INTRODUCTION TO MATHCAD

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Mathcad is a program that solves equations, graphs functions and does symbolic manipulations. The big advantage of Mathcad is how easy it is to learn and use - especially how easy it is change the value of a parameter and see what happens to all the variables and graphs that depend on it.

BASIC CALCULATIONS

Open up the Arithmetic Palette by double clicking on the calculator icon in the Math Palette. If the Math Palette is not on your desktop then open it from the View Menu.

EXAMPLE 1 - Simple Calculating

$2 + 3 \quad \sqrt{5} =$

1. The square root symbol is on the arithmetic palette
2. When you type the equal sign Mathcad will display the answer just like a regular calculator

EXAMPLE 2 - Variables

x := 5
y := x + 3
y =

1. Press the return after entering each line
2. The symbol := can be obtained by typing a *colon*. It's also on the Arithmetic Palette. In the the first line it tells Mathcad that x is equal to 5 and in the second line it tells Mathcad that y is equal to the expression x+3
3. Typing y and then a "regular" equal sign on the keyboard tells Mathcad to find the value of y
4. If you change the value of x then the value of y will change
5. The placement of equations matters. The equation for y cannot come before you tell Mathcad the value of x. If you do something Mathcad doesn't like then the corresponding equation or variable will turn red.

EXAMPLE 3 - Range Variables I

n := 2, 3 .. 5
2∗n =

1. The first line tells Mathcad that
   a. The first value of n = 2
   b. The second value of n = 3
   c. The difference between consecutive values of n is 3-2 = 1
   d. The last value of n = 5
2. The symbol .. can be obtained by typing a *semicolon*. It's also on the Arithmetic Palette as m..n
3. When you type 2∗n = Mathcad will generate a table of numbers - one for each value of n

EXAMPLE 4 - Range Variables II

a := 1, 1.1 .. 1.3
2∗a =

1. The first line tells Mathcad that
    a. The first value of a = 1
    b. The second value of a = 1.1
    c. The difference between consecutive values of a is 1.1-1 = 0.1
    d. The last value of a = 1.3
2. When you type 2∗a = Mathcad will generate a table of numbers - one for each value of a

EXAMPLE 5 - Functions

x := 0, 0.1 . . 0.5
y(x) := 2∗x
y(x) =

1. Mathcad evaluates the function y(x) for every value of x
2. Note that Mathcad won't accept y := 2∗x when x is a range variable

EXAMPLE 6 - Subscripted Variables

n := 0, 1 . . 5
$y_n := 2*n$
$y_n =$

1. The subscripted variable is from the Calculator Palette
2. The subscripts n must be positive integers with n ≥ 0

EXAMPLE 7 - Summations I

$$y := \sum_{n=0}^{3} n^2$$

y =

1. The summation sign is from the Calculus Palette

EXAMPLE 8 - Summations II

a := 0, 1 . . 3

$$y(a) := \sum_{n=0}^{3} a \quad n^2$$

y(a) =

1. The summation will be calculated for each value of a

EXAMPLE 9 - Vectors and Matrices I

$$X := \begin{bmatrix} 1 \\ 3 \\ 5 \end{bmatrix}$$

Y := 2∗X
Y =

1. Create the 3x1 vector by first clicking on the the icon in the upper left hand corner of the Vector and Matrix Palette and then entering the number of rows and columns.
2. Matrices (arrays) are particularly nice for storing data points

EXAMPLE 10 - Vectors and Matrices II

$$X := \begin{bmatrix} 1 \\ 3 \\ 5 \end{bmatrix}$$

a := 2∗X_0
b := 3∗X_1
c := 4∗X_2
a = b = c =

1. The elements in the vector X are subscripted variables as follows

   $X_0 = 1$ $X_1 = 3$ $X_2 = 5$

   with subscripts $n \geq 0$

EXAMPLE 11 - Complex Numbers

z := 1j*(1 + 1j)
real := Re(z)
imaginary := Im(z)
r := |z|
θ := arg(z)
α := arg(1 + 1j*2)
φ := angle(1, 2)

