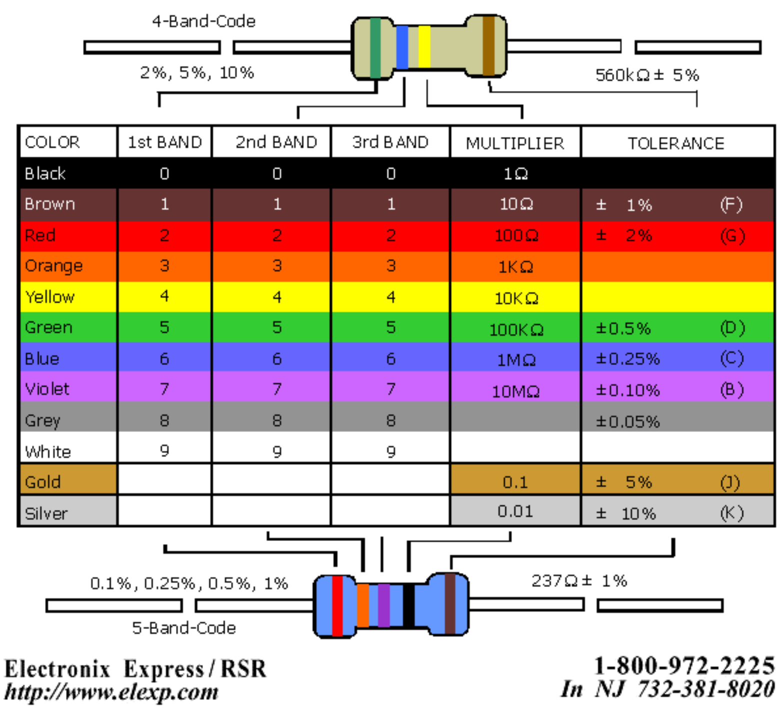
Passive DC electrical circuits review:

This review will begin with an overview of basic electrical elements:

Resistors:
A resistor is a dissipative element that converts electrical energy to heat and follows Ohm's law as:

$$V=IR$$

with $R=\rho L/A$, ρ the resistivity of the material, L and A the length and cross-sectional area of the material. Typical resistors are used in logic circuits and can handle up to ¼ Watt of power ($P=I^2/R$).



COLOR	1st BAND	2nd BAND	3rd BAND	MULTIPLIER	TOLERANCE
Black	0	0	0	1Ω	
Brown	1	1	1	10Ω	± 1% (F)
Red	2	2	2	100Ω	± 2% (G)
Orange	3	3	3	1KΩ	
Yellow	4	4	4	10KΩ	
Green	5	5	5	100KΩ	±0.5% (D)
Blue	6	6	6	1MΩ	±0.25% (C)
Violet	7	7	7	10MΩ	±0.10% (B)
Grey	8	8	8		±0.05%
White	9	9	9		
Gold				0.1	± 5% (J)
Silver				0.01	± 10% (K)

Equivalent resistance for resistors in series:

$$R=R_1+R_2$$

Resistors in parallel:

$$R=R_1R_2/(R_1+R_2)$$

Capacitors:
A capacitor is a passive element that stores energy in the form of an electric field as a result of a separation of electrical charge. DC current does not flow through a capacitor. Instead, charges are transferred from one side of the capacitor to the other through the surrounding circuit, thus causing a displacement current. This is governed by the equation:

$$I(t)=C*dV/dt$$

With *C* the capacitance in farads.

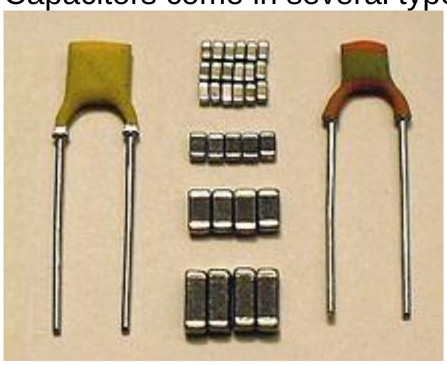
Equivalent capacitance for capacitors in series:

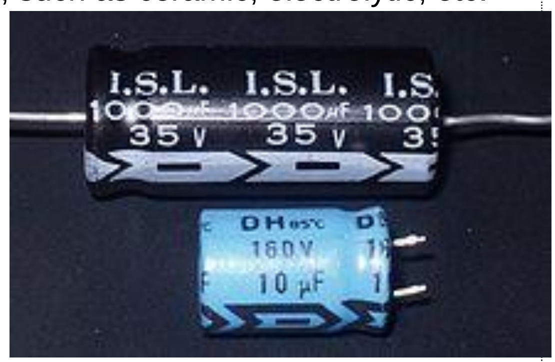
$$C_{eq}=C_1C_2/(C_1+C_2)$$

Capacitors in parallel:

$$C_{eq}=C_1+C_2$$

Capacitors come in several types, such as ceramic, electrolytic, etc.


