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AnalogDialogue

StudentZone—November 2016 Breadboarding and Prototyping Circuits

By **Walt Kester**

At some point as a student or engineer you will probably need to breadboard a circuit either to verify its performance or for use in a project. If it's a student project, your breadboard may actually be the final system. Fortunately, you can use modern solderless techniques to build breadboards that are robust enough to use with most student projects.

In addition to constructing circuits for projects, the breadboard is often used to verify circuit performance. While SPICE simulations are great tools (see https://wiki.analog.com/university/courses/electronics/circuitsimulationnotes), they have their limitations and often times at least a portion of the critical circuit (usually the analog section) needs verification with a breadboard. On the other hand, breadboards have their own set of limitations, so you need to be sure to read the Breadboarding Caveats section below.

Breadboards vs. Prototypes

Although the terms breadboard and prototype are often used interchangeably, a prototype usually implies soldered connections on some type of printed circuit board where copper traces are used to make the interconnections. On the other hand, the connections in solderless breadboards (more about them later) are not permanent, and the breadboard can be reused to make different circuits.

Various techniques have been developed for constructing hardwired prototype circuits on printed circuit boards; some of these are described in Tutorial MT-100[1] and the Jim Williams application note AN47[2] However, as a student you may find this approach too time consuming and difficult, and that the solderless breadboard is a more practical solution.

Breadboarding Integrated Circuits with Solderless Breadboards

Modern electronic circuits are manufactured with surface-mount components that are placed automatically and solder reflowed to densely populated multilayer printed circuit boards, making breadboarding or prototyping difficult. For this reason, many engineers find it more efficient to actually lay out the board on a CAD system and assemble a small quantity of boards for the first prototypes.

However, as a student you probably don't have access to a CAD system, printed circuit board assembly house, or the required finances. You may not even have access to a soldering iron station and other tools and machinery needed to work with small electronic components, so you need another reliable method to construct a prototype.

This is where a solderless breadboard is an invaluable aid to prototyping a circuit for an experiment or a project. These are readily available from distributors such as Digi-Key Electronics, as well as Amazon. Start with an internet search for solderless breadboards. There are a good number of them—many at very reasonable prices.

Figure 1 shows the top view of a typical solderless breadboard. The holes are designed to accept standard IC pins on 0.1" centers. The internal view of Figure 2 shows the details of the connections between the pins. The center part of the board is divided into two rows that are subdivided into a number of vertical columns having five pins connected together. The two horizontally connected rows at the top and bottom of the board make convenient buses for supply voltages and ground connections.

Integrated circuits in a standard dual in-line package (DIP) are placed horizontally across the center area of the breadboard as shown in Figure 3.

Figure 1. Solderless breadboard top view.

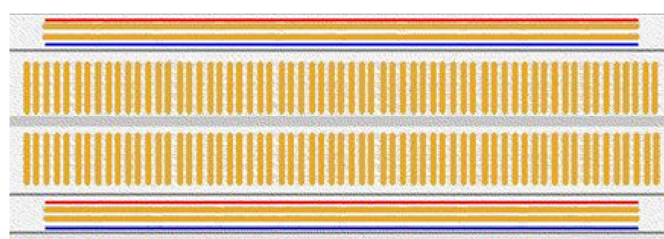

Figure 2. Arrangement of solderless breadboard internal connections.

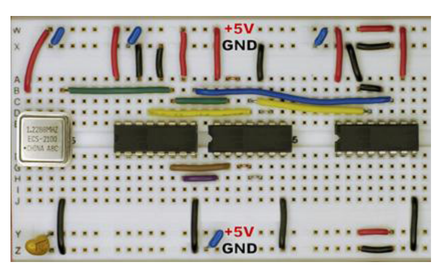

Figure 3. Wired solderless breadboard using leaded components and dual in-line packages.

The leads of components such as resistors and capacitors are inserted into the holes. Each set of five holes connected by a metal strip underneath forms a node. A node is a point in a circuit where two or more components are connected. Connections between different components are made by inserting their leads in a common node. The long top and bottom row of holes, indicated by the red and blue stripes are used for power supply connections. The rest of the circuit is built by inserting components and connecting them together with jumper wires. Solid rather than stranded wire is the best to use with breadboards like these. Jumper wires fitted with plug-in pins are also available for convenience.

