Coupling Between Wire Lines and Application to Transfer Impedance Analysis

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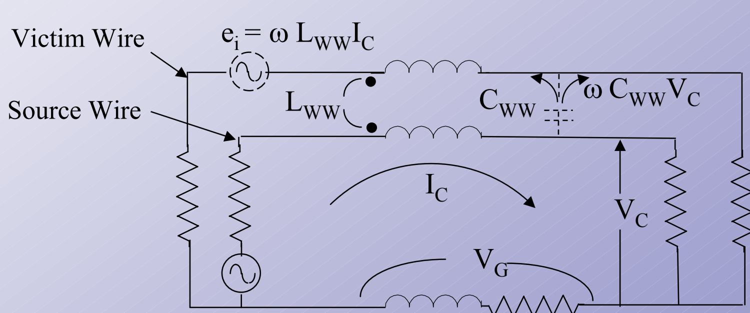
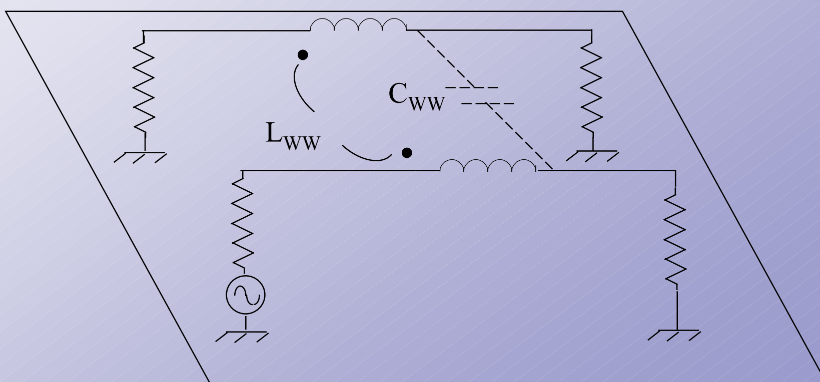
Cross Coupling in Interface Wiring

- Cross coupling can occur via common return impedance, mutual inductance, and mutual capacitance



Employment of Ground Reference Plane

- Ground plane reference provides low-impedance return; essentially eliminates coupling via common return.
- Physical separation of signal lines minimizes mutual inductance and mutual capacitance.



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Characteristics of Coupled Interference

- Electrically coupled current (via mutual capacitance)
  - Current divides between source and load ends of victim
  - Net voltages at each end are equal and in-phase
- Magnetically coupled voltage (via mutual inductance)
  - Voltage is series-injected and divides between source and load ends of victim
  - Voltages at each end are proportional to the impedance and tend to be out of phase
- Electrically-induced voltages and magnetically induced voltages tend to reinforce at the source end and to cancel at the load end.

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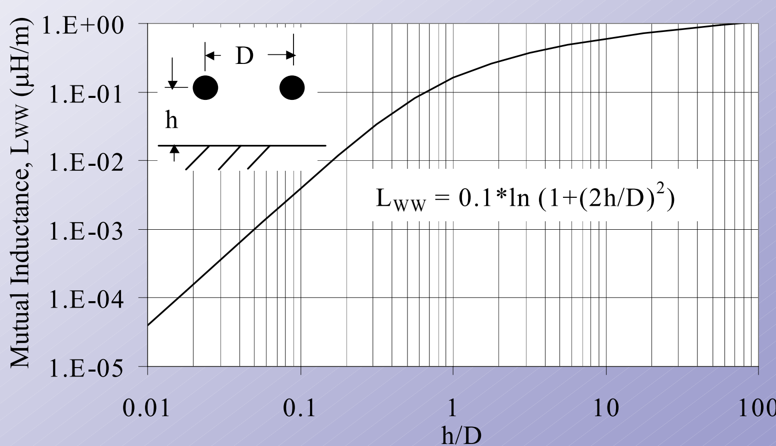
 For more information, please visit www.spira-emi.com/shieldingworkshop

