EMC STANDARDS

Another EMC resource
from EMC Standards

Understanding EMC Basics Part 1

Helping you solve your EMC problems

9 Bracken View, Brocton, Stafford ST17 0TF T:+44 (0) 1785 660247 E:info@emcstandards.co.uk

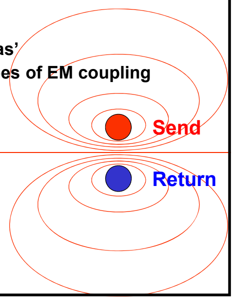
Understanding EMC Basics series
Webinar #2 of 3, May 29, 2013

Waveforms & Spectra, 4 types of EM coupling, Differential Mode and Common Mode, Overview of Emissions

Eurlng Keith Armstrong
CEng, FIET, Senior MIEEE, ACGI

Presenter Contact Info
Email: keith.armstrong@cherryclough.com
Website: www.cherryclough.com

Contents of Webinar #2



Understanding EMC Basics

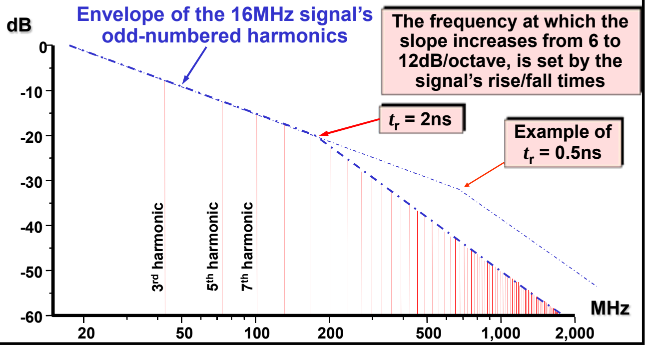
5

Waveforms, spectra, and "accidental antennas"

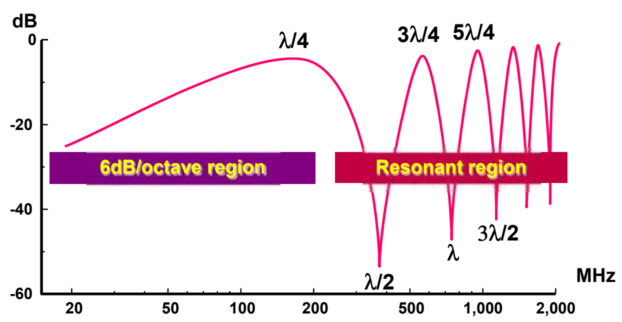
Waveforms and Spectra

- On/off and discontinuous waveforms (e.g. digital, PWM, switch-mode, etc.) are rich in harmonics
  - it is not unusual for a 50kHz switch-mode power converter to cause high levels of emissions at 50MHz
  - or for 50MHz digital clocks to cause 900MHz emissions
- When resonant frequencies happen to lie at the same frequencies as these harmonics…
  - they can 'amplify' the common-impedance, E, H and EM coupling effects
- *So please don't use voltages or currents that change faster than they really need to !*

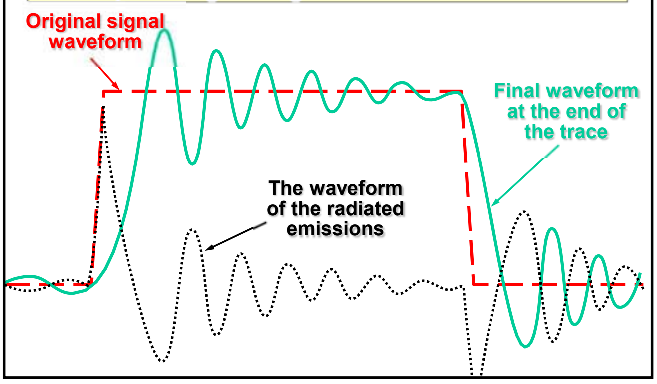
The spectrum of a 16 MHz squarewave with 2ns rise/falltimes (idealised analysis)



