Fault Detection of Digital I&C Systems Using Integrated Electromagnetic Compatibility and Automated Functional Testing

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Phase II SBIR R&D Project Related to Digital I&C Testing

Fault Detection of Digital I&C Systems Using Integrated Electromagnetic Compatibility and Automated Functional Testing

Goal: Develop a system to perform simultaneous EMC and AFT of digital I&C during development/commercial dedication phase.

Fault Detection of Digital I&C Using Integrated ECM and AFT

OVERVIEW

Purpose:
Develop a commercial system to automate and integrate Electromagnetic Compatibility (EMC) testing and automated functional testing (AFT) of digital instrumentation and control (I&C) into a common platform. The combination of EMC and AFT represents a unique and powerful technique for detecting faults that would not normally be identified using conventional EMC and AFT practices separately.

Objectives:
- Develop a system that uses simultaneous EMC testing and functional testing to reveal digital device susceptibilities/emissions not detected using conventional EMC testing methods.
- Develop hardware/software automation systems to enhance the efficiency of conventional EMC and functional testing.

IMPACT

Logical Path:
1. Research methods to automate EMC testing and AFT
2. Develop software modules to implement automated EMC and AFT methods.
3. Develop a software architecture for integrating automated EMC testing and AFT
4. Integrate individual EMC and AFT software modules into integrated system architecture
5. Test and validate integrated system

Outcomes:
Exercising the inputs of a digital I&C equipment-under-test (EUT) and verifying the outputs (functional testing) while simultaneously performing EMC testing can reveal operating modes of the digital device that produce more electromagnetic emissions than expected. Similarly, subjecting a DUT to a range of electromagnetic/radio frequency interference (EMI/RFI) in different operating modes can reveal functional faults that may not be detected during conventional EMC testing.

DETAILS

Principal Investigator: Greg Morton

Institution: Analysis and Measurement Services Corporation (AMS) www.ams-corp.com

Collaborators: N/A

Duration: 36 Months (24 Months + 12 Month No-Cost Extension)

Funding: $999,775 (FY2019 $499,959; FY2020/2021 $499,816)

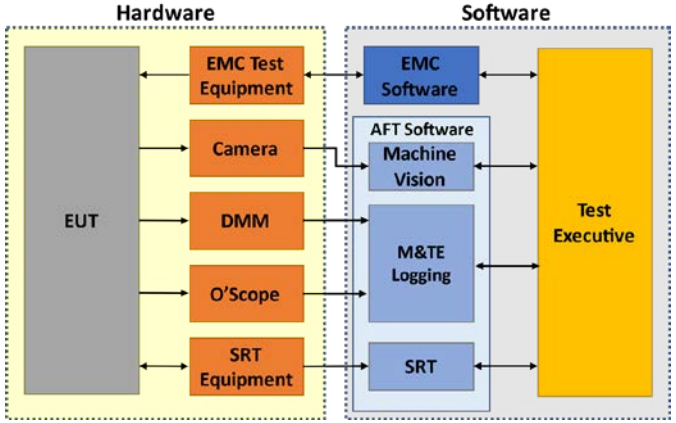
TPOC (Technical Point of Contact): Greg Morton

