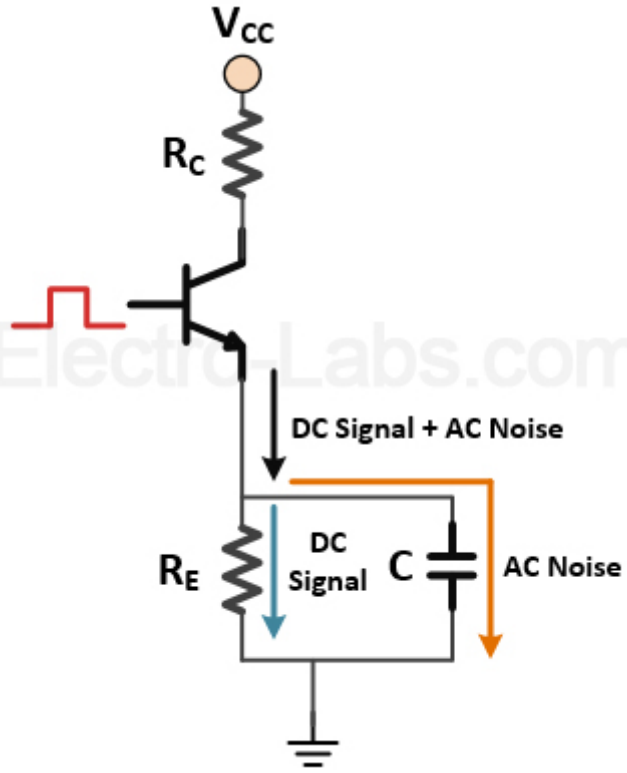
Bypass Capacitors – Why and How to Use Them?

January 30, 2014 by — 20 Comments

You may have heard about the phenomenon of bypassing in circuits, however, we may not have sufficient knowledge of how to apply this technique in real circuits. In this tutorial, we will discuss about the bypass capacitors, why we need to use and how to use these capacitors in circuits.

What is a Bypass Capacitor?

A capacitor that filters out the AC signal removing the noise and provides a DC signal is known as a bypass capacitor. The capacitor connected in the figure below is a bypass capacitor bypassing AC noise and allowing pure DC signal to pass through the component.



Operation of a Bypass Capacitor

Why Use Bypass Capacitors?

In electronics, most of the circuits are digital in nature using direct current (DC). It has been observed that variations in voltage can cause problems to the circuit operation. A circuit may operate incorrectly due to voltage swing. In practical circuits, the voltage fluctuation is usually caused by the AC component that may ride over DC signal causing noise. Therefore, a bypass capacitor is needed to dampen the AC or noise present at all frequencies. Also, it prevents the unwanted communication between devices sharing the same power source.

When do you Need Bypass Capacitors?

Firstly, the low frequency circuits may not require bypass capacitors. However, many low frequency active devices comprise of high frequency units. For example, a microcontroller is a low frequency device using a clock making a low frequency system, but the rising and falling glitches can occur due to internal gate transitions without proper filtering of power supply that will traverse the circuit. Therefore, you may need a bypass capacitor with an appropriate value to achieve proper filtering of power supply.

Secondly, you may have this misconception that only digital devices need bypass capacitors. However, bypass capacitors also benefit the analog circuits and devices in a different way. In digital systems, bypass capacitors control the fast timing of rising and falling glitches. Conversely, bypass capacitors help in reducing noise of power supply in analog systems. Generally, analog devices have built in capability of filtering power supply that is effective for reducing low frequency power supply noise, but it is not useful at higher frequencies.

Types of Bypass Capacitor

Bypass capacitors are usually used in high speed environments where the capacitor inductances play a very critical role. The output of a part generates high frequency noise, typically greater than 100 MHz, on the power line at high speed switching. A high lead inductance capacitor will behave as an open circuit due to these harmonics which prevents it from providing the needed current to the power line to maintain a stable level, which results in failure of circuit functionality. Therefore, capacitors with very small inductances are required to bypass the internal noise of the device.

