Decoupling, Passive Components

Choose yourself and new technologies

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References

Basic:

Ott H. W., *Electromagnetic Compatibility Engineering*, Wiley, Hoboken, NJ, 2009

Additional:

Williams T., *EMC for Product Designers*, Elsevier-Newnes, 4-th ed., Oxford, 2007

Decoupling part is based on an unpublished paper:

„Decoupling Circuits of Power Distribution Networks for Boards without Power Planes" by A.E.Sowa and J.S.Witkowski

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Source of illustrative materials

Illustrative materials have been taken from:

Ott H. W., *Electromagnetic Compatibility Engineering*, Wiley, Hoboken, NJ, 2009

and from an unpublished paper:
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Decoupling

Decoupling systems are an essential component of a power distribution network (PDN) of digital ICs. Ensuring the adequacy of the PDN has become and is still one of the most important elements of the design of digital systems. In particular, the PDN cannot restrict the speed of the digital IC.

The importance of this issue increases with the degree of integration of digital integrated circuits. The increase in the number of switching transistors on a chip leads directly to an increase in the power dissipated in the system. In order to reduce this, the supply voltage is lowered, which, unfortunately, leads directly to a lowering of resistance to changes in supply voltage. This results in a steady increase in the demands placed on power distribution systems.

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Decoupling

The purpose of decoupling the power supply to the digital circuit is, generally speaking, to eliminate the pulse shape changes that occur in the system and loads due to momentary changes in the supply voltage of the chip. These momentary changes of supply voltage can lead to malfunctioning of the chip. The primary effect of momentary changes in the power is the change of the characteristics of the switching chip systems, resulting in the emergence of jitter in its various circuits.

The design of decoupling circuits is based on the specific use of capacitors as complex RLC circuits. The development of technology, especially SMD ceramic capacitors with excellent frequency characteristics, allows the construction of decoupling circuits with very good, precisely controlled performance.

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Decoupling

The causes of changes in the supply voltage of the chip

You can specify several causes of momentary changes in the supply voltage of the chip. These include, in particular:
- supply current changes as the result of the switching processes in the chip
- interference from the power source,
- interference coupled with a power trace derived from other circuits on the same PCB and from the more remote areas of the electromagnetic environment.

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Decoupling

The basic method for power decoupling

Providing a constant voltage supply of the chip, regardless of the changing current of the chip and independently of the instantaneous voltage changes from the power source requires that the voltage is effectively stabilized. **The only practically used method of stabilization is to use a sufficiently large capacitor**, having a capacity sufficient to cover the current changes occurring with only minor, acceptable changes in voltage on the capacitor. At the same time, current changes of the capacitor must be done fast enough so that there were no additional instantaneous voltage changes due to the delay. This requires that the used capacitor (capacitor structure) had no excessive delays the reaction. This leads to bring very strict requirements for decoupling capacitors circuits and power distribution circuits.

Decoupling

Performance measure of decoupling systems

Although digital systems mainly use the time domain, performance measures of the effectiveness of the decoupling systems are formulated primarily in the frequency domain.
Basic measures correspond to the previously mentioned causes of the occurrence of momentary changes in the supply voltage of the chip.
These include:
- PDN impedance seen from the load (the chip)
- supply voltage filtration,
- filtration of interference coupled with the power trace.

Decoupling

Effective elimination of momentary supply voltage changes, regardless of changes of the chip current, requires delivery of a relatively large charge from decoupling capacitors. At the same time, the charge must be delivered without delay. In the frequency domain to meet these requirements requires a power supply with a constant value vs. frequency.

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Decoupling

Having the power consumed by the chip and its supply voltage and ripple limit value is sufficient to determine the so called target impedance for this system. Its definition can be written as follows:

$$Z = \frac{V_{core} \times 0.05}{I \times 0.5}$$

where: Vcore – supply voltage of the chip
I – supply current

Ripple is determined percentage of the supply voltage (here assumed 5%), or by specifying the maximum amplitude.

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Decoupling

The effectiveness of ripple attenuation is decided by a PDN impedance seen by the chip at the point of power connection. This impedance may not exceed the target value of impedance, which means that do not exceed the permissible level ripple for the chip.

Of course, the requirement for the PDN impedance must be realized to the extent required for the chip maximum frequency.