Federal Manager: Daniel Nichols

PICS:NE Workpackage: DOE Award Number DE-SC0018867

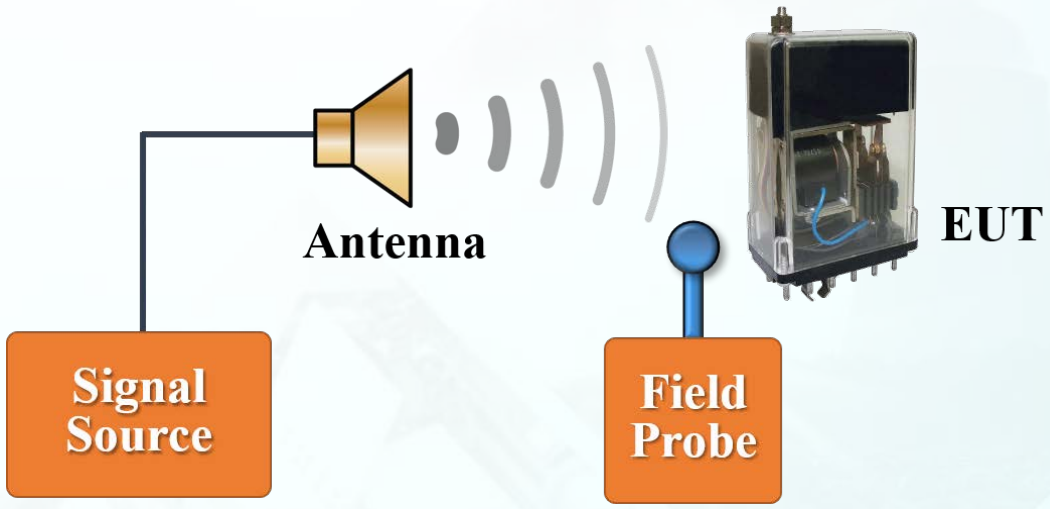
RESULTS

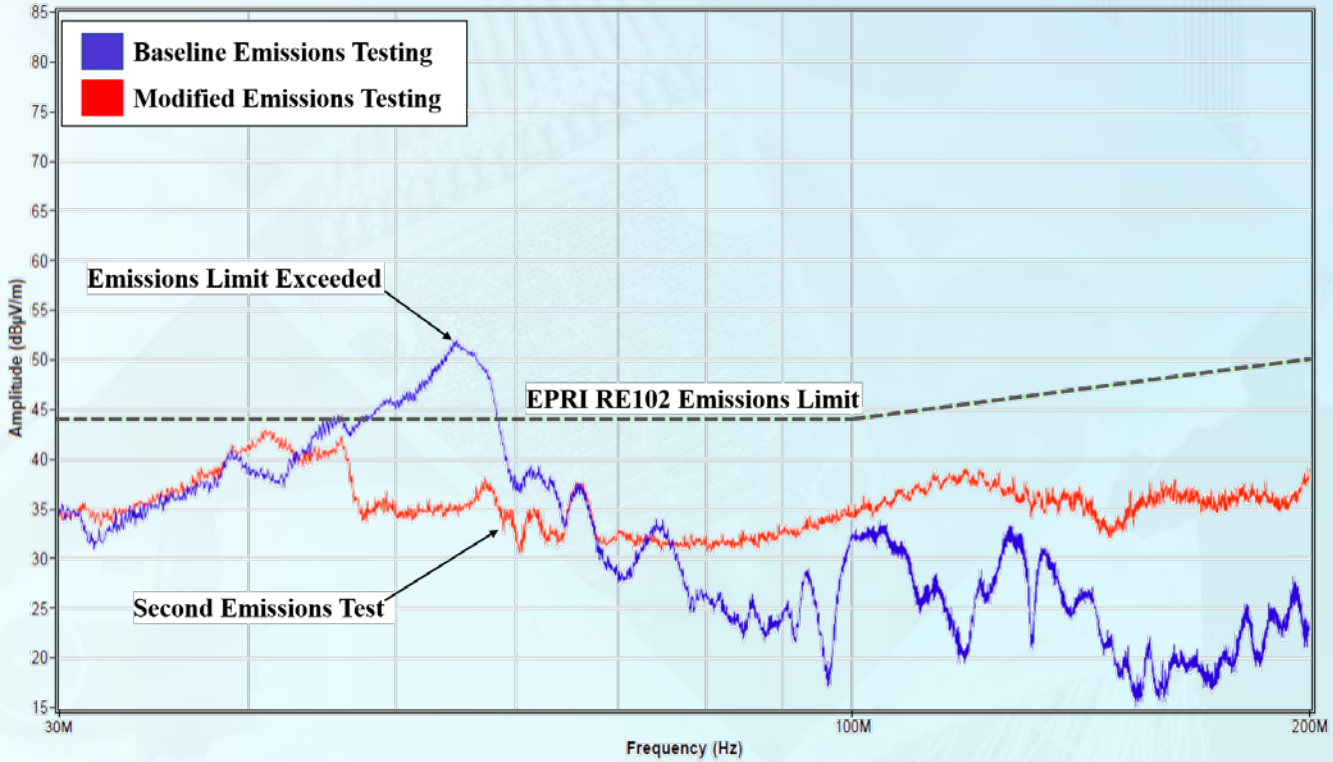
Accomplishments:
1. Developed several individual software modules for automating EMC and functional testing.
2. Developed an architecture for integrating software modules into a combined testing system.
3. Integrated several EMC/AFT software modules into the combined architecture
4. Preliminary testing of integrated system
5. Published several papers on project accomplishments



What is Electromagnetic Compatibility Testing?

Ability of device under test (EUT) to perform its intended function without adversely affecting or being affected by the electromagnetic environment (EME) in which it is installed.



