IEEE EMCS Distinguished Lectures

" Why Does My Product Fail EMC ?"

And How To Fix it.

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Outline / Overview

- Thanks For The Invitation !
- EMC Process Overview & Fundamentals <brief>
- Illustrate the 4 Quadrants Through Case Studies
- Problem Solving Methods: Technical & Humanistic
- Measurements, Experiments, Theory Formation, Modeling, Solution Generation & Maintaining Progress
- Lessons-learned

EMC Tech Overview

EMC Definition

The Beneficial Property of a Device / System :

- Not to Create Excessive E-M Energy
- Not to be Disturbed by Expected E-M Energy

- Practical Design Goals & Regulatory Limits
- & Within Constraints

EMC Tech Overview

The 3 Players

- Source
- Path / Coupling Mechanism
- Affected Device or System / Receptor

  -Choose the “Best” One(s) to Attack-

- Consider Constraints :
  Performance, $, Time

EMC Tech Overview

SOURCE	PATH	RECEPTOR
Radio/TV/Cell	**wires**	Radio:AM/FM/TV
GPS Satellites	**cables**	Cell Hand-set
BlueTooth	**earth**	GPS -TomTom
High Voltage Lines	**metal**	BluetoothHeadset
Car	**building**	Car
iPOD	**person**	Pace-maker
Cell Hand-set	**air**	Hearing Aid

EMC Tech Overview

The EMC Matrix

Conducted Immunity	Conducted Emissions
Radiated Immunity	Radiated Emissions

EMC Tech Overview

4 Mechanisms + Plus One

Rank-order... Depends On Situation

- Conducted (mutual inductance)
- Magnetic Field
- Electric Field
- Electro-Magnetic Field (radio)

+ Path of Least Impedance

Re: Dr Tom VanDoren

EMC Case Studies

- Narrative Illustrations of ..
- Physical Principles
- Analysis Approaches
- Problem Solving
- Making Progress
- Working Well With Others
- “Best Solutions” Within Constraints

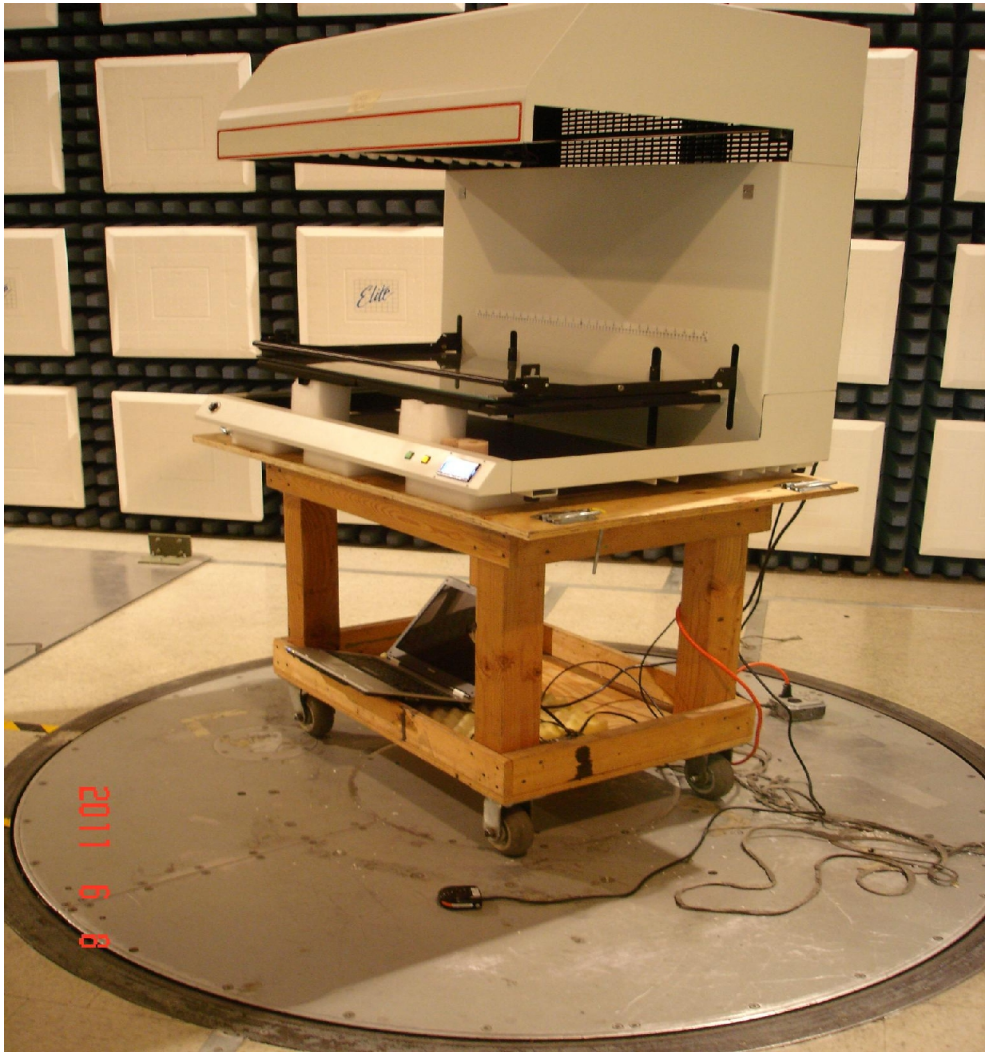
Process Words of Wisdom

Henry Ott's Big 4

1. Divide & Conquer : Structures, Freq's & Modes
2. Find The Dominant Mechanism : Pile On Fixes
3. Kill It Dead : Optimize Later
4. Implement Fixes : Best Possible Fashion

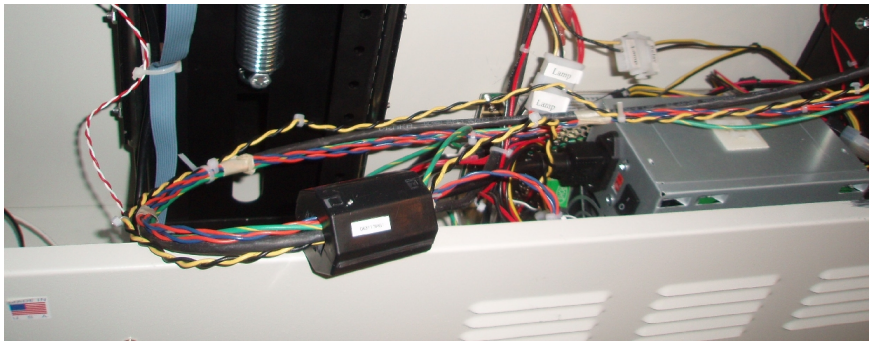
CE Case 1 Scanner 1

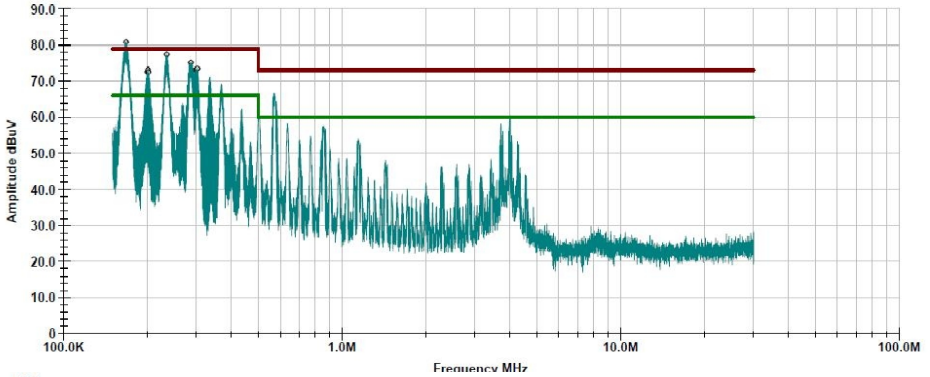
- The “Story”
- Large Table-top Commercial Document Scanner
- Goal : CE Mark
- Design Approach: PC-AT Supply CE-Marked

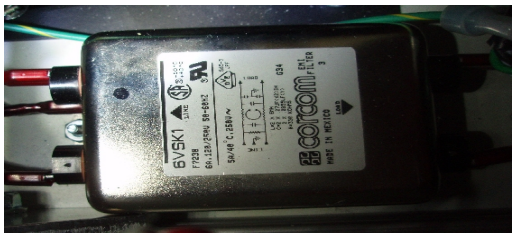


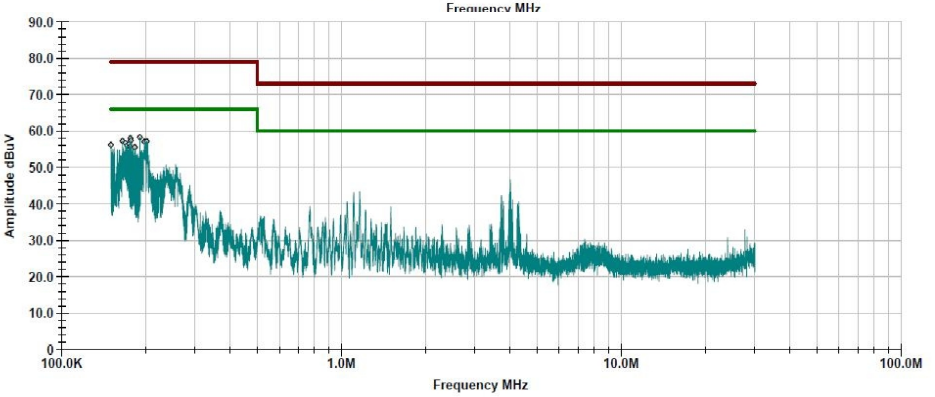
CE Case 1 Scanner 2

- Verification Test :
  Fails CE @ Low MHz
- Fix : Add “Can” Filter
  Pi+X/Y Caps
- So We're Done, Right ?
  Uh-Oh, Not so Fast !



