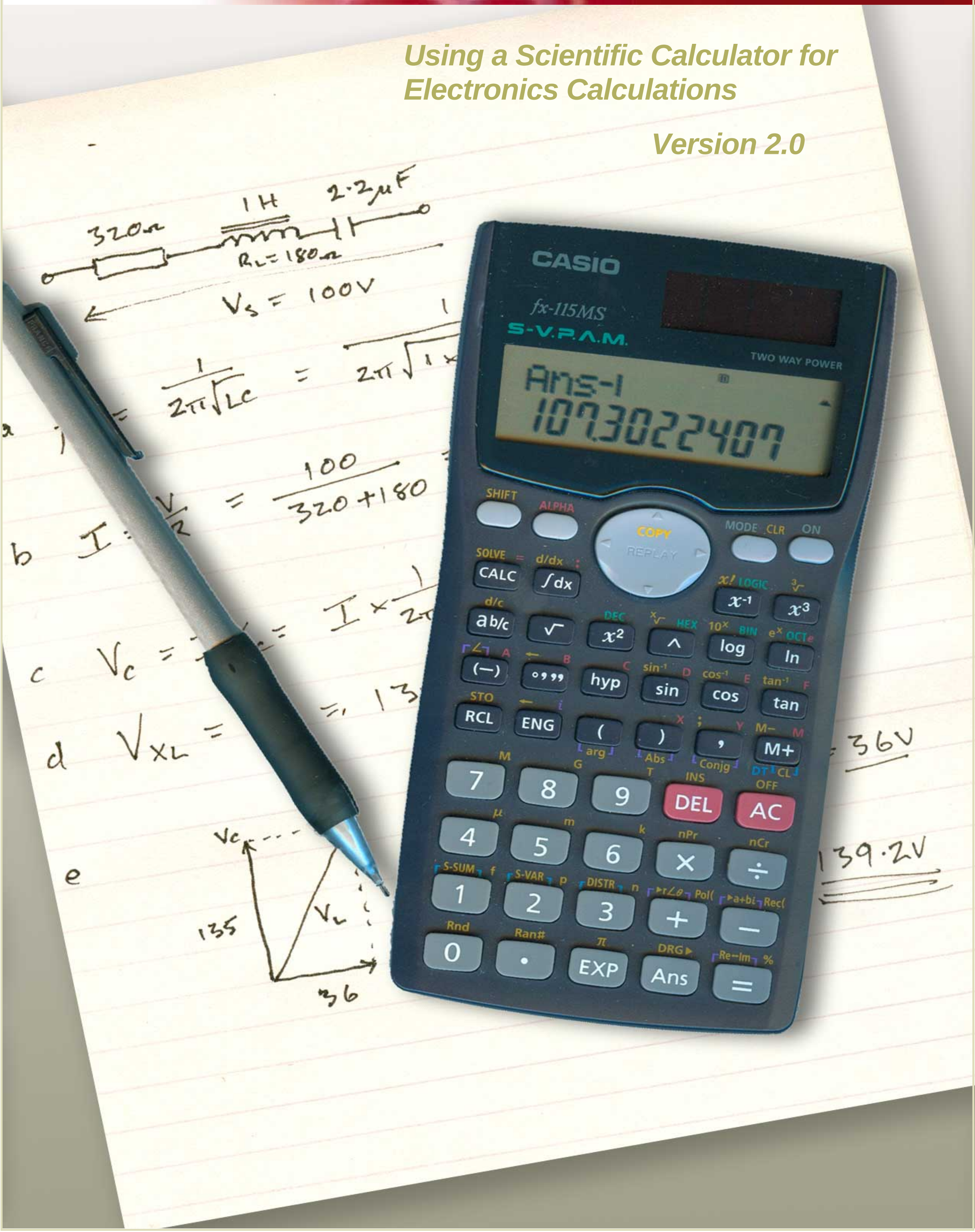
Learnabout Electronics
Maths Tips

Using a Scientific Calculator for Electronics Calculations

Version 2.0



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This booklet will explain…

- Things to look for when buying an electronic calculator for electronics.
- Powers of ten and express numerical values for units in standard form for multiples and submultiples
- The use of SI prefixes with electrical units:
  - mega
  - kilo
  - milli
  - micro
  - nano
  - pico
- The relationships between quantities:
  - V=IR
  - P=IV etc
  - W=Pt
- Decimal places, significant figures, squares, ratios, and averages
- Transposing basic electronics formulae for calculations.
- Basic Trigonometry

Contents

Introduction.

