element14 Essentials: Power I

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Power I: Power Essentials for Makers

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1. Introduction

Power is a requirement for every piece of equipment or product developed, whether it's from a large original equipment manufacturer (OEM) or a maker building his next home automation project. If you are a maker or a DIY hobbyist, you may have asked yourself, "What should I know about electrical power that would help me in my next project?" This learning module hopes to answer that question, as well as some fundamental questions about electrical power: what it is, and tips for using it in projects. This learning module will also highlight a variety of power solutions, which can be an off-the-shelf product (AC/DC power supplies, DC/DC converters, etc.) or discrete power converters (magnetics, passives, and semiconductor devices). Finally, to provide the maker with a "jump start" (pun intended) on his or her electrical power knowledge, this learning module will list and define best power practices, power considerations, and power design tips for the maker.

2. Objectives

Upon completion of this module, you will be able to:

- Discuss power fundamentals in AC and DC circuits; the difference between apparent, reactive, and real power; sinusoidal and non-sinusoidal waveforms
- Describe line-commutated and pulse-width modulated (switching) power
- Identify the common types of passive and semiconductor components used in power designs
- Understand the power architectures for common Maker boards
- List and define best practices, power considerations, and design tips for the Maker

3. Fundamentals Review

What is power? Most people would say it is watts. While that is true to some degree, power is more than the unit of measurement, watts. In physics, power is the rate of doing work per unit of time (e.g., one joule per second). Electrical power is the rate by which electrical energy is transferred from an electrical circuit (e.g., spinning a motor under load). In this section, we will discuss power fundamentals and review the main concepts and terms regarding both AC and DC power.

- 3.1 Power in DC Circuits

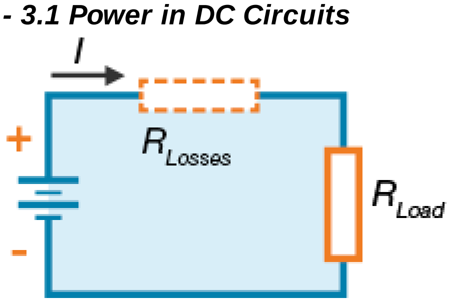


Figure 1: Simple DC Circuit

Direct current (DC) is used as a power supply for electronic systems. A direct current circuit is an electrical circuit that consists of any combination of constant voltage sources, constant current sources, and resistors. Figure 1 on the left is an example of the most basic DC circuit.

The battery is the constant DC energy source of the circuit and delivers power to the load (R_L). The power or electrical energy supplied by the battery is the product of source voltage and circuit current and is described in the following equation:

Power (watts) = Voltage (volts) x Current (amps)

The actual power delivered to the load is the power at the source minus any transmission losses, R_{Losses} (for example, due to the resistance of the wire). For simple DC circuits, transmission losses can be negligible. However, long cable runs or other losses can impact true power at the load as well as the efficiency of the circuit.

While the electrical power of an electric circuit or a circuit component is measured in watts, it actually represents the rate at which energy is converted from the electrical energy of the moving charges to some other form, for example, heat, mechanical energy, or energy stored in electric fields or magnetic fields. In electronics, it is common to refer to a circuit that is powered by a DC voltage source, such as a battery or the output of a DC power supply, as a DC circuit or a DC-powered circuit.

- 3.2 Power in AC Circuits

In alternating current (AC) circuits, the electricity or current flow alternates directions. Like DC power, the instantaneous electric power in an AC circuit is given by P = VI, but these quantities are continuously varying, which changes the way power in an AC circuit is determined.

To better understand the above point, let's discuss how current flows in a DC circuit. A magnet near the wire in a DC circuit attracts the electrons on its positive side and repels the electrons on its negative side. This causes the electricity to flow in one direction only; DC power from a battery works this way (Figure 1). However, DC is not an efficient way to transfer electricity over long distances, because it begins to lose energy due to the power dissipated from the resistance of the circuit wires or cables.

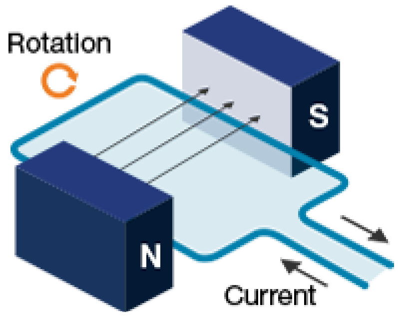


Figure 2: Generating an AC current

In an AC circuit, current flow is generated using rotating magnets instead of applying magnetism along the wire. When the magnet is facing one direction, the electricity flows in that direction. When the magnet is flipped, the flow of electricity changes direction as well (Figure 2). Thus, the voltage oscillates in AC circuits, while voltage in a DC circuit is constant.

Unlike a DC circuit, where circuit current and voltage are constant with a given R_L, the voltage and current in an AC circuit vary and are not in phase with each other due to the inductance and capacitance, that is, the reactive components of the AC circuit (Figure 3). This changes how power in an AC circuit is determined.

