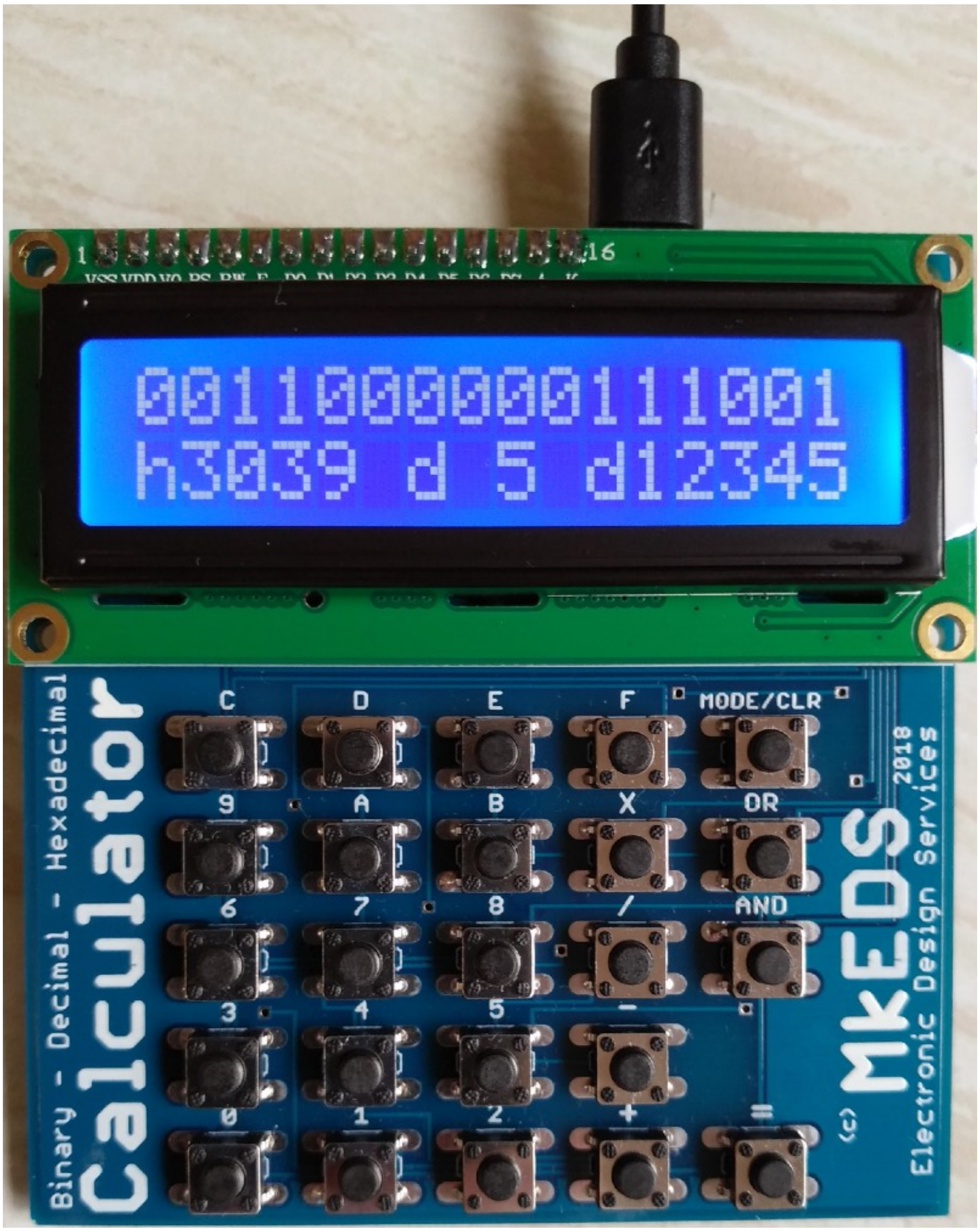
Binary - Decimal - Hexadecimal Calculator



Build instructions.