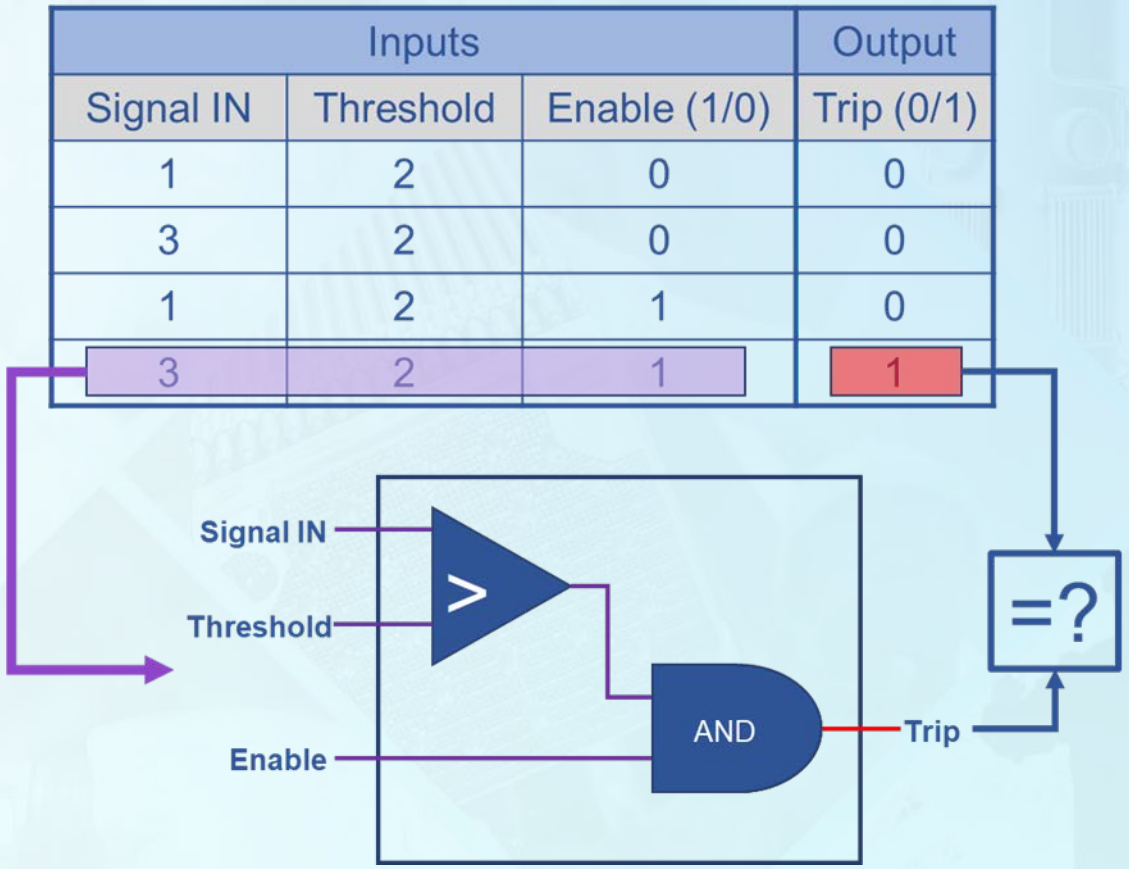


What is Functional Testing?

Functional testing exercises digital equipment inputs and compares the outputs to expected values to quantify system reliability.

- Table defines the operation of a simple digital device.
- The inputs are sent to the EUT
- The output of the EUT is measured
- The output of the EUT is compared to the predicted output
- Repeat for x number of test cases

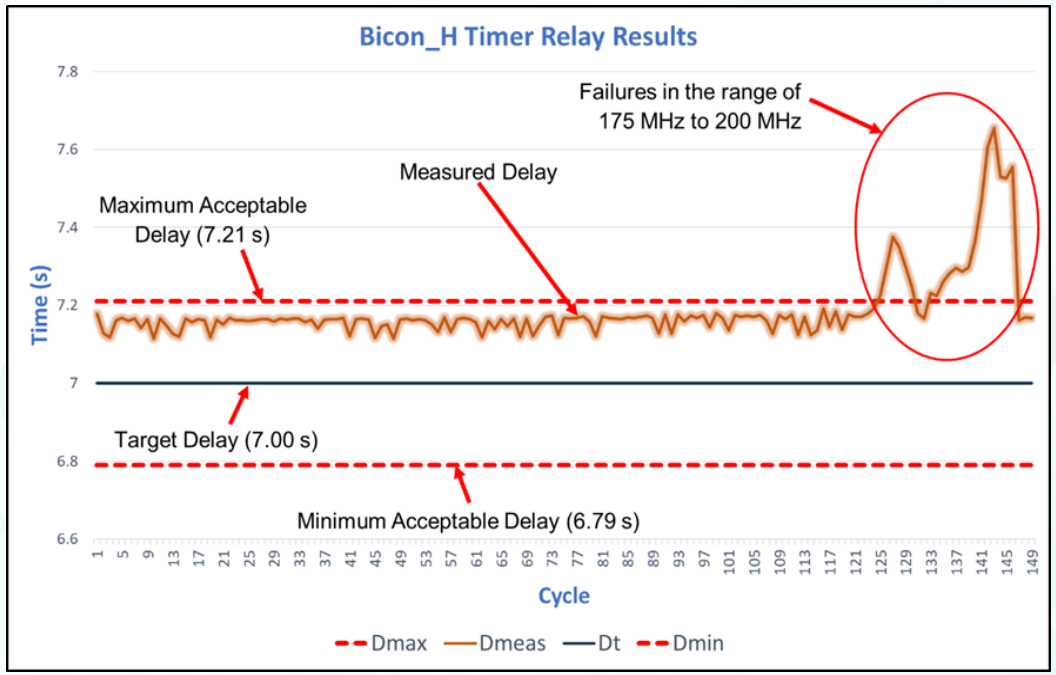
Inputs			Output
Signal IN	Threshold	Enable (1/0)	Trip (0/1)
1	2	0	0
3	2	0	0
1	2	1	0
3	2	1	1

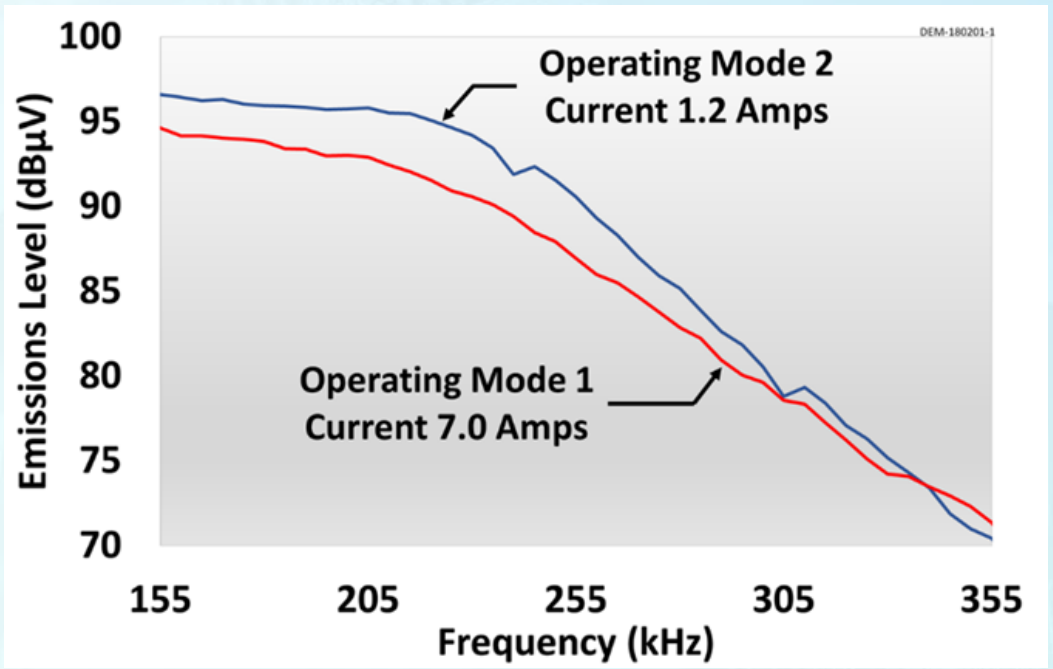


Does the output match the predicted output for the given set of inputs?

