Electrical Infrastructure Research Team (EIRT) Cape May Test Results Summary

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Electrical Infrastructure Research Team (EIRT)

- **The EIRT was formed in 2011 to investigate optimal ways that power could be delivered to airfield fixtures that use Light Emitting Diode (LED) components.**
- **The EIRT is made up of the following:**
  - FAA Researchers
  - Lighting Manufacturer Product Design Engineers
  - Academic Researchers
  - Airfield Lighting Subject Matter Experts

EIRT Testing and Reports

- There has been previous testing and reporting on architectural concept infrastructures
- Cape May testing completed to develop information on some outstanding questions from previous testing.
- Detailed test results will be in the report that was completed and will be published

EIRT Electrical Infrastructure Concepts

- **Two LED infrastructure concepts have been selected by the EIRT for further testing:**
  - “Vault-centric”: Light intensity is controlled by a power source for the entire circuit. The fixtures are passive and directly track circuit current.
  - “Fixture-centric”: Each fixture controls its intensity level after intensity information is conveyed to it.

Cape May Testing

- Each LED lighting infrastructure concept was tested under a series of stress conditions to assess operational margins and overall suitability of each concept for the airport environment.
- Testing was conducted at the FAA's Research Taxiway at Cape May County Airport. (WWD)

Cape May Airport

Cape May Research Taxiway

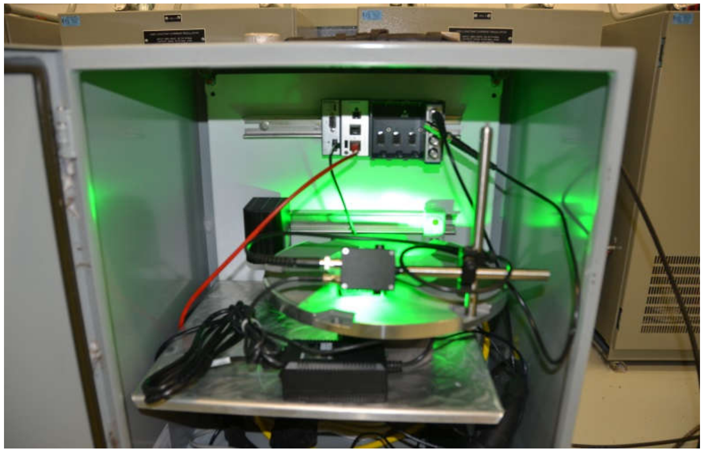
Field Service Panels

Research Taxiway Lighting Vault

Vault Interior

Vault-Centric Infrastructure

- 146 LED light fixtures installed along FAA Research Taxiway including taxiway centerline and runway edge light fixtures.
- Series topology PWM On Circuit, with 10/15 watt isolation transformers
- Three additional fixtures (for 149 total) instrumented with photometric sensors to measure relative light output and current probes to measure fixture current.
- Each instrumented fixture is mounted in a separate mobile cabinet that was located at various points on the circuit, depending on requirements of specific tests.

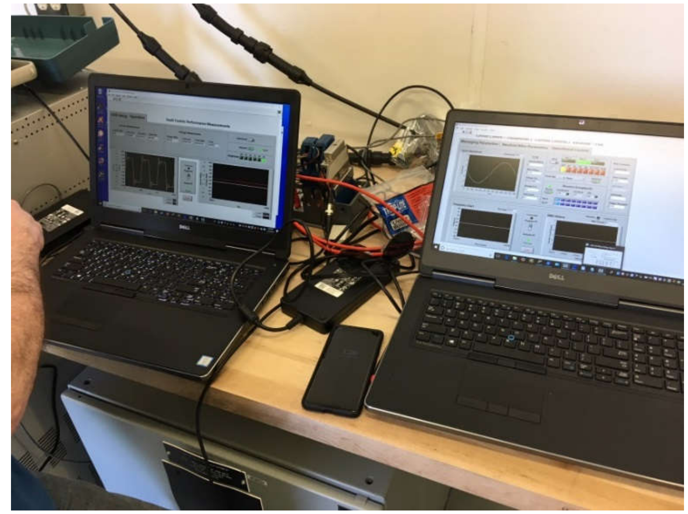


Fixture-Centric Infrastructure

- **136 LED fixtures, supplied by three manufacturers, placed on 3 sign pads along FAA Research Taxiway.**
- **Light fixtures were production units with modified firmware placed on sign pad on series circuit**
- **Three light fixtures instrumented for a total of 139, with current probes to measure fixture current and count occurrences of successful intensity commands.**
- **Each instrumented fixture is mounted in an orange electrical panel located adjacent to one of the groups of fixtures.**

