Electromagnetic Compatibility (EMC)

Topic 1

Introduction to EMC

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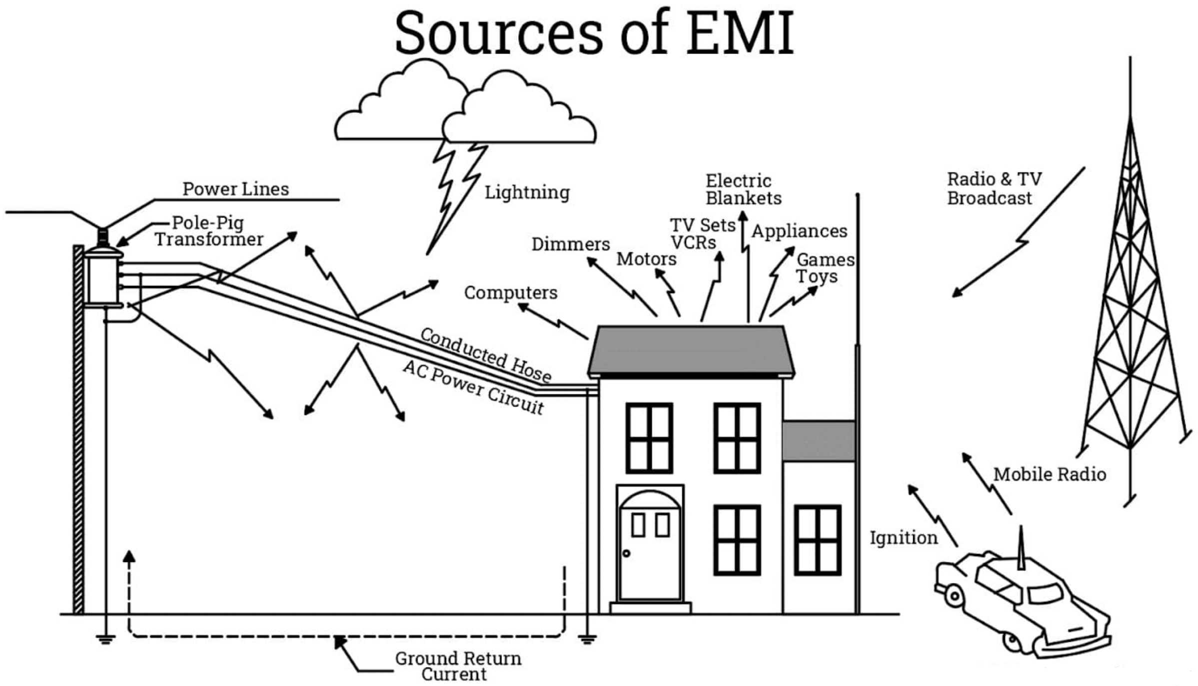
Introduction

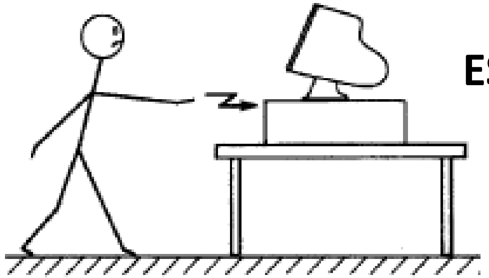
- The proliferation of electronic equipment, wireless systems, power distribution, and the wide sources of noise can cause electromagnetic interference (EMI) to other electrical or electronic equipment of devices.
- Designing equipment and devices that are not affected by such external interferers and that also do not pollute and generate interfering signals is the focus of Electromagnetic compatibility (EMC).
- EMC should be a design objective when developing real world devices and solutions.
- Governmental agencies have put several regulations for EMC.
- A system is Electromagnetically compatible if:
  1- It does not cause interference to other systems
  2- It is not susceptible to interference from other systems
  3- it does interfere with itself

Introduction

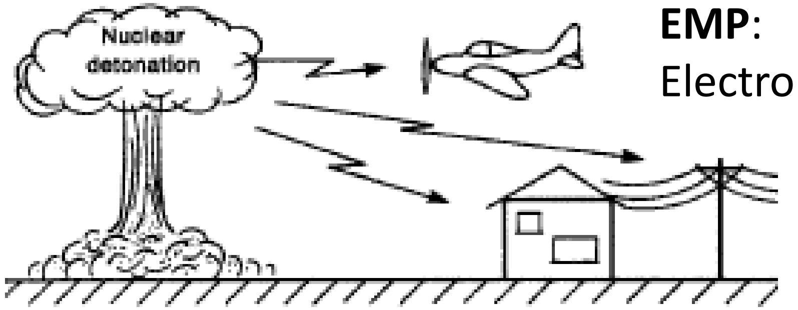
- Interference can come from direct coupling between systems, cables, or via radiation pickup or generation, or from other noise sources.
- Noise sources:
  - *Intrinsic noise sources* within electrical and electronic systems, i.e. thermal and shot noise
  - *Man-made* noise sources such as motors, switches, computers, radios, etc
  - *Natural disturbances*, i.e. lightning and sunspots

→ Interference is the undesirable effect of noise!