1. Type 1j for the imaginary number j and 1i for the imaginary number i
2. The absolute value or magnitude operator | | is from the Arithmetic Palette
3. Arg(z) is the angle of the complex number z in radians
4. Arg(1 + 1j*2) is the angle of the complex number 1 + j2 in radians
5. Angle(1, 2) is the angle of the complex number 1 + j2 with real part 1 and imaginary part 2
6. You can tell Mathcad to display answers in terms of j from the *Format Menu* by selecting *Result* and then *Display Options*

EXAMPLE 12 - Phasors and Transfer Functions

ω := 1000

$$Vs := 2\ \ e^{1j\ \ 1.2}$$

$$G(\omega) := \frac{1000}{1j\ \ \omega + 1000}$$

Vo(ω) := G(ω)∗Vs

|Vo(ω)| = arg (Vo(ω)) =

1. ω is on the palette of Greek symbols
2. Note that we write G(ω) and Vo(ω) as functions of ω (not jω)

EXAMPLE 13 - Integration

$$a := \int_0^{0.001} 2 \cdot t \cdot \sin(t)\,dt \qquad \text{TOL} := 0.00001$$

$a =$

1. The integral sign is from the Calculus Palette
2. The accuracy of the integral can in general be improved by making TOL smaller. Note that the nominal value of TOL is 0.001 as shown in *options* under the Math Menu.

EXAMPLE 14 - The Sinc Function

x := -0.5, -0.4 . . 0.5

$$\text{sinc}(x) := \left|\begin{array}{ll} 1 & \text{if } x = 0 \\ \dfrac{\sin(\pi \cdot x)}{\pi \cdot x} & \text{otherwise} \end{array}\right.$$

$\text{sinc}(x) =$

1. We have to tell Mathcad the value of the sinc function at x = 0 because when x = 0 the denominator of the function is equal to zero
2. In the equation for sinc(x)
   a. The vertical line is obtained by clicking on *add line* in the Programming Palette
   b. *if* and *otherwise* are from the Programming Palette
   c. The bold equal sign in the equation **x = 0** is from the Evaluation and Boolean Palette

EXAMPLE 15 - Fourier Series of a Sawtooth

k := 1, 2 . . 5

$T := 4 \qquad \omega o = \dfrac{2\pi}{T}$

x(t) := 3∗t

$$ao := \frac{1}{T}\int_0^T x(t)\,dt \qquad co := ao$$

$$a_k := \frac{2}{T}\int_0^T x(t)\cos(k \cdot \omega_o \cdot t)\,dt \qquad b_k := \frac{2}{T}\int_0^T x(t)\sin(k \cdot \omega_o \cdot t)\,dt$$

$$c_k := \sqrt{(a_k)^2 + (b_k)^2} \qquad \theta_k := \text{angle}(a_k, -b_k)$$

1. Use *angle* instead of *atan* because *atan* is only defined in the range $-\pi/2$ to $\pi/2$

EXAMPLE 16 - Difference Equations

n := 0, 1 . . 5

$y_{-1} := 0$

$y_n := 0.5 * y_{n-1} + 1$

$y_n =$

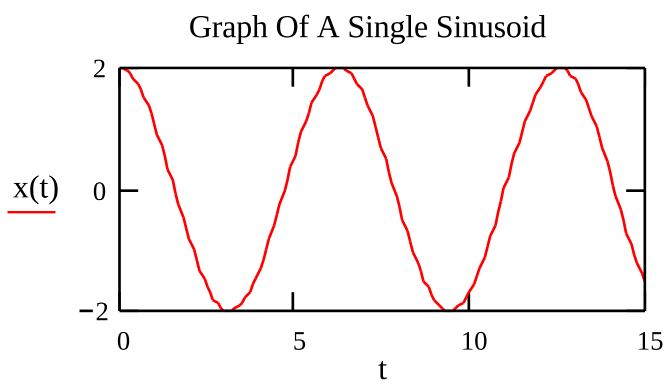
1. For these equations to work you first need to go to *Options* in the *Math Menu* and change the origin to –1

BASIC GRAPHING

Open up the Graphing Palette by double clicking on the corresponding icon in the Math Palette.