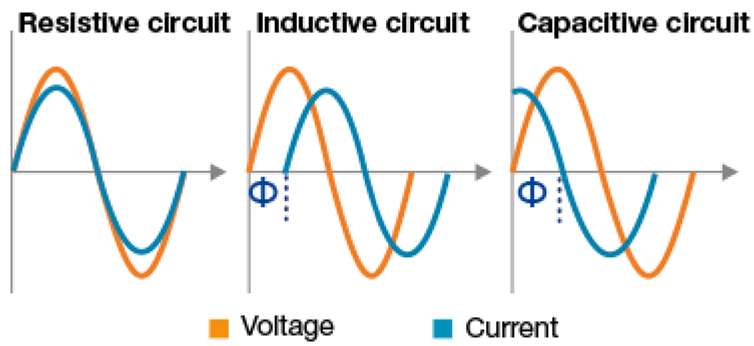


Figure 3: Phase relationship of voltage and current in an AC circuit

Since the instantaneous power in an AC circuit is constantly changing, it's harder to calculate. It's easier to determine the average value of instantaneous power in an AC sinusoidal circuit, using the following:

$$P_{avg} = VI \cos \Phi$$

where V and I are the sinusoidal RMS values, and Φ is the phase angle between the voltage and the current. Power in an AC circuit is also measured in watts.

- 3.3 Effective / RMS Values / Average / Peak Values

The values of voltage and current in a DC circuit are constant, so there is no issue in evaluating their magnitudes, but in an AC circuit, the alternating voltage and current vary from time-to-time, so it is necessary to evaluate their magnitudes. Three ways (peak value, average value and RMS value) have been adopted to express the magnitude of the voltage and current in an AC circuit.

We've already discussed that the average power in an AC circuit is given by the equation, $P_{avg} = VI \cos\Phi$, where Φ is the phase angle between the voltage and the current (effective or RMS values). An effective or RMS value is equivalent to the value of the direct current that would produce the same average power dissipation in a resistive load. We've mentioned in the previous section that the term cos Φ is the phase angle between the voltage and current; this term is also called the "power factor" for the circuit.

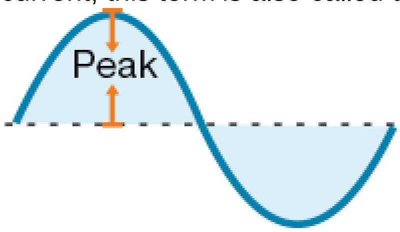


Figure 4: Peak Value of AC Current

Finally, let's talk about the peak value, which is the maximum value attained by an alternating power source during one cycle (Figure 4). It is also known as the maximum value, maximum amplitude, or crest value.

- 3.4 Apparent, Reactive, and Real Power

Power in an electric circuit is the flow rate of energy past a given point of the circuit. In AC circuits, there are three classifications of power: real (true), reactive, and apparent (Figure 5).

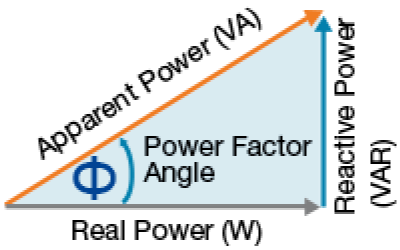


Figure 5: The power triangle expressing the relationship between real (true), reactive and apparent power. Note: As reactive power is decreased, the power factor angle approaches 0 degrees, which at this point, the circuit is most efficient.

- **Real (True) Power:** Active power is that portion of power, averaged over a complete cycle of the AC waveform, and resulting in the net transfer of energy in one direction. It is more commonly known as "real" power in order to avoid ambiguity, especially in discussions of load with non-sinusoidal currents.
- **Reactive Power:** In alternating current circuits, energy storage elements, such as inductors and capacitors, may result in periodic reversals of the direction of energy flow. The portion of power due to stored energy, which returns to the source in each cycle, is known as reactive power. It's measured in the unit of Volt-Amps-Reactive (VAR).
- **Apparent Power:** This is power in an AC circuit which combines both, real power and reactive power. It's measured in Volt-Amps (VA).

- 3.5 Power Factor (Efficiency)

The ratio of active (real) power to apparent power in a circuit is called the power factor. For two systems transmitting the same amount of active power, the system with the lower power factor (cos Φ) or higher phase angle will have higher circulating currents, due to energy that returns to the source from energy storage in the load. These higher currents produce higher losses and reduce overall transmission efficiency.

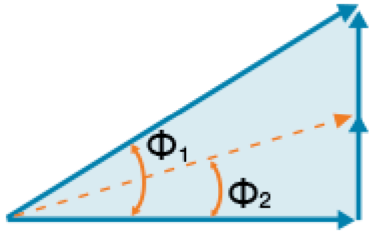


Figure 6: Power Factor Efficiency

Phase Angle (Φ)	Cos (Φ)	Efficiency
0	1	Very High
45	.707	Moderate
90	0	Very Low

A lower power factor circuit will have a higher apparent power and higher losses for the same amount of active power. The power factor is 1.0 when the voltage and current are in phase. It is zero when the current leads or lags the voltage by 90 degrees (Figure 6). Power factors are usually stated as "leading" or "lagging" to show the sign of the phase angle of current with respect to voltage. Voltage is designated as the base to which current angle is compared, meaning that we think of current as either "leading" or "lagging" voltage. Where the waveforms are purely sinusoidal, the power factor is the cosine of the phase angle (Φ) between the current and voltage sinusoid waveforms.

