Unintentional Antennas

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Purpose

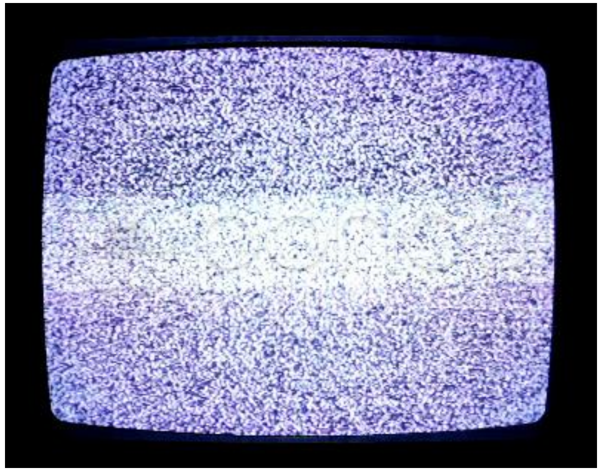
- For audience members who are just starting out:
  - A brief introduction to how electromagnetics manifests in some electrical systems as electromagnetic radiation
  - Common pitfalls to watch out for

- For audience members who have experience with EMC, antenna design, or both:
  - Introduce some examples and analogies that may help explain these phenomena to customers, management, or non-specialist engineers

What is EMC?

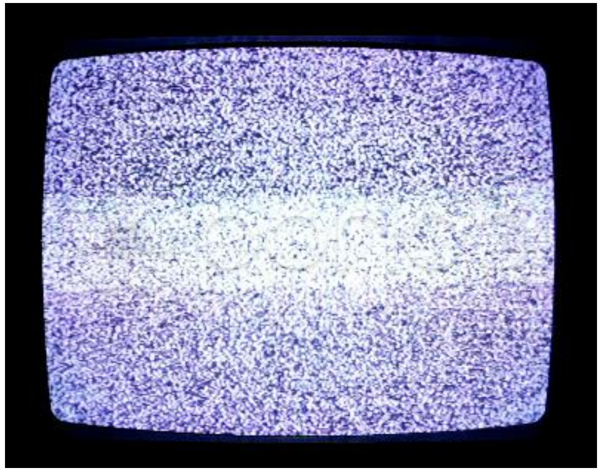
- EMC = Electromagnetic Compatibility

EMC has the goal of making sure that all the electronics on a platform will perform correctly with no interference to each other or with the outside world

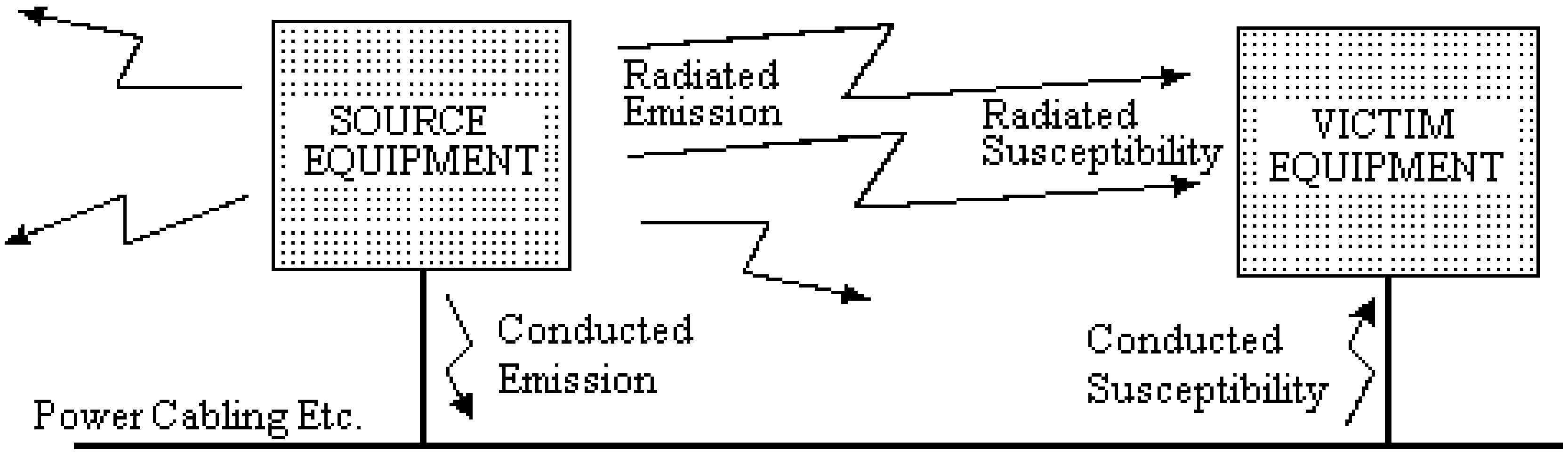


What is EMC?

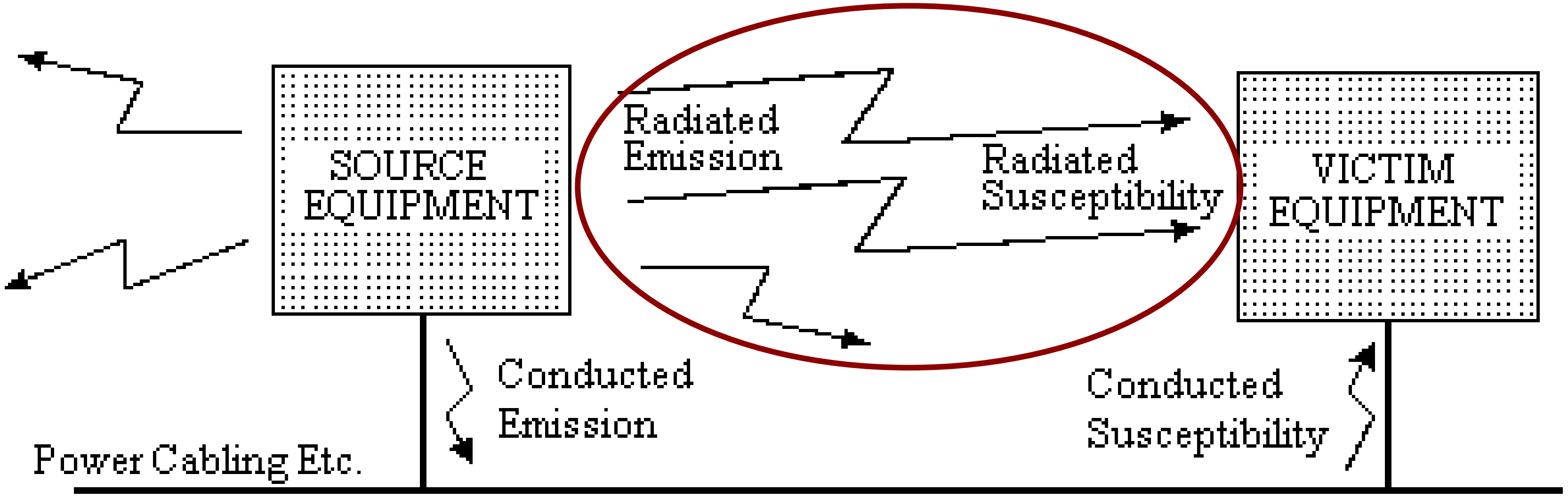
- You may also see:
  - EMI = Electromagnetic Immunity
  - EME = Electromagnetic Effects
  - EEE = E3 = Electromagnetic Environmental Effects
  - EMR = Electromagnetic Resiliance



EMC Problems

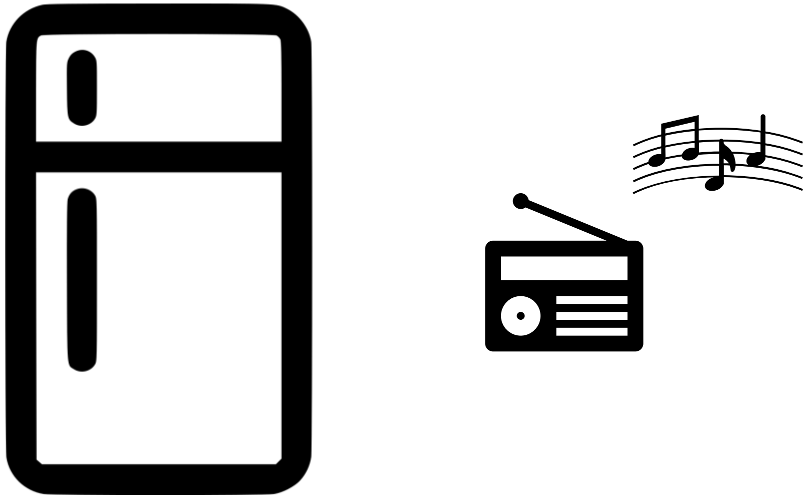


EMC Problems



EMI – Radiated Emissions

A real-world example of EMI is a person who bought a new refrigerator in 2021. When the doors were closed the FM radio they'd always listened to worked fine; when the right-hand door was opened the FM radio signal fritzed out—radiated emissions problem



Source: onlinewebfonts

Source: IconFinder

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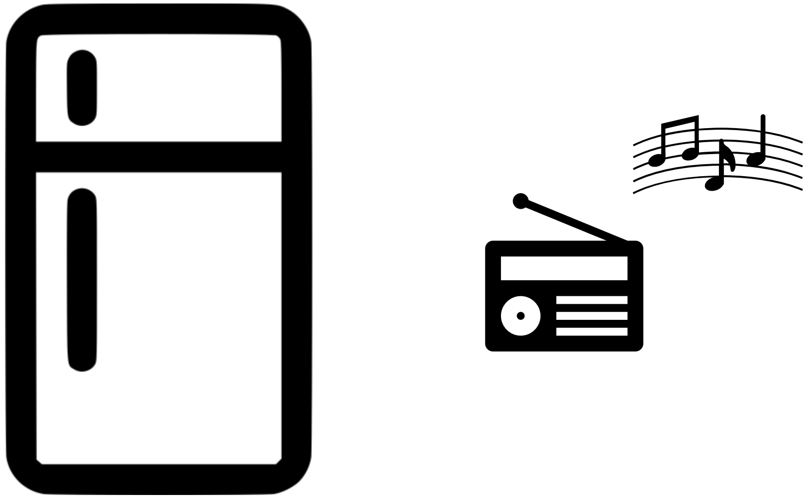


Source: onlinewebfonts

Source: IconFinder

But who put a (non-WiFi) antenna in a refrigerator?