EXAMPLE 1 - Graphing of a Function

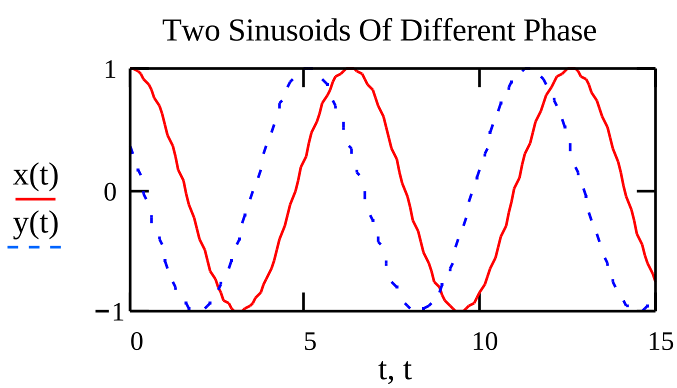
t := 0, 0.1 . . 15
x(t) := 2*cos (t + 1.2)



1. To obtain the graph of x(t)
   a. Click on the x-y plot icon in the Graphing Palette
   b. Use the tab to move from one location to another as you type the parameters x(t), t, . . .
   c. Click anywhere outside the frame of the graph
   d. You can now go in and change the values over which t and x(t) are plotted
2. Resize a graph by first selecting it and then holding down the mouse button as you drag along one of the highlighted dots
3. Change the *format* of a graph by first double clicking on it. You can then change its color, choose solid or dashed lines and so on. You can also change the title by clicking on *labels*

EXAMPLE 2 - Graphing Two Functions I

t := 0, 0.1 . . 15
x(t) := cos (t)
y(t) := cos (t + 1.2)



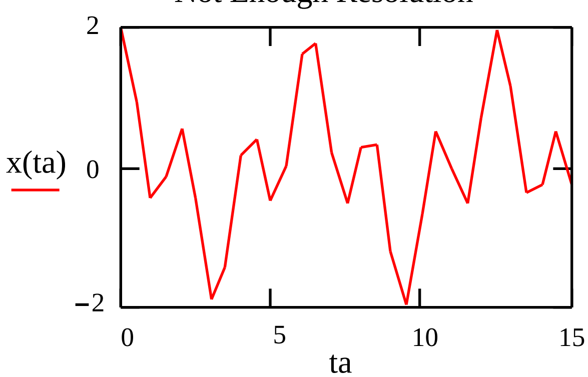
1. To graph both x(t) and y(t) on the same graph
   a. Type x(t), y(t) with a comma between the functions
   b. Click on the x-y plot icon in the Graphing Palette
   c. Click anywhere outside the frame of the graph

EXAMPLE 3 - Graphing Two Functions II

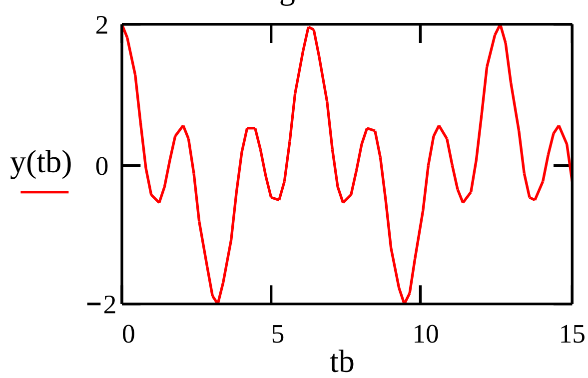
ta := 0, 0.5 .. 15
x(ta) = cos(ta) + cos (3*ta)

tb := 0, 0.2 .. 15
y(tb) = cos(tb) + cos (3*tb)

Not Enough Resolution



Enough Resolution



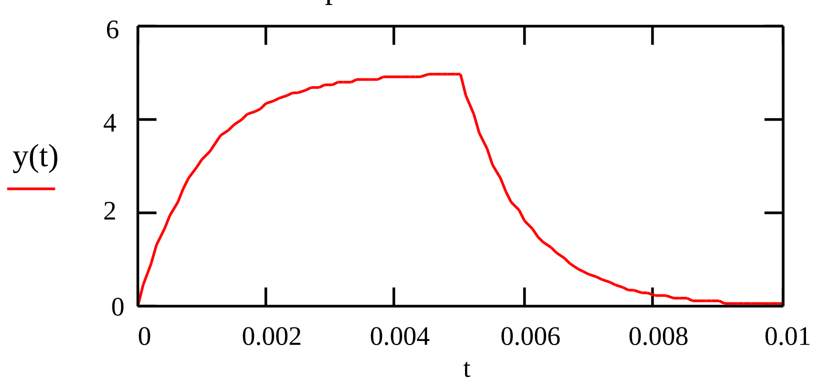
1. From these two graphs we see that y(t) is better than x(t) because its resolution - the time between successive values of t - is small enough for us to see the true affect of the higher frequency sinusoid.
2. Also note that the total time interval must be long enough for us to see at least one full cycle of the lower frequency sinusoid.

