EMC Overview

- What is EMC?
- Why is it Important?
- Case Studies.
- Examples of calculations used in EMC.
What Is “EMC”? 

• Electromagnetic Compatibility (EMC): The process of determining the interaction between electrical and electronic devices with respect to unwanted effects due to:

  – Electromagnetic Interference (EMI)
  – Radio Frequency Interference (RFI)
EMI / RFI and the Electromagnetic Spectrum
Challenge of EMC

- Typical EMC problems can involve any combination of the disciplines and may vary as a function of the frequency of the electromagnetic energy involved.
Physics of Electromagnetic (E/M) Waves

• Documented in “Maxwell’s Equations” which state:
  – A changing magnetic (H) field creates a changing electric field.
  – A changing electric (E) field creates a changing magnetic field.
  – An enclosed charge creates an electric field.
  – There can not be magnetic “monopoles”.

• Detailed by Professor Maxwell in his 1864 paper: “A Dynamical Theory of the Electromagnetic Field”
As Professor Maxwell stated...

VIII. A Dynamical Theory of the Electromagnetic Field. By J. CLERK MAXWELL, F.R.S.

Received October 27,—Read December 8, 1864.

PART I.—INTRODUCTORY.

(1) The most obvious mechanical phenomenon in electrical and magnetical experiments is the mutual action by which bodies in certain states set each other in motion while still at a sensible distance from each other. The first step, therefore, in reducing these phenomena into scientific form, is to ascertain the magnitude and direction of the force acting between the bodies, and when it is found that this force depends in a certain way upon the relative position of the bodies and on their electric or magnetic condition, it seems at first sight natural to explain the facts by assuming the existence of something either at rest or in motion in each body, constituting its electric or magnetic state, and capable of acting at a distance according to mathematical laws.
...Prof. Maxwell continued...

PART VI.—ELECTROMAGNETIC THEORY OF LIGHT.

(91) At the commencement of this paper we made use of the optical hypothesis of an elastic medium through which the vibrations of light are propagated, in order to show that we have warrantable grounds for seeking, in the same medium, the cause of other phenomena as well as those of light. We then examined electromagnetic phenomena, seeking for their explanation in the properties of the field which surrounds the electrified or magnetic bodies. In this way we arrived at certain equations expressing certain properties of the electromagnetic field. We now proceed to investigate whether these properties of that which constitutes the electromagnetic field, deduced from electromagnetic phenomena alone, are sufficient to explain the propagation of light through the same substance.
...and then said...

(3) The theory I propose may therefore be called a theory of the *Electromagnetic Field*, because it has to do with the space in the neighbourhood of the electric or magnetic bodies, and it may be called a *Dynamical Theory*, because it assumes that in that space there is matter in motion, by which the observed electromagnetic phenomena are produced.
Metrics of Electromagnetic (E/M) Waves

• Travel at/near speed of light (in vacuum/air/free space) = (nearly) $3.00 \times 10^8$ meters/sec.

• Can be expressed as frequency.

• “Length” of one cycle is expressed as “wavelength”, or “Lambda”.
  – Lambda ($\lambda$) = Propagation speed / frequency
  – For 1 MHz, $\lambda = 300$ meters
  – As frequency increases, wavelength decreases.

• Frequency and wavelength used interchangeably.
  – E.g. 15 MHz = 20 meter
Terminology in EMC – RF Signals

- Radio Frequency (RF) – E/M wave frequencies used typically for communication.
- kHz – \(1 \times 10^3\) Hertz (cycles per second)
- MHz – \(1 \times 10^6\) Hertz
- GHz – “1000 MHz”, or \(1 \times 10^6\) Hertz
- THz – \(1 \times 10^{12}\) Hertz
Circuit Theory “Quiz”

• Every current must return to it’s source.

• The path of the “source” and “return” current should be determined.

• Current “takes the path of least” ___________________.

[315x31]EMC Overview

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Circuit Theory Realities!

