

# AN11400

## Properties and application of bypass capacitors

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Application note

### Document information

Info	Content
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## Revision history

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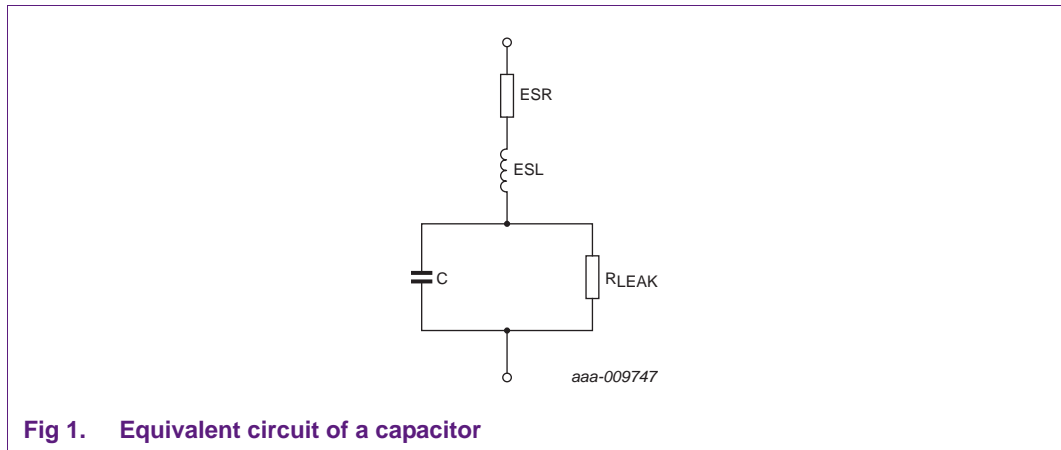
## 1. Introduction

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Bypass capacitors are applied between the power supply pins  $V_{CC}$  and GND of integrated circuits. They reduce both the power supply noise and the effect of spikes on the supply line. They also provide instantaneous current demands of the integrated circuit as it switches. This application note describes the different properties of bypass capacitors and provides a guide to their use.

## 2. Properties of capacitors

The equivalent circuit model of a capacitor is shown in [Figure 1](#). The main component, the capacitance, has a leakage resistance in parallel with it to represent any losses through the dielectric. In series with that RC pair is a parasitic resistor (ESR) and a parasitic inductor (ESL). The two values represent the entire amount of both DC and frequency-dependent losses of the capacitive structure. ESR is the equivalent series resistance that is determined by the wire and connections to the plates. ESL is the equivalent series inductance that is determined by the type of package.



**Fig 1. Equivalent circuit of a capacitor**

These parasitic parameters determine the frequency response of the capacitor. The impedance magnitude is calculated as shown in [Equation 1](#):

(1)

$$X(f) = \sqrt{ESR^2 + \left(2\pi fL - \frac{R}{2\pi fRC}\right)^2}$$

where:

**ESR** = equivalent series resistance ( $\Omega$ )

**L** = equivalent series inductance (H)

**R** = dielectric loss ( $R_{LEAK}$ ) ( $\Omega$ )

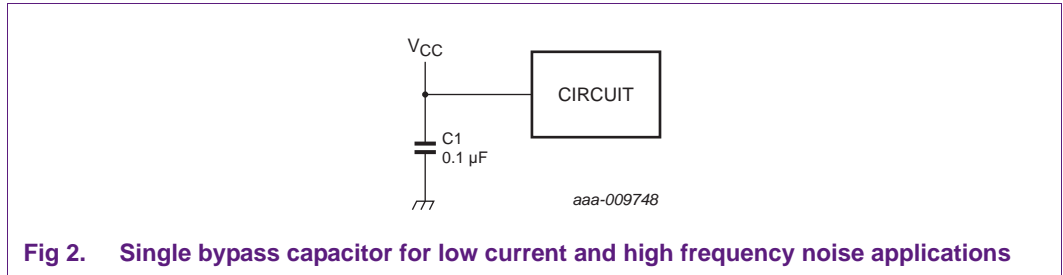
**C** = capacitance (F)

**f** = frequency (Hz)

The data sheets of effective bypass capacitors should specify low parasitic parameter values (ESR, ESL and  $R_{LEAK}$ ).

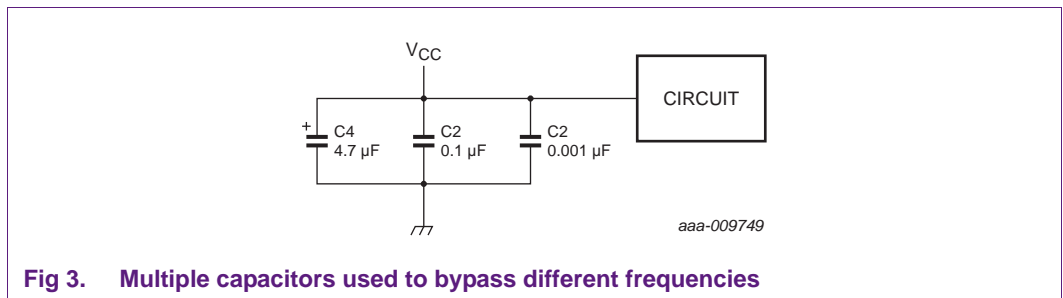
### 3. Bypass capacitor solutions

The value of the bypass capacitor selected is dependent upon the frequency component of the supply noise that requires filtering. To simplify, higher value capacitors are used to filter lower frequency supply noise and lower value capacitors are used to filter higher frequency supply noise. Typically, for low current applications with high frequency supply noise, a 0.1  $\mu\text{F}$  or 0.01  $\mu\text{F}$  bypass capacitor is used as shown in [Figure 2](#).



**Fig 2. Single bypass capacitor for low current and high frequency noise applications**

In some applications multiple frequencies couple into the power supply lines and a single capacitor is not sufficient. In these cases, a bypass network must be used to filter a wider range of frequencies. Figure 3 shows such a network, C4 is used to catch larger voltage dips which are at relatively low frequencies. C2 and C3 filter the mid-range and higher frequency events respectively.



**Fig 3. Multiple capacitors used to bypass different frequencies**

Longer printed circuit board traces, increase inductance and lower the useful frequency of the bypass path. Therefore, bypass capacitors should be placed as close to the power supply pins as possible.

## 4. Summary

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High frequency noise is commonly present on DC power supplies. Bypass capacitors are applied to integrated circuits to filter out noise on power supply lines and to provide additional, instantaneous current during output switching. An effective bypass capacitor has minimum equivalent series resistance, minimum series inductance and minimum parallel leakage resistance over a wide range of frequencies and operating temperatures. Multiple bypass capacitors can be used in applications where different noise frequencies are present. Printed circuit board traces, increase the series inductance which reduces the effectiveness of bypass capacitors. As a result, bypass capacitors must be placed as close to the power supply pins of the integrated circuit as possible.

## 5. References

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- [1] D. Walton: "P.C.B. Layout for High-Speed Schottky TTL".
- [2] Howard Johnson and Martin Graham: "High-Speed Digital Design: A Hand Book of Black Magic" Englewood Cliffs, NJ: Prentice Hall, ISBN 0-13-395724-1.
- [3] Robert Pease: "Troubleshooting Analog Circuits" Stoneham, MA: Butterworth-Heinemann, ISBN 0-7506-9184-0.
- [4] Philips Semiconductors, Application note AN203: "Test fixtures for high-speed logic".

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