Coupling Mechanisms In A Radiated Emissions Setup

MPS Webinar

April 6, 2022

Webinar Session will begin at 8:45am PST-US | 11:45am EST-US

Material:
Todd Toporski – Principal Field Applications Engineer

Presented By:
Todd Toporski

MPS

Todd Toporski – Principal FAE, Detroit area, Michigan

25+ years of designing & supporting EMC-compliant systems/PCB's

FAE at MPS: March 2020 - Present

- Principal FAE, supporting automotive customer power designs; EMC test/debug/support
- Work closely with product teams to define robust automotive power & lighting solutions

FAE at TI: 2003 - 2020

- Senior Member Technical Staff (SMTS) supporting automotive customers
- Support of power, Class D audio, data converters, op amps, high speed interfaces, EMC
- Worked closely with product teams to define automotive solutions

Hardware & System Design Engineer at several companies: 1992 - 2003

- Automotive audio, radio, & infotainment designs
- Audio & consumer electronics, set top boxes
- Industrial power, motor starters, meters
- HW & SW design, PCB design, EMC design/support

Education:

- Georgia Institute of Technology – MSEE
- Michigan Technological University - BSEE

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POP QUIZ

190 kHz	Table 7 - Class 5	LW	Vertical	Average	10.19	9kHz	Average	26.00	9kHz	-15.81	✓
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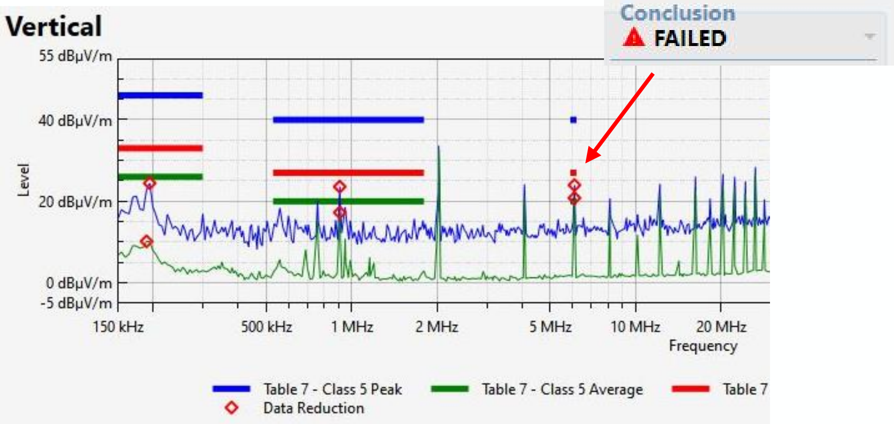


Details:

- CISPR25, Monopole test (antenna 1m from table/DUT setup)
- DUT = Power supply board, Buck DC/DC (12V to 5V, 2A, Fsw = 2MHz)
- DUT not shielded
- Cable harness = 2m long (V+, GND), unshielded/untwisted pair

QUESTION: What is likely the largest contributor of noise measured in this spectrum?:

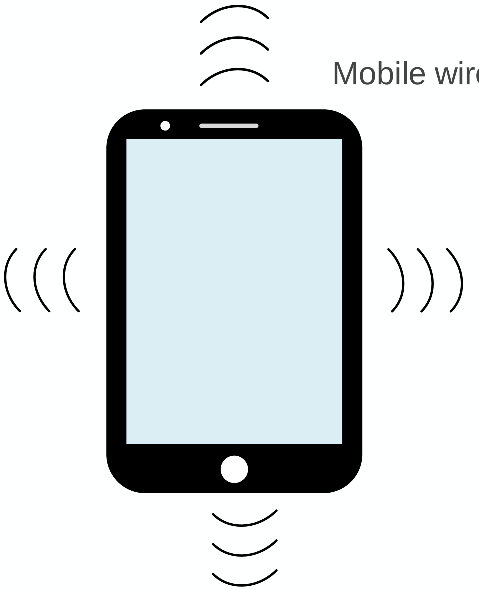
a) Electromagnetic waves emitting from DUT (buck DC/DC board)
b) Electric fields coupling from DUT (buck DC/DC board)
c) Electromagnetic waves emitting from 2m cable harness
d) None of the above

Defining Radiated Emissions

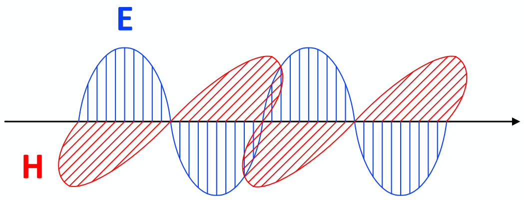
Defining radiated emissions…

Radiated emissions, or **radiated coupling**, occurs when:

- Electromagnetic energy (E-field and H-field) is emitted from a source
- The resulting electromagnetic (E-M) wave propagates to the far-field
- Voltages & currents are induced in another circuit, often far from the source

