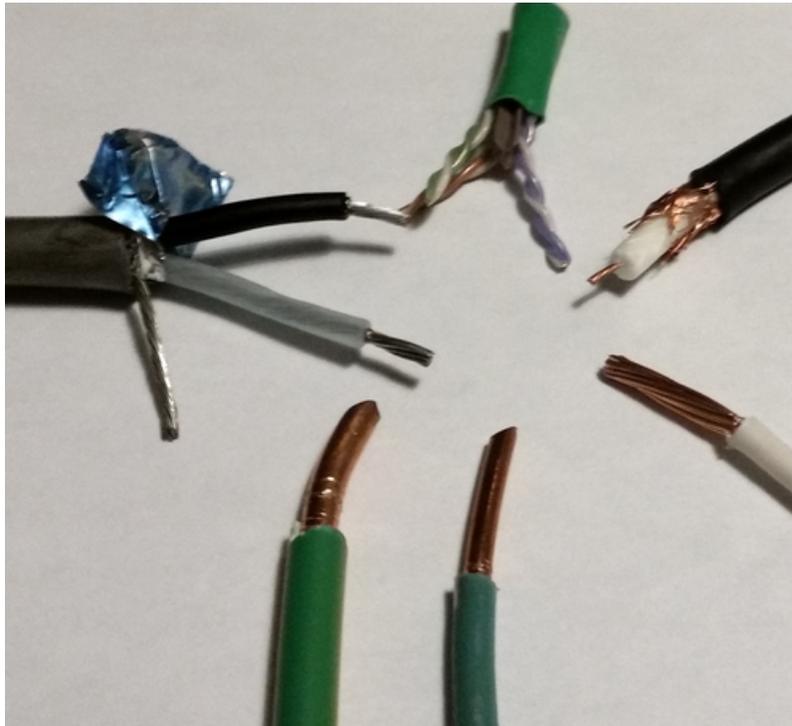


 adafruit learning system

Wires and Connections

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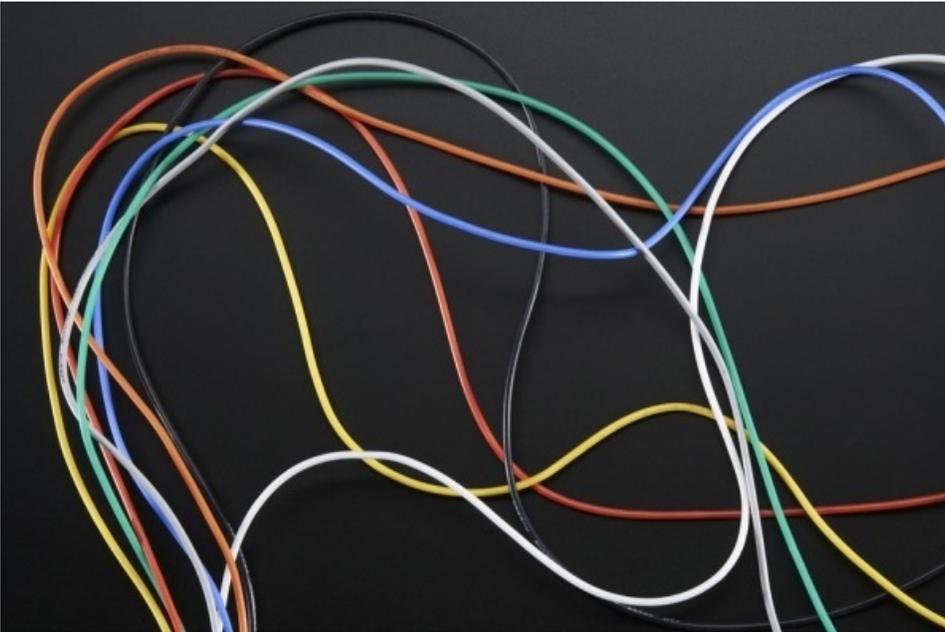
Overview

Wires are the electrically conductive connections between the elements in electronic circuitry. Designing your project or following many Adafruit guides, there are wires interconnecting different parts. Theoretically, these are zero resistance, perfect connections. On the breadboard, they are nice colored jumper wires. In practice, the designer has a many possible choices of how to connect electronic parts together.

Connections may be broken down into three categories:

1. Wires
2. Cables
3. Connectors on the ends of wires

Adafruit carries a wide variety of materials to help the hobbyist wire projects.



