Altium

ALTIUMLIVE 2018:
THE EXTREME IMPORTANCE OF PC BOARD STACK-UP

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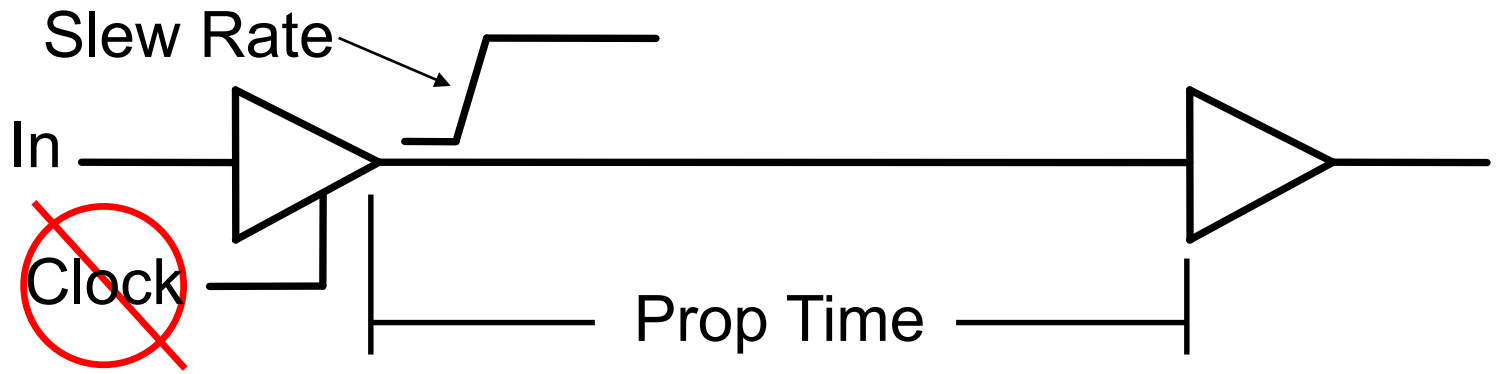
Circuit Behavior –

- From the 1950s into middle 1980s, Digital PC boards could be laid out in almost ANY manner.
- Yet seldom had Noise / Interference Problems…. Why?
- Because frequencies were SO Low that every circuit was a Lumped Length Element.
- The circuits we put on PC Boards are –
  - A Lumped Length at Low Frequencies
  - A Distributed Length at High Frequencies

Circuit Behavior –

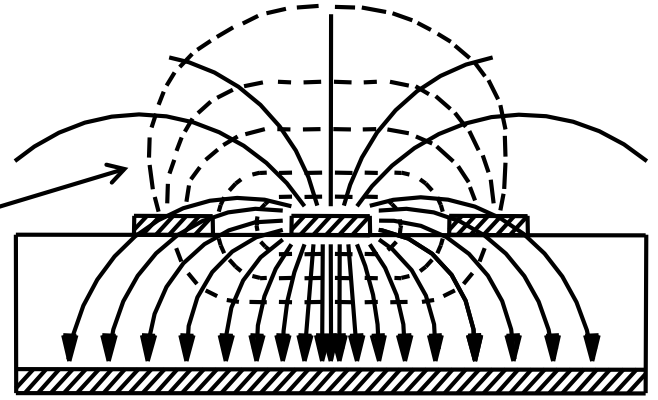
- Thinking in terms of the propagation time and slew rate (Rise Time) of a circuit –



- Lumped Circuits have Long Rise Time Compared to Propagation Time
- Distributed Circuits have Long Propagation Time Compared to Rise Time

Circuit Behavior –

- Inductance is an Impedance to Change in Current Flow Caused by the Mass of the Magnetic Field.
- Keep Field Volume Low, Energy in the Field is mostly Contained and Inductance will be Low.



- Tight Coupling between Forward and Return path are the Secret to Low Inductance and to Low Field Volume.
- To keep Capacitance High… Same thing, Tight Spacing.
- Doing this minimizes the Spread of Both E & H Fields and creates Low Impedance Paths and Low Inductive Losses.

Circuit Behavior –

- What is Energy? The property of matter that manifests itself as the capacity to perform work (Motion or Interaction of Molecules).
- Energy exists in many forms –
  - Mechanical
  - Sound
  - Light
  - Electrical
  - Heat
  - Etc.

Circuit Behavior –

- Where is Energy in a Circuit?
  - In the Voltage?
  - In the Current?
  - Neither ……

    …… Energy is Mostly in the Fields!!!

  - Better known as the Electric (E) and Magnetic (H or M) Fields!!!

Circuit Behavior –

- Where are the Fields Located in a Circuit?
  - In the Traces?
  - In the Planes?
  - Neither ……

    … in the space between the Trace and Plane…. in the Dielectric!!!

  - That's Right… the Energy in a Circuit travels in the Plastic and Fiberglass material of the PC Board, NOT in the Copper!!!

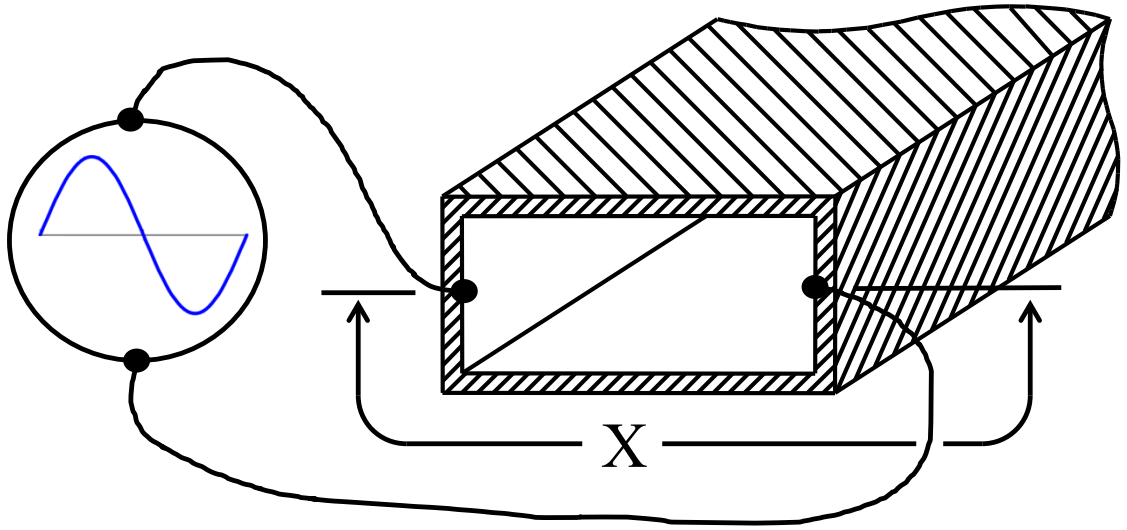
Circuit Behavior –

- The Energy (E & H/M Fields) in a transmission event is called a Wave, an Electro-Magnetic Wave.
- The Traces or the Trace and Plane that make up the Transmission Line steer the Energy from Point ‘A’ to Point ‘B’.
- These copper elements act as a Wave Guide!!!