Electronics, like most other branches of science and technology involves mathematics. Some of the maths used for electronics calculations are very complex. This does not mean however, that in electronics servicing there is a need to get too involved with complex mathematical problems.

The reason for this is that, unlike electronics design engineers, the problems facing SERVICING personnel are with circuits and equipment that have already been designed and built, and which have been working properly. The maths has already been done and so doesn't really concern the servicing technician. What is chiefly necessary is to understand electronics circuits, their components and the basic principles that make them work.

To properly understand circuits and their principles a certain amount of calculation is needed, this basic guide will therefore concentrate on examples of mathematical calculations necessary for electronics servicing, and in particular the use of scientific calculators in solving these problems.

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Buying a scientific calculator.

Calculations in electronics need a scientific calculator, not the one on your mobile phone or your digital watch! There are many types to choose from so here are a few tips to help you choose the right model.

Don't spend too much! There are many suitable scientific calculators and prices range from quite cheap to "Forget it!" Remember, spending too much simply buys extra functions you won't use. Generally, for the maths you need for electronics servicing or anything other than advanced electronics, you won't need a top of the range calculator:

Calculators with QWERTY (typewriter style) keyboards and DATA BANK models.

If you are planning to take formal exams, you will find that many examining bodies ban their use in exams and they are far more complex than you need.

Programmable models and palmtop computers.

You will find that you will spend more time learning to program the calculator than it would take to do the calculation with a much simpler model.

Graphical display models and phone apps.

You will mainly use it to show off to your friends.

Functions to look for:

Whatever you use, your calculator **should have** these keys:

EXP or EE (exponent key)

ENG (engineering notation)

x^2 (square)

$\sqrt{x}$ (square root)

$\frac{1}{x}$ or x^{-1} (reciprocal)

x^y or y^x (powers)

log & ln (logarithms)

sin cos tan (trigonometrical functions)

In addition it will be helpful if your calculator will accept numbers in number systems such as;

BIN OCT HEX (Binary - Octal - Hexadecimal)

All these features and more are found on inexpensive scientific calculators. If you are not sure what to buy for use on a particular electronics course, your tutor will be happy to give you advice - just ask.

Decimal Numbers.

Decimal numbers are very familiar in everyday life. They are used to express most of the quantities in everyday use. Money, ages, street numbers, weight and quantities are all expressed in decimal numbers. A decimal number is written in COLUMNS, each column having a value that is a multiple of TEN e.g.

15 is a decimal number which means 1 TEN & 5 UNITS

124 means 1 HUNDRED + 2 TENS + 4 UNITS

The right hand most figure is called the LEAST SIGNIFICANT FIGURE because it has the smallest value, and the left hand most figure the MOST SIGNIFICANT FIGURE because it has the largest value

MOST SIGNIFICANT FIGURE >1 2 4< LEAST SIGNIFICANT FIGURE

Fractions can be expressed using decimal numbers, by placing a decimal point . between the whole number part (called the INTEGER) and the fractional part (called the FRACTION) of a number

56.25

Means; **5 TENS + 6 UNITS** *Integer* **+** . **2 TENTHS + 5 HUNDREDTHS** *Fraction*

Decimal point

Powers of Ten.

