Glossary of Terms

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Words or phrases in *italics* preceded by an asterisk are cross-references to keywords where the concept is further explained

absolute value The size of a **real number* without regard to sign: Abs(5) = 5; Abs(-5) = 5. If the number is **complex*, the absolute value is also called the "modulus"; it is the (positive) square root of the sum of the squares of the real and imaginary parts: Abs(3+4i) = 5

acceleration Rate of change of **velocity*. Acceleration is a particularly important quantity because it enters **Newton's second law* (**mass*). "Rate of change" in the above definition refers not only to changes in magnitude but also to changes in direction; for example, a mass going around a circle with constant speed is experiencing an acceleration

admittance **mobility*

alias in digitizing a continuous curve, a frequency that can masquerade as another frequency. For example, if the **sampling* rate is 1000 Hz, the set of samples of the function sin510t is identical to that of sin490t. That's why we say that, **sampling* at a particular frequency, we must first eliminate all frequencies above the **Nyquist's frequency* — that way we get rid of all aliases. (A particular frequency has many more aliases, but they are even higher.)

amplitude For a **sinusoid*, the maximum positive or negative swing relative to the zero axis. The word is sometimes used for a function other than a sinusoid, with a meaning that is not always obvious

analog **digital/analog*

anechoic ["devoid of echoes"] Used of a chamber whose walls absorb sound perfectly; by extension, a chamber whose walls absorb strongly. Generally, it is more difficult to make a wall that absorbs low frequencies than to make one that absorbs high ones; hence, actual anechoic chambers have an absorption characteristic that gets worse at low frequencies

anisotropic not the same in all directions

antinode ["opposite of node"] for a **normal mode*, a point where the amplitude of vibration is larger than at any neighboring points; by extension, a place where the vibration is large. Unlike **nodes,* antinodes are always points, regardless of whether the vibrating system has one, two, or three dimensions

antiphase [“opposite phase”] two **sinusoids* of the same **frequency* are said to be “in antiphase” if the maxima of one coincide in time with the minima of the other. Their zeros will then coincide (*phase; *quadrature)

arching the property of violin plates that makes it impossible to fit them into a plane, and which causes their **bending stiffness* to increase dramatically

argument the most common mathematical use of this term is in connection with a **function;* but it has quite a different meaning when discussing **complex numbers*

bending stiffness the resistance of a plate (or rod) of material to bending. If the plate is comparatively thin, the bending stiffness comes from the resistance of the outside layer of the plate to extension and the simultaneous resistance of the inside layer to compression

bending wave a wave in a thin plate of a solid medium whose displacement is perpendicular to the plate, so that the **restoring force* comes from the **bending stiffness.* Vibrations of the wooden shell of a violin are bending waves, though the presence of arching complicates the situation

binary file Unlike a **text file,* a “binary file” is a simple sequence of **bits.* The program that reads it (or writes it) must know how to interpret it; that is, it must know the code in which it is written. Some types of binary files begin with a so-called “header” that instructs the program (**wave format*); at other times, the program knows how to read the file because the same programmer devised both the writing program and the reading program

binary number *bit

bit One digit in a binary number. Probably the easiest way to explain it is to compare the binary with the decimal system, which everybody knows: there are ten decimal digits (0123456789) and their numerical value is determined by the position they occupy in the number; this position is figured relative to the **decimal point.* For example the value of the digit 3 is three if it appears immediately to the left of the decimal point, thirty if it appears shifted one position to the left, three hundred if two positions, &c. If the 3 appears immediately to the right of the decimal point it signifies three tenths, one more place to the right makes it three hundredths, &c. Any empty spaces between the 3 and the decimal point are indicated by the digit 0, as 30 = thirty, 0.0003 = three ten-thousands. In the binary system, there are only two digits (01), and the “decimal point” is now called a “binary point.” A 1 immediately to the left of it signifies the number one; one shift to the left changes it to two; one more is four; one more is eight; &c. Again, we use zeros for padding, so that 10 = two; 10000 = thirty-two; 10010 = thirty-six; 0.01 = one-quarter. As in the decimal system, if the binary point is missing its position is assumed to be immediately to the right of the rightmost binary digit.

bulk modulus **elastic modulus*

byte a group of binary digits; in the most common computer systems today, a byte is comprised of eight **bits*

calculus any branch of mathematics; usually refers to **differential calculus* and/or **integral calculus,* both of which discuss situations that arise when **limits* are taken of certain quantities

character any member of a "character set", an extended alphabet that includes captial and lower-case letters, numerals, punctuation marks, spaces, as well as other often-used symbols and whole or partial non-Roman alphabets. In today's computer usage, a typical character set has 256 members.