Example: The active power is 700W and the phase angle between voltage and current is 45.6°. The power factor is cos(45.6°) = 0.700. The apparent power is then: 700W / cos(45.6°) = 1000 VA

For instance, a power factor of 68 percent (0.68) means that only 68 percent of the total current supplied is actually doing work; the remaining 32 percent is reactive.

- 3.6 Power for Sinusoidal and Non-Sinusoidal Waveforms

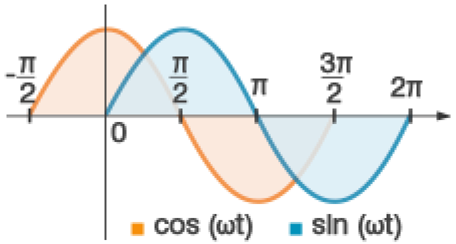


Figure 7: Phase Shift of Since and Cosine Functions

A sine wave is the graph of the sine function, usually with time as the independent variable. A cosine wave is sinusoidal. It has the same form but it has been phase-shifted one-half π radians (Figure 7).

Conversely, a non-sinusoidal waveform is one that is not a sine wave and is also not sinusoidal (sine-like). This may sound like a minor distinction, but there are actually some substantive implications.

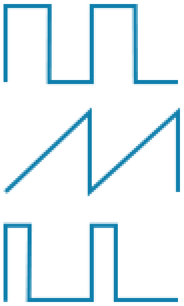


Figure 8: Examples of Non-Sinusoidal Waveforms

A non-sinusoidal waveform is typically a periodic oscillation (Figure 8). Some examples are triangle waves, rectangle waves, square waves, trapezoid waves, and saw tooth waves. Non-sinusoidal waveforms are prominent in the world of electronics and they are readily synthesized. A non-sinusoidal waveform can be constructed by adding two or more sine waves.

Although the sine wave is the ideal wave-form and is closely approached in modern alternators operating at no-load, the load conditions in generators and commercial circuits frequently cause considerable deviations from the sine wave.

The widespread use of power electronic devices (such as different kinds of rectifiers and converters) for electric drives and other industrial load control usually results in heavy distortion of the sine waves of currents and also voltages.

4. Power Supplies

In this section, we will cover two important classifications of electronic power supplies: line-commutated and pulse width modulated.

- 4.1 Line-Commutated

A converter is a power conversion stage for control and conversion of electrical energy that utilizes power semiconductor devices (electronic switches, e.g., thyristors or transistors) controlled by signal electronics.

In contrast to forced-commutated converters, line-commutated converters (naturally commutated converters) do not require active turn-off semiconductor switches but can use thyristors, which can only be forced to turn on. Thyristors operate in single-phase, as well as three-phase AC power grids in which the current in one thyristor becomes zero before another thyristor is turned on (discontinuous operation), or the thyristor current is forced to zero by turning on another thyristor, because the load current changes from one thyristor to the other one (commutation).

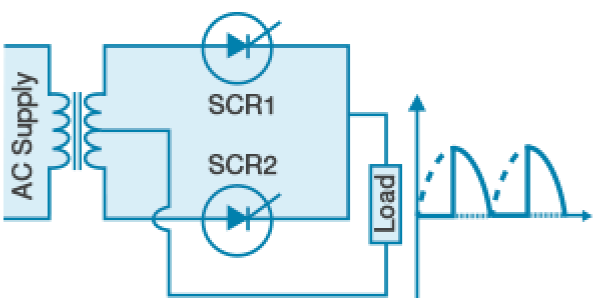


Figure 9: Line-commutated, single-phase full-wave controllable rectifier using thyristors. The dotted line part of the graph illustrates that varying the triggering current to the SCRs.When these devices turn on in the AC half-cycle, the average power delivered to the load can be changed.

A converter which is used to convert single-phase or three-phase AC voltage to DC voltage is called a rectifier. There are two kinds of rectifiers: controllable and uncontrollable rectifiers. A rectifier is controllable if the electric "valves" or switches, e.g., thyristors/silicon controlled rectifiers (SCRs), can be forced to turn on by control signals (Figure 9). A rectifier whose electric "valves" are all diodes is an uncontrollable rectifier. Using controllable rectifiers, the output quantities can be adjusted. A controllable rectifier can also be used to convert energy from DC voltage to a single-phase or three-phase AC grid. In this, case the rectifier is operating in the inverting mode.

- 4.2 Pulse-width Modulated

Pulse-width modulation (PWM), or pulse-duration modulation (PDM), is a modulation technique used to encode a message into a pulsing signal. Although this modulation technique can be used to encode information for transmission, its main use is to allow the control of the power supplied to electrical devices. The most common type of power supply today is the switching supply. These units use pulse-width modulation (PWM) to regulate output.

A switch-mode power supply converts the AC line power directly into a DC voltage without a transformer, and this raw DC voltage is then converted into a higher frequency AC signal, which is used in the regulator circuit to produce the desired voltage and current. This results in a much smaller, lighter transformer for raising or lowering the voltage than what would be necessary at an AC line frequency of 60 Hz. These smaller transformers are also considerably more efficient than 60 Hz transformers, so the power conversion ratio is higher.

