Understanding EMC Basics series
Webinar #3 of 3, August 28, 2013

Grounding, Immunity, Overviews of Emissions and Immunity, and Crosstalk

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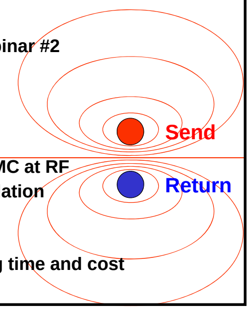
Contents of Webinar #3

Topics 1 through 9 were covered by the previous two webinars in this series, and can be downloaded from Interference Technology's website

I'm sorry, but I made an error in the title!
Overview of Emissions was covered in Webinar #2



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Safety earthing/grounding does not help EMC at RF

Safety earthing (grounding) does not help EMC at RF

- So far in this series I haven't mentioned grounding (earthing)...
  - because these terms are so widely misused and misunderstood that it is best to use them only for <u>safety</u>, and *never for circuit design or EMC*
- Wired connections to the protective (safety) earth have little effect at frequencies >100kHz...
  - because they have far too much inductance
  - and are also accidental antennas, just like all other wires and other conductors (see Webinar #2)

The idea that "Earthing" or "Grounding" is an "infinite sink for unwanted currents", is a fallacy

- Because according to all the Laws of Physics (Maxwells, Ampéres, Conservation of Energy, etc.) any/all DM and CM currents can only flow in *closed loops*…
  - and so and "grounds" ("earths") only carry current when they are part of a circuit loop…
    - there can be no such thing as a sink for unwanted currents
- So what must we use for our 'RF Ground'?
  - and how should we electrically connect ('bond') to it?

The only effective 'RF Ground' is what I call an *RF Reference*

- This is a conductive area, as large as possible, e.g. a chassis, or a 0V plane in a PCB...
  - or the inside surface of a conductive enclosure…
    - the better the shielding, the better its RF Reference
- *And* – is very close by...
  - <<λ/10 at the highest frequency of concern, i.e. << $30/f_{max}$
  - much closer spacing is better, i.e. << λ/100, i.e. << $3/f_{max}$
    - spacing in metres, if f_{max} is given in MHz
    - spacing in mm if f_{max} is given in GHz

'Grounding' to an RF Reference Plane is called 'RF Bonding'…

– and should achieve <<1Ω at f_{max}

- Direct metal-to-metal connections give the best RF-bonds (i.e. the lowest impedances at f_{max})…
  - where two conductive parts are to be joined, they should be 'RF-bonded' at *multiple* points equally spaced <λ/10 apart along the entire perimeter of the seam or joint…
    - single-point RF-bonding cannot work, it just creates resonances...
  - ideally, use using seam-welding, seam-soldering, or a continuous conductive gasket all around the perimeter...
    - although multiple wide braid straps <150mm long spaced <λ/10 apart *might* be OK – but probably << 100MHz

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Non-linearity, demodulation and intermodulation

All the previous slides, in this and the previous 2 Webinars in this series, are equally valid for emissions *and* immunity...

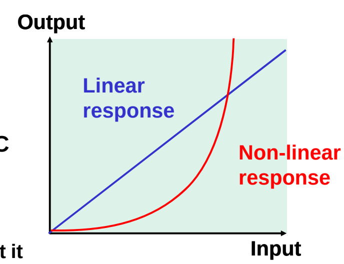
– because they are all concerned with controlling the propagation of E, H and EM fields...
  - that we generally call: electrical signals and power...

– and these techniques are equally valid for controlling RF emissions and immunity at the same time

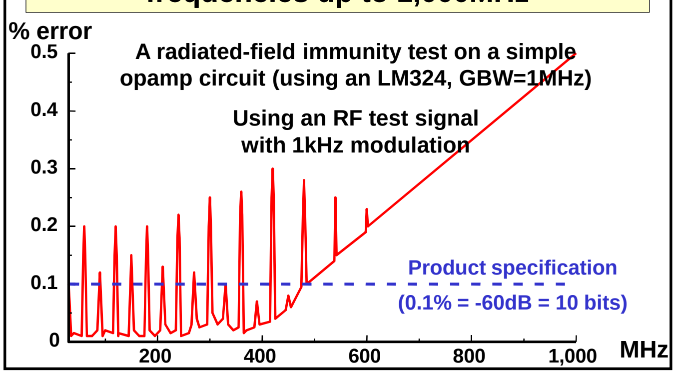
- However, the following slides cover some additional topics that we have to cover...
  - that concern RF immunity only