Ceramic



Electrolytic capacitors

Note: Electrolytic capacitors are polarized and have a positive and negative end, and must be placed in the circuit in the proper direction.

Note: Capacitance values are either printed directly with a label, ex. 70 pF or in a 3-digit code as: $X_1X_2X_3$ with the capacitance given as: $X_1X_2\ 10^{X3}$ pF.
Note: Use caution when working with capacitors, they can retain their charge long after power is removed from a circuit (ex, TV).

Inductors:

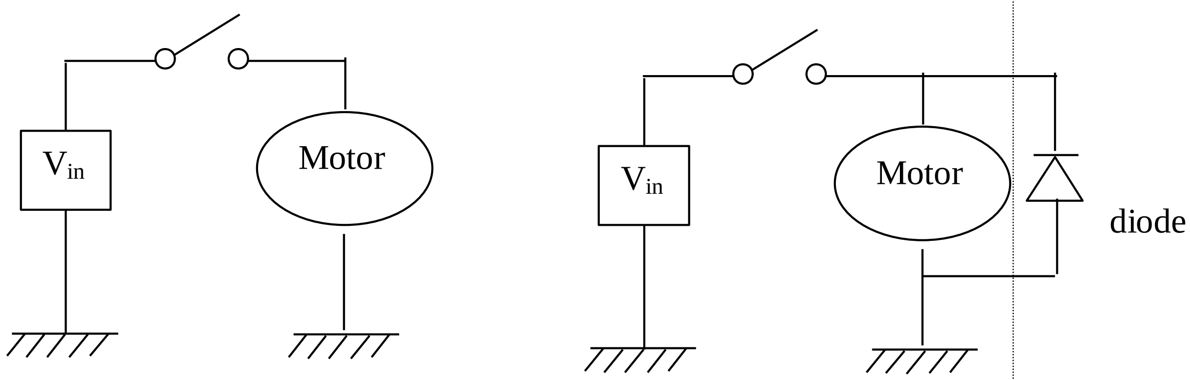
An inductor is an element that stores energy in the form of a magnetic field, and can be created in a simple form as a coil of wire. The voltage to current relationship is given as,

$$V(t) = L*dI/dt$$

with L the inductance measured in Henry's. The current is given as,

$$I = \frac{1}{L}\int_0^t V(\tau)d\tau \ .$$

Note from this equation that the current cannot change instantaneously, but increases or decreases over time as a function of the voltage. This is an important consideration to keep in mind in any circuit that contains an inductive load. A good example is an electric motor which has a large inductance, and therefore cannot be turned on or off in a very short period of time. This is also true of relays and solenoids. This is true even in the simplest of circuits and must be considered in high frequency circuits. One phenomenon common in switching circuits is called inductive kick and can cause arcing in the switch. This can be corrected with a diode as shown in the circuit below.



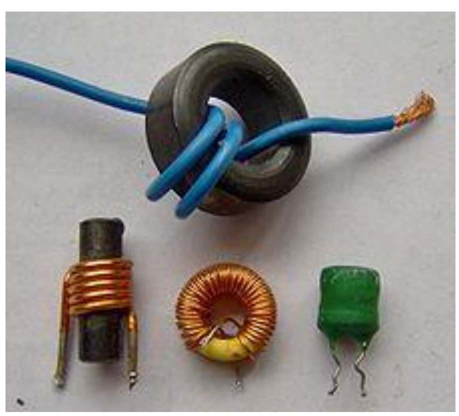
Circuit experiencing inductive kick Circuit corrected with a diode

Equivalent inductance for inductors in series:

$$L_{eq}=L_1+L_2$$

Inductors in parallel:

$$L_{eq} =L_1L_2/(L_1+L_2)$$



Evaluating Circuits:
Circuits are evaluated using Kirchoff's laws.