coincidence frequency the frequency at which **bending waves* in a thin solid plate have the same velocity as **compression waves* in the surrounding fluid (usually air). Spruce, the typical material for violin tops, is quite **anisotropic,* in that its stiffness modulus for bending in such a way that the longitudinal fibers are not bent is considerably smaller than the modulus when they do bend. Therefore the coincidence frequencies for the two directions differ by something like a factor of 3 (~700 Hz and ~2000 Hz). Estimates of coincidence frequency should never be taken at face value, however, because of complications introduced by **arching*

complex numbers mathematical quantities each consisting of a pair of real numbers, called the **real part* and the **imaginary part*. If the real part is a and the imaginary part is b, the complex number is often written $a+ib$, where i is the **imaginary unit* whose square is -1 by definition. A complex number can also be written in the "polar representation" $Ae^{i\theta}$, where **e* is the base of natural logarithms, i again the **imaginary unit*, A the "modulus", and θ the "argument". The modulus and argument can be obtained from the real and imaginary parts by simple formulas. Complex numbers close upon themselves algebraically; that is, any algebraic operation carried out on complex numbers results in a complex number.

compression wave a **wave* in which the **restoring force* comes from the compression of a medium. Most often, but not always, the medium is a **fluid* like air

convolution A particular way of combining two sequences of numbers to produce a third sequence of numbers: (1) the two sequences are written above each other with the first members of the two coinciding in position; (2) the top sequence is shifted by n places to the right (or, if n is negative, to the left); (3) each member of the top sequence is multiplied by the number directly below it, and the resulting products added together. The result is the n^{th} member of the convolution sequence. A **digital filter* often consists of a given finite (=not infinitely long) sequence with which the sequence to be filtered (often infinite in length) is convolved (note the use of the verb)

coupling of normal modes it is the nature of **normal modes* that any one can be excited without disturbing the others; in other words, normal modes do not couple. Nonetheless, the physicist often deals with systems that are perturbed by a small change, so that the normal modes are almost the same and yet not exactly the same (**perturbation*). It can be proved that, in such a case, the new normal modes are linear combinations of the old normal modes. We say that the old normal modes *have been coupled* by the perturbation

critical frequency another name for **coincidence frequency*, although the word “critical” is often used differently and hence not recommended here.

damping refers generally to forces that reduce the energy of a vibrating system. **Linear damping* means that the damping forces are proportional to the velocities of the particles of the system. In such a case, amplitudes of vibration decay following an **exponential function.*

dashpot a device, generally imaginary, that exerts an exactly **linear damping* force on a particle to which it is attached

delta function a **function* of a **variable t* such that it is equal to zero for all values of t except when t=0, in which case it jumps to infinity in such a way that the area under the curve is exactly 1. The delta function is, of course, a figment of our imagination. It can, however, be defined as a result of a *limiting process (*limit).* But when we deal with functions of a **discrete* variable, such as a sequence of samples, the name *delta function* is used for a function all of whose sample values are zero except sample number 0, which has a value of 1. Note that sample number 0 need not be at the beginning of the function (which may, in fact, have no beginning or end)

decibels (abbreviated “dB”) a quasi-linear unit applied to a **logarithmic scale.* Because decibels are almost always used in connection with power, we first make a distinction between quantities that need to be squared to be converted to energy or power, such as displacement (of an oscillator), particle velocity in a sound wave, or voltage or current in a transmission cable; and those that do not, like power or energy itself. In the latter case, being multiplied by ten is considered an increase of ten decibels; in the former case, it is an increase of 20 decibels. Remembering that $\log_{10}2=0.30103\ldots$, we conclude that doubling a “power quantity” constitutes an increase of 3.0103.. dB, whereas doubling a “linear quantity” is an increase of 6.0206… dB. The last two cases are often abbreviated to “3 dB” and “6 dB” respectively, since measurements of power seldom justify the higher precision.

decimal point a point (sometimes, especially in Europe, a comma) used in a decimal number to define the positional value of the digits: 1.0 means one, 10.0 means ten, 0.1 means one tenth. In the case of an integer the decimal point is often omitted. The corresponding object in a binary number is properly called “binary point”

deconvolution the mathematical operation that is the inverse of **convolution*

density mass per unit volume of a substance. If we are dealing with a sheet, the word may be used to mean mass per unit area; for a string, it may mean mass per unit length

differential calculus the branch of mathematics that deals with “derivatives” of **functions,* which are new functions that give the rate at which the value of a function changes with respect to its **argument.* The process of finding the derivative is called “differentiation”

digital/analog an analog quantity is exemplified by a length, or a voltage, or a mass, or a time interval. Although each of these can be represented by a number, this number can be infinitely subdivided. By contrast, a digital quantity is exemplified by a bank balance, or the count of ticks that a clock makes, or the quantity of children that you have. These can be represented by numbers which are necessarily integers and cannot be subdivided. If your bank notified you of your balance by sending you an analog message in the form of a ribbon whose length in millimeters signified your balance in cents, and that ribbon got wet and shrank, you would still know *approximately* how much money you have, and your maximum error could be estimated by knowing the properties of the material of which the ribbon is made. By contrast, if your bank statement consists of a piece of paper with the balance printed on it in decimal numbers (as it actually is) and the paper got wet, you could still read your *exact* balance so long as the numerals were not smudged so badly that you could not tell them apart; in that case, you would end up *knowing nothing.* That is characteristic of digital records, as opposed to analog record, in general: up to a certain critical amount of **noise*, they are immune to it; above that critical quantity, they become totally wiped out.