Antennas

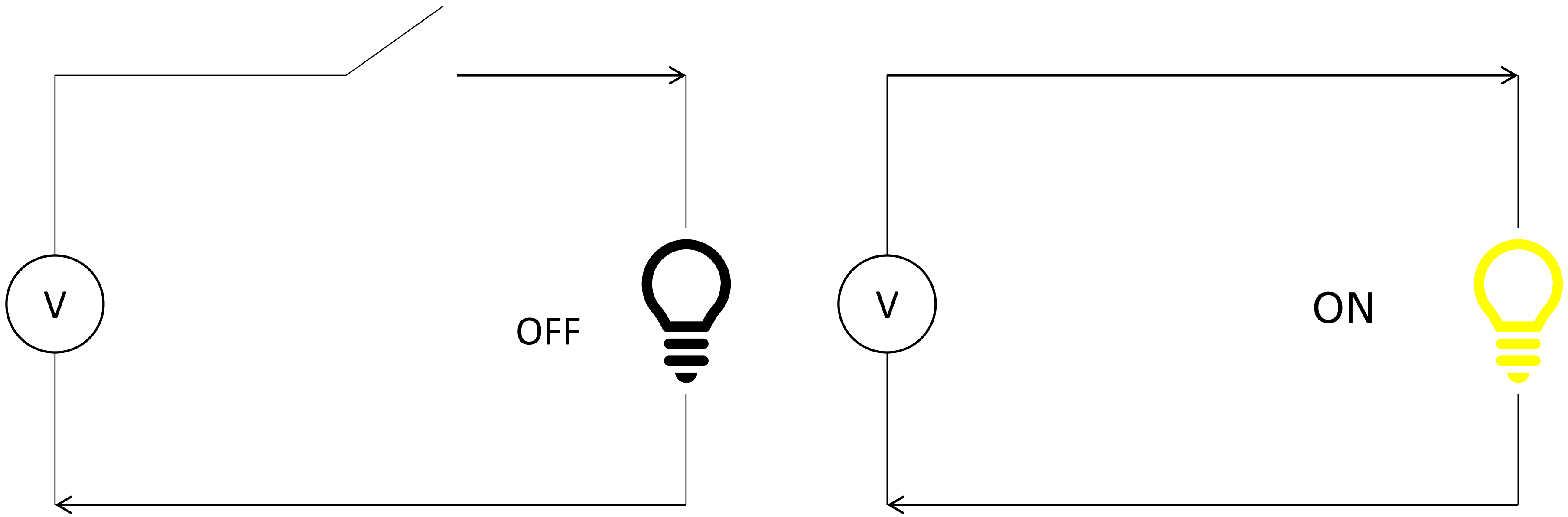

Heart Rate
Blood Pressure
Blood Oxygen
Steps counter
Distance
01/08 SUN
08:56
PM
12589
Sleep Monitor
Call Remind
Social App Notification
SMS
Message remind
Calories

Antennas

Antennas

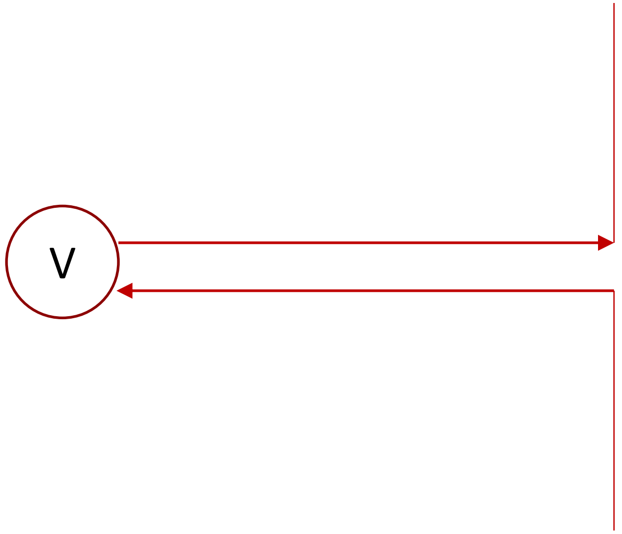
How does an antenna radiate?

We've always learned that no current flows in an open circuit



How does an antenna radiate?

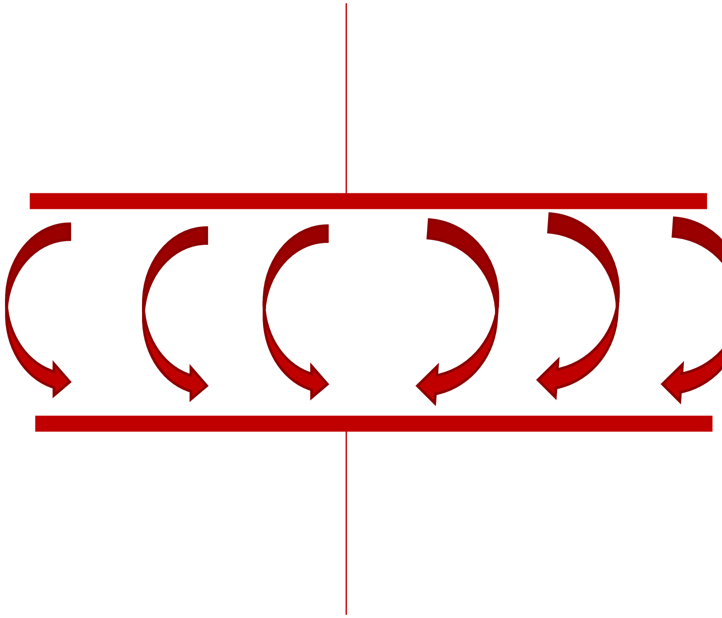
So how does current flow in a system like this (classic center-fed dipole antenna)?

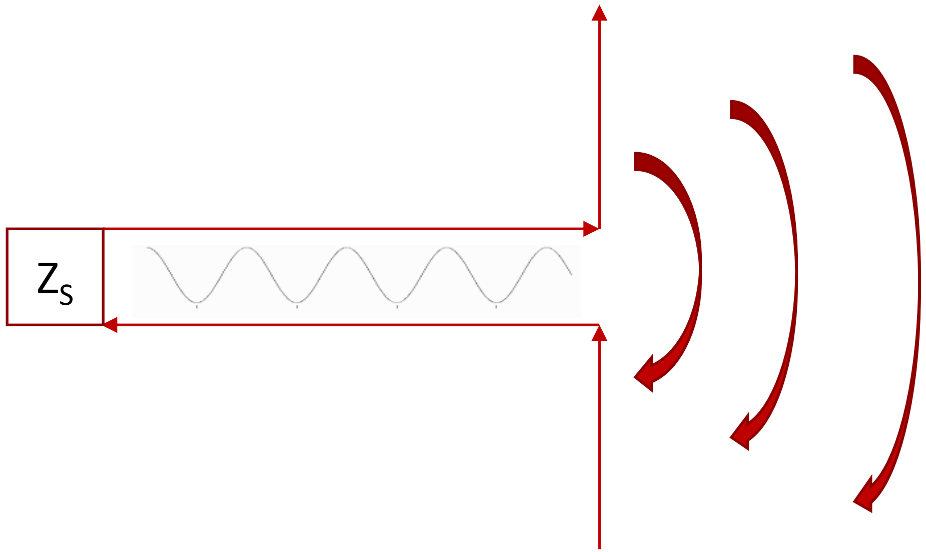


This sure looks like an open circuit

Displacement Current/Capacitive Coupling

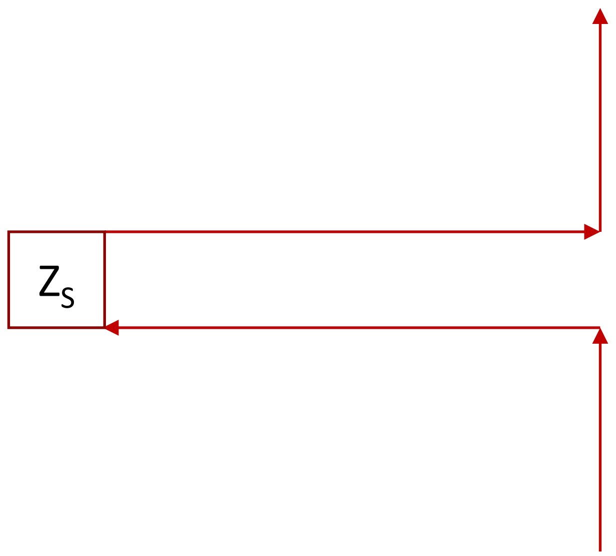
The time varying electric field (e.g., RF energy) between the two conductors of the dipole creates a "displacement current" between the two—the same effect seen in a capacitor in an AC circuit. Like any other changing current, this produces an electromagnetic field



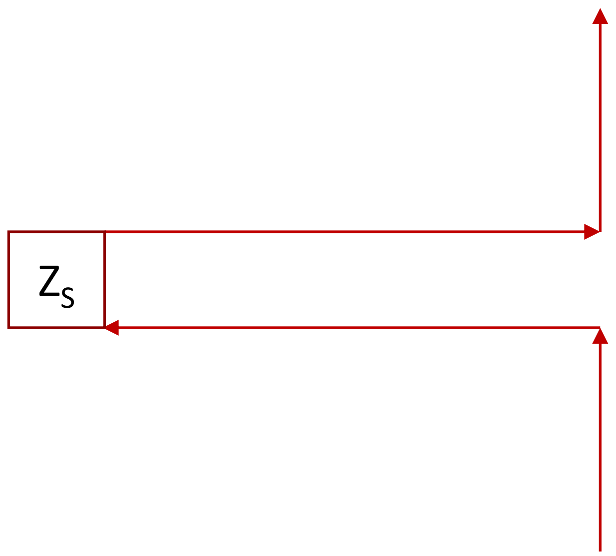


Antennas

So fundamentally, all it takes to make a dipole antenna is two pieces of metal (conductors) with an RF potential difference between them