What is the Advantage of Combining EMC and Functional Testing?

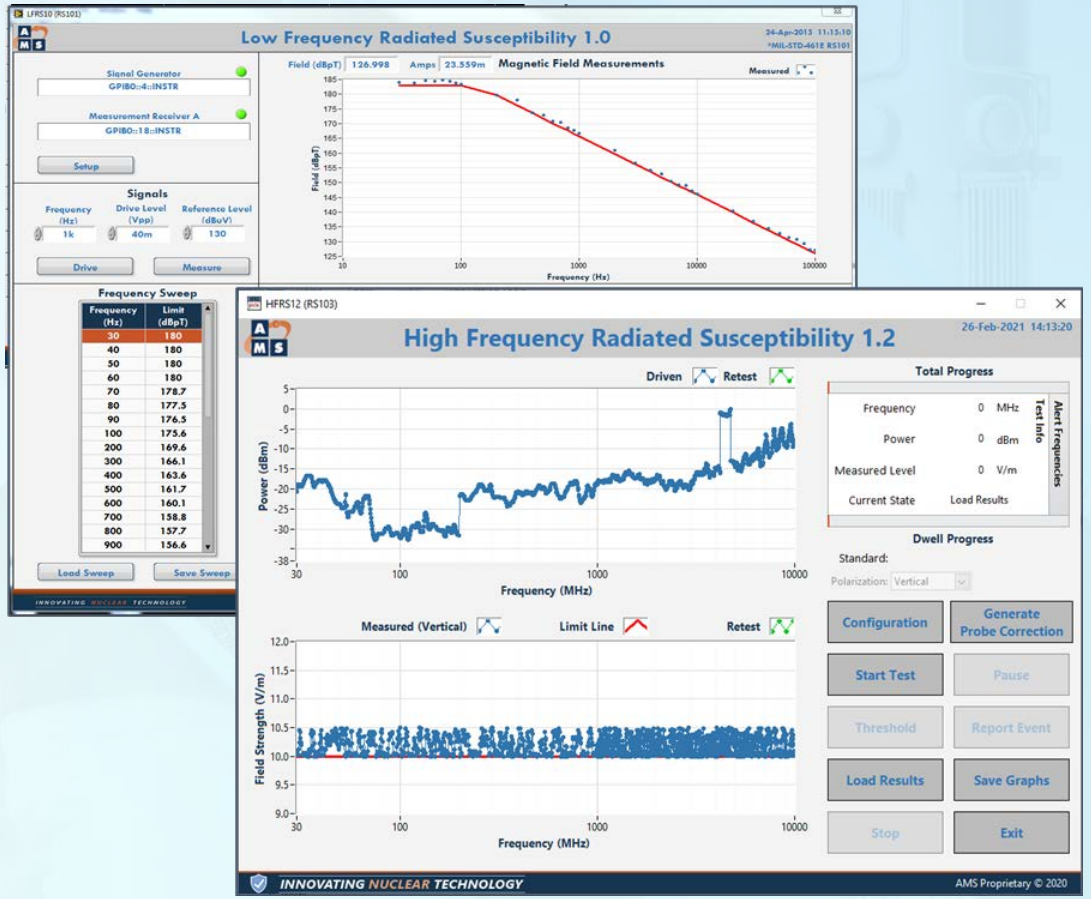
- Functional testing can be used to access different device states during testing
- Functional testing can reveal hidden faults that would not normally be found during typical EMC testing
- Benefits OEMs, EMC testers, and industry by providing more thorough fault detection





