Conducted Susceptibility CS101

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CS101

- Applicability
  - DC and AC Input Power Leads
  - Does NOT include RETURNS or Output Power Leads
- Frequency Ranges
  - DC Power: 30 Hz to 150 kHz
  - 60Hz Power: 120 Hz to 150 kHz
  - 400Hz Power: 800 Hz to 150 kHz

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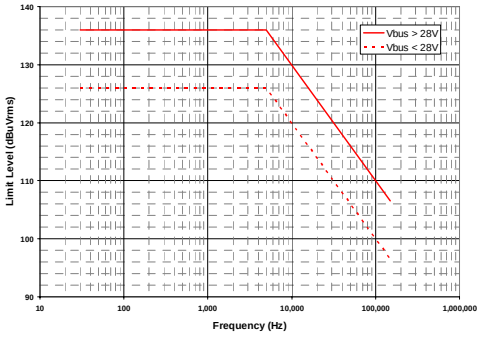
CS101 Limits



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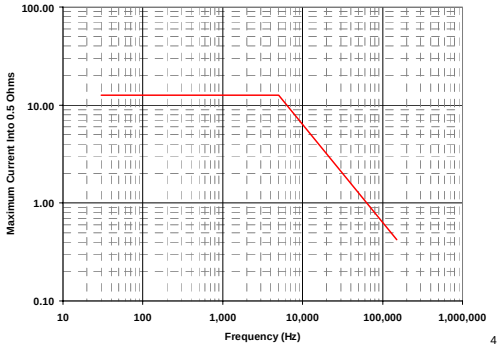
CS101 Maximum Current



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Basis For CS101 Limits

- Similar to CE102
- Based on Review of Power Quality Standards
- Emphasis on MIL-STD-704 Spectral Content Curves
- Voltage Amplitude Is Approximately 6 dB above typical power quality limits and is somewhat generalized to avoid complex curves
- Difference Between CE102 and CS101 of 26 dB SHOULD NOT be viewed as MARGIN
- CE102 Limit Set Such That Ripple Voltages Do Not Exceed That Allowed By Power Quality Standards For Multiple Unit Contributions
- Power Quality Standard is ONLY VALID Basis of Comparison
- Tailoring Limit Is Allowable But Primary Consideration Should Be To Closely Follow A Particular Power Quality Standard

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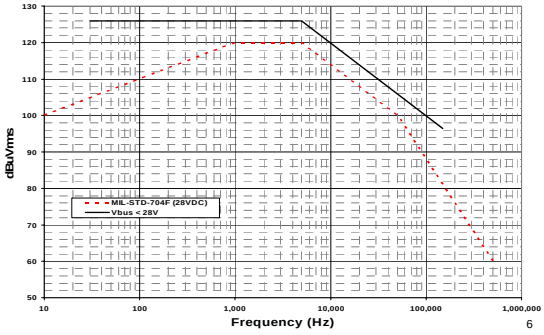
Comparison To MIL-STD-704 28Vdc or Less



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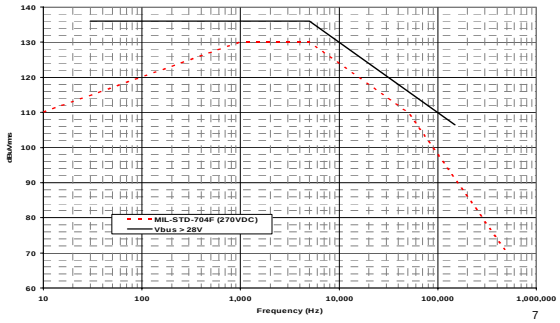
Comparison To MIL-STD-704 Greater Than 28Vdc



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CS101 Test Procedure

- Calibrate Test Setup Across 0.5 Ohm Resistor
- Configure Test Setup Properly For Power Type (DC, AC Single Phase, Three Phase AC)
- Power Up EUT and Allow Time To Stabilize
- Inject The Required Interference Voltage Level Per The Approved EMC Test Procedure Into The EUT
- If Unable To Inject The Required Voltage STOP At The Predefined Current or Power Limit Into 0.5 Ohm Load.