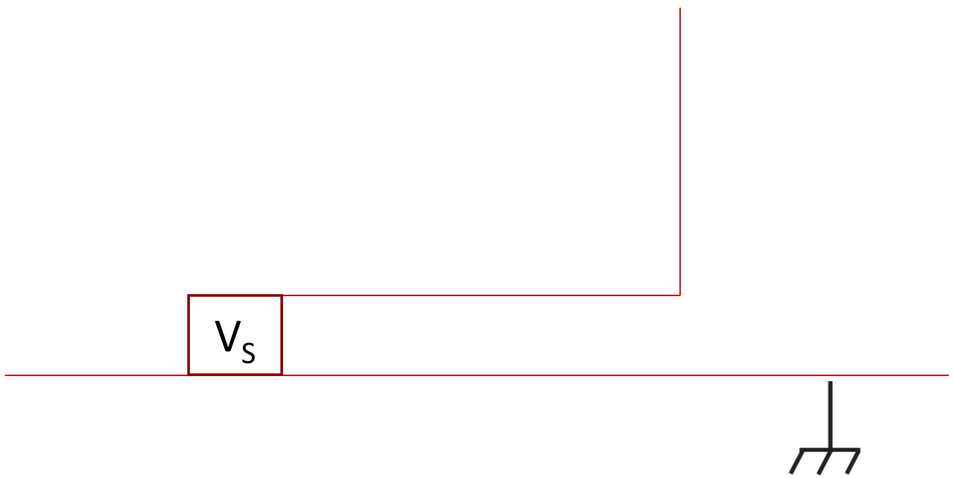


Consider the analogy of clapping: you generate sound waves by using two hands to clap together



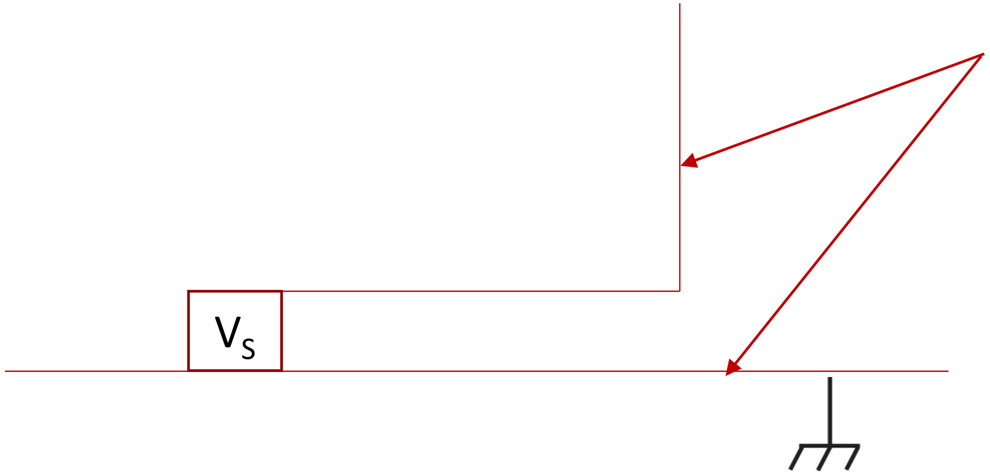
Monopoles

However another classic antenna is the monopole. How is it generating EM waves?



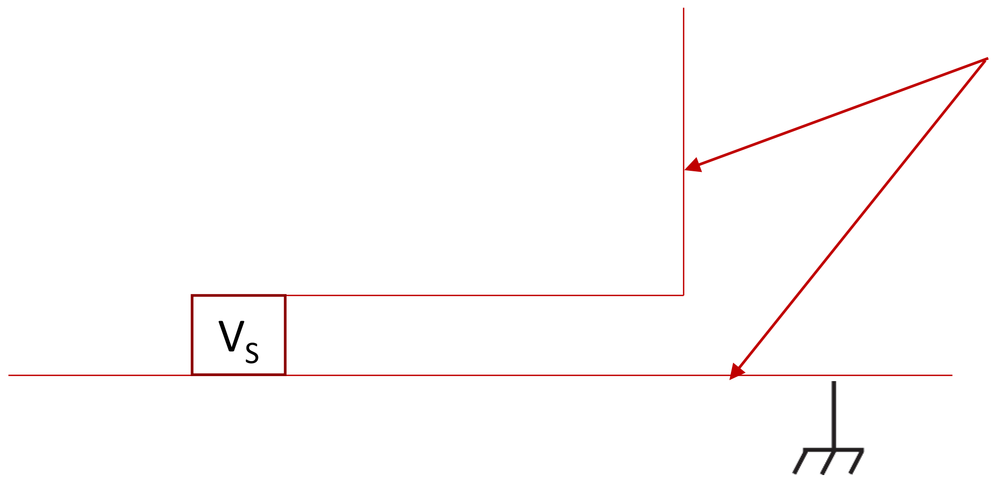
Monopoles

There are still two conductors with an RF potential difference between them: The single antenna element and the reference plane



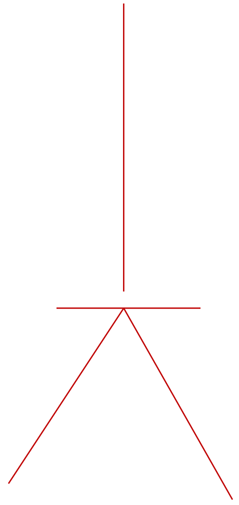
Monopoles

With our clapping analogy, if you have to clap with one hand in your pocket, you can clap your free hand against a table or other object to generate sound waves

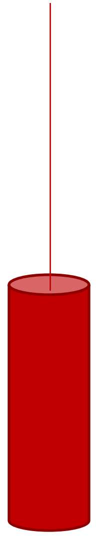


Monopoles

The second conductor in a monopole system doesn't have to be a ground/reference plane, it can be any other conductor around



Reference compared to a mounting stand



Reference compared to the "shield"/outer conductor of a coax

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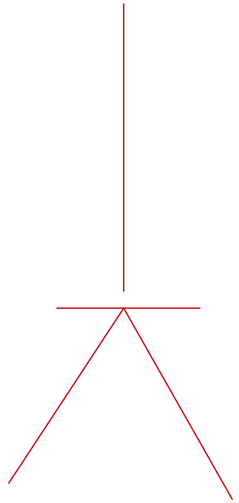
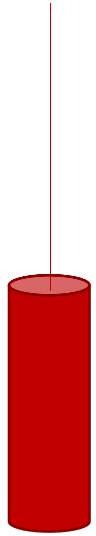
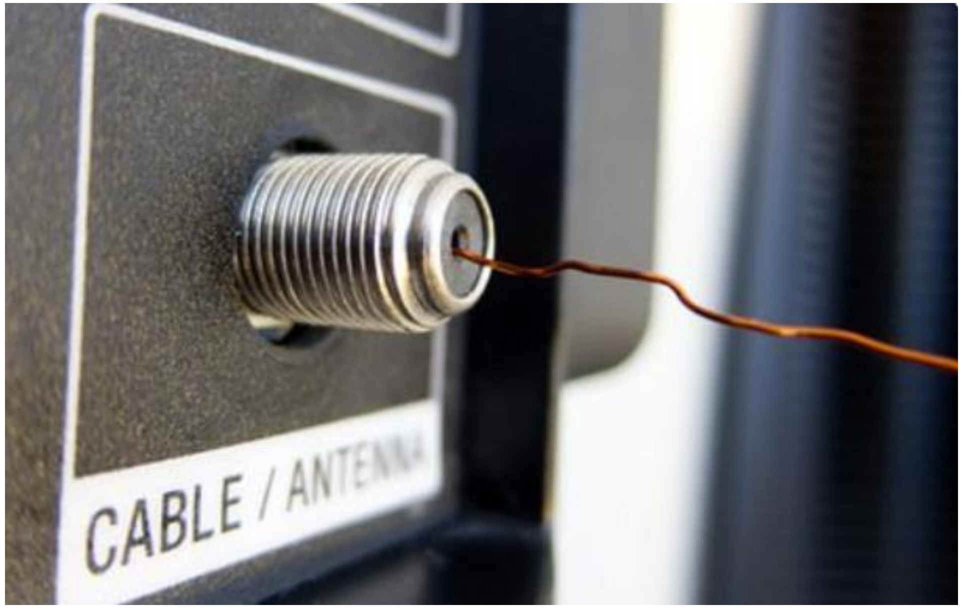


Reference compared to a mounting stand



Reference compared to the "shield"/outer conductor of a coax



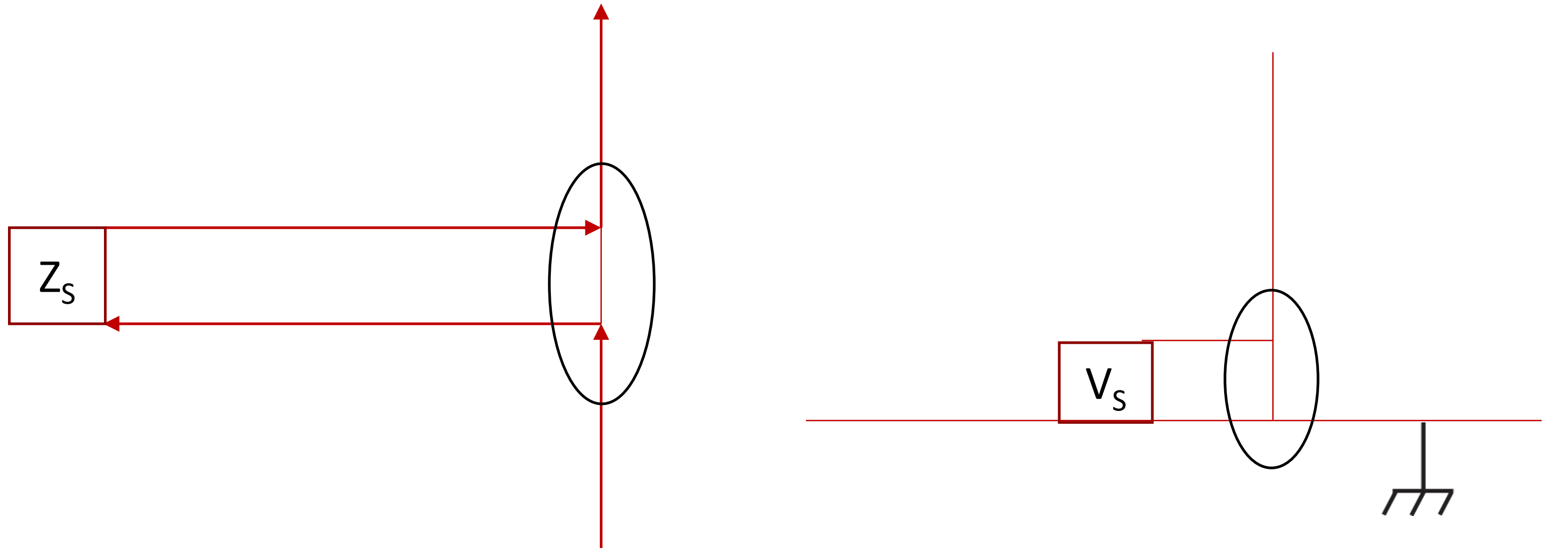
Monopole?