Vault-Centric and Fixture-Centric Test Interfaces

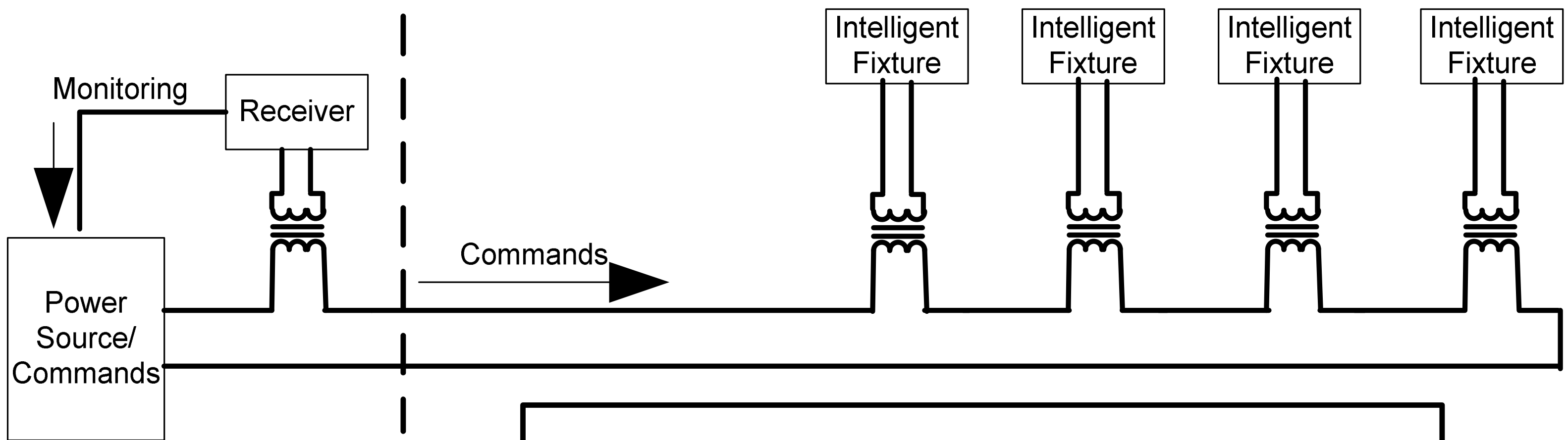
- **Test data recorded on laptop computers and oscilloscopes located in lighting vault.**
- **Vault Centric Performance Data from photometric and current sensors recorded during testing.**
- **Fixture Centric Data consists of successful intensity messages also recorded during testing**
- **Remote Data from field instrumentation uses the existing Cape May fiber network.**

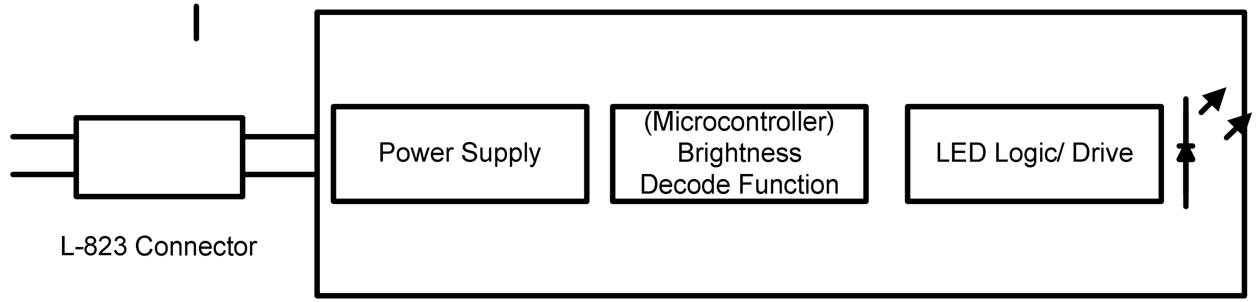


Fixture Centric Architectural Characteristics

- Interoperability has been demonstrated
- Uses existing infrastructure of cables and transformers
- Reduced circuit current
- Modified 6.6 amp platform
- Reduced power consumption
- Robust performance in poor electrical environment
- Fixture controls its light engine, not impacted by incorrect current
- Retains support for shared signs, windcones or similar components
- Addressable in groups– Selecting direction and/or groups of lights
- Eliminates selector switch requirement
- Heater control is independent of fixture intensity
- Can support Legacy Mode for 6.6 amp operation