"Antenna efficiency" of a 200 mm PCB trace
(on FR4, no 0V plane, low-Z drive, high-Z load, idealised analysis)



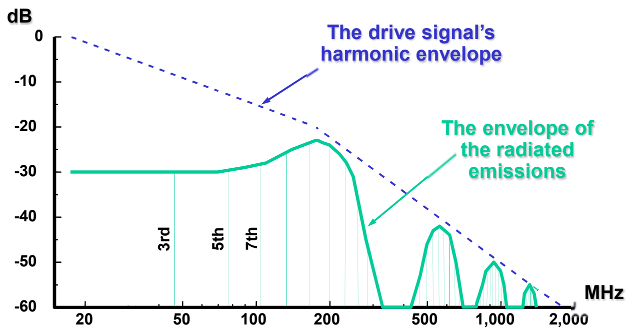
The resulting waveforms after passing along the 200 mm PCB trace



The close relationship between EMC and Signal Integrity (SI)

- Rectangular waveforms with overshoot and ringing are losing some of their energy into the air…
  - at the frequencies at which their traces/wires behave as efficient "accidental antennas"…
    - we can easily determine the worst emitted noise frequencies from the frequency of the ringing seen on the oscilloscope
- A circuit that has excellent SI (low, or no, overshoot or ringing on all signals) has good EMC…
  - and using good EMC design techniques from the start of a project achieves excellent SI…
    - because EMC is harder to achieve than SI

The spectrum of the radiated emissions from the 200mm PCB track (an idealised analysis)



Structural resonances also create 'accidental antennas'

- Similar figures can be drawn showing how the E and H fields associated with conductors can suffer resonances due to:
  - 2-dimensional structures (e.g. printed-circuit boards)
  - 3-dimensional structures (e.g. metal boxes)
  - resulting in high levels of emissions (or poorer immunity) at those frequencies

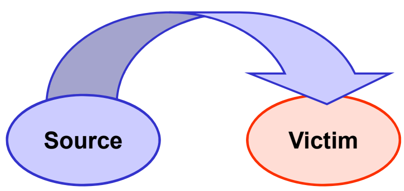
Understanding EMC Basics

6

Three parts to every EMC issue, and four types of EM coupling

The three parts to *every* EMC issue

- A circuit (a source of EM fields, a possible threat)
- Another circuit (a potential victim)
- And at least one EM coupling path between them



There are four types of EM coupling...

1. Common impedances
2. Electric (E) fields
3. Magnetic (H) fields
4. Electromagnetic (EM) fields

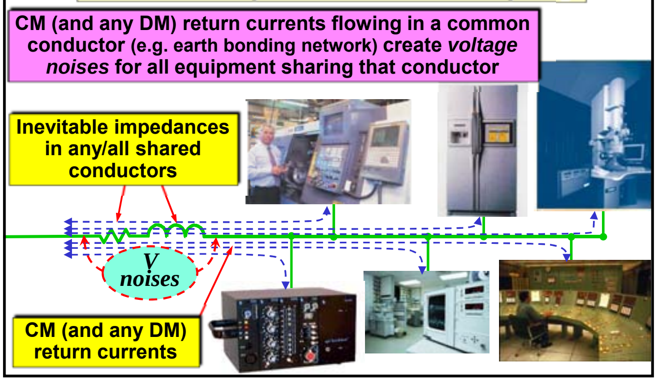
Common-impedance coupling

- Every conductor has intrinsic R, L, and C
  - so there is always an impedance in a shared conductor
  - e.g. AC or DC supply conductors, grounds, earths, 0Vs, cable shields, enclosure shields, connectors, etc.
- The impedance is generally worse at higher frequencies
  - because the skin effect increases the resistance R
  - and because of increasing inductive impedance ($2\pi f$ L)