dirac function another name for the **delta function*

directional tone color the quality of the violin sound (and that of some other instruments) which results from the fact that its angular distribution alters sharply and rapidly with frequency

discrete fourier transform: a form of **Fourier Transform* which deals with sampled waveforms

double bounce in experiments with an impact hammer, the situation in which the hammer, having been released, bounces off its intended target and returns to hit it a second time. Given the signal from the hammer sensor and the signal from a microphone/accelerometer, the appropriate **impulse response* can still be found by **deconvolution*

double precision **number representation*

driving-point mobility **mobility*

dry damping a force which, because it acts consistently in a direction opposite to a particle's velocity, causes the particle to lose energy; unlike **linear damping*, it is not proportional to the velocity, but rather approximately constant, simply changing its direction when the particle's velocity does

e the base of **natural logarithms*, probably the best known **transcendental number* after π. An approximate value of e is 2.718281828459

eigenmode **normal mode*

elastic modulus a number characterizing the rigidity of a substance, defined as the ratio of **stress* to **strain*. In a **fluid*, there is a single independent elastic modulus, usually specified as the (negative) ratio of pressure change to relative volume change (“bulk modulus”). In an **isotropic* solid, there are two independent elastic moduli, usually specified as a “Young’s modulus” and a “shear modulus”; the first is the ratio of a longitudinal stress to the corresponding longitudinal strain, with all other stresses kept at zero (“free surfaces”). The second is the ratio of a shear stress to the corresponding shear strain, again with free surfaces. In **anisotropic* substances, the number of independent elastic moduli can be as large as 36 depending on the degree of anisotropy

energy a quantity that characterizes the state of a system and signifies the ability of the system to do work. In a mechanical system, energy is classified as “kinetic” (ability to do work by virtue of motion) or “potential” (ability to do work by virtue of distortion or, if gravity is an important factor, by virtue of position). The motion of a vibratory system consists of a continuous transformation of kinetic into potential energy and back again. In practice, such a system loses energy with time, either by transforming its internal kinetic and potential energy into radiated energy (in the cases that interest us, into radiated sound energy, which can itself be described as kinetic and potential energy of the air); or else into thermal energy, which is kinetic and, possibly, potential energy on a molecular level. Conversion into thermal energy is called “dissipation”; from the point of view of macroscopic physics, such energy seems to disappear

exponential function a function whose value gets *multiplied* by a fixed amount every time a fixed amount is *added* to its variable. Thus a function which, for successive integers, takes on the values 1, 10, 100, 1000… is an exponentail function; as is one for which successive values are 4000, -2000, 1000, -500

fast fourier transform: an algorithm for computing **discrete fourier transforms* efficiently on a computer

feedback loop a feature of an amplifier circuit in which some fraction of the output is added (“fed back”) to the input; it is called *positive feedback* or *negative feedback* depending on whether the feedback results in the input becoming larger or smaller. Negative feedback tends to make an amplifier more stable; positive feedback does the opposite, in the extreme case turning the circuit into an oscillator

fft a common abbreviation for **fast fourier transform*

fft size the number of (complex) quantities encompassed by the fourier transform, which must be a power of 2 (such as 256 or 65536) for the usual fft algorithm to be applicable

fluid a substance whose shear modulus is zero, so that it is incapable of supporting a shear stress without flowing. The opposite is **solid* or, in some cases, **glass*

force a push or a pull exerted on an object. Two or more forces can be added by the rules of vector addition to form a resultant force. According to Newton’s Second Law, the resultant force on an object, if not zero, causes the object to accelerate

force hammer **impact hammer*

forced harmonic motion **harmonic* motion of a system caused by an application of a **harmonic* force to some point in it. If the system is *linear, the application of such a force will, after all **transients* have died off, result in the system moving harmonically with the frequency at which it is driven

forcing frequency the frequency in forced harmonic motion

fourier component when a time-dependent quantity is subjected to a fourier transformation, the resulting frequency-dependent quantities are called its "fourier components"

fourier integral in general, the **fourier transformation* of a continuous function of time will yield a continuous function of frequency, and *vice versa.* The mathematical expressions employ **integrals* and are called "fourier integrals".

