

RADIO MAGIC

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“Tinker Tailor Circuit CAD”

Introduction

Those of us of a certain fine “vintage”, fondly remember cutting our tech teeth on various Radio Shack (RS) “Science Fair” electronic project kits. We built circuits by connecting coloured wires strung between flexible springs attached to resistors, capacitors and transistors, etc. (Figure 1, next page). Of course, I (and perhaps you, too) blew up at least one of something learning what not to do in the process! These kits fascinated us for hours on end, magically sparking something within that led many of us to careers in science, technology, engineering and mathematics (STEM) or “STEAM” to include liberal arts: “I think that I shall never see / A μ -controller lovely as a tree”.

Fast forward 50 years and you can buy rebranded kit clones (Maxitronix), but in year 2021 we also have virtual electronic kits available via computer-aided design (CAD) software. The one that I’m going to talk about is Autodesk Inc.’s “Tinkercad” or “TC” for short (Figure 2, next page). TC is accessed and controlled by a web browser and your mouse. Originally designed to create three-dimensional (3D) architectural and mechanical CAD drawings and models, it now has a “simulation program with integrated circuit emphasis” (SPICE) module called “Circuits”. You can design, build and simulate the operating behaviours of virtual analog and/or digital electrical/electronic circuits. Best of all, you can’t blow up any thing no matter how hard you try (and I tried!). You simply stop the TC Spice simulation, correct whatever is wrong and carry on—as if nothing ever happened.



Figure 1: Science Fair Electronic Project Kit

Golden oldies like this are still being sold on eBay. Credit: eBay.

