Electronic Supplementary Material (ESI) for Environmental Science: Water Research & Technology.

Affordable, Flexible, and Modular: A Guide to Open-Source Membrane-Based Water Treatment Systems

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Appendix B

Circuit Diagram Tutorial

Circuit diagrams are generally explained in this appendix. There exists myriad methods of connecting circuits, depending on the application and requirements. For rapid circuit prototyping solderless breadboards may be used to test functionality. Once correct operation has been verified, then circuit connections should be soldered to prevent broken circuits and unexpected system performance.

A representation of a solderless breadboard will be used to illustrate how to create and connect the requisite circuits. Most solderless breadboards work well with Arduino microcontrollers as they use the same 0.1 inch pitch layout for their connections.

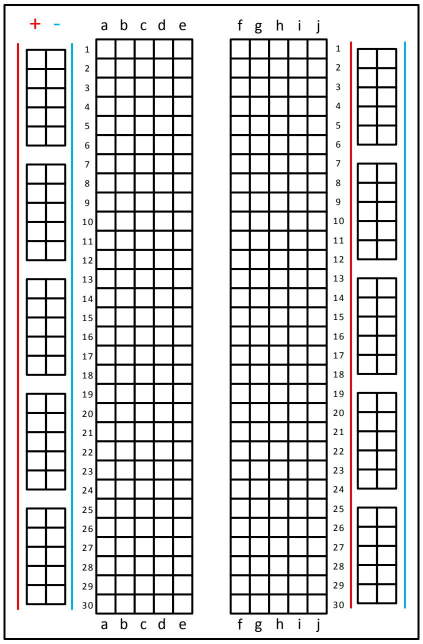


Figure 1: 400-point solderless breadboard

The solderless breadboard has a grid of locations where electrical connections may be placed. The example shown in Figure 1 shows a smaller breadboard with 400 connection points. Breadboards organize the connection points into a regular grid of rows (denoted by number) and columns (denoted by letter). Typically there are two sides of a breadboard, mirrored along the vertical axis. There exists internal connections which are common among various breadboard designs, as shown in Figure .

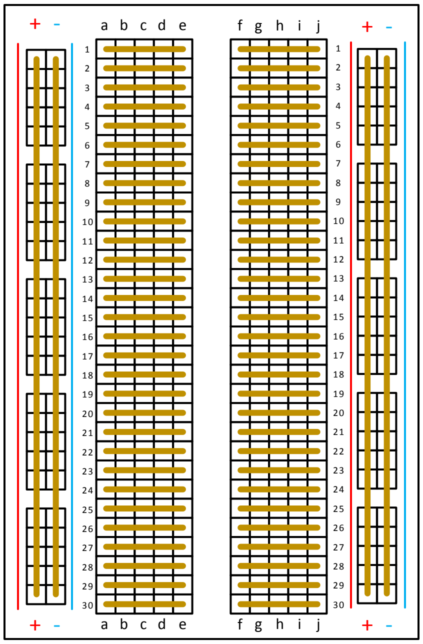
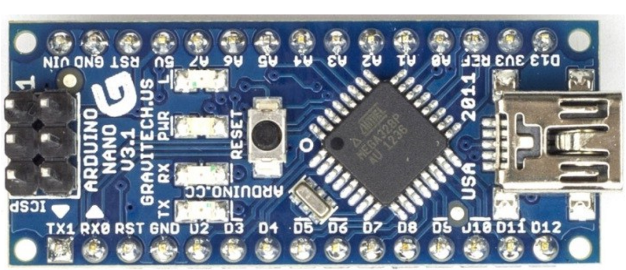
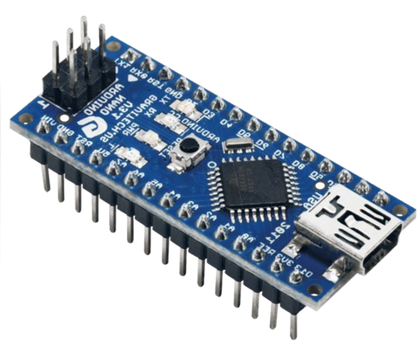


Figure B2: Solderless breadboard internal connections

Each power terminal (the sides of the board) runs the vertical length of the board, while each row (numbered) of the center part of the board is connected. This allows the user to make common connections between components, which will be further explained and demonstrated.

The following circuit diagrams all utilize a basic representation of an Arduino microcontroller, with the required inputs/outputs labeled. There exist various Arduino microcontroller boards, however an Arduino Nano will be used for demonstration purposes.