fourier expansion **fourier transformation*

fourier series the special case of a **fourier transform* of a function which is periodic in the **time domain*, and which therefore has discrete components in the **frequency domain* at frequency values that are multiples of the frequency that characterizes the original periodicity in the time domain

fourier transformation a procedure that converts a signal from the **time domain* to the **frequency domain* or vice versa. Signals that are periodic in the time domain with **frequency f* will, in the frequency domain, have a discrete structure whose **fourier components* are at 0, f, $2f$, $3f$, …. The converse is also true, so that [periodic in one domain] ↔ [discrete in the other domain]. In **Signal processing*, we often deal with signals that are discrete in time because they are **sampled*. They may also be periodic in time with a **period* of N samples. In such a case their frequency representation will also be both discrete and periodic with period N

frequency a specification of how often a repetitive phenomenon repeats, by stating the number of repetitions that it executes in a unit of time. (**period*). Very often it is more convenient to use the "circular frequency", which specifies, not the number of repetitions per unit time, but the number of radians in the mathematical argument of a sinusoid. The circular frequency is 2π times the ordinary frequency, and is commonly denoted by the symbol ω (omega) instead of f

frequency component **fourier transformation*

frequency domain: to specify a signal *in the frequency domain* means to specify it as a function of frequency; that is, giving the frequency, amplitude, and phase of each frequency component. The same signal (with some restrictions) could alternatively be specified in the **time domain*

frequency function: a record of how something varies with frequency, for example, sound pressure level of a signal. This is synonymous with specifying the amplitude and the phase as a function of frequency. In thus describing a signal in the **frequency domain,* we assume that all frequencies are present; if one or more are absent, we simply ascribe zero amplitude to them. In thus describing a frequency function, we have equivalently described a **complex* function of frequency

frequency response we discourage the use of this phrase because of its ambiguity: any number of variables are functions of frequency and their specification could be described as a “frequency response.” It is better to be specific and say “the driving-point mobility as a function of frequency,” or “the radiativity as a function of frequency,” and so on

function a relation between two variables. We distinguish the **independent variable,* or “argument”, whose value can be varied, and the **dependent variable,* whose value changes as a result; alternatively, the dependent variable can be thought of as the value of the function itself. Some functions can have more than one independent variable, as when we specify the air pressure in a sound wave as a function of position x, y, and z and the time t. The converse of this — a “function” that has more than one **dependent variable* — is in most cases much better thought of as simply a number of separate functions

fundamental period, fundamental frequency any function that is **periodic* with period T is automatically also periodic with periods $2T$, $3T$, … ; in other words, a periodic function has not just one period but many. The shortest one of these is called the “fundamental period.” Similarly, a periodic function of frequency f can have components of frequency $2f$, $3f$, $4f$, ... added to it without losing its original periodicity. The lowest frequency which can be so added is called the “fundamental frequency”.

glass generally, a fluid whose viscosity is so high that it acts like a solid under ordinary circumstances

harmonic as an adjective, describes a quantity that varies sinusoidally with time; as a noun, one of the terms in a fourier series

helmholtz motion an idealized motion involved in the motion of a **bowed string* which, at any instant of time, consists of two straight line segments. One of these segments extends from the (fixed) bridge to a point in space called the “helmholtz corner” or “helmholtz kink”; the other continues from the same kink to the nut (also assumed fixed). The kink itself moves along a shallow parabolic trajectory from bridge to nut and back again in a similar parabola but on the other side of the quiescent string. The round trip of the kink occupies one **fundamental period* of the string (the reciprocal of the **fundamental frequency*). If the string is idealized to zero stiffness and zero damping, helmholtz motion turns out to be one of its possible free motions

helmholtz resonance a common, if informal, name for the lowest important radiative normal mode of a violin, found in the vicinity of 280 Hz. Most of the **energy* in this mode is in the motion of air in or out through the *f*-holes (kinetic) and then, a quarter of a period later, in the compression or rarefaction of the air inside the body of the instrument (potential). For this reason, the helmholtz mode is often described as an “air mode,” though this is not exactly true: when the air pressure in the violin body is largest, the body also becomes a little larger, like a balloon, and *vice versa*

hysteresis a relationship between two variables which is not single-valued; typically, as x varies back and forth between -1 and +1 and back (for example), y follows one set of values for increasing x and another set for decreasing x

imaginary numbers square roots of negative **real numbers*. Since the square of any real number, positive or negative, is positive, no real number can be the square root of any negative. In **complex number* algebra, a quantity is invented (usually denoted by i or j) which is the square root of -1; obviously, it cannot be a real number. It is sometimes called "the imaginary unit." In terms of the imaginary unit, we can write the square root of any negative real number; for example, the square roots of -64 are $\pm 8j$. Also, in terms of **complex numbers*, the square roots of 3+4i are ±(2+i)

imaginary part **complex number*

impact hammer an instrument (usually quite small if it is to be used on a violin) in the shape of a hammer with a piezoelectric force sensor mounted on its tip. The procedure is to tap the violin with the impact hammer and simultaneously record both the force as a function of time and the sound generated by the violin as a result, or perhaps the motion of some point of the violin with an *accelerometer or another type of motion sensor. The comparison of the two gives information about some type of *transconductance

impedance *mobility

impulse a very large **force* applied for a very short time; in the limit, the force has the form of a **delta function*

impulse response the response to an **impulse.* Because an ideal impulse contains all frequencies, a **Fourier Transform* applied to the impulse response will yield the corresponding quantity in the frequency domain. This is the basis of the use of an **impact hammer;* although in careful work we do not simply assume that the impact is a perfect impulse, but use the actual signal from the sensor in the tip of the hammer to obtain the real impulse response by a mathematical process called **deconvolution*