In this case the conductor (cord) of the power cable could easily have an RF potential compared to a circuit ground plane in the PCB, or a heat sink, or the housing of the power brick (if it's metal)

$$E = \frac{12.6 \times 10^{-7}(f * l * I)}{r}$$

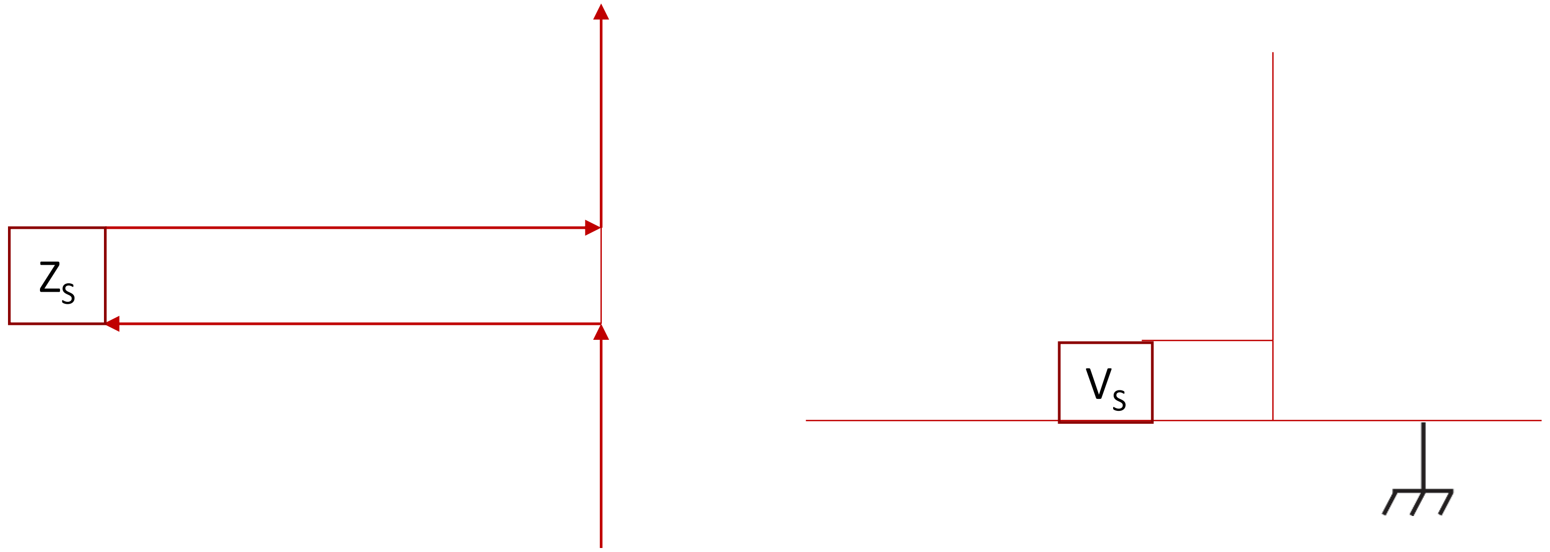
How to stop an antenna from radiating

The easiest way is to bring the two elements to the same potential, whatever that is, by shorting them together



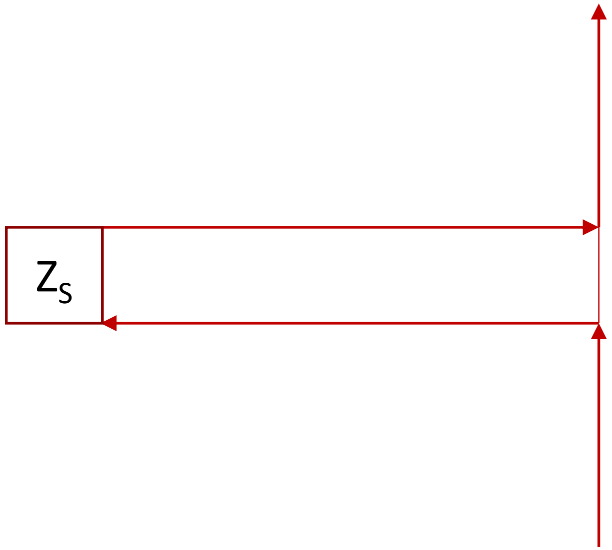
How to stop an antenna from radiating

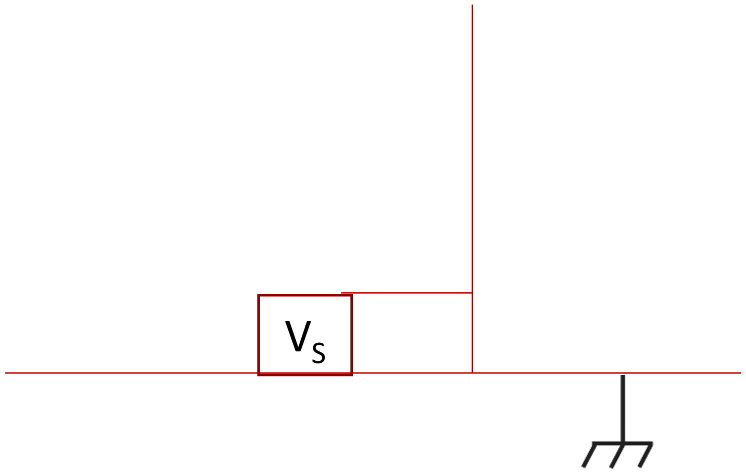
In the hand clapping analogy, we just duct taped our hands together—when they can't separate, they can't clap back together to make waves



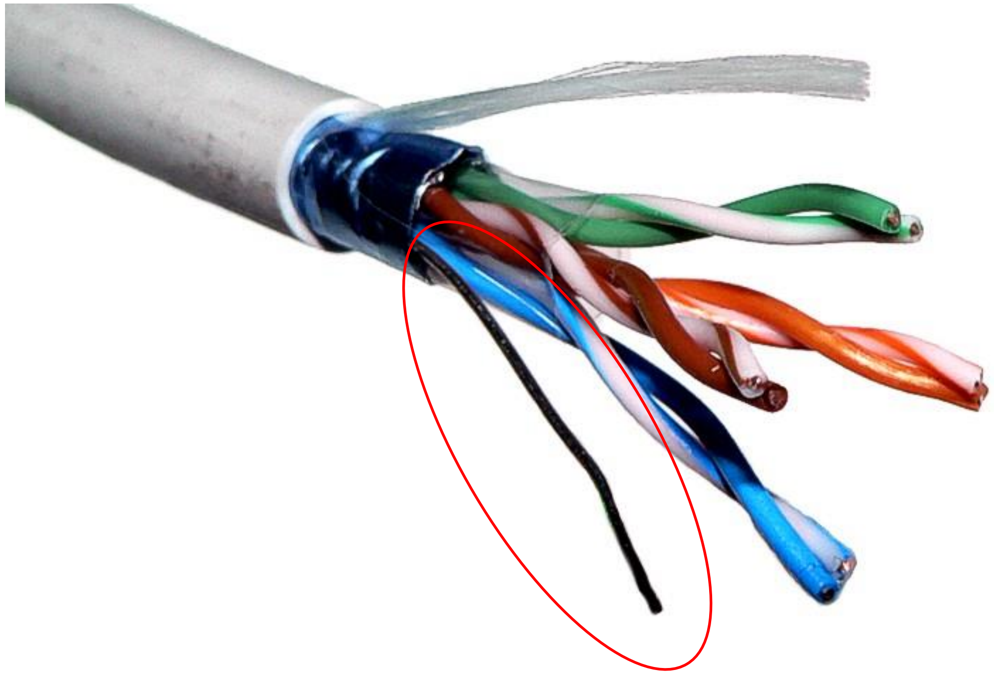
How to stop an antenna from radiating

This is why bonding and grounding are so critical for EMC success—keeping metallic elements at the same potential keeps them from becoming antennas



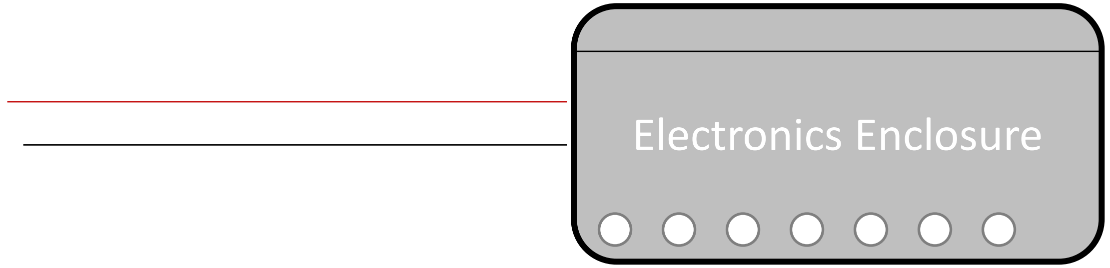


Good vs. Bad Bonding



Enclosures

Real enclosures generally have penetrations for I/O cables and power, vents for thermal control, and seams where lids can be removed for assembly/servicing



Insulated Surfaces

In this case the lid of the electronics box is painted, as is the box itself. When the lid is seated there will be an insulating layer between the metal elements—essentially forming a capacitor. With a significant impedance between the two pieces of metal, the assembly can start radiating in the presence of RF power