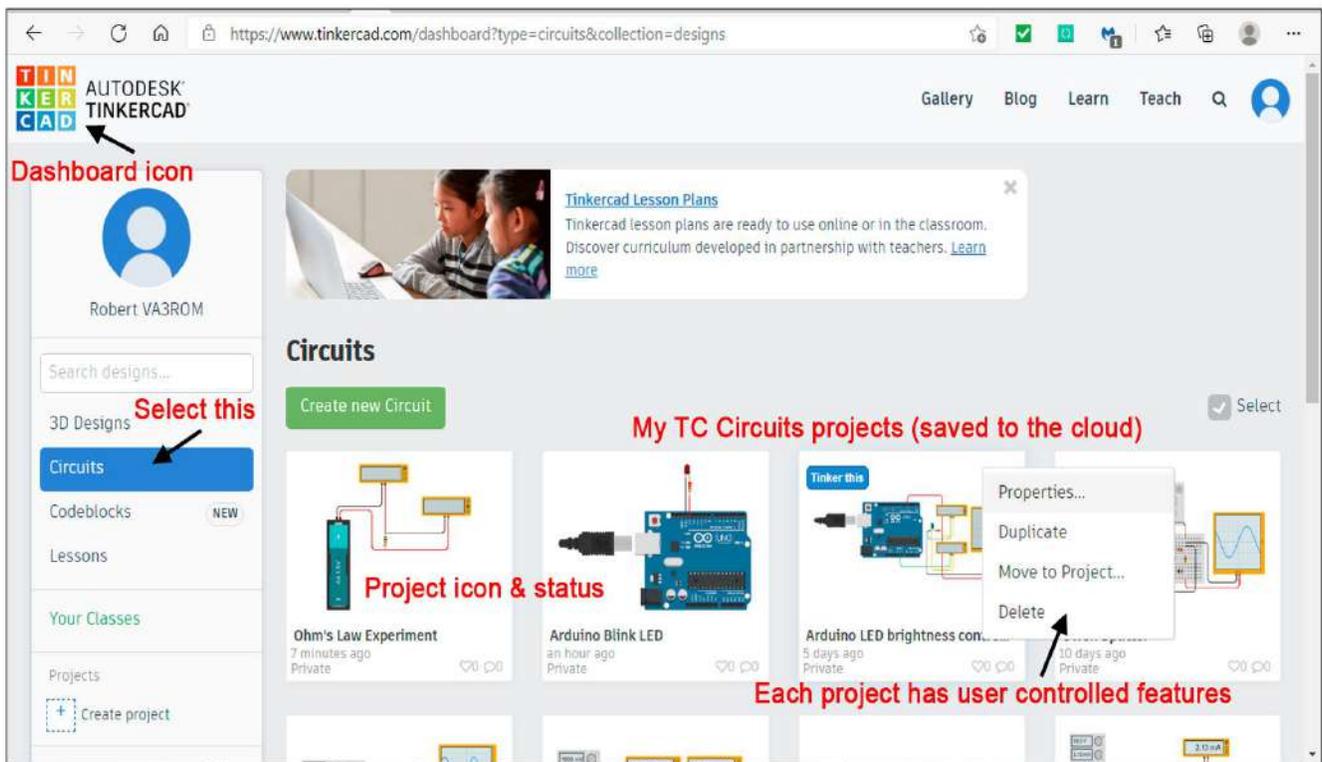


Figure 2: Tinkercad Dashboard

The web based control centre that for all of Tinkercad's various functions and features. Credit: Tinkercad.

Besides being free and very easy to use, all TC Circuits components are depicted as colourful 3D computerized “black boxes” with autonomous built-in artificial intelligence (AI) so they behave exactly like their real-world counterparts! But you don’t need to know how they actually work their magic; just mouse point and click on the one you want to use, drag it over to the workspace then connect it to another black box device using virtual wires. Popular μ -controllers (Arduino Uno, Microchip ATtiny and BBC micro:bit) are included in the virtual parts box to build and program analog/digital circuits using C, C++ or Block “Scratch”. Scratch is a building block-based visual programming language (VPL) developed by the Massachusetts Institute of Technology (MIT) Media Lab for use in elementary and middle schools STEAM courses. It’s a great way to teach young STEAM students how to integrate electrical/electronic circuits with μ -controllers and code. Microsoft’s MakeCode (BBC micro:bit) and Google’s Blockly (Revolution Education PICAXE) are “first cousin” VPL variants. The TC tutorials section has a plethora of μ -controller projects to help you if this is your main area of interest.

Now to nitpick! You can’t create new or customize existing components; what you see is what you get. And you can’t design, build and simulate radio frequency (RF) circuits—for now. You’ll also need a fast dual-core computer for the AI routines to think and react as quickly as possible, especially when running complex simulations with many