Kirkhoff's current law (KCL) states that the sum of currents flowing into or out of a node is zero:

$$\sum_{k=1}^{n} I_k = 0$$

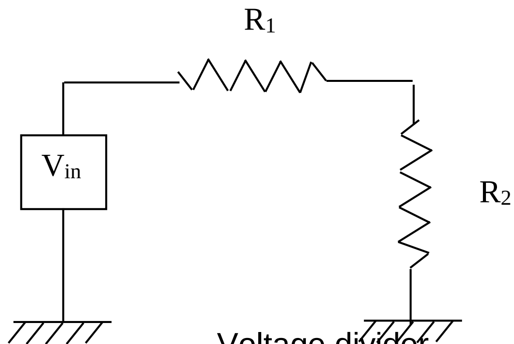
Kirkhoff's voltage law (KVL) states that the sum of the voltages around a closed loop is zero.

$$\sum_{i=1}^{N} V_i = 0$$

To apply KVL to a circuit, first assume current directions through every element and assign the appropriate voltage polarity across each element assuming the voltage drops across an element in the direction of the current. Then, apply KVL in any direction and complete the loop.

Example, Circuit Analysis:

Voltage Divider:
A voltage divider can be used to divide a source voltage to a lower, desired rate. Consider for example the circuit below:



Voltage divider

The voltage at each location is given as:

$$V_{R1}=R_1V_s/(R_1+R_2)$$
$$V_{R2}=R_2V_s/(R_1+R_2)$$

Voltage dividers are appropriate only in circuits that use a small amount of current, for example when a reference voltage is needed. For applications requiring more current, a voltage regulator should be used.

Alternating Current Circuit Analysis:
A sinusoidal ac voltage $V(t)$ is:

$$V(t) = V^*\sin(\omega t+\phi)$$

with V the amplitude, ω the frequency and ϕ the phase angle. The frequency and period of the waveform are related as,

$$f=1/T=\omega/2\pi$$

Steady-state analysis of AC circuits proceeds using phasor analysis, in which the voltage and current through each element in the circuit is described as a complex number. For example:

$$Ve^{i(\omega t+\phi)} = \mathrm{V}[\cos(\omega t+\phi)+\sin(\omega t+\phi)] = V_x + V_y i$$

In a steady state condition, the voltage across each element in the circuit will oscillate at the driving frequency, w and will have a constant voltage and phase shift from the input. Thus, the magnitude and phase shift are variables to be determined. The impedance of resistors, capacitors and inductors are given as:

$$Z_R = R$$

$$Z_c = -i/(\omega C)$$

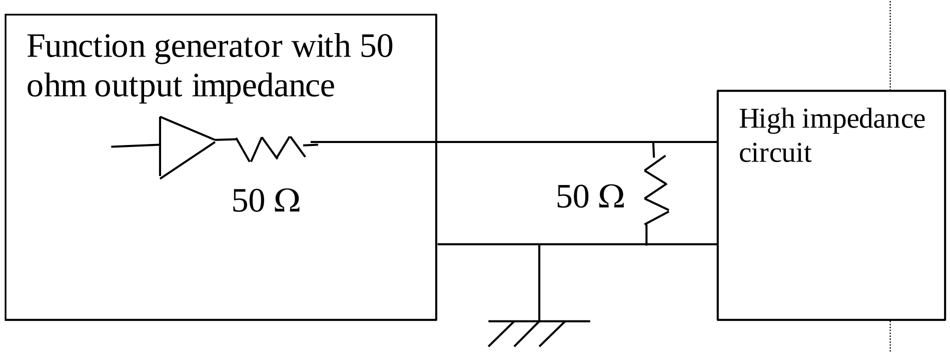
$$Z_L = i\omega L$$

Note that the inductor will act as a short circuit in a dc circuit and as an open circuit in an ac circuit with a high frequency. Conversely, the capacitor will act as an open circuit in dc circuit and as a closed circuit in an ac circuit.

Example: AC circuit analysis

Impedance matching:

When connecting devices or circuits, care must be taken to match the impedance of each device. For example, consider a function generator driving a higher impedance system as in the figure below. The 50 Ω resistor is added in parallel with the high impedance circuit to match impedances. Without this resistor, frequency elements from the function generator will be reflected backward to the driver. A good mechanical analogy is a wave transferring from one medium to another and being reflected at sharp boundaries.

