High Frequency Measurements, Noise, and Troubleshooting in Electronic Circuits

Day One - Measurements

Scope Probe Measurements

- Introduction and background including **live demonstration**
- Kirchoff and Faraday voltage measurements
- Noise sources and effects
- Experiment that lowers confidence in measured results
- Useful tools for measurements and troubleshooting
- Technical background
    - Null experiments to validate measured results
    - Skin effect
    - Inductance and mutual inductance
    - Capacitive and inductive coupling
    - Shielded cable operation using a graphical intuitive method (little math needed)
    - Practical experiment on shielded cables
- Scope probe characteristics
    - 10X "high" impedance passive probes
    - "Low" impedance passive probes
    - Active probes – single ended and differential
    - Balance coaxial probe (500 MHz)
    - Passive differential probe (2 GHz)
    - Easy to build DC to 1 GHz probe
- The probe ground lead – resonance and input impedance
    - 10X high impedance effects
    - Low impedance passive probe effects
    - Active probe effects
    - Doubling the accurate bandwidth of most any probe with a capacitive input impedance
    - Probe resonance experiment – **live demonstration**
    - Active probe simulations – **live demonstration**
    - Measured data on 4 GHz active probe
- Induced voltages in measurements – a source of error
    - Error induced by ground currents into unbalanced measurements
    - Ways to minimize the error
    - **Live demonstration**
- Differential Measurements
    - Types of differential measurements and probes
    - Why most active probes did not work until a few years ago (2X error in peak reading)
    - Lab data on a popular active differential probe showing the large error and high circuit loading
    - 7 GHz and higher new generation active differential probes
    - Balanced coaxial probe in detail (500 MHz)
    - Passive differential probe in detail (2 GHz)
    - Lab data and **live demonstration**
- Overview of Active Probe Design Philosophy
    - Two approaches
    - Using the wrong one will lead to significant error, and the choice is not obvious
    - Why one brand of probe looks better its data sheet than the competition

Non-Contact Measurements – magnetic coupling

- Shielded and unshielded magnetic loops
- How to interpret the loop output and relate to circuit noise, crosstalk, and general operation.
- Magnetic loop equivalent circuit and operation – graphical/intuitive approach
- Why shielded magnetic loops operate differently than engineers think and the implications

Current Measurements

- Types of current probes and operation
- Equivalent circuit of a current probe
- Modifying the probe frequency response
- Null experiments to check probe operation and accuracy
- Limitations
    - Circuit loading through capacitance
    - Core saturation
- Modifying probe response experiment, **live demonstration**
- A surprising experiment involving skin effect, shielded cables, and ground loops, **live demonstration**

Coupling Between Circuits and Equipment (Ground Loops Past, Present, and Future)

- Brief history
- Examples with data at <10 MHz, tens of MHz, and hundreds of MHz including CW sources and ESD
- How grounding at high frequencies is very different than at AC mains frequencies

Day Two – EMC and Design Troubleshooting

Integrated Circuit Noise Measurement

- How to measure noise, crosstalk, and ground bounce inside the package with no direct connection
- How to gauge the impact of noise, crosstalk, and ground bounce in the package on IC operation
- Identifying signal integrity problems including those that occur with very low probability
- Identifying EMC problems
- Measuring internal risetimes in the chip itself

EMC Troubleshooting

- Useful for both design engineers on the lab bench and EMC personnel
- Brief background and theory
- Relating common mode current to FCC/CISPR limits
- Troubleshooting EMC issues in the development lab
- Setting up the spectrum analyzer to measure common mode currents and spot problems.
- Experiments and demos

EMC Experiments

- Pigtail and system cable experiment in the time domain, **live demonstration**
- Pigtail and system cable data in the frequency domain, sometimes live demonstration
- Effects of board layout, ground plane splits in the time domain, **live demonstration**
- Effects of board layout, ground plane splits data in the frequency domain, sometimes live demonstration
- Emissions data from a PCB, paths that change layers
- Board layer stack-up effects
- IC coupling to nearby conductors, data and **video**
    - Inductive and capacitive coupling

Resonant Frequency of Physical Structures

- How to measure structural resonance
- Needed equipment
- Several examples with data
- Kinds of operational and EMC problems that can be found
- Sometimes as live experiments
- What does "grounding" mean in an EMC sense?

Cellphone Induced Problems

- Examples of field problems (devices destroyed by signals in the environment)
- Why you can't just use a cellphone to test for problems.
- A simple test for the development lab

Analog Design - RF and EMC issues

- Effect of RF on opamps
- Grounding and loop size is very important even for 1 MHz gain-bandwidth product devices
- Why GHz layout techniques may be needed even for 1 MHz gain-bandwidth product devices
- Mitigation via added components
- Mitigation via selecting suppliers of opamps

EMC Lab Test Errors – "Trust but Verify"

- How test lab errors can cost you in a big way
- Radiated Emissions
- Conducted Emissions
- Radiated Immunity
- Conducted Immunity
- Check list
- Test equipment to bring with you to the EMC lab

Day 3 – ESD/EMI at the System Level

System Level ESD/EMI

- Introductory **live demonstrations**
- IEC 61000-4-2 System ESD Testing
    - Description of the test
    - Problems with the test
    - Common errors that can fail a piece of equipment that should have passed
    - Application (or misapplication) to IC devices
- Cable discharge – a problematic form of ESD
    - Description of phenomena
    - Experimental data
    - A cable discharge test proposal (no current testing standard available)
- Unusual forms of ESD
    - Why passing standard tests still leaves equipment vulnerable in the field
    - di/dt and dv/dt effects
    - Characteristics of ESD
    - Unusual ESD sources not covered in any standard but that have caused field problems
    - Characteristics of unusual forms of ESD
    - Examples, experimental data, and **live demonstrations**

- Troubleshooting ESD problems
  - Equipment and methods needed
  - Experimental data
- Software considerations
  - An impressive example
  - I/O, memory, and processor issues
  - Software simulation of an ESD event
  - Methods to minimize risk from software
- Experiments (**live demonstrations** or by data depending on time and available equipment)
  - Transient suppression plane (Where is "quiet" ground? Where you least expect it!)
  - Using small inductors to improve ESD performance of equipment
  - Parallel wire experiment in the time domain with ESD
  - ESD effects in PCBs and cables

Advanced Troubleshooting Techniques for Circuits and Systems

- Stressing circuits and systems – pulsed excitation
  - Stressing individual ports of equipment
    - Tools
    - Methods
      - Capacitive coupling
      - Bulk injection probes and current probes
    - Results
    - Case histories
  - Stressing PCBs and IC devices
    - Tools
    - Method
      - Magnetic
      - Characteristics of the injected pulse
    - Results
    - Case histories
    - Video of the method in operation
    - Live demonstrations on test and operating PCBs
- Stressing circuits and systems – CW excitation
  - Tools
  - Methods
    - Similar to pulsed method but utilizing RF signal generators
  - Results
  - Case histories
- Locating impulsive events in 3D space
  - Room level – mobile event locator
  - Equipment level
  - PCB level
- Sources of tools and equipment