Insulated Surfaces

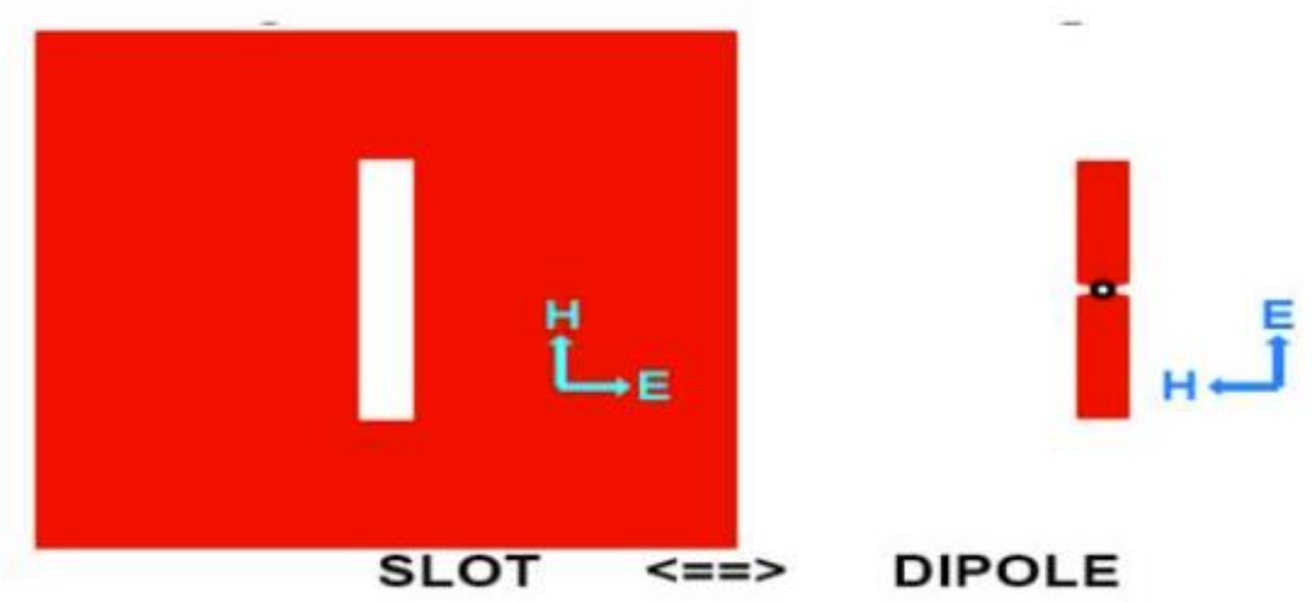
There's an easy fix on this box: sand the paint off the installation tabs and off the corresponding spots on the lid, allowing for solid metal-to-metal contact

Slots

Slots can be problematic for two reasons: 1) they can allow the ingress of EM fields; 2) they can act as antennas themselves

Babinet’s principle

Babinet’s principle: an aperture in a solid conductor will have the same impedance and produce similar fields (although with reversed polarity)



Slot antennas

As RF power is fed into this assembly by a transmission line, each slot in this marine radar will start radiating power as if it were a dipole antenna of the same dimensions. The array configuration gives more gain to the antenna system as a whole

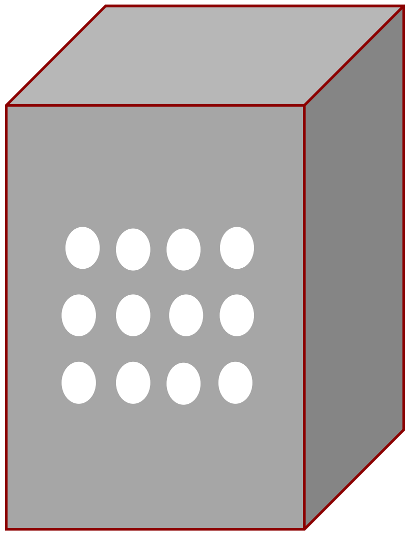
Public Domain

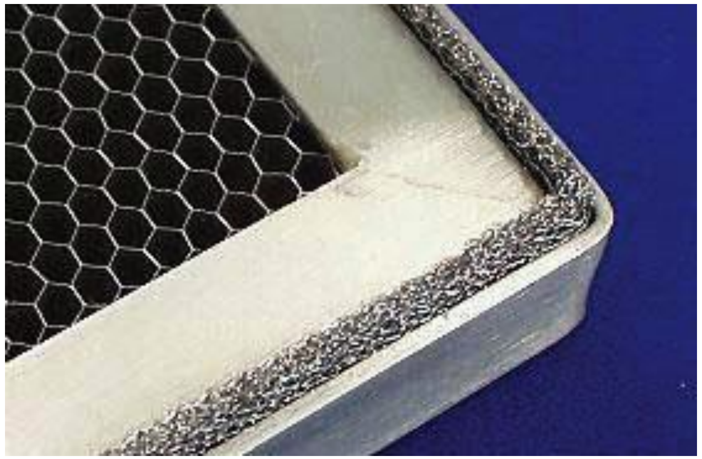
Vent antennas

In the wrong circumstances, these vents in our enclosure can act as an antenna array

Honeycomb

For EMC purposes an array of small holes (or honeycomb) is superior to long slots—each small hole will only radiate effectively at much higher frequencies which are less likely to be powerful



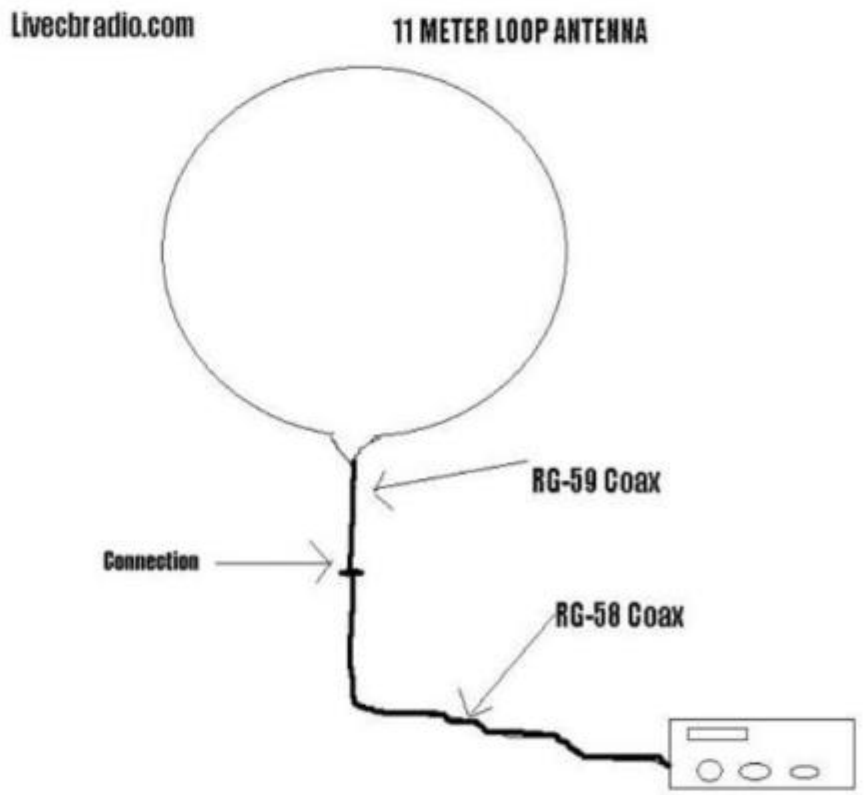


Loop Antennas

Along with dipole/monopole and slot antennas, the other most common form of intentional/unintentional antenna is the loop antenna

$$E = 263 \times 10^{-16}(f^2 A I_{dm})\left(\frac{1}{r}\right)$$

The electric field generated by a loop antenna is linearly dependent on the area of the loop (generally independent of loop shape—a rectangle is just as good as a circle for this relationship)

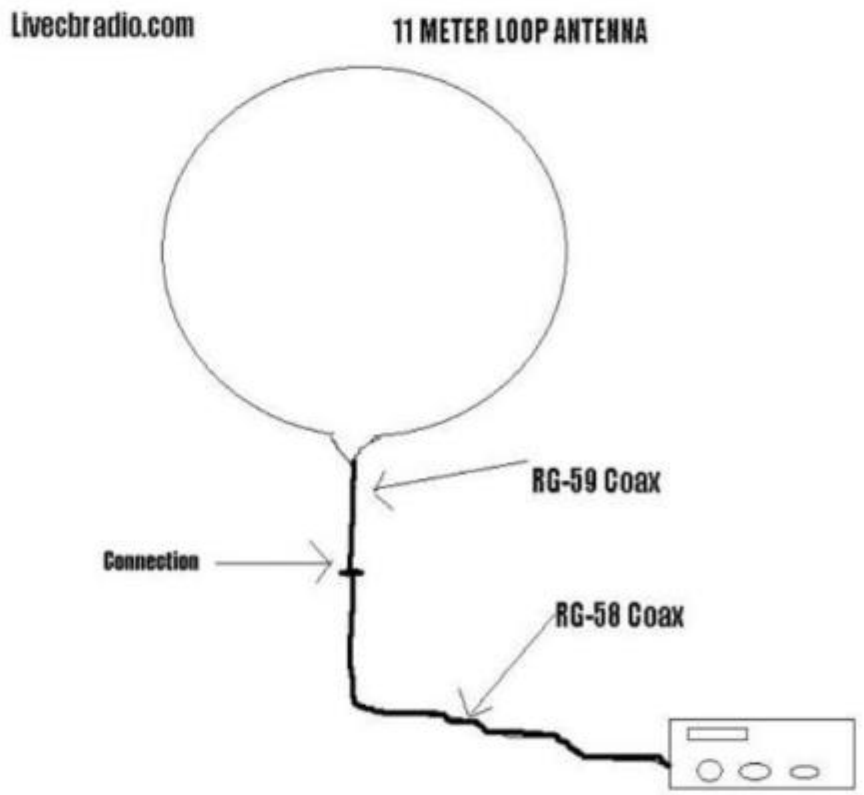


Loop Antennas

Along with dipole/monopole and slot antennas, the other most common form of intentional/unintentional antenna is the loop antenna