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CS101 Test Procedure

- Use Table III of Paragraph 4.3.10.4.1 as a guideline for Maximum Scan Rates or Maximum Stepped Frequencies
- Observe Minimum Dwell Times And Adjust As Necessary
- Monitor The EUT For Susceptibility
- Threshold The EUT As Required
- Repeat For All Required Voltage Lines or EUT Operational Modes
- Document The Test Results

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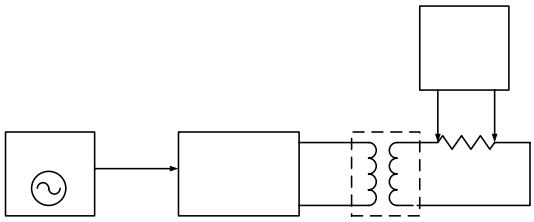
CS101 Calibration Setup



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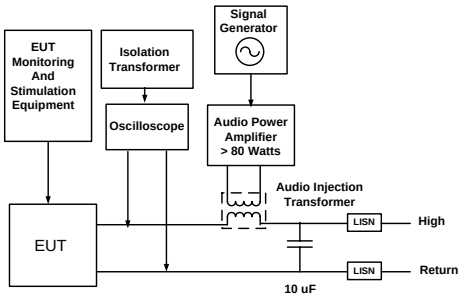
DC or Single Phase AC



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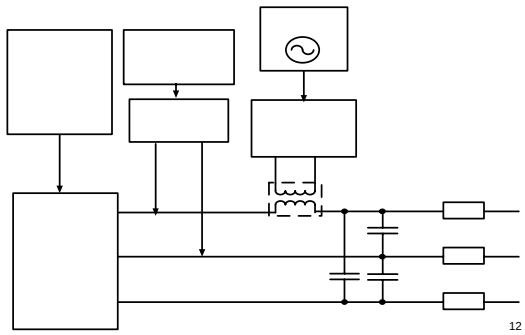
Three Phase AC Ungrounded



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Three Phase Ungrounded (Three Wire)

Coupling Transformer in Line	Voltage Measurement From
Phase A	Phase A to Phase B
Phase B	Phase B to Phase C
Phase C	Phase C to Phase A

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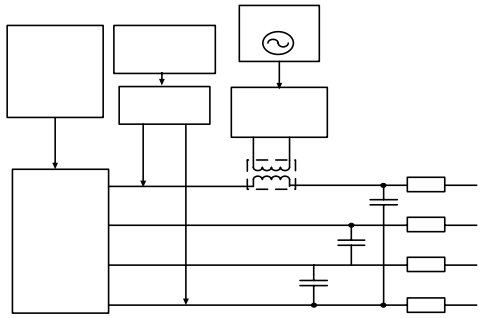
Three Phase AC WYE



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Three Phase Wye (Four Wire)

Coupling Transformer in Line	Voltage Measurement From
Phase A	Phase A to NEUTRAL
Phase B	Phase B to NEUTRAL
Phase C	Phase C to NEUTRAL

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Basis For CS101 Scan Rates

- Assumed Maximum Response Time of 3 Seconds Considered Appropriate For Large Percentage of Possible Cases
- Typical "Q" Values of 10 or less for Frequencies Below 1 MHz
  - $Q = f_o/BW$
- Analog Scan Rate 0.0333 f_o / Sec
- Stepped Scans 0.05 f_o

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Adjustments To Scan Rates

- The Time An EUT Is In Susceptible State May Be Limited, THEREFORE Scan Rates Must Be Adjusted.
- Mechanical Outputs May Require More Time To Respond Than Electronic Outputs.
- Analog Scan Rates May Be Inappropriate In Some Cases And Stepped Scans With Long Dwell Times May Be Required.
- Using Stepped Guidelines, 176 Frequency Steps Are Required For The Entire CS101 Range

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Threshold of Susceptibility

- When Susceptibility Is Detected Reduce Interference Signal Until EUT Recovers
- Reduce Interference By an Additional 6 dB
- Gradually Increase Interference Until Susceptibility Reoccurs. The Resulting Level Is The Threshold Of Susceptibility
- Record This Level, Frequency Range Of Occurrence, Frequency And Level Of Greatest Susceptibility And Other Test Parameters As Applicable.