Fixture Centric Amplitude Shift Keying (ASK) and Frequency Shift Keying (FSK)
Digital Bit Stream

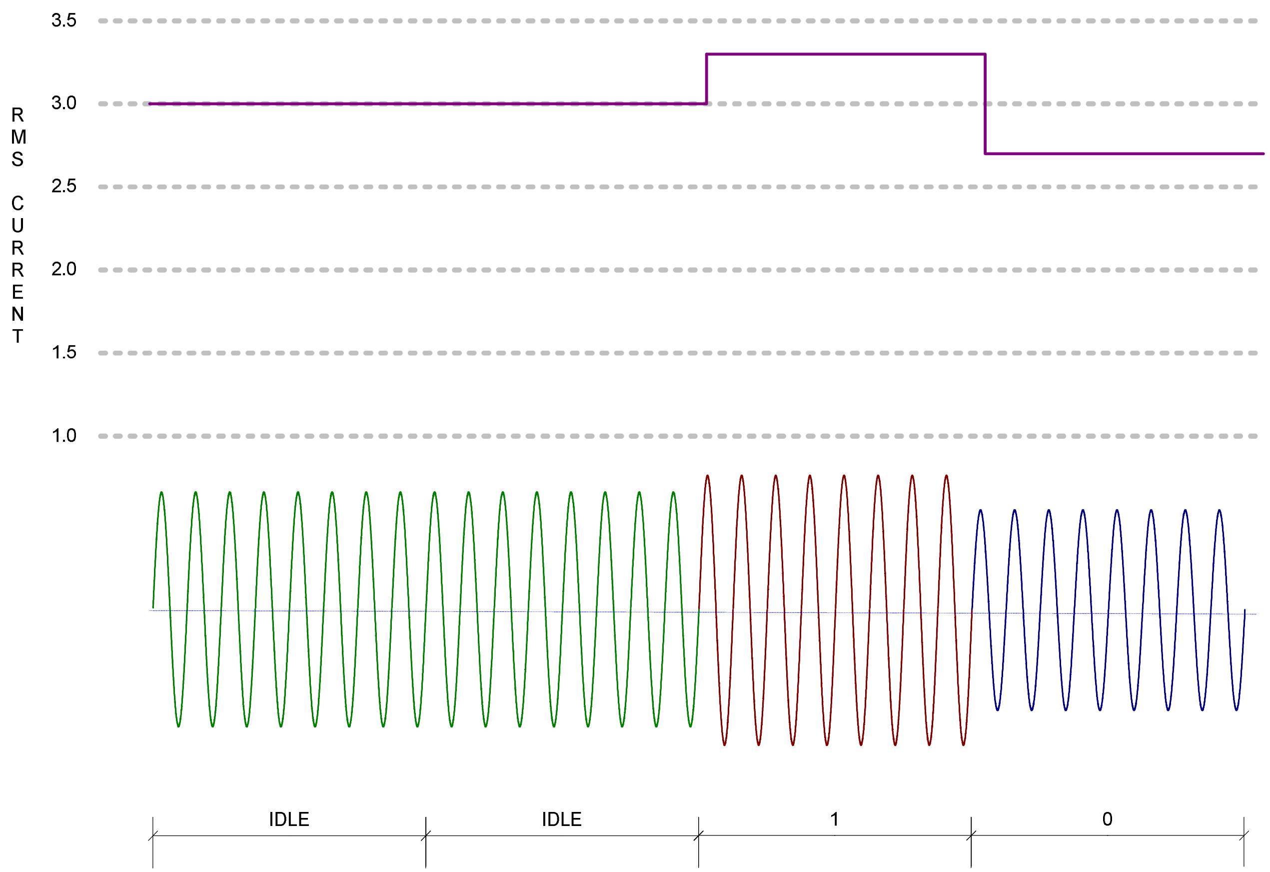




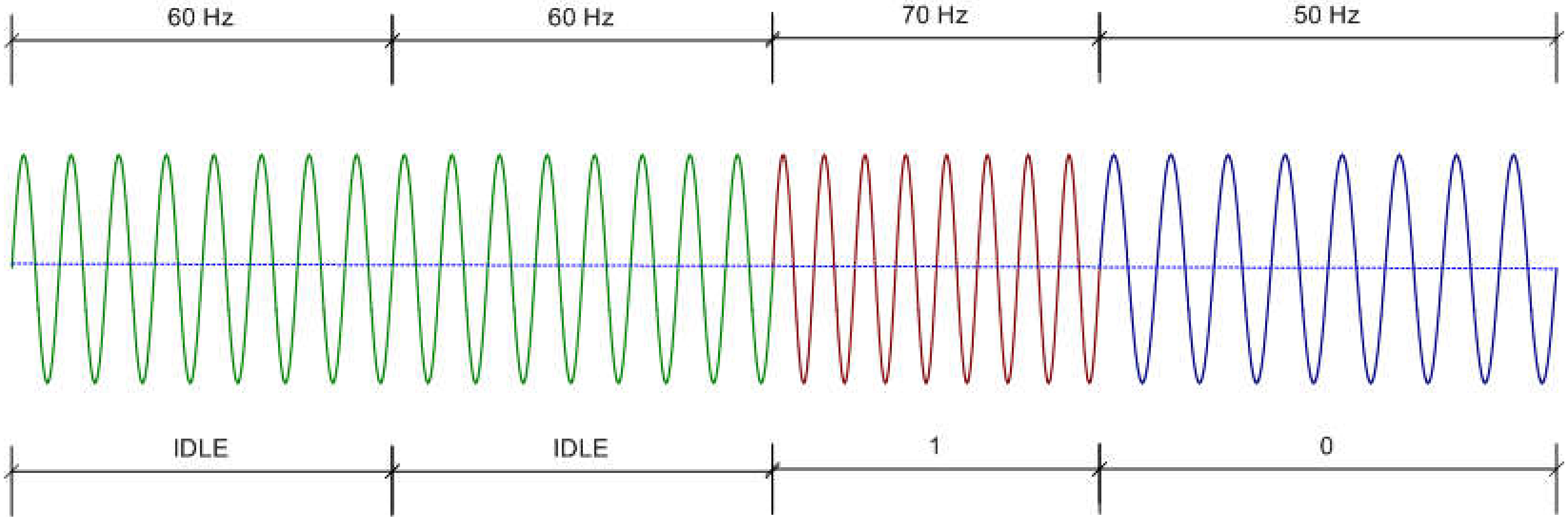
Fixture Centric
- Intensity is driven by fixture
- Intensity information is conveyed digitally
- Compensation for current variation
- Extended functionality is supported

Fixture Detail, same as 6.6 amp Fixture

ASK
Three State Symbols



FSK
3 state Symbols



Strawman Message Format

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
PREAMBLE				SEQUENCE NUMBER					PAYLOAD					CRC								EOM	
1	2	3	4	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	6	7	8	1	2
p3	p2	p1	p0	s4	s3	s2	s1	s0	d4	d3	d2	d1	d0	c7	c6	c5	c4	c3	c2	c1	c0	e1	e0
1	1	0	1	n	n	n	n	n	x	x	x	x	x	x	x	x	x	x	x	x	x	1	0

s4:s0 Sequence Number		
	00000:	initial
	11111	final
	Increment on each message	
	Roll over from 11111 to 00000	