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Passive Components

Actual components are not "ideal"; their characteristics deviate from those of the theoretical components. Understanding these deviations is important in determining the proper application of these components.

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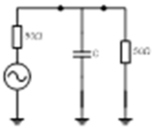
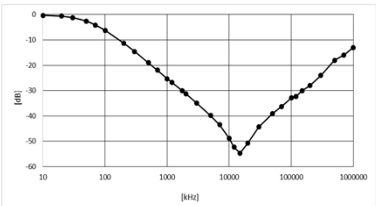
CAPACITORS



Schematic diagram of the capacitor measurement system

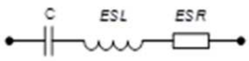
CAPACITORS



Measured voltage gain for a SMD ceramic capacitor 10nF

CAPACITORS

An actual capacitor is not a pure capacitance; it also has both resistance and inductance,



L is the equivalent series inductance (ESL) and is from the leads as well as from the capacitor structure.
R1 is the equivalent series resistance (ESR) of the capacitor and a function of the dissipation factor of the capacitor.

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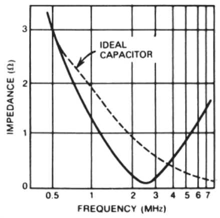
CAPACITORS

Operating frequency is one of the most important considerations in choosing a capacitor. The maximum useful frequency for a capacitor is usually limited by the inductance of the capacitor structure as well as by its leads. Figure shows how the impedance of an example 0.1μF capacitor varies with frequency.



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CAPACITORS

Capacitors are most frequently categorized by the dielectric material from which they are made.

Surface-mount capacitors, because of their small size and absence of leads, have significantly less inductance than leaded capacitors; therefore, they are more effective high-frequency capacitors.

In general, the smaller the capacitor's package or case, the lower the inductance.

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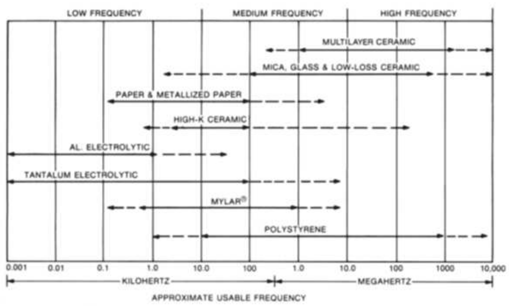
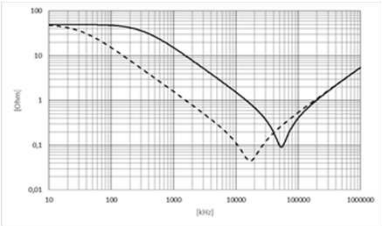
CAPACITORS



SMD Ceramic Capacitors



Impedance for a SMD ceramic capacitor 10nF and a SMD ceramic capacitor 100nF

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Electrolytic Capacitors

The primary advantage of an electrolytic capacitor is the large capacitance value that can be put in a small package. The capacitance-to-volume ratio is larger for an electrolytic capacitor than for any other type.

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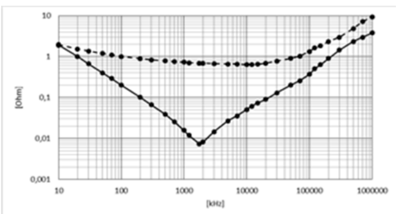
SMD Electrolytic Capacitors



Impedance for a SMD tantalum capacitor 10µF and a SMD aluminum capacitor 10µF

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Film Capacitors

Film capacitors have series resistances considerably less than electrolytics but still have moderately large inductances. Their capacitance-to-volume ratio is less than electrolytics, and they are usually available in values up to a few microfarads.

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Mica and Ceramic Capacitors

Mica and ceramic capacitors have low series resistance and inductance. They are therefore high-frequency capacitors and are useful up to about 500 MHz—provided the leads are kept short. Some surface-mount versions of these capacitors are useful up into the gigahertz range.

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Ceramic Capacitors

Table shows the effect of lead length on the resonant frequency (in MHz) of small ceramic capacitors.

Capacitance Value (pf)	Self-Resonant Frequency 1/2-in Leads
10,000	12
1000	35
500	70
100	150
50	220
10	500

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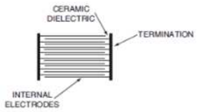
Multilayer Ceramic Capacitors (MLCCs)

Multilayer ceramic capacitors (MLCCs) are composed of multiple layers of ceramic material, often barium titanite, separated by interdigitated metal electrodes as shown in the figure. Contact to the electrodes is made at the ends of the structure. This construction effectively places many capacitors in parallel.