And these are: non-linearity, demodulation and intermodulation

- In a linear material the output is linearly proportional to the input
- But *all* semiconductors are non-linear…
  - as are some oxidised electrical connections…
  - so they tend to rectify AC signals (including RF)…
    - in a radio receiver this is called demodulation, or detection, and we want it

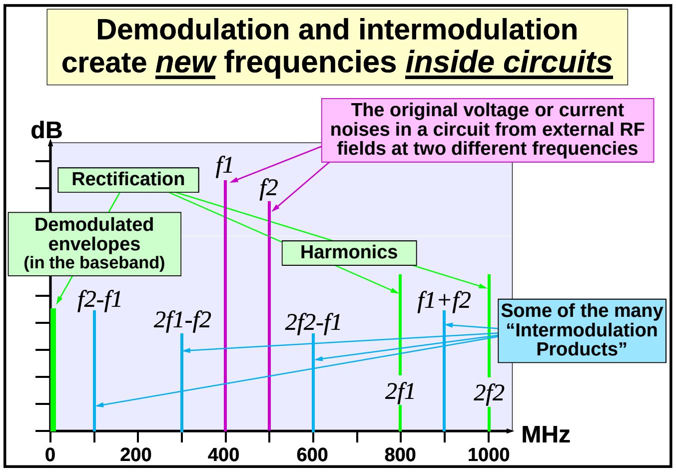


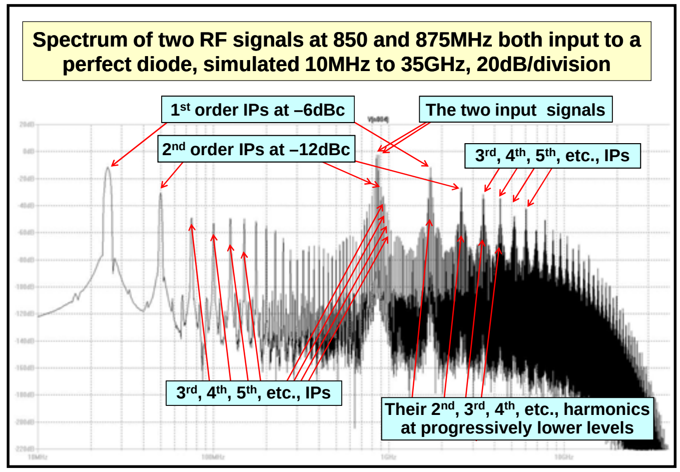
Example of a 'slow' opamp rectifying (demodulating) the 1kHz modulation of radio frequencies up to 1,000MHz



Non-linearity, demodulation and intermodulation continued…

- Where two or more frequencies are simultaneously present in a non-linear device…
  - new frequencies are created from their sums and differences…
  - and then from the sums and differences of these new frequencies (and so on)…
    - it gets very complicated indeed when there are more than three frequencies present at the same time





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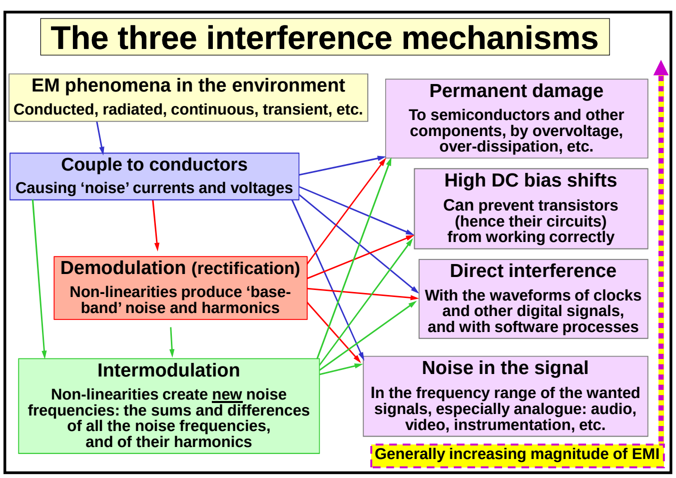
The 3 interference mechanisms



An example of intermodulation

- **Conventional (single frequency) RF immunity testing over the range 150kHz - 1GHz reveals susceptibility over 50 - 200MHz…**
  - **shielding and filtering that is effective over 50 - 200MHz is added, and the equipment now passes that test**
- **But no protection was added from 200MHz - 1GHz…**
  - **allowing *simultaneous* frequencies in this range, in the real-life EM environment, to enter the equipment and intermodulate *inside its devices*...**
  - **creating internal noises within the susceptible range (50 - 200MHz), causing immunity problems**