Wire

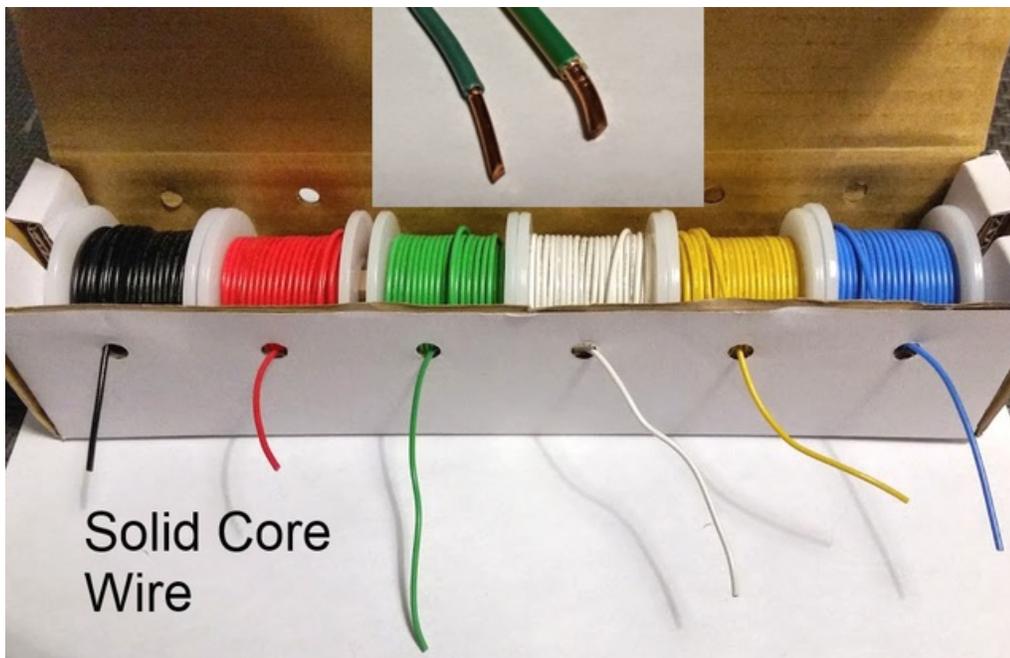
Wires are method for conducting electrons from component A to part B. Folks ask Adafruit: which wires should I choose for my project? To make an informed decision, one must know how wire is constructed and made available to consumers.

Materials

Wire may be drawn from different conductive materials, most often metal. Gold and silver are excellent conductors of electricity. But exotic metals are often soft and expensive. Most practical wires you may use are made mostly of copper and tin.

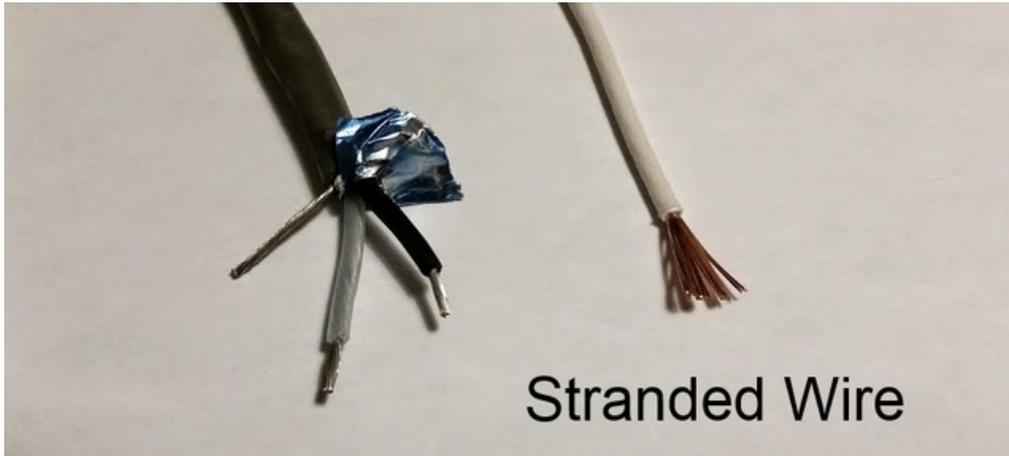
Solid verses Stranded Wire

A good number of wires you may use are fabricated as a solid cylinder of metal. These are called solid conductor wires. Solid wires, tend to be hard to bend as they get bigger in size.



Some smart person found that, like rope, if you make a larger wire out of smaller strands of wire twisted together, you get the benefits of a bigger wire while getting the benefits of bendability.