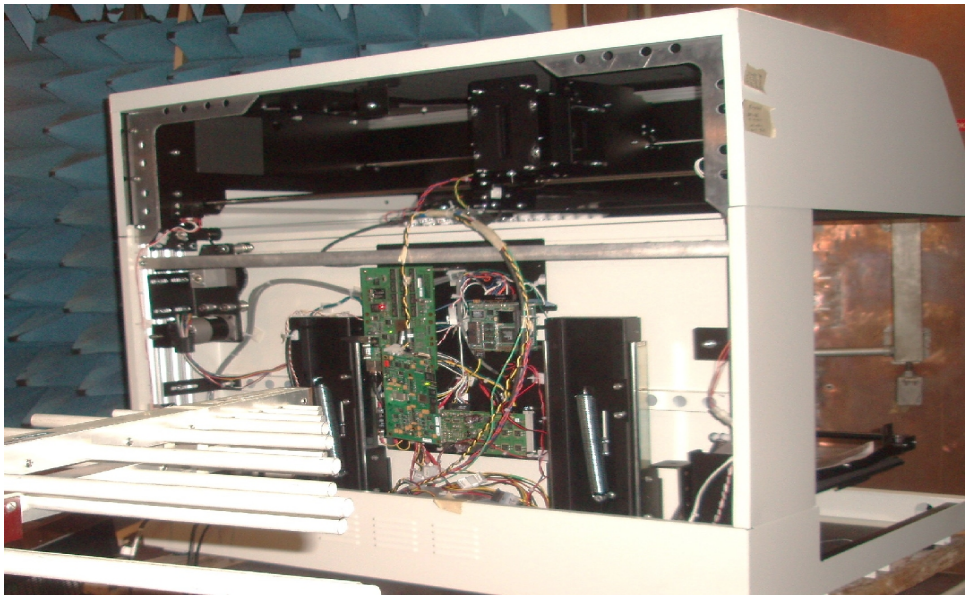


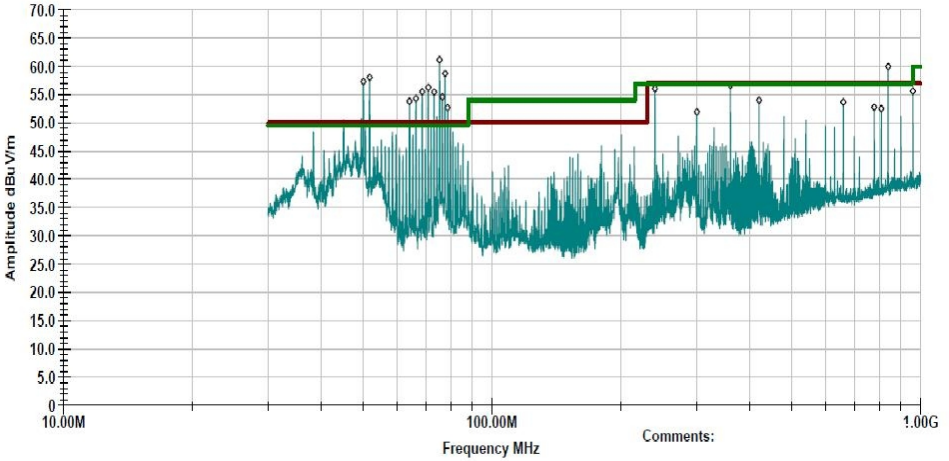




RE Case 2 Scanner *Reprised* 1

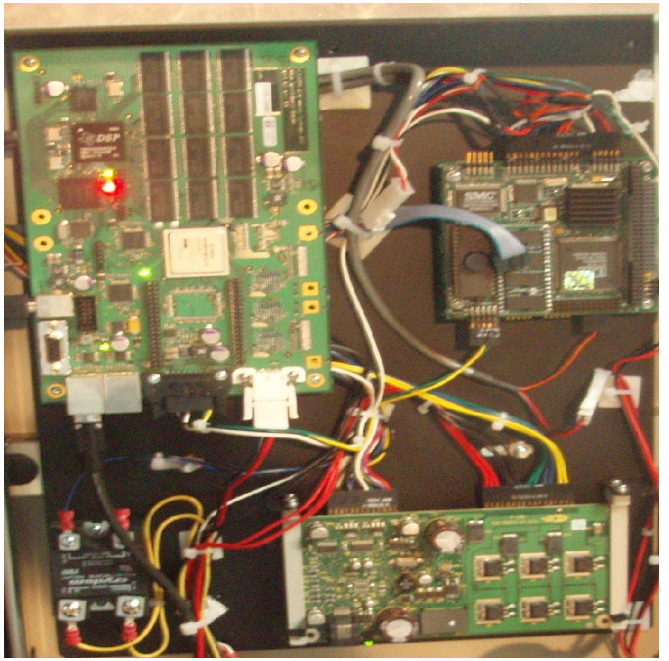
- Large Table-top Commercial Document Scanner
- The Plot Thickens Way Beyond CE
- Boards & Lotsa Wires
- Sources, Paths & Radiators
- Where 2 start ?

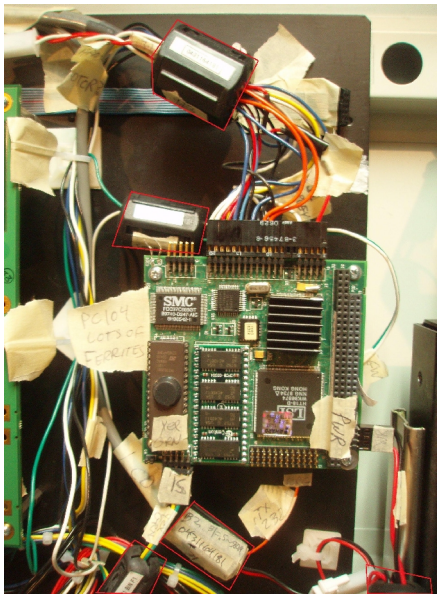




RE Case 2 Scanner *Reprised* 2

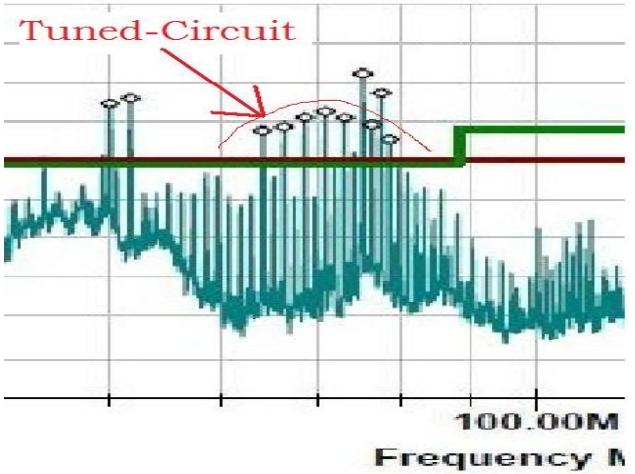
- Purist Find the Source & Stop It There
- Close-field Probe The “PC-104 Brains”
- Choke it Off 5X
- Not Enough !
- Keep Moving !

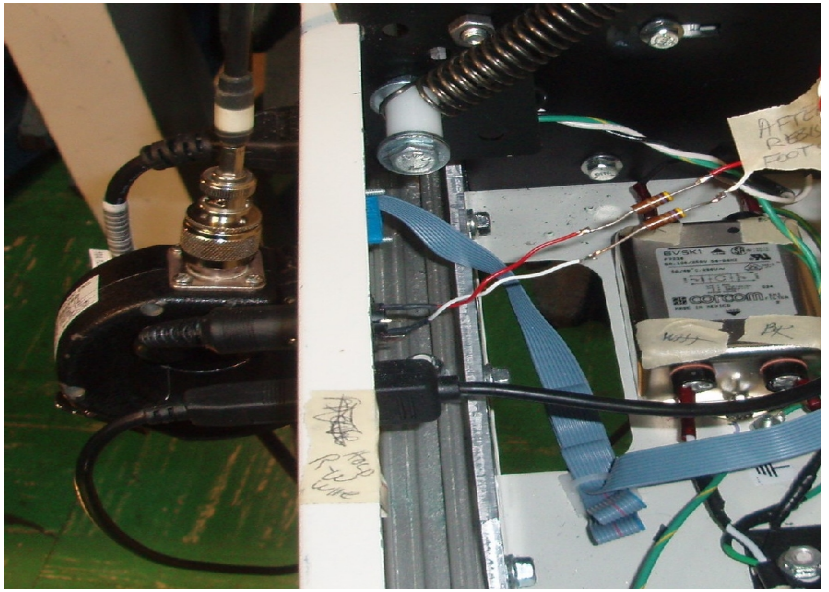


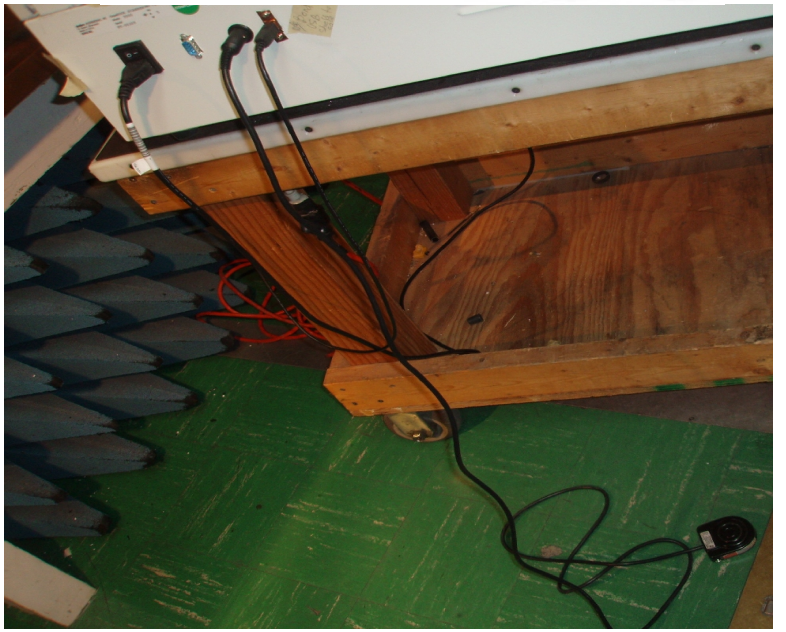


RE Case 2 Scanner *Reprised*

- I see 3 Antennas:
  USB, FootSwitch, AC
- Measure Currents as
  Lee Hill Advises

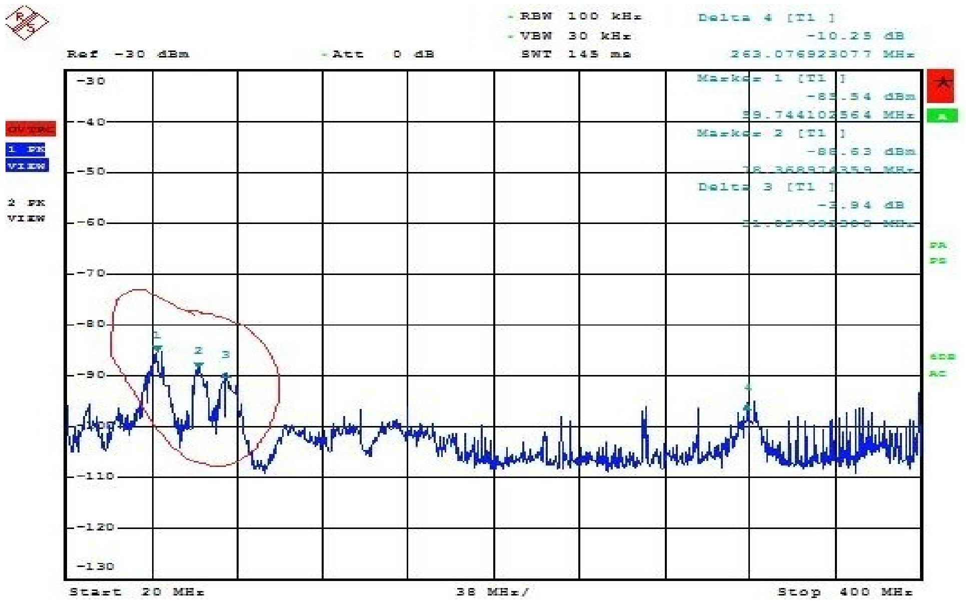


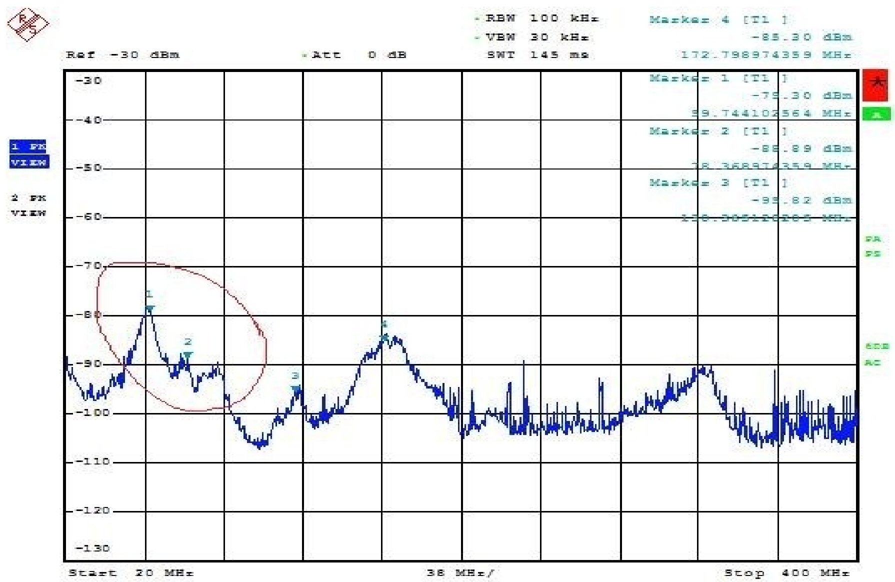


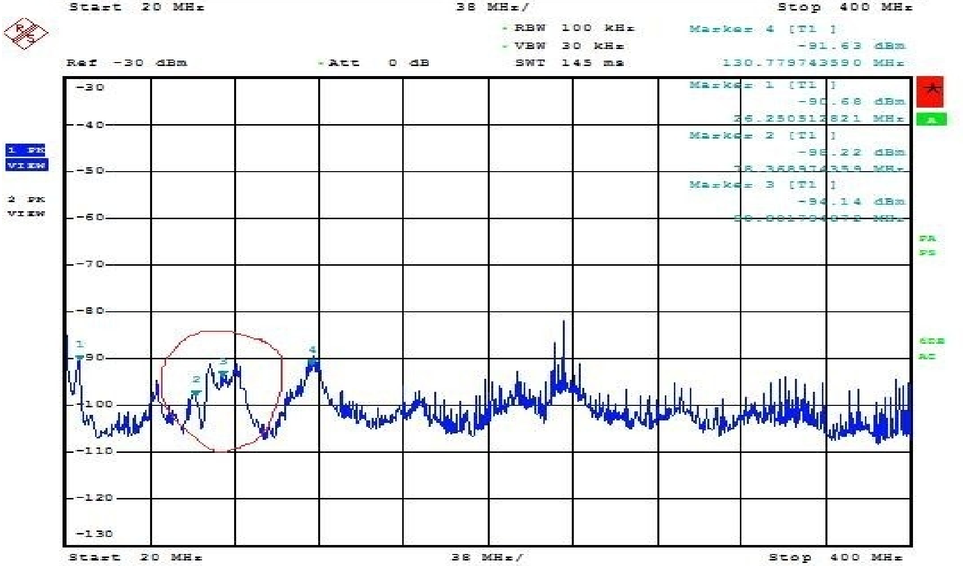


RE Case 2 Scanner *Reprised* 4

- Currents on 3 "Antennas"
- Same but different !