components, connections and metering (measuring) devices. It becomes really noticeable with virtual audio output circuits where sounds can crackle and stutter on your computer’s speaker. This is where “gamer” customized computers really shine especially if you want to get serious about AI and 3D virtual worlds.

Using TC Circuits

Point your browser to <https://www.tinkercad.com> and create your free and private TC cloud account. Click on the colourful 9-block dashboard TINKERCAD icon then on the sidebar menu item “Circuits”. All TC Circuits are stored in your TC cloud account and will exist therein as you work on them or until you delete them. You can also make any of your projects public for other tinkerers to find and import into their TC cloud workspaces. The TC Gallery has many sample circuits from easy to complex that you can tinker with to your heart’s content. You can also mouse click on the magnifying glass icon to expand your cloud search because there’s no point in reinventing a virtual wheel if someone else has already done it for you!

For more advanced tinkerers, there're two really nice features if you plan on making a printed circuit board (PCB) of your project(s). TC Circuits can create the bill of material (BOM) saved as a .CSV file, and it can also create and export an Autodesk Inc. Eagle single-layer PCB layout saved as a .BRD file. Eagle is a free (for personal use) and commercial schematic drawing and PCB design CAD program. In this case, you *must* build your TC Circuit using a virtual solderless breadboard and carefully plan the layout of all the components and wiring to make it easier for you to work on the exported Eagle .BRD file. Else you will generate a jumbled mess to untangle!