Circuit Behavior –

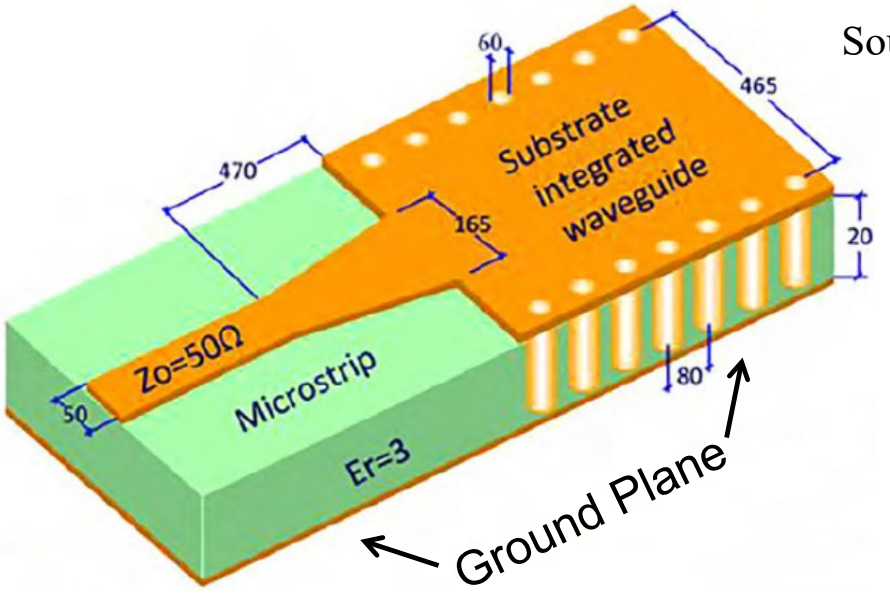
- What is this? …… A Wave Guide!

- Apply a Wave whose ½ Wavelength is equal to distance ‘X’, we have perfect balance and a True Wave Guide



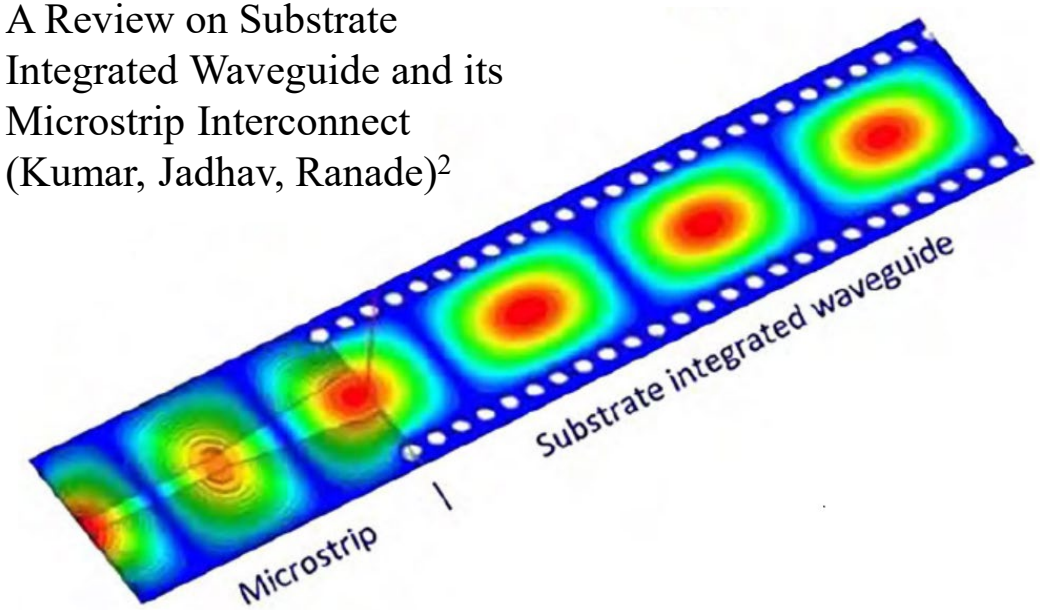
Circuit Behavior –

- Microstrip Fed, Substrate Integrated Wave Guide –



Units: Mils
Copper: 1/4oz
Not to Scale!

Source: iCD Pty Ltd (Olney)[1]
A Review on Substrate Integrated Waveguide and its Microstrip Interconnect (Kumar, Jadhav, Ranade)[2]



Both Microstrip and SIW are Wave Guides!!!

Circuit Behavior –

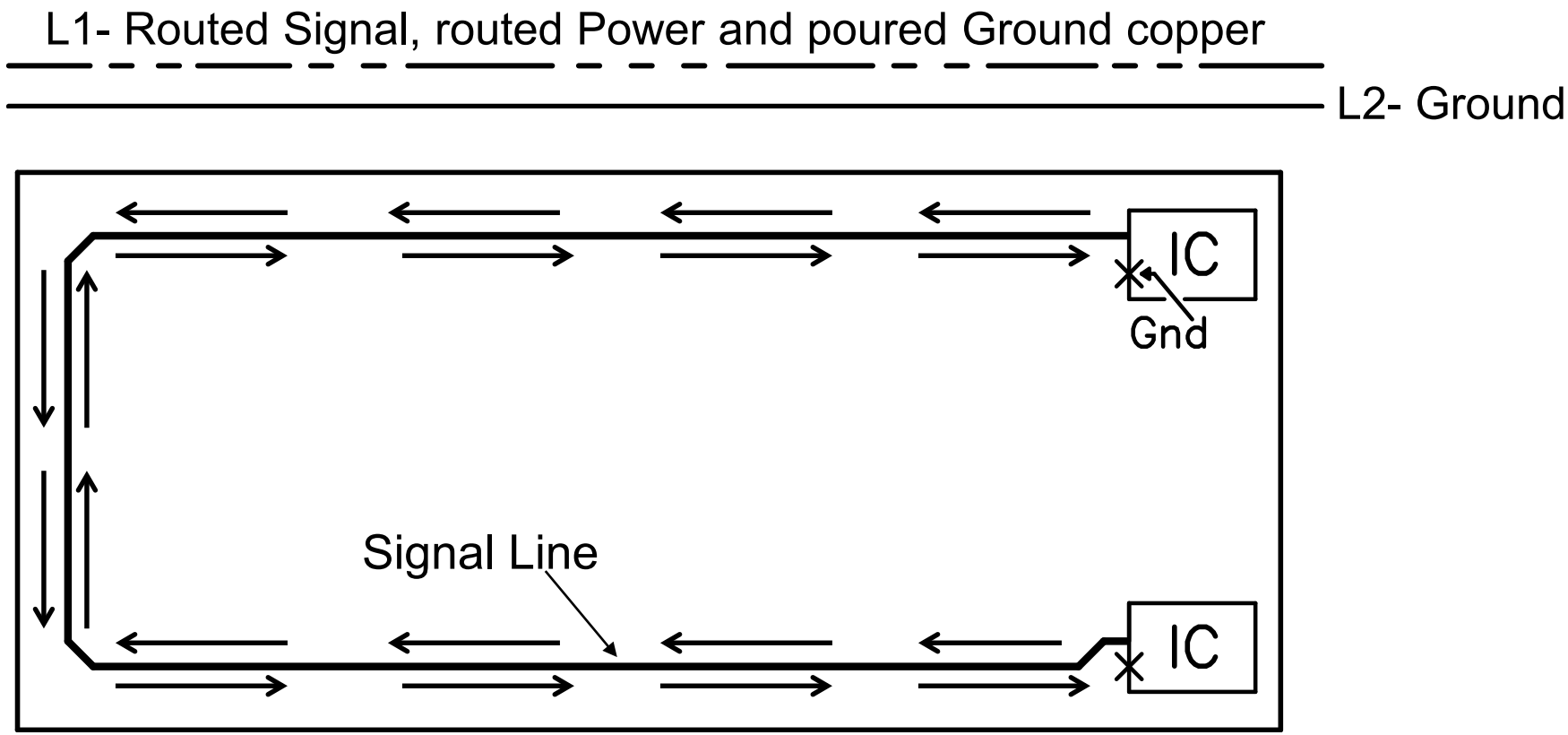
- Whenever we route a Trace on some layer of a PC board, we are routing Half of a Transmission Line (Half of a Wave Guide).