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CS101 Analog Scan Rates

Frequency Range	Maximum Scan Rate	Actual Scan Time
30 Hz – 100 Hz	1 Hz / Sec	1.2 Minutes
100 Hz – 1 kHz	3.33 Hz / Sec	4.5 Minutes
1 kHz – 10 kHz	33.3 Hz / Sec	4.5 Minutes
10 kHz – 100 kHz	333 Hz / Sec	4.5 Minutes
100 kHz – 150 kHz	3.33 kHz / Sec	0.3 Minutes
	TOTAL SCAN TIME	**~ 15 Minutes**

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Comments About Injection Transformer Use

- May Be Required If Power Return Not Connected To Shielded Room Ground
  - Electrically "Floats" Oscilloscope
  - Creates Potential Shock Hazard!
- Differential Voltage Measurement Preferable
  - Eliminates Floating Oscilloscope
  - Eliminates Potential Shock Hazard
- Digital Oscilloscope Using Two Channels and Waveform Math
- Differential Voltage Probes

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Comments About AC Power

- Monitoring Injected Voltage Can Be Difficult on AC Lines
  - AC Power Frequency Voltages Much Larger Than CS101 Injected Signal
    - Typically, 25 to 65 dB!
  - Limited Dynamic Range of Oscilloscopes
  - Aliasing of Digital Oscilloscopes
    - Difficult, if not impossible to SIMULTANEOUSLY display large amplitude low frequency signal and low amplitude high frequency signal with accuracy!

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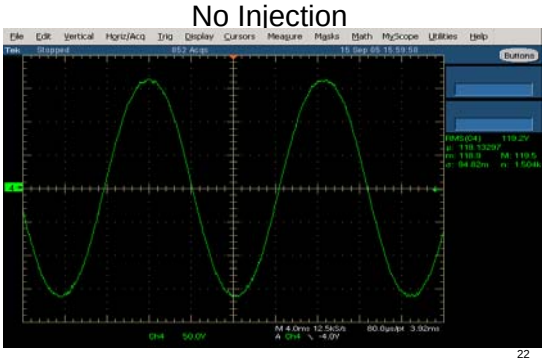
120VAC, 60 Hz EUT Monitoring No Injection



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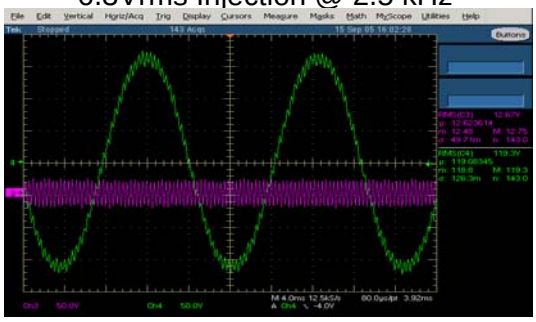
120VAC, 60 Hz EUT Monitoring 6.3Vrms Injection @ 2.5 kHz



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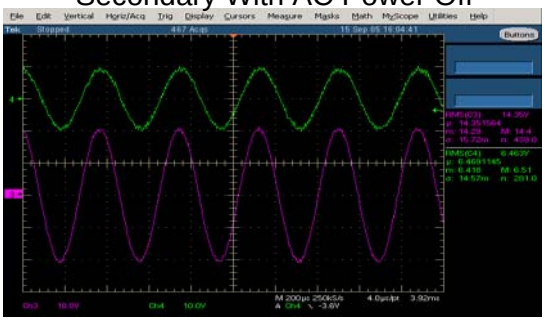
Transformer Primary and Secondary With AC Power Off



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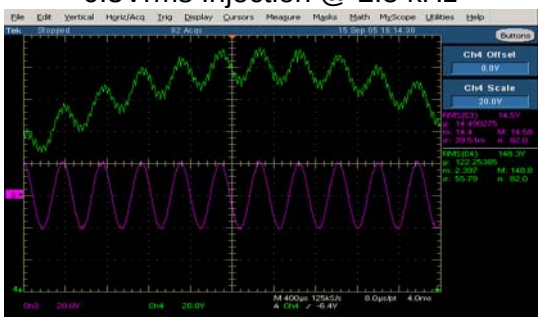
ZOOM IN:120VAC, 60 Hz EUT Monitoring 6.3Vrms Injection @ 2.5 kHz