- Path is by “conduction” or “displacement”.
- The majority of the current takes the path of least *impedance*.
  - If current is DC (impedance is determined by resistance).
  - If current is not DC (including pulsed DC), impedance is determined by reactance.
  - Capacitance determined by conductor proximity
  - Inductance determined by current loop path
What Do These Symbols Mean?
What is “Grounding”?

From “PCB Design for Real-World EMI Control”, by Dr. B. Archambeault

The term “ground” is probably the most misused and misunderstood term in EMC engineering, and in fact, in all of circuit design. Ground is considered to be a zero potential region with zero resistance and zero impedance at all frequencies. This is just not the case in practical high-speed designs. The one thing that should be remembered whenever the term “ground” is used, is that “Ground is a place where potatoes and carrots thrive”! By keeping this firmly in mind, many of the causes of EMC emissions problems would be eliminated.

The term “ground” is a fine concept at DC voltages, but it just does not exist at the frequencies running on today’s typical boards. All metal has some amount of resistance, and even if that resistance was near zero ohms, the current flowing through a conductor in a loop creates inductance. Current through that inductance results in a voltage drop. This means that the metal ground plane/wire/bar/etc. has a voltage drop across it, which is in direct contradiction with the intention and definition of ground.
Early “Ground” Connections

quickly discovered that if one side of the sending circuit and one side of the receiving circuit were connected to the earth (ground), then only half the wire was needed and the system worked fine. The send and receive ends were "grounded" as in Figure 4-1 and the telegraph circuit was complete.

Figure 4-1 --- Ground Current for Very Low Speed Communications
Risk of Using “Ground” As Return Path

• “Assumption” is that “ground” has zero (0) impedance for all frequencies.

• Since impedance cannot be zero (0) for all frequencies – at some point the current will NOT flow along the" ground” path, when other paths of lower impedance exist!
Is This “Grounding”?
Better Use of Return and Ground Symbols

Symbols to understand & know:

- Safety Ground (Φ current)
- Signal Ground (Φ current)
- Signal Return (Current carrying)
Important “Take-Away” Points

• Signal ground not equal to signal return.

• Misconceptions:
  – A “good ground” reduces noise.
    • What is a good ground?
    • When does it occur?
  – The path the engineer believes is ground is the actual power (or signal) return path.
The EMC “Model”

- The EMC model consists of three key elements
  - In theory, elimination of any element will eliminate EMC issues.
  - In practice, we can only minimize their impact.
Use of the EMC Model

- Items to consider – nature of the “source” (such as high “E-field”, “H-field”, or plane wave conditions).
- “Path” of the current flow (either conducted or by displacement).
- Receiver of the energy – “intentional” or “unintentional”.
The “Source-Path-Receiver” Interaction

- The path of the energy to the receiver may be via radiation or conduction.
- If path is radiated, the intensity is reduced as a function of distance (*similar to a flashlight*) - the intensity is lower the greater the distance away - the “inverse distance” property.
The Radiated Path

- The E-field and H-field vectors are orthogonal to each other (always at 9:00 position).
- Direction of propagation is orthogonal to vectors.
Radiated “Regions”

- The radiated E/M wave characteristics depend on the distance of source from the receiver.
- Primary regions are “Near Field” and “Far Field”.

![Diagram showing near-field and far-field regions with distance from the source and wavelength.]
Near and Far Field Physics

• Location of a receiver in the near field may affect the source and a receiver in the far field has no impact upon the source.
• The E/M wave in each region has a “Characteristic Impedance” of Zw.
• In the far field, the Zw = 377 ohms.
Near Field Physics

• In the near field $Z_w < 377$ or $> 377$ ohms.
• Wave impedance is determined by:
  \[ Z_w = \frac{|E|}{|H|} \]
  
  $E$ is the electric field vector.
  