You will need a soldering iron, side cutters, solder, multimeter to check your work, a clean and tidy workspace, some patience and around two to three hours to complete the build. If it takes you longer, don't worry. Take your time, do a good job.

Parts List:

Micro USB Socket	x 1
Tact switches, 5x5mm Square	x 24
47R (Backlight limiting)	x 1
220R (Switch Row buffers)	x 3
10k (Switch Column pull-ups)	x 8
10k preset - display contrast	x 1
100nF capacitor	x 2

220uF 16V capacitor	x 1
Slide switch (optional)	x 1
16 way DIL IC socket	x 1
20 way DIL IC socket	x 1
16 way 2.54 mm vertical header	x 1
1602 LCD display (16x2 line)	x 1
74HC165 parallel in - serial out - switch decoder	x 1
PIC16F1829 processor with calculator software programmed	x 1

I recommend that the micro USB socket is installed before anything else. This is the hardest component to solder and requires a keen eye and a tender touch. Tin both the outermost solder terminals of the micro USB socket and the two outermost solder pads on the PCB with a very thin layer of solder. Place the micro USB socket onto the PCB, ensure that the five solder terminals are lined up accurately with the solder pads on the PCB, solder just one of the lugs that fit through the mounting holes on the board. At this point, do not solder any of the connection terminals to the PCB contacts, ONLY one of the lugs that form the outer frame of the USB socket. Check that the solder terminals are accurately aligned still, if not, very gently flex the micro USB socket until they are aligned correctly. Solder the other lugs of the USB socket making sure not to move it out of alignment. **Do not use too much solder on the lugs.** If you do, solder may be wicked up inside the micro USB socket making it very difficult to insert the micro USB plug into the socket. Solder the lugs using the least amount of solder possible to fill the mounting holes. Use only enough to secure the socket firmly to the PCB and prevent it from being able to be pulled off the PCB when the plug is removed. Only the two outermost terminals of the USB socket need to be soldered to the PCB contacts, so gently warm the terminals with the soldering iron while at the same time applying a very small downward pressure on them to push them slightly towards the PCB terminals. **DO NOT** push them sidewards. If they bend it is almost impossible to straighten them. To test if they are connected correctly, plug a micro USB connector into the socket, and plug the opposite end into a 5V USB charger. With a multimeter you should be able to measure 5V between the terminals labelled 'USB_5V' and '0V'. If you do not get 5V at this time, check that the USB charger is not one that requires a load be present to provide power and then check that your soldering on the terminals is done correctly. Once the IC sockets are fitted, it is nearly impossible to resolder the micro USB socket. Get it right now. Check it is right now. Don't leave it until later!

Once this is done, the rest is easy.

Solder in the 24 tact switches for the keypad. These switches and the LCD are the only components to fit to the top of the PCB, all others fit on the back. A little time spent here making sure that each switch is in neatly and squarely will make the finished calculator look so much better. Don't rush!

There are 12 resistors that need soldering, 1x 47R, 3x 220R and 8x 10k. These are in groups with all the 10k resistors next to one another, all the 220R together and the one 47R all alone. None of the values are critical, if you have 150R instead of 220R, this will be fine, 8k2 instead of 10k? No problem. The 47R resistor reduces the current for the LCD backlight. For some LCD displays this may need to be a lower value if you want the backlight brighter. If you wanted to experiment with this, perhaps leave it out until you've tried the LCD display with some different values of resistor? Alternately, check your LCD display's datasheet and calculate the correct value for your LCD display. Some LCDs have a built in resistor and don't need an external resistor, some do not. I've found 47R to be a reasonable compromise for most of the displays I've tried and suggest that unless you have a good reason to change it, use 47R.

Next up, fit the 10k contrast preset, the two 100nF capacitors and the 220uF electrolytic capacitor. The capacitor should lie flat to the board making sure that the polarity is correct as indicated by the row of + + + + symbols. Most electrolytic capacitors have a marking on the case for the negative terminal, this should be the lead farthest from the + + + + symbols.