EXAMPLE 4 - Pulse Response Of A First Order Circuit

t := 0, 0.0001 .. 0.01

$$y(t) := \begin{cases} \left(5 - 5\ e^{-1000*t}\right) & \text{if } 0 \le t \le 0.0005 \\ 5\ e^{-1000*(t-0.005)} & \text{otherwise} \end{cases}$$

Pulse Response Of A First Order Circuit

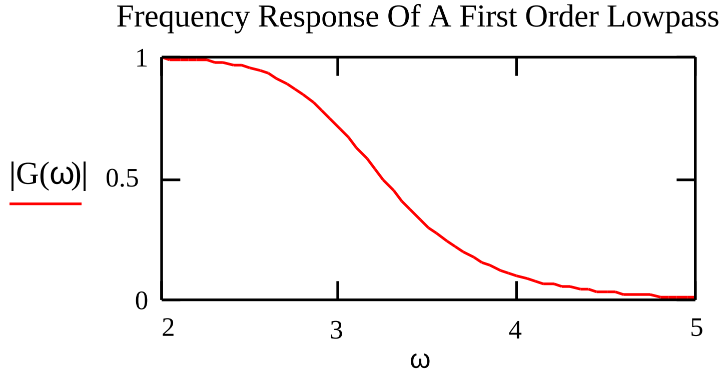


1. Note that the pulse width is a = 5 msec.

EXAMPLE 5 - Frequency Responses With Frequency Plotted on a Log Scale

$\omega := 2, 2.05 \,..\, 5$

$$G(\omega) := \frac{1000}{1j \quad 10^{\omega} + 1000}$$



1. The magnitude operator | | is from the Arithmetic Palette
2. The frequency variable 10^{ω} gives us $|G(\omega)|$ versus ω on a log scale from 10^2 to 10^5

EXAMPLE 6 - Fourier Series of a Pulse Train

$k := 0, 1 \,..\, 5 \qquad t := 0, 0.1 \,..\, 10 \qquad TOL := 0.0001$

$T := 4 \qquad \omega o = \frac{2\pi}{T}$

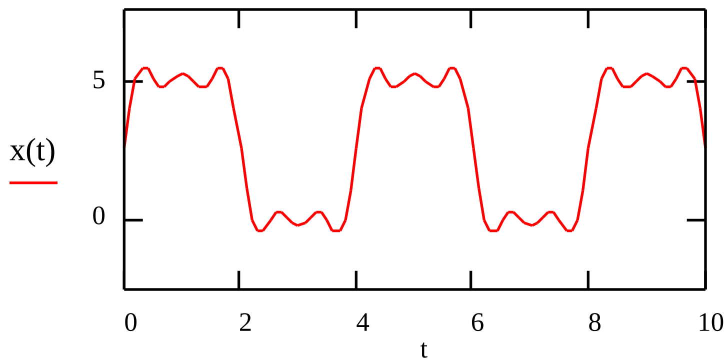
$$x(t) := \begin{vmatrix} 5 & \text{if } 0 \le t \le 2 \\ 0 & \text{otherwise} \end{vmatrix}$$

$$a_k := \begin{vmatrix} \frac{1}{T}\int_0^T x(t)dt & \text{if } k = 0 \\ \frac{2}{T}\int_0^T x(t) \quad \cos(k \quad \omega o \quad t)\,dt & \text{otherwise} \end{vmatrix} \qquad b_k := \frac{2}{T}\int_0^T x(t) \quad \sin(k \quad \omega o \quad t)dt$$