ESD: Electrostatic discharge



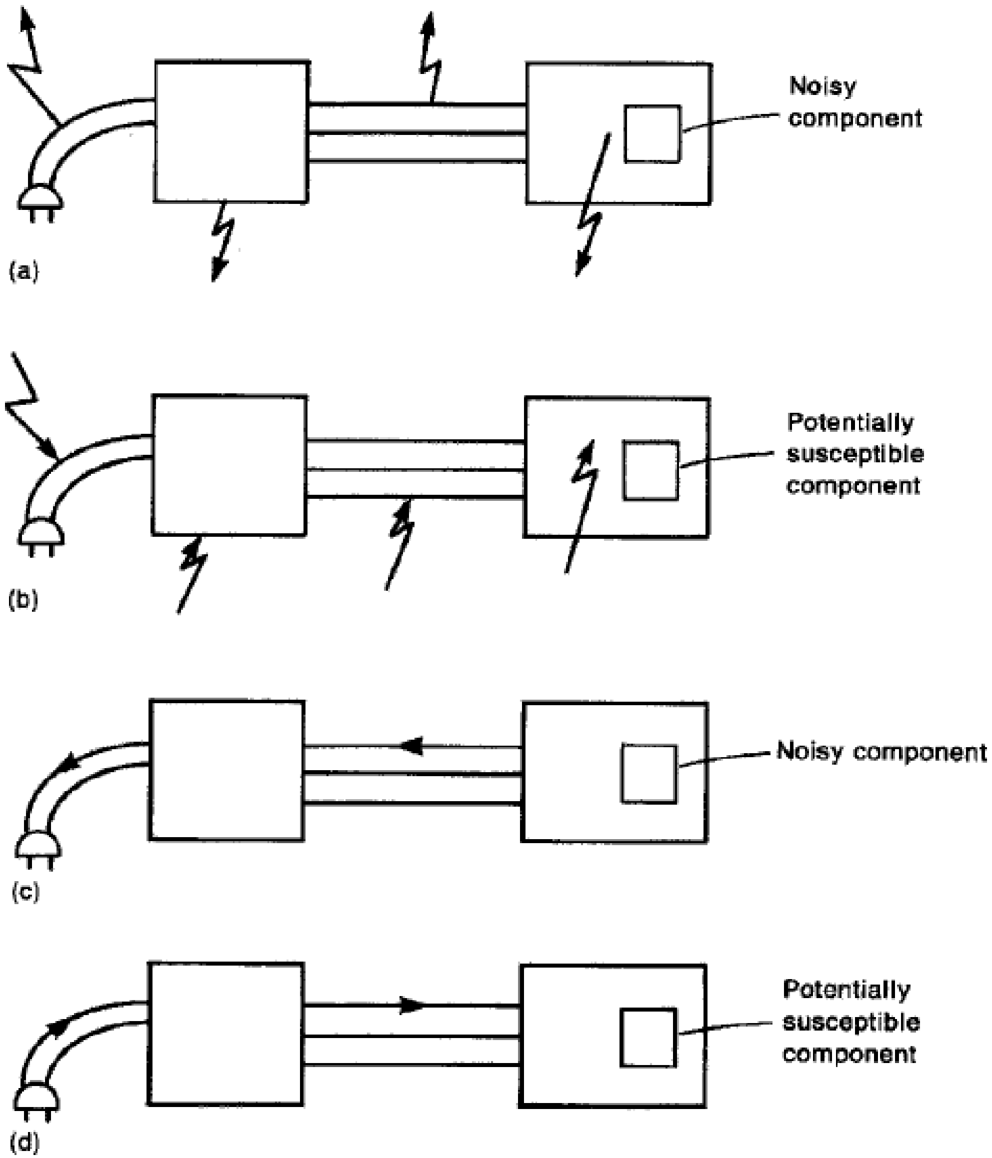
EMP: Electromagnetic Pulse

Introduction

- EMC is concerned with the ***generation*** (source, emitter), ***transmission*** (coupling path) and ***reception*** (receiver) of EM energy.
- Interference occurs only if the received EM energy causes the receiver to mis-behave (interpret the wrong message).
- To supress/prevent interference we can:
  - Remove or reduce source emissions
  - Eliminate or reduce the efficiency of the coupling path
  - Protect or make the receiver less susceptible to interference
- ***Susceptibility***: is the capability of the device or circuit to respond to unwanted EM energy. Opposite of susceptibility is immunity.
- ***Emission***: is related to the ability of the product to cause interference.

Introduction

- Interference can occur in wired (conducted) and wireless (radiated) fashions.
- We can break down the transfer of EM energy into:
  - (a) Radiated emissions
  - (b) Radiated susceptibility
  - (c) Conducted emissions
  - (d) Conducted susceptibility
- A time-saving and cost effective way is to consider EMC throughout the design process, and minimize effects for sub-systems and consider compliance verification early on and not to wait until all is put together…



Fundamentals Revision

- The electrical dimensions of a structure determines its ability to radiate or pickup interference. This electrical dimension is given in ***wavelengths*** (wrt to the operating frequency).
- EM phenomena are ***distributed-parameter*** process dependent, in that the properties of the structure such as Capacitance and Inductance are distributed throughout space rather than ***Lumped*** at discrete points.

In Free Space, sine wave frequencies and their Corresponding wavelengths

Frequency (f)	Wavelength (λ)
60 Hz	3107 miles (5000 km)
3 kHz	100 km
30 kHz	10 km
300 kHz	1 km
3 MHz	100 m
30 MHz	10 m
300 MHz	1 m
3 GHz	10 cm
30 GHz	1 cm
300 GHz	1 mm

$$\lambda = \frac{v}{f} \quad \left(\frac{\text{m/s}}{1/\text{s}} = \text{m} \right)$$

- The Lumped element circuit model approximation is only valid when the length of the circuit is less than **0.1λ** → **Electrically small** structure/circuit/element.
- *Circuit analysis for electrically small circuits, and wave analysis (Maxwell's Equations) for electrically large*.