- The ‘Return’ side of the Transmission Line is the return plane, or in some cases, the return trace.

- If we fail to fully understand how to setup the Return Side of the Transmission Line, we create Field Spread and put our circuits in ‘Harm’s Way’ with regard to Noise or Interference. (In other words, if we do not contain fields, we are ‘Toast’)

Circuit Behavior –

- 2 Layer PC Board



Where does the Signal's Return Current Flow?

Circuit Behavior –

- Which of these PCBs Radiates Least, which Radiates Most?

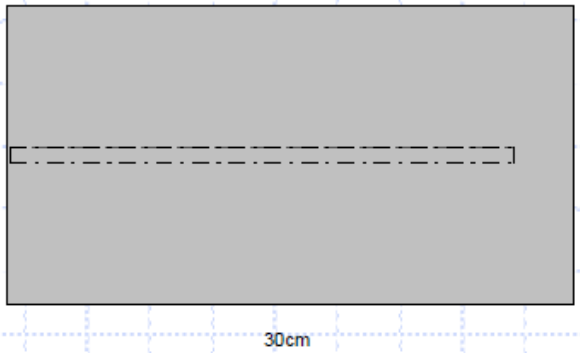


Fig 1. case 1

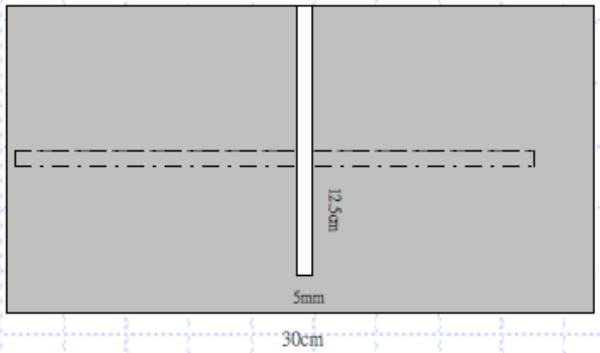


Fig 2. case 2

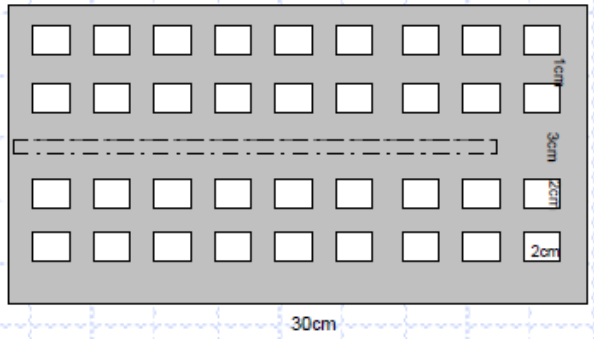


Fig 3. case 3

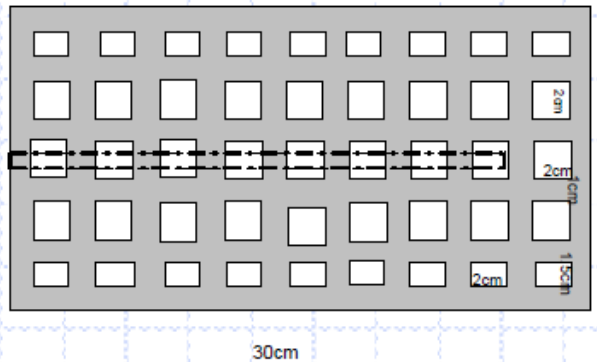
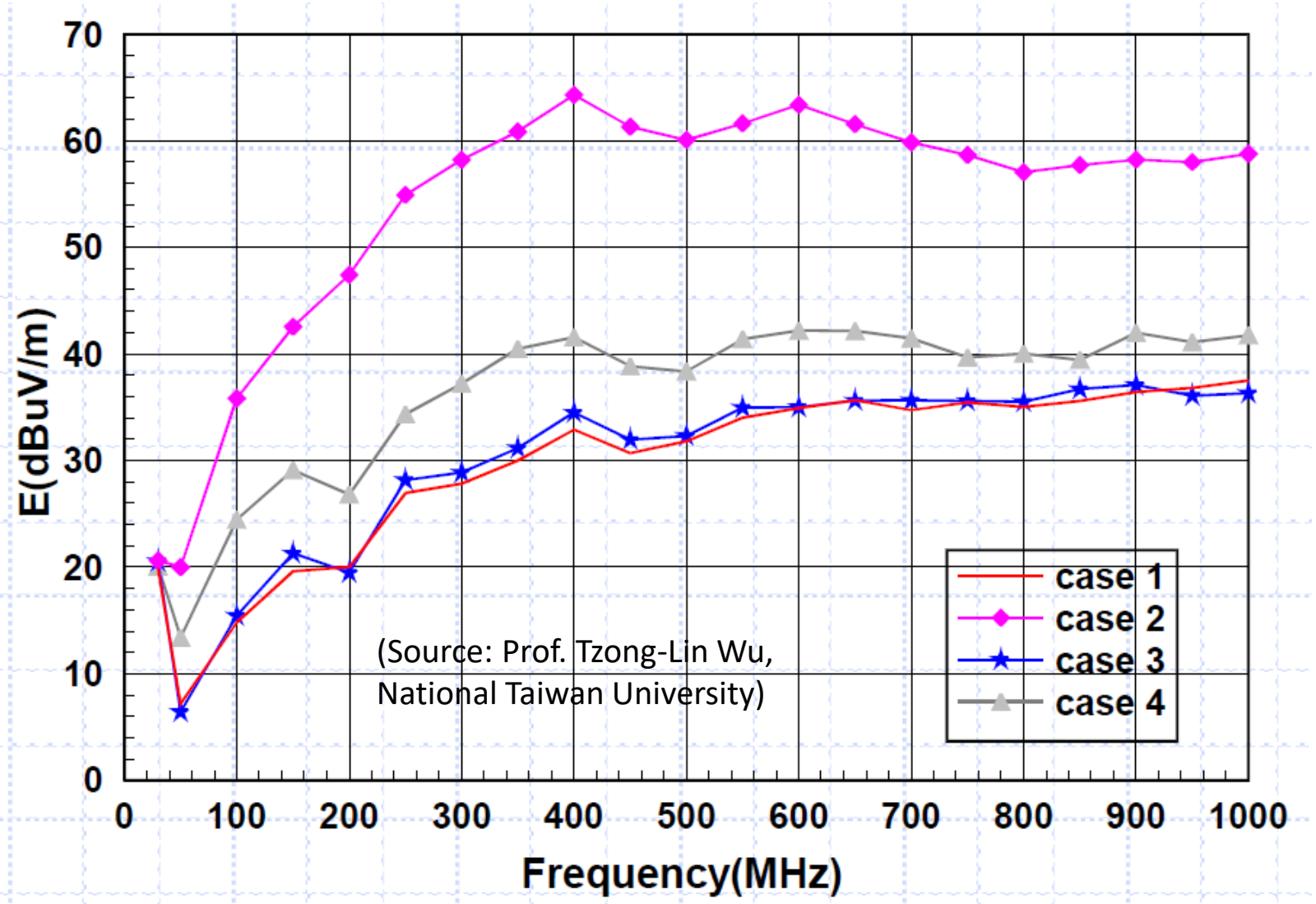