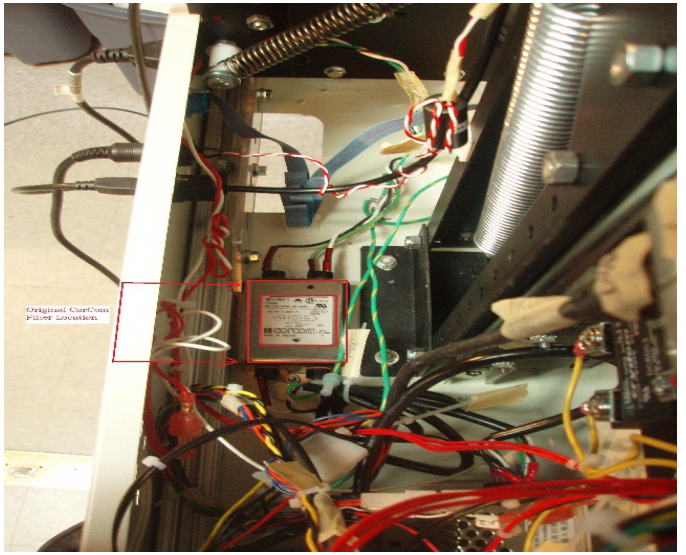


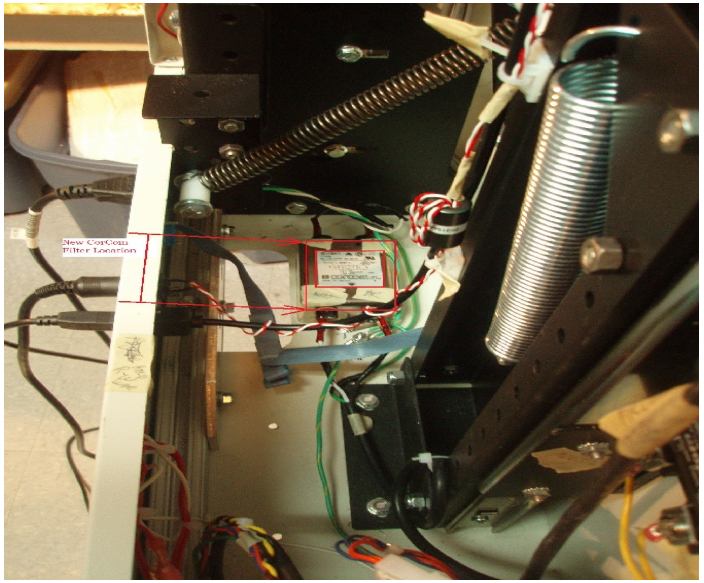


RE Case 2 Scanner *Reprised*

What to do ? All Three !
"Kill It Dead" H.Ott

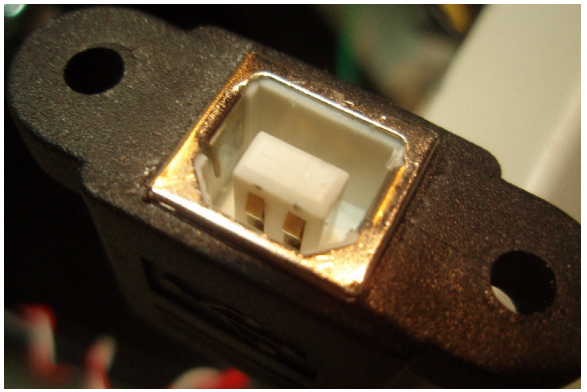
- Move AC Filter. Isolate & decouple wires
- Got a "Free" 2nd Use for Filter = TriZ principle
- Sounds easy now, but then?

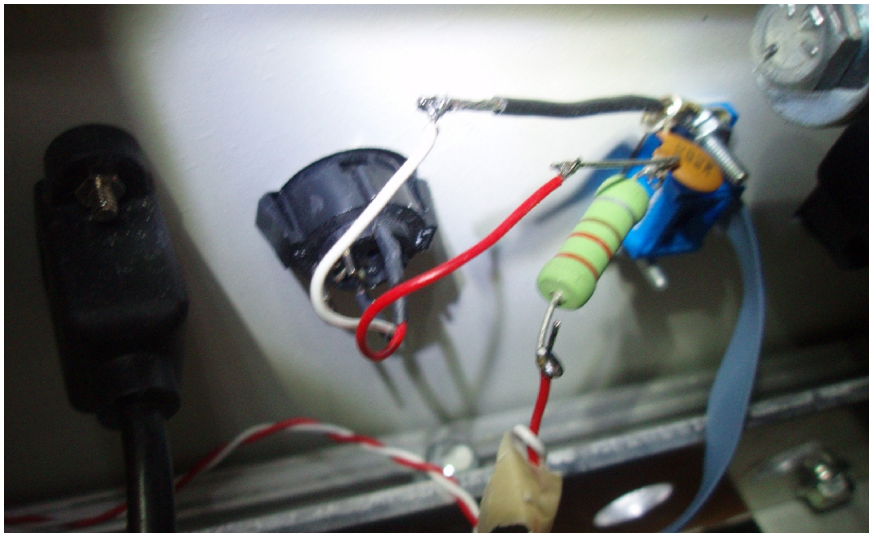




RE Case 2 Scanner *Reprised* 6

- USB Gnd Floats in Plastic
- USB GND bond demo
- Crude R/C filter in Foot Switch





RE Case 2 Scanner *Reprised* 7

Industries Inc. Fixes Ver1.1

, Inc. EMC Fix Summary

#	Name	Corrective Action	Impact	Notes	Follow-up
1	USB Connector	Use Shield Grounding USB connector @ Rear Panel. Remove paint in contact area. Use star washers.	40-80 MHz	Demo: 3M brand copper tape w/ conductive adhesive folded into female opening	BOM : Specify New USB connector, starwashers, Drawing: Paint mask
2	AC Mains Filter Location	Align Corcom filter's AC mains terminals adjacent to IEC power cable receptacle	40-80 MHz	Wire now 8" vs. 13" Corcom filter has 2 new mounting holes. Use star washers.	Drawing : Holes, BOM: Star washers
3	Chassis "Hood" bonding	Bond across gap between hood sheetmetal and vertical side sheetmetal.	40-80 MHz	Demo: Copper tape across gap on rear outside surface both sides.	NEED PRODUCTION METHOD
4	Rear Panel Bonding	Remove rear panel paint under 3 screw fastener heads, use star washers	40-80 MHz	Assure black metal brackets have EMC bond to silver irridite girders , More star washers ?	BOM: star washers, Drawing: Paint masking
5	Footswitch DIN Connector Ground	White ground wire from DIN connector short connection to rear chassis ground.	40-80 MHz	Use adjacent DB9 connector mounting screw with ring lug ,remove panel paint & add star lockwasher	BOM : ring lug + wire , starwasher. Drawing : cable design
6	Footswitch signal wire filter (Ver1.1)	Add series 100 Ohm filter resistor in red wire at PC104 connector J4-P19	40-80 MHz	Lower $ as/more effective as ferrite bead. Logic Low now 0.97 Volts (lower resistance to meet logic Volts)	BOM:resistor, Drawing:cable design. VERIFY LOGIC LEVEL NOISE IMMUNITY OK
7	LCD Cables Shield	Bond black metal sheetmetal "L" cover (over 3 gray cables under scan table) to silver irridite coated girder	40-80 MHz	Remove black paint around 2 hole's inside where star washer is adjacent to silver girder.	BOM: star washers, Drawing: Paint masking
8	LCD Panel as Shield	Bond LCD front sheetmetal panel to main chassis through 2 existing fasteners	40-80 MHz	Remove paint around screw holes in main sheetmetal & front panel, use starwashers	BOM: star washers, Drawing: Paint masking
9	Decouple / Isolate AC Mains Wiring	Dress all non-AC mains wires min 4" from wiring between IEC receptacle & Corcom filter	40-80 MHz	Twist white & black wires between IEC receptacle & filter	BOM: cable, Drawing: wire routes
10	Decouple / Isolate DC supply output Wiring	Dress all 5 and 12 Volt wiring from PC-AT supply to its right side as they exit. Minimize volume of rats-nest, locate & secure against chassis sheetmetal.	40-80 MHz	Route & secure wiring bundles from black PCB mounting plate toward right side of PC-AT supply	Drawing: wire routes

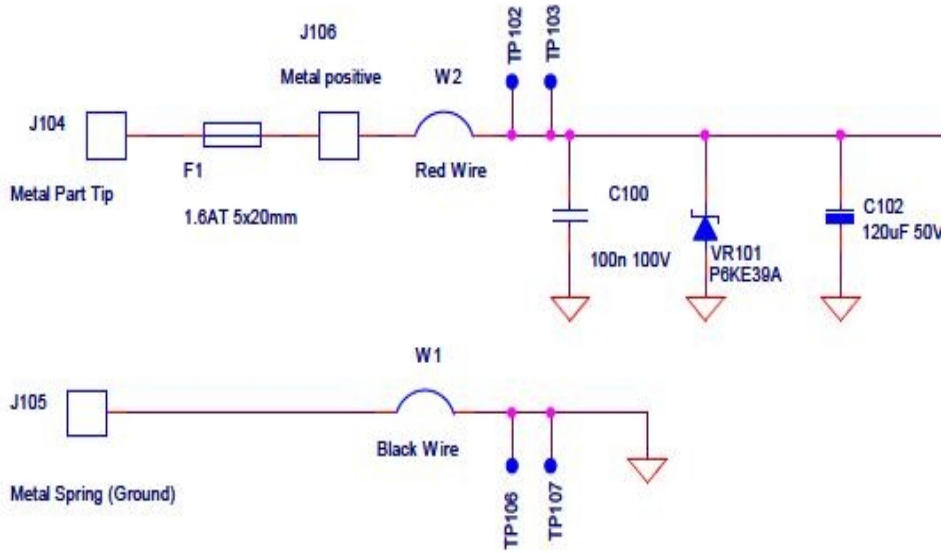
RE Case 2 Scanner **Lessons** 8

- Do not have to always contain it @ Source
  PC104 cards: Just too many I/O & wires
- Thankfully found Dominant Effect (H-Ott)
  Cables = Antennas & K-I-D @ low $
- Did not have to “predict” Pre-Compliance levels
  Relative improvement @ Current Probe Enough
- Problems were Frequency & Source
  independent / separable – Allowed independent
  fixes applied **w/o interactions** , whew :)