in phase two sinusoids of the same frequency are said to be "in phase" if their maxima (or minima) occur at the same instants of time

instrumentation hammer **impact hammer*

integral; integral calculus the **limit* of a sum of which the individual terms approach zero while the number of such terms increases without limit, in such a way that the sum approaches a well-defined limit, is called an "integral". The branch of mathematics that deals with integrals is called "integral calculus". In sampled series, integrals are generally replaced with sums

isotropic the same in all directions; for example, glass is isotropic but wood and crystalline quartz are not

kinetic energy **energy*

limit a fundamental concept of both **differential calculus* and **integral calculus.* Given a dependent variable y which depends on an independent variable x, "the limit of y as x approaches a" is defined as follows: we examine y when x is in the vicinity of a. If we find that the closer x is to a, the closer y comes to a certain number L (formally: for every positive η, no matter how small, we can find a positive ε such that if $x - \varepsilon < x < x + \varepsilon$, then $L - \eta < y < L + \eta$) then we say that "the limit of y as x approaches a is L"; or, in symbols,

$$\lim_{x \to a} y = L$$

linear characterized by a mathematical relation of the form $y=ax$, whose graph is a straight line (hence the name). In vibration theory, the term is used for a system such that if a certain pattern of motion is possible for that system, then a pattern in which every displacement is doubled (or tripled, or halved, &c) is also possible

linear damping **damping* wherein the force is proportional to the (negative) **velocity* of the particle

logarithm if $z = y^x$, then we say that "x is the logarithm of z to the base y"; in symbols, $x = \log_y z$. Tables of logarithms are useful because products of numbers can be computed just by adding the corresponding logarithms (although in this day and age one does better with a handheld calculator). Two bases are in general use: "common logarithms" have base 10, and "natural logarithms" have base e. Natural logarithms have the special notation $ln\, x$ that some people use.

logarithmic scale a graphing scale on which, instead of equal intervals denoting equal amounts *added* to the quantity being graphed, they denote instead that the quantity being graphed is *multiplied* by the same amount. A logarithmic scale becomes more detailed as the quantity is decreased, as is indicated by the fact that zero is never reached. For example, on a logarithmic scale of frequency, all octaves (factors of 2) take up equal-sized segments. A scale labeled in **decibels* can be said to be a "hidden logarithmic" scale, because even though the divisions appear to be linear (for example, the segments allocated to 5 dB are always the same size), 5 dB does not represent a fixed addition, but rather a fixed multiplication.

magnitude **absolute magnitude*

mass a measure of the inertia of an object; that is, of how much net force needs to be applied to produce a certain acceleration. This meaning is embodied in Newton's Second Law of Motion $F=ma$, where F is the net force, m the mass, and a the acceleration. In the metric system, mass is measured in grams. Mass is often confused with "weight", the force exerted on an object by the gravitational pull of the earth. It is true that, at a given location, the weight of an object is proportional to its mass, but if you transport the same object to the moon it will have a different weight but its mass will remain the same

mobility in the frequency domain, the velocity achieved by a given point of a system when a unit force of given frequency is applied to that point. The specification of mobility can be complicated by the fact that both force and velocity are **vector* quantities. Mobility is sometimes called "admittance". Its reciprocal is sometimes called *impedance*. The term *driving-point mobility* expresses, somewhat confusingly, the fact that in a mobility experiment the velocity is measured at the same point to which the force is applied. Another type of quantity called **transmobility* or "transadmittance" (or sometimes "transconductance") refers to an experiment in which the force is applied to one point of a system and the resulting velocity is measured at another point

modal analysis an analysis of a **linear* vibratory system into **normal modes*

mode in the analysis of vibratory systems, the word usually refers to a **normal mode* of the system under consideration, or perhaps of a closely related system

mode shape description of a **normal mode* in terms of the displacement of the various points of the system which, together, constitute the mode. Since a motion in which every point has a displacement two (or three, or N,…) times a normal mode would still be regarded as the same normal mode, the question of **normalization* is usually left open

modulus a confusing word because of its many uses. The two most common ones are **elastic modulus* and modulus of a **complex number.*

monopole radiation sound radiation due to a fluctuation in the total volume of an object (the "monopole moment" is either that volume fluctuation itself or a closely related quantity proportional to it). In principle, any fluctuation in the shape of an object will move the outside air and give rise to a sound wave, but if the wavelength is sufficiently long, the wave radiated by one part of the object surface will be "short-circuited" by another part moving in the opposite direction (that is, inward instead of outward). Under such circumstances, no energy will be radiated unless the net volume of the object, that is, the monopole moment, undergoes a fluctuation. Monopole radiation is by its nature **isotropic*.