You should have a few simple hand tools available as well:

- A pair of small wire cutters, often also called diagonal cutters to cut wires and component leads to length
- A small pair of long-nose pliers to bend and shape wires and leads
- A pair of wire strippers to remove the insulation from the ends of jumper wires
- A small screwdriver to adjust potentiometers and such

Using ICs

A solderless breadboard is designed for ICs available in DIP packages. While some ICs are available in both DIP and surface-mount packages, many are only offered in surface-mount versions. This makes breadboarding them next to impossible. As a solution, surface-mount parts can be mounted on adapter or breakout boards, which have DIP-compatible pins as shown in Figure 4.

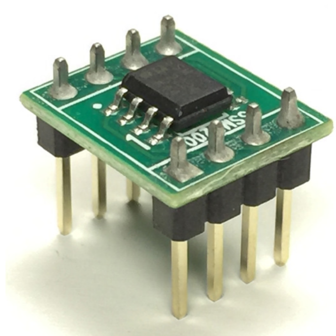

Figure 4. DIP-compatible breakout board for surface-mount devices.

The ADALP2000 Parts Kit from Analog Devices offers a number of popular surface-mount ICs on DIP breakout boards. If preassembled breakout boards are not available, you will have to use a blank breakout board and solder the surface-mount components to it yourself. Surface-mount-to-DIP breakout boards are also available from electronic component manufacturers such as Aries Electronics, Inc. (search for DIP breakout board).

Breadboarding Caveats: Beware of Parasitic R, L, and C

The pins, sockets, and jumper wires associated with a breadboard add parasitic resistance, inductance, and capacitance that can cause degradation in precision dc applications as well as high speed circuits. Since the breadboard has no ground or power plane, you must rely on ground and power busses that are difficult to decouple and have parasitic impedance. Proper decoupling between the power and ground pins of each IC is therefore mandatory in a breadboard.[3] With no ground plane it is impossible to maintain the controlled impedances required in RF circuits.

If you stick with the parts in the ADALP2000 Parts Kit, you will probably not run into trouble with analog circuits having bandwidths less than 1 MHz. However, it is always a good idea to run a sanity check on a breadboard by probing several points in the circuit with an oscilloscope to make sure nothing is oscillating—unless you are building an oscillator.

Breadboarding Digital Circuits

Up to now, we've been talking about analog circuit breadboarding, but digital circuits present significant challenges because of their extremely fast edge speeds. Even though you may operate a digital circuit at a clock rate of less than 1 MHz, chances are the rise and fall times of the logic transition edges are less than 1 ns. Without controlled connection impedances, these fast edges can produce frequencies well into the GHz range. The resulting ringing due to parasitics can produce false triggering and other effects that will make the digital circuit unreliable or useless.

How to Get Started

As with any skill, it's a good idea to practice before you actually need to use it (that is, your project is due in a week). You can get some practical experience with solderless breadboards by building a simple circuit. Start with building some analog circuits in the lab activities available in the Analog Devices Electronics I and II courses:

http://www.analog.com/en/education/courses-and-tutorials/electronics-i-and-ii/lab-activity-material-outline.html.

Most of these simple circuits can be built from the parts in the ADALP2000 Parts Kit. The kit includes an assortment of transistors, LEDs, resistors, potentiometers, capacitors, diodes, inductors, and sensors. It also includes a variety of useful ICs, including op amps, comparators, and regulators. There's also a solderless breadboard, and the kit comes with an assortment of jumper wires with pin ends. A complete parts list for the ADALP2000 kit can be found at: http://www.analog.com/en/education/.html.

There's a lot more that can be said about breadboarding, and we have just covered the basics here. The best way to learn this skill is by doing it and profiting from your mistakes. Good luck and have fun.

Reminder and Quiz Problem

If you missed the first installment of StudentZone in the last issue of *Analog Dialogue*, you might want to check it out using this link.

Please remember to register for a myAnalog and EngineerZone account so you can access resources and join in the student discussions. Please let us know of topics you would like covered.