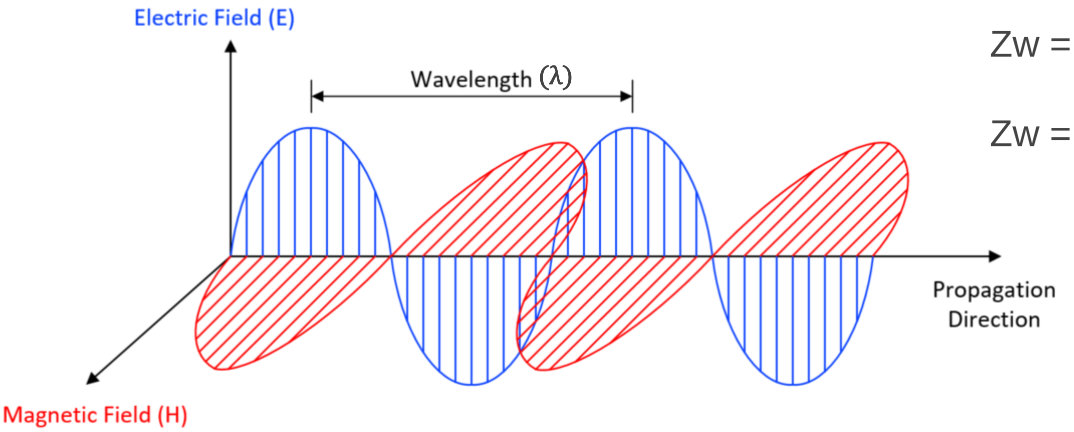


Mobile wireless device



Victim Circuit

Electromagnetic wave properties



Zw = E/H

Zw = 377 Ohms

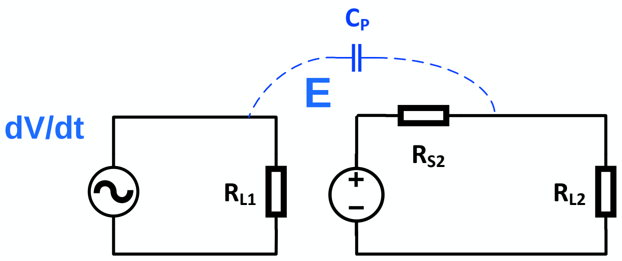
Electromagnetic (E-M) waves exhibit these properties:

- Plane wave propagating in the far field
- E-field (V/m) and H-field (A/m) components are perpendicular (at right angles) to each other
- Travel at speed of light ($c = 3 \times 10^8$ m/s) in a vacuum
- *Wave impedance* Zw = 377 Ohms, where Zw = E/H (Ohms)
- Both E & H attenuate at rate of 1/d as distance ‘d’ increases

Electric Field Coupling

In the near field, Electric fields (**E**) and Magnetic fields (**H**) exhibit a different properties than far field E-M waves.

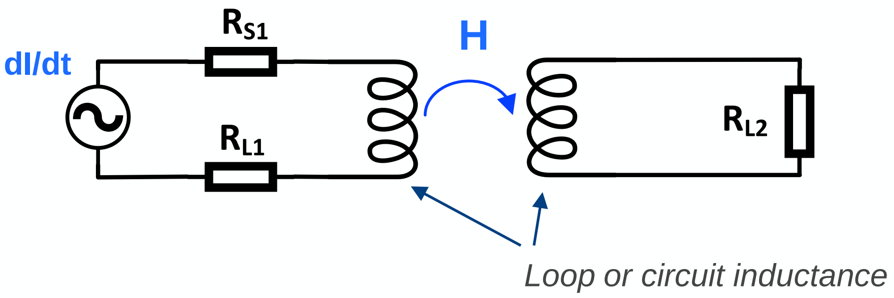
Electric field coupling (near field):



- **E** (V/m) typically driven by large dV/dt source
- **E** coupling is typically a problem near high-impedance victim circuits
- **E** attenuates faster than E-M wave with increasing distance (attenuates at $1/d^3$ or $1/d^2$, depending on conditions)

Magnetic Field Coupling

Magnetic field coupling (near field):



- **H** (A/m) typically driven by large dI/dt source
- **H** coupling is typically a problem near victim circuits with high impedance or large loop area
- **H** attenuates faster than E-M wave with increasing distance
  (attenuates at $1/d^2$ or $1/d^3$ depending on conditions)

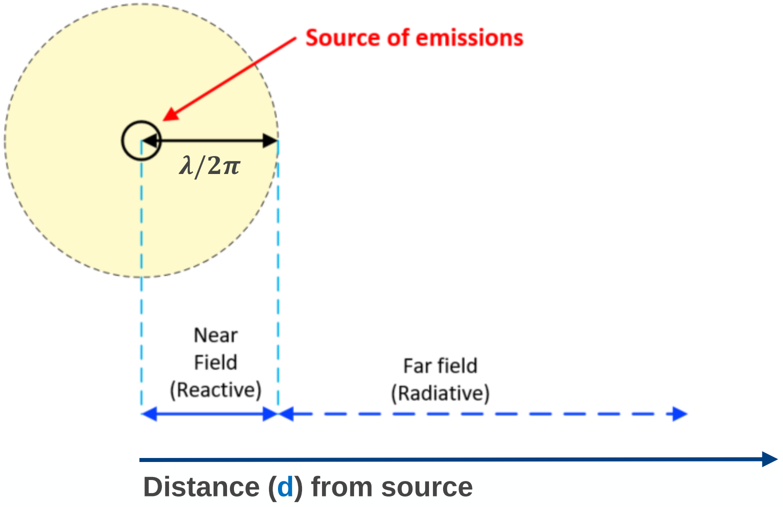
Transitioning from Near Field to Far Field

Ask an RF or EMC engineer the definition of "far field", and you'll likely get different answers…

In general, **RF engineers** often define multiple transition regions between near field & far field, based on wave impedance regions within the first few wavelengths (*see Appendix for details*)

EMC engineers often use a simpler "2-region" approach. In this model, far field is defined near the point where E & H approach radiative (plane wave) behavior:

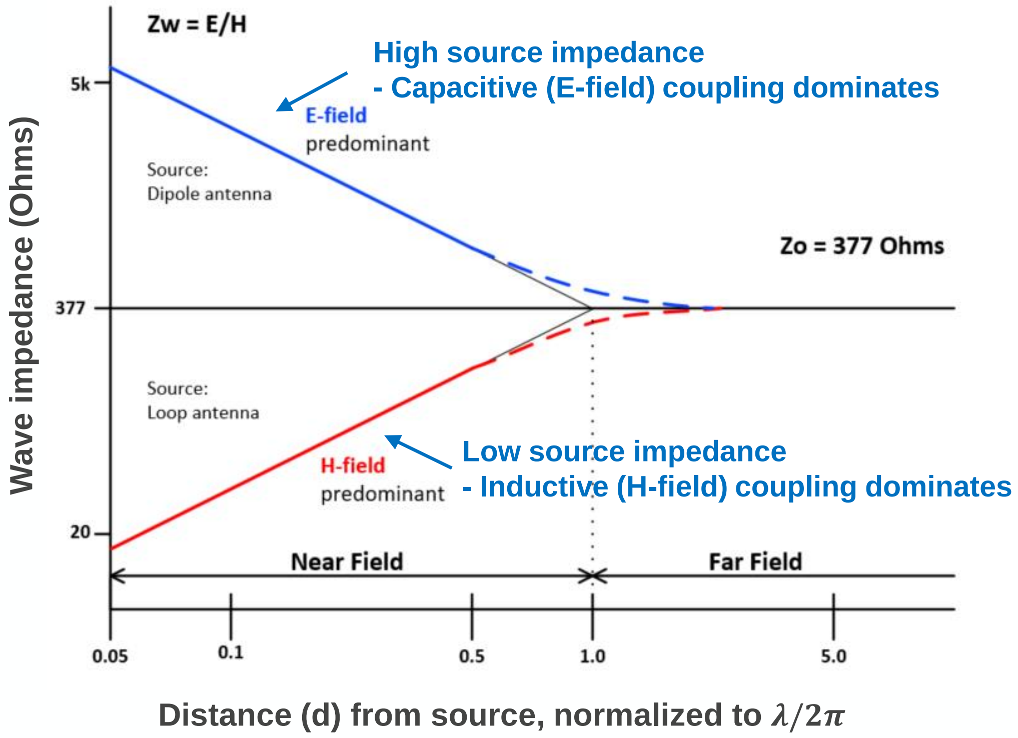
1) **Near field (reactive):** d <= $\lambda/2\pi$
2) **Far field (radiative):** d > $\lambda/2\pi$



We'll use the "2-region" approach for this topic & discussion.

Wave impedance versus distance from source

Wave impedance:



Near-field near Dipole antenna:
E varies as $1/d^3$
H varies as $1/d^2$
Zw varies as $1/d$

Near-field near Magnetic dipole (loop):
H varies as $1/d^3$
E varies as $1/d^2$
Zw varies as d

Far-field :
E decreases as $1/d$
H decreases as $1/d$
Zw = 377 Ohms

Field boundaries for various frequencies

Frequency (MHz)	Near field $\lambda/6$ (m)
0.100	500
0.200	250
0.300	167
0.400	125
0.500	100
1	50
2	25
4	12.5
10	5
30	1.67
50	1
100	0.5
200	0.25
300	0.167
500	0.1
1000	0.05

Estimating near field boundary…

λ = c/f, where
λ = wavelength (m)
c = speed of light (m/s)
f = frequency (Hz)

Near-field boundary:
$\lambda/2\pi \sim \lambda/6$

EMC measurements, distance 'd' from source:
Near field, **d =< $\lambda/6$** from the source
Far field, **d > $\lambda/6$** from the source

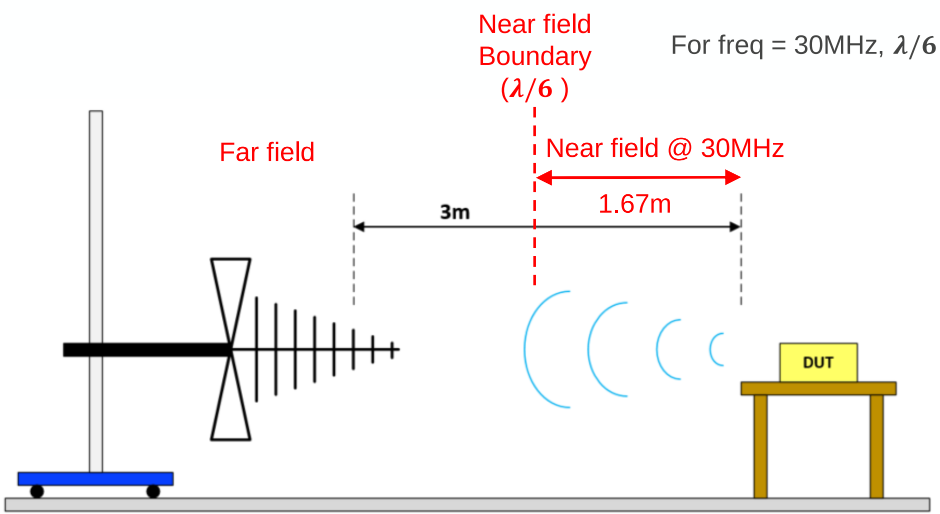
A Closer Look at
Radiated Emissions Setups

Typical setup for FCC RE

Setup for FCC, Part 15, Class B

FCC 3m chamber
At MPS EMC Lab
Livonia, Michigan

For freq = 30MHz, $\lambda/6$ = 1.67m

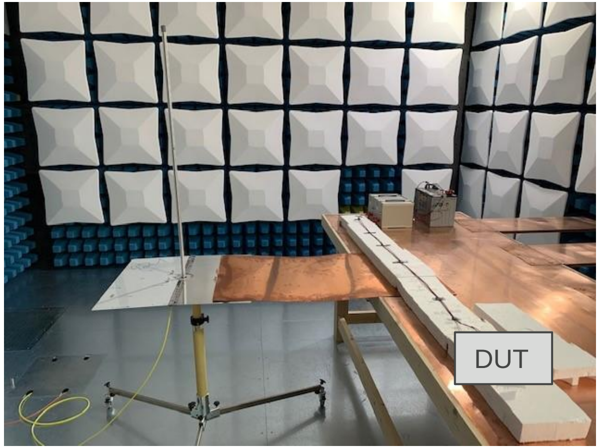


Observations:

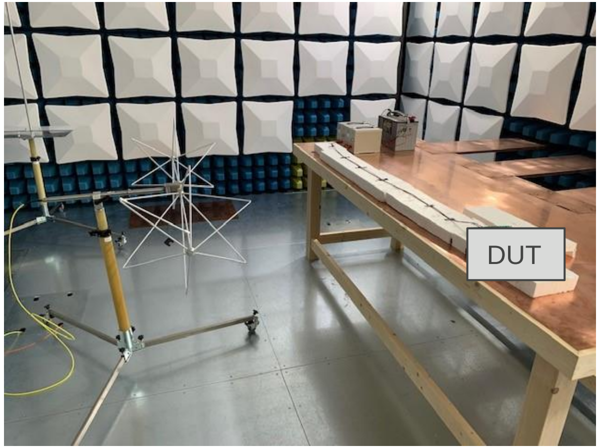
- Bi-Log antenna used to measure 30MHz – 1GHz
- At 30MHz, $\lambda/6$ (near-field boundary) is ~ 1.67m
- For antenna distance = 3m, we meet far field requirement at 30MHz
- **Therefore, for all frequencies in 30MHz – 1GHz range we're measuring far field (propagating E-M waves)**

Typical setup for CISPR25 RE

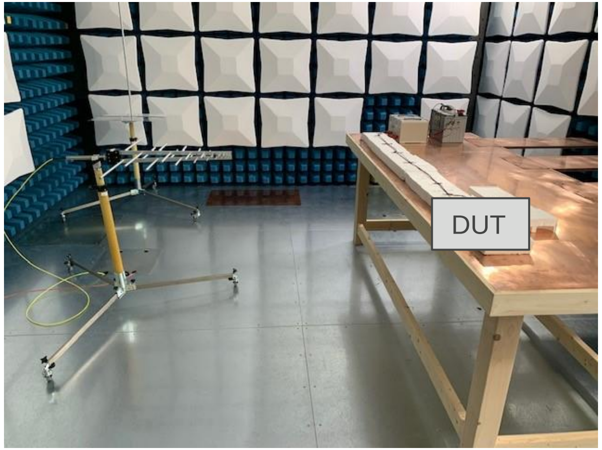
Monopole (Rod) antenna
150kHz – 30MHz



Biconical (Bicon) antenna
30MHz – 300MHz



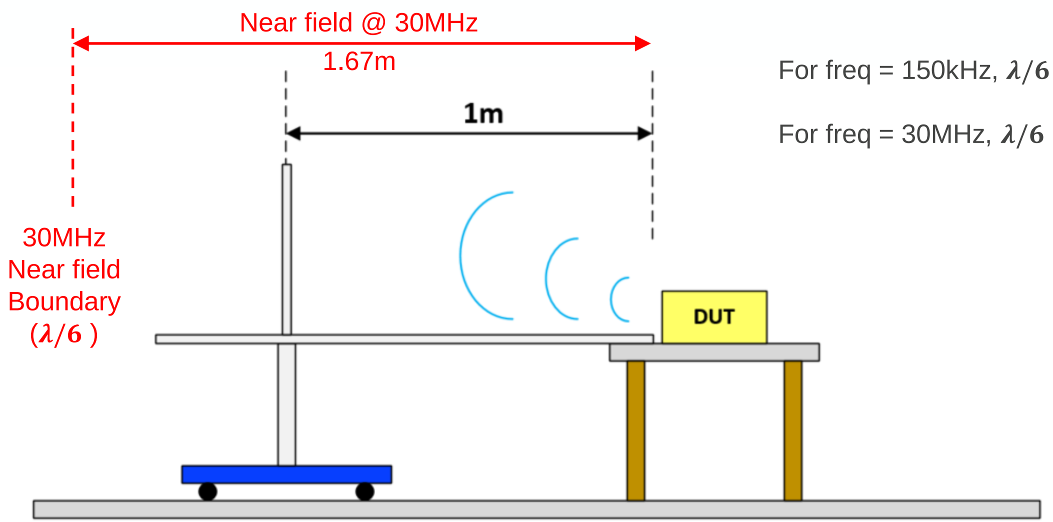
Log-periodic (Log) antenna
300MHz – 1GHz



For CISPR25 Radiated Emissions (< 1GHz):
- DUT and wire harness are placed on top of 50mm of insulation on the table
- Wire harness is ~1.5m - 2m long
- DUT/harness are powered by 12V battery connected to LISN's
- Table has conductive surface, and is connected to GND
- Antenna is positioned to the side of the table, 1m away from the wire harness
- Antenna is centered in the middle of the wire harness