Loop: $$E = \frac{263 \times 10^{-16}(f^2 A I)}{r}$$

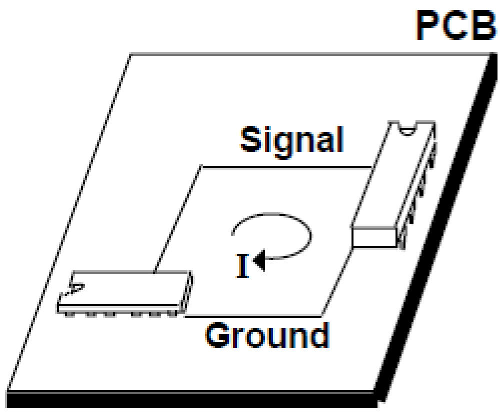
Dipole: $$E = \frac{12.6 \times 10^{-7}(f * l * I)}{r}$$



Collapsing loops

$$E = 263 \times 10^{-16}(f^2 A I_{dm})\left(\frac{1}{r}\right)$$

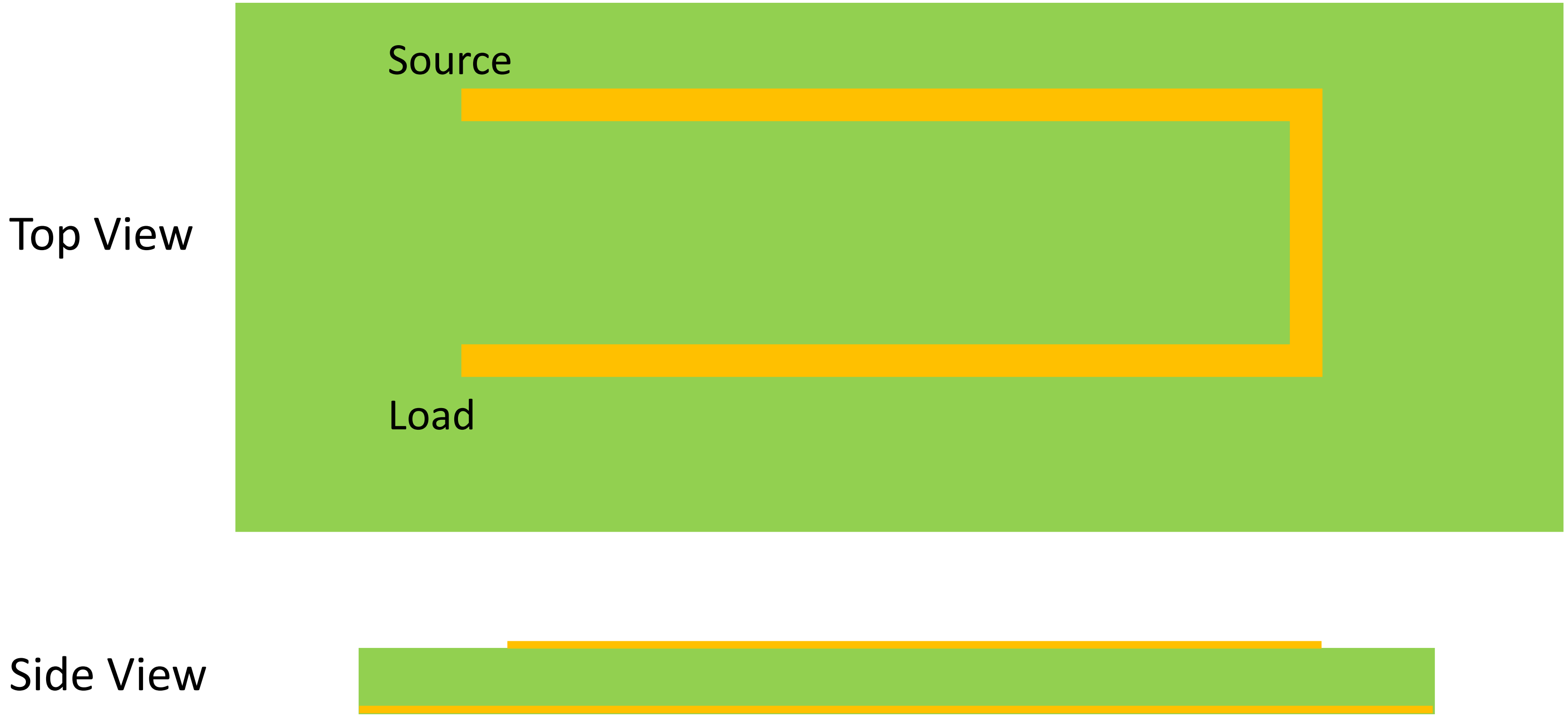
Digital, high-speed electronics have made this problem worse over time



Credit: Henry Ott, Invisible Antennas

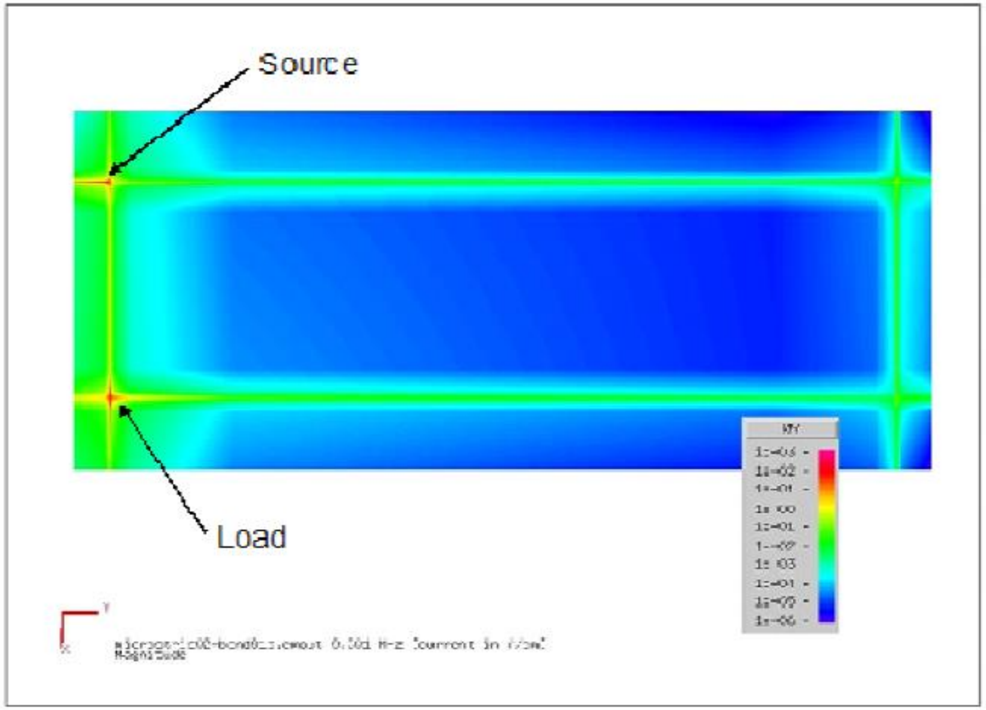
PCB Trace Return

When looking at a PCB trace (orange) over a reference plane (green), it starts to look very much like a microstrip transmission line at higher RF frequencies

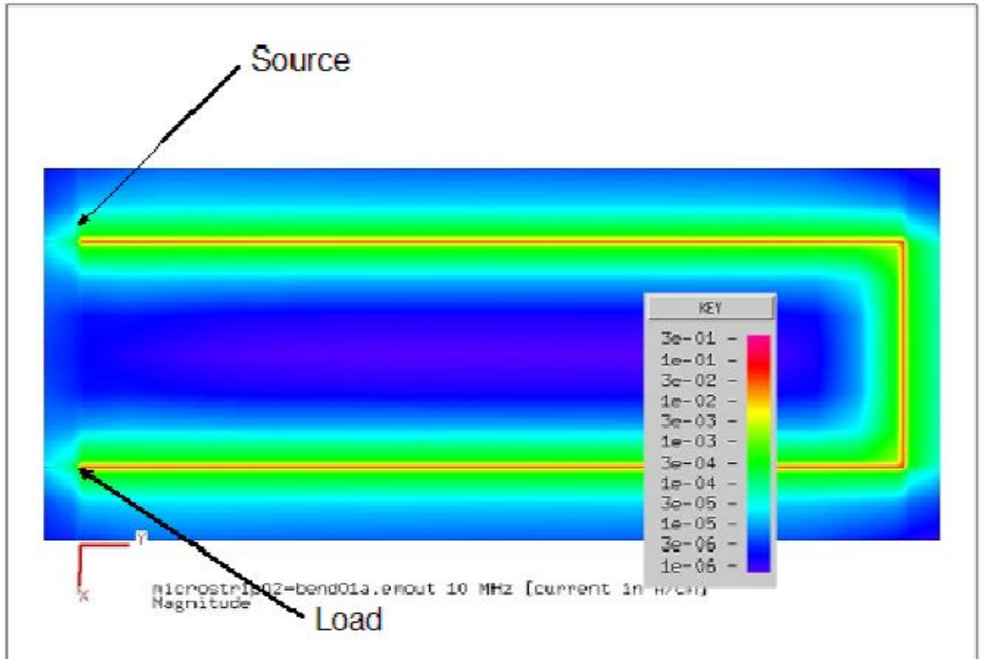


PCB Trace Return

And we can see that it contains and transmits power from RF signals very efficiently—much more efficiently than low frequency signals