CI Case 3 Load-Dump 1

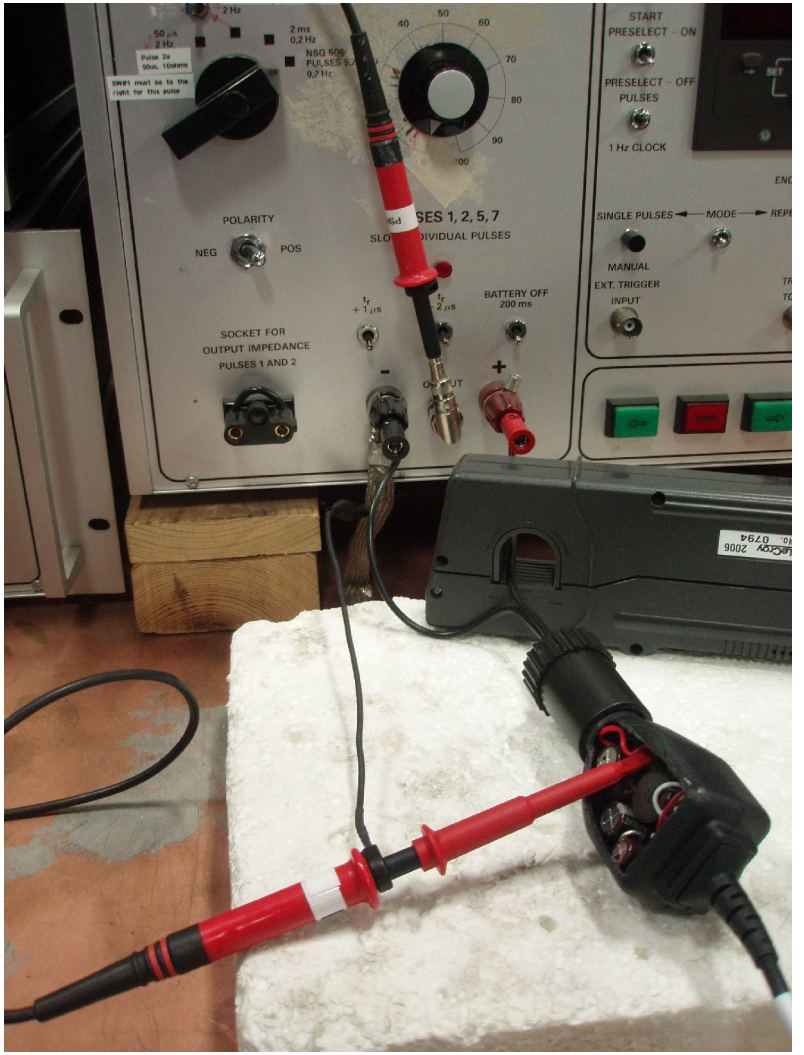
- Vehicle Power Socket Charger
- 24 V “Design”
- 600 Watt 39 V TVS
- Passed 12 Volt “Load Dump”
- Verify 24 V Dump

  110 ~ 170 Volts
  200mS , 2~ 4 Ohm



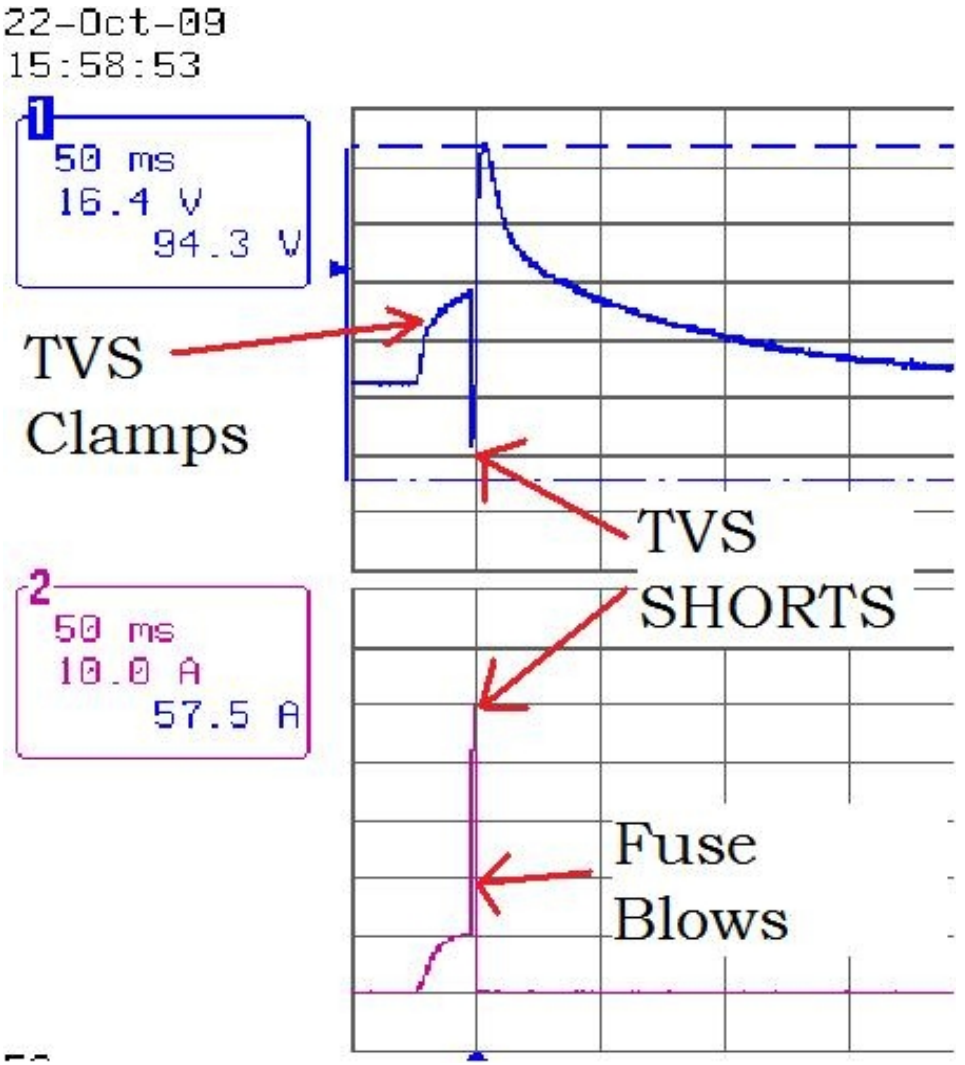
CI Case 3 Load-Dump 2

- Monitor I & V
- Ramp Up Stress Volts
- 1.6 A slo-blow I2t=6.4



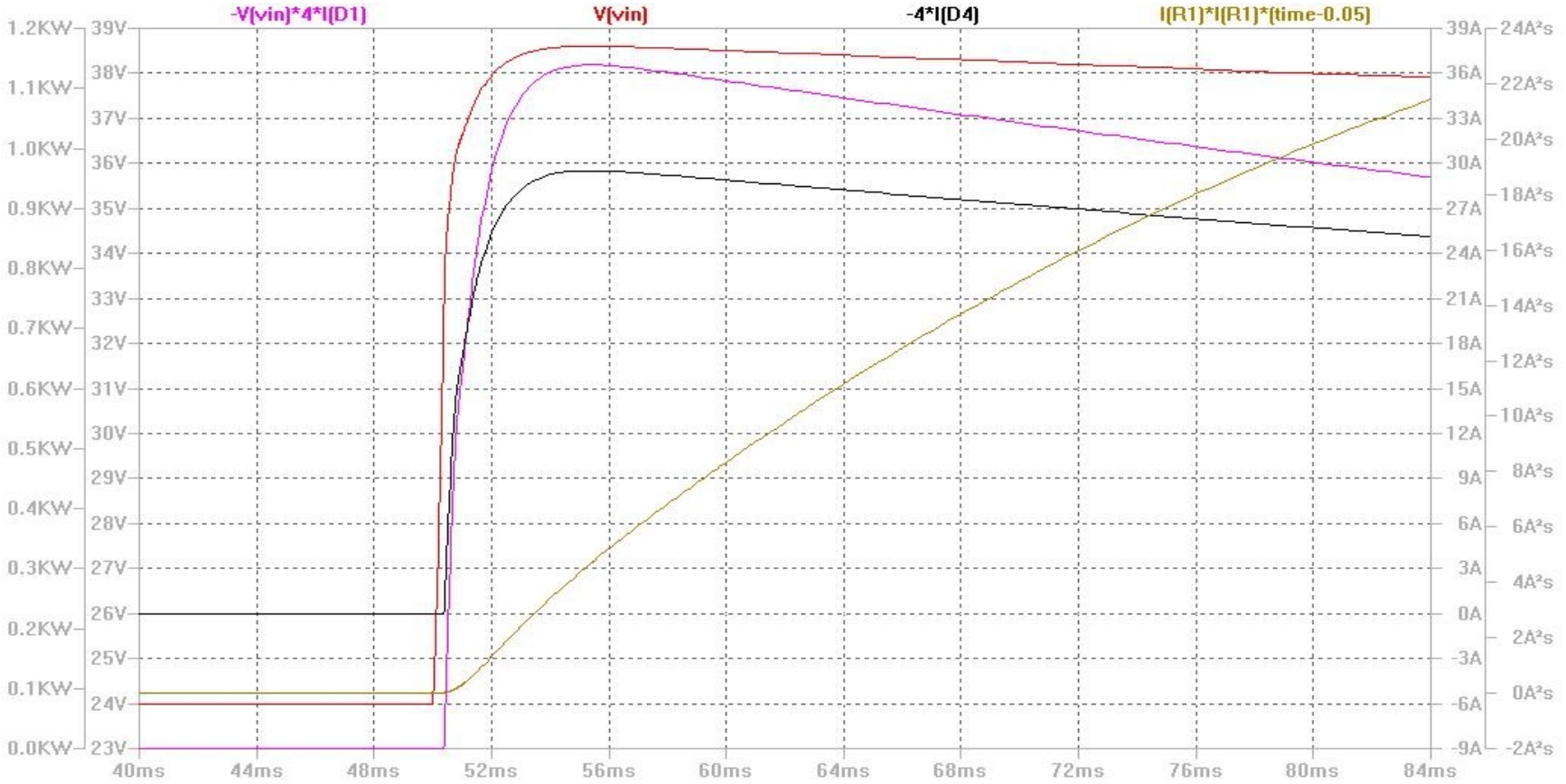
CI Case 3 Load-Dump 3

- 600 Watt TVS
- Clamps “soft”
- TVS Overheats to SHORT
- Blows Fuse
- NOT Acceptable



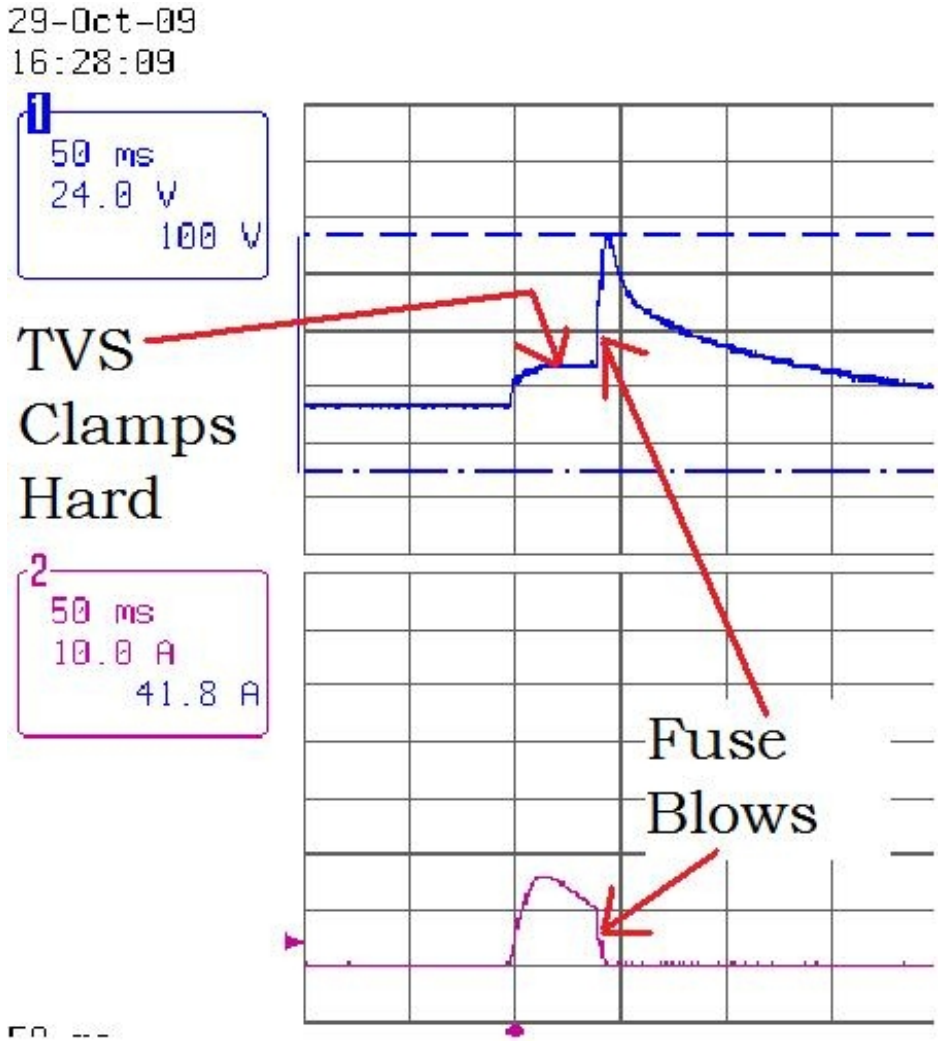
CI Case 3 Load-Dump 4

- SPICE for Insights – kW , I^^2*t



CI Case 3 Load-Dump 5

- 5 kW TVS
- Clamps at Voltage
- Holds Voltage
- Clears Fuse, Slow I2t
- TVS Survives
- Change the Fuse OK