*All photos taken at MPS EMC Lab, CISPR25 chamber, located in Livonia, Michigan

CISPR25 RE – Monopole antenna



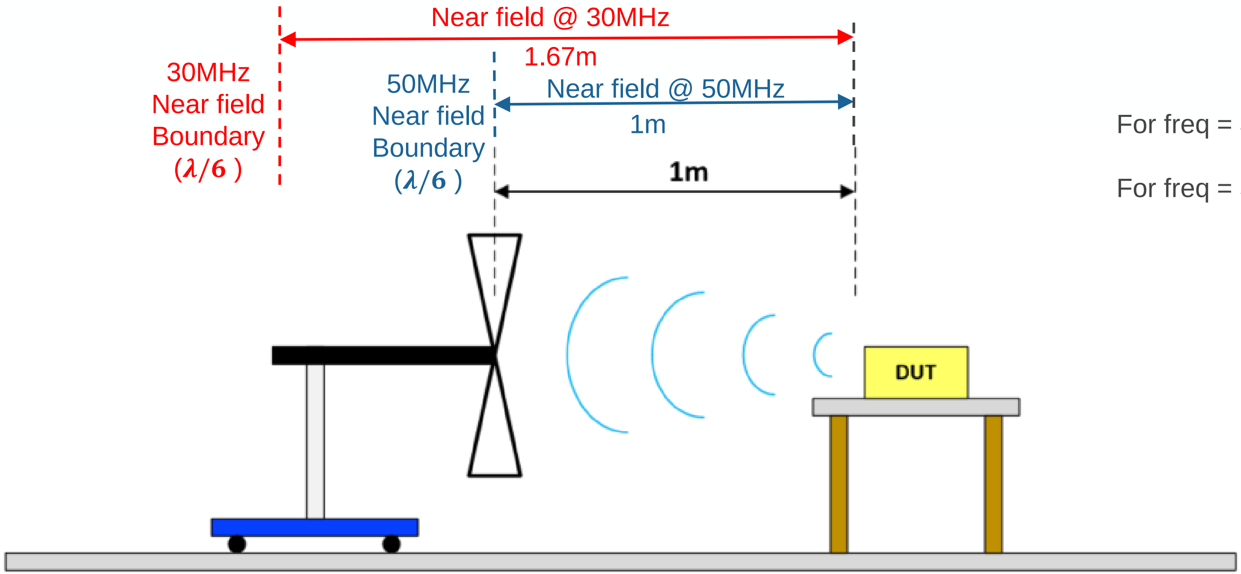
For freq = 150kHz, $\lambda/6$ = 333m (!!!)

For freq = 30MHz, $\lambda/6$ = 1.67m

Observations:

- Monopole antenna used to measure **150kHz – 30MHz**
- Antenna distance is 1m from wire harness & DUT setup
- **We are NOT dealing with far field radiated emissions!!**
- **Antenna measurements in this range will be NEAR FIELD!!!**
- **E-field coupling (capacitive coupling) will be significant for this antenna measurement**

CISPR25 RE – Bicon, Log antennas



For freq = 30MHz, $\lambda/6$ = 1.67m

For freq = 50MHz, $\lambda/6$ = 1m

Observations:

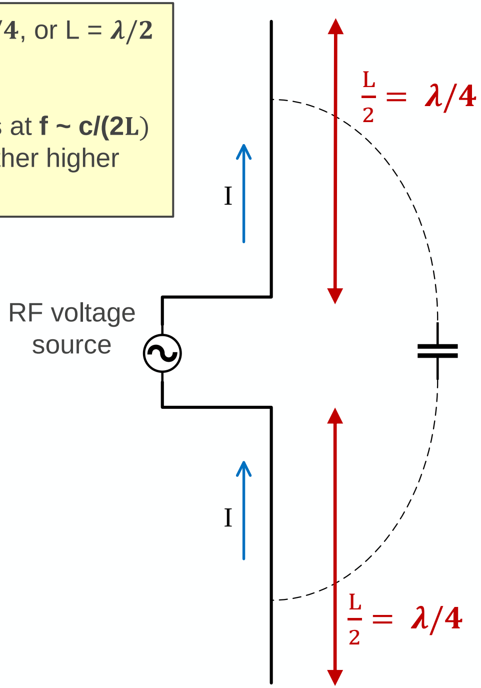
- **Bicon** antenna used for **30MHz – 200MHz**; **Log** antenna used for **200MHz – 1GHz**
- Between approximately 30MHz – 50MHz, measurements are NEAR FIELD!
- **At ~50MHz measurements start to become radiative**
- **Measurements become predominantly FAR FIELD above 50MHz!!**

Unintentional Coupling Paths In the DUT Setup

Short review of dipole antenna structure

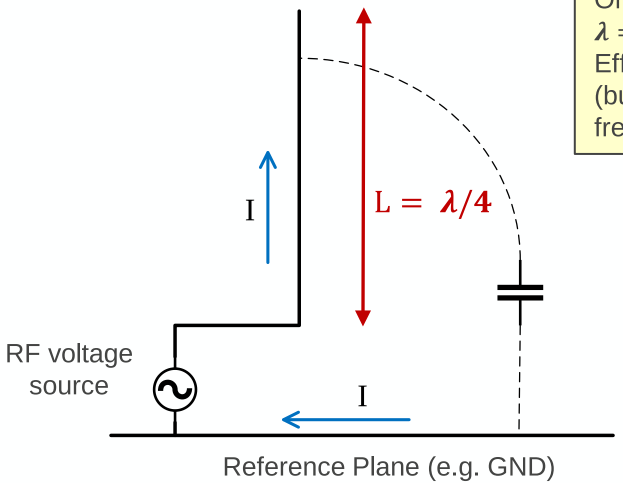
Half-wave dipole

Two legs, L/2 = $\lambda/4$, or L = $\lambda/2$
$\lambda/2 = \mathbf{L}$
$\lambda = \mathbf{2L}$
Efficiently radiates at **f ~ c/(2L)**
(but can radiate other higher frequencies)



