Important notice

Dear Customer,

On 7 February 2017 the former NXP Standard Product business became a new company with the tradename **Nexperia**. Nexperia is an industry leading supplier of Discrete, Logic and PowerMOS semiconductors with its focus on the automotive, industrial, computing, consumer and wearable application markets

In data sheets and application notes which still contain NXP or Philips Semiconductors references, use the references to Nexperia, as shown below.

Instead of http://www.nxp.com, http://www.philips.com/ or http://www.semiconductors.philips.com/, use **http://www.nexperia.com**

Instead of sales.addresses@www.nxp.com or sales.addresses@www.semiconductors.philips.com, use **salesaddresses@nexperia.com** (email)

Replace the copyright notice at the bottom of each page or elsewhere in the document, depending on the version, as shown below:
- © NXP N.V. (year). All rights reserved or © Koninklijke Philips Electronics N.V. (year). All rights reserved
Should be replaced with:
- **© Nexperia B.V. (year). All rights reserved**.

If you have any questions related to the data sheet, please contact our nearest sales office via e-mail or telephone (details via **salesaddresses@nexperia.com**). Thank you for your cooperation and understanding,

Kind regards,

Team Nexperia

AN11400

Properties and application of bypass capacitors

Rev. 1 — 13 December 2013 Application note

Document information

Info	Content
Keywords	-
Abstract	This application note describes the properties and application of bypass capacitors

Revision history

Rev	Date	Description
v.1	20131213	draft version

Contact information

For more information, please visit: **http://www.nxp.com**

For sales office addresses, please send an email to: **salesaddresses@nxp.com**

1. Introduction

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.

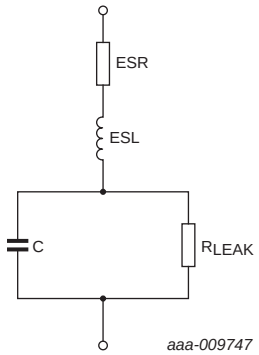

Fig 1. Equivalent circuit of a capacitor

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 (Ω)

L = equivalent series inductance (H)

R = dielectric loss (R_{LEAK}) (Ω)

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 μF or 0.01 μF bypass capacitor is used as shown in Figure 2.

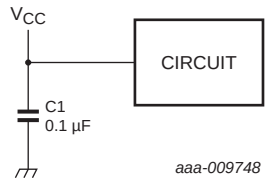

Fig 2. Single bypass capacitor for low current and high frequency noise applications

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.

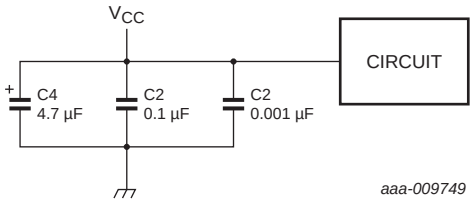

Fig 3. Multiple capacitors used to bypass different frequencies

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

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

[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”.

6. Legal information

6.1 Definitions

Draft — The document is a draft version only. The content is still under internal review and subject to formal approval, which may result in modifications or additions. NXP Semiconductors does not give any representations or warranties as to the accuracy or completeness of information included herein and shall have no liability for the consequences of use of such information.

6.2 Disclaimers

Limited warranty and liability — Information in this document is believed to be accurate and reliable. However, NXP Semiconductors does not give any representations or warranties, expressed or implied, as to the accuracy or completeness of such information and shall have no liability for the consequences of use of such information. NXP Semiconductors takes no responsibility for the content in this document if provided by an information source outside of NXP Semiconductors.

In no event shall NXP Semiconductors be liable for any indirect, incidental, punitive, special or consequential damages (including - without limitation - lost profits, lost savings, business interruption, costs related to the removal or replacement of any products or rework charges) whether or not such damages are based on tort (including negligence), warranty, breach of contract or any other legal theory.

Notwithstanding any damages that customer might incur for any reason whatsoever, NXP Semiconductors' aggregate and cumulative liability towards customer for the products described herein shall be limited in accordance with the *Terms and conditions of commercial sale* of NXP Semiconductors.

Right to make changes — NXP Semiconductors reserves the right to make changes to information published in this document, including without limitation specifications and product descriptions, at any time and without notice. This document supersedes and replaces all information supplied prior to the publication hereof.

Suitability for use — NXP Semiconductors products are not designed, authorized or warranted to be suitable for use in life support, life-critical or safety-critical systems or equipment, nor in applications where failure or malfunction of an NXP Semiconductors product can reasonably be expected to result in personal injury, death or severe property or environmental damage. NXP Semiconductors and its suppliers accept no liability for inclusion and/or use of NXP Semiconductors products in such equipment or applications and therefore such inclusion and/or use is at the customer's own risk.

Applications — Applications that are described herein for any of these products are for illustrative purposes only. NXP Semiconductors makes no representation or warranty that such applications will be suitable for the specified use without further testing or modification.

Customers are responsible for the design and operation of their applications and products using NXP Semiconductors products, and NXP Semiconductors accepts no liability for any assistance with applications or customer product design. It is customer's sole responsibility to determine whether the NXP Semiconductors product is suitable and fit for the customer's applications and products planned, as well as for the planned application and use of customer's third party customer(s). Customers should provide appropriate design and operating safeguards to minimize the risks associated with their applications and products.

NXP Semiconductors does not accept any liability related to any default, damage, costs or problem which is based on any weakness or default in the customer's applications or products, or the application or use by customer's third party customer(s). Customer is responsible for doing all necessary testing for the customer's applications and products using NXP Semiconductors products in order to avoid a default of the applications and the products or of the application or use by customer's third party customer(s). NXP does not accept any liability in this respect.

Export control — This document as well as the item(s) described herein may be subject to export control regulations. Export might require a prior authorization from competent authorities.

Translations — A non-English (translated) version of a document is for reference only. The English version shall prevail in case of any discrepancy between the translated and English versions.

Evaluation products — This product is provided on an "as is" and "with all faults" basis for evaluation purposes only. NXP Semiconductors, its affiliates and their suppliers expressly disclaim all warranties, whether express, implied or statutory, including but not limited to the implied warranties of non-infringement, merchantability and fitness for a particular purpose. The entire risk as to the quality, or arising out of the use or performance, of this product remains with customer.

In no event shall NXP Semiconductors, its affiliates or their suppliers be liable to customer for any special, indirect, consequential, punitive or incidental damages (including without limitation damages for loss of business, business interruption, loss of use, loss of data or information, and the like) arising out the use of or inability to use the product, whether or not based on tort (including negligence), strict liability, breach of contract, breach of warranty or any other theory, even if advised of the possibility of such damages.

Notwithstanding any damages that customer might incur for any reason whatsoever (including without limitation, all damages referenced above and all direct or general damages), the entire liability of NXP Semiconductors, its affiliates and their suppliers and customer's exclusive remedy for all of the foregoing shall be limited to actual damages incurred by customer based on reasonable reliance up to the greater of the amount actually paid by customer for the product or five dollars (US$5.00). The foregoing limitations, exclusions and disclaimers shall apply to the maximum extent permitted by applicable law, even if any remedy fails of its essential purpose.

6.3 Trademarks

Notice: All referenced brands, product names, service names and trademarks are the property of their respective owners.

7. Contents

For more information, please visit: http://www.nxp.com
For sales office addresses, please send an email to: salesaddresses@nxp.com

Date of release: 13 December 2013
Document identifier: AN11400