MAX17572 EVM High-Efficiency, Synchronous Step-Down DC-DC Converter with Internal Compensation

An example of this type of power supply is Maxim Power Solutions' high-efficiency switching regulator IC. It provides longer battery life, generates less heat, and requires less board space. The MAX17572 is a high-efficiency, high-voltage, synchronous step-down DC-DC converter with integrated MOSFETs that operates over a 4.5V to 60V input. The converter can deliver up to 1A and generates output voltages from 0.9V up to 0.9 x V_{in}. It's typically applied in a variety of industrial control power supplies and point-of-load applications.

MAXM17503 DC-DC Step-Down Power Module Evaluation Kit

When you would like reduce the number of components in your power supply design, then power modules should be applied. They enable cooler, smaller and simpler power supply solutions. This step-down power module combines a switching power supply controller, dual n-channel MOSFET power switches, fully shielded inductor, and the compensation components in a low-profile, thermally-efficient, system-in-package (SiP).

The MAXM17503 evaluation kit is a demonstration circuit of the MAXM17503 high-voltage, high-efficiency, current-mode scheme, synchronous step-down DC-DC switching power module.

The device operates over a wide input voltage range of 4.5V to 60V and delivers up to 2.5A continuous output current with excellent line and load regulation over an output voltage range of 0.9V to 12V. The device only requires five external components to complete the total power solution. The high level of integration significantly reduces design complexity.

MIC2295 Analog Switching Regulator

Another example is the MIC2295 analog switching regulator by Microchip Power Solutions, which is a 1.2Mhz, PWM DC/DC boost switching regulator. High power density is achieved with the MIC2295's internal 34V / 1.2A switch, allowing it to power large loads in a tiny footprint. The MIC2295 offers internal compensation that offers excellent transient response and output regulation performance.

MIC22950 10A Synch Buck Reg Eval Board

The MIC22950 Evaluation Board was developed to evaluate the capabilities of the MIC22950 high-efficiency, 10A integrated switch, synchronous buck (step-down) regulator. The MIC22950 achieves over 95% efficiency while still switching at 2MHz over a broad load range.

Considering the multiple DC voltage levels required by many electronic devices, designers need a way to convert standard power-source potentials into the voltages dictated by the load. Voltage conversion must be a versatile, efficient, and reliable process. Switch-mode power supplies are frequently used to provide the various levels of DC output power needed for modern applications, and are indispensable in achieving highly efficient, reliable DC-DC power-conversion systems. Here are a few of the most common types:

- **Buck:** The buck switching regulator is a type of switch-mode power supply that is designed to efficiently reduce DC voltage from a higher voltage to a lower one.
- **Boost:** The boost converter is a type of switch-mode power supply that is designed to convert electrical energy from one voltage to a higher one.
- **Buck-boost:** A type of DC-to-DC converter that has an output voltage magnitude that is either greater than or less than the input voltage magnitude.
- **Inverting:** The inverting converter reverses the polarity of the input voltage, yet permits the output voltage to be higher or lower than the input.
- **Split-rail:** This power supply generates both positive and negative output voltages using a variety of topologies, including inverting buck-boost topology.

5. Passive and Semiconductor Devices Used in Power Circuits

While makers often will use off-the-shelf AC/DC power suppliers or DC/DC converters to power their projects, it's useful for them to get a better understanding of the components used in these power supplies. This section examines the common components, both passive and semiconductor, that typically are used in a power supply design.

- 5.1 Capacitors

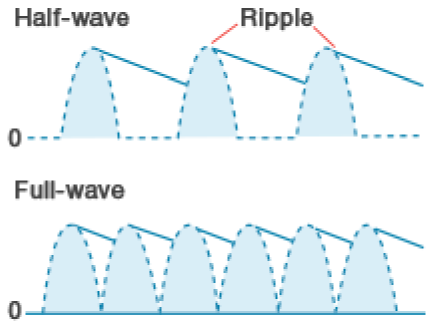
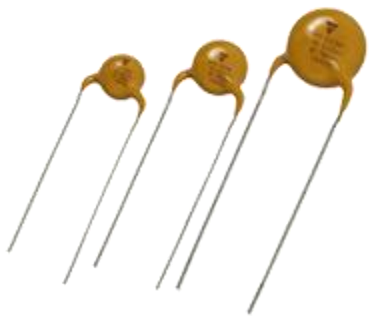


Figure 10: Filter ripple in a half-wave and full-wave rectifier

Capacitors can be used to smooth out voltage, a process also known as filter ripple (Figure 10). They can also be used as reservoirs for electrical energy storage, and to block DC current. A capacitor consists of two metal plates that are separated by an insulator, the dielectric. One of the most notable features of capacitors is that they resist voltage changes, so that if the voltage applied to a capacitor is suddenly changed, the capacitor cannot react immediately and the voltage across the capacitor changes more slowly compared to the applied voltage.