MLCCs are excellent high-frequency capacitors and are commonly used for high-frequency filtering as well as digital logic decoupling applications.

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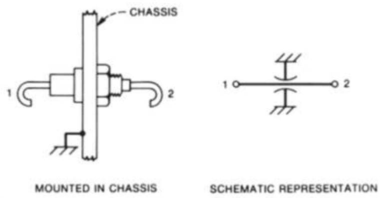
Feed-Through Capacitors

A capacitor mounted in a chassis or shield, along with its schematic representation.



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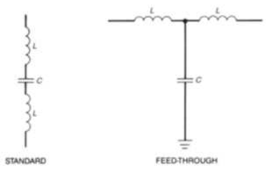
Feed-Through Capacitors

Feed-through capacitors are three terminal devices. The capacitance is between the leads and the case of the capacitor, not between the two leads.



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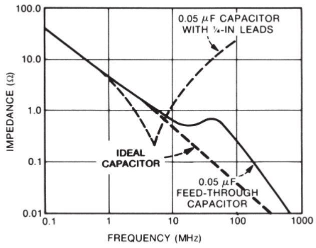
Feed-Through Capacitors

Figure shows the impedance versus frequency characteristics of both a 0.05μF feed-through capacitor and a standard 0.05 μF capacitor.



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Paralleling Capacitors

No single capacitor will provide satisfactory performance over the entire frequency range from low to high frequencies. To provide filtering over this range of frequencies, two different capacitor types are often used in parallel.

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Decoupling

Paralleling Capacitors

Typical capacitors used in the PDN on the power source side have values ranging from 10 to 100μF and used on the load side from 10 to 100 nF.

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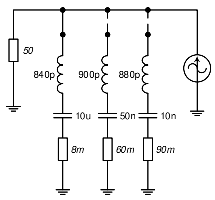
Decoupling

Paralleling Capacitors



Three capacitors connected in parallel: 10μF, 50nF and 10nF

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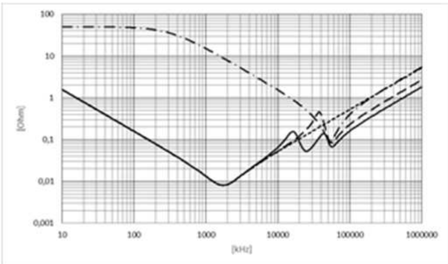

Impedance of the two capacitors connected in parallel (10μF and 10nF - dash) and of the three capacitors (10μF, and 10nF 50nF – cont.). Also impedance for the single 10μF (dash) and 10nF (dash-dot) capacitors.

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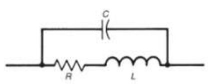
INDUCTORS

Inductors may be categorized by the type of core on which they are wound. The two most general categories are air core and magnetic core. Magnetic core inductors can be subdivided depending on whether the core is open or closed.



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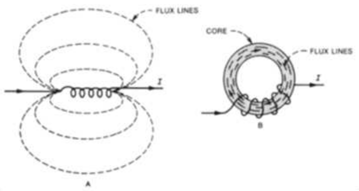
INDUCTORS

Another important characteristic of inductors is their susceptibility to, and generation of, stray magnetic fields.



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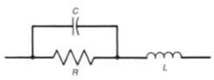
RESISTORS

Fixed resistors can be grouped into the following three basic classes:
(1) wirewound,
(2) film type, and
(3) composition.



The shunt capacitance can be important when high-value resistors are used.

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CONDUCTORS

Conductors are not normally considered components; however, they do have characteristics that are very important to the noise and high-frequency performance of electronic circuits.

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FERRITES

Ferrite is a term for a class of nonconductive ceramics that consists of oxides of iron, cobalt, nickel, zinc, magnesium, and some rare earth metals.

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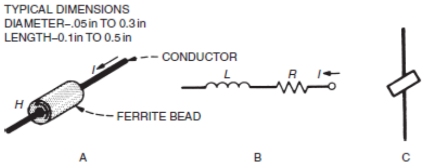
FERRITES

Ferrites provide an inexpensive way of coupling high-frequency resistance into a circuit without introducing power loss at dc or affecting any low-frequency signals present.



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