Quarter-wave monopole

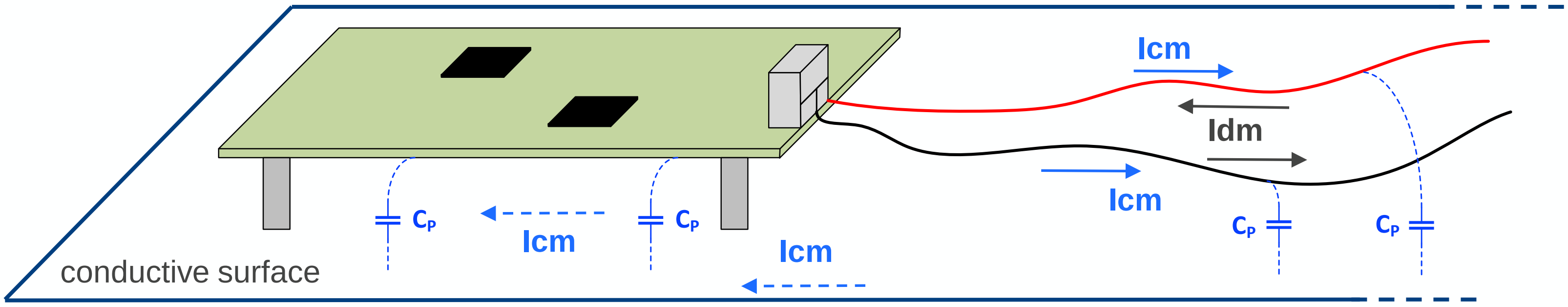
Half the length of dipole
One leg, L = $\lambda/4$
$\lambda = \mathbf{4L}$
Efficiently radiates at **f ~ c/(4L)**
(but can radiate other higher frequencies)



Cabling in the RE setup

Large (long) conducting objects can act as unintentional antennas, to form dipole or monopole structures

- **Cables/wires up to 1.5m – 2m in length can efficiently radiate up to 200MHz – 300MHz**
- **Large metal surfaces or enclosures can act as part of the antenna**



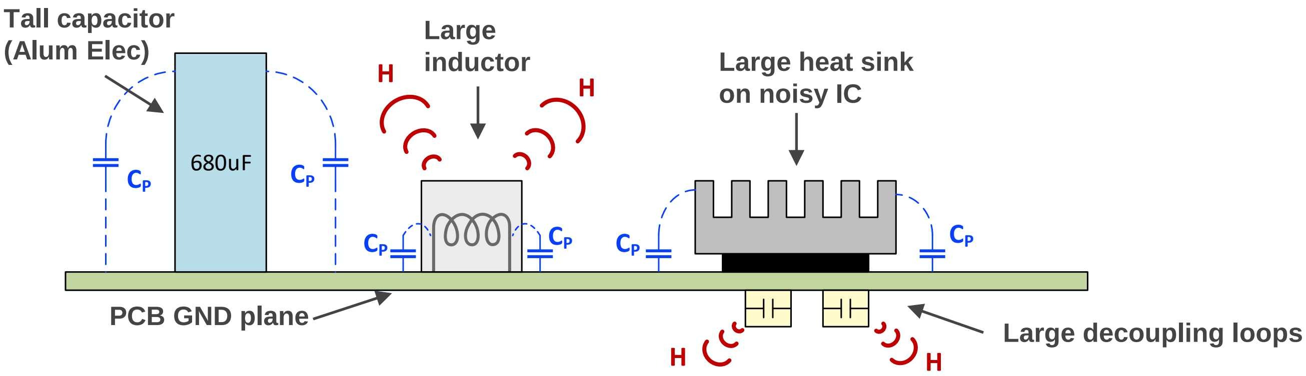
Small common-mode currents (Icm) on long cabling can generate emissions problems in 10's MHz up to few hundred MHz!!

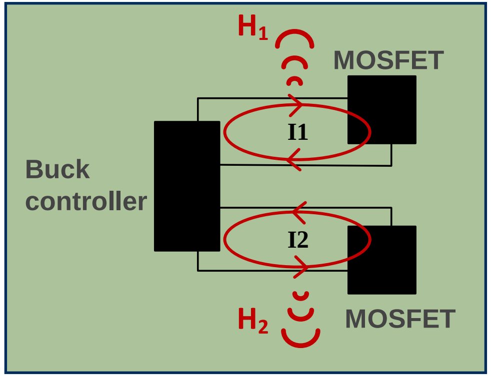
Icm can be created as a result of:

- parasitic fields/coupling in the PCB layout and power/GND planes
- parasitic coupling between the PCB and metal surfaces or enclosures
- parasitic coupling between cabling and metal surfaces or enclosures

PCB in the RE setup

For freq >200MHz (λ getting smaller), size of components & circuits on PCB start to matter.
Metal objects and "small" conduction paths can form parasitic coupling paths.

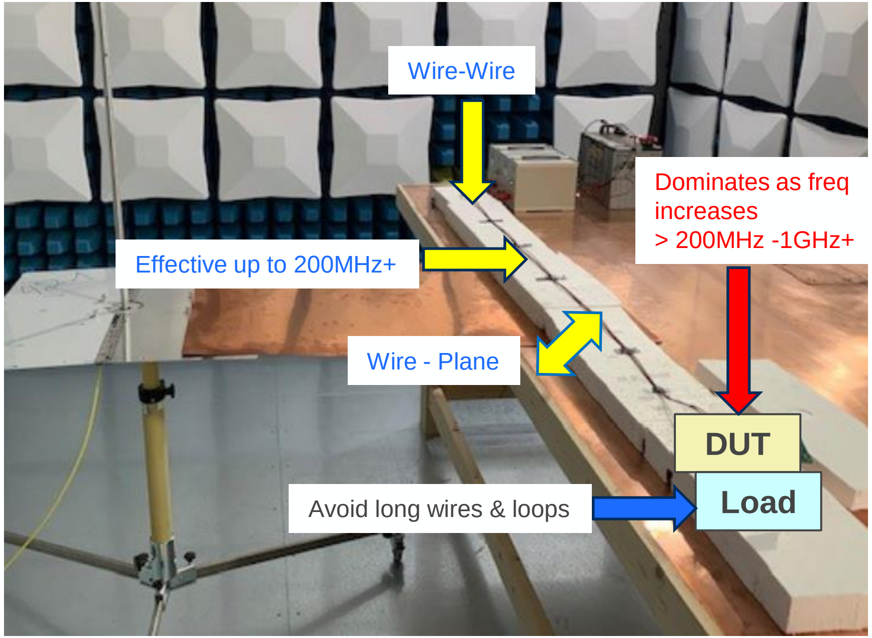




Current loops from
DC/DC controller
generating H fields

REMEMBER:
E-fields measured in the far field can be generated by H-fields on the PCB