Fundamentals Revision

- Consider the current wave:

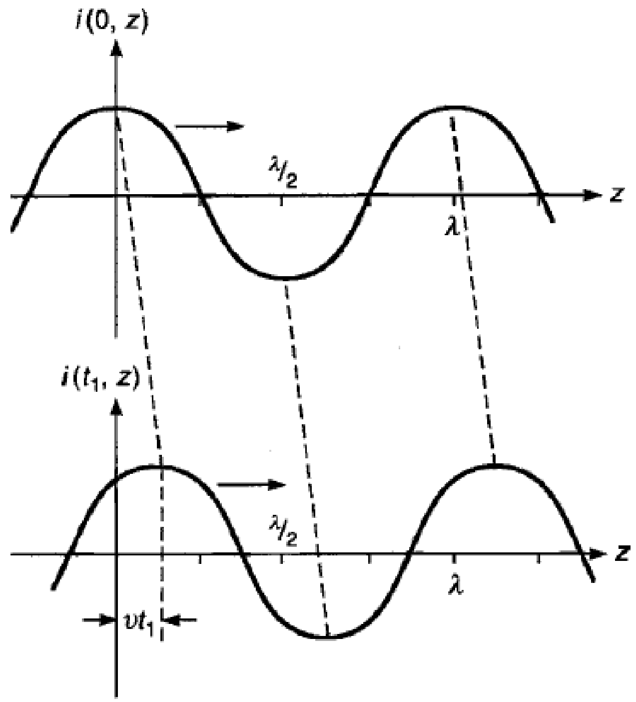
$$i(z,t) = I\cos\left(\omega t - \underbrace{\beta z}_{\varphi}\right)$$

$$\omega = 2\pi f \qquad \text{and} \qquad \beta\lambda = 2\pi \rightarrow \beta = \frac{2\pi}{\lambda}$$

thus,

$$i(z,t) = I\cos \underbrace{\left(\omega t - \frac{2\pi}{\lambda} z\right)}_{\text{constant wave front, traveling in +z}}$$

$$\underbrace{v}_{\text{wave phase velocity}} = \frac{dz}{dt} = \frac{\omega}{\beta} = \lambda f$$



- A physical medium will have a permittivity (ε) a permeability (μ) and conductivity (σ).
- The velocity of the wave will depend on ε and μ of the medium.

$$\varepsilon_0 = \frac{1}{36\pi} \times 10^{-9} \quad \text{(F/m)}$$

$$\mu_0 = 4\pi \times 10^{-7} \quad \text{(H/m)}$$

$$\varepsilon = \varepsilon_0 \varepsilon_r$$

$$\mu = \mu_0 \mu_r$$

$$\boxed{v = \frac{1}{\sqrt{\varepsilon\mu}} \quad \text{(m/s)}}$$

Tables of use

Material	ϵ_r
Air	1.0005
Styrofoam	1.03
Polyethylene foam	1.6
Cellular polyethylene	1.8
Teflon	2.1
Polyethylene	2.3
Polystyrene	2.5
Nylon	3.5
Silicon rubber	3.1
Polyvinyl chloride (PVC)	3.5
Epoxy resin	3.6
Quartz (fused)	3.8
Epoxy glass (printed circuit substrate)	4.7
Bakelite	4.9
Glass (pyrex)	5.0
Mylar	4.0
Porcelain	6.0
Neoprene	6.7
Polyurethane	7.0
Silicon	12.0

Conductor	σ_r	μ_r
Silver	1.05	1
Copper-annealed	1.00	1
Gold	0.70	1
Aluminum	0.61	1
Brass	0.26	1
Nickel	0.20	600
Bronze	0.18	1
Tin	0.15	1
Steel (SAE 1045)	0.10	1000
Lead	0.08	1
Monel	0.04	1
Stainless Steel (430)	0.02	500
Zinc	0.32	1
Iron	0.17	1000
Beryllium	0.10	1
Mumetal (at 1 kHz)	0.03	30,000
Permalloy (at 1 kHz)	0.03	80,000

Example 1

- A circuit/radiating structure has a physical dimension of 3.6 m and is operating at a frequency of 86 MHz. What would be its electrical length in free space and when immersed in polyvinyl chloride (PVC) with $\varepsilon_r = 3.5$ and $\mu_r = 1$.

Sol.

On the BOARD!

Common EMC units

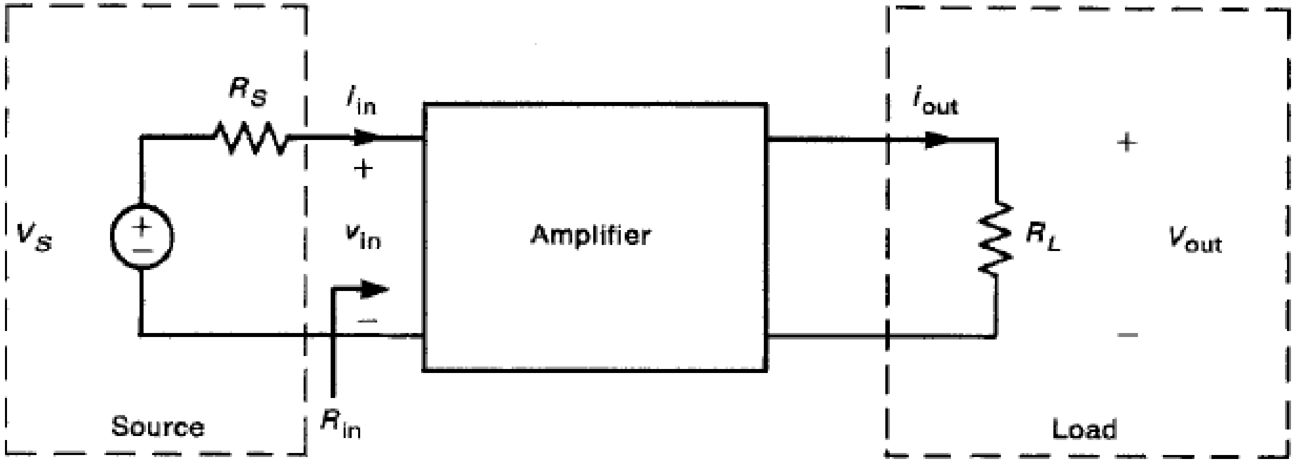
- EMC quantities are measured in dB (condensing the ranges, adding powers)
- Conducted emissions are measured in V and A
- Radiated emissions are measured in V/m and A/m
- Also we use power in W and power density in W/m^2
- Root mean square (RMS) values are used in power relations
- Test and measurement equipment are almost universally calibrated in RMS not peak.