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Comments About AC Power

- AC Line Voltage on Transformer Primary Induces Voltage on Transformer Secondary
  - High Current Loads Produce Larger Voltages
  - 400Hz Produces A Larger Voltage Than 60Hz
  - Significant Line Voltage Component Induced into Power Amplifier Output
    - Can Cause Problems or Damage Amplifier
- Impact on Power Amplifier Can Be Minimized
  - Two Identical Injection Transformers
  - Dummy Load
    - Same Current Draw
    - Same Power Factor

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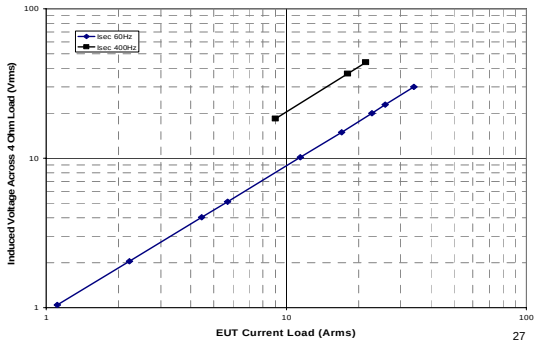
AC Line Voltage Into Amplifier



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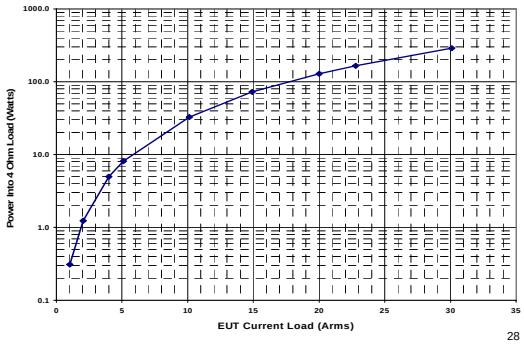
AC Line Power Into Amplifier



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Comments on AC Power (Continued)

- Impact on Power Amplifier Can Be Minimized (Continued)
  - The Secondary Side of Transformers Have Equal Loads
  - The Primary Sides are wired such that the loads are 180 Degrees out of phase
    - Thus "nulling" the AC Line Frequency component injected into the power amplifier output

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Comments on AC Power (Continued)

- Practical Limitations
  - Power Factor difference between EUT and Dummy Load
    - Phase Difference Impacts Cancellation
  - Difference in Injection Transformer
    - Voltage Amplitudes of Transformer Primaries

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Phase and Amplitude Imbalance

- The Imbalance Between The Amplitude And Phase Is Important
  - Phase Must be Within +/- 10 Degrees and Amplitude Within 6 dB for Rejection Better Than 6 dB!
  - See Graph

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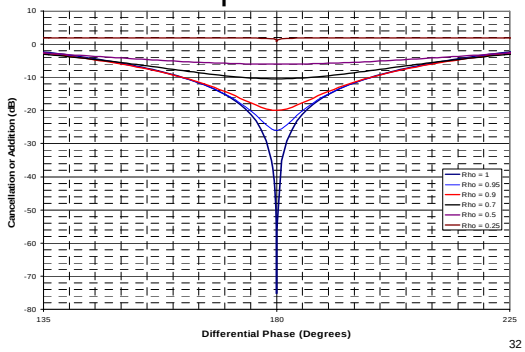
Phase & Amplitude Imbalance



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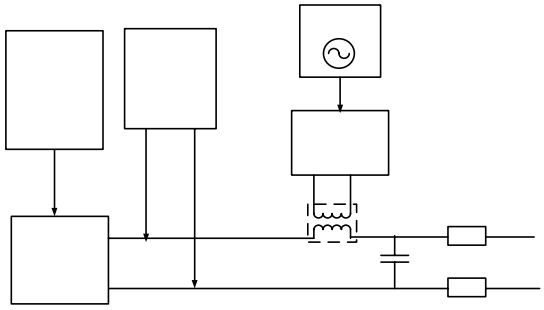
Setup Without Floating O'Scope