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Overview of RF immunity

All semiconductor circuits are really "accidental" radio tuners

- For immunity, all electronics can be thought of as many tens of thousands (maybe millions) of 'accidental demodulators' (rectifiers) *and* 'accidental superheterodynes' (intermodulators)...
    - i.e. the diodes and transistors in ICs and power devices...
  - coupled to thousands of tuned antennas....
    - e.g. 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)

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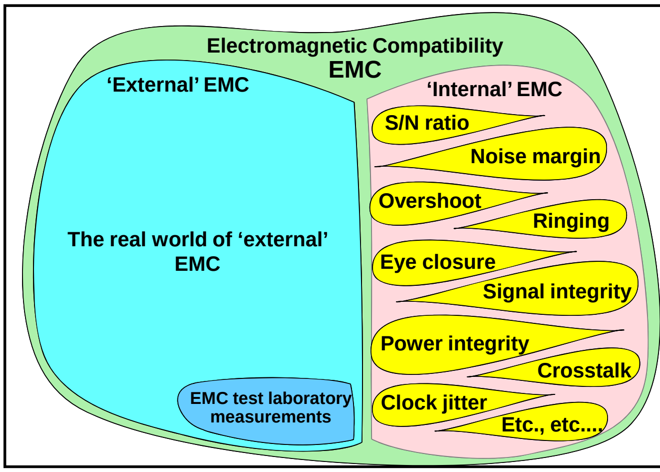
"Internal EMC", crosstalk, SI, PI, and saving time and cost

Crosstalk and other EM interactions *inside* equipment

- For EMC compliance we are only concerned with the EM interactions between an item of equipment and its external environment
- But EM interactions also occur between devices, traces and wires *inside* an item of equipment…
  - and we care about these because they affect the number of design iterations and time-to-market…
  - and we also care because they can affect reliability and warranty costs…
  - we might call this issue: "internal EMC"



Crosstalk and other EM interactions *inside* equipment continued…

- The material in this series of three webinars applies equally well whether the issue is "external" or "internal" EMC
- Internal EM interactions are traditionally called crosstalk…
  - and analysed in terms of stray capacitance and stray mutual inductance…
  - i.e. a 'Lumped Analysis' approach…
  - which only works when the victim is in the near-field of the E of H field emissions from the noise source

Crosstalk and other EM interactions *inside* equipment continued…

- **But this traditional 'crosstalk' approach is often inadequate for modern designs…**
  - because the high frequencies we now employ (e.g. clock harmonics) have such short wavelengths that parts of the inside of the equipment are in their far field…
  - and the wires and cables inside an equipment; PCB traces; heatsinks and even devices themselves, can behave as resonant 'accidental antennas'…
  - and far-field EM interactions *cannot* be estimated by using lumped analysis methods (see Webinar #1)

Using good EMC design techniques throughout a project, e.g…

- in choosing components, circuit design, software design, PCB design and layout, cables and connectors, mechanical packaging, etc.…
  - as well as the usual EMC shielding and filtering…
- controls Internal EMC *and* External EMC, reducing…
- project costs and timescales…
  - by reducing the number of design iterations that achieves the functional spec's, reliability and regulatory approval…
- product overall cost of manufacture…
  - by reducing the cost of the filtering and shielding required to achieve regulatory approvals

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Some useful formulae and references

Very simplified formulae for emissions

DM. For current in a loop the maximum *possible* far-field E-field emission (maximised by varying antenna height over a groundplane as per normal OATS emissions-testing method) occurs when the diameter is λ/2 (or an integer multiple of λ/2) at:

$$E = \frac{263 \cdot 10^{-16} (f^2 \cdot A \cdot I)}{R} \text{ V/m}$$

E = electric field in Volts/metre
f = frequency in Hz
A = loop area in square metres
I = the loop's differential-mode current in Amps
R = measurement distance from loop in metres
(divide result by 2 for free-space emissions)

CM. For a monopole (wire perpendicular to large 0V plane) the *max possible* E-field emission (maximised by varying antenna height over a groundplane as per normal emissions-testing method) occurs when the length L is λ/4 (or integer multiple of λ/4) at:

$$E = \frac{1.26 \cdot 10^{-6} (f \cdot L \cdot I)}{R} \text{ V/m}$$

E = electric field in Volts/metre
f = frequency in Hz
L = length of wire in metres
I = the wire's common-mode current in Amps
R = measurement distance from wire in metres
(divide result by 2 for free-space emissions)