$$v(t) = V\sin(\omega t) \quad \text{(V)}$$

$$P_{avg} = \frac{V^2}{2R} \quad \text{(W)}$$

$$V_{RMS} = V\sqrt{2} \quad \rightarrow \quad P_{avg} = \frac{V_{RMS}^2}{R} \quad \text{(W)}$$

- Consider the amplifier shown,



$$P_{in} = \frac{V_{in}^2}{R_{in}} \quad , \quad P_{out} = \frac{V_{out}^2}{R_L}$$

$$\text{The power-gain} = \frac{P_{out}}{P_{in}} = \frac{V_{out}^2}{V_{in}^2}\frac{R_{in}}{R_L} \xrightarrow{in-dB} 10\log_{10}\left(\frac{P_{out}}{P_{in}}\right)$$

$$\text{The voltage-gain} = \frac{V_{out}}{V_{in}} \xrightarrow{in-dB} 20\log_{10}\left(\frac{V_{out}}{V_{in}}\right)$$

$$\text{The current-gain} = \frac{I_{out}}{I_{in}} \xrightarrow{in-dB} 20\log_{10}\left(\frac{I_{out}}{I_{in}}\right)$$

$$\text{Power-gain} = 20\log_{10}\left(\frac{V_{out}}{V_{in}}\right)_{R_L=R_{in}}$$

- Note that, a voltage ratio of 2 is ~ 6dB, while a power ratio of 2, is 3 dB.
- And, a voltage ratio of 3 is ~10dB, while a power ratio of 3 is 5dB.

- We have the dB values with respect to some reference value,

$$dB\mu V \equiv 20\log_{10}\left(\frac{Volts}{1\mu V}\right)$$

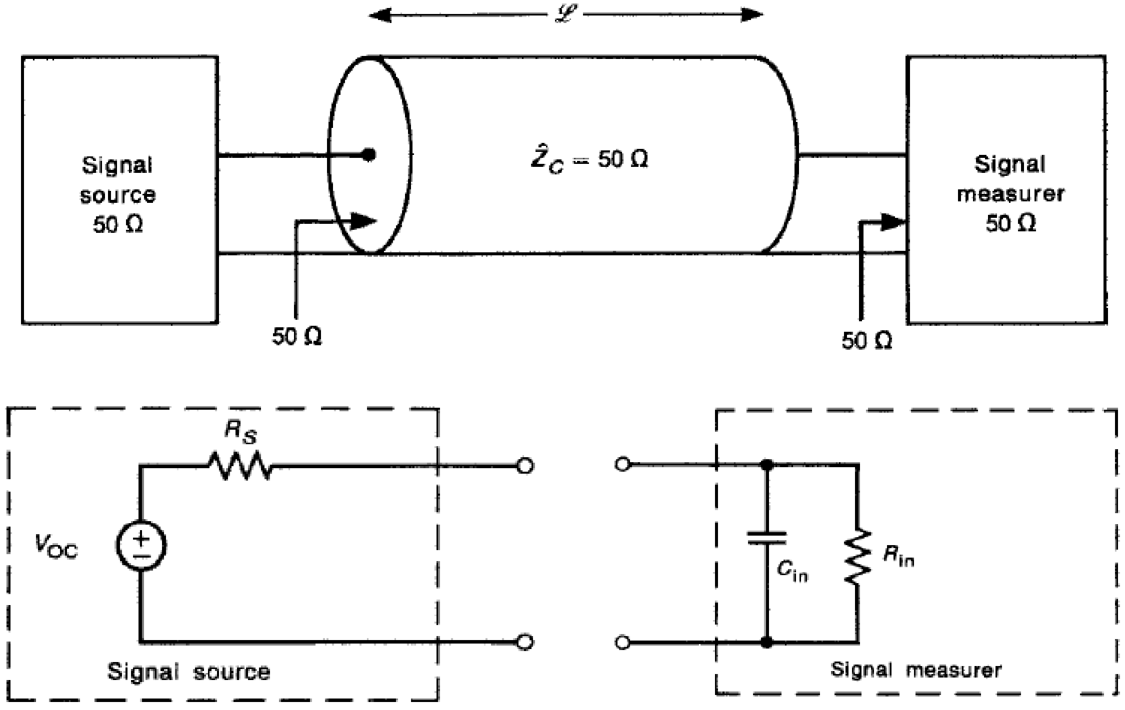
$$dBmV \equiv 20\log_{10}\left(\frac{Volts}{1mV}\right)$$

$$dB\mu W \equiv 10\log_{10}\left(\frac{watts}{1\mu W}\right)$$

$$dBmW \equiv dBm \equiv 10\log_{10}\left(\frac{watts}{1mW}\right)$$

Basic Models

- The value of 50 was determined as the standard impedance for sources and measurement equipment because it balances between providing maximum power (30Ω) and minimum loss (77Ω).
- A source is represented by a Thevenin equivalent circuit with Rs = 50Ω.
- The measurer is modeled as a parallel RC circuit with $R_{in} = 50\Omega$ and $C_{in}=0$ (in Spectrum Analyzers). In Oscilloscopes, usually the values are $R_{in} = 1M\Omega$ and $C_{in}=47pF$.
- Should cover the operating frequencies.
- Remember, RMS values in instruments.



Example 2

Find the Power delivered to a load in dBm if we measure an output voltage across a 50Ω load as $V_{out} = 120\ \mu V$.

Sol:

On The BOARD!

Example 3

Suppose we have a 50 Ω source delivering -26dBm to a 150 Ω load. What would be the actual output voltage across the load terminals.

(note that the meter is calibrated for 50 Ω!)

