s Law

Watt’s Law describes the relationship between voltage, current and power. Power is simply current times voltage, as shown by:

$$P = I \cdot V$$

Where P is power in watts, I is current in amperes (amps), and V is voltage in volts.

Related Glossary Terms

Current, Power, Resistance, Voltage