Mutual Inductance, Wires Over a Ground Plane



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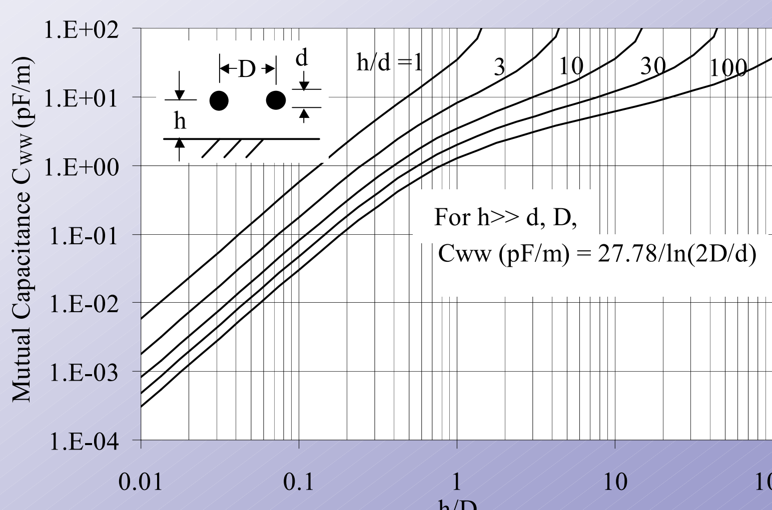
Mutual Capacitance, Wires Over a Ground Plane



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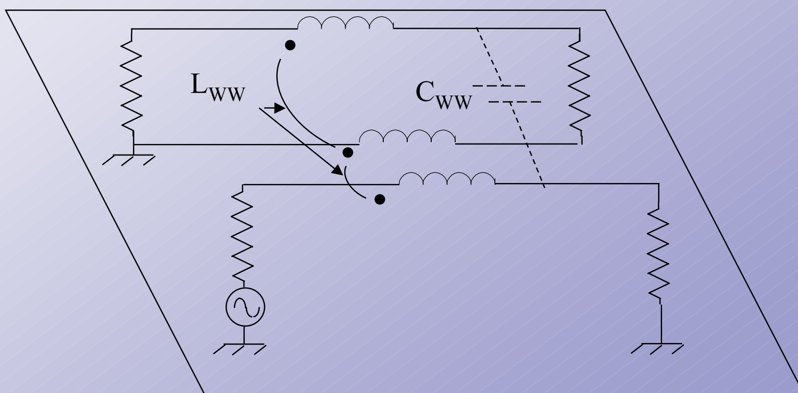
Single-Point Grounding (SPG) of Return

- Single-point grounding (SPG) of either (as illustrated) or both signal circuits eliminates coupling via common impedance and reduces mutual inductance



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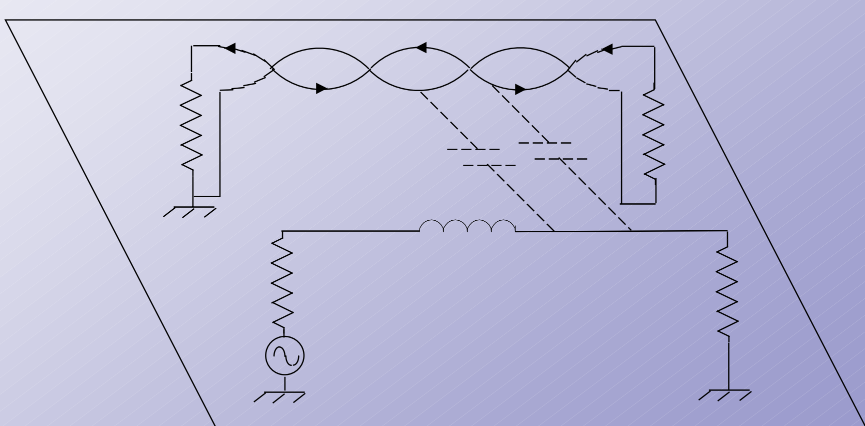
Employment of Twisted Pair Wiring