Fig 4. case 4

(Source: Prof. Tzong-Lin Wu, National Taiwan University)

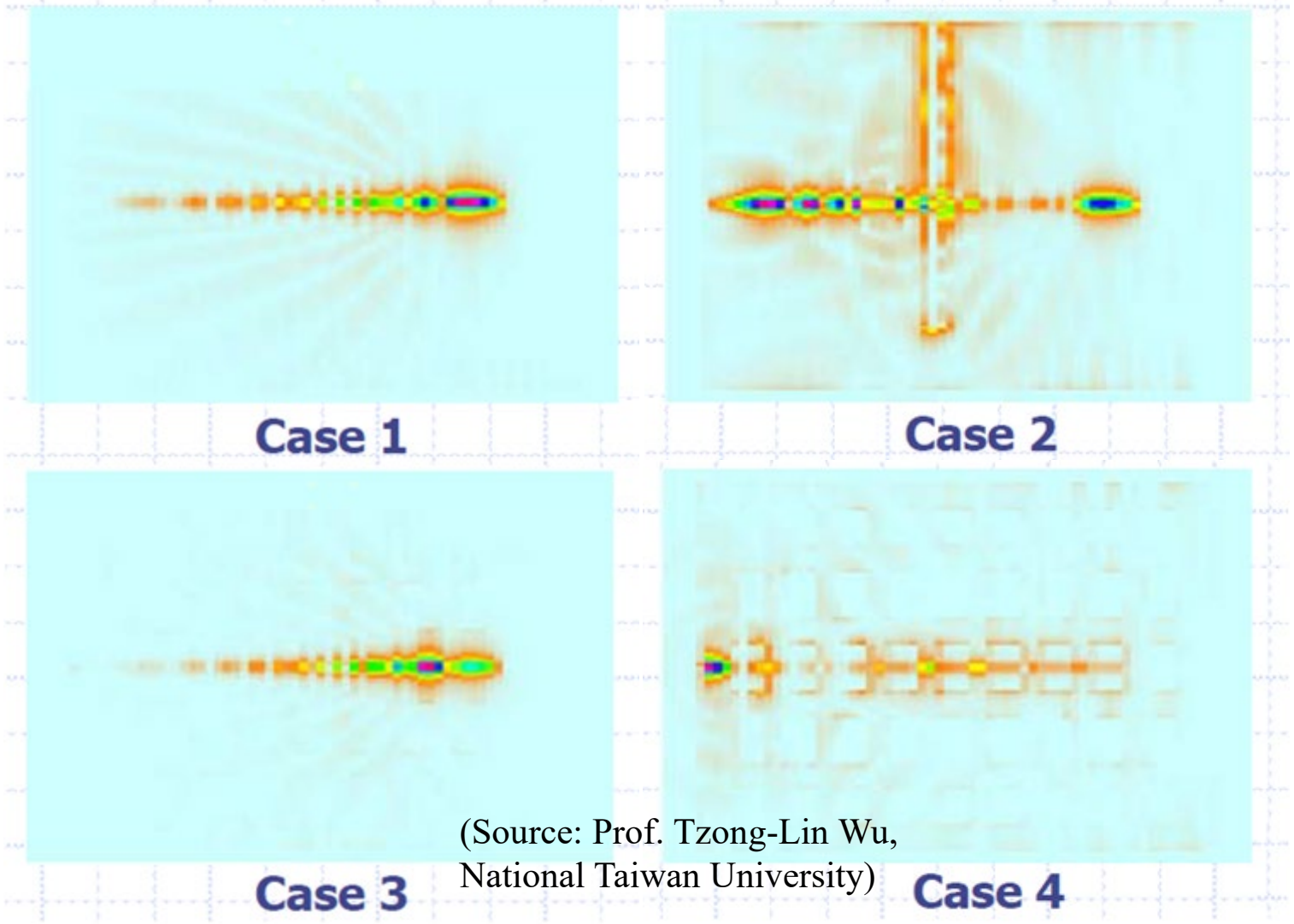
Circuit Behavior –

- EMI Signatures-



Circuit Behavior –

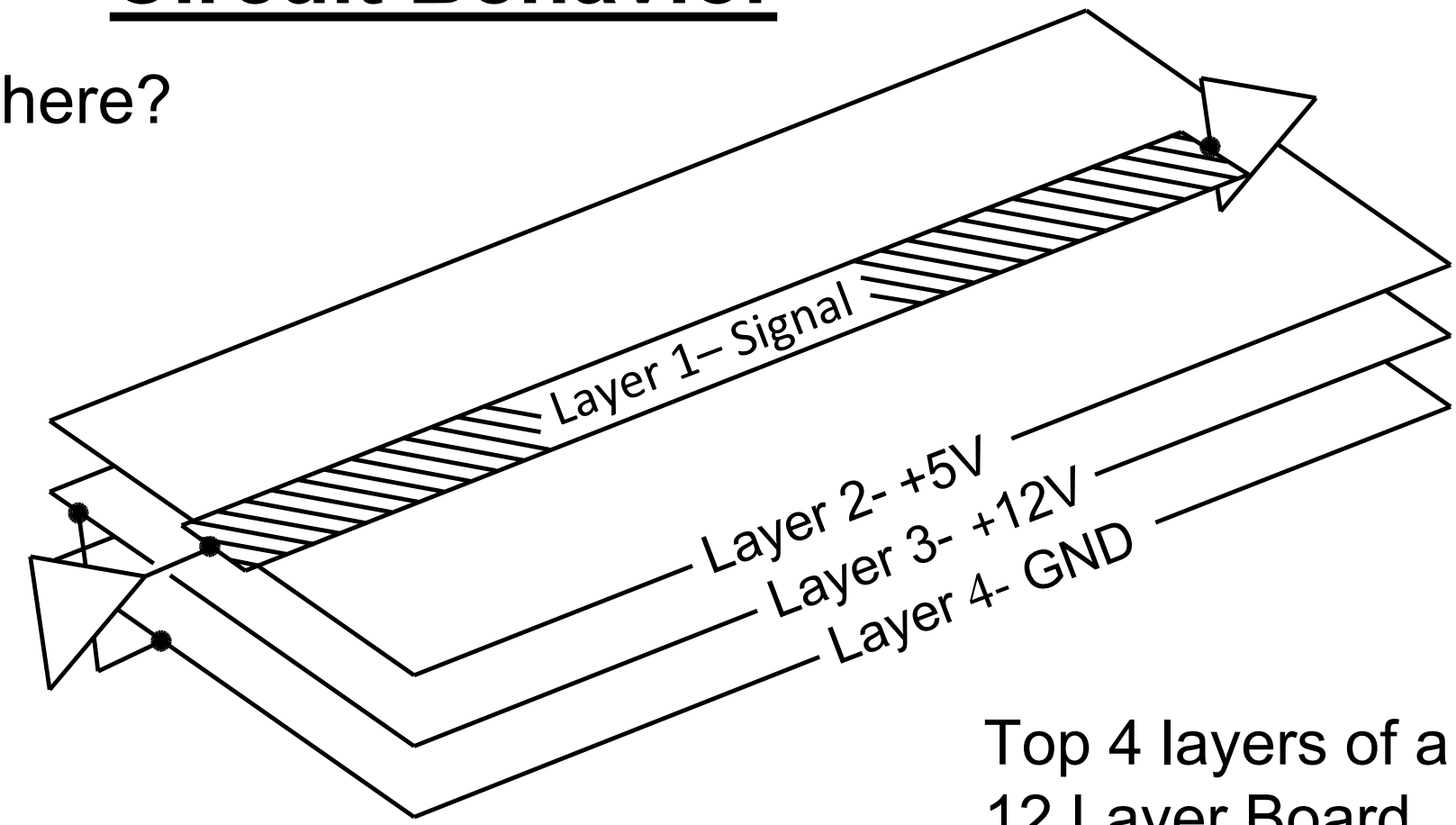
- Current Patterns from each Scenario-



(Source: Prof. Tzong-Lin Wu, National Taiwan University)

