# Mastering the Details of EMI Suppression Ferrites


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## Instructor Biography

Lee Hill is Founding Partner of SILENT Solutions LLC, an independent electromagnetic compatibility (EMC) and RF design firm he established in 1992. Besides providing EMC design review and troubleshooting services, Lee is also a member of adjunct faculty at Worcester Polytechnic Institute (WPI) where he teaches graduate courses in EMC. He is also an EMC class instructor at the University of Oxford (England), and for the IEEE EMC Society's annual Global University program and EMC Fundamentals workshop. In past years Lee was also an EMC course instructor for UC Berkeley Extension as well for Hewlett Packard and Agilent Technologies. Previously Lee was Principal EMC and Systems Engineer at Digital Equipment Corporation's Workstation Systems Engineering Group in Palo Alto, CA. In 2017 Lee founded SILENT Solutions GmbH in Munich, Germany.

Lee received the Master of Science Degree in Electrical Engineering & Electromagnetics with highest honors from the University of Missouri-Rolla, (now Missouri University of Science and Technology). He is an inventor of three US patents for EMI control in electronic systems, and provides expert witness services for patent litigation.

In the past fifteen years he has been a frequent featured speaker at IEEE EMC Society fundraising events in cities throughout the US including Santa Clara, Seattle, Portland, Chicago, Milwaukee, Dallas/Fort Worth and Detroit. He has also provided technical presentations to Society chapters in Los Angeles, San Diego, Santa Clara, Boston, Austin, Colorado Springs, Pittsburgh, and Orange County, CA. He served a term as an IEEE EMC Society Distinguished Lecturer from 1994-1996.

Lee has over twenty-five years of experience in the EMC design and retrofit of complex electronic systems. He has been teaching short courses on EMC design and troubleshooting for twenty years. Lee consults and teaches worldwide, and has presented classes in Taiwan, Singapore, Mexico, Norway, Canada, South Korea, France, Germany and United Kingdom. He has completed a three-year term on the Editorial Review Board of Printed Circuit Design Magazine.. He is an avid father, runner, motorcyclist, table tennis player and Amateur Radio operator, and has served as an officer on the board of directors of several non-profits.

Lee is past member of the IEEE EMC Society Board of Directors (2004-2007). From 1999-2006 he chaired the IEEE EMC Society's Distinguished Lecturer Program, and served as Co-Technical Chair of the 2003 IEEE Symposium on EMC in Boston, MA.
In 1999 Lee received a Certificate of Appreciation from the EMC Society for significant contributions to education through his annual participation in the Demonstrations and Experiments portion of annual IEEE EMC Symposia.

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# Outline

- WHY
- Definitions
- Equivalent Circuits + A Little Bit of Math
- Datasheets
- Effect of DC Bias
- Common-Mode vs. Differential-Mode
- Common False Beliefs (myths)
- Demonstrations
- No Summary to Save Time ☺




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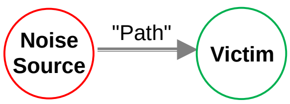
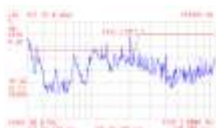
# WHY

Every noise problem is source – path – victim




“Chip beads” can:



- Help us pass regulatory noise tests
- Stop or prevent oscillations in underdamped circuits



- Prevent self interference (intra-system) between RF circuits (wireless PCB) and digital control circuits

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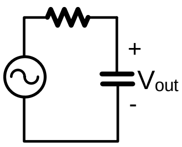
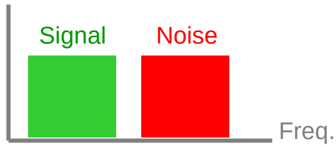
# Ferrite Beads as “Filters”

Noise Source —"Path"→ Victim

- FILTERS provide solutions for noise problems where:
  the PATH from SOURCE to VICTIM is _____________