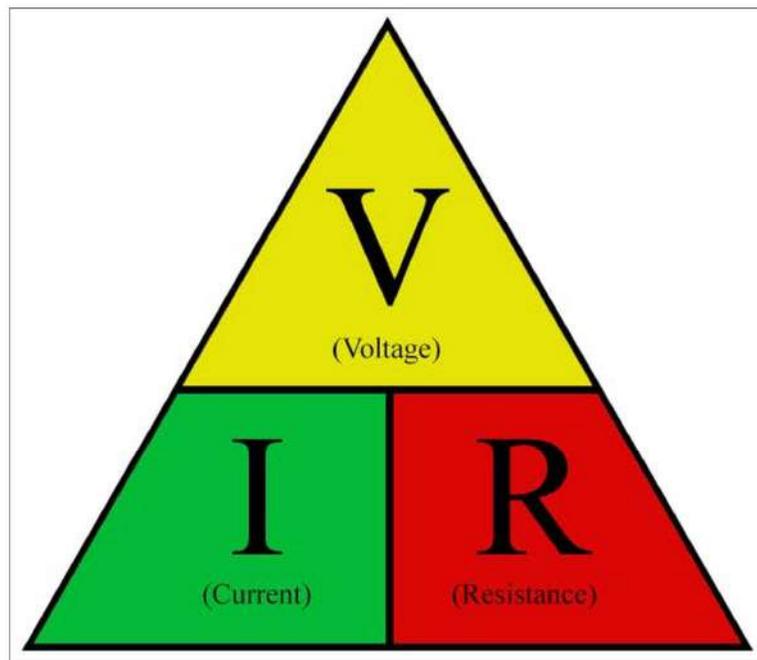


Figure 3: Ohm's Law Triangle

Also as a circle; even after 50+ years, I still doodle it on my notepad. Credit: Public domain.

Example 1: Virtual Ohm's Law

Here's a great virtual and visual way to use TC Circuits to explore and then expand upon George Simon Ohm's famous law: *"In any electric circuit, the Current 'I' is directly proportional to the applied Voltage 'V' and inversely proportional to the total circuit Resistance 'R' if the physical condition of the circuit remains unchanged (i.e. temperature, humidity, stress, pressure, etc)."* Written mathematically as: $I \propto V / R$ or more commonly as $I = V / R$ (Figure 3). We often forget about his caveats; these cause problems if we do in situations like: dry, frigid, low pressure outer space, extreme cold and intense pressure of ocean depths, dry and frigid Poles or dry and blazing deserts.

But when his revolutionary magnum opus "The galvanic circuit investigated mathematically" (English title) was published in 1827, his critics called it "a web of naked fancies" and "scientific heresy"! At the time, there were several alternate but incorrect theories (e.g. Barlow's law). But Ohm had the last laugh and became world renowned in his own time and then an immortal for all time. The physical unit of electrical resistance, the ohm (symbol: Ω) is named after him.

Note: In old text books, the symbol "E" (Greek uppercase letter epsilon) meaning electromotive force (EMF) was used for voltage, but it has reverted back to "V" because "E" is also used to represent the electrical energy produced by a non-electrical energy source i.e. a battery (chemical), generator (mechanical) or solar panel (photovoltaic) as well as the electrical field around a current carrying wire and also energy. And also for energy; as in $E = mc^2$.

Why did Ohm use the capital letter "I" to represent current? Well, a few years earlier, another pioneering genius of electricity and magnetism, which were thought to be two separate and distinct forces at the time, one André-Marie Ampère, discovered that a wire carrying an electric current will attract or repel another wire next to it that's also carrying electric current depending on the intensity ("I") of the currents. This was a magnetic effect without using a magnet. Electricity was also thought to be a fluid flowing like water hence the other common term "current". The physical unit of electrical current, the ampere (symbol: A) is named after him.