Circuit Behavior –

- What is Wrong here?
- IC powered by +12V & Gnd –

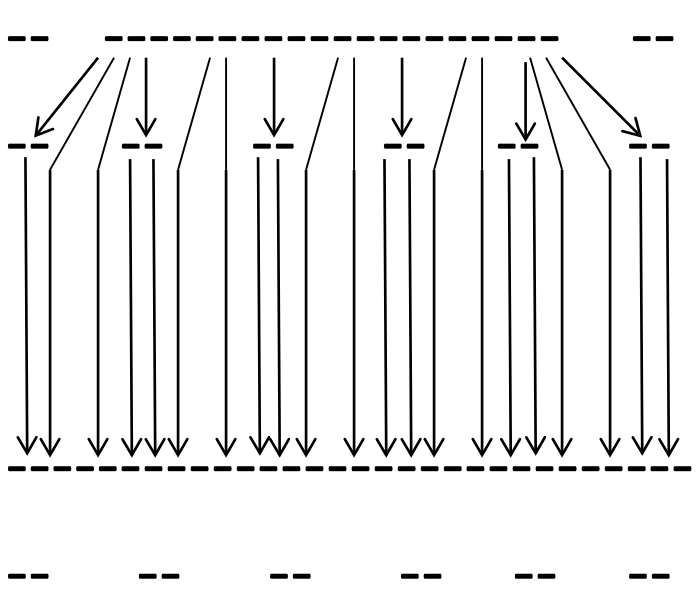


Top 4 layers of a 12 Layer Board

- Where is the Return Current?

Circuit Behavior –

- What's Wrong with this Board Stack-up???



Signal – Layer 1

Signal – Layer 2

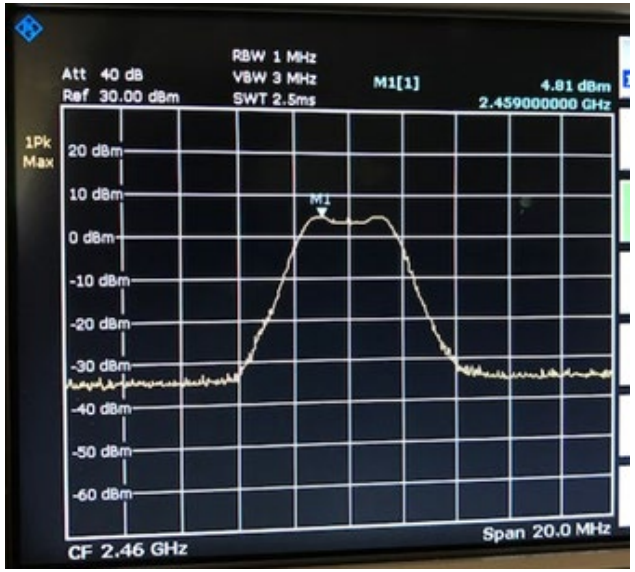
Ground – Layer 3

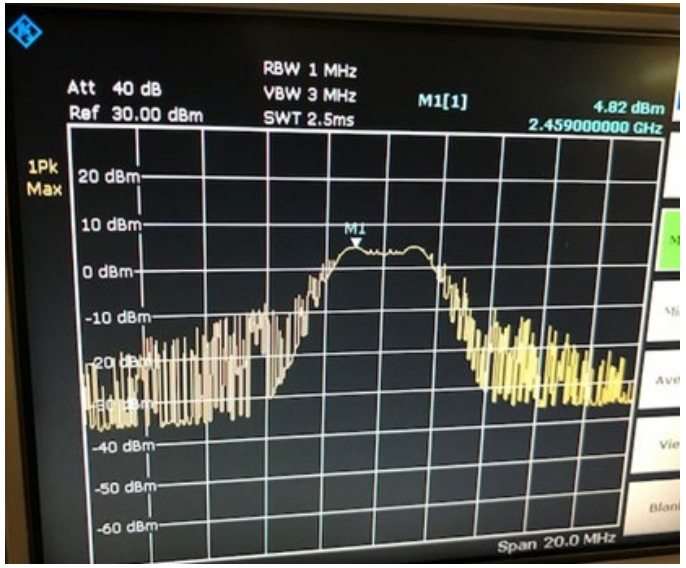
Signal – Layer 4

- The fields associated with the signals on layer 1 will couple to and through layer 2, and to the plane on layer 3, causing coupling between the fields from layer 1 and layer 2…… serious potential EMI issue!!!

Circuit Behavior –

- Analog Circuit Output, when functioning as intended –





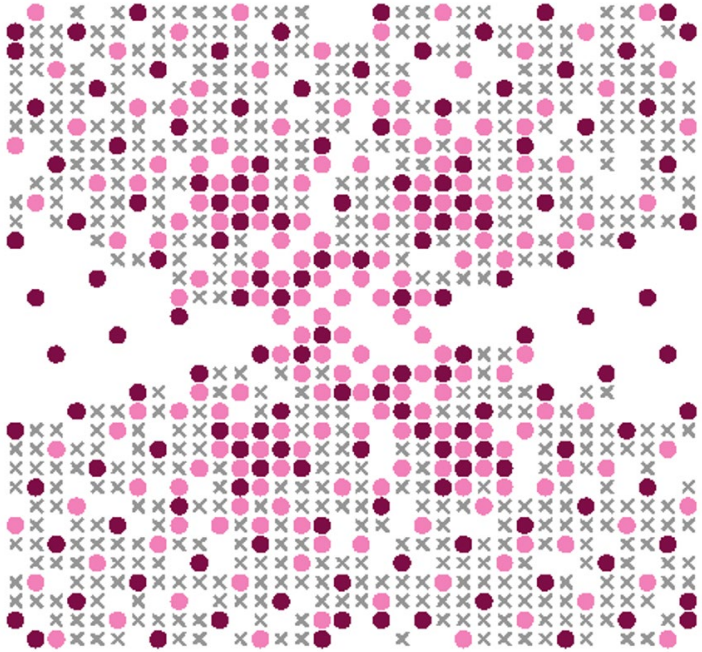
- When a second circuit on the PCB is sampling an accelerometer, output of first circuit looks like this!!!!!!

- This PCB used the stack-up on the previous page (sig, sig, gnd, sig).
- PCB that eliminated the problem used a high quality 6 layer stack-up, described later in this presentation.