Now, here's your next problem. When you're done, you can check your answer on the StudentZone community on EngineerZone:

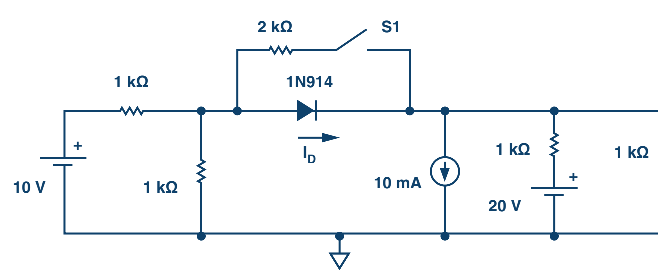

Figure 5. Quiz problem: Calculate the diode current I_D for two conditions: S1 open and S1 closed. Diode V-I curve can be found in the 1N914 data sheet at https://www.fairchildsemi.com/datasheets/1N/1N914.pdf.

Real Breadboards

The term breadboard originated during the vacuum tube era in the early 1920s. Tubes were plugged into sockets. The sockets and other large components were then screwed or nailed to wooden boards used for rolling dough. These breadboards made an ideal mounting platform for the components, and gave birth to the technique's name. Interconnections were made by soldering wires between appropriate pins on the tube sockets. Power and ground buses—made from heavy copper wire—were nailed or screwed to the wooden board. Early breadboards often used additional nails as connection points where wires could be wrapped and soldered. Terminal strips were also used for interconnection points.

Figure A shows a 1923 radio using the original breadboard construction technique. It was manufactured by Signal Electric Manufacturing Company, in Menominee, Michigan.

Figure A. Early radio receiver constructed using wooden breadboard techniques. Note that vacuum tube plate voltages can be as high as 300 V dc, so some caution must be exercised after power is applied.

As vacuum tubes became smaller and frequencies increased, aluminum chassis boxes were often used for breadboarding circuits. Holes were punched in the chassis for mounting the tube sockets, and terminal strips allowed point-to-point wiring of the circuits as shown in Figure B. This technique reduced circuit size, and the aluminum chassis provided a low impedance ground plane often needed for high frequency circuits.

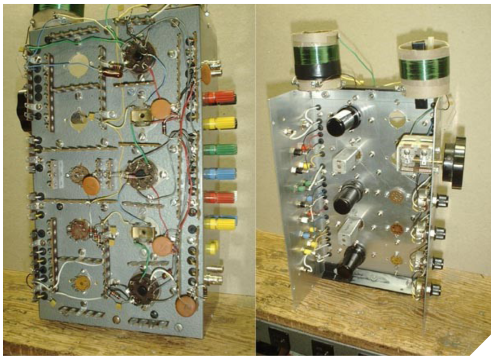

Figure B. Top and bottom view of a 3-tube radio, breadboard constructed from an aluminum chassis showing tube sockets and terminal strips for interconnect points.[4]

With the introduction of transistors in the 1950s and integrated circuits in the 1960s, the tremendous reduction in component sizes led to other, more appropriate construction techniques for prototyping circuits as described in this column (also see MT-100 and the application note AN47 by Jim Williams), but the term breadboard is still in common use to describe them.

References

[1] Tutorial MT-100, *Breadboarding and Prototyping Techniques*. Analog Devices, Inc.

[2] Jim Williams. Application Note 47, *High Speed Amplifier Techniques*. Linear Technology Corporation, August 1991. Before his untimely passing in 2011, Jim was a legendary circuit designer, application engineer, and expert in constructing prototypes of high performance analog circuits. This application note has numerous examples of Jim's high speed prototype construction techniques.

[3] Tutorial MT-101, *Decoupling Techniques*. Analog Devices, Inc.

[4] Max Robinson. *Fun with Tubes*. Be sure to read an inspirational EE Web article about Max at http://www.eeweb.com/spotlight/interview-with-max-robinson.

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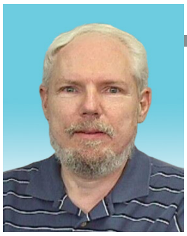

Walt Kester [walt.kester@analog.com] is a corporate staff applications engineer at Analog Devices. During his many years at ADI, he has designed, developed, and given applications support for high speed ADCs, DACs, SHAs, op amps, and analog multiplexers. An author of many papers and articles, he prepared and edited 11 major applications books for ADI's global technical seminar series; topics include op amps, data conversion, power management, sensor signal conditioning, mixed-signal circuits, and practical analog design techniques. His latest book, *Data Conversion Handbook* (Newnes), is a nearly 1000-page comprehensive guide to data conversion. Walt has a B.S.E.E. from NC State University and an M.S.E.E. from Duke University.