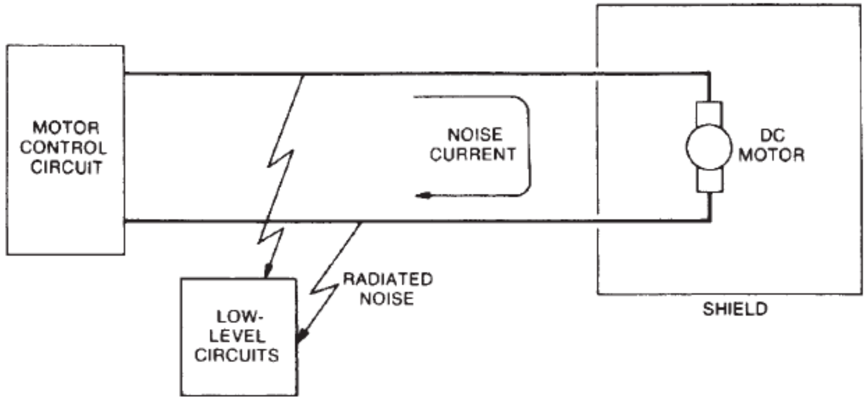
Sol:

On The BOARD!

Methods of Noise Coupling

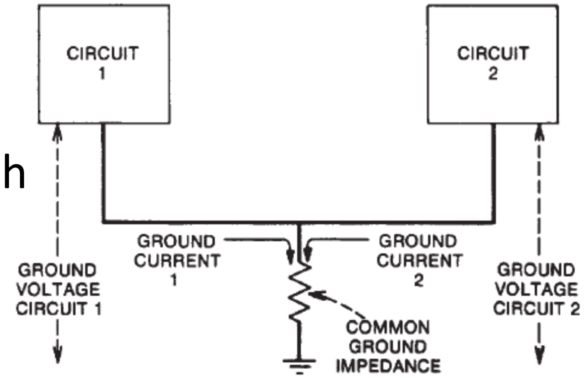
(1) Conductively Coupled Noise:

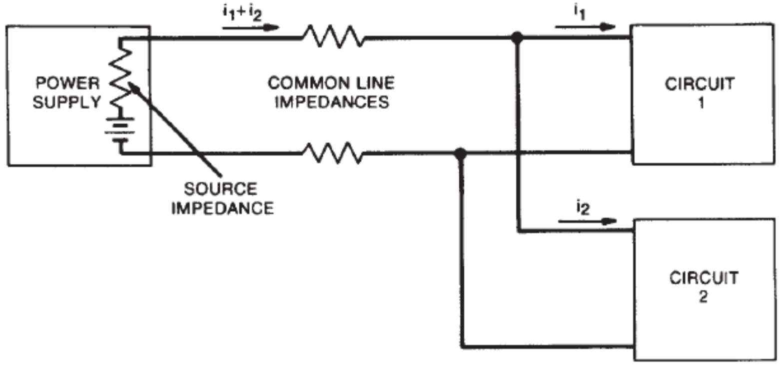
- A wire passing through a noisy environment may pick up noise and pass/conduct it to another circuit within the system causing interference.
- Can be reduced with proper wire shielding or filtering the noise (more later)



(2) Common Impedance Coupling:

- When currents from two different circuits flow through a common impedance
- Voltage drop across impedance observed by each circuit is influenced by the other
- Occurs in PWR/GND system
- Some noise is coupled from circuit 2 to circuit 1 and vice versa through he common GND impedance
- Best to connect the leads directly to PWR and avoid common impedance path