d4:d3 light

00	reserved
01	side A
10	side B
11	Both

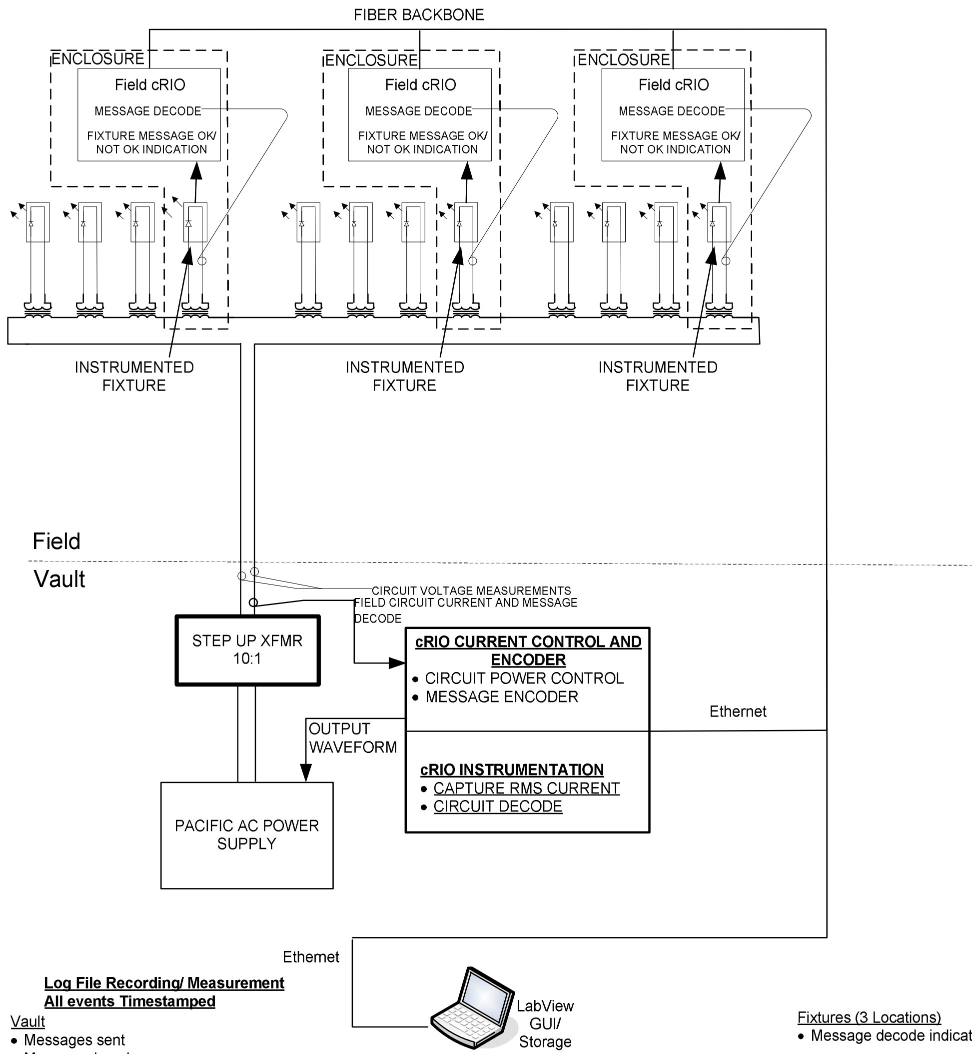
d2:d0 Intensity

000	off
001	b1
010	b2
011	b3
100	b4
101	b10
110	b30
111	b5/b100

Fixture Centric Testing Setup

- Fixtures and cans were returned from Preliminary testing at Purdue University Airport
- Fixtures were arranged on sign pads on cans.
- Three sign pads were used to place 3 groups of fixtures 1 per manufacturer
- Sign Pads were near existing field service panel that contained the instrument and fixture to be monitored
- Field Location Populations:
- 45 fixtures from manufacturer 1 on the sign pad and one instrumented (RCL BIDI)
- 45 fixtures from manufacturer 2 on the sign pad and one instrumented (TCL BIDI)
- 46 fixtures from manufacturer 3 on the sign pad and one instrumented (RCL BIDI)
- Total: 139, All on one circuit

Cape May Fixture Centric Setup



Log File Recording/ Measurement
All events Timestamped

Vault
- Messages sent
- Message decode
- Intensity State
- Cycle by cycle frequency (FSK)
- Cycle by cycle current (ASK)

Laptop
- Local Control and monitoring HMI
- Log File Storage
- Time Stamp incoming Events

Fixtures (3 Locations)
- Message decode indication

Field circuit (3 Locations)
- Circuit Message decode
- Cycle by cycle frequency (FSK)
- Cycle by cycle current (ASK)