Technical Highlights:
Development of EMC Test Automation Software in Phase II

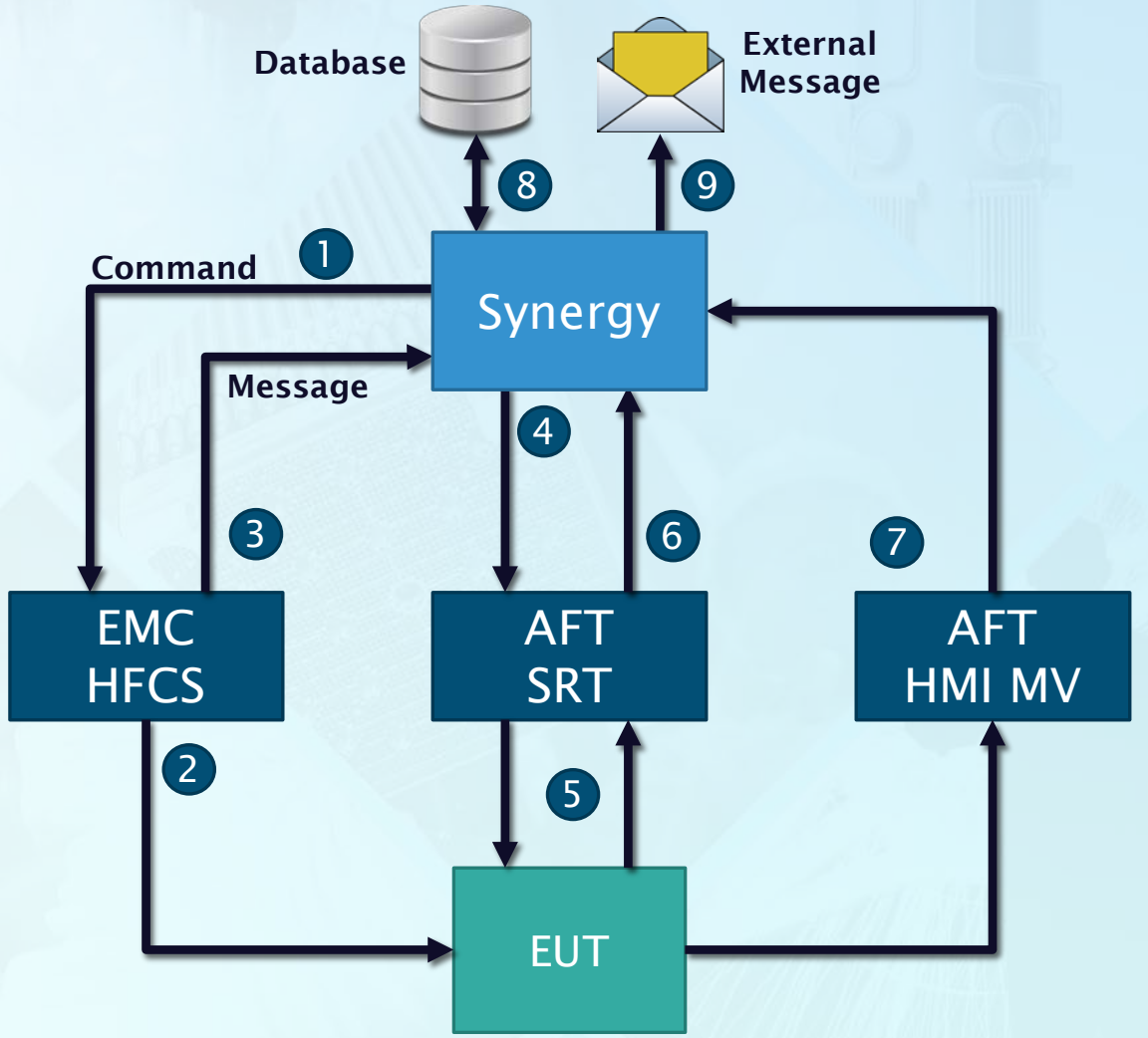
Test	Description
CE101	Low Frequency Conducted Emissions
CE102	High Frequency Conducted Emissions
RE101	Low Frequency Radiated Magnetic Field Emissions
RE102	High Frequency Radiated Electric Field Emissions
RS101	Low Frequency Radiated Magnetic Field Susceptibility
RS103	High Frequency Radiated Electric Field Susceptibility
CS101	Low Frequency Power Leads Conducted Susceptibility
CS114	High Frequency Bulk Cable Injection Conducted Susceptibility
61000-4-3	High Frequency Radiated Electric Field Susceptibility
61000-4-6	High Frequency Conducted Susceptibility
61000-6-4	Conducted and Radiated Emission Standard for Industrial Environments
61000-6-13	Low Frequency Conducted Harmonics and Inter Harmonics Susceptibility
61000-6-16	Low Frequency Conducted Common Mode Susceptibility



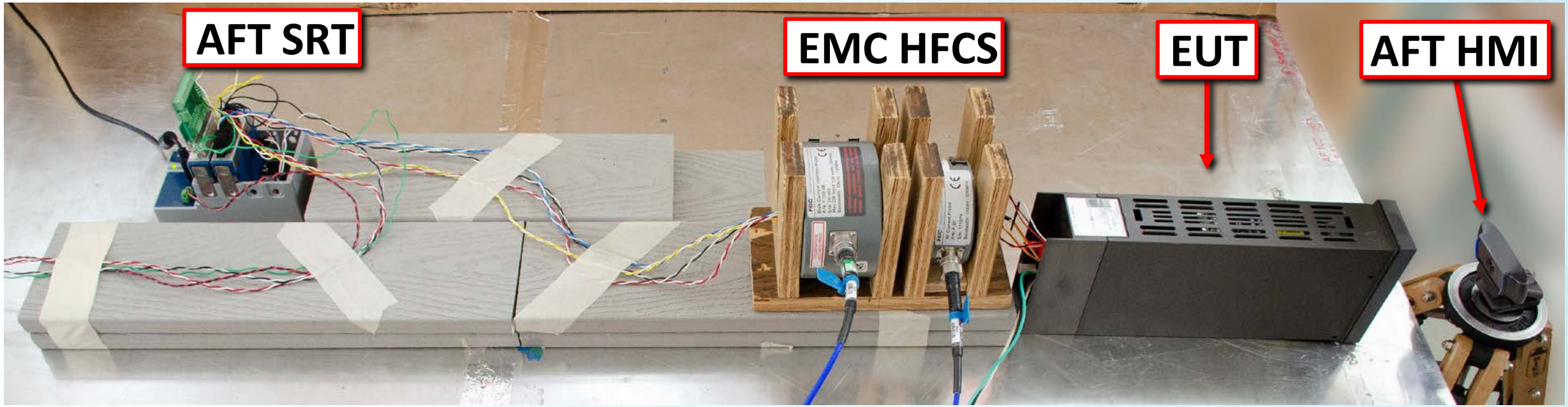
Technical Highlights:
Implementation of System Architecture in Phase II