The figures to the LEFT of the decimal point represent increasing powers of ten, moving column by column left from the decimal point, for example,

1456.00

can be written as a series of powers of ten, so 1456 can be written as:

$(1 \times 10^3) + (4 \times 10^2) + (5 \times 10^1) + (6 \times 10^0)$

Although this may seem a laborious way to write a number, the idea of using powers of ten is extremely useful. So much so that calculators have a special key that helps in entering numbers this way. More about this later, but firstly it is important to understand what these powers of ten mean;

10^3 means 10 x 10 x 10 (10 multiplied by itself 3 times) i.e. 1000 (1 followed by 3 noughts)

10^2 means 10 x 10 (10 multiplied by itself 2 times)

i.e. 100 (1 followed by 2 noughts) etc.

Therefore 1456.00 is;

(1 x 1000) + (4 x 100) + (5 x 10) + (6 x 1)

Writing the fractional part of a number can be carried out in a similar way, but this time the powers of ten have NEGATIVE values.

00.256 can be written

$(2 \times 10^{-1}) + (5 \times 10^{-2}) + (6 \times 10^{-3})$

Where 10^{-1} means 1/10 10^{-2} means 1/100 10^{-3} means 1/1000 etc.

WHY use this method of writing numbers? Well, electronics uses a very wide range of numbers. Some radio frequencies may have values of many millions of Hertz (the standard unit of frequency)

e.g. 500,000,000 Hz

While the values of some components may be expressed in very small numbers. A capacitor could have a value of only a few millionths of a millionth of a FARAD (the standard unit of capacitance)

e.g. 0.0000000000047 Farad

To avoid having to read or write these very long numbers, they can simply be written as powers of ten.

Number	Written as;
1,000,000	10^{6}
100,000	10^{5}
10,000	10^{4}
1,000	10^{3}
100	10^{2}
10	10^{1}
1	10^{0}
1/10	10^{-1}
1/100	10^{-2}
1/1,000	10^{-3}
1/10,000	10^{-4}
1/100,000	10^{-5}
1/1,000,000	10^{-6}
1/1,000,000,000	10^{-9}
1/1,000,000,000,000	10^{-12}

Using this system,

0.000005 becomes 5×10^{-6}

and

500,000 becomes 5×10^{5}

Using very small, or very large numbers such as these is made much easier by using a scientific calculator. A typical calculator keypad has a key marked

EXP or **EE**

This key is used to avoid having to key in " x 10 " every time.

For example, the number 500,000 or 5 x 10^5 is entered by pressing just three keys;

5 **EXP** **5** or **5** **EE** **5**

The display will normally show something like -

5^{05} or 5_E5 (different models may have slightly different displays)

Note that this is 5 **x 10^5** (5 followed by 5 zeros) and NOT 5^5 (5 x 5 x 5 x 5 x 5)

0.0000047 (4.7 millionths) would be entered as

4 **.** **7** **EE** **+/-** **6**

Note the use of the +/- key (change sign key) on the calculator when to a NEGATIVE POWER of ten is required.

(N.B. some calculators use different versions of the change sign key. For example (-) or even just -. Consult your calculator instructions for more information.)

When correctly entered, our display should show something like; **4.7^{-06} or 4.7E - 6**

Standard Form.

Electronics quantities need to use powers of ten (or EXPONENTS as they are called) with standard electrical units such as the OHM, the AMPERE etc. These units however, are normally using a system of **standard prefixes**.
For example the standard prefix for 1000 volts is 1 **kilo**volt.

The following table lists some of the common prefixes used in standard electrical units. Their names usually derive from a suitable Greek or Latin word. Note that it is **very important** to use the correct capital or lower case letter when using the abbreviated version of these units. For example, M means mega- (a million) whilst m means milli- (one thousandth). If the result of an otherwise correct calculation simply used M instead of m in the answer, it would be not just be wrong - it would be 1,000,000,000 times bigger than it should be! Because of the enormous range of sizes of electrical units this apparently stupid answer could also be mistaken for a correct answer. BE CAREFUL! Such mistakes do happen and have been known to kill people!