- Filters pass or reject signal energy on the basis of
  - amplitude,
  - mode of travel,
  - _________







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# Noise CURRENT is the SOURCE

Conducted Emissions

EUT — $I_{cm}(+I_{dm})$ → Network or current probe → MEASURED RF voltage

Conducted Susceptibility

EUT ← $I_{cm}(+I_{dm})$ — Network or current probe or transformer ← GENERATED RF Power

Radiated EMISSIONS

EUT — $I_{cm}$ → “Transmitting” antenna → Radio Wave E,H

Radiated Susceptibility

EUT ← $I_{cm}$ — “Receiving” antenna ← Radio Wave E,H

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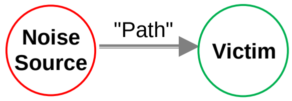
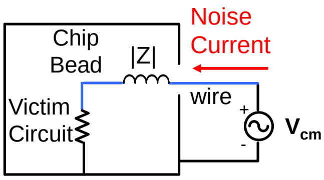
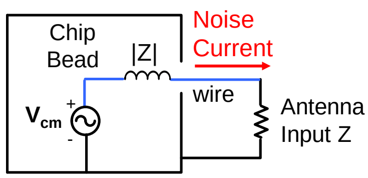
## Noise Filtering with Series Element




- Improve System Level Immunity and Emissions
- Want |Z| LARGE while maintaining good signal integrity




Filtering of wires
to decrease susceptibility




Filtering of wires
to decrease emissions

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## Definitions

- Chip Bead = Ferrite Bead = SMT Ferrite
  - used for EMI attenuation (loss due to resistance Ω)
  - not used for energy storage (inductive reactance ωL Ω)
- Two terminal device with magnetic core
- Current ratings from Milliamperes to Amperes
- Size 0201 to….. BIG
- 1 MHz < F < 2 GHz+

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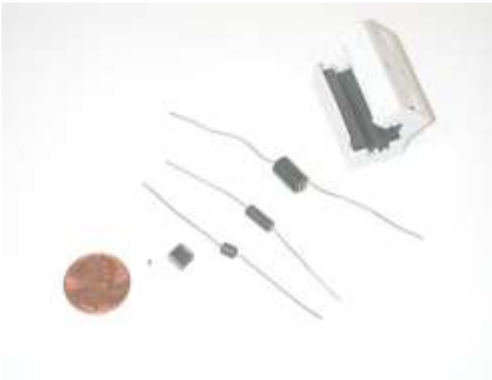
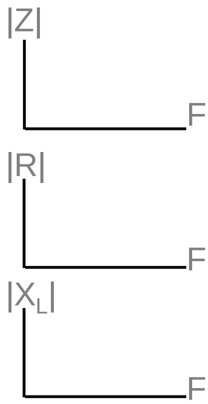
# Ferrite "Beads", Cores, Chips

“All ferrite chips / beads / cores  for EMI suppression are the same”









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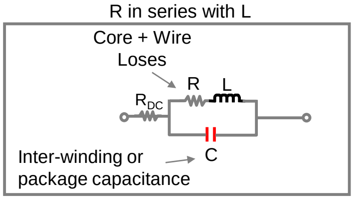
# Chip Bead Equivalent Circuits

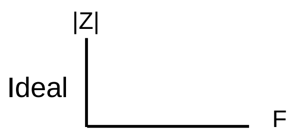
Consistent with device physics
R in series with L




At F = $F_o$   |Z| =  Big, ≠ R

<u>“Inductor”</u>
|Z| (peak) @ resonance >>R
Series R, L not strong f(frequency)