The inductance of a typical surface mount ceramic capacitor is 0.5nH, while the inductance of an electrolytic capacitor is 15nH. By calculating the inductive impedance of these bypass capacitors, we can observe the effect on bypassing:

ELECTROLYTIC CAPACITOR	CERAMIC CAPACITOR
$$Z_L = 2pifL$$ $$Z_L = 2x3.142x1.5x10^8x15x10^{-9}$$ $$Z_L = 14Omega$$	$$Z_L = 2pifL$$ $$Z_L = 2x3.142x1.5x10^8x0.5x10^{-9}$$ $$Z_L = 0.4Omega$$
$$V_{drop} = IxZ_L$$ $$V_{drop} = (0.04A)x(14Omega)$$ $$V_{drop} = 0.56V$$	$$V_{drop} = IxZ_L$$ $$V_{drop} = (0.04A)x(0.4Omega)$$ $$V_{drop} = 0.016V$$

From this example, we have observed that supply voltage drops below the operating voltage of the device due to more than one channel switching at the same time. Therefore, it is important to use the correct type of bypass capacitor. This is the reason that ceramic capacitors are more favorable than electrolytic capacitors for bypassing. They allow easy flow of charge when needed due to negligible internal inductance.

How to Select Value of Bypass Capacitor?

Now we know why and when we need to use bypass capacitors, but we still need to find out the appropriate value of the capacitor to use for a particular device. The typical values considered for bypass capacitors are 0.1 µF and 1 µF. The higher the frequency, the smaller the value; while the lower the frequency, the large the value.

$$f = frac12t_R$$

where t_R = rise time.

The most important parameter to select an appropriate bypass capacitor is its ability to supply instantaneous current when it is needed. In order to select the capacitor size for a particular device, we have the following methods:

1. Firstly, the bypass capacitor size can be calculated using the following equation:

$$C = fracI * N * DeltatDeltaV$$

I = amount of current needed to switch one output from low to high

N = switching number of outputs

Δt = time required to charge the line by the capacitor

ΔV = tolerated drop in V_{CC}

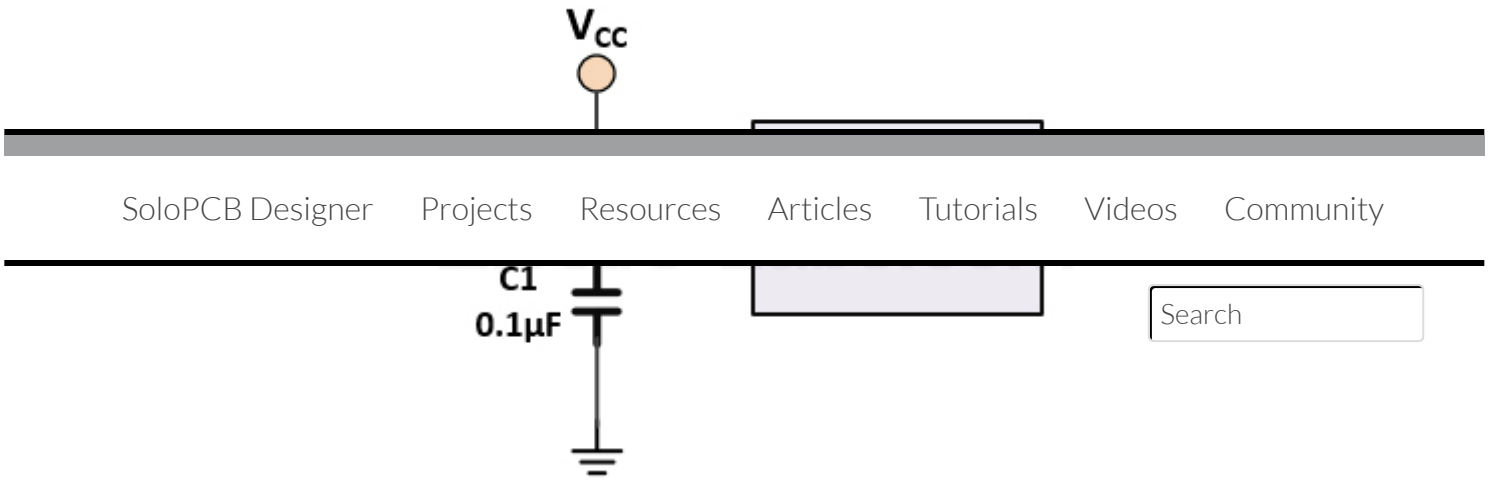
The values given in the formula should be known, where Δt and ΔV can be assumed.