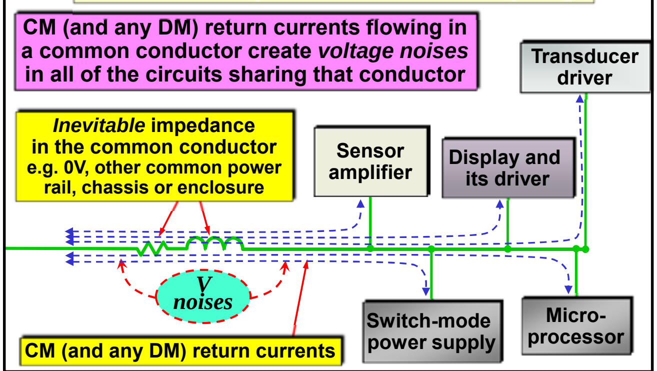
Common-impedance coupling continued...

- Currents flowing in the impedance of a shared conductor generate a "Common-Mode" (CM) voltage noise
  - it is called CM because it is common to all of the circuits that share the conductor
- So the common impedance of the shared conductor causes the currents of one circuit to couple CM voltage into other circuits

Example of *inter-system* common-impedance noise coupling



Example of *intra-system* common-impedance noise coupling

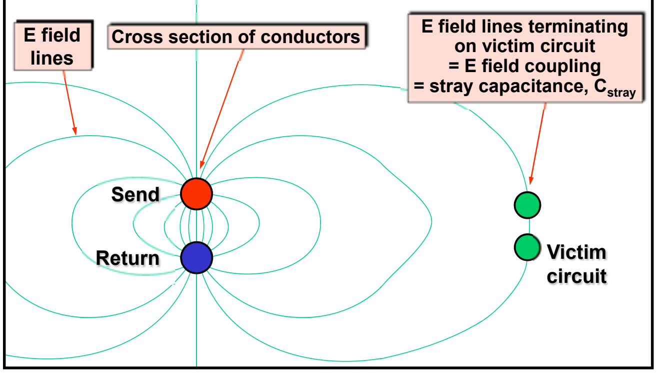


Circuit design is taught as if power rails and 0V returns have zero impedance

- so they are not drawn on the schematic
- This approach ***guarantees*** that circuits will ***not*** work correctly in real life…
  - because the real world is now full of noise frequencies that are so high that the common impedances of power rails and 0V 'grounds' are very important indeed
  - for the emissions/immunity of digital circuits
  - and for the immunity of analogue circuits
    - even DC and low-frequency instrumentation/audio circuits

Electric (E) field coupling

(E field lines always terminate on conductors, at 90° to their surfaces)



E-field coupling causes noise ***currents*** to be injected into victim circuits

- Basically: $I_{COUPLED} = C_{STRAY}\,(dV_{SIGNAL}/dt)$
    - this assumes that the victim's impedance is << $1/(2\pi f\, C_{STRAY})$ and that the size of the victim circuit is << $\lambda/6$
  - and all stray currents flow in closed loops
- A stray capacitance of just 0.1pF between a victim circuit and a 100MHz 5V squarewave signal
  - would couple 310μA of noise current into the victim's circuit at the 100MHz fundamental frequency

E-field coupling continued...

- The impedance of C_{STRAY} reduces as frequency increases

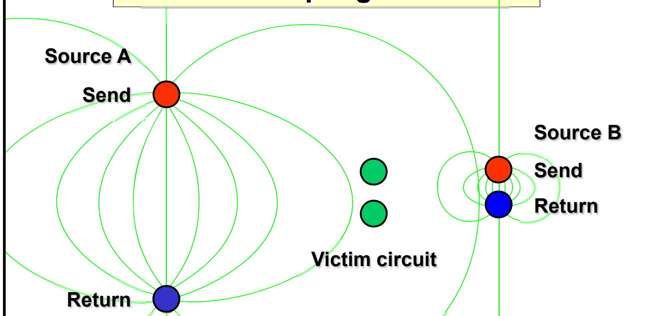
$$Z_C = 1/(\,2\,\pi f\,C\,)$$

- Reducing a signal's rate of change of voltage (dV/dt) reduces its high frequency content *(Fourier transform)*
  - and therefore reduces its E-field emissions, and the noise current that it injects (couples) into victim circuits

E-field coupling continued...