<u>Ideal Inductor:</u>
R= C = $L_{interconnect}$=0
| Z | = ω L = 2 π FL




<u>Real Inductor:</u>
Usually choose L>>$L_{interconnect}$
“High Q” if ω L >> R
“Low Q” if R >> ω L


$$\omega_o = \frac{1}{\sqrt{LC}},$$

$$F_o = \frac{1}{2\pi\sqrt{LC}}$$

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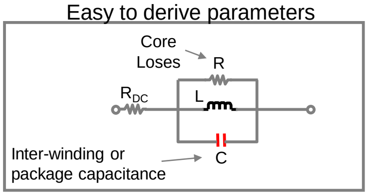
# Chip Bead Equivalent Circuits

Ferrite Bead

|Z| @ resonance ~ R

1) Series R, L *ARE* strong f(Frequency)
2) |Z| ➜ 0 at “low” F
3) Peak Z at “mid” F
4) |Z| ➜ 0 at “high” F

Convenient for |Z| measurements
Easy to derive parameters




At F = $F_o$ |Z| ~ R

Ferrites - class of relatively non-conductive ceramics (iron Fe)

Above ~10 MHz, Nickel-zinc core is used. Relatively good insulator for voltages < 50 volts.

Below ~10 MHz, Manganese-zinc core is used. The volume resistivity is MUCH lower than for low permeability, “high frequency” nickel zinc materials.

What is the difference between "Ferrite Bead" and "Inductor? Ferrite bead specification is |Impedance| versus Frequency. Inductor specification is Inductance versus Frequency or I

Often (not always) "Ferrites" dissipate energy ("loss" = heat) , "Inductors" store energy.



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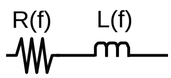
# A Little Bit of Math

- Series R, L *ARE* strong f(Frequency)
- Series circuit is straightforward to understand




$|Z| = R + jX_L$

$|Z| = R + j\omega\mu L_o$

Define permeability to be a complex number $\mu = \mu' - j\mu''$

$$\mathbf{|Z| = R + j\omega\,[\,\mu' - j\mu''\,]\;L_o}$$

$$\mathbf{|Z| = \underbrace{R + \omega\mu'' L_o}_{\text{Real}} + \underbrace{j\,\omega\,\mu' L_o}_{\text{Imaginary}}}$$

Resistance = Loss Reactance = Storage

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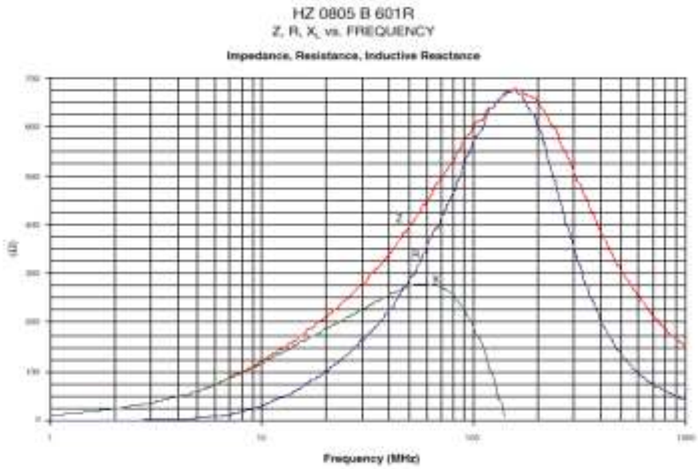
## Typical Impedance Curve – Ferrite Bead #1

QUALITY (Q) factor of an inductor is calculated from Im[Z] / Re [Z]



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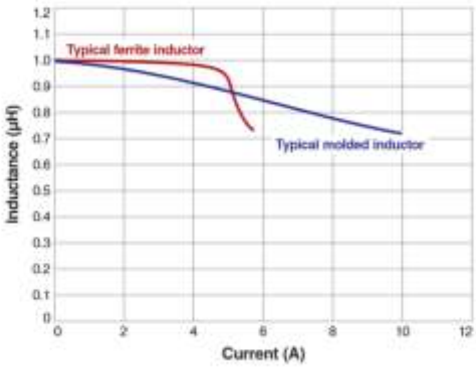
## Chip Bead and Inductor Current Ratings

Inductor: Current $I_{sat}$ that causes X% reduction in inductance (usually)

Chip bead: Current $I_{RMS}$ that causes 20° C (or 30 ° C) temperature rise

Chip bead: OTHER UNIQUE EFFECTS




These current plots are "$I_{SAT}$" , indicating % decrease of inductance.