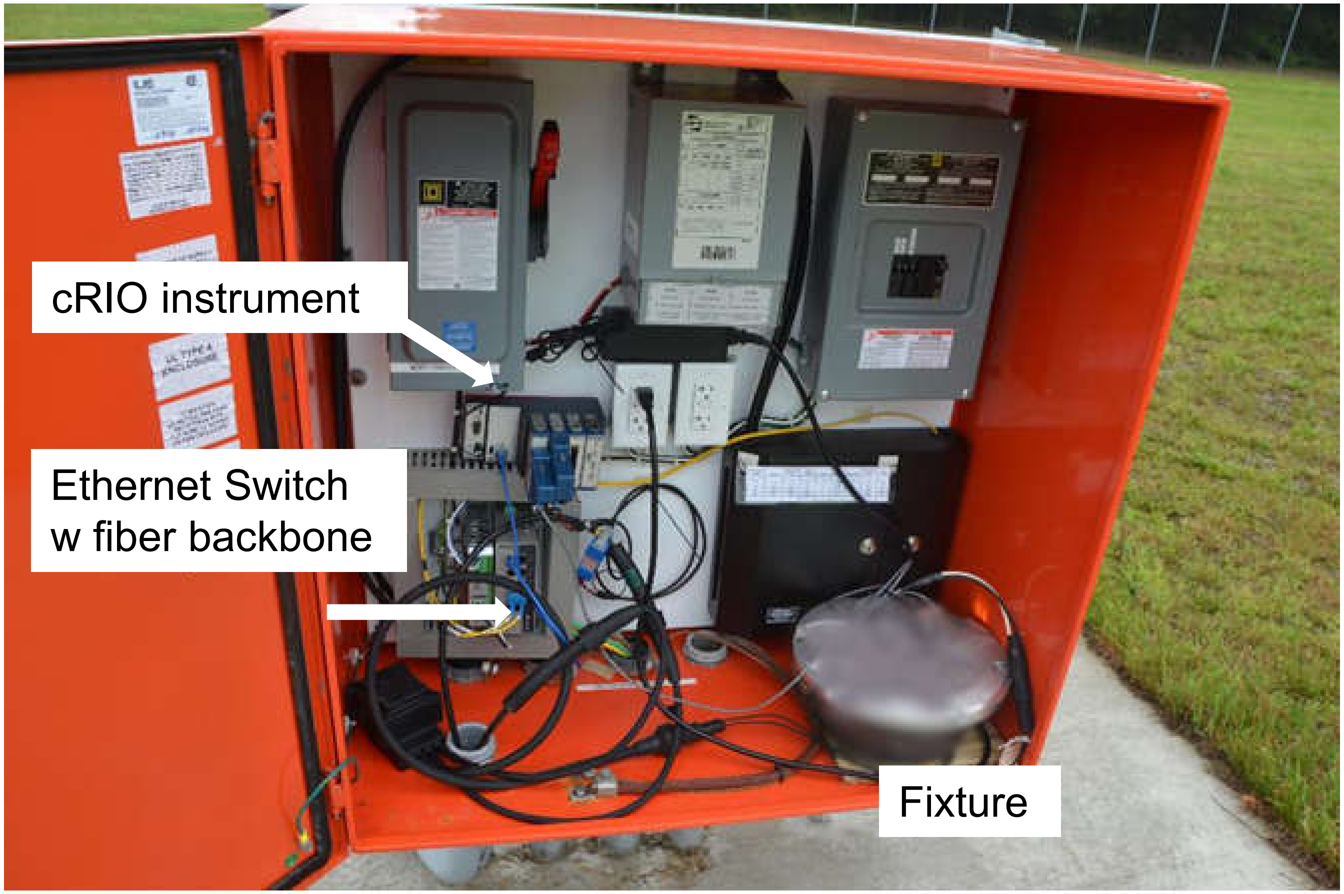
Topology


Sign Pad 3
Sign Pad 2
Instruments 3
Sign Pad 1
Vault
Instruments 2
Instruments 1