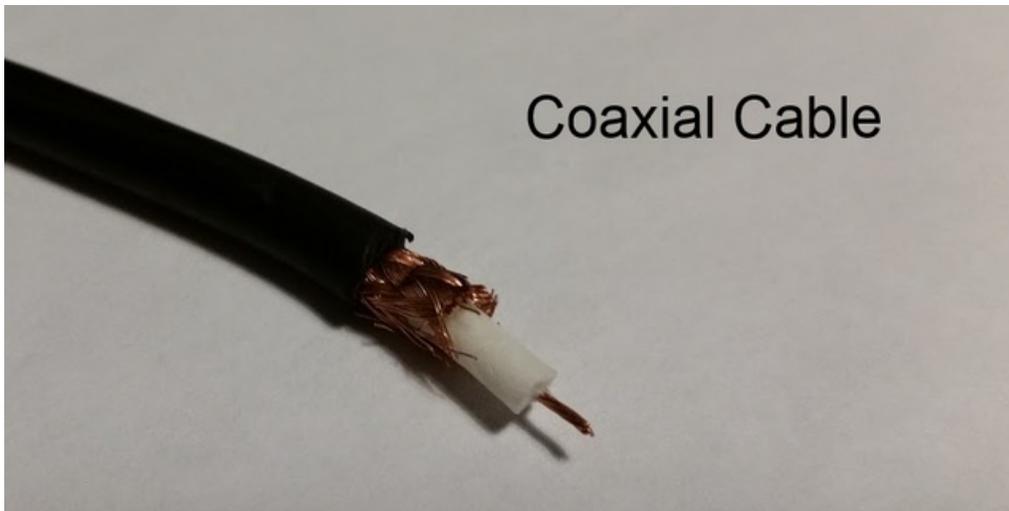
Why wouldn't one always use stranded wire? Stranded wire can be harder to make connections on the ends - all those wire strands make it hard to put connectors on.



Wire Covers and Jackets

Anyone who has accidentally touched some metal to the wrong part of a circuit and gotten a spark has found out that it is very important to have circuit parts not touch where they are not supposed to. The method of doing this with wires is to coat them in a sheath of insulating (non-conductive) material. Older wires used paper or cotton, very hard to deal with. Modern wires most often use some sort of plastic coating for most wire sizes. Tiny wires used in transformers, relays, and other coils may coat the wire in a clear enamel so it looks like it is bare but it isn't.

To connect to the ends of insulated wire, you must remove a bit of insulation from end. This is called *stripping* the wire and should be done carefully to avoid cutting through the wire or slipping and cutting your hand. Wire stripping tools make the job easier. Even enamel wire must be stripped on the ends, often gentle scraping with a knife or sand paper will do the trick. Once stripped, the wire is ready to connect to the proper point in your circuit.



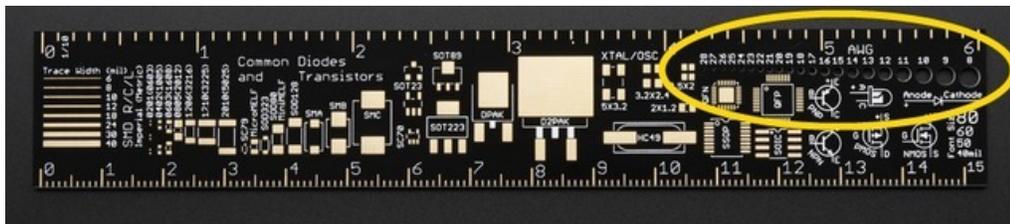
Wire Gauges

Size Matters

You'll probably have noticed wires come in many different sizes. Take apart a relay and the coil has fine copper wire thinner than human hair. On the other side are thick cables feeding power into homes and businesses.

With increasing size, wire can handle more electron flow (current, measured in [Amperes \(https://adafru.it/CeQ\)](https://adafru.it/CeQ)). Just like a garden hose, a larger diameter hose carries more water in a given time over a given distance.

Wire sizes are most often measured in standardized *American Wire Gauge* (AWG) sizes. The electronics industry uses the diameter of the wire in predefined sizes for manufacturability and known electrical characteristics.