- Twisting signal wire with its return essentially cancels mutual inductive coupling; capacitive coupling is slightly decreased



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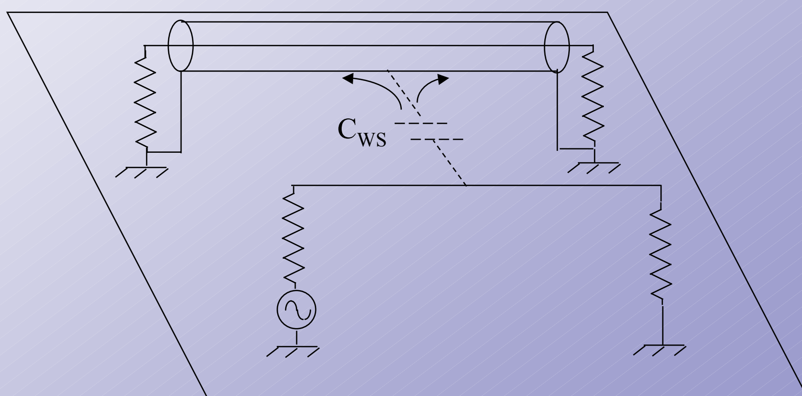
Effect of Wire Shield

- Wire shield protects victim circuit by draining capacitively-coupled currents to ground through its low impedance.



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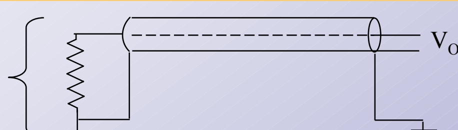
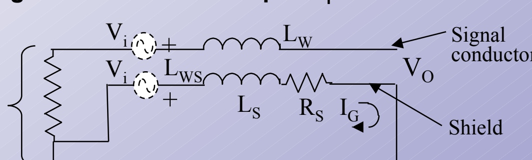
How Does Grounded Shield Protect Against Magnetic Induction?

Shielded wire with grounded shield



External magnetic field induces equal V_i in both wire and shield

Equivalent circuit



$$V_O = I_G(-j\omega L_{WS} + R_S + j\omega L_S) + V_i - V_i$$

But $L_{WS} = L_S$, and $I_G = V_i/(R_S + j\omega L_S)$, therefore,

$$V_O/V_i = R_S/(R_S + j\omega L_S)$$

At high frequencies, where $\omega L_S >> R_S$,

$$V_O/V_i = R_S/\omega L_S << 1$$

Shorted current in shield induces canceling voltage in shielded wire.

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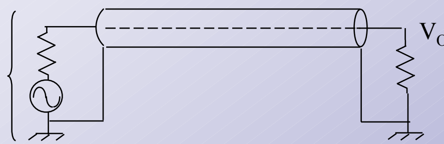
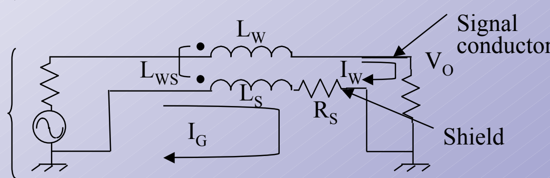
With shielded wire as a source, why does signal current not return entirely via low-impedance reference ground?

Shielded wire with grounded shield



Equivalent circuit



Shield-Ground Plane mesh:

$$0 = I_G(R_S + j\omega L_S) - I_W(j\omega L_S + R_S - j\omega L_{WS})$$

But $L_{WS} = L_S$, therefore, $I_G/I_W = R_S/(R_S + j\omega L_S)$,

At High frequencies, where $\omega L_S >> R_S$,

$$I_G/I_W = R_S/\omega L_S << 1$$

Shield return impedance is much lower than that of Reference ground plane loop

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Attenuation Characteristics of Shielded Line