"Unintentional" coupling paths in the DUT setup



CISPR25 RE setup

Cables:

- Electrically *LARGE* conductors
- Can act as *unintentional* dipoles (e.g. multiple cables connected to different parts of DUT/EUT
- Can act as *unintentional* monopoles (e.g. table surface acting as plane under wires)
- Effectively driven by Common-mode (CM) energy created by PCB circuits
- **Can effectively radiate energy up to 200MHz – 300MHz** (sometimes higher) depending on cable length

PCB (DUT):

- Electrically SMALL circuits & conductors
- As frequencies increase, and λ becomes smaller, IC's, components, and their connections become critical
- **>200MHz, PCB circuits, components, and connections can radiate emissions from the PCB**

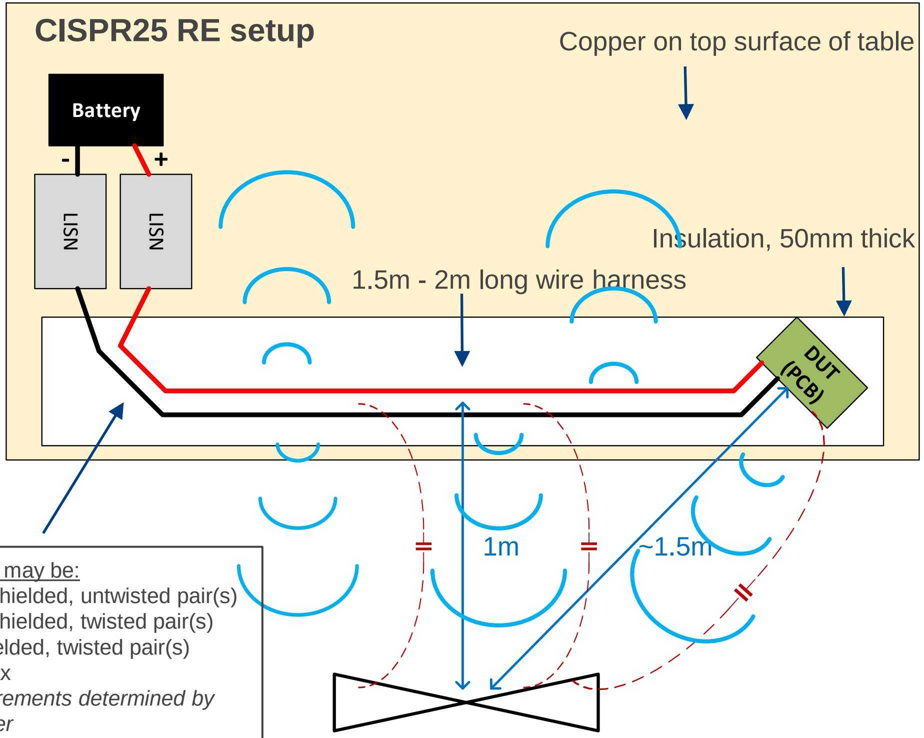
Load:

- Load connection is critical, don't neglect!!
- Long wires may act as unintentional dipole or monopole
- Large loops may act as magnetic dipole

Tips: Considerations When Measuring Radiated Emissions

Making sense of measurements

Based on our review, <u>what can we determine??</u>



Cabling may be:
- Unshielded, untwisted pair(s)
- Unshielded, twisted pair(s)
- Shielded, twisted pair(s)
- Coax

** Requirements determined by customer*

RE antenna (receiver)	Freq Range	Dominant Coupling Mechanism/Path	Coupling Source
Monopole	150kHz – 30MHz	E-field (near field)	Unshielded DUT, Cables
Bicon	30MHz – 200MHz	E-field near 30MHz (near field) E-M wave >50MHz (radiated)	<u>Near field:</u> DUT, cables <u>Far field:</u> Mostly cables, driven by CM noise from DUT DUT at higher freq's
Log	200MHz – 1GHz	E-M wave (radiated)	Mostly DUT (PCB circuits); Cables at freq's closer to 200MHz

Now back to the QUIZ…

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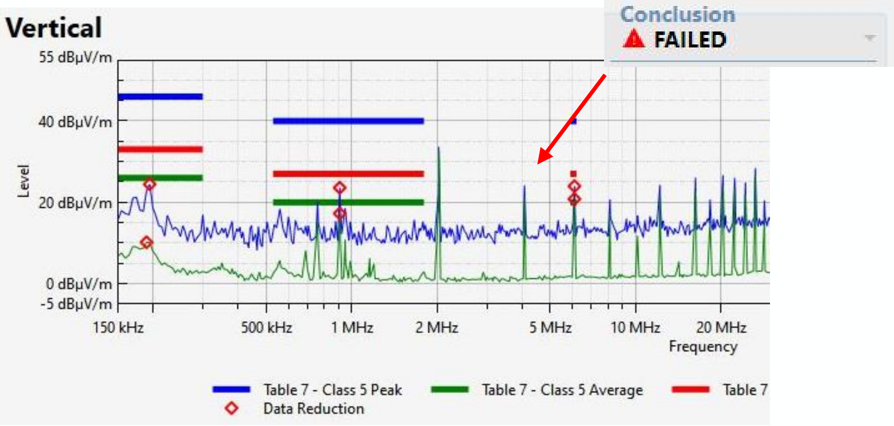