AC Line Rated Ceramic Disc Capacitors

Capacitors are commonly used in power supplies; the AC line rated safety capacitor on the left is a good example from Vishay Power Solutions. The capacitor consists of a ceramic disc which is silver plated on both sides. Connection leads are made of tinned copper clad steel having a diameter of 0.6 mm. Encapsulation is made of flame retardant epoxy resin in accordance with UL 94 V-0.

There are various types of capacitors available today, depending on their construction and the materials used. Some of the most common types are dielectric, film, ceramic, electrolytic, glass, tantalum, and polymer. In power designs, the most common types are electrolytic and polymer capacitors.

Types: Aluminum, Ceramic Disk, Film, Glass, Multi-Layer Ceramic Chip, Multi-Layer Ceramic Radial, Super Capacitor and Tantalum

- 5.2 Diodes

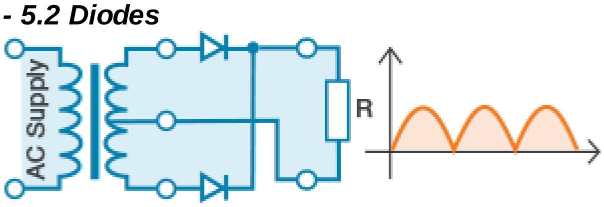


Figure 11: Full Wave Rectifier with Center-Tapped Transformer

A diode can be likened to a one-way valve. When voltage is applied to it — that is, when it is forward-biased and turned on — it allows current to flow in one direction but not in the other direction. This process is also called the rectifying process (Figure 11). One end of a diode is called an anode (triangle side of the symbol) and the other a cathode (bar side of the symbol). Most diodes allow current to freely flow from anode to cathode.

SiC Schottky Barrier Diodes

SiC is a compound semiconductor comprised of Silicon (Si) and Carbon (C). Compared to conventional Silicon Power Devices, SiC Power Devices deliver higher voltage breakdown, lower ON resistance, faster switching, and higher temperature operation. This translates to lower switching losses, reduced power loss, and smaller module size, allowing designers to make more robust products using fewer components.

ROHM SiC Schottky Barrier Diodes are majority carrier devices featuring ultra-fast reverse recovery. As a result, switching loss is reduced, enabling high-speed switching operation. In addition, unlike silicon-based fast recovery diodes where the reverse recovery time (trr) increases with temperature, SiC devices maintain constant characteristics that improve performance.

Types: Bridge Rectifiers, Power, Rectifiers, Schottky, TVS/ESD Protection and Zener

- 5.3 Inductors

Inductors, or induction coils, store electrical energy in a magnetic field. Inductors play an important role in power designs and are simply a coil of wire wrapped around a core, which is composed of iron, ferrite, or simply air. They act as an open circuit at first when DC (direct current) is applied to them, but after a while they freely allow it to pass. They oppose current changes. They are also commonly referred to as coils. Chokes are another name for a specific type of inductor which blocks or "chokes" high frequencies, while allowing low frequencies to pass.

IHLP® - Low-Profile, High-Current Inductors

A good example of inductors used in voltage regulator module (VRM) and DC-to-DC converter applications is Vishay Power Solutions' IHLP® low-profile, high-current inductors.

The IHLP inductor is constructed using an "open" or "air coil" inductance coil. The two ends of the coil are connected to a lead frame that acts as the final termination pads. A powdered iron core is pressed around the inductor coil after the inductor coil is welded to the lead frame. The characteristics of the powdered iron enhance the magnetic properties of the inductor and also give the inductor its final shape or footprint.

Types: Chip Inductors, Leaded Inductors, Power Inductors and RF Inductors

- 5.4 Integrated Circuits

In power electronics applications, a power semiconductor is specifically designed to carry currents larger than 100 mA in an on-state and block voltages greater than 10 V in an off-state. They are generally used as switches, or in the case of a diode, as a rectifier or clamp. For some devices, the state of the device can be controlled by an external signal and, for others, the state is determined by circuit parameters (e.g., uncontrolled). Some of the controllable devices are "latching" devices, meaning that they only turn off when the conducting current returns to zero (e.g., commutation).

Low Dropout Linear Regulators (LDO)

Low dropout linear regulators (LDO) are used for or powering general-purpose portable devices. A good example of an LDO is Microchip Power Solutions' MIC5501/2/3/4.

This LDO family is an advanced general-purpose LDO ideal for powering general-purpose portable devices. The MIC5501/2/3/4 family of products provides a high-performance 300mA LDO in an ultra-small 1mm x 1mm package. The MIC5502 and MIC5504 LDOs include an auto-discharge feature on the output that is activated when the enable pin is low. The MIC5503 and MIC5504 have an internal pull-down resistor on the enable pin that disables the output when the enable pin is left floating. This is ideal for applications where the control signal is floating during processor boot up.

Types: Battery Management, Boost, Buck, Buck/Boost, Charge Pumps, DDR Termination, Digital Power Controllers, Diodes, FET Drivers, Flyback, Hot Swap, Integrated Sequencers, LDO, LED Drivers, MOSFETs, Multi-Phase, Off Line (AC/DC), PFC, PMICs, POE, and VRM

- 5.5 Magnetics

Typically, inductors are shielded so that their magnetic fields do not interact with other components in the same circuit. However, if we place two unshielded inductors side-by-side and feed one of them with AC (alternating current), then its magnetic field induces a voltage not only in the AC current applied inductor, but also in the other inductor, despite the fact that the latter inductor is physically close, but not electrically connected, to the former inductor. The process of inducing voltage in the second inductor is called mutual inductance. So, if you pass current in one inductor, you create voltage in the inductor near it.