Note: The problems with the general acceptance of the now-famous Ohm's law were two-fold. One was purely political because his mathematician brother Martin was in a vitriolic conflict with the German educational system. The second and real reason was that his theory was one of "contiguous action" whereby objects can only be moved or affected by physical contact with other objects, which opposed the widely held belief of "action at a distance". In physics, action at a distance is the concept that objects can be moved or affected without being in physical contact with other objects. But Ohm believed that the "communication of electricity" occurred between "contiguous particles" (his terms). Ampère agreed with Ohm and then he boldly predicted that a negatively charged particle must exist within all electrical conductors and that it was responsible for this contiguous action. Talk about scientific heresy! But he was right.

But Ohm's law is not a universal law because it's only applicable to "ohmic" electrical conductors and resistive devices wherein the current and voltage are always directly proportional to the other. It's not applicable to "non-ohmic" (non-linear) solid-state devices such as transistors, diodes, et al. And it's generally applied only to direct current (DC) and not alternating current (AC) circuits because the current is constantly changing so an AC equivalent DC circuit must be used.

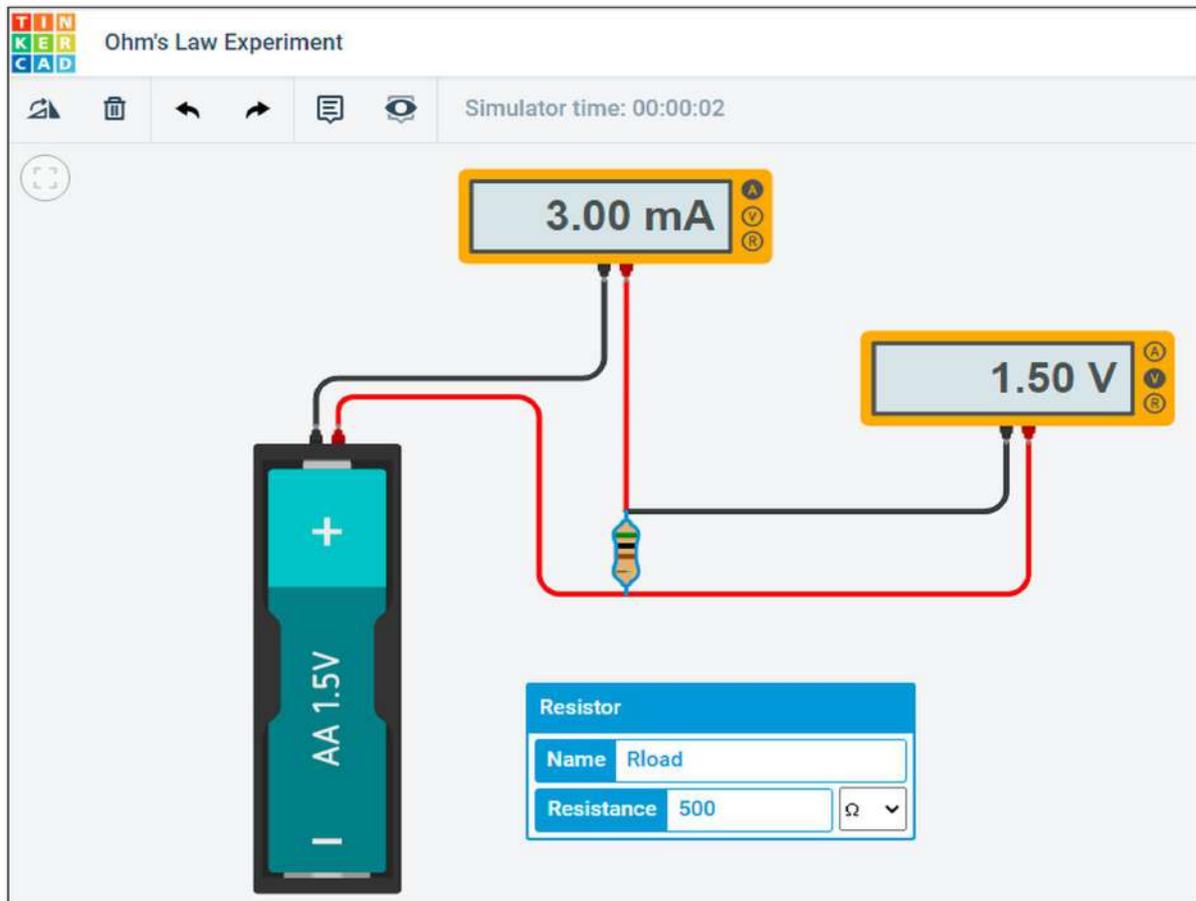


Figure 4: Virtual Ohm's Law

Learn the basic concepts of Ohm's law then expand upon the circuit by adding serial then parallel resistors leading towards Joule's law (electrical power relationships) and Kirchoff's laws (voltage and current). Credit: Tinkercad.

In Figure 4, I've used TC Circuits to build a very simple circuit using one load resistor, a fixed voltage (AA cell) plus meters to measure the circuit's voltage and current to prove (or disprove) Ohm's law. Prior to running the simulation, mathematically calculate the circuit voltage and current using a 1000 ohm resistor to start off the experiment.

Press the “Run simulation” button to see if the virtual measurements match the mathematics (it takes several seconds for meter readings to stabilize). Stop the simulation; change the load resistor to 10,000 ohms; redo the math and the simulation. Stop the simulation; change the load resistor to 1 ohm; redo the math and the simulation. Is the result what you calculated? Can you explain what’s happening if the math differs from the results? Try using the virtual power supply instead of the AA cell and then see what happens. Can you explain why the results are different?

Example 2: Virtual NE555 LED Flasher

The 555, triple-5 was created by Hans Carmenzind for Signetics (now NXP Semiconductors). First manufactured in 1972 for use in timer, delay, pulse generation and oscillator circuits, it quickly became ubiquitous, and it’s used in much of today’s consumer, commercial and military electronics. The most popular integrated circuit (IC)—ever—with an estimated *one billion* triple-5’s produced annually!