2. Another way to find out the bypass capacitor size is by calculating its maximum current with the specified maximum pulse slew rate. Maximum pulse slew rate is specified by several capacitor manufacturers.

$$I = Cfracdvdt$$

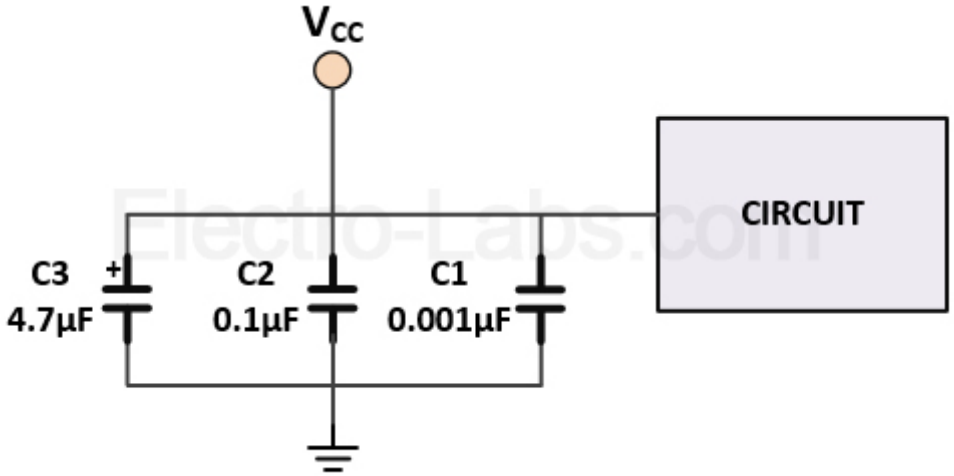
How to Use Bypass Capacitors?

The bypass capacitor value depends on the noise frequency of the supply that requires filtering. Therefore, a typical bypass capacitor of 0.01 µF or 0.1 µF is connected for high frequency supply noise and low current applications as shown in figure below:



Bypass capacitor for low current and high frequency application

However, power supply lines may have multiple frequencies in some applications where a single bypass capacitor is not sufficient. Thus, a network of bypass capacitors is used to filter the noise of wider range of frequencies. An example is given in the circuit below where capacitor C2 filters mid range frequencies, C3 filters higher frequencies and C4 filters low frequencies.

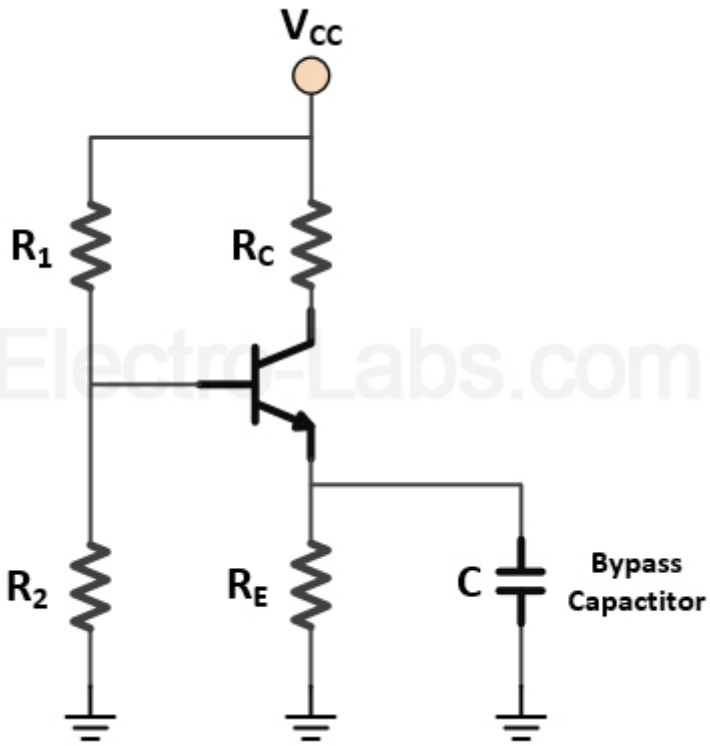


Bypass capacitor network for filtering multiple frequencies

It is also important to know that the bypass capacitors should be connected closer to the power supply pins because longer traces on printed circuit boards will increase the inductance and lower the frequency of the bypass track.