A transformer is nothing more than two inductors, or coils, wound around the same core material so that mutual inductance is at a maximum level. The coil that lets the current pass is called a primary coil, and the coil that is induced with voltage is called a secondary coil.

A transformer can electrically isolate two circuits and also step voltages up or down. Alternating current voltage can be increased (stepped-up) or decreased (stepped-down) using a device called a transformer. The turns ratio of a transformer is the ratio of the number of turns of windings between the primary and secondary. The turns ratio determines whether the transformer is a step up or step down transformer (Figure 12).Transformers reduce the high voltage of AC to a lower voltage for use in home appliances. (While Thomas Edison's work led to the DC battery system, Nikola Tesla came up with the AC generator by using a rotating magnet).

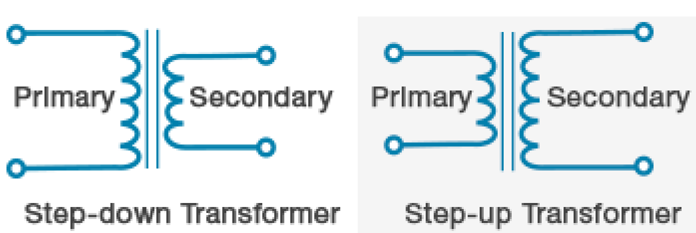


Figure 12: Comparison of turns ratio in a step-up and step-down transformer

Types: AC Line Filters, Broadband Modules, Chokes, Current Sense, Filtered RJ Jacks, LAN Modules, Power Magnetics, Telecom Modules, and Transformers

- 5.6 Resistors
Resistors are the most commonly used electronic component. Their role is simply to restrict the flow of electrical current when necessary and make sure that the correct voltage is supplied to a component. Resistance is measured in ohms Ω.

Types: Carbon, Chip, Chip Resistor Array, Current Sense, Film, Trimmer Pots, and Wirewound

- 5.7 Transistors
The transistor is considered to be the biggest technological discoveries or innovations of the 20th century. Indeed, inside every electronic device nowadays you will find transistors working effortlessly and reliably. The two most common types of transistors are bipolar junction transistors (BJTs), which can be broken down into NPN and PNP transistors, and field effect transistors (FETs). Similar to BJTs, FETs come in N-channel and P-channel types. The two major types of FETs are MOSFETs (Metal-Oxide Semiconductor FETs) and JFETs (Junction FETs).

Types: Darlington, High Voltage > 500 V, IGBTs, NPN, PNP and Small Signal

6. Power Architecture Overview for Common Maker

- 6.1 Raspberry Pi 3 Model B

The Raspberry Pi 3 is powered by a +5.1V Micro USB supply. Purchasing a 2.5A power supply from a reputable retailer will provide you with ample power to run the Raspberry Pi. You can also purchase the official Raspberry Pi Power Supply.

Power requirements by product:

Product	Recommended PSU Current capacity	Max total USB peripheral draw	Typical bare board current consumption
Raspberry Pi Model A	700mA	500mA	200mA
Raspberry Pi Model A+	700mA	500mA	180mA
Raspberry Pi Model B	1.2A	500mA	500mA
Raspberry Pi Model B+	1.8A	600mA/1.2A (switchable)	330mA
Raspberry Pi 2 Model B	1.8A	600mA/1.2A (switchable)	350mA
Raspberry Pi 3 Model B	2.5A	1.2A	400mA

Typically, the model Raspberry Pi 3 Model B uses between 700-1000mA depending on what peripherals are connected; the model A can use as little as 500mA with no peripherals attached. The maximum power the Raspberry Pi can use is 1 Amp. If you need to connect a USB device that will take the power requirements above 1 Amp, then it must be connected to an externally-powered USB hub.

The power requirements of the Raspberry Pi increase as you make use of the various interfaces on the Raspberry Pi. The GPIO pins can draw 50mA safely, distributed across all the pins; an individual GPIO pin can only safely draw 16mA. The HDMI port uses 50mA, the camera module requires 250mA, and keyboards and mice can take as little as 100mA or over 1000mA! Check the power rating of the devices you plan to connect to the Pi and purchase a power supply accordingly.

Almost any deployment scenario will work, because the BitScope Blade supports most common DC power sources. While BitScope Blade started life as Blade Server for Raspberry Pi, it has since evolved into a full range of power, mounting, and deployment solutions for Raspberry Pi, HATs, the Raspberry Pi Display, and of course, BitScope.

- 6.5 MiniZed™

The MiniZed™ is a single-core Zynq 7Z007S development board. This board targets entry-level Zynq developers with a low-cost prototyping platform. The integrated power supply from Dialog generates all on-board voltages. An auxiliary microUSB supply input can be used to power designs that require additional current.