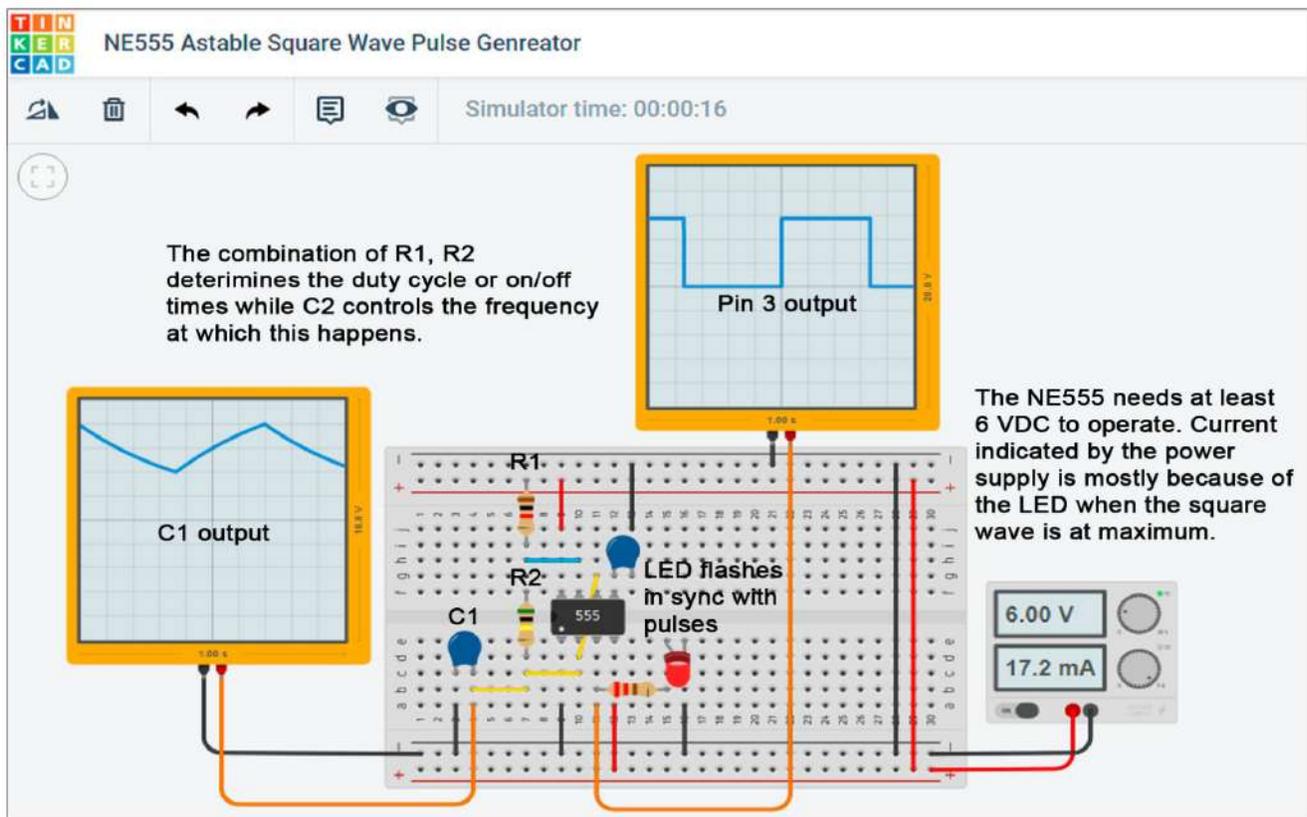


Figure 5: Virtual NE555 LED Flasher

Credit: Tinkercad image. If you want, you can also build the same circuit as a life size transistorized working version kit, which is great classroom demos: <https://www.adafruit.com/product/1526> the perfect blending of technology and liberal arts, as in “STEAM”.

Figure 5 (previous page) depicts the classic 555 “astable” (free running or self-triggering) oscillator. It’s often called a “multivibrator” (Abraham and Bloch, *Annales de Physique* 12, 252, 1919) by old-school electrical engineers because these types of oscillators generate square waves rich in “multiple vibrations” (harmonics), which are still used for calibrating high frequency (HF) radio equipment. By connecting pins 2 and 6 together, the triple-5 flip-flops back and forth from low to high voltage (hold for a certain period) then high to low voltage (hold for a certain period) and repeat forever or until the power is removed.

A light emitting diode (LED), connected to pin 3, flashes in sync. To calculate the values for R1, R2 and C1 for a slow enough visual flash rate, I used this handy calculator <https://tinyurl.com/cbd6u3jd>. Two virtual oscilloscopes monitor C1’s charge/discharge cycle voltages (a triangle wave) and pin 3’s on/off voltages (a square wave). Why the difference between the two? That’s a very good question for you to answer!