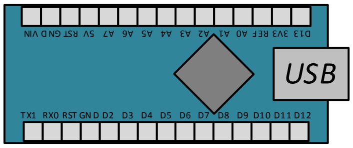


Figure B3: Arduino Nano v3

The photo representations of the Arduino corresponds to the simplified graphical representation of Figure . The Arduino Nano (Figure) has a series of pins (seen in the oblique view) that fit perfectly into a solderless breadboard. Additionally it has a mini-B USB receptacle. Digital pins are denoted by the letter "D" before the pin number, while analog pins are denoted by the letter "A" before the pin number. "5V" refers to the 5 VDC output of the Arduino (when supplied with USB power), and "GND" refers to 0 VDC. The Arduino can be supplied with USB power, or by a DC voltage ranging from 6-20 in the "VIN" pin. Certain digital pins on Arduinos have special abilities, such as pulse width modulation (PWM), which are documented in the Arduino's datasheet. Other pin labels are beyond the scope of this project and won't be discussed here.

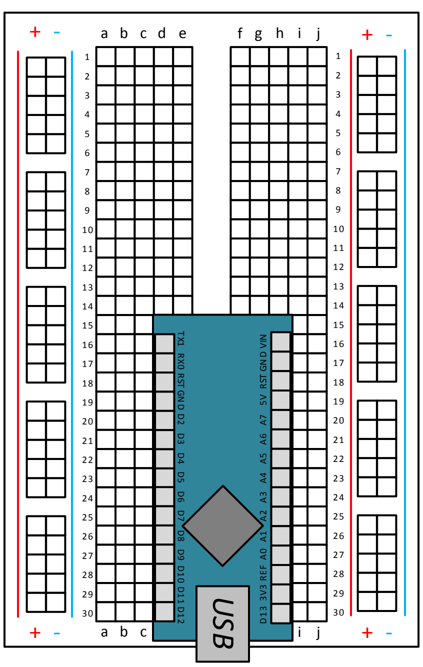


Figure B4: Arduino interfaced with breadboard

As already stated, the Arduino interfaces perfectly with the solderless breadboard, and is attached here in Figure in such a way that its D12 pin is connected at location 30d on the breadboard, and its VIN pin is connected at location 16h. All other Arduino pins are seated in the breadboard as shown in Figure .

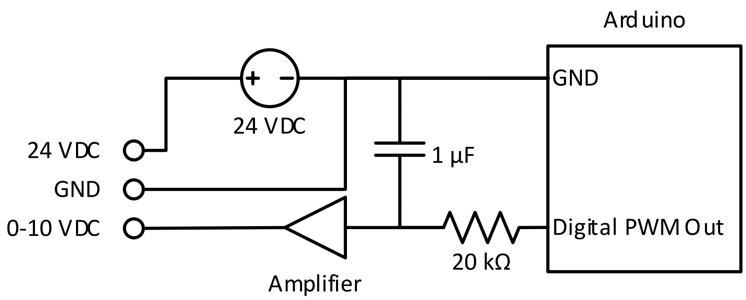


Figure B5: Example circuit

Figure represents one of the more complicated circuits diagrammed in this paper. It is a duplicate of Figure 6 which represents a proportional control valve actuator. The actuator itself requires a power source of 24 VDC, and a variable signal from 0-10 VDC which indicates its relative position. Also, as with all devices, it needs a reference point or ground. The needs of the device are represented as terminals on the left side of Figure . On the right side there is a simplified representation of the Arduino microcontroller, with only the pins that are used to control this particular device. In this case, only the ground and digital PWM pins (a specialized digital output pin) are used. Other symbols in the figure represent standard electronic components, including a power supply (round with +/-), capacitor (parallel lines), resistor (zig-zag line), and amplifier (triangle).