monopole régime the frequency range in which monopole radiation, which is **isotropic*, predominates. For a violin, this encompasses frequencies up to about 800 Hz. There is also a region of very low frequencies (<180 Hz or so) which does not belong to the monopole régime because the "toothpaste effect" is complete (**sound hole sum rule*)

natural logarithm **logarithm*

newton's second law of Newton's three laws of motion, the important one in our context is the "second law", which states that the total force on an object is the mass of that object times its **acceleration*

node for a **normal mode*, a location where the motion is zero. If the system is one-dimensional, as a string, the nodes are points; if two-dimensional, as the wooden structure of a violin body, they are curves ("nodal lines"); if three-dimensional, as the air in an enclosed space such as a room, they are surfaces ("nodal surfaces")

noise any part of a signal whose exact magnitude is unknown, even though its source and approximate magnitude (as well as other characteristics such as its frequency spectrum) may be known. Noise is the general reason why experimental data can never yield absolutely exact results

normalization for some purposes, it is convenient to define **normal modes* so that they have a definite amplitude (ordinarily, twice a normal mode is still the same normal mode). This process is called “normalization”. The best criterion to use for this standard amplitude is the one that makes the mode contain unit energy.

normal mode a pattern of a vibrating system which, once correctly started, will continue in the same shape oscillating sinusoidally in time with a single frequency; that is, every point of the system will oscillate with that same frequency, so the whole system will periodically return to the exact same configuration in which it began. Although in principle this definition requires a dissipationless system (otherwise the motion will be damped), it is very useful if the damping is small (so that the vibrations have a high **Q*). It can be shown that *any* free motion of the system is a superposition of normal modes, each oscillating with its own frequency, and with an **amplitude* and **phase* determined by the initial conditions. If the motion is sinusoidally forced; that is, a force that varies sinusoidally in time with its own frequency is applied to some point of the system, the **steady-state* motion that results will be sinusoidal with the frequency of forcing. The pattern of the motion will again be a superposition of the same normal modes, but their amplitudes and phases will be as given under **steady state*. The fact that, when all modes have high **Q*s, the normal modes themselves are sometimes (unfortunately and incorrectly) referred to as “resonances” is explained under **resonance.* A normal mode is sometimes called an “eigenmode” after the German

number representation in binary computer files, numbers can be represented as “fixed-point” **binary numbers*, which means that the program that reads the file knows both the number of bits allocated to the number and the location of the binary point. Alternatively, information about the position of the binary point can be incorporated into the number itself, in which case we have a “floating point” number. For a given total number of bits, a fixed-point representaion is more accurate, whereas a floating-point representation covers a larger range of values. The term “double precision” refers to floating-point numbers that have a larger-than-usual number of bits allocated to each floating-point number, typically eight **bytes* instead of four.

nyquist frequency **sampling*

orthogonal [right angled] two vectors are “orthogonal” if there is a right angle (90º, or π/2 radians) between them. It is shown in vector analysis that in such a case the sum of products of corresponding components of the vectors is zero. By analogy, two numeric sequences are said to be “orthogonal” if the sum of products of their corresponding terms is zero. Orthogonality is important in the theory of normal modes, where it can be shown that the sum over mass points of a vibratory system of the product of (1) the displacement of the mass point in a normal mode, (2) the displacement of the same mass point in another normal mode, and (3) the **mass* of that mass point, is zero. We say that the two normal modes are “orthogonal” to each other

period the time required for a single repetition of a periodic phenomenon. Period T is the reciprocal of frequency – thus the period of concert A is 1/440th of second. In terms of the circular frequency ω, $T=2\pi/\omega$

periodic function (or waveform) a function (or waveform) which repeats exactly after a time which is called its **period.* The period can be any finite length: for example, a continually repeated recording of a Beethoven symphony could be considered a periodic waveform

perturbation a small change in one or more of the parameters of a system, such as the masses of the particles that comprise it, which naturally alters all its properties but not by very much. The concept comes into play when we are dealing with a system whose properties are such that we cannot find its possible motions by exact mathematics; but we can (often with a lot of ingenuity) devise a hypothetical system whose parameters differ only a little bit from the one we are interested in, and whose possible motions *are* susceptible to exact calculation. We can then say that the system we are interested in is “a perturbation” of the one we can analyze, and we use various methods known collectively as “perturbation theory” to go from one to the other

phase two sinusoids of the same frequency are “in phase” if their maxima occur simultaneously, which also implies that their minima, as well as their zeros, are simultaneous (*antiphase, *quadrature). More generally, “phase” can mean any specification of where on the time axis a sinusoid lies

polar representation **complex number*

potential energy **energy*

Q (originally from the phrase “Quality Factor”) a dimensionless measure of the amount of dissipation of an oscillator. In the time domain it is defined as the number of **radians* of **free oscillation* traversed by the oscillator in the time it takes for it to have its stored energy decrease to 1/*e* of its original value (**transcendental numbers*). In the **frequency domain*, the same number appears as the ratio of the **resonant frequency* to the **response curve* peak width at the place where the response curve has dropped from its maximum by a factor of $\sqrt{2}$

quadrature a specification of the *phase relation between two sinusoids of the same frequency. Two such sinusoids are “in quadrature” if the zeros of one occur at the same time as the maxima and minima of the other. (*in phase, *antiphase)

quality factor **Q*

radian a measure of angle, defined by placing the vertex of the angle at the center of a circle and taking the ratio of the arc length intercepted by the angle to the radius of the circle. For example: since the length of a semicircle of radius R is πR, an angle of 180° is π radians. Because a size of an angle measured in radians is a quotient of two lengths, it is considered to be dimensionless; in other words, it is correct to say that “a right angle is $\pi/2$” rather than “$\pi/2$ radians”.