MiniZed™ supports the input and output voltages and currents shown below:

Bank	Voltage	Current (A)
V_{ccint}/V_{ccpint}	1	1.5
V_{ccaux}/V_{ccpaux}	1.8	0.5
V_{cco} (DDR)	1.35	1
V_{cco} 3.3	3.3	1
V_{term}	0.68	0.5
V_{in}	5	2.4

PS and PL subsystems are powered from the same supplies to save board size and cost. Sequencing requirements are as follows: **1V → 1.8V → 1.35V/3.3V/0.68V**

MiniZed™ supports the input and output voltages and current. All supplies maintain monotonic rise. Input power is provided via a MicroUSB connector.

These power figures reflect worst case consumption with a 7010 Zynq device populated. The 7007S device is standard on MiniZed™; however, the board was designed to potentially support a 7010, hence the power system being designed to support the larger device. These figures do not include extra capacity to support powering a shield (3.3V at 500mA) or USB host mode (5V at 500mA). The V_{in} current requirement reflects the use of the Monoprice 14578 USB supply included in the Avnet AT&T cloud connect kit. This external supply is sufficient to support the addition of USB host mode, as well as powering a shield. This supply is a 2.4A 5V supply using a standard USB interface.

7. Power Considerations and Tips for the Maker

We cannot possibly cover all of these topics in depth, but want to give you an idea of basic power considerations and tips, and encourage you to do additional research as required.

- 7.1 Cable Runs, Lengths

The main concern here is voltage drops. Voltage drop on a lighting circuit in a 120V system isn't considered a major issue. The branch circuit currents are relatively low—usually 20A or below—and the standard wire sizes are usually large enough to minimize resistance problems.

But voltage-drop issues can occur with lower voltage systems. Depending on its size and length, the conductor serving the fixtures of a low-voltage design acts as a resistor. As current runs through the conductor, a voltage drop occurs: the voltage at the end of the conductor is lower than at the source. Wires with smaller cross-sectional diameters (e.g., 20 AWG) that conduct higher currents will increase the voltage drop by raising resistance and increasing the fixture load, respectively.

- 7.2 Terminations/Connectors
Current ratings are important, since a signal connector failure can cause issues from a minor nuisance to shutting a system down; a power connector failure can lead to catastrophic failure, causing system or structural damage.

Considerations:

- **Wire-to-wire** - heavily influenced by wire gauge
- **Board-to-board** - heavily influenced by PCB copper and overall size
- **Current Rating** - there is no one standard body to define common means of rating current; look to the supplier specs and compare
- **Voltage** - Look at geometry (creepage and clearance) and dielectric properties
- **Environmental Factors** - ambient temperature and system airflow

- 7.3 Thermal Issues
Quite often the power supply is the last item specified for many new designs. But just finding something that will fit a system power budget may not be "good enough" anymore. With the increasing demands for greater efficiency, high reliability, and faster design cycles, as well as increasing regulation, this approach may not always be acceptable.

A good engineer will consider all aspects of power needs early in the project, including thermal dissipation, air flow, and packaging. Thinking about the power system early in the project is essential if the unpleasant surprises of needing a bigger supply or a new cooling strategy are to be avoided.

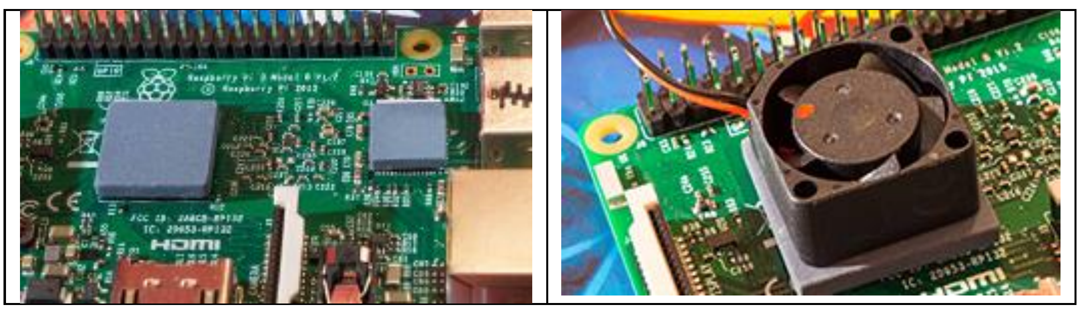


Figure 13: Adding a heat sink or a cooling fan to the Raspberry Pi's Broadcom processor and memory chips can address thermal issues.

- 7.4 Voltage Drops
Common to all power supplies is the fact that they have internal conductors. These conductors (internal wiring) will act to drop voltage with current. This wiring will create a "real" series resistance. This is modeled as a series resistor, although there is no physical unit which causes the voltage drop.

Batteries have another effect. Current is produced by electrochemical reactions, and these reactions can only occur so fast. In a lead-acid battery, for instance, sulfuric acid reacts with the lead/lead oxide terminals, and once the sulfuric acid has reacted new acid must take its place, which requires time. As a result, the maximum current is limited by the geometry of the battery plates, and this shows up as a drop in voltage when current increases. This is modeled as a series resistor, although there is no physical unit which causes the voltage drop.

A good power supply these days will sense the output voltage and adjust the voltage of the internal source to compensate for internal voltage drops, and for slowly changing loads will approximate an ideal voltage source closely.