For some inductors.
"$I_{SAT}$" > "$I_{RMS}$"
(Inductance) (heating)

For other inductors
"$I_{SAT}$" < "$I_{RMS}$"

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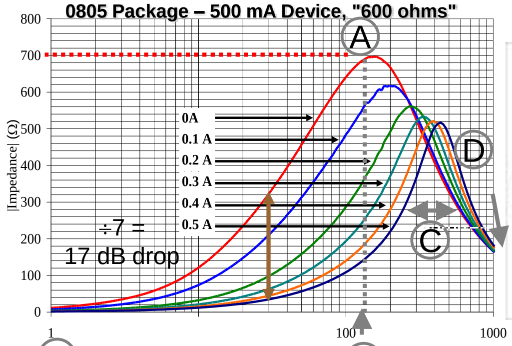
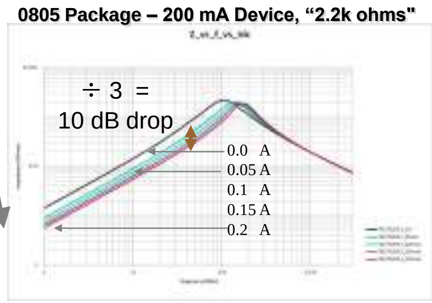
# Effect of Bias Current on SMT Chip Bead Z vs. Freq.




- A Peak |Z| is a f($I_{BIAS}$)
- B Freq of Peak |Z| is f($I_{BIAS}$)
- C "Q" is f($I_{BIAS}$)
- D No difference at very high F

Note:
Lin-Log vs. Log-Log
Different current ratings
600 Ω vs. 2.2k Ω part
Different $R_{DC}$'s



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# A Few Myths

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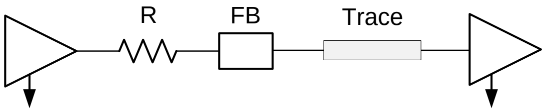
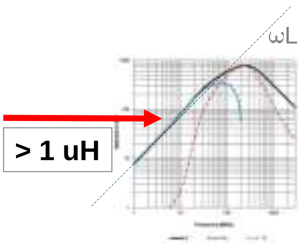
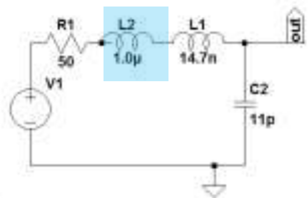
# Myth: "EMI Ferrites Behave Like Resistors"




**Vendor part #** xxxxxx:
0402 100ma

AC 3 0
PULSE(0 3 0 1.5n 1.5n 2.5u 5u 10)
Rser=0
.tran 0 50u 0 1n
.options plotwinsize=0