- We want to have a low stray capacitance (E-field coupling) between the source and victim circuits
    - to reduce their noise coupling (interference)
- But for a single signal's <u>own</u> send/return paths…
  - we generally want a *high capacitance* between its send and return current paths, because this makes its E-fields more compact
    - which reduces its stray capacitance to other circuits, thereby reducing the amount of noise coupling (interference)

E-field coupling continued...

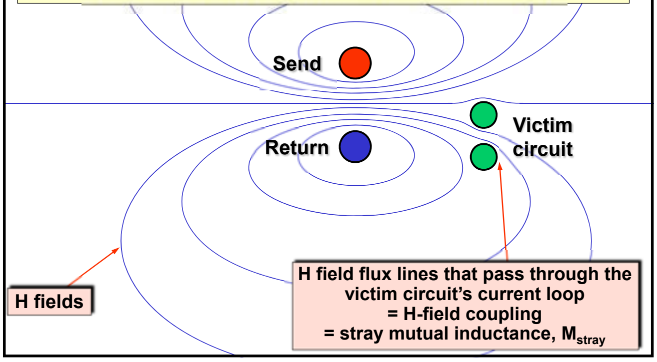


Source A couples to the Victim circuit more strongly than Source B, because Source B has more capacitance between its send/return conductors, so its E field is more compact and causes less stray field coupling (less stray capacitance) to the victim circuit

POLL QUESTIONS

Magnetic (H) field coupling

(H flux lines never terminate on conductors)



H-field coupling causes noise voltages to be injected into victim circuits

- Basically: $V_{COUPLED} = -M_{STRAY}\,(dI_{SIGNAL}/dt)$
  - this assumes victim circuit impedance >> $1/(2\pi f M_{STRAY})$ and that the size of the circuit is << $\lambda/6$
  - – and all stray currents flow in closed loops
- A mutual inductance of only 10nH between a victim circuit and a circuit carrying a 100MHz squarewave at 100mA…
  - – would couple 630mV of noise into the victim at the 100MHz fundamental frequency

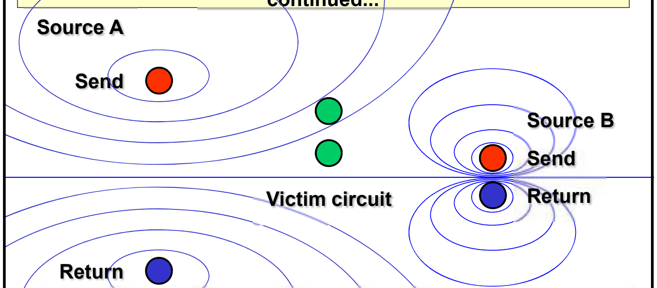
H-field coupling continued...

- Impedance of M_{STRAY} decreases with increasing f : $Z_M = 1/(2\pi f M)$
- Reducing a signal's rate of change of current (dI/dt) reduces its high frequency content *(Fourier transform)*
  - – and therefore reduces its H-field emissions, and the noise voltage that it injects (couples) into victim circuits

H-field coupling continued...