E.g. For 10m OATS Class B ≤230MHz: 3.3µA CM max. For Class A: 10.5µA CM max

Simplified formulae for DM voltage noise 'pick-up' from external E and H fields

For a small circular loop (max dimension λ/2) the maximum *possible* differential-mode voltage induced in it by an external H field is:

$$V_{DM} = 8 \cdot 10^{-6} (f \cdot H \cdot A) \text{ Volts}$$

V_{DM} = the loop's induced differential-mode voltage
f = frequency in Hz
H = the external magnetic field in Amps/metre
A = the loop's area in square metres

$A=\lambda^2/4\pi$ gives the max. voltage in any size of loop, so $V_{DM(max)} = 60\pi \cdot H \cdot \lambda$ or $(5.73) \cdot 10^{10} \cdot H/f$

For a small loop (max dimension <λ/2) the maximum *possible* differential-mode voltage induced in it by an external E field is same as the above equation divided by 377 (the impedance of free space, in ohms):

$$V_{DM} = 2.1 \cdot 10^{-8} (f \cdot E \cdot A) \text{ Volts}$$

V_{DM} = the loop's induced differential-mode voltage
f = frequency in Hz
E = the external electric field in Volts/metre
A = the loop's area in square metres

$A=\lambda^2/4\pi$ gives the max. voltage in any size of loop, so $V_{DM(max)} = E \cdot \lambda/2$ or $(1.5) \cdot 10^{8} \cdot E/f$

For the induced DM current in the loop, divide the induced voltage by the circuit loop's (complex) impedance (vector calculation finds the phase angle between the induced current and voltage)

Simplified formulae for CM voltage noise 'pick-up' from external E fields continued...

For a short monopole (wire perpendicular to reference plane, maximum length λ/4) the maximum *possible* common-mode voltage induced by an external E field is:

$$V_{CM} = E \cdot L \text{ Volts}$$

V = the induced common-mode voltage in Volts
E = the external electric field in Volts/metre
L = the length of the wire in metres

L = λ/4 gives the highest voltage possible in a length, so $V_{CM(max)} = E \cdot \lambda/4$ or $(0.75) \cdot 10^{8} \cdot E/f$

For a small loop (max dimension <λ/4) the maximum *possible* common-mode voltage induced in it by an external E field is:

$$V_{CM} = \frac{E \cdot 2\pi \cdot A}{\lambda} \text{ Volts}$$

V = the induced common-mode voltage in Volts
E = the external electric field in Volts/metre
A = loop area in square metres
λ = the wavelength of the external electric field

(For a given loop, this gives the same V_{CM} (in V) as I_{DM} (in A))

$A=\lambda^2/4\pi$ gives the highest voltage possible in any loop, so $V_{CM(max)} = E \cdot \lambda/4$ or $(0.75) \cdot 10^{8} \cdot E/f$

For the induced CM current, divide the CM voltage by the (complex) CM impedance of the affected circuit (vector calculation finds the phase angle between the induced current and the induced voltage)

Some useful references

- *The Physical Basis of EMC*
  Keith Armstrong, Nutwood UK October 2010
  ISBN: 978-0-9555118-3-7, full colour graphics throughout
  - order from www.emcacademy.org/books.asp *(NOT available from Amazon!)*
  - provides an understanding of electromagnetic phenomena, in a way that can be easily understood by practising electronic engineers.
  - Chapter 2 of my book "EMC Design Techniques for electronic engineers" (below) is the complete text of this book, so don't purchase both of them!
- *EMC Design Techniques for electronic engineers, Chapter 2,* **Keith Armstrong, Nutwood UK November 2010**
  ISBN: 978-0-9555118-4-4, full colour graphics throughout
  - order from www.emcacademy.org/books.asp *(NOT available from Amazon!)*
  - covers all electronic applications, with a practical approach to good EMC design practices proven over many years in real life to save time and cost, reduce time-to-market, and reduce warranty costs and financial risks

Some useful references continued…

- *EMC for Product Designers 3rd edition*
  Tim Williams (Newnes, 2001 ISBN 0-7506-4930-5)
  Chapter 5 and Appendix C
  - or 4th Edition, Newnes 2007, 0-7506-8170-5, Chapters 1-3 and Appendix D
- **Clemson University Vehicular Electronics Laboratory: www.cvel.clemson.edu/emc/**
  - an introduction to EMC, plus some useful EMC calculation tools
- **A reference for the Skin Depth formula and properties of numerous metals…**
  - www.rfcafe.com/references/electrical/skin_depth.htm

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the end

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