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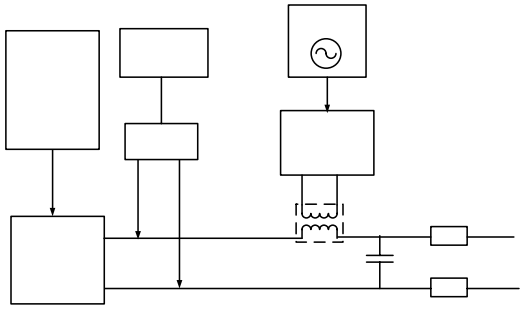
Setup Without Floating O'Scope



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Comments About 10 uF Capacitors

- The 10uF capacitor is meant to "control" the injected signal loop.
  - The 10uF is not ideal at low frequencies
  - Xc ~ 530 ohms at 30 Hz
  - Suggest using larger capacitor (~10kuF) with appropriate voltage ratings to better control the injected signal loop

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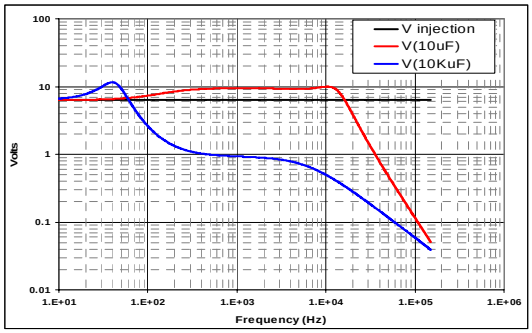
Replace 10uF Capacitor With 10kuF Capacitor



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Generator

EUT Monitoring And Stimulation Equipment

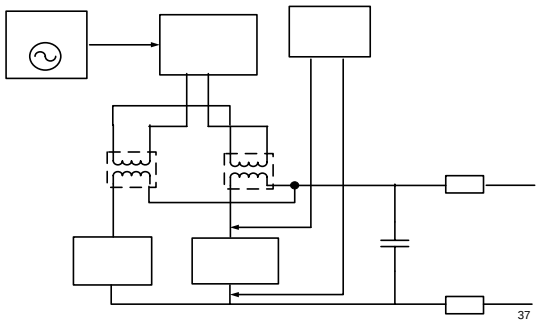
Oscilloscope

Waveform Math
Ch A + (Ch B)Inverted

Ch A **Ch B**

Audio Power

AC CS101 Power Amp Protection



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Other Uses Of CS101 Test Data

- The Injected Current and Voltage Can Be Used To Calculate The Input Impedance of The EUT
  - Measured With A Spectrum Analyzer
  - Can Be Compared To EUT Input EMI Filter Impedance
    - SPICE Simulation of Test Setup With EMI Input Filter
  - This Approach Has Found "Miswired" Filter Components
    - i.e. Wrong Winding Sense on Common Core "L"

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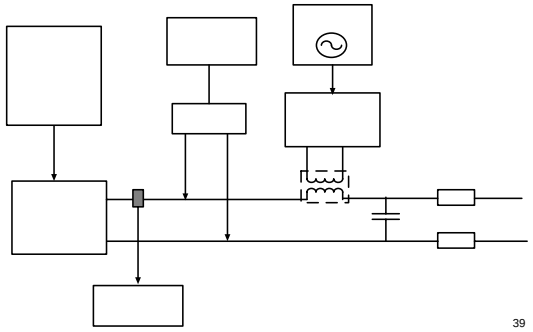
Signal Generator