$$c_k := \sqrt{(a_k)^2 + (b_k)^2} \qquad \theta_k := \text{angle}(a_k, -b_k)$$

$$x(t) := c_o + \sum_{k=1}^{5} c_k \cos(k \quad \omega o \quad t + \theta_k)$$

Sum Of The First Five Harmonics Of A Pulse Train



1. Note that the pulse train has a period of T = 4 and pulse width a = 2

EXAMPLE 7 - Fourier Series Frequency Domain Analysis

N := 20   k := 0, 1 . . N   t := 0, 0.0001 . . 0.01   TOL := 0.0001

T := 0.01 $\omega o = \frac{2\pi}{T}$ ω3dB := 1000

$$x(t) := \begin{cases} 5 & \text{if } 0 \le t \le 0.005 \\ 0 & \text{otherwise} \end{cases}$$

$$a_k := \begin{cases} \frac{1}{T}\int_0^T x(t)\,dt & \text{if } k = 0 \\ \frac{2}{T}\int_0^T x(t)\cos(k\;\omega o\;t)\,dt & \text{otherwise} \end{cases}$$

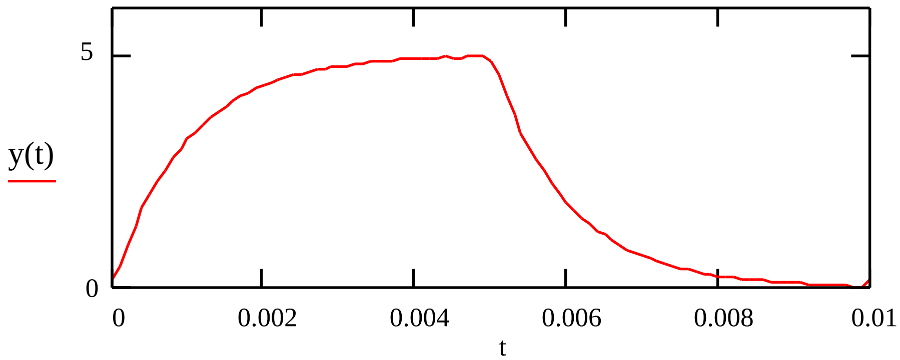
$$b_k := \frac{2}{T}\int_0^T x(t)\sin(k\;\omega o\;t)\,dt$$

$$c_k := \sqrt{(a_k)^2 + (b_k)^2} \qquad \theta_k := \text{angle}(a_k, -b_k)$$

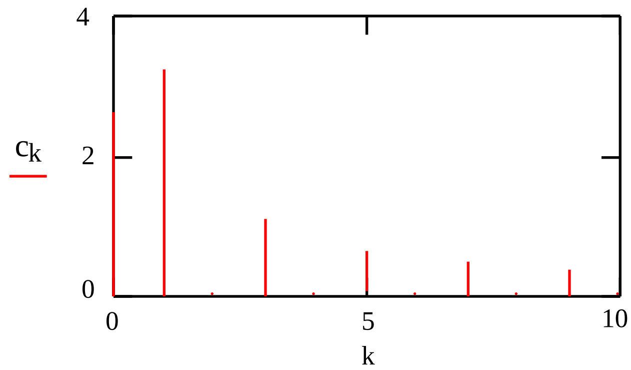
$$G(k) := \frac{\omega 3dB}{1j\;k\;\omega o + \omega 3dB}$$

$$y(t) := c_o\;G(0) + \sum_{k=1}^{N} c_k\;|G(k)|\;\cos(k\;\omega o\;t + \theta_k + \arg(G(k)))$$

Steady State Response To The Pulse Train x(t)



Spectral Plot of The First Harmonics of x(t)



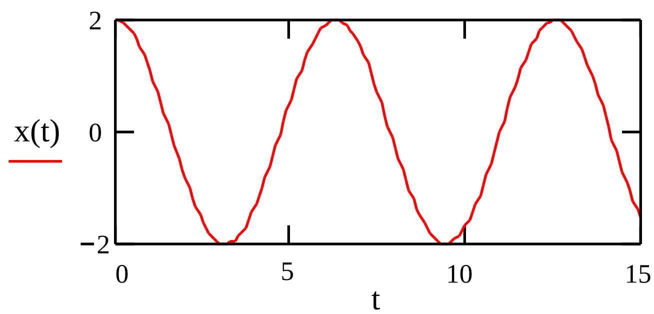
1. The input is a pulse train with period T = 10 msec and pulse width a = 5 msec. The circuit is a first order lowpass with ω_{3dB} = 1000 rad/sec. Note that y(t) is the steady state response.
2. Obtain the lines for the discrete signal y(n) by double clicking on the graph and choosing *stem* from the Type Menu