Synergy Test Sequence

1. Command EMC to Output Test Frequency
2. EMC HFCS Output Test Frequency to EUT
3. EMC HFCS Message in Dwell
4. Command AFT SRT to Start Functional Test
5. AFT SRT Exercise EUT Inputs / Measure Outputs
6. AFT SRT Message Any Faults or Done
7. AFT HMI Machine Vision Message Any Faults
8. Log Messages in Database / Repeat Until Done
9. Send External Message Test Completed



AFT + EMC Lab Test Setup



Automated Functional Test Cases

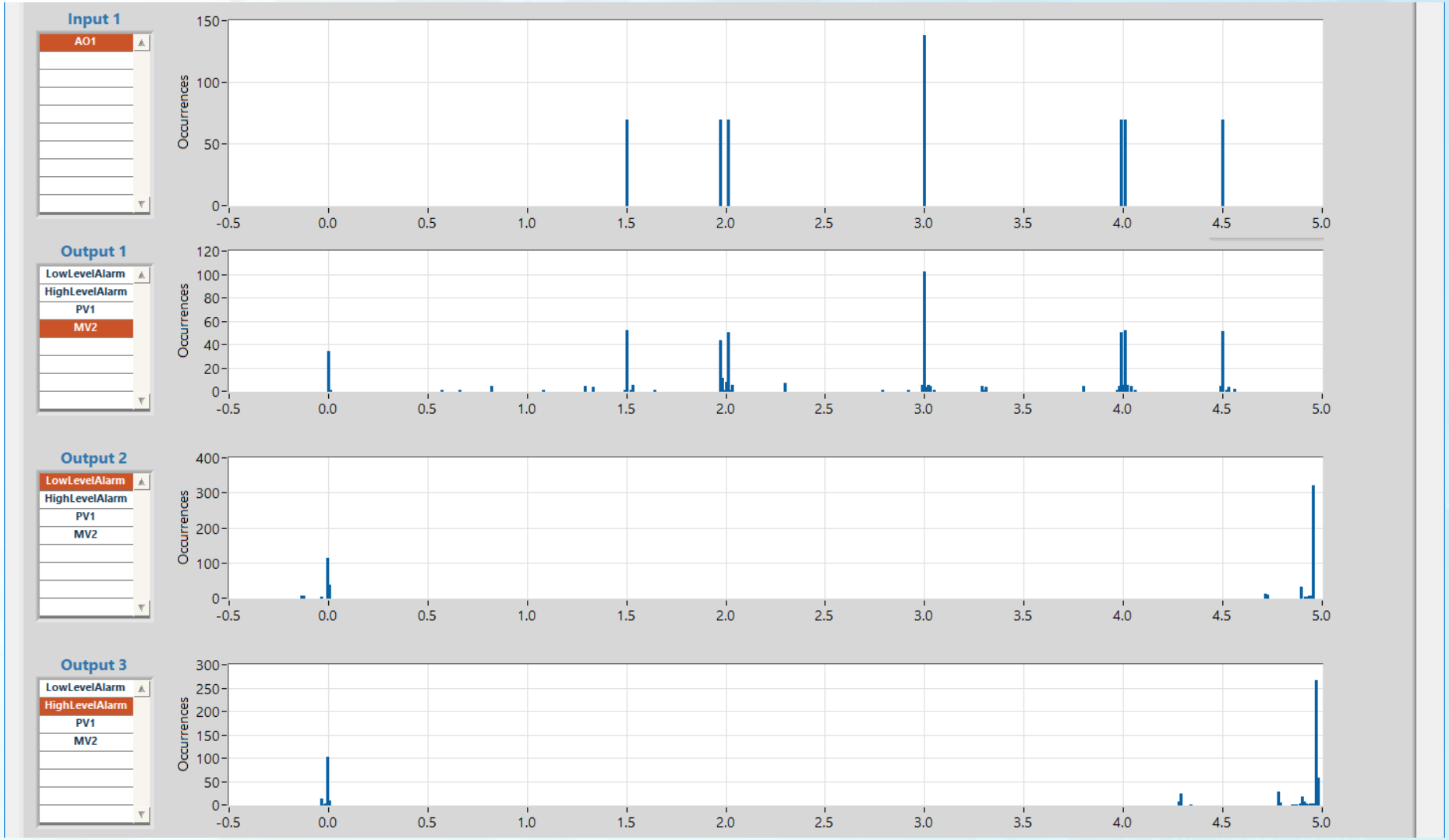
Test Cases	Inputs	Outputs							
	AO1	PV1		MV2		Low Alarm		High Alarm	
	Volts	Min	Max	Min	Max	Min	Max	Min	Max
1	3.000	2.800	3.200	2.800	3.200	4.800	5.200	4.800	5.200
2	1.972	1.772	2.172	1.772	2.172	-0.200	0.200	4.800	5.200
3	1.500	1.300	1.700	1.300	1.700	-0.200	0.200	4.800	5.200
4	2.009	1.809	2.209	1.809	2.209	4.800	5.200	4.800	5.200
5	3.000	2.800	3.200	2.800	3.200	4.800	5.200	4.800	5.200
6	4.009	3.809	4.209	3.809	4.209	4.800	5.200	-0.200	0.200
7	4.500	4.300	4.700	4.300	4.700	4.800	5.200	-0.200	0.200
8	3.988	3.788	4.188	3.788	4.188	4.800	5.200	4.800	5.200