Audio Power Amplifier > 80 Watts

Voltage Monitoring Device*

*Oscilloscope or Spectrum Analyzer

Setup For Measuring Z_{EUT}



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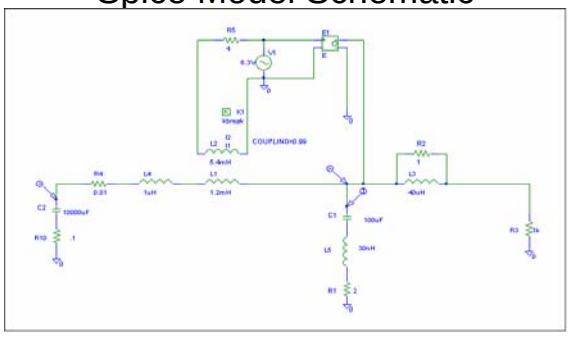
Spice Model Schematic



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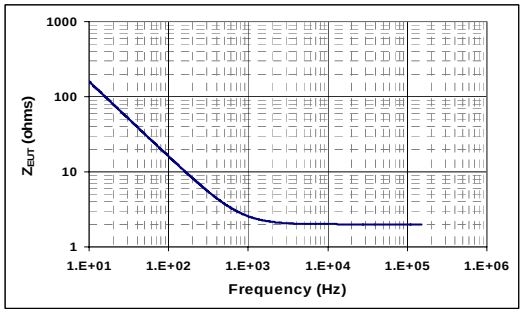
Equi Un Te

Return

LISN

Z_{EUT} From Spice Simulation



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Modeling The CS101 Test Setup

- Evaluate EMI Filter Design
- Find Problems Early
- Correct Sizing Of Damping Resistor Wattage
  - Compare To Current/Wattage Limits
- Can Help With Troubleshooting Out-Of-Specification Conditions
  - Test Data Should Trend Spice Simulation
    - Injected Voltage
    - Injected Current
    - Impedance

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Signal Generator

Spectrum Analyzer (Voltage)

EUT Monitoring And Stimulation Equipment

Differentia Voltage Probe

Audio Power Amplifier

EUT Monitoring Considerations

- If EUT Current Draw Varies Significantly
  - Test At Low EUT Current
  - Test At Nominal Current
  - Test At High EUT Current
- Non Air Core Inductors Will Lose Inductance With Increased Current
  - Design With This In Mind
  - Can Be Modeled in Spice with BH Curves If Available
- Bus Voltages
  - Always Set Voltage At EUT Under Load
  - Nominal, Minimum and Maximum
  - Injected Ripple When Imposed On Minimum Voltage Can Be Problematic If EUT Has Linear Regulator.

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Summary

- Conducted Susceptibility Test Limits Are Based Upon Power Quality Specifications Not CE102 Levels.
  - Tailoring Is Allowable With This In Mind
- Scan Rates Are Based Upon Unit Q of 10 And Assumed 3 Second EUT Response Time
  - Scan Rates Should Be Adjusted If Necessary
- If Voltage Level Can Not Be Met Use Power Limit Curve Into 0.5 Ohms
- 10uF Capacitor Should Be Increased To "Control" Injected Signal Loop.
- AC CS101 Testing Starts At 2nd Harmonic
- Monitoring The Injected Voltage on AC Power Lines Is Difficult With An Oscilloscope.
  - Recommend Using A Spectrum Analyzer or EMI Receiver With Properly Rated Probe
- Specific Injection And Monitoring Configurations Are Outlined For Single Phase, Three Phase Ungrounded, And Three Phase Wye

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Summary (Continued)

- AC High Current EUT Can Induce Significant Voltages Into The Power Amplifier Via The Injection Transformer And Damage Power Amplifier
- Power Amplifier Can Be Protected With Two Transformers
  - Primaries Phased To Cancel Power Line Frequency
  - Secondaries Are Tied To EUT and Dummy Load of Same Current /Power Factor
- Modeling The Input EMI Filter With Spice Is A Valuable Tool
  - Can Find Problems Early
  - Check Input Damping Resistor Power Rating
  - Can Let You Know What To Expect BEFORE The Test
  - Can Be Used In Conjunction With Test Data To Check Schematic To "As Built" For Errors
- Account For Heavy Current Loads When Sizing Non Air Core Inductors
  - Test Multiple Current Levels
- Always Set EUT Voltage At EUT Under Load
  - Account For Voltage Drops
  - Know Whether To Test At Nominal, Minimum or Maximum Voltage(s)
  - Be Wary Of EUT's With Linear Regulation

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