MULTIPLIER	POWER	PREFIX	ABBREVIATION
1,000,000,000,000	10^{12}	TERA-	T
1,000,000,000	10^9	GIGA-	G
1,000,000	10^6	MEGA-	M
1,000	10^3	kilo-	k
1/1,000	10^{-3}	milli-	m
1/1,000,000	10^{-6}	micro-	µ
1/1,000,000,000	10^{-9}	nano-	n
1/1,000,000,000,000	10^{-12}	pico-	p

The standard abbreviations used in electronics for units and sub units change in multiples of 1000, i.e. nano is 1000 times bigger than pico, and mega is 1000 times bigger than kilo etc. There are no standard abbreviations for 10^4 for example. This means that the **number** of units described in this way will always be between 1 and 999.

For example if in describing current in a circuit (basic unit AMPERES), if there are 1500 milli-amperes, this is not written as 1500mA but 1.5A. 1500 is not between 1 & 999 so Amperes(A) is a better unit.

This may seem tedious to start with but using standard units does pay off, especially when making calculations from instrument readings. Real instruments use these standard abbreviations all the time.

On a scientific calculator, an answer may be something like 5×10^4 , which does not fit the scheme of standard units. However another short cut button is available on many scientific calculators. This is a key marked ENG (Engineering notation) and an essential for electronics.

ENG

This button is usually accompanied by additional "arrow" functions

sometimes **←ENG** or two keys **ENG→** and **←ENG**

These keys can be used to convert your answer into an appropriate standard abbreviation (kilo micro etc).

Try entering the number 5×10^4 into your calculator and using the ENG keys to put it into STANDARD FORM as the use of these engineering prefixes is called.

Key; 5 EXP 4 **5** **EXP** **4**

The calculator display should read

$5.^{04}$ or 5E4

Now press one of your ENG keys. You should see the display convert to standard form and show either

$50.^{03}$ or 0.05^{06}
(You may need to press = before the ENG key will affect the display)

It would be preferable for the answer to be between 1 & 999, therefore

$50.^{03}$ i.e. 50 milli- would be preferable to 0.05^{06}

So, when the calculator displays something like

0.05^{04}

as an answer, this is not a problem - just pressing the ENG converts the answer to engineering format and the arrow functions associated with the ENG key can be used to select a more appropriate unit (e.g. change milli to micro) if required. Notice how the calculator adjusts the value of the answer by a factor of 1000 at each press of the arrow ENG key to match the abbreviation selected. Some calculators have two arrow keys for up or down conversion or the added luxury of displaying the appropriate symbol (μ, m, k, M etc).

When using formulae to calculate results in electronics, the formulae given in books and manuals (and on websites) are designed to use the **basic units** for the quantities involved, i.e. Volts Amperes etc. To make sure the right result is achieved by the calculation, it is important that the quantities entered into the formula are entered in BASIC UNITS and not the multiples or sub-multiples such as kilovolts or milli-amperes that may be required in results.

Often however, the available data to be used for a calculation is already in multiples or sub-multiples of the basic units. Entering data as a sub multiple when it should be a basic unit can easily lead to mistakes give an answer thousands of times too big or too small. For example V = IR requires the data be entered as Amperes and Ohms to get a result in Volts, if the available current value is 500mA and this is entered as 500, this will be recognised as 500 Amperes not of 500 mA! This will have disastrous results in the final answer. The entry must therefore be 0.5 Amperes, not 500.

However, if Standard Form is used to enter data, all will be well without having to perform any complicated conversions. All that is needed is a little care. Take the following problem as an example.

A resistor passes a current of 100μA. What is the resistance of this component, if the voltage across the resistor is 3V?

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

A suitable formula to use is;

Notice that the current is given in micro-amperes (μA). Now from the table on the previous page μ means 1/1000,000 so 100(μA means 0.000001 x 100 = 0.0001A

The formula needs the current to be in Amperes, not μA so it would seem necessary to convert μA to A, but there is really no need if standard form is used.