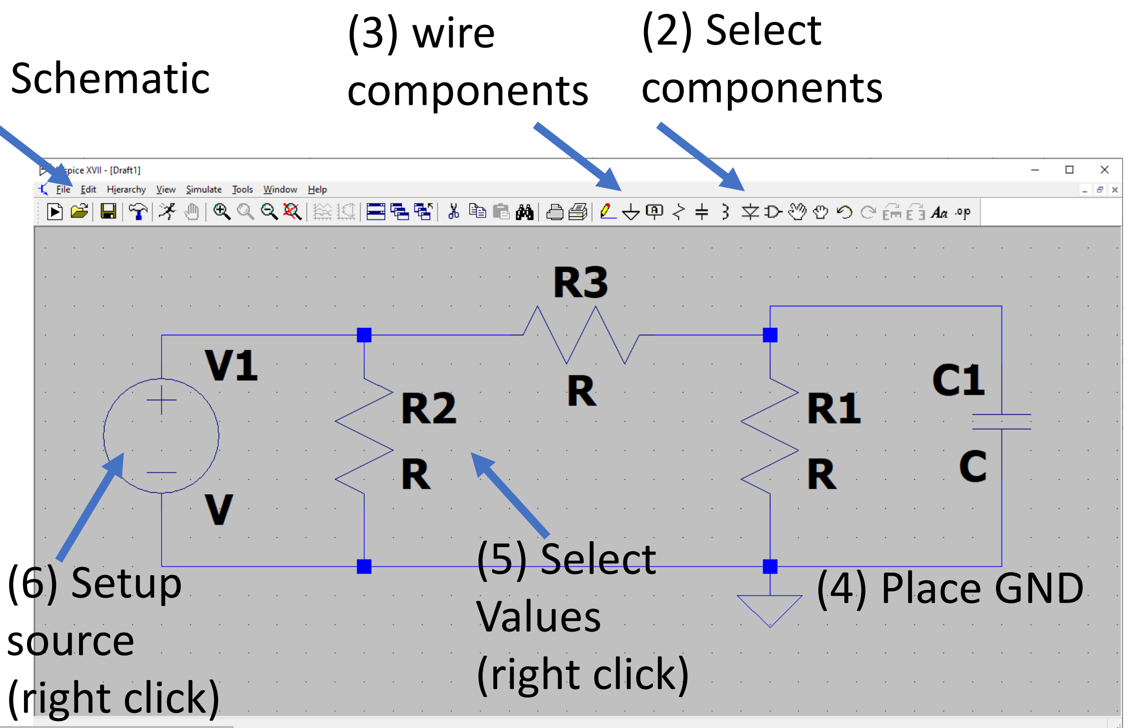
Methods of Noise Coupling

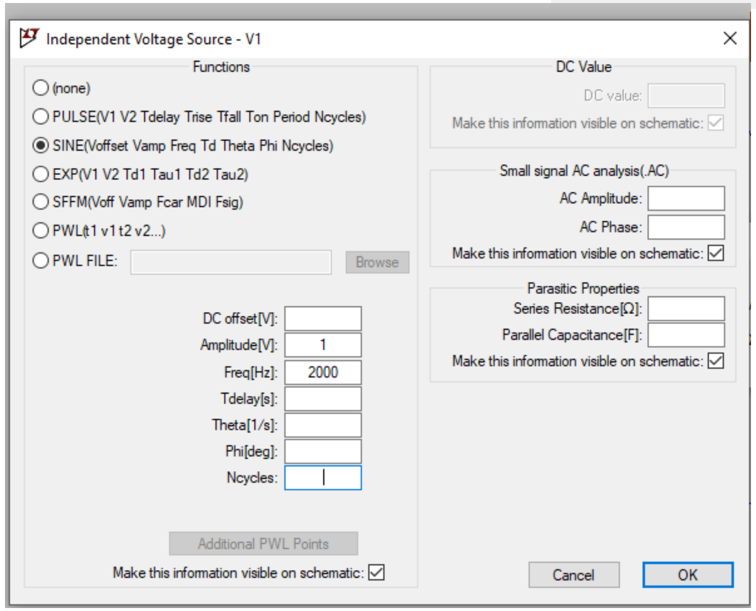
(3) Electric and Magnetic field coupling:

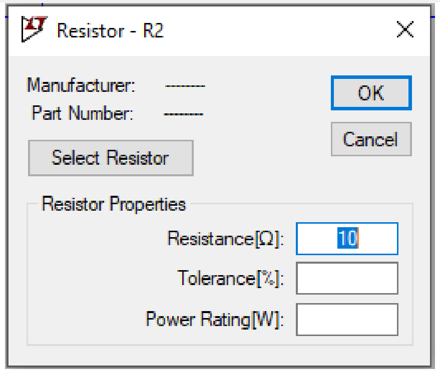
- All circuit elements, including conductors, radiate EM fields whenever a charge is moved.
- Unintentional and intentional (broadcasting stations and radar systems) systems radiate
- When receiver is close to the source (near-field), electric and magnetic fields are considered separately.
- When receiver is far from the source (far field), the radiation is considered a combined EM radiation.

Introduction to LTSPICE

- We will use in HW and assignments
- Several tutorials online
- FREE to download on your own PCs
- Start Program → File → New Schematic



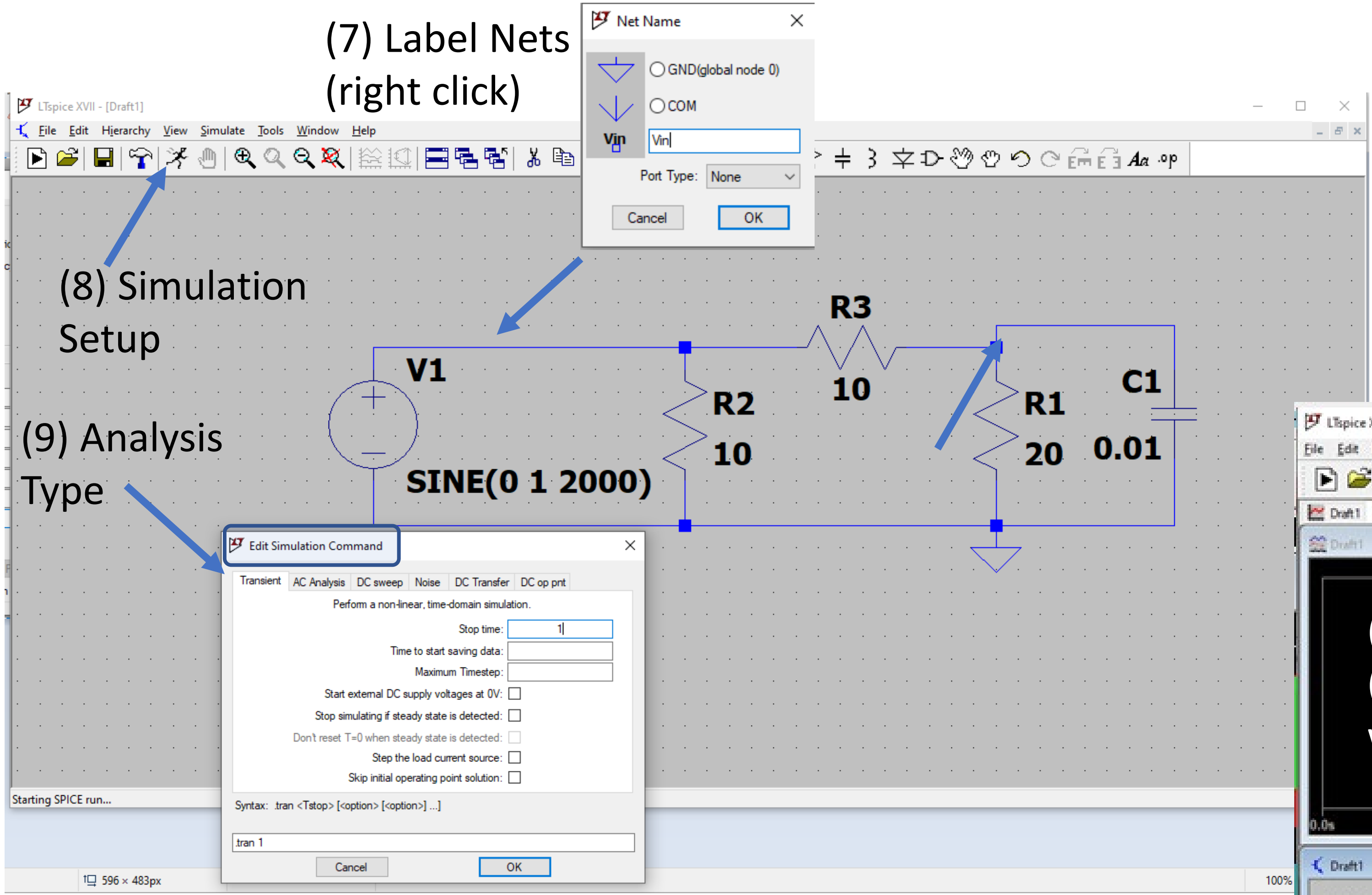




(7) Label Nets (right click)