Circuit Behavior –

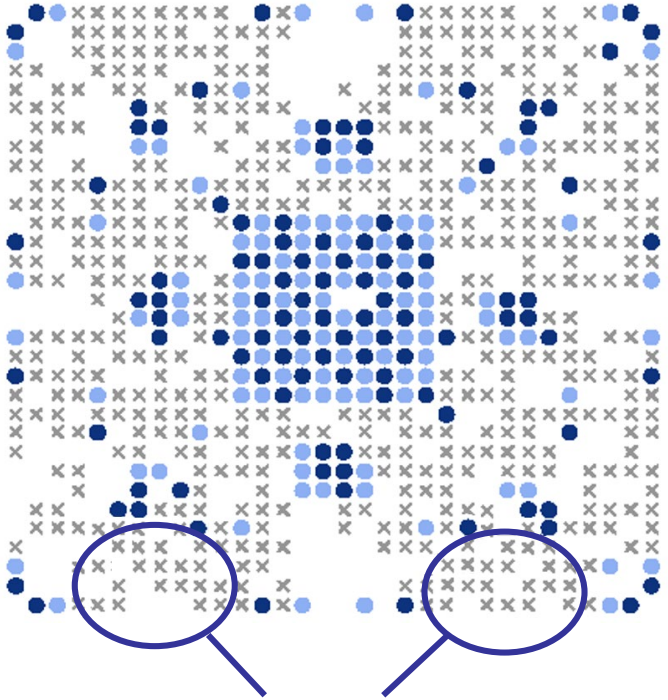
- Though much better than many devices, IC on right is far less than ideal.

Xilinx Vertex-4 FF1148



Returns Spread Evenly

Altera Stratix-2 F1120



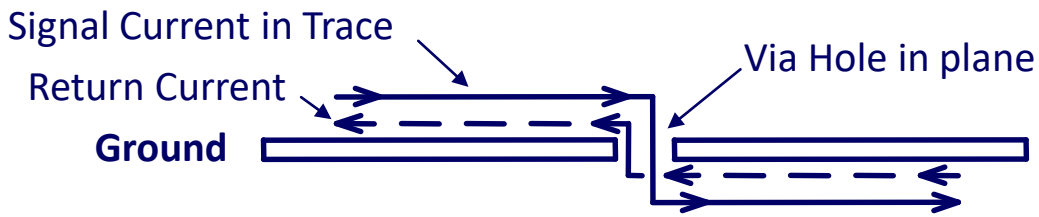
Many regions devoid of Returns

- The F1120 has 5X Greater signal interference than the FF1148

(Source: BGA Crosstalk - Dr. Howard Johnson)

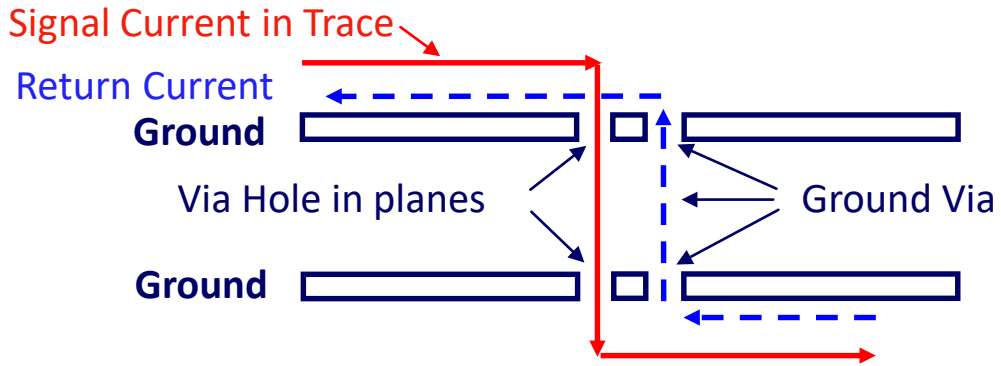
Circuit Behavior –

- When moving energy between layers, route on either side of the same plane, as much as possible!!!



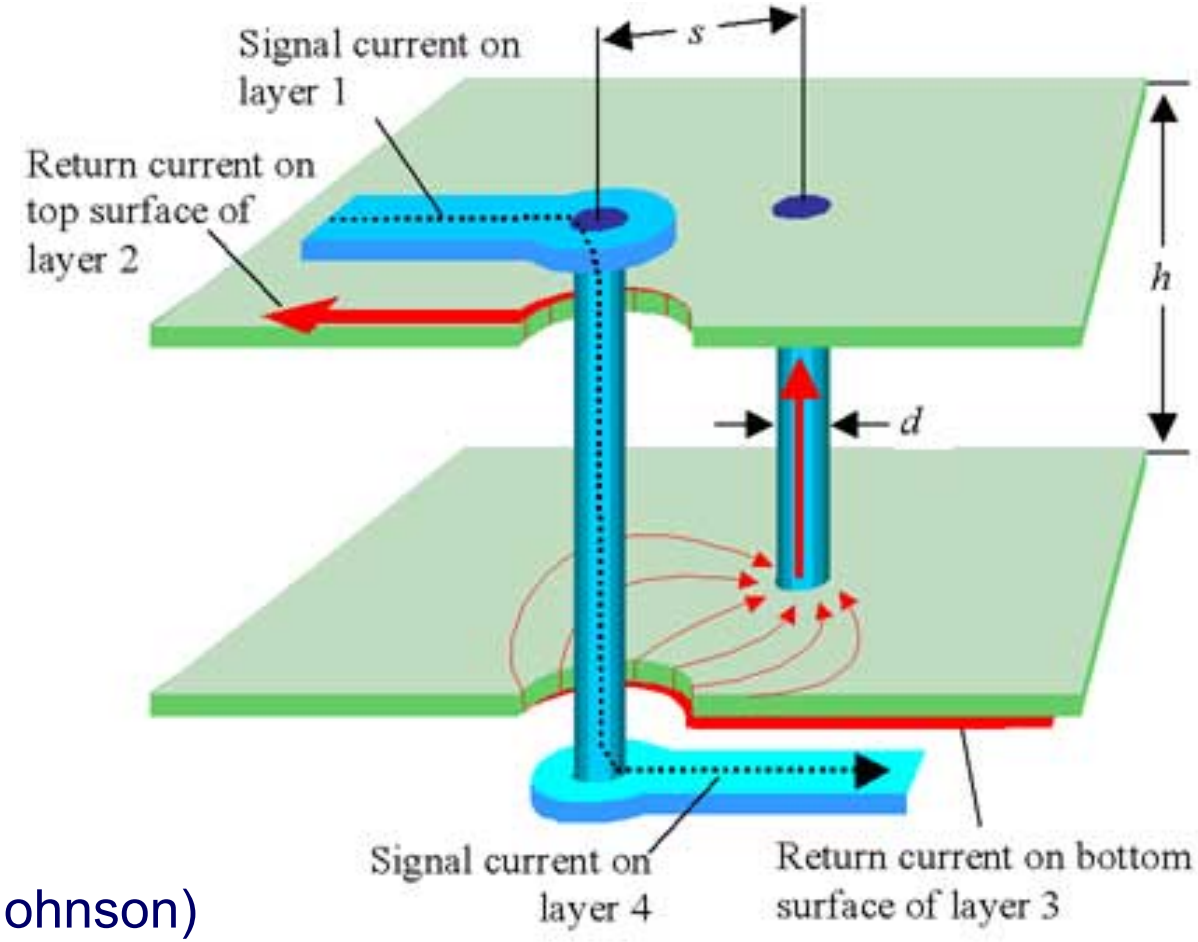
Picture:
Susy Webb

- When moving energy between 2 Ground Planes, use a transfer via VERY near the Signal via.