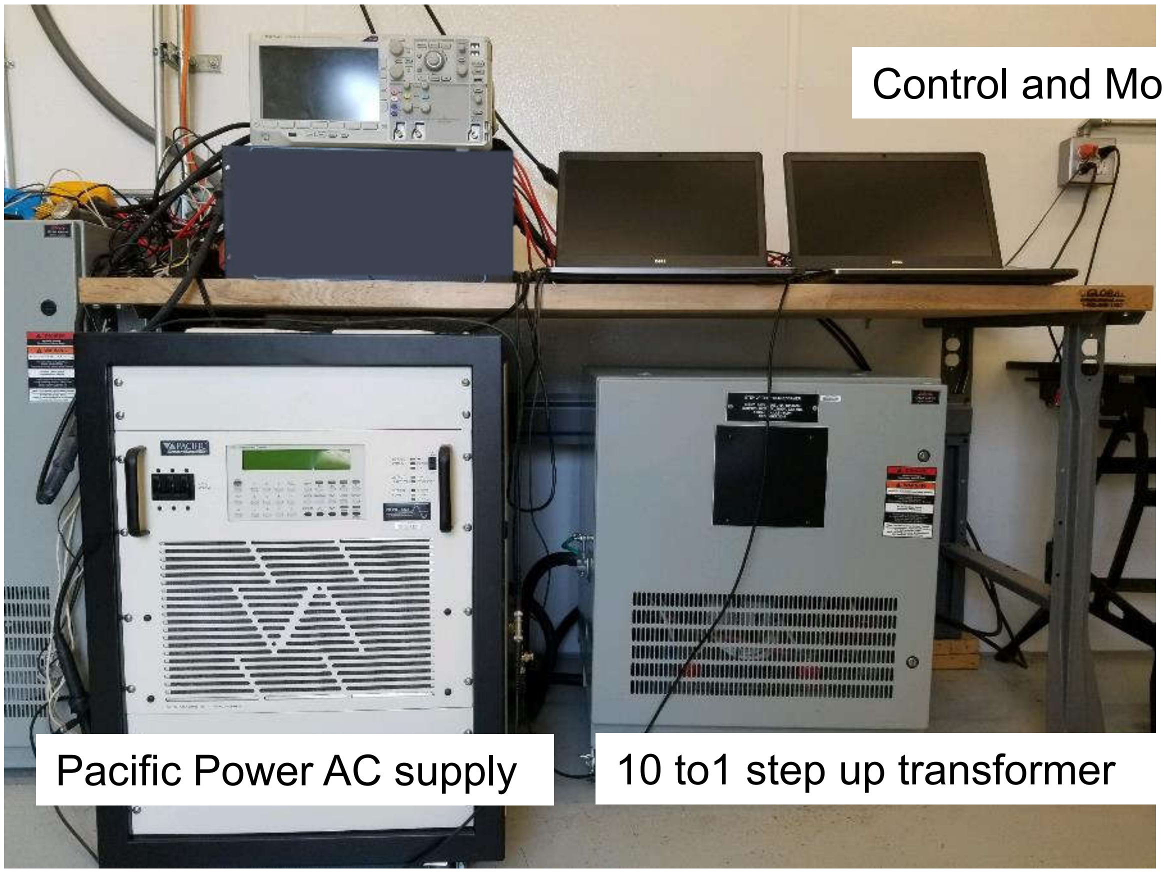
Cape May Fixture Centric Setup

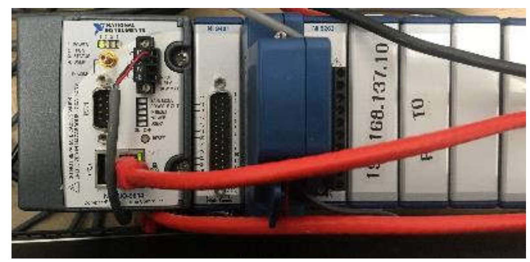
Field Service Panel with
Instrument and monitored fixture