(8) Simulation Setup

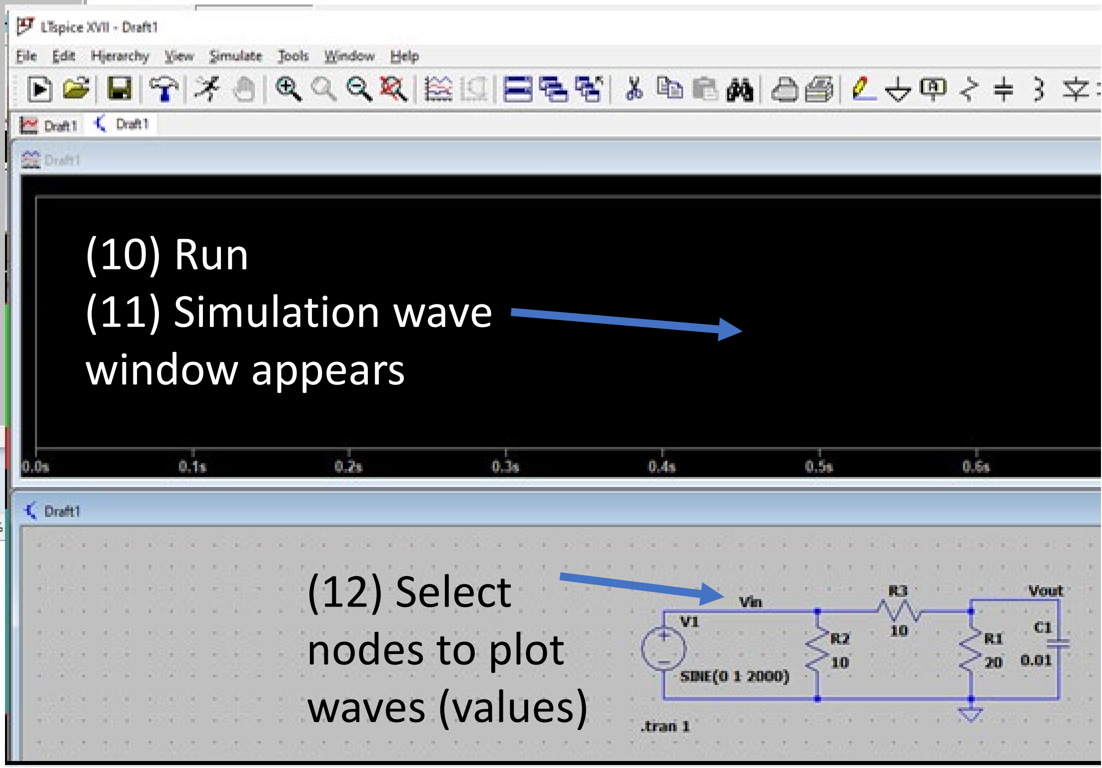
(9) Analysis Type



(10) Run

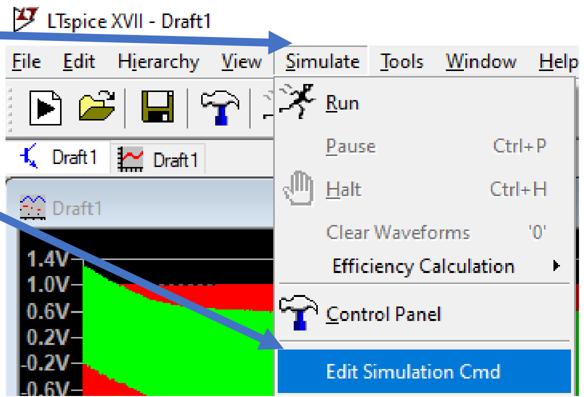
(11) Simulation wave window appears

(12) Select nodes to plot waves (values)