Fit the two IC sockets (1x 16 way, 1x 20 way) being sure to check the alignment. Both IC sockets should have their PIN 1 notches on the right, looking at the board from underneath. The 74HC165 and PIC16F1829 are positioned on the board so that they form a rest for the calculator, tilting the display towards you by a few degrees, for this reason it is suggested that you use IC sockets that are from the same manufacturer so that the two ICs when fitted are at the same height off the PCB. The turned pin IC sockets are expensive, but very good quality and just the right height. If you choose to solder the ICs directly to the PCB, the two 100nF capacitors could perform the same function of a tilt stand if you fit two rectangular 7.5mm x 7.5mm x 2.5mm capacitors in these positions.

There is a position for a slide switch. This is optional, fitting it allows you to turn the calculator off, or switch between battery power and USB power if required. If you are happy to leave the calculator on permanently there are three solder pads just behind the switch, solder the middle pad and the right most pad for permanent USB power, or the middle pad and the left pad for permanent battery power or if your battery holder has a switch. The calculator can be powered from three 1.5V cells if using battery power. **Do not use four 1.5V cells as this could cause the LCD and processor to be irreparably damaged.** These should be fitted into an appropriate holder with the positive terminal being connected to the pad on the PCB marked ‘5V’ and the negative to the pad marked ‘0V’. If there is a switch on the battery holder and you are not using USB power, the slide switch could be eliminated as suggested.

Triple check all soldering at this point. Make sure that there are no bridges between the pins of the ICs or from any adjacent resistor pads. Plug a micro USB connector into the socket, and plug the opposite end into a 5V USB charger. With a multimeter you should be able to measure 5V between the terminals labelled ‘USB_5V’ and ‘0V’. If you do not get 5V at this time, check that the USB charger is not one that requires a load be present to provide power and then check that your soldering on the terminals is done correctly. If using batteries, check the voltage using the ‘5V’ and ‘0V’ terminals. It is much easier to correct any problems at this point than it is once the display is fitted. If you have the correct 5V present on either the ‘USB_5V’ or ‘5V’ and ‘0V’ pads, put the multimeter on pins 1 and 20 of the PIC16F1829 socket and check for 5V here too (pin 1 = 5V, 20 = 0V). If you have no volts here, check the position of the slide switch or, if the switch isn’t fitted, that the solder pads behind the switch are soldered in the correct position for either micro USB power, or battery power. Check for 5V across each of the capacitors in turn, the two 100nF and the 220uF capacitors should all have 5V between their two terminals with the top terminal of each capacitor being 0V and the bottom being 5V. The two connections for the LCD display labelled ‘A’ and ‘K’ (‘A’ = 5V, ‘K’ = 0V) should also have 5V on them (with the 47R resistor fitted) as should the pins at the opposite end of the LCD display connector, pins 1 and 2 (1 = 0V, 2 = 5V). Assuming all is well, continue to fit the display. If not, check your soldering again, possibly asking a friend to check the joints if you can’t see the problem. I do not recommend fitting the display if these tests fail. With the display in, it is almost impossible to rectify any faults and taking the display out once it has been soldered in is very, very difficult indeed.

Fit a 16 way vertical 2.54mm pitch terminal pin row to the LCD making sure it is perfectly lined up so that the pins point downwards as you view the display window. Then solder these in turn to the PCB, with the screen of the LCD facing upwards when looking at the switches. **Before soldering the display into position**, check that any of the metal tabs on the underside of the LCD display do not touch any of the contacts for the resistors, capacitors and ICs that lie underneath the display. If they do (or look as though they might) place a length of insulation tape on the affected metal tabs before soldering the display in. The positioning of the components on the PCB should ensure that the tabs do not foul any of the contacts, but double check beforehand. The displays are very difficult to remove once soldered in, and if every time you touch the display the power cuts out, or a random key gets activated it will be hard work trying to slide a layer of tape between the two with tweezers. I’ve had to do this on other circuits, and trust me, it isn’t easy. Check first!