- **Net voltage relative to total induced voltage:**

$$V_O/V_i = R_S/(R_S + j\omega L_S)$$

- **Net leakage current relative to internal shield signal current:**

$$I_G/I_W = R_S/(R_S + j\omega L_S)$$

- **The shielding effectiveness of the cable can be defined as:**

$$SE\ (dB) = 20 \log (|R_S + j\omega L_S| / R_S) \cong 20 \log \omega L_S/R_S$$

- **Note that in shielding calculations in general, and particularly at high frequencies, the shield resistance, R_S, is replaced with the transfer impedance, of the shield, $|Z_T|$**

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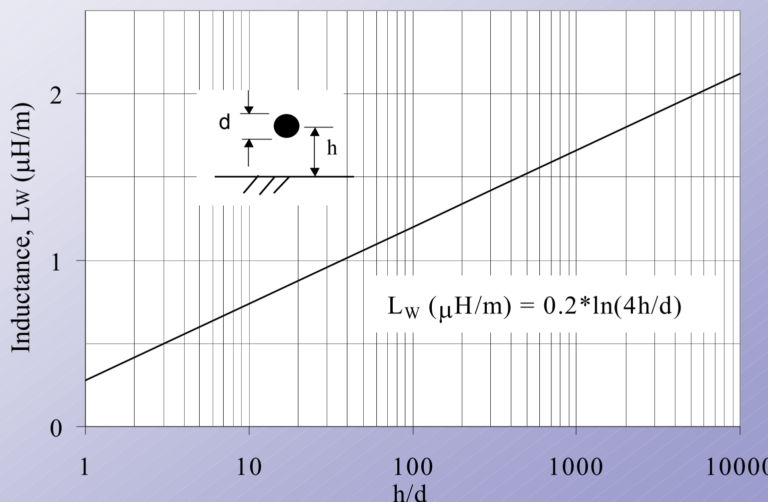
Inductance of a Wire Over a Ground Plane



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Transfer Impedance and Shielding Effectiveness (SE) of Typical Cables

	Single-Shielded Cable (Note 1)		Double-Shielded Cable (Note 2)	
Frequency (Hz)	$\lvert Z_T \rvert$ (Ohms/m)	SE (dB)	$\lvert Z_T \rvert$ (Ohms/m)	SE (dB)
DC	0.015	-	0.008	-
0.1M	0.015	31.0	0.006	39.5
1 M	0.020	48.5	0.002	68.5
10 M	0.085	56.0	0.001	94.6
100 M	0.5	60.6	0.004	102.5
1000 M	5	60.6	0.04	102.5

Notes:
1. Shield diameter: 0.116 inches; cable 2 inches over ground plane
2. SE (dB) = $20 \log(2\pi f L_S/|Z_T|)$

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Summary of Shield Action

- **In victim circuit, inductive voltage drop in shield return is precisely cancelled by the magnetically induced voltage in the signal circuit**
- **Net voltage induced in victim circuit is equal to the product of the shield current and the shield resistance acting as a transfer impedance**
- **The transfer impedance of a shield at frequencies below about 100 kHz (typically) is precisely equal to the resistance of the shield**
- **Depending on shield type and construction, at higher frequencies the transfer impedance can be lower or higher than the shield resistance**

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Selected References

1. Richard J. Mohr, "Coupling between Open and Shielded Wire Lines over a Ground Plane", IEEE Transactions on Electromagnetic Compatibility, Vol. EMC-9, September 1967, pp. 34-45.
2. Richard J. Mohr, "Coupling between Lines at High Frequencies", IEEE Transactions on Electromagnetic Compatibility, Vol. EMC-9, No. 3, December 1967, pp.127-129.
3. S.A. Schelkunoff & T.M. Odarenko, "Crosstalk between Coaxial Transmission Lines" Bell Systems Technical Journal, Vol. 26, April 1937, pp. 144-164. This paper is a classic- should be consulted when considering crosstalk in lines comparable to, or exceeding a wavelength in length.

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