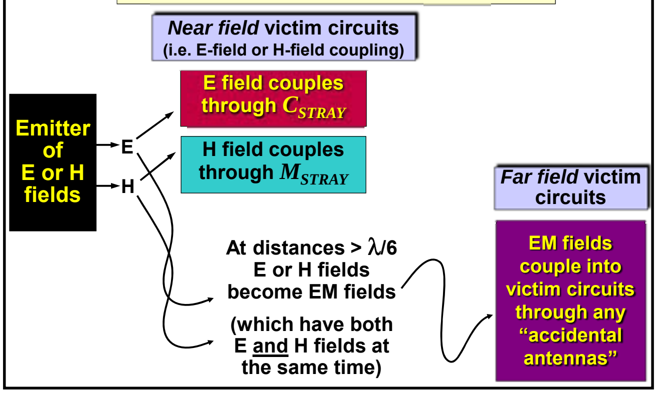
- We want to have low mutual inductance (M_{STRAY}) coupling between *different* circuits
  - to reduce their noise coupling (interference)
- But for a single signal's own send/return paths...
  - – we generally want a *high* mutual inductance, because it makes its H-fields more compact
    - reducing its stray mutual inductance with other circuits, thereby reducing the amount of noise coupling (interference)

H-field coupling continued...



Source A couples to the Victim circuit more strongly than Source B, because Source B has more DM mutual inductance between its send/return, so its H field is more compact and causes less stray field coupling (less stray mutual inductance) to the victim circuit

EM-field coupling



Understanding EMC Basics

7

Differential Mode (DM), and Common Mode (CM)

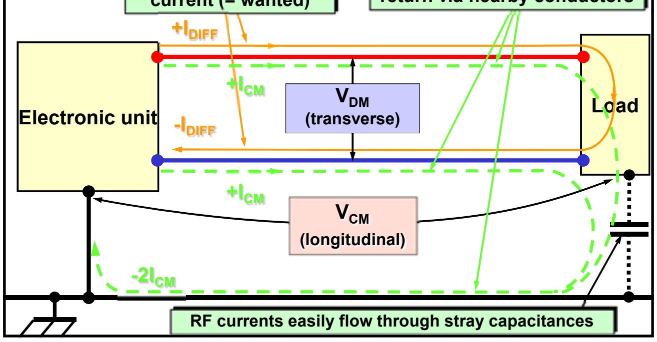
Differential Mode and Common Mode

- Differential Mode (DM) is where the send and return conductors carry opposing voltages or currents
  - – wanted signals and power are always DM
- Common Mode (CM) is where the voltages or currents are the same on both send *and return* conductors
  - ◆ measured with respect to a remote 'earth' reference
  - – CM is accidental, and is unwanted

Common Mode

- We *intentionally* create DM signals and power…
  - – these are our wanted signals and power, sometimes called 'transverse' (because they appear across two conductors)
- But unbalanced 'stray' coupling converts some DM signal or power into *unwanted* CM current and voltage noise…
  - – and these accidental CM currents and voltages also have 'stray' couplings into victim circuits…
    - • CM is sometimes called 'longitudinal' when it appears along the length of a cable…

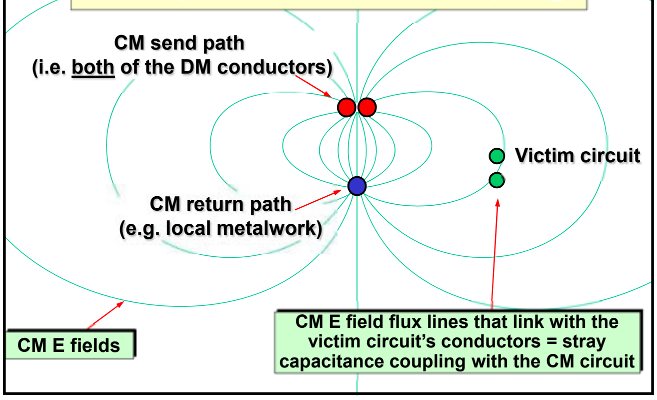
An example of DM (wanted) signals causing CM noises, for a 'floating' load



Common Mode continued…

- Remember, the four causes of 'stray' coupling are…
  - Common-impedance
  - E-field
  - H-field
  - EM-field
  - – and they all couple stray CM current and voltage noises just as well as they couple stray DM currents and voltages as described earlier