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- DUT not shielded
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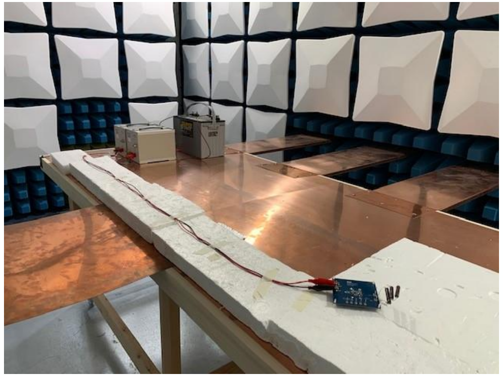
QUESTION: What is likely the largest contributor of noise measured in this spectrum?:

a) ~~Electromagnetic waves emitting from DUT (buck DC/DC board)~~
b) Electric fields coupling from DUT (buck DC/DC board)
c) ~~Electromagnetic waves emitting from 2m cable harness~~
d) None of the above

NOT Far Field!

Near field experiment

Original measurement

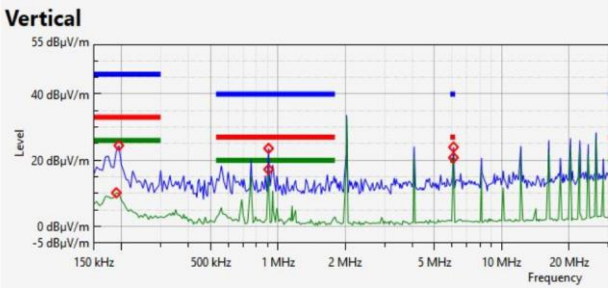


Shield cable only

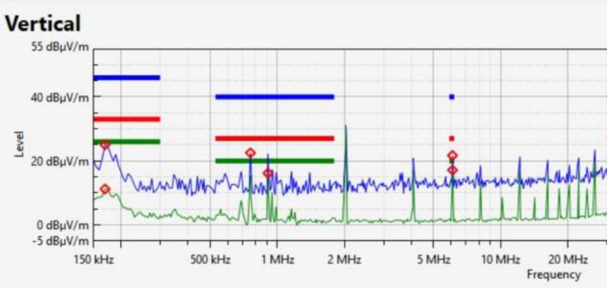
(Cables isolated from shield using cardboard, foam, or wood)

Shield DUT/board only

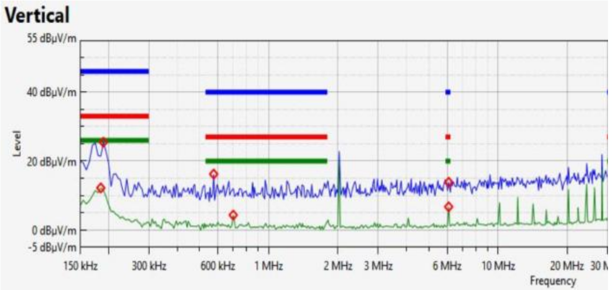
(Shield does NOT connect to DUT/Cable)



3-5dB reduction at most freq's



10-15dB reduction at most freq's!!!



What is the largest contributor??

Based on these results, we see that:
(b) is CORRECT, the DUT/board is the largest noise contributor in the near field

Is this ALWAYS the case?
NO, depending on the circuit or module results can vary. But it shouldn't always be assumed that cables are the primary issue (for CISPR25 Monopole).

Why does this matter?

- It may change your approach to mitigating the problem in this frequency range.
- In the near field, significant E field noise can couple to antenna directly from the DUT or cable (or both).
- If we assumed the cable was the main problem, we may have spent a lot of time trying to filter the noise at the cable connector. In this case, it would have shown small improvement.
- Since we determined (in this case) the DUT is a larger noise problem at these frequencies, we should focus on finding the culprit on the PCB. It may be a layout issue, a noisy component (e.g. inductor) or other problem. An additional EMI filter at the connector likely won't help much, we need a different solution.

Summary

Summary

In this session, we discussed:

- Far field radiated coupling from E-M waves
- Near field coupling from E & H fields
- Estimating the boundary between near & far fields
- Understanding the RE setup, and determining the coupling mechanism based on:
  - antenna type (freq range, wavelength)
  - distance from source
  - near/far field boundary
- Unintentional coupling paths in the DUT setup
- Tips/considerations when measuring & debugging radiated emissions

THANK YOU!!

Q&A

Let us know your questions

References

List of references:

1) https://www.osha.gov/radiofrequency-and-microwave-radiation/electromagnetic-field-memo#section_1

2) https://incompliancemag.com/article/near-and-far-fields-simplified-for-emiemc/

3) https://www.itu.int/en/ITU-D/Technology/Documents/Events2013/CI_Training_ARB_Tunis_April13/UIT_EMC_fundamentals.pdf

Appendix: RF definitions for near field, far field

RF & antenna engineers often define several regions from near field to far field. In terms of distance 'd' from the source:

1) **Near field (reactive):** **d** <= $\lambda/2\pi$
2) **Near field (radiative):** $\lambda/2\pi$ < **d** < λ
3) **Transition zone (radiative):** λ < **d** < 2λ
4) **Far field (radiative):** **d** >= 2λ *Zw = 377 Ohms*