.29 nh/m, 7.37 nH/inch
.12 pF/m 3 pF/inch
5 pF load
2 inches trace





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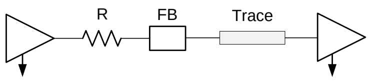
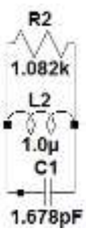
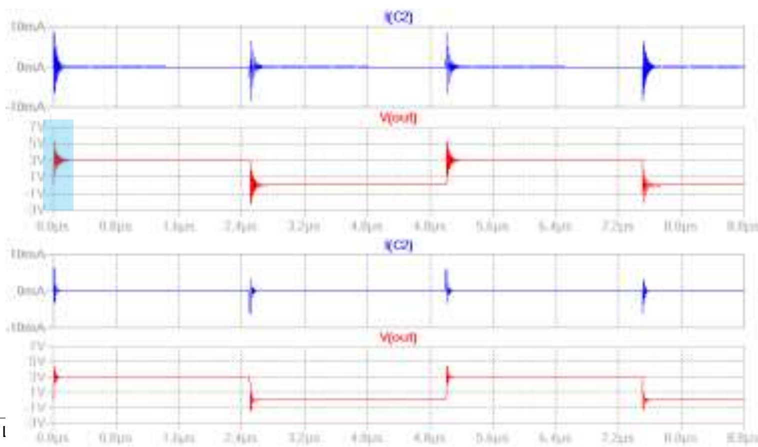
# Myth: "EMI Ferrites Behave Like Resistors"



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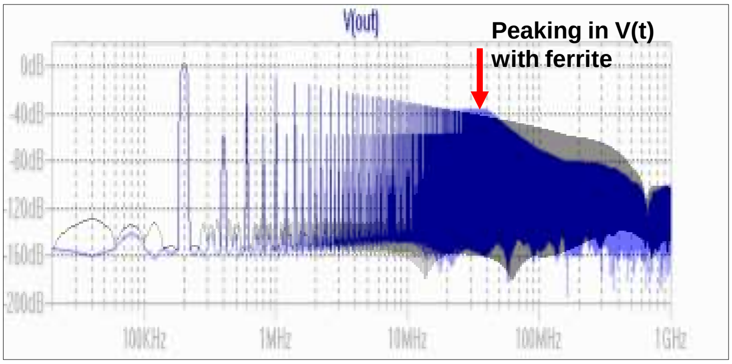
## Be Careful Where You Put Your Ferrite….USE SPICE MODELS

0402 100ma







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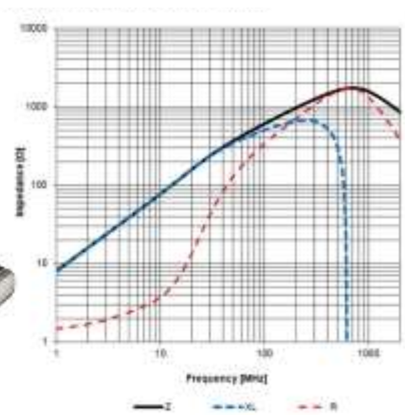
## "EMI Ferrites Don't Suppress Noise above 1 GHz

Yes they do!

- WiFi, Bluetooth
- Unmanned Aircraft Vehicle
- Mobile phones

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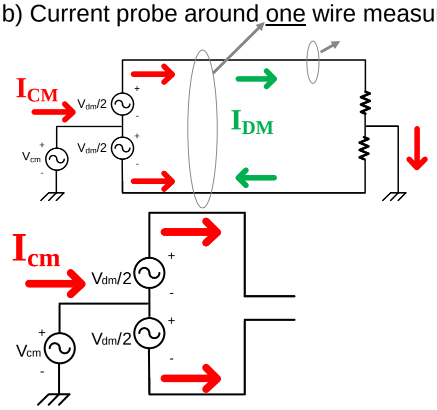
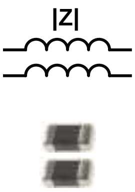
## 2 SMT Beads = One 2 Line Common-Mode Choke?

a) Current probe around <u>both</u> wires measures $I_{cm}$.
This is the “net”, unbalanced current of the cable bundle

b) Current probe around <u>one</u> wire measures $I_{cm}/2$ +/-$I_{dm}$




OR





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**For more EMC education with theory, applications, and live demos:**

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|---|---|
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| Advanced PCB Design for EMC. | June 18, 20 |
| Mechanical Design for EMC | June 18, 21 |

***Dresden, Germany***

| | |
|---|---|
| *Advanced PCB Design for EMC* | *April 17-18* |
| *Mechanical Design for EMC* | *April 17,19* |