radian frequency (sometimes called “circular frequency”) the **frequency* times 2π. Generally represented by the symbol ω (omega)

radiation the sending out of waves by a vibrating system. The loss of energy due to radiation is called “radiation damping”.

radiation efficiency the fraction of the energy fed into a musical instrument that is radiated in the form of sound

radiation pattern the pattern that defines the amount of energy that a source of waves radiates in different directions. The radiation pattern almost always changes with frequency, sometimes very rapidly (**directional tone color)*

real number any number that can be represented as a decimal fraction—non-repeating, repeating, or finite number of decimal places; positive, negative, or zero; and with any number of digits to the left of the decimal point—is called a real number. Examples are 0.0, 55, 12.95, -759.3, -4.2365656565... (repeating), π=3.14159...(non-repeating). Note that an **integer* is a special case of a real number, but see **number representations*

real part **complex number*

reciprocal the reciprocal of x is $1/x$. The reciprocal of $1/x$ is x

reciprocity principle in acoustics, the theorem that the acoustic field at point P due to a source at point P' is the same as the field at P' due to the same source at P. This is true not only in free space (in which case it is obvious), but also in the presence of arbitrary obstacles. The theorem has been used to make various measurements possible which would otherwise be difficult or impossible.

resonance the characteristic strong response of a **linear system* when the **forcing frequency* is close to the frequency of a **normal mode.* Generally, such a response is a sum over normal modes of a product of three factors: (1) the strength of the mode in question at the location of forcing; (2) the strength of the mode in question at the location of observation; (3) the **resonance denominator*, a quantity that gets progressively larger as the frequency of the mode is approached, reaching a value of approximately **Q* times the “shoulder” when the forcing frequency and normal frequency are equal. The word “resonance” is sometimes used as a synonym for **normal mode,* a usage to be discouraged

restoring force the force that arises when a particle is displaced from its equilibrium position. The name implies that this force has a direction opposite to the displacement, which is true if the equilibrium is “stable”; otherwise, it is “unstable”

resultant total, especially as applied to a **vector* quantity

sampling a “digital computer” operates with data that consists entirely of **bits* (**digital/analog*). Consequently, beginning, say with a microphone signal, the only way to get it into a computer file is to sample it sufficiently frequently so that (a) nothing significant happens between the samples, (b) each sample is recorded in sufficiently many bits to produce the needed accuracy. This number, often called the “sample depth”, is typically 16 bits, which can represent all integers from -32768 to +32767, thus producing a **signal-to-noise ratio* of about 90 **decibels.* As to (a), it can be shown (“Nyquist’s theorem”) that a sampling rate of S samples per second can reproduce a wave form perfectly if it has no **fourier components* higher than S/2 (“Nyquist frequency”);

thus a sampling rate of 44.1 kHz, standard for CD recordings, can reproduce perfectly all frequencies up to about 20 kHz, provided a low-pass filter in the circuit first eliminates all higher frequencies

sawtooth wave a periodic wave each period of which consists of two straight lines: a sloping one going from a negative value to an equal positive value, and a vertical one connecting the end of that line to the beginning of the next period. Sometimes the same term is applied even if the second straight line is not quite vertical

shear modulus **elastic moduli*

shear stiffness**elastic moduli*

signal processing the study of signals, mostly of a digital nature

simple harmonic motion many, many oscillators are characterized by a (possibly generalized) displacement whose square gives rise to a **potenial energy*, and the square of its rate of change gives rise to a **kinetic energy*. The resulting motion, called "simple harmonic", has the shape, when the displacement (or velocity, or acceleration…) is plotted as a function of time, of a **sinusoid* whose frequency is determined by the two coefficients that define the two energies

sinusoid (also known as a "sine wave"), a periodic curve whose fundamental property is that the result of adding two sinusoids of the same frequency, with arbitrary **amplitudes* and **phases,* is still a sinusoid

solid a substance which, unlike a **fluid,* is capable of supporting a shear stress forever. The difference between a true solid and a **glass* may be a matter of time scale on which an experiment is done

sound hole sum rule a rule governing musical instruments (such as a violin) consisting of an almost-closed shell with openings (in the violin's case, *f*-holes) which requires the **monopole moment* to go to zero as the frequency does. Because of the form of a simple proof of this rule, it is also called the "toothpaste rule"

spectrum a collection of characteristic **frequencies,* typically of **normal modes*

square wave a periodic wave that has one constant value for half of the period and the exact negative of that constant value for the remainder of the period

stable equilibrium **restoring force*

steady state a signal is "in a steady state" if it can be described in the **time domain* with parameters that do not change in time. All periodic signals are in steady state, but they are not the only ones: for example, a sine wave ("the carrier") whose amplitude is modulated at a modulation frequency that is incommeasurable with the carrier frequency is in a steady state. A signal that is not in a steady state is in a **transient* state