CI Case 3 Load-Dump **Lessons** 6

- Go / No-Go Testing Insufficient
- Gather “Real” Data While Verifying
- Understand the Physics .. Fuse I2t
- Simulate to Communicate
- Knowledge Makes it Easier to Sell Solutions
- Do Not Fear Going For The Max : 5kW

RI Case 4 - Big PCB 1

- So I Get an e-mail
- Commercial Vehicle Control System
- Fails 3V/m @ 3 Labs Copper Tape the Box
- Can I Fix It ?
- Client Visit - Overload
- Just Say Yes

RI Case 4 - Big PCB 2

Assessment

- ~15 cables (antennas)
- Plastic Box
- Huge PCB : Area & Thickness
- Multiple uP's & Analogue - Loosely Populated
- Minimal Failure Data – Something Resets
- “I'm the Expert” – Make *Recommendations*

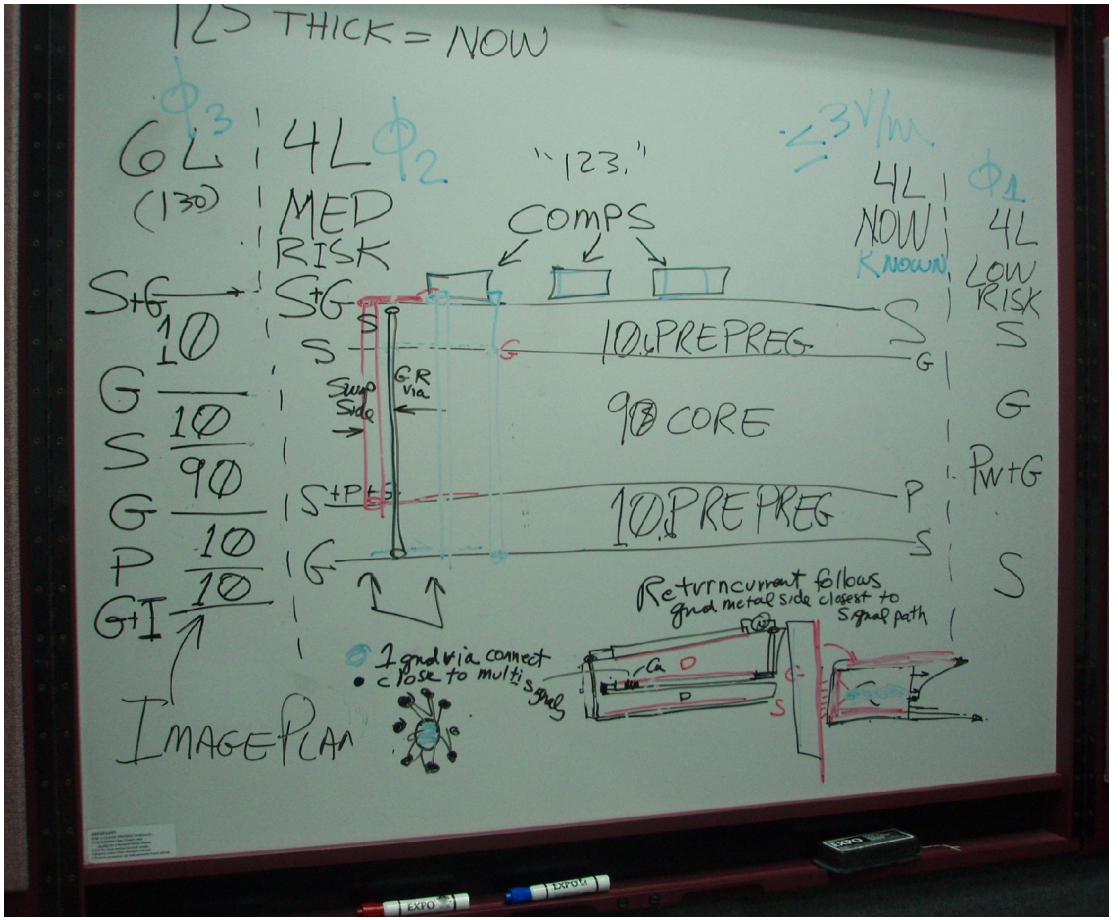
RI Case 4 - Big PCB 3

How To Approach ?

- Study Schematic & Layout
- List of Best Design Practices & Why
- Pictures of PCB modifications
- Alternate PCB Stackups & Why: H Ott's Book
- Expectations Set : 3 Iterations
- Constraints : “If it took a little more $ to solve it for The Holidays I'd be good with that ”

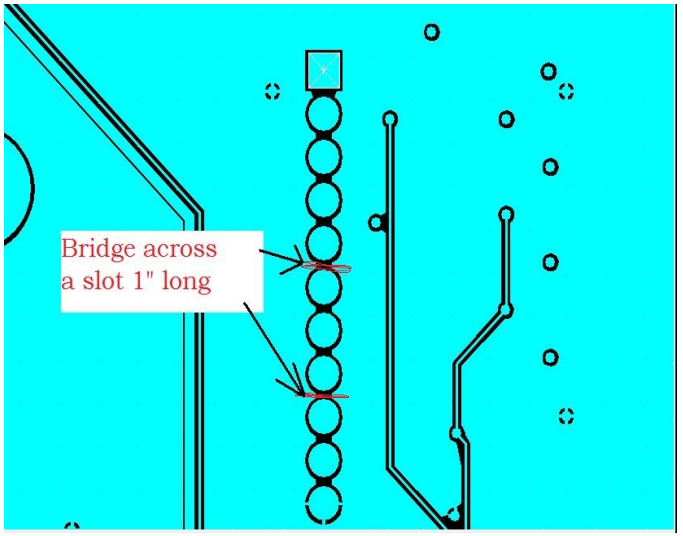
RI Case 4 - Big PCB 4

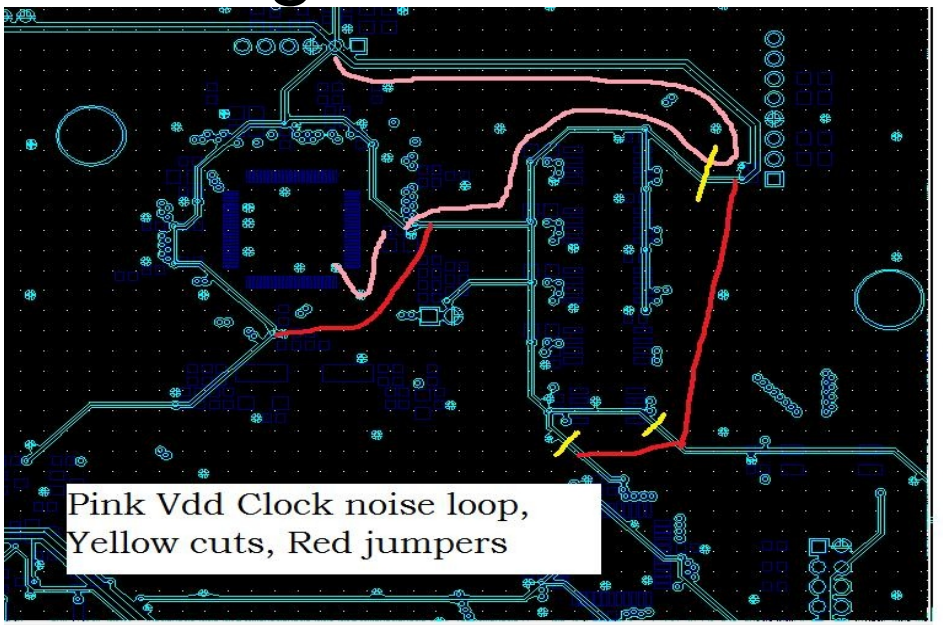
- PCB Stackup 4 layers
- 0.125” thick
- Signals Outers
- Power/Gnd Inners
- No Gnd Fills
- The Opportunity !

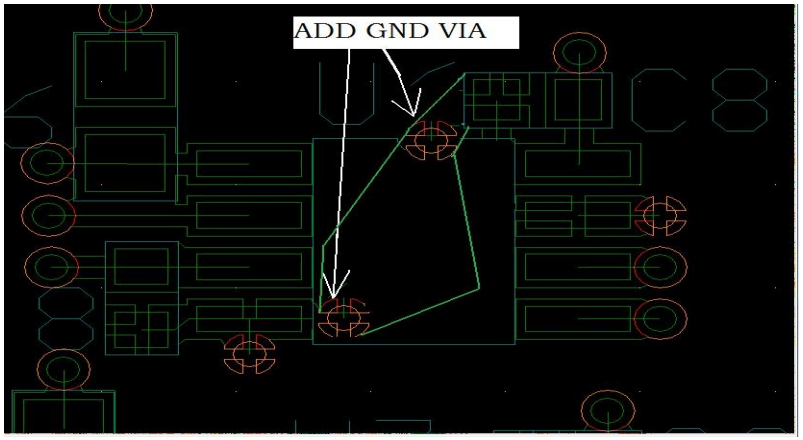


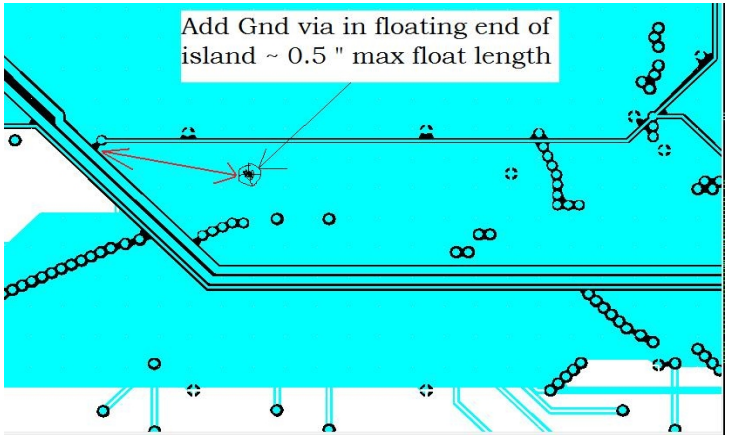
RI Case 4 - Big PCB 5

Marked-up PCB changes









RI Case 4 - Big PCB 6

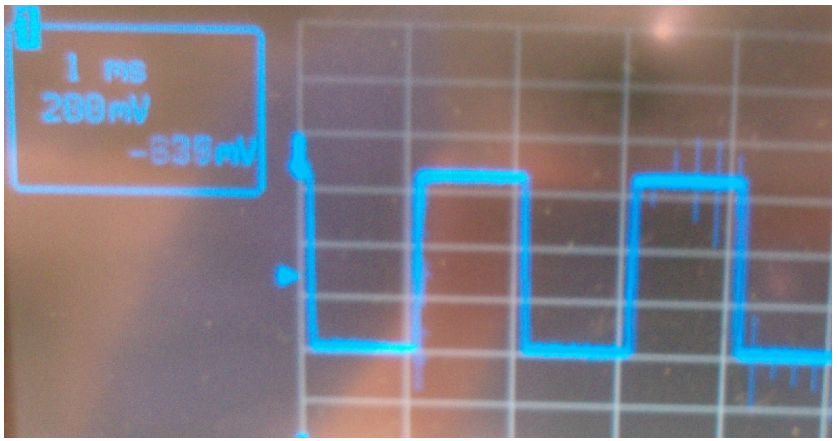
- Found Allies : PCB Design Engineer & Ott Book
- Chapter 16 “The Rosetta Stone” of Stackups
- Bury Signals In Between Ground Planes
- Back-fill / Gnd-pour Open Signal Layer Areas
- Via-Stitch all Gnds Together Densely
- Bypass / Choke Every Cable (Antenna) Wire

RI Case 4 - Big PCB **LESSONS** 7

- Being There & Establishing Trust
- Just Say Yes .. Someone Else Would Too
- Find The Ally Within
- Use Common Language / Framework
- Ask For Everything & Early
- Communicate Frequently (Over Distance)
- Set Expectations & Limitations – Best Efforts
- Best Practices in Circuit & PCB, Work ...It Depends...