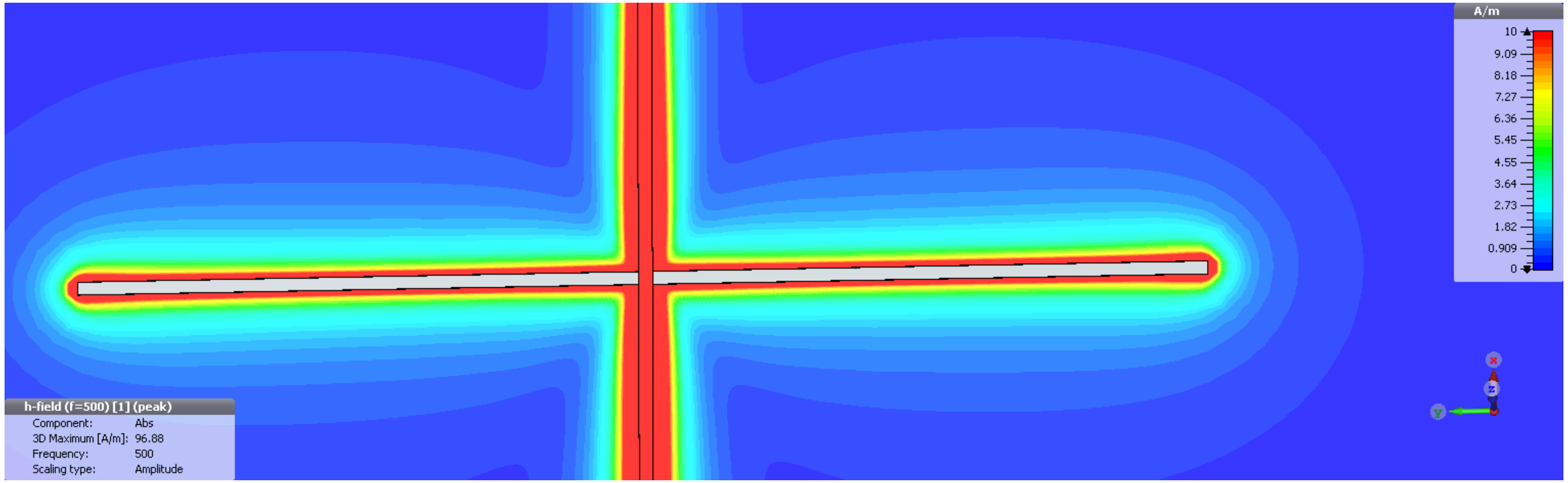
1 kHz
Mostly following the path of least <u>Resistance</u>



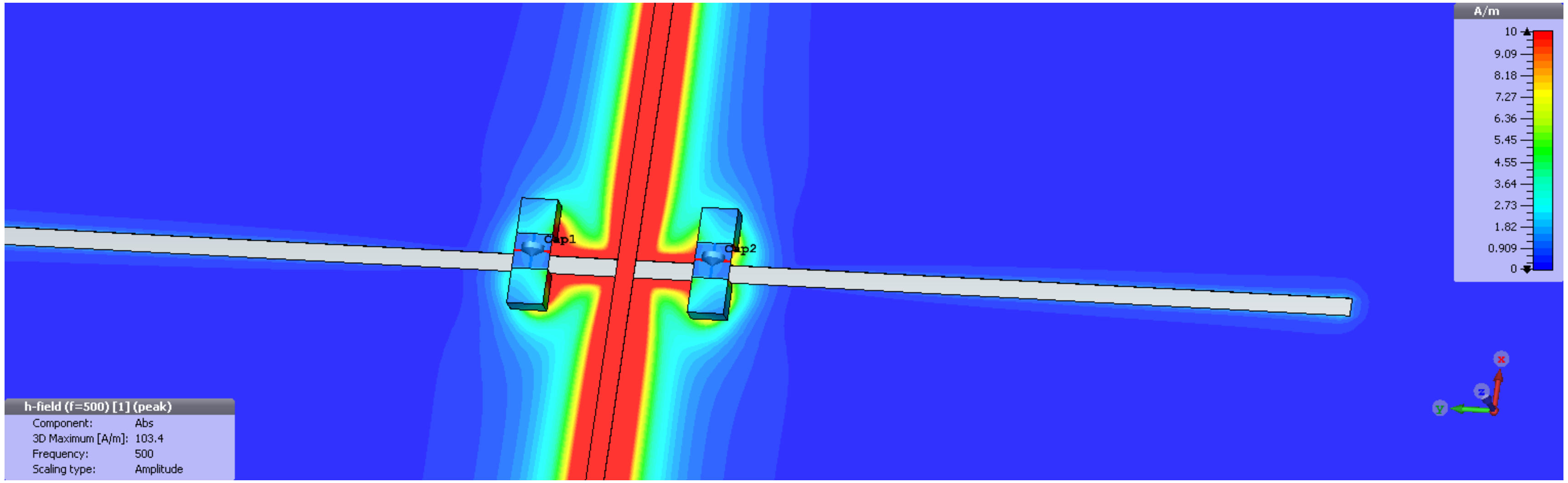
Used by permission of Bruce Archambeault, 2016