Voltage is given in Volts, which are already are basic units so they can be entered directly.

$$R = \frac{3}{100x10^{-6}}$$

The method for entering the values into the is formula as follows:
and to find the value of the resistance using the calculator, the data is entered as:

3 ÷100 EXP +/-6 =

3 **÷** **1** **0** **0** **EXP** **+/-** **6** **=**

EXP means the Exponent Key and +/- means the change sign key)

and the answer comes up as; 30000

As the standard unit for resistance is the Ohm so the answer must be 30,000 Ohms

To show the answer in its correct standard form, the ENG key is now pressed to put 30000 Ohms into standard form. One press on the appropriate ENG key changes the display to;

30. ^{03}

Which means 30 x 10^3. If your calculator doesn't display the appropriate ohms prefix you can find it from the table below, shows (in the red cell) that for this answer 30. ^{03} means

30 kilohms (30 kΩ)

SI Units with multiples and sub-multiples commonly encountered in electronics.

	QUANTITY	UNIT	SUB-DIVISIONS				UNIT	MULTIPLES		
			Unit x 10^{-12}	Unit x 10^{-9}	Unit x 10^{-6}	Unit x 10^{-3}	Unit	Unit x 10^{3}	Unit x 10^{6}	Unit x 10^{9}
C	Capacitance	farads	pF	nF	μF		**F**			
E	Voltage Source	volts			μV	mV	**V**	kV		
f	Frequency	hertz					**Hz**	kHz	MHz	GHz
G	Conductance	siemens				mS	**S**			
I	Current	amps			μA	mA	**A**			
L	Inductance	henrys			μH	mH	**H**			
P	Power	watts				mW	**W**	kW		
Q	Charge	coulombs			μC	mC	**C**			
R	Resistance	ohms				mΩ	**Ω**	kΩ	MΩ	
T	Time Constant	seconds		ns	μs	ms	**s**			
t	Time (instantaneous)	seconds		ns	μs	ms	**s**			
V	Voltage Drop	volts			μV	mV	**V**	kV		
X	Reactance	ohms				mΩ	**Ω**	kΩ	MΩ	
Z	Impedance	ohms				mΩ	**Ω**	kΩ	MΩ	

Remember:

When using formulae to calculate any of these quantities, always convert the known quantities you are using into their standard units.

Enter any multiples (e.g. 30 kiloHertz as 30 x 10^3 Hz or 25milli-volts as 20 x 10^{-3} V)

Notice in the table that multiples (except k) are written as capitals, and sub-multiples as lower case.

Significant Figures.

Sometimes the results of calculations produce more digits after the decimal point than are needed for a realistic level of accuracy. When this happens, the result may need rounding off. For example,

15.627654 can be rounded to give an approximate answer of 15.628

This is still accurate to the nearest 1/1000th

Notice that if the result had been 15.627454 the answer would be rounded **down** to

15.627

The digit after the seven is 4 (less than 5) so the answer is **rounded down**. If the first discarded digit is more than 5 the answer is **rounded up**. If the first discarded digit is 5, it doesn't matter which way the answer is rounded, it will still be just as accurate.

Note: When a long answer is an intermediate result that is going to be used as part of some further calculation, i.e. part way through a problem, try to avoid rounding off at this point, save it until the final answer. Sometimes the error introduced by rounding off by a small amount can get much bigger if further operations, such as multiplying using a rounded number. This is sometimes difficult to avoid, and then errors will creep into the final answer.

However, many of the answers to electronics calculations will be to find the value of an actual component, which are typically only available in certain "preferred values" (33, 47, 56 etc.)

Also components are subject to variation in value due to "tolerance values", so realistically some approximation of results will not affect a practical outcome regarding component values..

Generally the number of "significant figures", (the number of digits after the decimal point) will depend on the units being used. When using units in multiples of 1000 (pA, μA mA etc.) it is convenient to restrict the number of decimal places (significant figures) to no more than three. This gives an accuracy of 1/1000th (the full range) of the unit being used. Often however two decimal places are sufficient, when practical measurement to such accuracy is unlikely in a given application. For example, it is unlikely that the mains (line) voltage of 110 or 230VAC would need to be measured to an accuracy of +/- 1/1000th of a Volt, so there is little point in this case of quoting an answer as 229.927V

Squared Numbers.