HMI Camera Monitor

- VisionTRX software from ETS-Lindgren was used to monitor the EUT front panel
- The AFT was used to apply the 8 test cases and measure the outputs while the EMC HFCS testing was being performed
- Synergy was then used to aggregate this data and determine what frequencies had valid faults.
- Some faults only exist in specific test cases

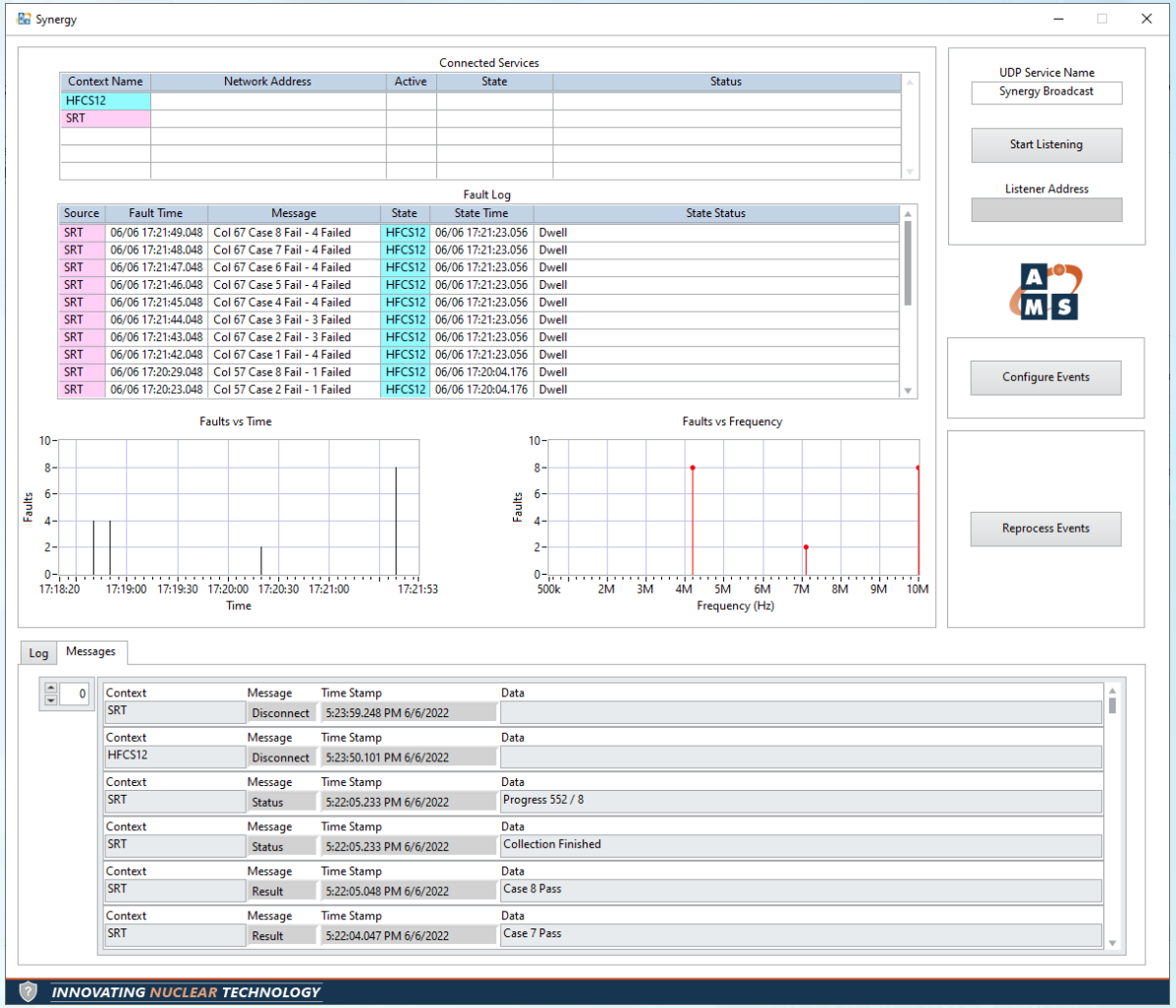
Input and Output Measurements During AFT and EMC

- Traditional EMC Testing would set the input in normal operation at 3 Volts in this example
- AFT test cases place the EUT in Normal, Low Alarm, High Alarm and tests the boundary conditions around the alarm setpoints.
- This uncovered some test cases (2 and 8) near the alarm setpoints that only fail at specific frequencies.



Synergy During AFT and EMC Testing

- Synergy receives messages from the EMC testing (HFCS12) and AFT (SRT)
- Synergy filters out any invalid faults when the EMC test was not dwelling at a test frequency
- The faults versus and time and frequency are plotted.
- This allows the individual test cases in AFT that failed to be evaluated