Circuit Behavior –

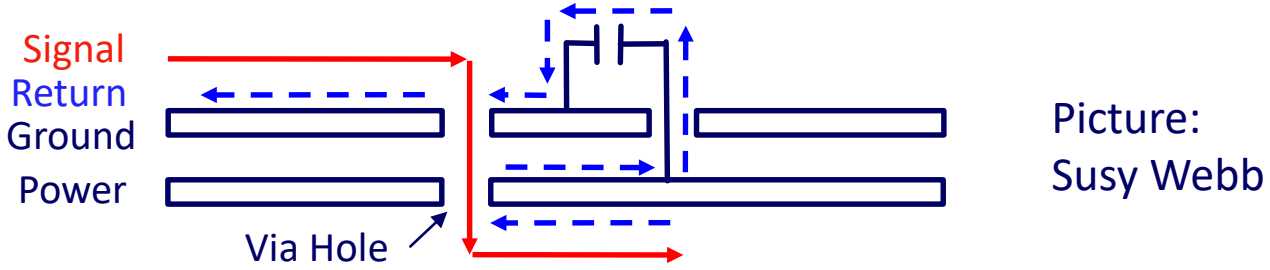
With ‘Ground Vias’ Bridging Planes, Loop Area between Forward and Return Path is contained and Field Spread is Minimized!!!



(Source: Dr. Howard Johnson)

Circuit Behavior –

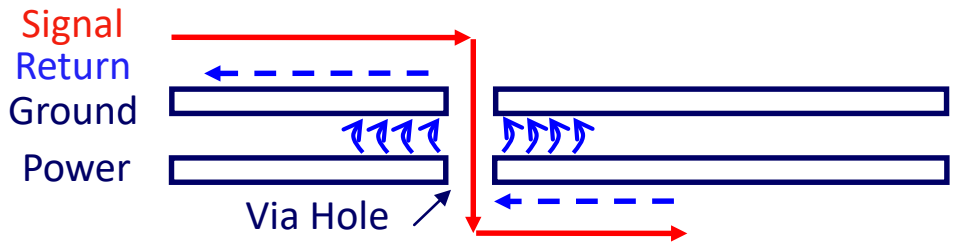
- When moving energy between a Power Plane reference and a Ground Plane reference –



- Only Return Current below 250ish MHz will travel through the local decoupling capacitors.
- At very high frequencies Capacitors are basically an Inductor.
- Beyond 200 to 300 MHz we need to find another path to move return current.

Circuit Behavior –

- Where does the return current above 200ish MHz travel during a Power-to-Ground layer change?
- High frequency ‘Returns’ form a displacement current through the natural capacitance formed by the Power and Ground Planes.

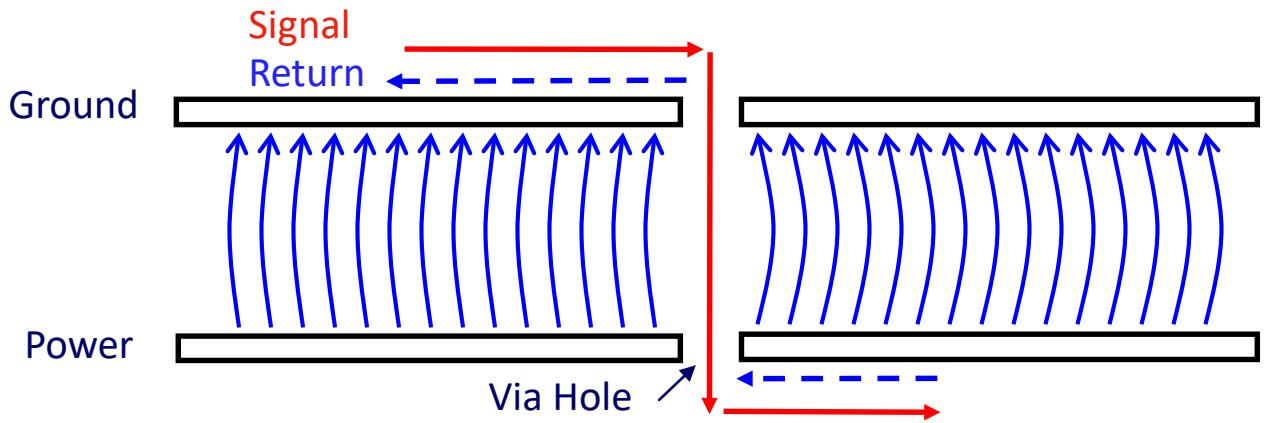


- This is acceptable when Power-to-Ground plane separation is reasonably small- ie: 0.2mm / 0.008”… or Less!!!

  Preferably Less!!!

Circuit Behavior –

- When routing signals from a Power reference to a Ground reference, with Widely Spaced Planes (ie: Conventional 4 Layer Board) –



- To form sufficient Displacement Current, Fields must spread over a fairly Wide Area, coupling energy into ALL other Vias and Traces in the area.

Circuit Board Stack-up –

- What is Wrong with this 62 mil thick (1.6mm) Board Stack-up???

-- -- -- -- -- -- Signal – Layer 1

---------- Power – Layer 2

---------- Ground – Layer 3

-- -- -- -- -- -- Signal – Layer 4

- MANY things …… Most severe are –
- Poor Field Containment when Signals Change Layers.
- Poor Power Delivery to ICs at High Frequencies.

Circuit Board Stack-up –

- What is the Solution to the 62 mil (1.6mm), 4 Layer Problems?

(A) ----Ground-----
----Sig/Pwr-----

(Core)

----Sig/Pwr-----
----Ground-----

(B) ---Sig/Poured Pwr---
-------Ground--------

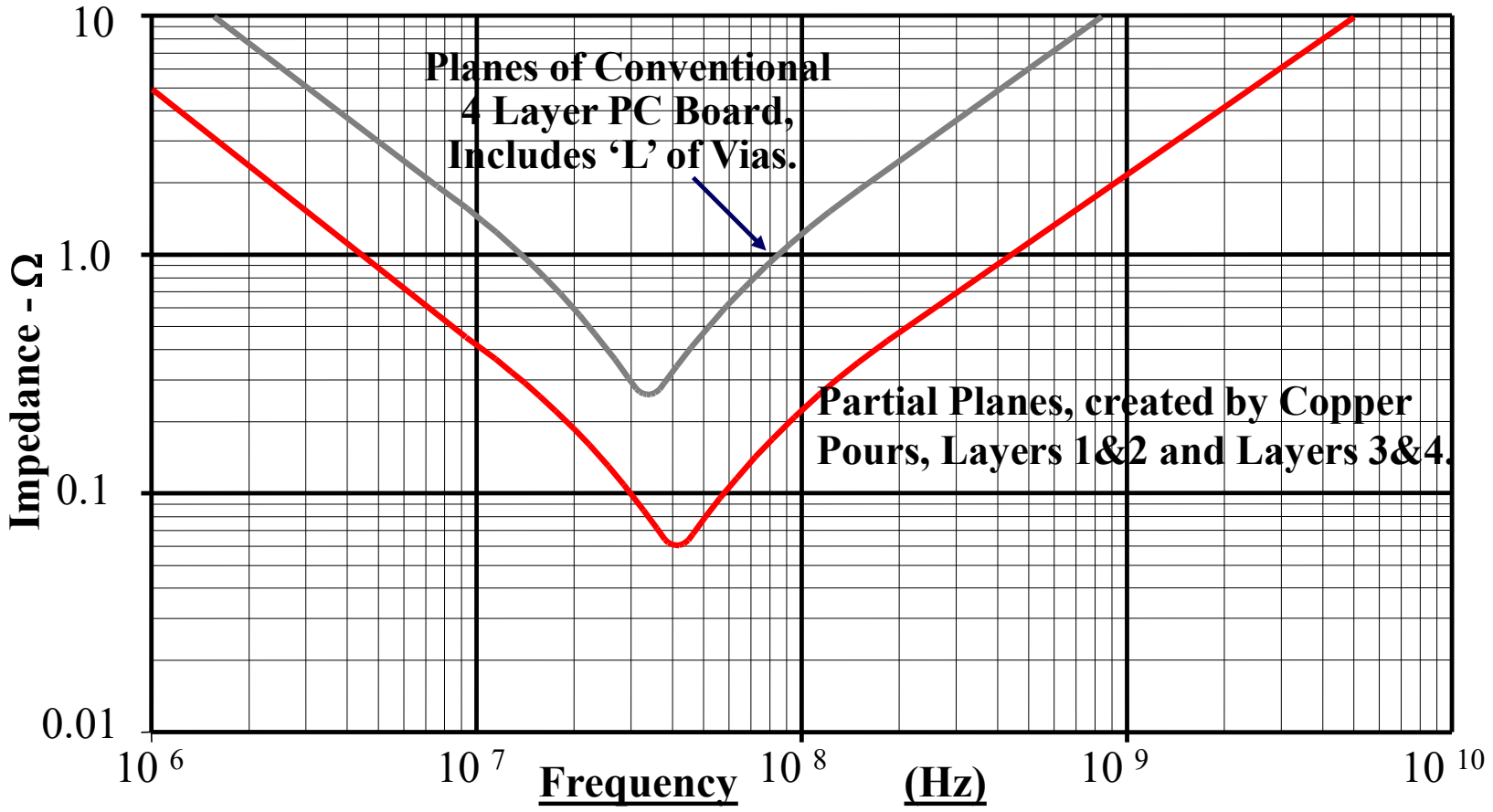
(Core)