When a number is said to be "squared" this means that it is simply multiplied by itself. For example 3^2 is the same as saying 3 x 3, which of course equals 9.
Squared numbers are often used in electronics calculations, such as when using the formula $\mathbf{P=I^2R}$ for power (P) using only current (I) and resistance (R).

It is tempting at first to type into your calculator 3 x 3 instead of 3^2 but the calculator has a special key for calculating the square of any number. USE IT! Whilst it may be simple to work out 3 x 3 but when a calculation requires $(157 \times 10^{-6})^2$ the value of the x^2 button becomes apparent.

The x simply means "the number on the display" so pressing x^2 simply squares whatever number is currently on the display.

Simply enter any number and then immediately press x^2 just as you would write the number in an equation. How the value of the squared number is displayed varies between calculators, but a number to be squared, entered in this way will generally be accepted in a calculation. Play with the x^2 button and some simple numbers to get used to how the calculator uses the number.

Reciprocals.

X^{-1}

Don't confuse the x^2 button with x^{-1}, this key provides a different and useful function. Many formulae in electronics use reciprocals; that is 1 over a certain value, as in

$$\textbf{frequency } f = \frac{1}{\textbf{periodic time T}} \qquad \textbf{or } f = \frac{1}{T}$$

If the periodic time (the time in seconds for one complete cycle of a wave) is known or can be measured, then the frequency of that wave (a more useful value) can be simply calculated by entering the periodic time into the calculator and pressing the x^{-1} key. The many electronics formulae that use the reciprocal in some form make this key a particularly useful one.

Ratios.

Ratios are also commonly used in electronics. A ratio is a measure of how many times bigger one thing is than another. For example the signal at the output of an amplifier may be 100 times bigger than the signal at the input. We say that the amplifier has an amplification ratio of 100:1. The colon (:) meant "to".
Any two numbers may be related to each other as a ratio; the number 5 is bigger than the number 1 by a ratio of 5:1. Also 4 is bigger than 2 by a ratio of 2:1

Note that it is usual to express a ratio as something to one. Sometimes however neither number is 1. When this happens, the ratio, can still be expressed as something to one, using the following technique.

To express a ratio such as 15:6 as "something to one" just divide 15 by 6 (15/6), this gives the answer 2.5, so this ratio can be expressed as

2.5:1

If the ratio is something like 6:15 this technique still works. Just divide 6 by 15 (6/15) which gives 0.4 The ratio 6:15 is the same as

0.4:1

Because ratios simply compare two values, they do not have any units (such as volts or ohms).

Averages.

To find the average of a range of values all the numbers are added together and the result is then divided by the number of values in the range, e.g.

Find the average of the following range of voltage readings;

2.3V+ 6.5V + 3.7V + 4.2V + 7.0V +1.5V = 25.2 ÷6 (values in range) = **4.2V**

Notice that it is quite likely that the average may be a value that does equal any of the numbers in the range but gives a new value, which can fall somewhere between any two of the values.

Trigonometry.

Trigonometry is the measurement of triangles and is very useful in calculations of values in phasor diagrams.

Basic Trigonometry is used for finding angles, and the lengths of sides of triangles. In phasor diagrams the angles will be angles of phase difference between two sine waves, and the lengths of phasors (the sides of the triangle) will be values of voltage, current, reactance etc.