The [Adafruit Ruler \(http://adafru.it/1554\)](http://adafru.it/1554) has a handy wire gauge finder built in from 8 to 28 AWG

Below is a table of American Wire Gauge standard sizes and the characteristics of each wire size. For a particular gauge, it has a set diameter and cross-sectional area. When winding wire around for an inductor, coil, or transformer it is handy to know how thick the wire will stack up, which increases by wire gauge. An important measure is the electrical resistance of the wire which increases as the gauge goes higher and the diameter decreases. This is measured on ohms per kilometer or milliohms per meter. Finally the last column for Americans lists national electrical code current capacity for larger gauge wires - it is a good demonstration of current capacity changing as wire area changes.

AWG	Diameter	Turns of Wire, no insul.	Area	Copper resistance	Maximum Amperage
	(mm)	(per cm)	(mm ²)	(Ω/km) (mΩ/m)	for wiring (amps)
0 (1/0)	8.251	1.21	53.5	0.3224	245
1	7.348	1.36	42.4	0.4066	211
2	6.544	1.53	33.6	0.5127	181
3	5.827	1.72	26.7	0.6465	158
4	5.189	1.93	21.2	0.8152	135
5	4.621	2.16	16.8	1.028	118
6	4.115	2.43	13.3	1.296	101
7	3.665	2.73	10.5	1.634	89
8	3.264	3.06	8.37	2.061	73
9	2.906	3.44	6.63	2.599	64
10	2.588	3.86	5.26	3.277	55
11	2.305	4.34	4.17	4.132	47

12	2.053	4.87	3.31	5.211	41
13	1.828	5.47	2.62	6.571	35
14	1.628	6.14	2.08	8.286	32
15	1.45	6.9	1.65	10.45	28
16	1.291	7.75	1.31	13.17	22
17	1.15	8.7	1.04	16.61	19
18	1.024	9.77	0.823	20.95	16
19	0.912	11	0.653	26.42	14
20	0.812	12.3	0.518	33.31	11
21	0.723	13.8	0.41	42.0	9
22	0.644	15.5	0.326	52.96	7, Common for breadboards
23	0.573	17.4	0.258	66.79	4.7
24	0.511	19.6	0.205	84.22	3.5
25	0.455	22	0.162	106.2	2.7
26	0.405	24.7	0.129	133.9	2.2
27	0.361	27.7	0.102	168.9	1.7
28	0.321	31.1	0.081	212.9	1.4
29	0.286	35	0.0642	268.5	1.2
30	0.255	39.3	0.0509	338.6	0.86
31	0.227	44.1	0.0404	426.9	0.70
32	0.202	49.5	0.032	538.3	0.53
33	0.18	55.6	0.0254	678.8	0.43
34	0.16	62.4	0.0201	856	0.33
35	0.143	70.1	0.016	1079	0.27
36	0.127	78.7	0.0127	1361	0.21
37	0.113	88.4	0.0100	1716	0.17
38	0.101	99.3	0.00797	2164	0.13
39	0.0897	111	0.00632	2729	0.11
40	0.0799	125	0.00501	3441	0.09

It is common to see the even size gauges in sizes 10 AWG and above. The smaller odd sizes are not seen as often.

For a majority of projects, getting the exact gauge of wire is not a critical factor - close enough is usually fine. Here are some things to consider for choosing a gauge:

1. Power - if you have high current requirements in a circuit like large motors or many LED lights, select thicker wire starting at 18 AWG and lower. The size is based on handling the current while remaining cool plus providing lower resistance. This goes for wearables also - do not sew too many power hungry LEDs with the thinnest wire that cannot handle the current draw.
2. Breadboards - typically breadboard holes only handle a small range of wire gauges. Too small a wire and it falls out or makes a poor connection. Too large a wire will bend out a hole or just not fit. It is best to buy some wire

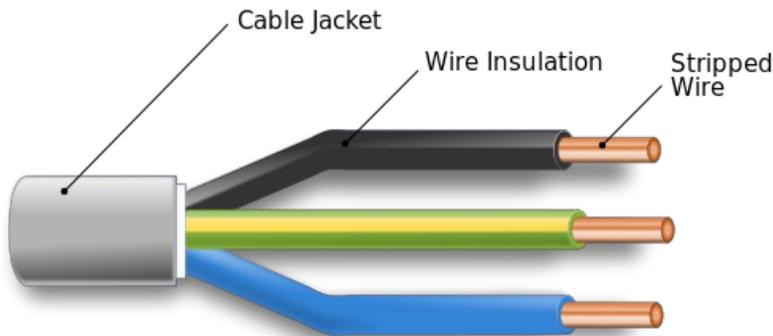
specifically marketed for breadboards, most often 22 gauge. Alternatively, if you run across some solid telephone wire from a recent installation, it's a tad smaller but works.