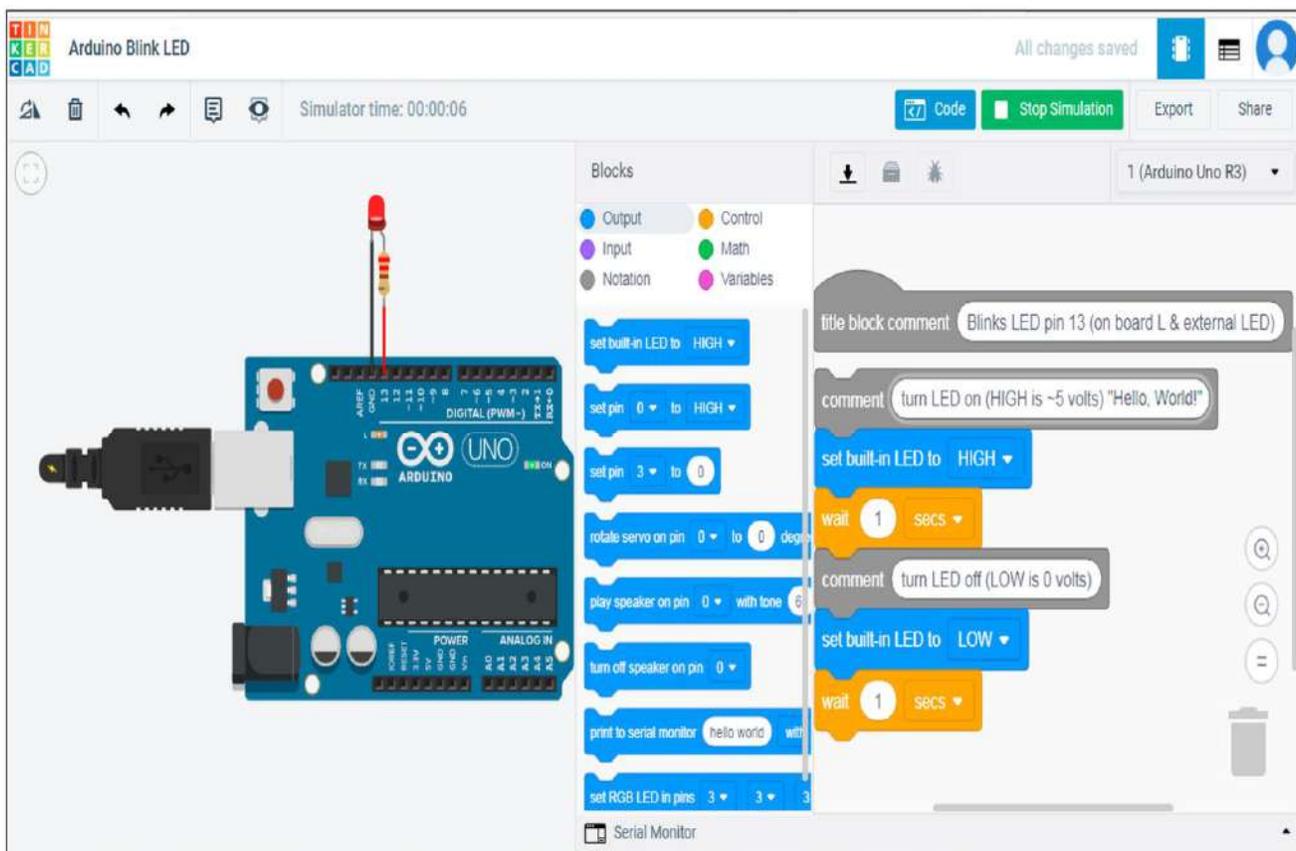


Figure 6: Virtual Arduino “Hello, World!”

The Block (Scratch) code is displayed on the right, but I often peek at the C/C++ text code hidden inside more complex Blocks to see how they make the “magic” happen. Credit: Tinkercad.

Example 3: Virtual Arduino μ -Controller

I don't want to go too deep into the world of virtual u-controllers because that's article for another time, but the traditional first program run on any computing device is called "Hello, World!" In this case, there's no display so a LED with a current limiting resistor is used instead (Figure 6, previous page). You can view the code as Block (Scratch), Block + Text (C/C++) or just Text (C/C++). The virtual programming and μ -controller simulation is so amazing and realistic that it has become my preferred method for developing programs for and experimenting with the Arduino Uno.

My Final

I found and included two excellent TC Circuits tutorials in the supplement zip file on my *Radio Magic* web page that greatly expands this cursory introduction. Highly recommend that you go through the basic TC Circuits online tutorials, especially if you're a new to building and programming real or virtual circuits.—73