1 MHz
Mostly following the path of least <u>Impedance</u>

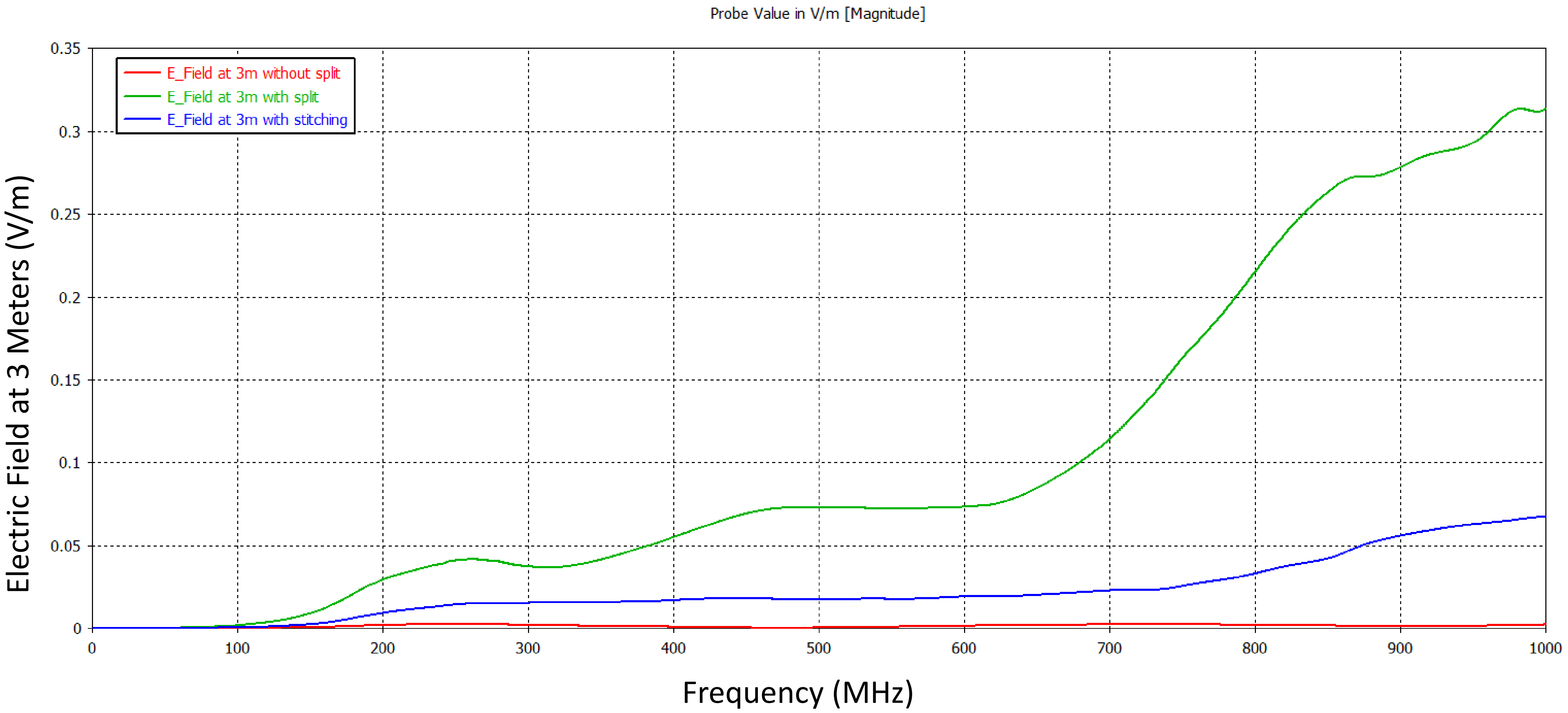
Trace Over a Slot – 500 MHz Signal



Stitching Capacitors Added

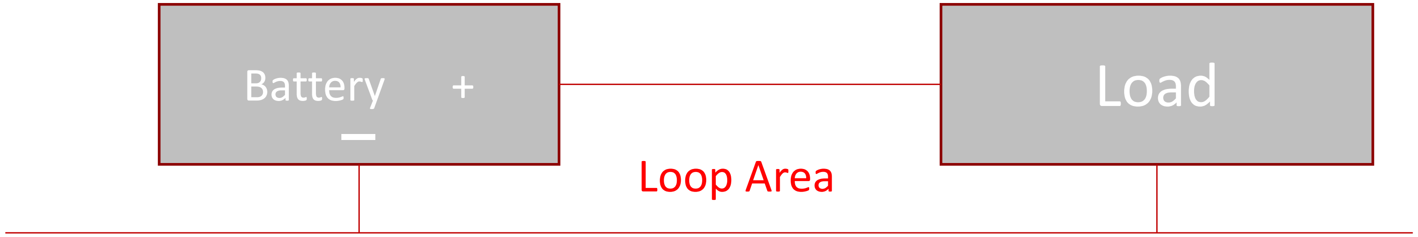


Traces Over a Slot – Radiated Emissions

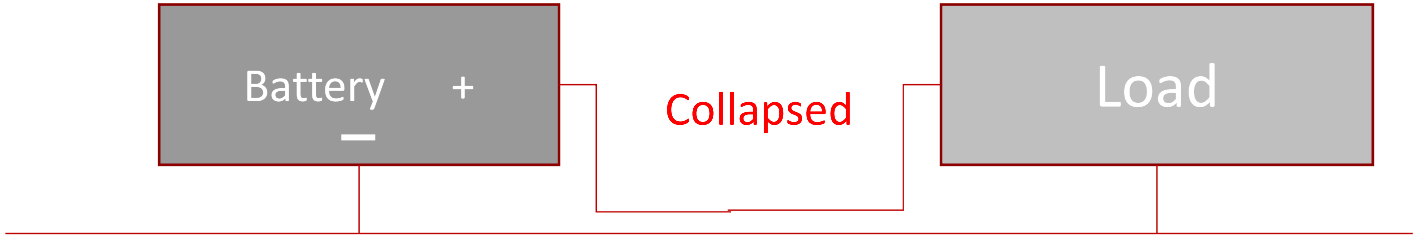


Collapsing Loops

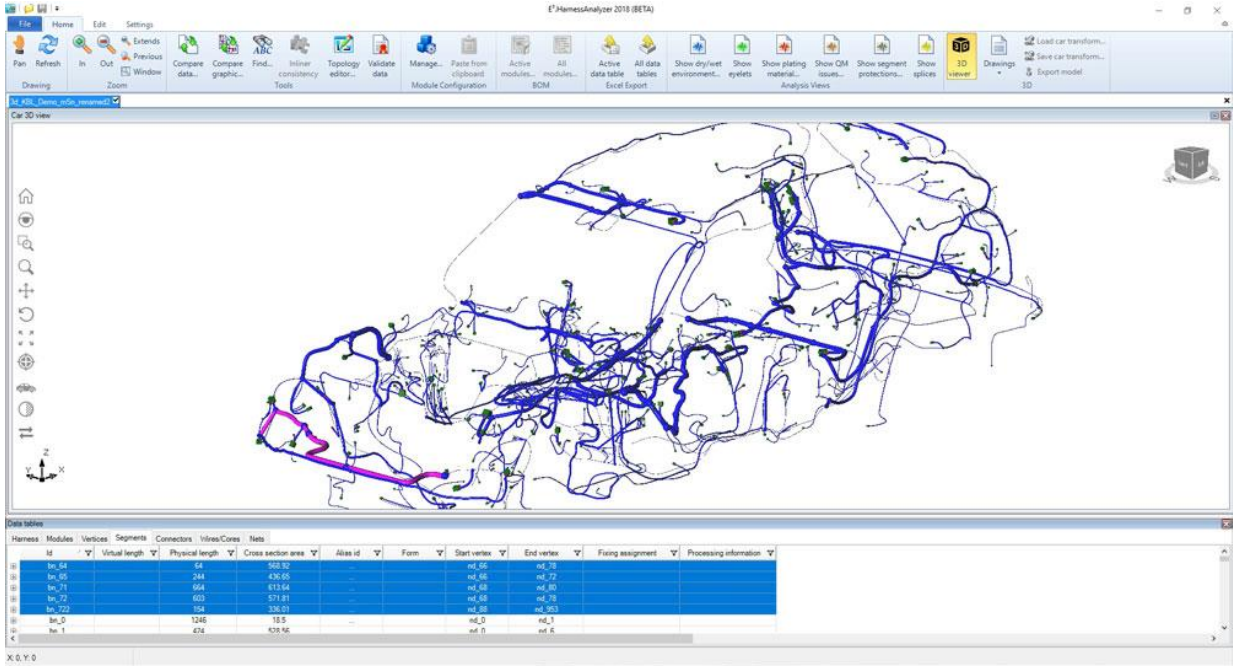
Vehicles using chassis as current return can be particularly vulnerable to this phenomenon



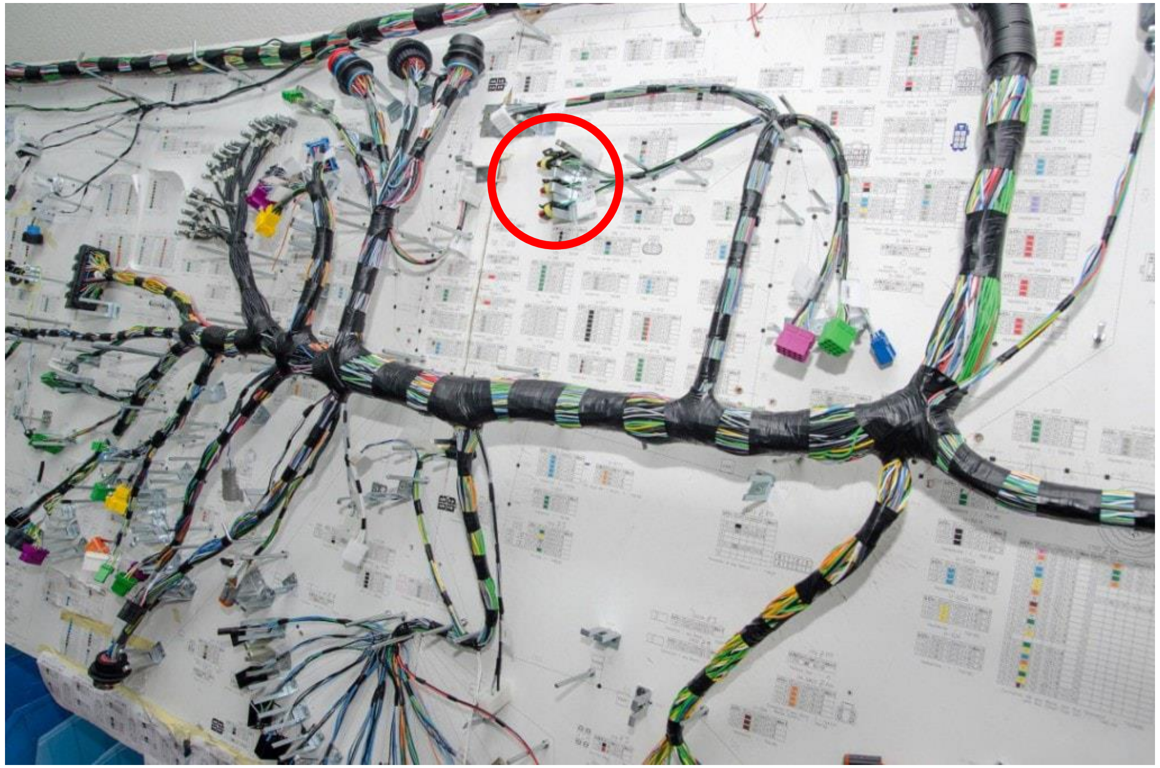
Keeping return connections as short as possible and routing power cables right next to the chassis can mitigate this issue



Vehicle Wiring



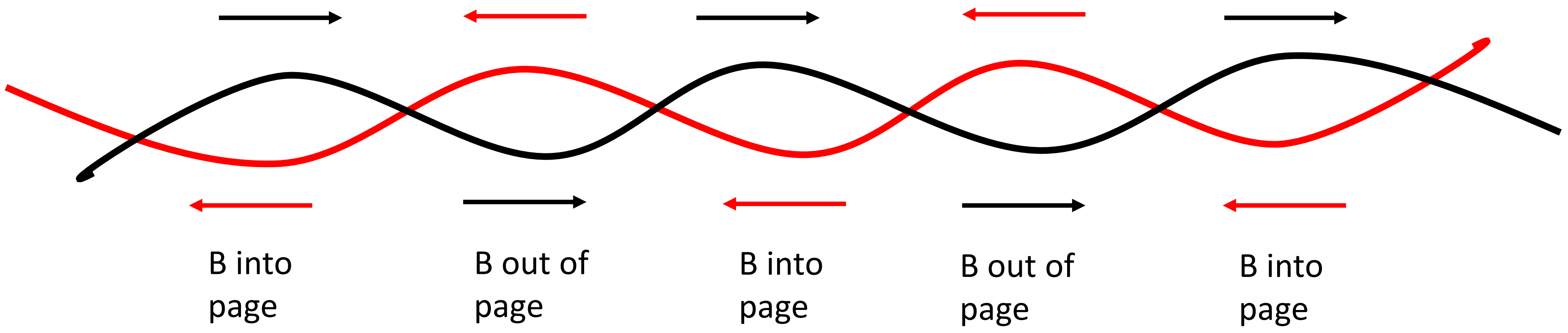
Source: Zuken



Source: AxesSim

Twisted Pairs

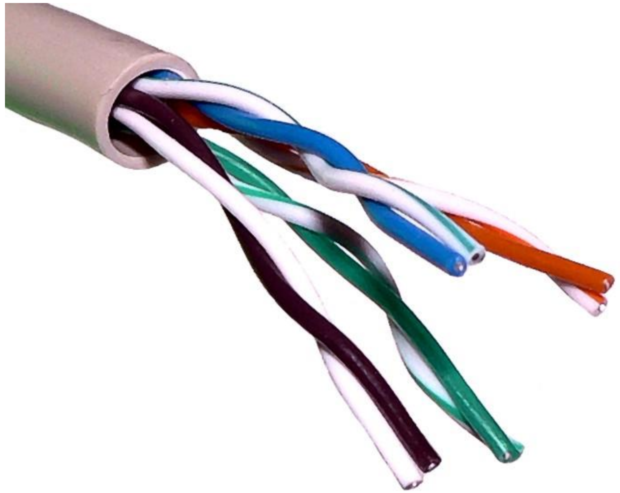
Twisting power + return together is even better: you get cancellation down the length of the cable, minimize any loops, and adjacent loops will tend to cancel each other out



Assuming the power and return currents are balanced (not always true), twisting will cut down on emissions and make the cable more robust to interference

Twisted Pairs

Digital communication lines, such as CAN, tend to be twisted unshielded pairs



Source: Wikipedia

Summary

- Any two pieces of metal with a RF potential between them can become a radiating antenna
- AC currents flowing in large loops can also become radiating antennas, whether on a large platform or a PCB
- Bond pieces of metal together to prevent them from becoming an antenna system
- Collapse loops that currents take to minimize their radiated emissions

Summary

- Any two pieces of metal with a RF potential between them can become a radiating antenna
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There are antennas hidden everywhere, but you can find them if you know what to look for

Questions?

- Karen Burnham, Principal Scientist
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- www.EMA3D.com
- Karen.Burnham@ema3d.com

Maxwell's Equations

$$B = V.\nabla A$$

$$E = V.vB - \dot{A} - \nabla\Psi$$

$$F = V.vB + eE - m\nabla\Omega$$

$$B = H + 4\pi M$$

$$4\pi J_{tot} = V.\nabla H$$

$$J = CE$$

$$D = \frac{1}{4\pi} KE$$

$$J_{tot} = J + \dot{D}$$

$$B = \mu H$$

$$e = S.\nabla D$$

$$m = S.\nabla M$$

$$H = -\nabla\Omega$$