Place the 74HC165 into the 16 pin IC socket observing the correct orientation (Pin 1 to the right as you look at the PCB from the underneath).

Program a PIC16F1829 processor with the calculator code. This can be done using a PicKit or similar programmer. Plug the processor into the 20 pin IC socket, again Pin 1 to the right looking at the PCB from underneath.

Testing:

Plug the micro USB connector into the PCB socket, and into a powered USB socket or charger. [If using battery power, insert the batteries] Switch on. If nothing else appears to happen, at least the LCD backlight should illuminate if the 47R resistor was fitted. Adjust the contrast preset resistor and the display should show some information. Probably a row of zeros along the top, and some other zeros along the bottom row. If the display doesn’t show anything with the preset in one direction, try moving it the opposite way. If the display is filled with two rows of blocks, the contrast may be too high. Slowly adjust the contrast until the display is clear with a good discrimination between lit segments and unlit segments. Switch off and on again and with the contrast correctly adjusted some information should briefly display, including the software version number and compile date.

If this doesn't happen, switch off, check the soldering of the USB socket, place a multimeter on the solder pads for the USB_5V and 0V and see if you have 5V, if not, check that the USB socket is powered, try another USB port, try another charger. If using batteries, check the batteries [if using batteries the multimeter should be placed on the 5V and 0V pads on the PCB]. Did you fit the slide switch? If not, did you solder the appropriate solder pads to link the power from either the micro USB socket or battery holder to the circuit? Does the LCD come on, but only show a top row of square blocks? If this happens, check your soldering on the connections between the LCD and processor. The row of blocks along the top line only indicates that the LCD is not being initialised by the processor, either the processor isn't communicating with the LCD or perhaps the processor is not fitted in the socket correctly. Is the processor programmed correctly?

Hopefully, you will now have a working calculator. Congratulations! Let's do some sums!

Using the calculator:

When first powered up, the calculator will show:

```
0000000000000000
h0000 d 0 d00000
```

The top row shows values in Binary (Base 2)
The four digits to the right of the first 'h' shows values in Hexadecimal (Base 16)
The five digits to the right of the rightmost 'd' shows values in Decimal (Base 10)

The single 'd' indicates that the calculator is in Decimal entry mode, and the single '0' indicates that the last key pressed was '0' (or no key was pressed). This single '0' may not be displayed at start up, if not, don't worry.

First, check all the buttons work. Press, 0, 1, 2, 3 and so on making sure that as you press them the correct button press is indicated in the position where the single '0' is in the above example. Do not worry what is displayed in the value positions for now, simply check that all buttons are working.

Once you've gone from 0 to 9, check the letter keys A - F. Now check the 'Sum' keys, 'x', '/', '-', '+' are indicated with their symbols, 'OR' is indicated by a lower case 'v' and 'AND' with '&'. The MODE/CLR button has a dual function, a short press changes the entry mode, and a longer press, clears all entries and any answers from previous sums. Press it and hold it now to clear the display. Check that the entry mode is still 'd' for Decimal. If it isn't, briefly press mode once, release it and check if 'd' is displayed for Decimal entry mode, if not, press mode briefly again until 'd' is displayed for Decimal entry mode.

Press the keys, 1,2 and 4. The display should show:

```
0000000001111100
h007C d 4 d00124
```

Now press 'x'.

```
0000000001111100
h007C d x d00124
```

Now press 5, 4

```
0000000000110110
```

```
h0036 d 4 d00054
```

Now briefly press ‘=‘

```
0001101000101000
h1A28 Ans d06696
```

The answer to 124 x 54 = **6696**

You should see that the calculator showed each part of the sum in all three bases (Binary, Decimal and Hexadecimal) at the same time.

If you simply want to know what 7869 (Decimal) is in Binary, just enter it and you can see instantly (and in Hex too!).