Three trigonometric functions are used, sine (shortened to sin) cosine (cos) and tangent (tan) together with their inverse functions $\sin^{-1}$ $\cos^{-1}$ and $\tan^{-1}$

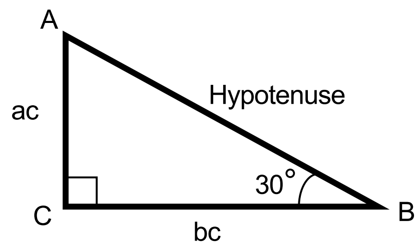
sin cos and tan can be used to find the lengths of sides (or phasor values)

$\sin^{-1}$ $\cos^{-1}$ and $\tan^{-1}$ are useful for finding angles.

Finding unknown sides.

The sides of triangles are given names in trigonometry; the longest side of a triangle is always called the hypotenuse, but the names given to the remaining two sides depend on which angle has a known value.

In the triangle on the right, the angle B has a given value and so the side ac, opposite the angle is named the OPPOSITE side. Side bc, being next to the angle (and not being the hypotenuse) is named the ADJACENT side. By this system, if angle A were the known value, bc would be the opposite, and ac the adjacent side.

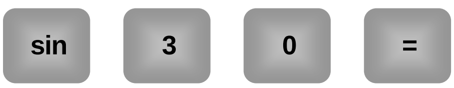


There are three possible choices of formula that may be used to find the length of an unknown side, depending on which combination of sides and angles are already known. If the known angle to be used is called θ (theta) then:

$$\sin\theta = \frac{opp}{hyp} \qquad \cos\theta = \frac{adj}{hyp} \qquad \tan\theta = \frac{opp}{adj}$$

The acronym **SOH CAH TOA** is often quoted as a useful way to remember the three formulae, although there are many others all over the Internet (of increasing - or decreasing silliness, depending on your point of view).

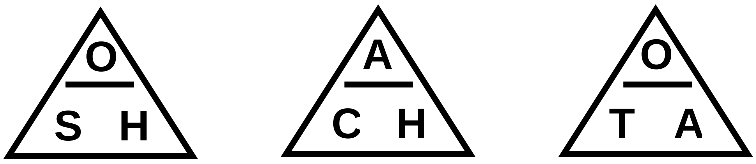
θ (Theta from the Greek alphabet) is normally used to label the "known angle". In the diagram above, this will be angle B = 30°, so the sin, cos or tan of theta (θ) can be found using a scientific calculator. For example to find sinθ simply press the sin key followed by the number of degrees in the angle, e.g.



and the answer comes up as; **0.5**

Finding the length of a side will involve re-arranging the formula. By either dividing both sides of the equation by the denominator (the bottom figure in a fraction) or, because the formulae all have a simple three term structure similar to the Ohms law formulae discussed on the Ohms Law Quiz page at http://www.learnabout-electronics.org/resistors_12.php , a similar "triangle method" can be used.

Using the "triangle method" for the formulae SOH CAH TOA

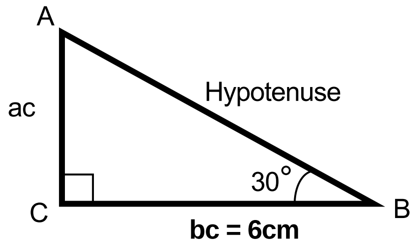


Arranging three letters SOH representing the sinθ formula in a triangle shows that:

$$S = \frac{O}{H} \quad \text{or} \quad O = S \times H \quad \text{or} \quad H = \frac{O}{S}$$

This allows the choice of side to be found, and the arrangement of a suitable formula to find it.

For example:



If the angle and side bc is 6cm, the length of side ac can be found by re-arranging the

tanθ = $\frac{opp}{adj}$ formula TOA to find side ac, which is the opposite side (or O) to angle B

so tanθ = $\frac{opp}{adj}$ is rearranged as O = T x A therefore the formula becomes:

ac = tanθ x 6

ac = 0.577 x 6 = **3.46cm**

The hypotenuse can be found by a similar method. This time the formula could be either SOH or CAH as both the adjacent side and the opposite are known

Using SOH	Using CAH
Hypotenuse H = O/S	Hypotenuse H = A/C
H = 3.46 / sin 30 °	H = 6 / cos 30 °
H = 3.46 / 0.5 = **6.9cm**	H = 6 / 0.866 =**6.9cm**

So, all three sides of the triangle are now known, the only thing left unknown is the angle at A.