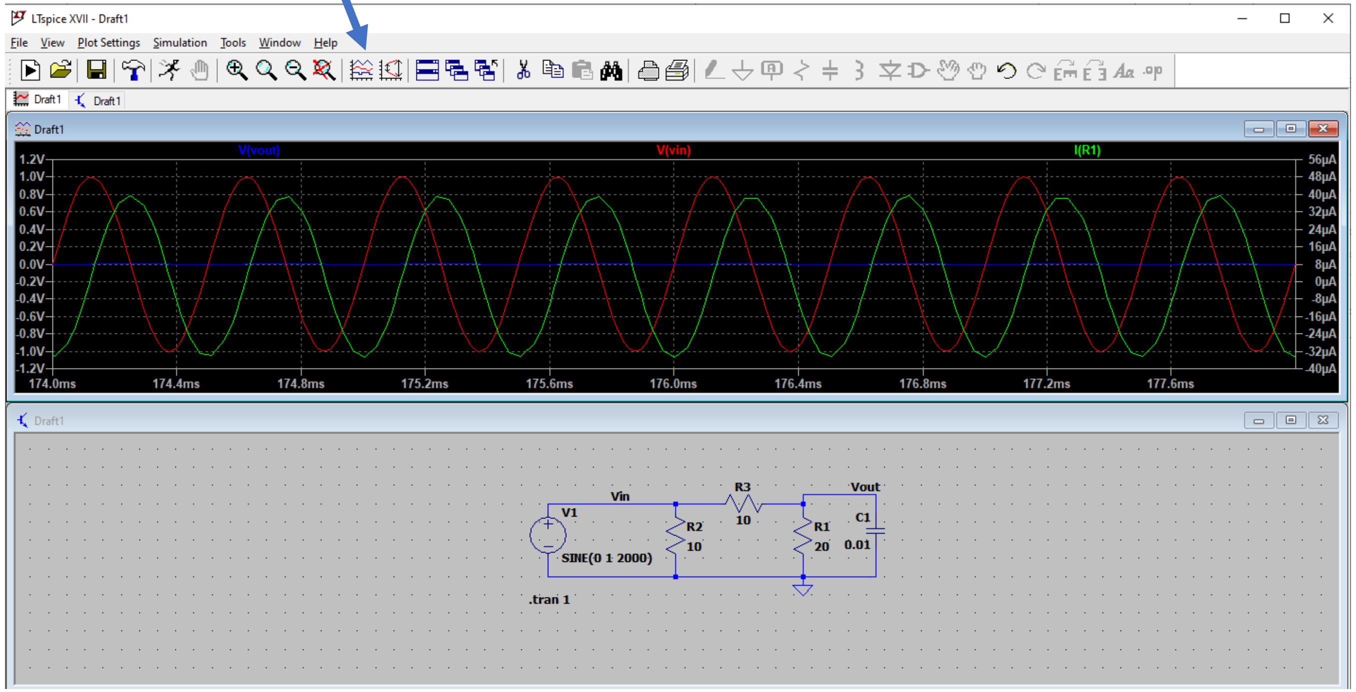


Analysis types:

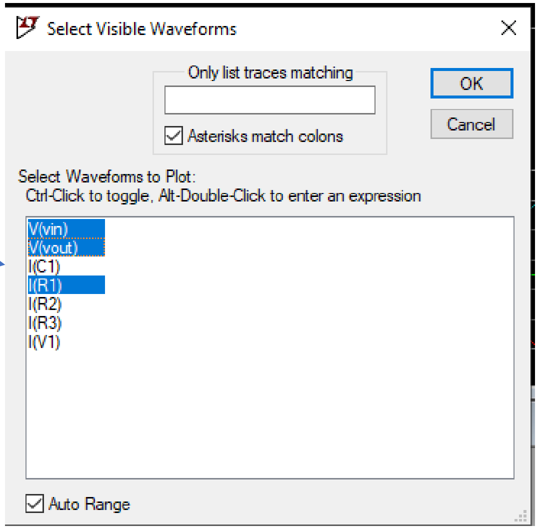
- **Transient**: time domain analysis and waveforms
- **AC**: frequency domain and Bode plots
- **DC Sweep**: DC step sweeps



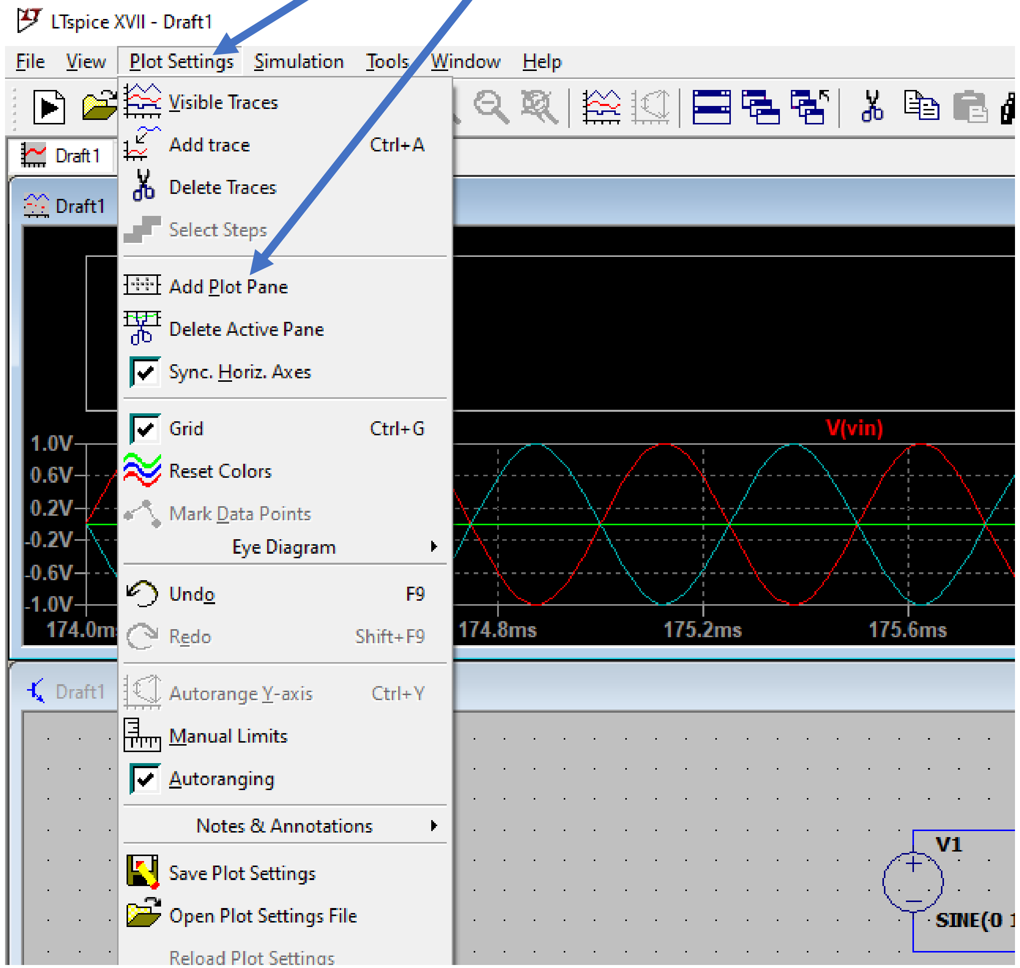
(13) You can plot voltages, and currents



(14) Select waveforms of interest



(15) You can add multiple plot windows, then add waves to them



Next class

- EMC standards and requirements
- Compliance testing measurements according to standards