- 7.5 Efficiency
The size or power density of a power supply is a key criterion when selecting the optimal product for a given application. In applications where fans are not desirable due to noise or reliability concerns, efficiency becomes a primary concern.

Power supply technology has evolved to a point where efficiencies in the 90-95% range are available. To put this into context, a typical power supply in the 1980s would have been in the region of 75% efficient. By considering efficiency as an important criterion, a designer can make fundamental design decisions that affect the overall system in a positive way by:

- Eliminating or reducing the need for system fan cooling
- Reducing the overall size and weight of the system
- Reducing the internal temperatures of the system and improving reliability
- Enhancing system reliability
- Reducing overall energy usage and the end user operating costs

- 7.6 Noise Issues

As power switching speeds and signal slew rates increase, and as the number of active pins on devices increase, more switching noise is induced in power supplies. At the same time, circuits are becoming more susceptible to power supply noise.

Almost all noise comes from one of two sources: switching power supplies create their own undesired noise, usually at harmonics of the switching frequency or coherent to the switching frequency. When gates and output pin drivers switch, this action creates transient current demands on the power supplies. This is usually the primary source of noise in most digital circuits.

Not all oscilloscopes can be used for measuring noise accurately. Because of the wide bandwidth of power supply noise, designers tend to choose oscilloscopes for measuring it. Real-time, wideband digitizing oscilloscopes and wideband scope probes have their own noise, which you must take into account. If the noise you're trying to measure on your power supply is of the same order as the noise floor for the scope and probe, you will be challenged to measure your noise accurately. Know how much noise your scope and probe contribute. Select a scope and probe with a sufficiently low noise floor to allow you to make your measurement accurately.

- 7.7 Safety

Safety directives and legislation specify the requirements for a power supply or converter, according to the final application. There are three main groups of directives: Protections, EMC/EMI Immunity, and Electrical Safety. The list below covers the main requirements for general, industrial, and specialized applications.

Protections	
OVP	Over-voltage protection, SELF/PELF
OCP	Over-current protection, overheating, fire
SCP	Short-circuit protection, hiccup/latching, fire
OTP	Over-temperature protection, overheating, fire
IP	Ingress protection scale on touch, dust and water protection
Class I/II	Protection against shock, w/wo protective earth
SELV	Safety/separated extra-low voltage
PELV	Protected extra-low voltage

EMC/EMI Immunity	
CE	EMC and safety LVD for EU directive 2004/108/EC
CISPR22/EN55022	EMC for EU ICT, light industry, general, class A/B
CISPR11/EN55011	EMC for EU heavy industry

FCC	Title 47 EMC for USA ICT, light industry, general
IEC61000/EN55024	EMC/immunity

Electrical Safety	
CE	LVD low voltage directive 2014/35/EU
EN60950-1	EU for ICT, light industry, general
EN60601-1	EU for medical equipment 4th edition
EN60335/UL1012	Household appliances
EN60945	Marine applications
UL508	USA for ICT, datacom, light industry
CSA C22,2	CND for ICT, datacom, light industry
EN50178/IEC62103	Electrical equipment power installations

Special Environments	
EN50155/RIA12	EU railway standard on EMC
EN50121	EU railway standard on immunity
EN 60079	Ex II 3G hazardous locations
CSA22,2/ANSI/ISA	ATEX hazardous locations with classes
IEC 60068	Shock and vibration tests

MDS Series External Power Supplies

External AC/DC power adapters are used in many different portable applications. A good example of an external power adapter is the MDS Series by Delta Electronics Power Solutions. They come with a universal input from 90 to 264 VAC. Product offerings range from 5W to 150W with full Medical safety certifications including Level VI efficiency and Medical EMC 4th Edition (IEC 60601-1-2:2014). The MDS series is certified for EMC standards according to EN 55011 for industrial, scientific and medical (ISM) radio-frequency equipment and EN 55022 for Information Technology Equipment (ITE) radio-frequency equipment.

- 7.8 Grounding

In electrical engineering, ground or earth has multiple functions, including (a) the reference point in an electrical circuit from which voltages are measured, (b) a common return path for electric current, or (c) a direct physical connection to the Earth. Connection to ground also limits the build-up of static electricity when handling electrostatic-sensitive devices.

Isolation is a mechanism that defeats grounding. It is frequently used with low-power consumer devices, and when electronics engineers, hobbyists, or repairmen are working on circuits that would normally be operated using the power line voltage. Isolation can be accomplished by simply placing a "1:1 wire ratio" transformer with an equal number of turns between the device and the regular power service, but it also applies to any type of transformer using two or more coils electrically insulated from each other.

For an isolated device, touching a single powered conductor does not cause a severe shock, because there is no path back to the other conductor through the ground. However, shocks and electrocution may still occur if both poles of the transformer are contacted by bare skin. Isolated power supplies do not provide any ground connection, and are designed to isolate the output from input.

Test Your Knowledge

Are you ready to demonstrate your Power Essentials for Makers knowledge? **Then take a quick 15-question multiple choice quiz to see how much you've learned from this Power Essentials for Makers 1 learning module.**

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