3. Resistance - Although much of the time you can design circuits thinking that wires have near zero electrical resistance to current flow, there are times where you must choose wire so that resistance is not a big factor. If temperature is a factor in resistance measurements, take the resistance per kilometer above (we'll label that R_0), and for copper wire, resistance related to temperature is $R = R_0 * (1 + 0.004 * (T - 20))$ where the temperature T is in Celcius. You can take resistance R and multiply by the number of kilometers for ohms, meters for milliohms.

Cable

Any wire run which uses more than one conductor is called a cable. While some rolls of "speaker wire" etc. may be called wire, they are actually cables. Cabling is used in everything from the smallest project to aircraft carriers and in the [Large Hadron Collider \(https://adafru.it/emO\)](https://adafru.it/emO).

The diagram below shows a typical cable consisting of three insulated wires:



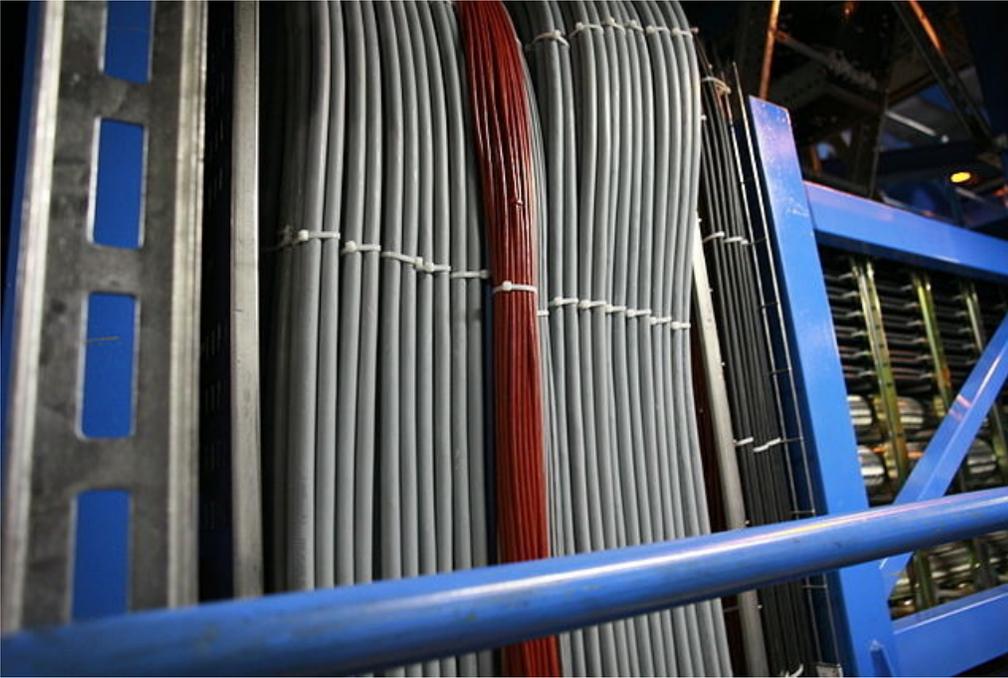
"Cable Cross Section" by Marekich - Own work. Licensed under CC BY-SA 3.0 via Wikimedia Commons

Selecting The Right Cable

You will want to specify the type of cable based on your application. Here are some steps to take to specify desired cable types:

1. Count the number of conductors - you will want to know how many power and signal wires you need to go from one point to another. If you have two wires performing a specific function (like a positive and negative power pair or a signal wire and its ground) then they may be considered a *pair*. If they are paired within the jacket by twisting them together this is called a *twisted pair*.
2. Size the wires appropriately - select the wire gauge for each conductor. For power wiring, size the conductors so the current flowing through them will not heat the wires or provide too much resistance over the given length.
3. Select solid versus stranded wire - most longer cables are stranded wire for flexibility. Solid conductor is used for smaller wires or specialty wire like that used in residential power in some countries.
4. Shield sensitive signal wiring - cables carrying higher-frequency signals may "bleed" those signals into other conductors or other wires. Wires that need to be protected from others can be twisted together and/or have a foil-like metal *shield* around them to provide protection for those wires. Some wire cabling has a non-insulated *drain* wire to provide a common ground between two points.
5. Individual conductor covering - you often have a choice of colors for conductors in a cable. For example a black and red (or white) twisted pair may be used for power and another twisted pair with different colors may be signal wires. Such a cable would be usually listed as two-pair. If the wires do not need to be paired together, for example you have four signal wires, you might specify 4 conductors. Four conductor and two pair both have four wires.
6. Overall bundle covering - the *jacket* is the overall cover for multiple conductors. It holds all the conductors together, keeps them waterproof and protected. For signal wiring, the jacket is often grey or black although specialty cabling like for LAN wiring may be of any color.