Example of a Bypass Capacitor Application

It is simple and easy to use a bypass capacitor in a circuit without changing the connections



Bypass Capacitor connected in a Circuit

In the given circuit, the bypass capacitor is responsible for holding the emitter voltage steady and maintaining voltage gain. For the transistor connected in the above given circuit, i_C increases as i_B rises, increasing the emitter voltage. This decreases V_{BE} that decreases i_C resisting the rise in emitter voltage. Here the bypass capacitor is connected to shunt the signal occurring at the emitter through to the ground.

Tutorials

Comments

Lova Kiranvarma says
February 17, 2014 at 10:53 am

Log in to Reply

Bill says
June 16, 2014 at 4:25 pm

I thought so too.

Log in to Reply

Lova Kiranvarma says
February 17, 2014 at 10:54 am

The section “How to Select Value of Bypass Capacitor” is some what confused. but it is good.
http://www.npeducations.com

Log in to Reply

Bill says
June 16, 2014 at 5:01 pm

Thanks for the link. That was interesting.

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This shows how critical these small parts, close to the edge of a board are. When I pull or install a circuit card, I always pay close attention to those small parts, If damaged and you don't see it, the circuit card could not work right and be junk.

Log in to Reply

Max says
March 18, 2014 at 7:38 am

Most people working with electronics will be aware to just slap a 0.1uF ceramic as close to the pins as possible, even if they are fuzzy on the theory behind this. The article fails to explain however why would one bother _selecting_ a value or using multiple caps – why does one not simply slap the biggest appropriate value on every time? Clearly too small is a problem, but why is too large a problem too? Clearly, the more charge you have on tap locally to smooth your circuit's transitions, the better – so why does that not apply?

Log in to Reply

RandomNut says
March 18, 2014 at 5:37 pm

I suspect the problem is effective series resistance. The larger the cap you use the higher the effective resistance is. But I am no expert.

Log in to Reply

foo says

forms an RC filter and shorts the noise to ground, using multi

widens the bandwidth of the filter.. in general EE's will stick to the cheapest part with the widest range.. enter the .1uF

oh yeah.. agree completely with the misuse of "X" as a multiply sign.. the formulas look confusing.. even worse the italics kinda /force/ me to think of it as a variable..

Log in to Reply

Bill says
June 16, 2014 at 4:22 pm

Look at the article again. Under the title "How to use Bypass Capacitors", the second example clearly demonstrates that and even explains it. The example is just before "Example of a Bypass Capacitor Application".
I thank the author for making the effort to give us some very useful knowledge.

Log in to Reply

John Smith says
March 19, 2014 at 8:29 am

What that ‘N = switching number of outputs’ from p.1 of the ‘How to Select Value of Bypass Capacitor?’ section does mean?

WinstonSmith2012 says
March 19, 2014 at 1:16 pm

Application Note 1325
Choosing and Using Bypass Capacitors

http://www.intersil.com/content/dam/Intersil/documents/an13/an1325.pdf

Log in to Reply

Gua says
March 20, 2014 at 2:07 am

You screwed up on the equations. Use the proper multipy sign instead of “x” in italics!

Log in to Reply

Bill says

June 16, 2014 at 4:00 pm

Since you are such a critic, show us your “How to” information. The italics is an option. By no means is it mandatory. I could use a large bold font, or a symbol. As long as the reader can determine the meaning the format is irrelevant. Stop being such a jerk. If you don’t like they they do it, you are welcome to go

Alan S says
July 23, 2014 at 4:31 am

The value of the internet is due to people who volunteer their time to create content. People who make moronic remarks with exclamation marks add nothing. I suggest you apologise.

Log in to Reply

Alan says
March 23, 2014 at 3:15 pm

This phrase is wrong: “capacitor C2 filters mid range frequencies, C3 filters higher frequencies and C4 filters low frequencies.” There is not C4 in the circuit!

It should be C1 and C3 respectively!

Log in to Reply

srikar says
April 22, 2014 at 12:29 pm

resistors allow only DC .. can anyone explain why ?

Log in to Reply

June 16, 2014 at 4:35 pm

I am no expert, but every resistor I have used works the same regardless of AC or DC. Capacitors and diodes, however are polarized. Am I missing something?

Log in to Reply

Roman Zbořil says
June 23, 2014 at 8:57 pm

Nice tutorial.

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SeAfasia says
February 8, 2015 at 12:53 pm

thanks….

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~~the bypass capacitors, why we need to use and how to use… Download Solor CB Tools for~~
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