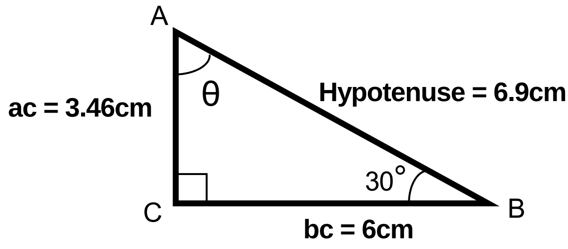
To find angles in degrees requires the use of the inverse trigonometric functions:

$\sin^{-1}$ $\cos^{-1}$ and $\tan^{-1}$

These are usually found on a scientific calculator by using the SHIFT or INV key with sin cos and tan.

Finding an unknown angle.

The value of an angle can be found using the same formulae format as for the sides -



But sin cos and tan must be replaced by

$\sin^{-1}$ $\cos^{-1}$ and $\tan^{-1}$

In this example, because all the sides are known, angle θ can be found using any of the three formulae, but generally an angle can be found using only two known sides.

To find angle θ using SOH

$\theta = \sin^{-1} O/H$

θ = sin-1 (6 / 6.9) = 60 °

Be careful to use the brackets here, $\sin^{-1} 6 / 6.9$ DOES NOT WORK!

(the calculator finds the sin 6° instead of 6/6.9)

Because all the above involves a right angle triangle, checking answers is easy.

If all the angles (without using decimal fractions of angles) are correct they will add up to 180°

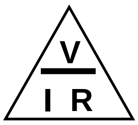
The lengths of the sides can also be checked using Pythagoras' Theorem:

The square of the hypotenuse is equal to the sum of the other two sides,

$$H^2 = A^2 + O^2 \quad \text{or} \quad H = \sqrt{(A^2 + O^2)}$$

For most problems involving phasors, the use of Pythagoras' theorem and/or the three trigonometry functions (and their inverse versions) discussed here will suffice. Trigonometry can be, and is used for much more, including calculations involving other types of triangle outside the scope of this booklet.

Facts and Formulae for Resistor Calculations

Subject	Useful Formulae	Facts to Remember
Resistance	Ohms law relates voltage (V) current (I) and resistance (R) in the formula; V = IR or $I = \frac{V}{R}$ or $R = \frac{V}{I}$  The Ohms law triangle	Electrical SI units; Potential difference = Volts (V) Current = Amperes (A) Resistance = Ohms (Ω) Voltage (V) is a difference in electric potential between two points in a circuit. When the two points are connected a current (I) flows between them. The current flowing between two points in a circuit depends on the voltage between the points and the resistance of the conductor between the two points.
Series & parallel circuits	Series resistors: Total resistance **Rt = R1 + R2 + R3** etc Parallel Resistors: $\frac{1}{Rt} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} etc$ Two parallel resistors: $Rt = \frac{R1xR2}{R1 + R2}$	**IN SERIES CIRCUITS;** The current is the same in all parts of the circuit. The sum of the voltages across individual components is equal to the total supply voltage. Total resistance Rt = R1 + R2 + R3 etc. **IN PARALLEL CIRCUITS;** The voltage across each component is equal and equal to the supply voltage. The sum of the individual component currents equals the total supply current. The RECIPROCAL of the total resistance () = the sum of the reciprocals of the individual resistors $\frac{1}{Rt} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} etc$ The total resistance of a number of parallel resistors is always less than the resistance of smallest resistor. Primary Cells & batteries produce e.m.f., The voltage at the terminals will be reduced by the **internal resistance (r)** of the cell. The e.m.f .may only be measured (approximately) when no current is flowing i.e. with a very high resistance voltmeter. The amount of internal resistance can be given as the "no current" or open circuit e.m.f. ÷ the short circuit voltage at the battery terminals.