The ‘+’, ‘-‘, ‘/‘ and ‘x’ are standard mathematical symbols, and perform exactly as expected, although it isn’t possible to perform a division where the numerator is greater than the denominator: 10 / 2 = 5 but 2 / 10 = 0 [Zero]. ‘AND’ and ‘OR’ perform logical AND and logical ‘OR’ functions. The ‘OR’ button has a dual function, if it is pressed and held, it changes function to ‘XOR’ [eXclusive OR] and the symbol changes from ‘v’ to ‘⊻’. These logical functions are used in the same way as the standard mathematical functions.

8 AND 9	= 8
8	= 0000000000001000
9	= 0000000000001001
8 AND 9	= 0000000000001000

8 AND 7	= 0
8	= 0000000000001000
7	= 0000000000000111
8 AND 7	= 0000000000000000

6 OR 7	= 7
6	= 0000000000000110
7	= 0000000000000111
6 OR 7	= 0000000000000111

6 XOR 7	= 1
6	= 0000000000000110
7	= 0000000000000111
6 XOR 7	= 0000000000000001

The ‘AND’ button has a dual function. Long press it and it generates a random number of between 0 and 255 - ‘R’ is displayed briefly to indicate the Random function was activated before the result is displayed. This random number can be used as the first number in a calculation, but not the second. **Little practical value.** There is a way of generating a random(ish) value with a range of 1 to 9,999 (decimal). Switch the calculator off. Switch the calculator back on whilst holding the ‘AND’ key down. As the version number and copyright information is displayed, an asterisk or star * will be displayed in the top right corner of the screen. Now release the ‘AND’ key. Long pressing the ‘AND’ key should now generate a random(ish) number between 1 and 9,999 (decimal). The randomness of the value returned may well turn out not to be truly random, I include it for entertainment purposes only. Could be useful to someone, somewhere?

The ‘=‘ button has a dual function. Long press it and it performs a logical ‘NOT’ on the current value displayed on the screen. This can be performed at any time during, or after a calculation has taken place. Enter any value, long press the ‘=‘ button and the inverted [Word] value of the entered value will be shown. The '=' symbol will be displayed inverted (white text in a black block) to indicate the 'NOT' function.

7 'NOT' 65528
7 = 0000000000000111
65528 = 1111111111111000

65528 'NOT' 7
65528 = 1111111111111000
7 = 0000000000000111

To change the entry mode simply press the 'MODE/CLR' button briefly. The entry mode should change from Decimal 'd', to Hexadecimal 'h', to Binary 'b' then back to Decimal 'd'. The entry mode can be changed part way through a calculation if desired so the following is valid:

[Mode 'd' Decimal]
10 + 'MODE/CLR', 10 = 26
[Mode changed to Hexadecimal 'h']
[10 in Hexadecimal is 16 in decimal]

When in each entry mode, only the valid keys for that entry mode are valid. In Binary, only '0' or '1' can be entered into a calculation, in Decimal, '0' to '9', in Hexadecimal, '0 to 'F'.

The calculator calculates strictly with integer [Word] values only. Any decimal places are lost. '5', '/', '2' = 2 (not 2.5). This is how the processor does maths and I specifically wanted this behaviour. Likewise any overflow is not trapped. A 16bit [Word] value can hold a maximum value of 65535 [Decimal] FFFF [Hexadecimal] or 1111111111111111 [Binary]. Values that exceed this overflow and start from 0, so 65535 + 1 = 0 [rather than 65536].

A calculated answer can be used in a further calculation simply by continuing with the sum:

123 x 9 = 1107 x 5 = 5535 / 7 = 790 + 30 = 820 / 2 = 410 AND 4000 = 384

It is strongly suggested that any display is cleared before starting a new sum, unless you are performing a multiple calculation as above. Unless you are sure what you are doing, you may find that a result is not as expected if the calculator is not cleared before starting a calculation. Press and hold 'MODE/CLR' for a short period to clear all memories.

The entry mode last used will be the one selected when the calculator is next started. When switched off, all other memories are cleared.