  $H$ is the magnetic field vector.
• For a low $Z$ source, $H$-field dominates.
• For a high $Z$ source, $E$-field dominates.
The Conducted Path

- Conducted paths have only small reductions in magnitude from source to receivers.
- Are due to currents that travel on circuit wiring and/or conductive assemblies.
Why Wiring Effects Are Important in EMC Work

- Early electrical and electronic systems had few components to be connected - recent systems have increased wiring complexity.
- Many engineers don’t focus on “just pieces of wire” and they may just attach these wires to “GROUND”!
- Wiring will still be used for many systems in the future, therefore it’s critical to understand relevant physical parameters.
**Electrostatic Discharge (ESD)**

- Exhibits conditions similar to both radiated and conducted paths.
- High voltage (4 - 25 kV) discharges.
- Can cause immediate failure or induce latent defect (such as in manufacturing process of customer use).
**Electrical and Electronic Systems as Sources of RF Noise**

- Most electrical and electronic systems can be responsible for RF noise generation as a byproduct of their normal operation.
- In many industries, this noise has been classified into two categories:
  - Broadband (typically due to electrical arcing)
    » *Referred to as “Arc and Spark” noise.*
  - Narrowband (typically due to active electronics)
    » *All other noise NOT due to “Arc and Spark”.*
Types of ("Noise") Sources of Energy

- Broadband noise is greater than the "width" of receiver of the energy.
- Narrowband noise is less than the "width" of the receiver.
“Broadband” Characteristics

- Spectrum (frequencies and amplitude) changes with time.
- Sources include high voltage discharge components and similar pulse-type systems.
- Brush-type motors also are sources.
Causes and Effects of Broadband Noise

• Typical sources include high-voltage devices and inductive elements.
• Can be difficult to control.
• Most noticeable effects may be on “intentional” receivers:
  – AM reception may have audible noise.
  – FM reception may lose some sensitivity.
• Can also cause “unintentional receivers” to react.
Consequences Of Broadband Noise Sources

• BAD – Due to functions that are required for system functionality (such as motors or inductive devices).
• BAD – Can have both conducted AND radiated coupling paths.
• GOOD – Energy spread out – may have minimal effect on potential receivers (intentional and unintentional).
“Narrowband” Characteristics

- Usually contains discrete frequencies.

- Typical sources are active semiconductor components - including microprocessors.
Spectral Representation of Narrowband Noise

- Result is a spectrum of a “comb-like” appearance.
- Spectrum stays approximately constant over time.

![Graph showing spectral representation of narrowband noise](image)
Characteristics Of
Narrowband Noise Sources

• May only affect specific frequencies.
• Receivers can appear to function “almost normal”.
• Can be addressed in component design process.
Common Sources of Narrowband Noise

• Digital logic

• Microprocessors
Microprocessors And Narrowband Noise

- Common source of Narrowband noise.
- Logic states depend on clocking from a square-wave source.
- Square waves contain many frequencies - which extend far into the radio spectrum.
Why Clock Signals Create Noise

Fourier series expansion explains emission profile.

Shows many frequencies in square wave.

Goal is to filter out higher frequencies.

\[ f(x) = \frac{a_0}{2} + \sum_{k=1}^{\infty} a_k \cos kx + b_k \sin kx. \]
Consequences Of Narrowband Noise Sources

• BAD - May be many sources in a system due to proliferation of active devices.
• BAD - Receivers (both intentional and unemotional) can appear to function “almost normal”.
• GOOD - Can be addressed in component design process OR can be identified by testing.
Unintentional Reception of Energy

- The reception of energy by either unintentional receivers or reception of energy that the receivers have NOT been designed to receive is also a concern.
- This is known as “Susceptibility” or “Immunity”.
  - Susceptibility - “Glass half empty.”
  - Immunity – “Glass half full.”
Immunity Issues Can Exist Due To The Following...

• Most of today’s electrical and electronic systems rely on active devices such as microprocessors and digital logic for:
  – Control of system functions.
  – User convenience / features.
  – Legislated system requirements (such as mobile telephone location reporting).

• With today’s vast networks for data communication there are serious implications when disrupted.
EMC Case Studies

• Emissions: Microprocessor clock harmonic was on a two way radio frequency – rendering radio communication impossible.
• Immunity: Production plant alarms were set when hand held radios were used near the control panel!
Why is EMC Important to All Industries and Business?

• Today’s electronic systems contain many more active electronic components than in the past.

• Those components and assemblies may emit RF noise or be exposed to external sources of interference - resulting in changes system operation, perhaps even having safety implications.