So as you see, cabling may range from a single pair (two-conductor) to cables with hundreds of conductors like that used in copper phone trunk lines.



Picture by Robert Scoble licensed under the [Creative Commons \(https://adafru.it/emP\)](https://adafru.it/emP) Attribution 2.0 Generic (<https://adafru.it/emQ>), [Wikimedia Commons \(https://adafru.it/emR\)](https://adafru.it/emR).

Finding Manufactured Cable

Once you have your cable requirements written down, you can go to a company or shop to find a cable which incorporates the features you need.

To look up what commercial wire matches your needs, you can go to a specific manufacturer's catalog. You can do this by one of three ways:

1. Browse the offerings of specific companies like [Adafruit \(https://adafru.it/dAR\)](https://adafru.it/dAR). Companies select products that may be useful for specific purposes. Specialty cable may be offered by companies not offered by other manufacturers or electronics companies.
2. Browse the offerings of a specific cable manufacturer. [Belden \(https://adafru.it/emS\)](https://adafru.it/emS) has a popular selection of multiconductor cabling as does other companies. For example, specifying Belden 5341, this is 18 AWG with two pairs of wires, non-shielded.
3. You can [search a vendor like Digi-key \(https://adafru.it/emT\)](https://adafru.it/emT) which has a form-based cable finding web page. The page has menus listing features, allowing one to narrow a search to a specific subset of cabling and the ability to list multiple manufacturers.

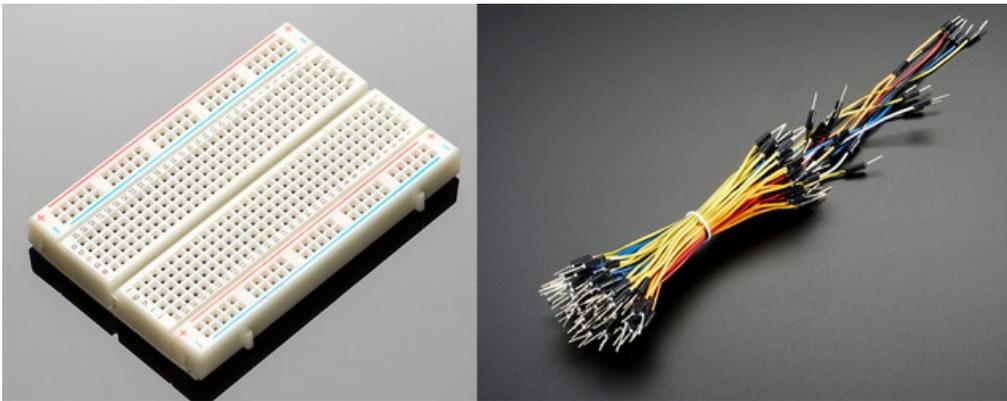
Top Wire Types to Consider

Which Wire To Use For My Project?

The choice of which wire and non-terminated cable to use depends solely on your application. For various categories, the types of wiring to consider are listed.

Breadboarding and Prototyping

Many designs are tested using a prototype, a functional mockup of the circuit. For electrical circuits, one of the most popular ways to prototype is to use a breadboard. The breadboard has electrical connections allowing wires to be easily placed and moved as needed.



Breadboard wires (<http://adafru.it/153>) are pre-cut flexible stranded wires of different lengths come with stiff tips. These allow for very fast wire routing.

Solid-core breadboard wire (<http://adafru.it/1311>) is usually 22 gauge and is stiffer than the pre-fab wires. Breadboard wire also comes in a number of colors. These wires are cut by the user and about 3/8 inch (4 mm) of insulation taken off using a tool like a [wire stripper](http://adafru.it/527) (<http://adafru.it/527>). If you use a smaller wire gauge and force it into the breadboard holes, you can damage the breadboard.