As of software version 2.01 (6th September 2018) the calculator can be switched into 32bit [Unsigned, LONG] mode from the usual 16bit [Unsigned, [WORD]. To change from 16bit to 32bit mode, switch the calculator off, wait for a few seconds and then press and hold the MODE/CLR switch while turning the calculator on, after a short delay, in the bottom left corner of the display the '^' symbol will be displayed and the MODE/CLR switch can be released. When the calculator displays it's information while it initialises, it will state that it is in either 32bit (or 16bit) mode. The 16/32bit mode last used is stored and selected when the calculator is next started. To change back again, simply repeat this procedure. While in 32bit mode the calculator allows calculations to have a maximum value of 4,294,967,295 [Decimal] or FFFFFFFF [Hexadecimal]. Once in 32bit mode no binary values are displayed, the top line of the display shows only Hexadecimal values with the decimal value underneath. All other operations are identical to the standard methods as shown above, although it is not possible to select the Binary entry mode as it cannot be displayed. In 32bit mode, all calculations are performed with 'Unsigned LONG' values, as with the 16bit mode, no overflows are trapped, values that exceed 4,294,967,295 [Decimal] simply overflow and start again from 0, so 4,294,967,295 [Decimal] + 1 = 0 not 4,294,967,296.

As of version 3.01 (8th September 2018) the calculator can be set to ‘animate’ the calculations. This only has any effect in 16bit mode, in 32bit mode no animation will take place even if animation has been requested. To activate the animation, switch the calculator off, wait for a few seconds and then press and hold the ‘A’ switch while turning the calculator on, after a short delay, in the bottom left corner of the display the letter ‘a’ will be displayed and the ‘A’ switch can be released. While the calculator is in 16bit mode, when a calculation is performed it will be broken down into repeated maths operations.

For example:

```
250 x 4, Equals
This will be calculated as:
250 + 0     (250  is briefly displayed on the LCD in binary,
            Decimal and Hexadecimal)
250 + 250   (500  is briefly displayed on the LCD)
500 + 250   (750  is briefly displayed on the LCD)
750 + 250   (1000 is briefly displayed on the LCD)
```

Eventually the answer of 1000 is displayed on the screen.

Addition is performed as:

```
250 + 250, Equals
250 + 1     (251  is briefly displayed on the LCD in binary,
            Decimal and Hexadecimal)
251 + 1     (252  is briefly displayed on the LCD)
. . .

498 + 1     (499  is briefly displayed on the LCD)
499 + 1     (500  is briefly displayed on the LCD)
```

Eventually the answer of 500 is displayed on the screen.

Subtraction is performed in a similar way to addition, but by deducting 1 repeatedly.

Division is performed by repeated subtraction until the remainder equals or is less than the divisor, the number of steps required to complete this are counted and returned as the answer.

These animated maths routines can take some time to complete (which is why they are not available in 32bit mode) the example for addition will take 250 steps to complete, each step takes the calculator 40 ~ 50 mS to calculate and display the result. 50 mS x 250 = 12500 mS = 12.5 seconds. I timed this calculation with a stopwatch and measured 10 seconds. A calculation of 250 + 60000 will take 50 mS x 60000 = 3000000 = 50 minutes. I timed this calculation and it took 38 minutes. Good fun if you are in no rush, but more a novelty than of any real use.

The animation can be turned off in the same way as it is turned on, To de-activate the animation, switch the calculator off, wait for a few seconds and then press and hold the ‘A’ switch while turning the calculator on, after a short delay, in the bottom left corner of the display the letter ‘a’ will be displayed and the ‘A’ switch can be released.

This is intended as a hobby device. It is in no way intended as a scientific nor as an accurate instrument. The calculator may perform unexpectedly. The accuracy of any results are not guaranteed in any way whatsoever. If you need accuracy this may not be the device for you. For any life critical calculations, use another calculator. No responsibility will be accepted for any injuries or failures which may arise from inaccurate results.