EXAMPLE 8 - Complex Exponentials

t := 0, 0.1 . . 15

$x(t) := e^{1j \cdot t} + e^{-1j \cdot t}$

Sinusoid Equal To The Sum of Two Complex Exponentials



1. The exponential function is from the Arithmetic Palette

EXAMPLE 9 - Frequency Domain Analysis With Complex Exponentials

N := 20 k := -N, -N+1 . . N t := 0, 0.0001 . . 0.01 TOL := 0.0001

T := 0.01 $\omega o = \frac{2\pi}{T}$ ω3dB := 1000

$$x(t) := \begin{vmatrix} 5 & \text{if } 0 \le t \le 0.005 \\ 0 & \text{otherwise} \end{vmatrix}$$

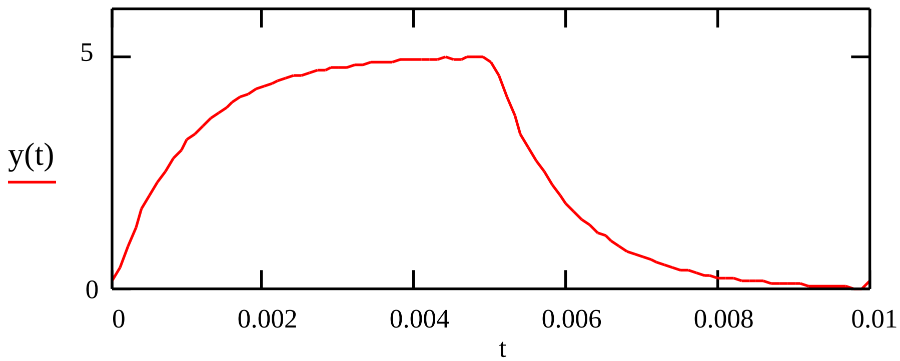
$$X(k) := \frac{1}{T} \int_0^T x(t) \; e^{-j\,k\,\omega o\,t} dt$$

$$G(k) := \frac{\omega 3dB}{1j \cdot k \cdot \omega o + \omega 3dB}$$

$$Y(k) := G(k) \cdot X(k)$$

$$y(t) := \sum_{k=-N}^{N} Y(k) \cdot e^{j \cdot k \cdot \omega o \cdot t}$$

Steady State Response To The Pulse Train x(t)



1. The input is a pulse train with period T = 10 msec and pulse width a = 5 msec. The circuit is a first order lowpass with ω_{3dB} = 1000 rad/sec. y(t) is the steady state response.
2. Note that the complex calculations may take your computer a minute or two to plot the graph - depending on your computer.

EXAMPLE 10 - Difference Equations

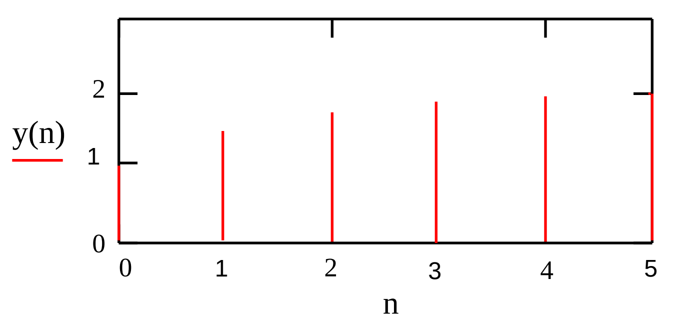
n := 0, 1 . . 5

$y_{-1} := 0$

$y_n := 0.5 * y_{n-1} + 1$

$y_n =$

Discrete Response Of The Difference Equation



1. For these equations to work you first need to go to *Options* in the *Math Menu* and change the origin to –1
2. Obtain the lines for the discrete signal y(n) by double clicking on the graph and choosing *stem* from the Type Menu
3. Remove the circles at the tops of the lines by selecting *none* from the symbol menu.