Wearables

Conductive Thread: Adafruit carries different weights of stainless steel thread which can be washed and last longer than older silver based thread. [Two-Ply](http://adafru.it/640) (<http://adafru.it/640>) is the lightest thread while [three-ply](http://adafru.it/641) (<http://adafru.it/641>) is a bit tougher and can handle more current. A final thread falls somewhere between a [thick thread and a thin yarn](http://adafru.it/603) (<http://adafru.it/603>). Most sewing machines wouldn't be happy with such thread since its thick, but it has the 'furry' soft feel of yarn, which makes it poor for most e-textiles/wearables but its high conductivity and softness make it a great thread for making [smartphone gloves](https://adafru.it/CeR) (<https://adafru.it/CeR>)!

Silicone-covered Stranded Wire: This wire bends well and the jacket covering is more flexible than morerigid PVC.

The [26 gauge wire](http://adafru.it/1970) (<http://adafru.it/1970>) is good for low power transfer while the [30 gauge wire](http://adafru.it/2051) (<http://adafru.it/2051>) is a bit thinner and good for signals or lower power transfer.

Ribbons: [Ribbons with conductive wires](http://adafru.it/1373) (<http://adafru.it/1373>) embedded or with conductive thread (in [black](http://adafru.it/1424) (<http://adafru.it/1424>) or [white](http://adafru.it/1139) (<http://adafru.it/1139>)) have the wires already built-in for stealth.

Final Projects

For non-wearables, you can encounter many different environments for your project. Here are a few examples of environments and materials you may use to built lasting projects.

Exterior Cabling requires taking into account changing temperatures and rough weather. Outside cabling should have a jacket that can withstand the weather it will be exposed to. Cable manufacturers provide temperature ratings for their cable (one hopes). If you need additional protection, cables may be run in PVC pipe, EMT conduit or rigid pipe (for buried cables). Local regulations may govern what type of conduit is acceptable.

Outdoor Enclosures protect your project from damage and dust while often providing the exterior finish to the electronics inside. For outside projects, [weatherproof enclosures \(https://adafru.it/emV\)](https://adafru.it/emV) are ideal. Plastic and metal boxes come in many shapes. But how can wiring enter an enclosure and maintain a weather-tight seal? [Cable Glands \(https://adafru.it/CeS\)](https://adafru.it/CeS) come in various sizes and allow cables to enter an enclosure with a tight seal.

Projects on the Move provide a particular challenge for wiring. This is true for robotics, automotive projects, and wearables. The vibrations while moving may loosen connections. Rather than use a breadboard as a permanent platform, soldered wire connections are often best. Adafruit's [breakout boards \(https://adafru.it/emX\)](https://adafru.it/emX) have presoldered components able to withstand normal vibrations in mounted projects. If any wiring will flex, select the wire to withstand repeated bending but be aware that any wire will break with severe stress or very frequent flexing.

Rotating Parts provide a tricky challenge for wiring. How does one connect electronics to something rotating like a robot's wheel or neck? Adafruit's [slip rings \(https://adafru.it/CeT\)](https://adafru.it/CeT) feed several wires through a rotating center providing the ideal coupling with no tension on the wires on either side.

Secure it - clips and bolts provide the mechanical connections in final projects. Most Adafruit circuit boards have *mounting holes* which accomodate mechanical screws to hold the board. [Standoffs \(https://adafru.it/emZ\)](https://adafru.it/emZ) are handy for spacing two circuit boards together. For wiring, you can look for plastic cable clips and tie wraps to secure wiring to other rigid structures. For tacking wires to a surface, a bit of hot glue or [Sugru \(https://adafru.it/en0\)](https://adafru.it/en0) works very well.

Connectors

Terminators

For wiring projects "on the fly", many people strip back two wires and twist them together. This usually makes a decent electrical connection (if twisted tight). But you run into the same trouble as with bare wires - bare metal may short out an electrical connection or break it if come untwisted. Fortunately, some clever people over the years have invented connectors to place on the ends of wire and cable to make good electrical connections that are mechanically easy to work with.

Top Picks

Here are some recommended connectors to consider based on typical projects:

Breadboards

Breadboards and many perforated boards come with 0.1 inch hole spacing. There are deviations from this including [Xbee radios \(https://adafru.it/en1\)](https://adafru.it/en1) as an example. A number of connectors support 0.1 inch spacing. Adafruit [premium \("rainbow"\) jumper wires \(https://adafru.it/CeU\)](https://adafru.it/CeU) have female or male connectors with individual 0.1 inch headers on each wire.