Example of CM E-field coupling



The very great importance of controlling CM

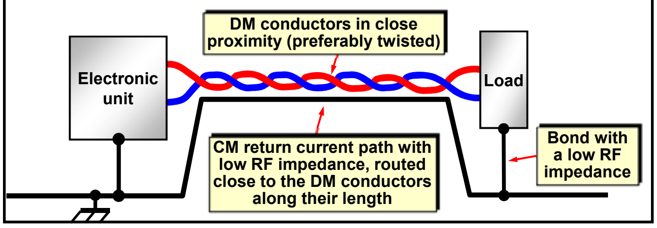
- Because CM currents tend to flow in large loops…
  - and because CM voltages tend to appear across large areas…
- The 'accidental' conversion of DM into CM is generally the main cause of emissions from 1 - 1000MHz
  - and the corresponding conversion of CM into DM noise signals is the main cause of poor immunity 1 - 1000MHz

Controlling CM return currents is very important indeed in EMC design

- *1st :* reduce CM generation by…
  - reducing the RF impedance in shared conductors
  - providing DM send/return paths in close proximity for both signals and power (e.g. twisted-pair conductors) to reduce CM field emissions
- *2nd :* where practical, provide a CM current return path in very close proximity *to each DM circuit…*
  - *could be the shield of a screened cable*
  - currents always take the path that uses the least energy
  - which is the path that emits the least E or H fields, and therefore causes the least CM stray coupling

Controlling CM return currents is very important indeed continued…

- *3rd :* where practical, reduce CM voltages by bonding 'floating' circuits to CM return current path
  - designing the bond to have the lowest practical impedance at the frequencies concerned



Controlling CM return currents is very important indeed continued…

- *4th* : where providing a CM path is impractical…
  - e.g. units not fixed to a metal structure, and not interconnected by screened cables…
  - increase the impedance of the CM path, for example by using CM chokes…
    - this can also be helpful when a CM path exists and is used

Understanding EMC Basics

8

The EMC benefits of metal planes

Metal planes bring many EMC benefits

- Planes have very much lower RF impedance than conductors such as wires, cables or PCB traces
  - so when used in a shared circuit they cause much lower common-impedance coupling
- Waves incident on a plane are partially cancelled out by their anti-phase reflections from the plane
  - so when a source or victim circuit is very close to a large area of metal plane…
  - this 'image plane' effect reduces its coupling with E, H and EM fields

More benefits from planes

- Nearby metal planes make ideal low-impedance return paths for both DM and CM currents…
  - closer planes means better DM and CM return paths, and lower E, H and EM field coupling
- So, metal planes are a powerful tool for EMC, and they are used in some ICs and most PCBs…
  - large systems sometimes use meshes instead…
    - their highest useful frequency depends on the diagonal size (D) of the mesh's elements: f_{MAX} = 30/D MHz (D in metres) but f_{MAX} = 3/D MHz gives better performance

Understanding EMC Basics

9

Overview of RF emissions

An overview of emissions

- For emissions, all electronics can be thought of as many tens of thousands (maybe millions) of noise sources
  - i.e. the transistors in their ICs, and power transistors
- All coupled to thousands of tuned antennas
  - i.e. PCB traces, wires and cables, metal structures, slots and gaps in shielded enclosure, etc....
  - all of which have resonant frequencies (that depend on their dimensions, build conditions, terminations, routing, and proximity to other conductors and materials)

POLL QUESTIONS

Understanding EMC Basics series
Webinar #2 of 3, May 29, 2013

Waveforms & Spectra, 4 types of EM coupling, Differential Mode and Common Mode, Overview of Emissions

the end

interference technology

CHERRY CLOUGH CONSULTANTS LTD

Presenter Contact Info
Email: keith.armstrong@cherryclough.com
Website: www.cherryclough.com