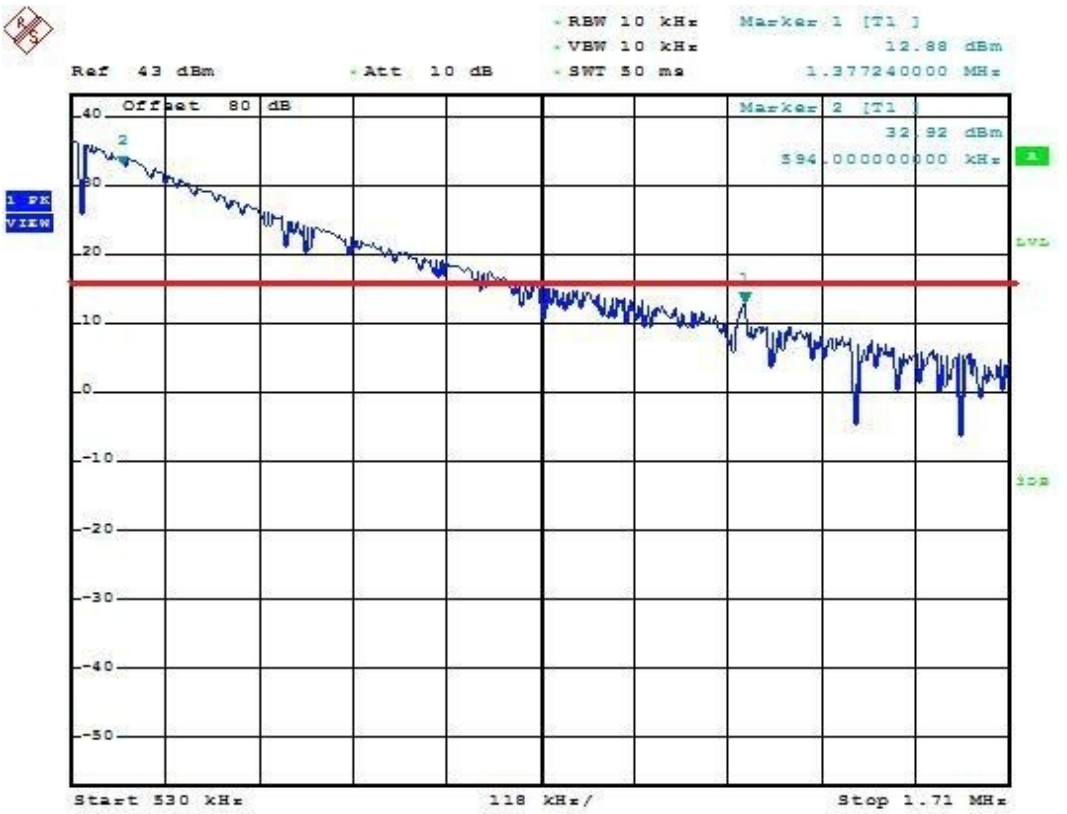
CE Case 5 – Hall Sensor 1

- Good IC RePackaged
- 2 terminals – simple !
- 500 Hz Pulses
  Wheel Speed



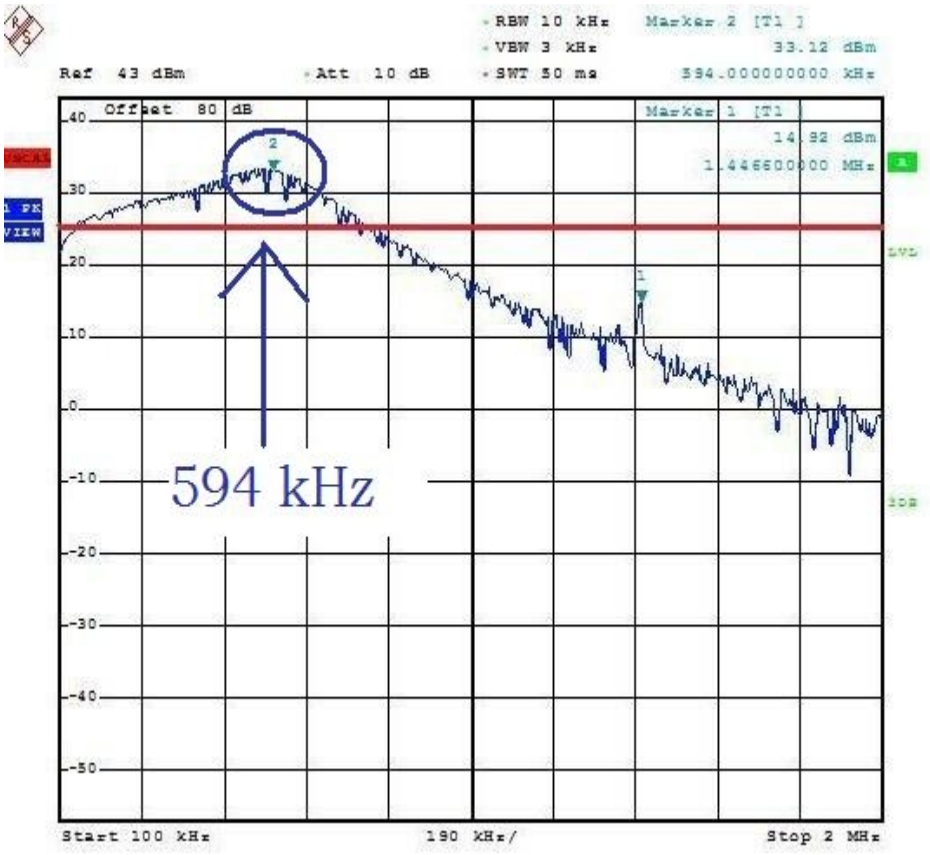
CE Case 5 – Hall Sensor 2

- Just Measure CE in AM Radio Band
- What The %#@&! Over the Line ?
- OK 10nF Shunt Cap Can Fix This
- & Need Cap for ESD "2 for 1 Sale"