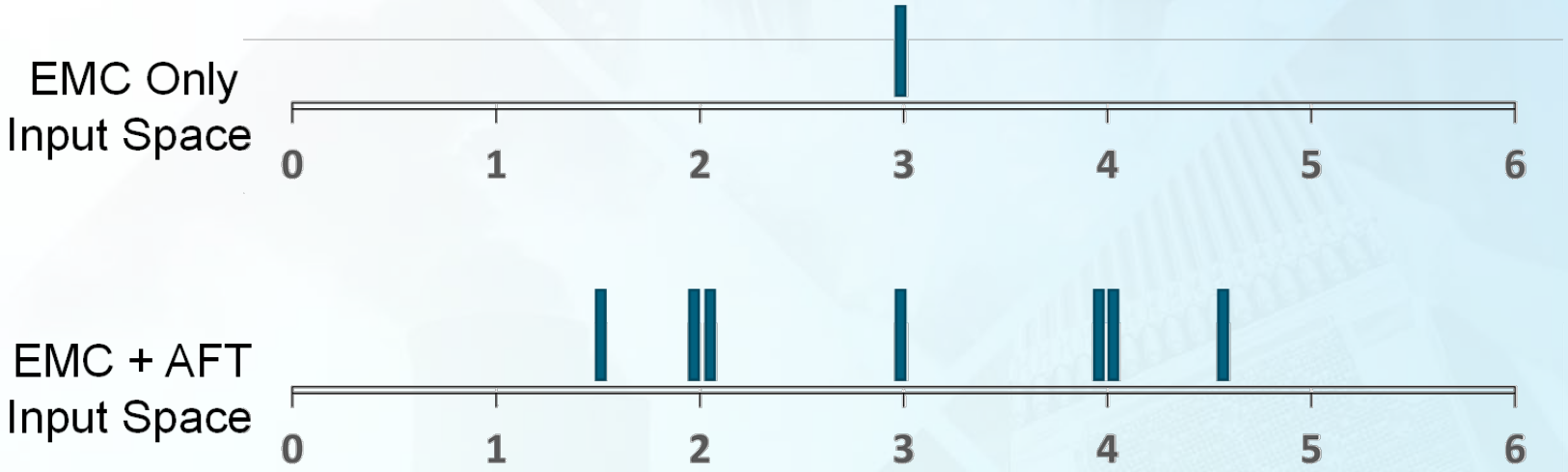


Example of AFT Low Alarm Test Case Failure

Test Cases

	Input Names	Input Values	Output Names	Expected Output Values	Measured Output Values	Pass / Fail
Test Case 1	AO1	3	LowLevelAlarm	[4.8-5.2]	4.899000911	Passed
			HighLevelAlarm	[4.8-5.2]	4.902811139	Passed
			PV1	[2.8-3.2]	3.058654549	Passed
			MV2	[2.8-3.2]	3.028631192	Passed
Test Case 2	AO1	1.972	LowLevelAlarm	[-0.2-0.2]	4.898841715	Failed
			HighLevelAlarm	[4.8-5.2]	4.902679545	Passed
			PV1	[1.772-2.172]	2.029390352	Passed
			MV2	[1.772-2.172]	2.000197544	Passed
Test Case 3	AO1	1.5	LowLevelAlarm	[-0.2-0.2]	-0.005573650833	Passed
			HighLevelAlarm	[4.8-5.2]	4.900495089	Passed
			PV1	[1.3-1.7]	1.559945267	Passed
			MV2	[1.3-1.7]	1.528726835	Passed
Test Case 4	AO1	2.009	LowLevelAlarm	[4.8-5.2]	4.89878865	Passed
			HighLevelAlarm	[4.8-5.2]	4.902600589	Passed
			PV1	[1.809-2.209]	2.067305434	Passed
			MV2	[1.809-2.209]	2.03452078	Passed
Test Case 5	AO1	3	LowLevelAlarm	[4.8-5.2]	4.899107041	Passed
			HighLevelAlarm	[4.8-5.2]	4.902758501	Passed
			PV1	[2.8-3.2]	3.05931926	Passed
			MV2	[2.8-3.2]	3.024867217	Passed
Test Case 6	AO1	4.009	LowLevelAlarm	[4.8-5.2]	4.896719109	Passed
			HighLevelAlarm	[-0.2-0.2]	-0.03103333	Passed
			PV1	[3.809-4.209]	4.069838623	Passed
			MV2	[3.809-4.209]	4.035112709	Passed
Test Case 7	AO1	4.5	LowLevelAlarm	[4.8-5.2]	4.896692576	Passed
			HighLevelAlarm	[-0.2-0.2]	-0.03158602375	Passed
			PV1	[4.3-4.7]	4.561671155	Passed
			MV2	[4.3-4.7]	4.528088082	Passed
Test Case 8	AO1	3.988	LowLevelAlarm	[4.8-5.2]	4.896692576	Passed
			HighLevelAlarm	[4.8-5.2]	-0.03216503625	Failed

Comparison of EMC and EMC+AFT



EMC Test Frequency	Fault Detected?	
	EMC Only	EMC + AFT
4.18 MHz	Yes	Yes
7.10 MHz	No	Yes
10 MHz	Yes	Yes

Conclusion

- **Benefits to Industry**

  This work enables faults to be detected that are not seen with EMC testing alone which allows these vulnerabilities to be mitigated before installed in the nuclear industry.

  The streamlining of EMC emissions and susceptibility testing in this project will greatly benefit the nuclear industry and the public by reducing the testing time, installation time, and downtime inherent in these complex systems.

  Reducing the costs for digital equipment development and validation also enables the introduction of new digital equipment into the market which will provide improved safety, more reliable power generation, and minimized electricity costs to the public.

Publications & Conferences

Automated Function Testing for Nuclear Digital Instrumentation and Control Systems

G. Morton, B. Shumaker, et.al.

ANS 2020 Annual Meeting, June 7-11, 2020

Methods for Automating Electromagnetic Compatibility Testing

G. Morton, B. Shumaker, et.al.

ANS 12th NPIC HMIT Topical Meeting, June 13-17, 2021.

Fault Detection During Electromagnetic Compatibility Testing

G. Morton, B. Shumaker, et.al.

ANS Annual Meeting, June 12-16, 2022

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Thank You