Power

There are quite a few types of power connectors. Some common ones you will find:

1. [2.1 mm power connector \(https://adafru.it/en3\)](https://adafru.it/en3) is very often used to connect low voltage power supplies to circuit boards like an Arduino Uno. When wiring these up, be sure to match the positive and negative wires to the right connections on each side. A common configuration is positive on the inside conductor but there are exceptions out there. If you need to make a 2.1mm connector, there are [adapters with screw terminals \(https://adafru.it/CeV\)](https://adafru.it/CeV) to make it easy.
2. [JST-PH \(https://adafru.it/en5\)](https://adafru.it/en5) is the connector used on common 3.7 volt lithium-ion batteries and 3 to 6 volt battery packs.
3. [USB connections \(https://adafru.it/en6\)](https://adafru.it/en6) and cables are now commonly carrying 5 volts for portable electronics. The main power connector on the [Raspberry Pi \(http://adafru.it/2125\)](http://adafru.it/2125) is a Micro-USB connector.

Radio Frequency Use

Circuits that have higher frequency signals should use specialized cables and connectors. Often coaxial cable is used to provide a known electrical characteristic and shielding profile. This helps keep signals from bleeding out to unwanted places and matches the electrical characteristics of the cable and the connection. Common RF connectors are SMA (and RP-SMA), uFL, and BNC. [Adafruit carries a number of these connectors and accessories \(https://adafru.it/CeW\)](https://adafru.it/CeW). Digi-Key and other large parts retailers will have good selections of RF connectors. You may wish to refer to more in-depth information on RF connectors and RF wiring for specialized uses.

Waterproof Connections

Besides [Cable Glands \(https://adafru.it/en8\)](https://adafru.it/en8) for box connections, there are [waterproof in-line connectors \(https://adafru.it/CeX\)](https://adafru.it/CeX) that are very handy for keeping water out of connections which need to be disconnected now and then. [Shrink wrap \(http://adafru.it/344\)](http://adafru.it/344) is also good for weatherproofing or [special wrap \(http://adafru.it/1020\)](http://adafru.it/1020) for food environments.

Audio and Video

In between low signal and radio frequency, A/V signals often have special connections. The standard is called the [RCA connection \(https://adafru.it/CeY\)](https://adafru.it/CeY), used for audio and older NTSC and PAL standard definition video. High definition video most often uses [HDMI cables \(https://adafru.it/CeZ\)](https://adafru.it/CeZ). Many non-fidelity audio signals are wires with different connections ranging from [terminal blocks \(https://adafru.it/enc\)](https://adafru.it/enc) to banana plugs.



Network and Telecom

Telephone wire in the U.S. uses an [RJ-11 \(https://adafru.it/end\)](https://adafru.it/end) jack while Ethernet LAN copper connections use an [RJ-45 \(https://adafru.it/end\)](https://adafru.it/end) connection. The connectors are most often placed onto 8 conductor LAN cable with a specialized [crimp tool \(https://adafru.it/dfN\)](https://adafru.it/dfN).

Other Multiconductor Cables

Many other cables have metallic pins which crimp on each wire and then the pins are held together in a connector assembly. A [general purpose crimp tool \(http://adafru.it/1213\)](http://adafru.it/1213) can make such pin connections easier. The specific connector should be selected according to your application.

Wrap-Up

While this tutorial has provided a fair amount of information about wire and cables, actually making the choices of which to use boils down to some simple steps:

1. If you are prototyping low power circuits, you can use breadboards, breadboard wire and/or some smaller gauge wire between components.
2. For low-power projects, batteries will most often have a JST connector. Low voltage power supplies most often have 2.1mm barrel connectors.
3. For high current projects such as using many LEDs (NeoPixels, DotStars, etc.), add up the maximum current of the LEDs and the project, then size the power supply to meet that current draw (and possibly a bit extra for headroom).
4. For flexibility, use stranded wire. For ease of soldering small wires to circuit boards, use solid-core wire.
5. For wall (mains) power, always follow the electrical code in your region and country. ALWAYS exercise caution as mains power can cause great harm if a bare conductor is touched. NEVER plug bare wire into a wall socket.
6. Make good electrical connections. Soldering permanent projects forms a good electrical connection and a fair mechanical bond. Specialized end connectors can provide a good mating surface with other components.
7. Insulation protects your wiring. After running your wire and making connections, be sure wiring is not exposed where it could touch other wires or small fingers.
8. Many cables come premade from companies like Adafruit. If you need a specialized cable, you can obtain the wire and connectors for a custom application.
9. If you use or reuse magnet or transformer wire, it has a clear laquer coating which you need to scrape off the ends when connecting to other circuit parts or a battery.