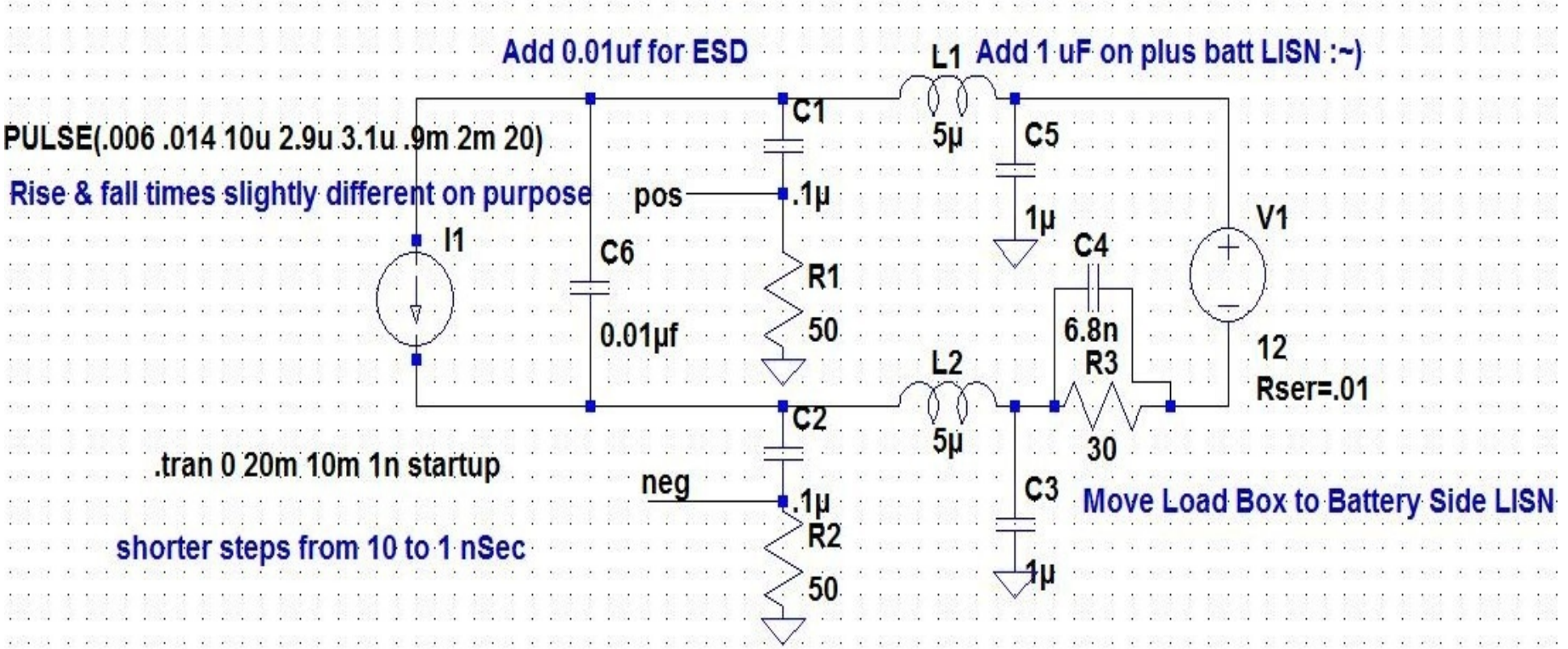
CE Case 5 – Hall Sensor 3

- Almost Better ...
- What's That Peak ?
- Find the Hidden Resonant Circuit



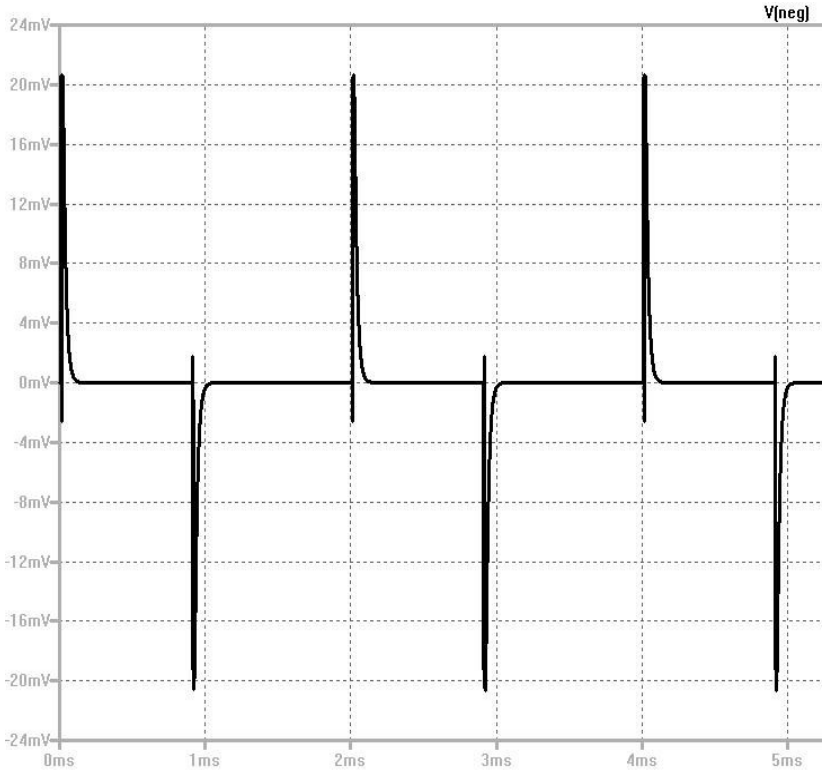
CE Case 5 – Hall Sensor 4

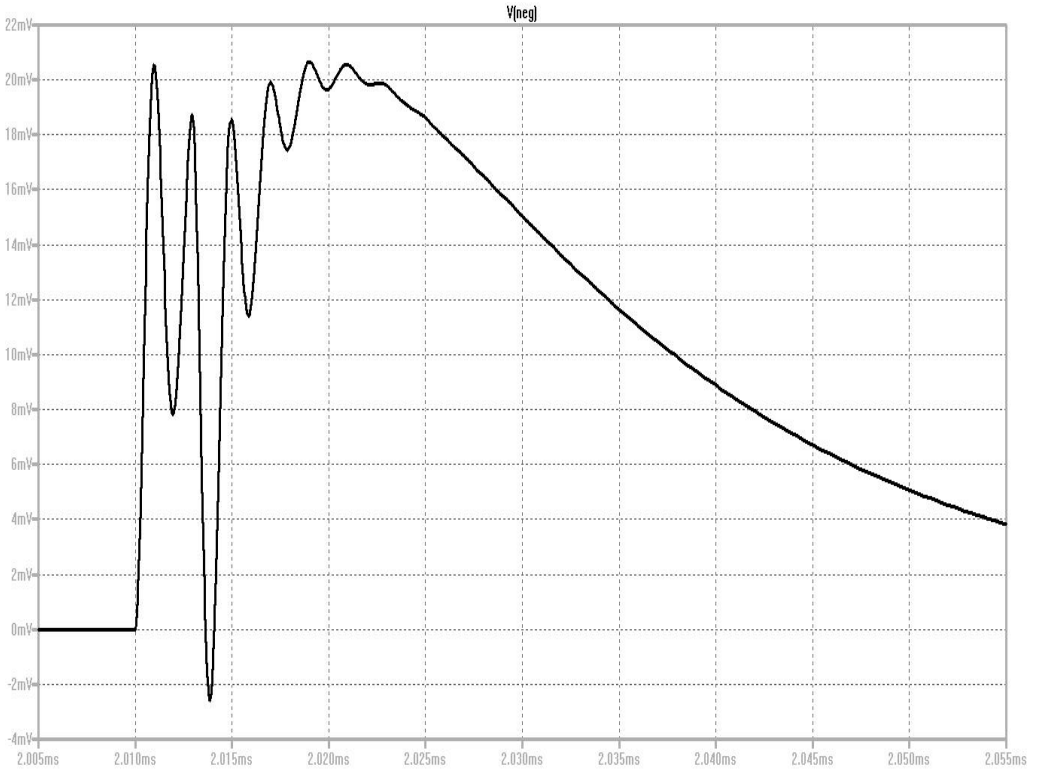
SPICE Model For Insights



CE Case 5 – Hall Sensor 5

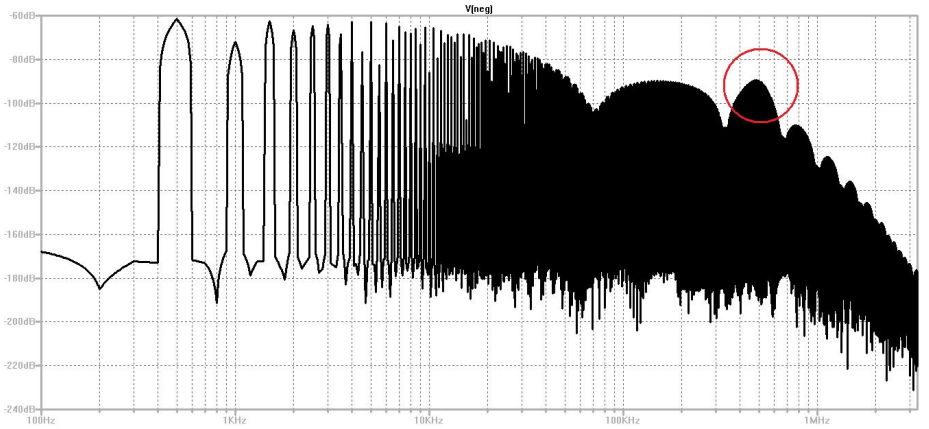
- LISN Gets Pulsed & Rung Out By SPICE

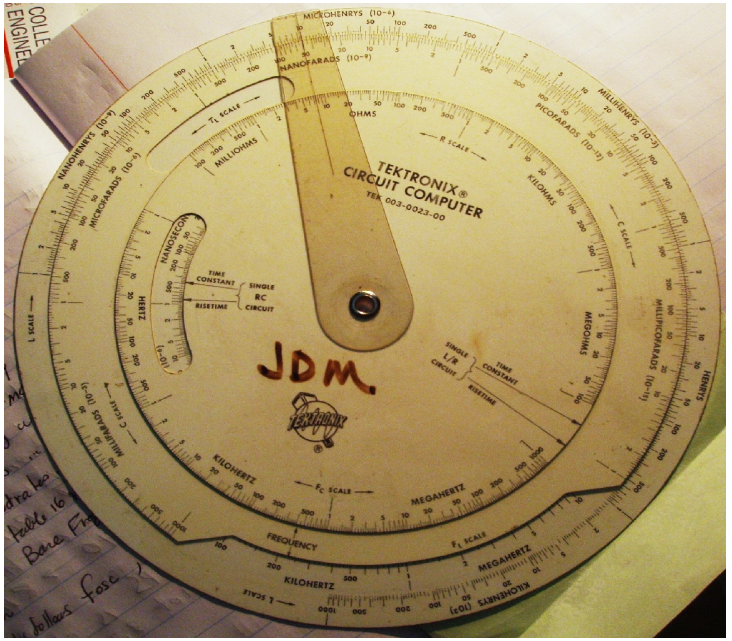




CE Case 5 – Hall Sensor 6

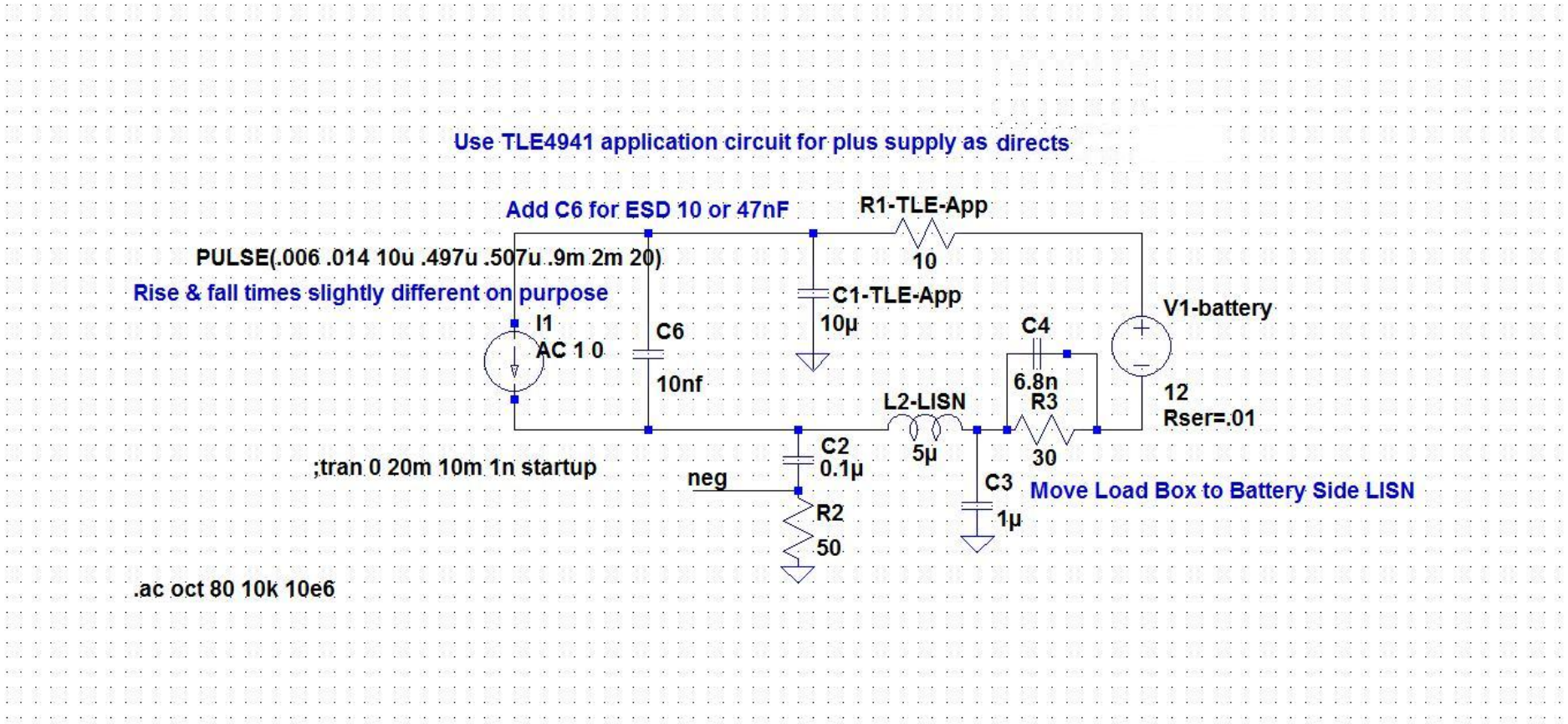
- FFT Peak ~500 kHz
- L-**IS**-N
- Impedance Stabilization?
- LISN Coils Resonance !
- 10nF & 10uH do the math
- ~500 kHz