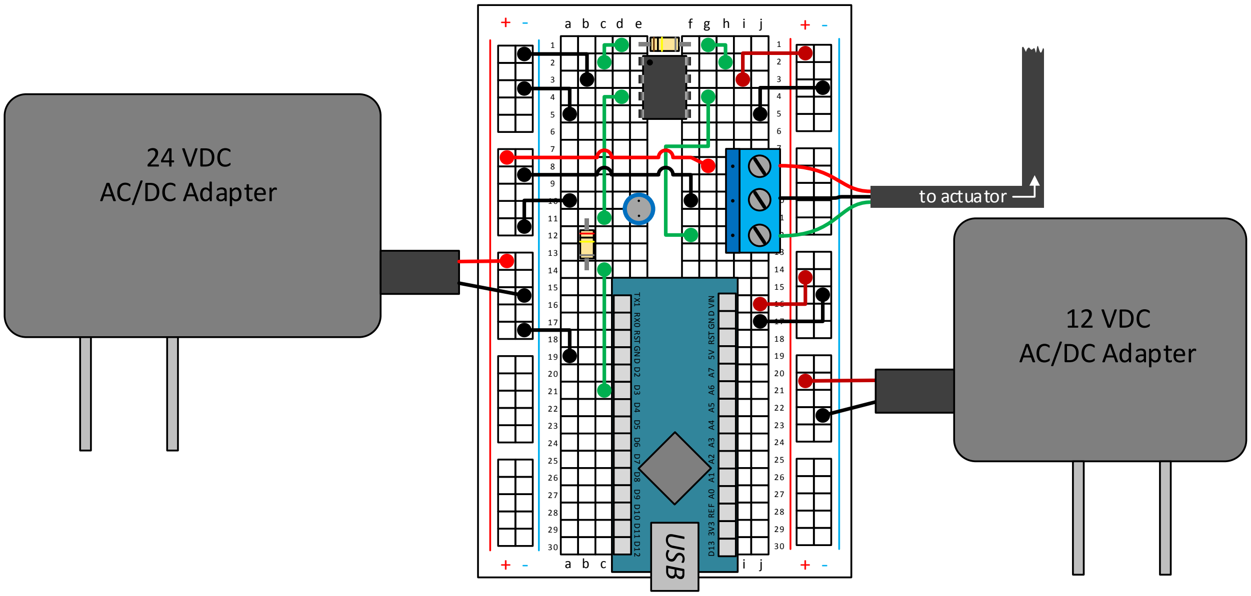


Figure B6: Breadboard layout for example circuit

Figure is a graphical representation of the assembled circuit on the breadboard. There is a screw-terminal installed with pins connected to the breadboard at 8j, 10j, and 12j. Wires leading to the valve actuator are inserted into the appropriate locations within the screw terminal. The top screw terminal, installed at 8j, is the power supply for the actuator with a value of 24 VDC, the center screw terminal is connected to ground, and the bottom screw terminal is connected to the variable voltage source from the Arduino. The 24 VDC connection is made by using a jumper wire, connecting the positive power rail to location 8g of the breadboard. The middle terminal is connected via another jumper wire to the negative left-side power rail, which represents ground, or zero volts. Each power rail is connected internally from top to bottom. The left-side power rails are connected to the 24 VDC power adapter, and thus each connection made to those rails share the same voltage as the power adapter. Likewise, a second power adapter on the right-side rails make those rails uniformly 12 VDC and 0 VDC.

The Arduino will be powered in this example via its VIN pin, connected to the right-side 12 VDC power rail. One of the Arduino's GND pins is connected to the right-side ground rail while the second GND pin is connected to the left-side ground rail, thus unifying the ground reference voltage.

At location 2e-5e and 2f-5f there is an integrated circuit (IC). The particular IC used is packaged in a common chip geometry, known as a dual in-line package (DIP). This particular 8-DIP, so-called for its 8 leads/pins, contains the internal circuitry necessary for the amplifier shown in Figure . Internally the layout and pin assignments can vary, so it is important to use the manufacturer's documentation to determine the correct pin connections. The datasheet for the IC used in these applications is shown below in Figure .

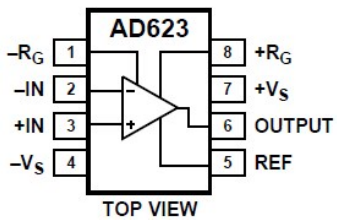


Figure B7: Datasheet for 8-DIP IC amplifier

Datasheets will often provide example circuits based on the desired use of the IC. This IC is used for simple doubling of an input signal. To achieve this result, pins 1 and 8 are connected via a 100 kΩ resistor (locations 1e and 1f), pins 2, 4, and 5 are connected to ground, pin 7 is connected to the power supply, and pins 3 and 6 are the voltage input and output, respectively. The voltage output needs to be a voltage between 0 and 10 VDC which controls the position of the valve actuator. The Arduino cannot provide a true analog voltage, and so a passive low-pass RC filter is added to the amplification circuit (as required by Figure), consisting of a resistor (location 11b, 14b) and capacitor (location 10e, 11e). All other connections are made using jumper wires.

The external circuits can become difficult to keep organized, so planning is important when deciding where to place components. Larger breadboards are often necessary, and ultimately the circuit should be soldered together to ensure good, stable connections. This example circuit only uses a single data pin of the Arduino. In applications where tens of Arduino pins are used, commercial circuit-layout software is often useful in organizing and planning circuit and component placement.