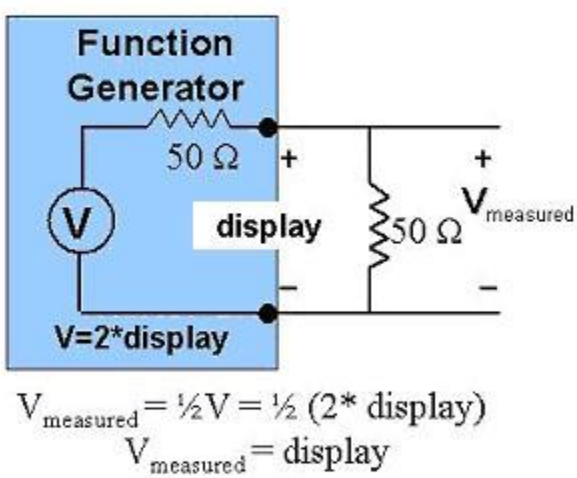


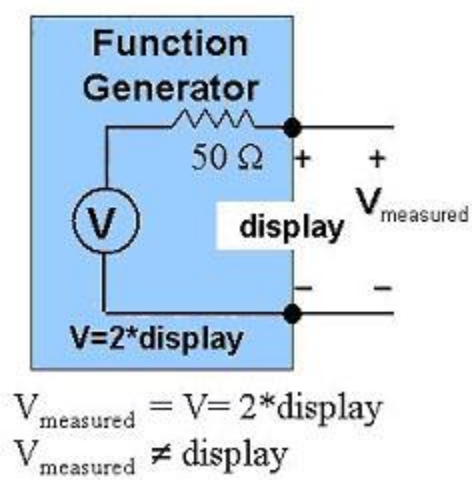
From www.agilent.com

Why your function generator outputs twice the programmed voltage

The default setting for Agilent function generators is to display the desired voltage as though terminated into a 50 Ohm load. When a high impedance device, such as an oscilloscope is used to measure the output of the function generator, the waveform appears to be twice the voltage set on the display of the oscilloscope.

Some oscilloscopes can change their input impedance from standard high impedance to a 50 Ohm termination. Another solution is to add a 50 Ohm feed through (Agilent part number: 0960-0301) to the end of the BNC cable.





Other common impedances are: 25, **75**, 93, 135, 150, and **600** Ohms -Video systems are most often 75 Ohms and many audio systems use a balanced 600 Ohm termination. If not terminating the output of the function generator into a 50 Ohm load, it may be necessary to adjust the output voltage to compensate for the different impedance. For a 50 Ohm source the desired voltage $V_{measured}$ into an impedance R can be calculated as $V_{measured}=\mathbf{V}(R/(R+50))$, where $\mathbf{V}$=2*display or $V_{measured}$=display(2R/(R+50))

The Agilent 33220A and 33250A function generators have the ability to do this calculation for you and directly display the desired voltage. They include a feature that allows the output termination to be set to any impedance from 1 to 10 k Ohm, or infinite. For example if the output termination is set to 75 Ohms and then generator is connected to an oscilloscope with a 75 Ohm termination (or 75 Ohm feed through). The function generator display will match what is displayed on the scope.

Designing a circuit to avoid noise interference:

Noise interference in circuits is one of the more common difficulties in designing a robust, working system. Remember that we are often designing circuits to amplify and observe small voltage signals, or pass digital information with assumed clean edges. Noise can be generated in a system due to many factors including motors, switches and electromagnetic interference perhaps from AC line voltage.

Here are some suggestions to alleviate noise in a circuit:

1. Design a single-point ground system, with a common ground bus. This will eliminate inductive coupling that can result from a ground loop.
2. Isolate and/or separate signal circuits and high-power circuits. Note- they must have a common ground. Separate with: Shielding (item 3), space/proximity, keep leads short (item 4,5). In some cases optoisolators or rf-isolators are used.
3. Shield signal leads with grounded metal covers or shielded cable
4. Use twisted pair cable in signal leads.
5. Use short leads to reduce inductive coupling between leads.
6. Use bypass capacitors over motor leads or other high voltage devices and ground. This will create a short circuit path for high frequency noise that may exist on power supply lines.

Electrical Safety:
Outlets must have three terminals: hot, neutral, ground.

- Equal Current flows on hot and neutral
- Neutral side could have non-zero voltage
- Ground provides an alternate path to ground.

What can go wrong: Current could flow on the ground path