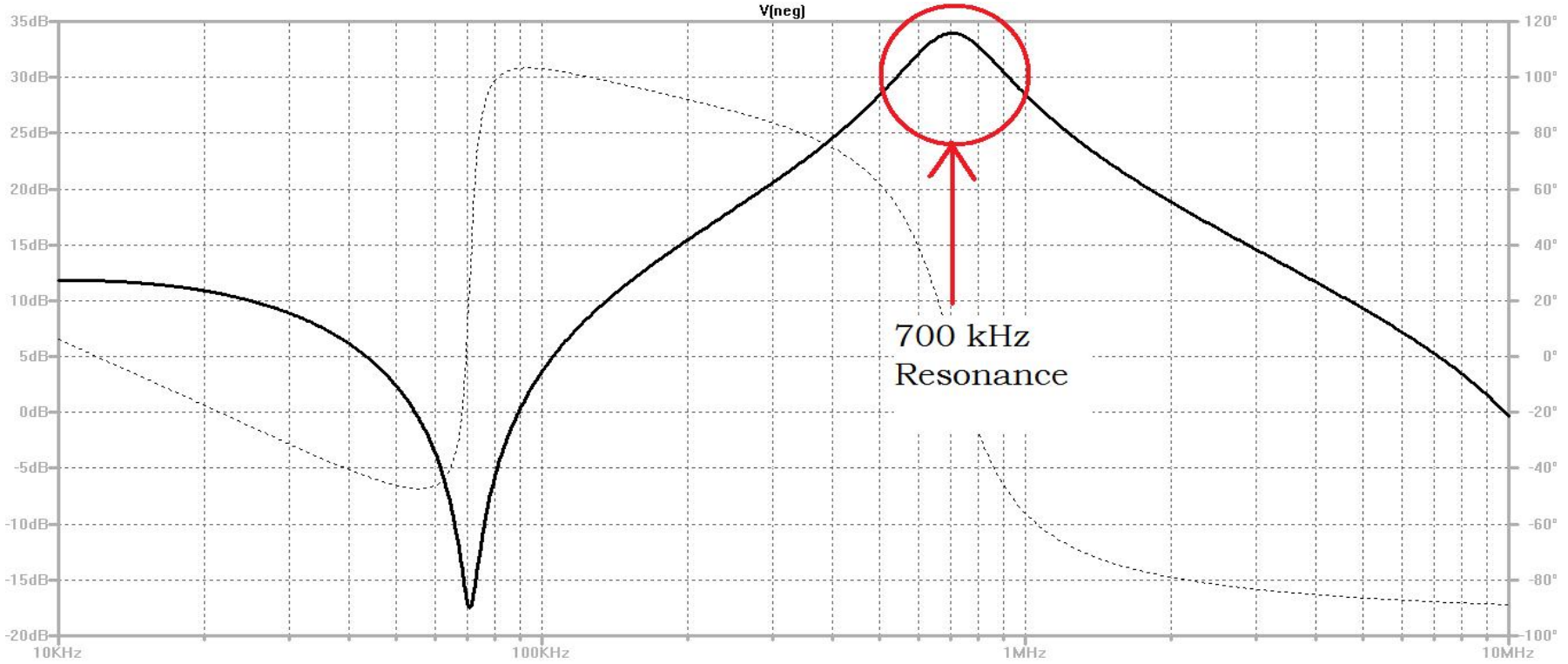
CE Case 5 – Hall Sensor 7

- A Better Idea ? Use IC Application Circuit
- Do AC Analysis This Time



CE Case 5 – Hall Sensor 8

- Now 10 nF & 5 uH = 700 kHz By SPICE AC
- Do The Math, It Will Not Be Better

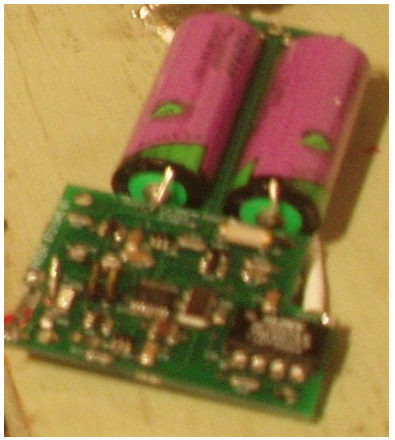


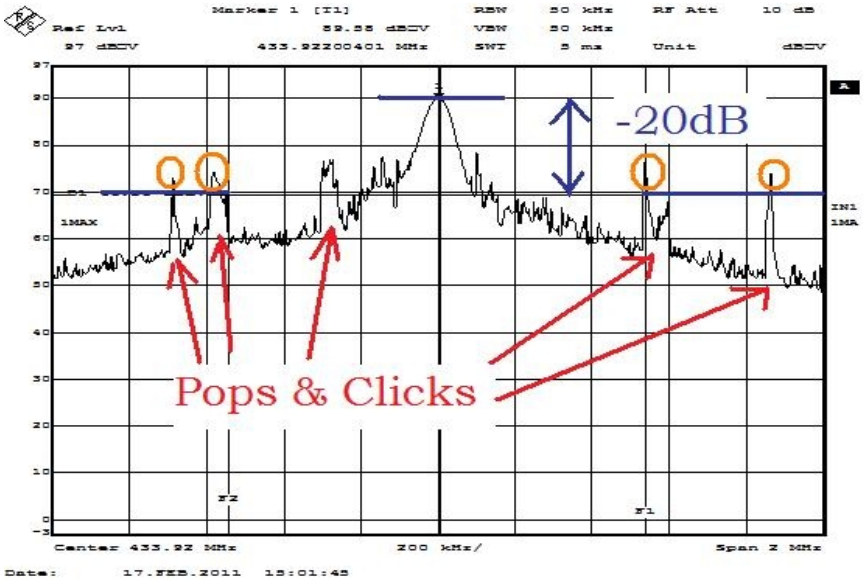
CE Case 5 – Hall Sensor **LESSONS** 9

- Beware of Fix's Unintended Interactions
- Industry Standard Fixtures Have Limitations
- Model All the Important Parts in SPICE
- As Simple As Possible But No Simpler (Einstein)
- Analyze By Inspection & Insight (resonance)
- Seek Corroboration : Analysis & Measures
  “3's A Charm”
- Model When You Cannot Get In the Lab

RE Case 6 – Data RF Transmitter 1

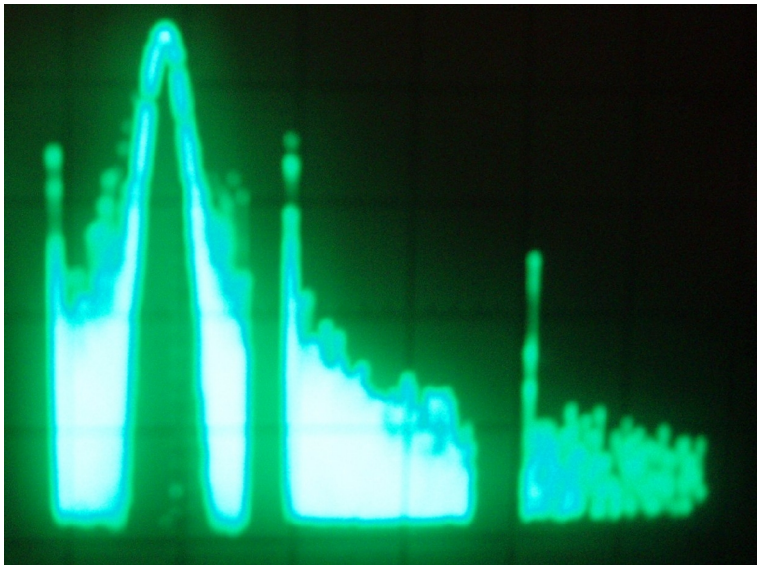
- 433 MHz ISM Band
- Battery Op'
- 1 Chip Tx (PLL)
- uP : Tx Control, Data
- -20 dBc @1 MHz BW
- Official Measure
  "Strange"
  Non-compliant





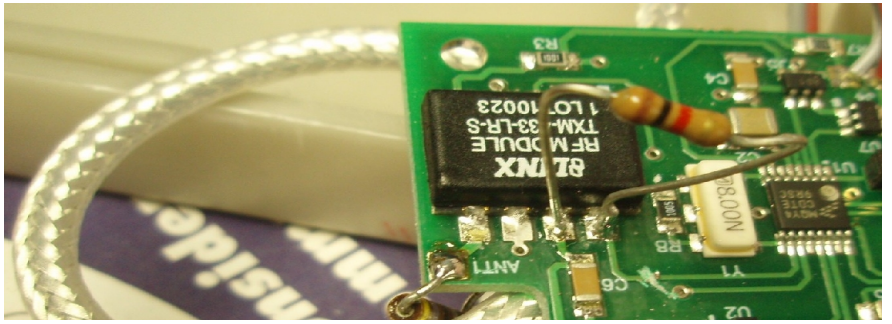
RE Case 6 – Data RF Transmitter 2

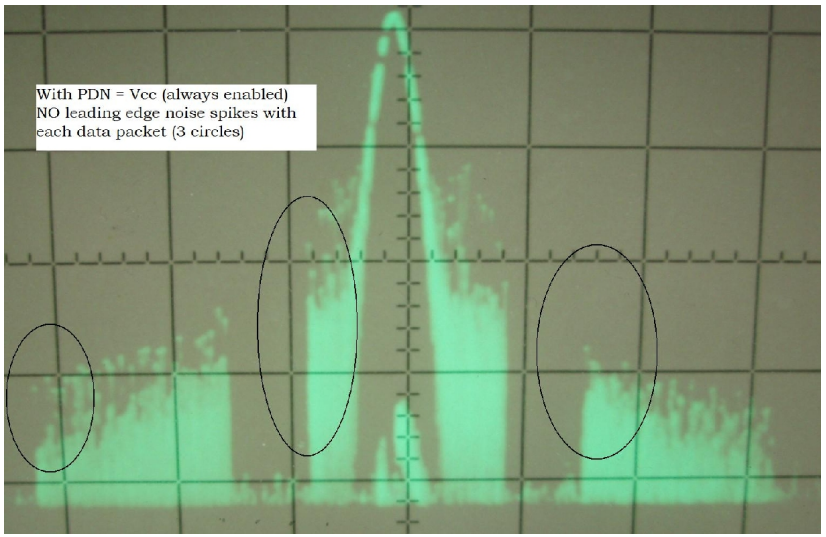
- Measure Real-Time
- Late 1900's Tech ;-)
- Key-on Clicks & Pops a'la HAM Radio

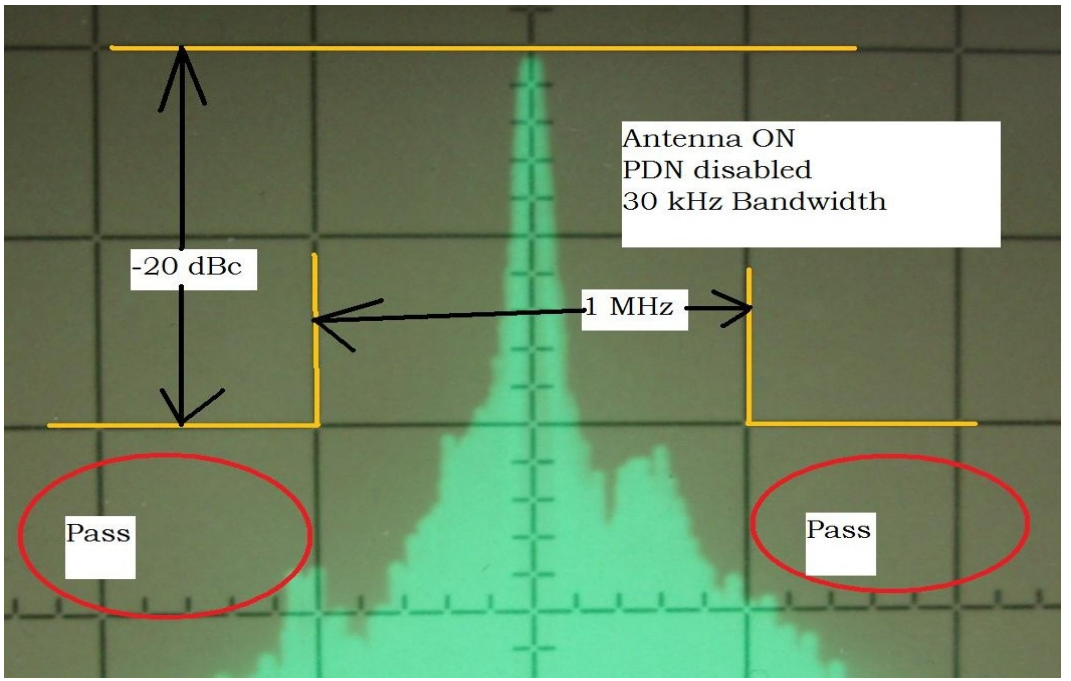


RE Case 6 – Data RF Transmitter 3

- Suspect Tx Enable Time Delay < 1 mS
- Force Tx On Always
- Crude But Effective







RE Case 6 – Data Tx **LESSONS** 4

- Official Data Often Hides Causal Evidence
- Use Real-time Detection Equipment
- Read Component Spec's
- List Many Ideas & Dispatch Rapidly
- Do Quick 'n Dirty / Is-IsNot Experiments
- Software Was the Fix, For Once
- Experience Can Make It Look Easy

Summary of Summaries

- Just 3 Things: Source, Path, Affected
- 4 Problem classes RE, RI, CE, CI
- 4 Coupling modes - Tom V'
- 4 Tactics: Divide, Dominant,Dead,Impliment- Ott
- Understand Limitations
- Model Appropriately
- Best Practices Work – Up To a Point
- Human Factors as Important As Tech

Summary of Summaries , more

- Observe in Real-Time & Parametric Sweeps
- Look For Interactions & Independences
- Precompliance Relative Measures Work
- See The Antennas
- Make / Take Time to Organize & Communicate
- Just One More Thing ? (Colombo)
- Keep On Learning

Thanks For Giving Me A Hand !

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