-------Ground--------
---Sig/Poured Pwr---

- Both of these have many design challenges but offer Vast Improvement.

Circuit Board Stack-up –

- Power Distributed on Layers 1&2 and 3&4 creates FAR Lower Impedance than Conventional 4 Layer PC Boards.

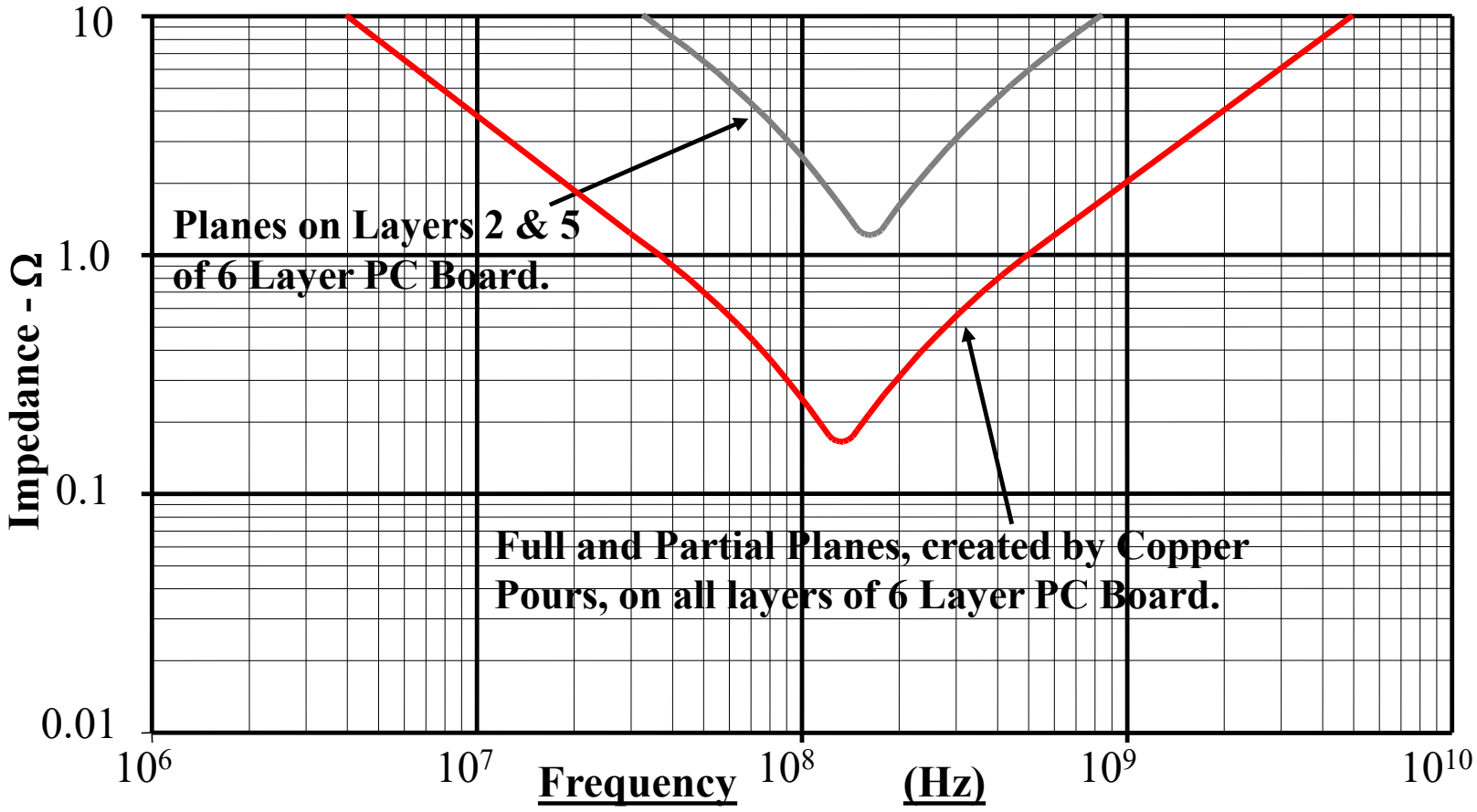


Circuit Board Stack-up –

0.062” 6 Layer PCB to AVOID	0.062” 6 Layer PCB Solution
-----Signal------	----Sig/Gnd-----
-----Power------	-----Power------
(Core)	**(Core)**
-----Signal------	---- Sig/Gnd----
-----Signal------	---- Sig/Pwr-----
(Core)	**(Core)**
----Ground-----	-----Ground-----
-----Signal------	-----Sig/Pwr-----

Circuit Board Stack-up –

- Adding Poured Copper on Signal layers greatly Lower Power Bus Impedance on 6 Layer PC Board.



Circuit Board Stack-up –

Even Better 6 Layer PC Board

-----Sig/Pwr-----

-----Ground-----

(Core)

-----Sig/Pwr-----

-----Ground-----

(Core)

-----Sig/Pwr-----

-----Ground-----

and Another 6 Layer PCB

----Sig/Pwr-----

----Ground-----

(Core)

----Sig/Pwr-----

----Sig/Gnd-----

(Core)

----Ground-----

----Sig/Pwr-----

Circuit Board Stack-up –

- 8 Layer Stack-Up recommended by a MAJOR IC company, for use with a Very High Speed Microprocessor.

----Signal------
---Ground-----
(Core)
----Signal------
---Power 1----
(Core)
---Power 2----
----Signal------
(Core)
---Ground-----
----Signal------

With enough Capacitance, both on Die and on Substrate, Signal Integriity of this board could be OK…….

BUT……

Clearly they completed **NO** EMI Testing!!!

The Extreme Importance of PC Board Stack-Up