stiffness moduli **elastic moduli*

strain the change in size and/or shape experienced by an object under **stress.* To specify the strain at a point requires six dimensionless numbers, three of which characterize "longitudinal strain", the remaining three "shear strain"

stress forces applied to a substance that cause it to experience a **strain,* that is, a change in size and/or shape. Stress is specified as a force per unit area. If the force is perpendicular to the area, we are dealing with a "longitudinal stress"; if it is parallel to the area, we are dealing with a "shear stress". To specify the stress at a point completely requires six numbers: three longitudinal stresses and three shear stresses. A substance is called "fluid" if it cannot support a static shear stress, that is, a shear stress that is constant in time (for shear varying in time see **viscosity*). Otherwise, it is called "solid"

text file a type of computer file that is coded directly from a text, with each character occupying a separate sequence of bits. Most commonly, the code that is used is the ASCII code, which (in its most frequent form) allows one **byte* (eight **bits*) for each character. This code allows for 256 different characters, which is enough for not only capital and lower-case letters but also numerals plus a generous number of symbols. On the other hand, if the file content is mostly numerical, a text file is rather wasteful of space; the number 254, for example, takes three bytes of file space in a text file (since it contains three characters), but only one byte in a binary representation (11111110)

time domain to look at a signal "in the time domain" means to express it as a function of time

time function a record of how something varies with time – for example, the sound pressure level at a particular microphone position

toothpaste rule **sound hole sum rule*

torsion twisting of a thin cylinder, as, for example a violin string. The torsional stiffness of a string together with the fact that a twisting string has kinetic energy means that there will be torsional normal modes

transadmittance **mobility*

transcendental number a number which is not a solution of any algebraic equation. The two in most common use are π, the ratio of the circumference of a circle to its diameter, and e, the base of **natural logarithms.*

transconductance **mobility*

transfer function **mobility*

transient a transition from one **steady state* to another. As a signal. a transient can be said to lie neither in the **time domain* nor in the **frequency domain*, but somewhere in between. It typically appears at the signal's beginning or end, when the parameters that determine the steady state are changing in time. Some signals, for example the voltage across a capacitor that has a resistor connected across it, have no steady state (except zero); we can then say that it is all transient (in fact, it is an exponential decay to zero). In spite of examples like that, it *is* possible to express a transient in the frequency domain if we allow a limiting case of an infinite number of sinusoidal components with vanishing frequency spacing (**fourier integral*)

transmobility the velocity attained by one point of a system when a unit sinusoidal force of a certain frequency is applied to another point. Since both quantities are vectors, expressing transmobility as a number, or set of numbers, can be quite complicated, unless one makes simplifying assumptions that are not always correct.

unstable equilibrium **restoring force*

vector a quantity whose magnitude cannot be specified by a single number because it has a direction as well. For example, when we say that (according to Newton's Second Law) the acceleration of a particle is proportional to the (resultant) force acting on it, the claim of that statement is that not just is the magnitude proportional, but the directions of the two quantities (acceleration and resultant force) are the same

velocity in most applications, "velocity" is the same as "speed": the distance covered by a particle in unit time. However, "velocity" emphasizes the directional (**vector*) aspect of the quantity in a way in which "speed" does not. For example, we would say that if a particle moves at 20 miles/hour from point A to point B and then returns at the same speed, then its average speed is 20 miles/hour but its average velocity is zero

viscosity the quality, in principle common to **solids* and **fluids*, that produces a stress proportional to a *rate of change of *strain.* A fluid whose coefficient of viscosity is so large that it acts like a solid for everyday purposes, and yet will flow if you give it enough time, is often called a "glass"

viscous damping **linear damping*

wave a disturbance that propagates through a medium. A sound wave, for example, is a pressure disturbance that moves through air, water, or some other medium (the original meaning of the word refers, of course, to surface waves on water). Although no two types of wave are identical in their mathematical description, they do have enough in common to make wave motion appear and reappear in the most diverse areas of physics

waveform (or waveshape): a graphic or numerical representation of a wave. By extension, *anything* that varies over time in a quantifiable way can be plotted as a waveform – temperature, humidity, the price of gold

wave format (more properly, ".wav format") a method of recording a sampled sound in the type of computer file whose name has the extension ".wav". Such a file is a **binary file* in which the sound **samples* are closely packed. This means that if we are, for example, dealing with 16-**bit* samples, they follow each other without either leaving a space in between or attempting to form themselves into legible strings of **characters.* Thus a sound 10 seconds long, sampled at 19200 samples per second and consisting of samples of 16 bits each would be 3072000 bits, or 384000 **bytes*, long. The actual file would, however, be somewhat longer because there would be a ".wav format header" in the beginning. This header, of a length that can vary but is typically around 40 bytes, identifies the file as a .wav file and lists the various parameters necessary to play it, such as **sample rate*, sample size, number of channels, &c

young's modulus **elastic modulus*