Cape May Fixture Centric Setup



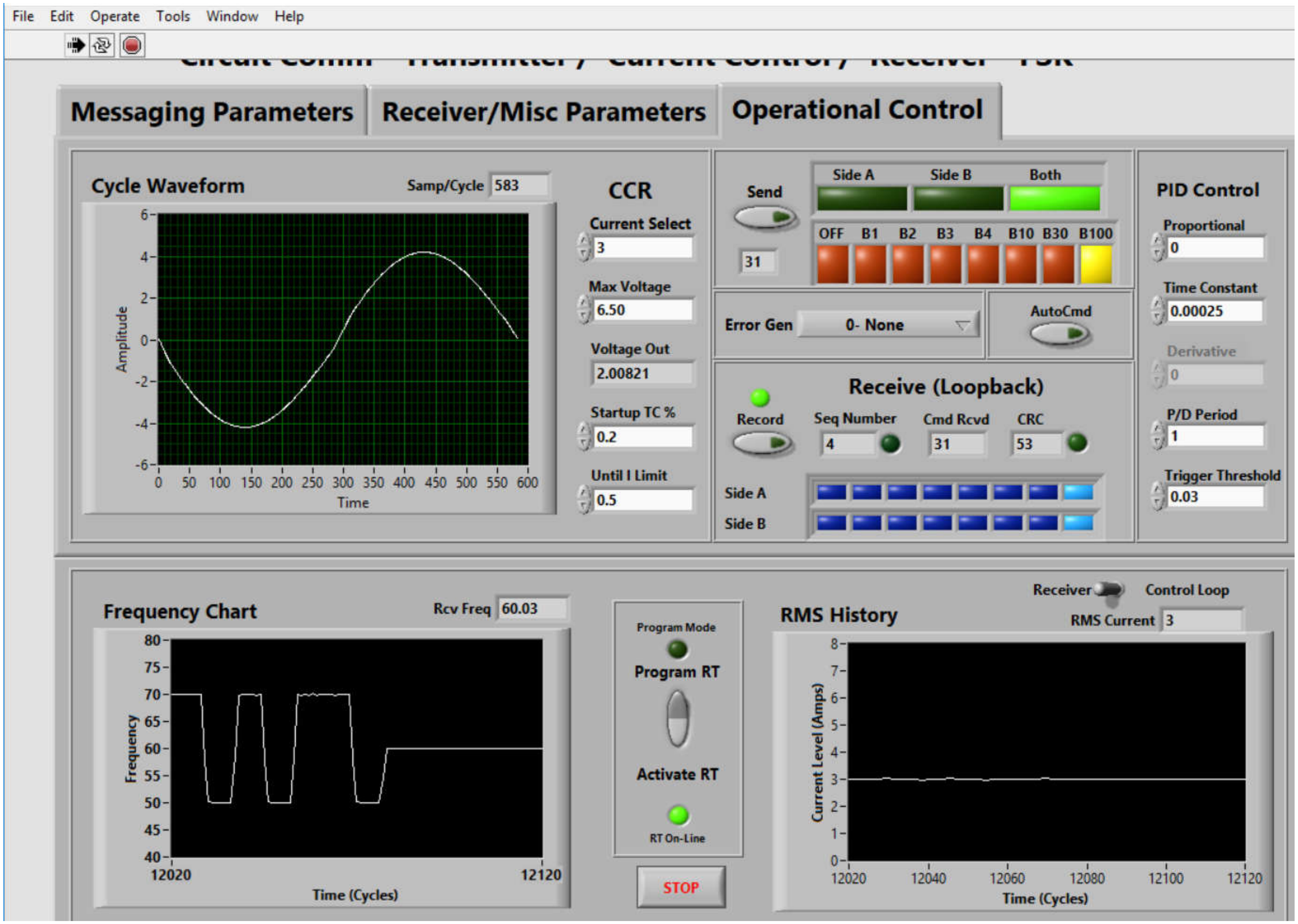
Cape May Fixture Centric Setup





LabView cRIO vault Target

Fixture Centric Control and Monitoring Screen



Data Collection Operation

- Intensity commands issued from encoder/ power source in the vault. A message is sent to the log file with a time stamp
- Messages are decoded in the field by the monitored fixtures. The fixtures send an indication to the field instrument.
- The field instrument also decodes the command, and sends the indication from the fixture and its own decode data over the network to the log file and is time stamped
- After the test session, log files are saved and later analyzed
- If all works properly, messages sent and messages received are the same.
- If a message is missed, there will be a mismatch in the log file as well as a break in the message sequence number.

Log file Excerpt

19	192.168.137.10	2018-02-20	15:12:06.315	T0	47	1	0	5	16	9	94	0	0
20	192.168.137.12	2018-02-20	15:12:09.650	R2C	96	2	0	192	1	1	1	1	1
21	192.168.137.12	2018-02-20	15:12:09.655	R2C	97	3	0	96	69.86	70	70	70	70
22	192.168.137.12	2018-02-20	15:12:09.657	R2C	98	3	1	96	50	50	50	50	50
23	192.168.137.13	2018-02-20	15:12:09.658	R3S	96	2	0	192	1	1	1	1	1
24	192.168.137.12	2018-02-20	15:12:09.658	R2C	99	4	0	5	16	9	94	0	0
25	192.168.137.11	2018-02-20	15:12:09.660	R1A	96	2	0	192	1	1	1	1	1
26	192.168.137.10	2018-02-20	15:12:09.661	R0N	192	2	0	192	1	1	1	1	1
27	192.168.137.13	2018-02-20	15:12:09.663	R3S	97	3	0	96	70	70	70	70	70
28	192.168.137.13	2018-02-20	15:12:09.664	R3S	98	3	1	96	50	50	50	50	50
29	192.168.137.11	2018-02-20	15:12:09.665	R1A	97	3	0	96	70	70	70	70	70
30	192.168.137.11	2018-02-20	15:12:09.666	R1A	98	3	1	96	50	50	50	50	50
31	192.168.137.13	2018-02-20	15:12:09.666	R3S	99	4	0	5	16	9	94	0	0
32	192.168.137.11	2018-02-20	15:12:09.668	R1A	99	4	0	5	16	9	94	0	0
33	192.168.137.10	2018-02-20	15:12:09.668	R0N	193	3	0	96	70	70	70	70	70
34	192.168.137.10	2018-02-20	15:12:09.675	R0N	194	3	1	96	50	50.07	50	50	50
35	192.168.137.10	2018-02-20	15:12:09.680	R0N	195	4	0	5	16	9	94	0	0
36	192.168.137.11	2018-02-20	15:12:09.869	R1A	100	5	0	1	2				
37	192.168.137.12	2018-02-20	15:12:09.994	R2C	100	5	0	1	2				
38	192.168.137.13	2018-02-20	15:12:10.068	R3S	100	5	0	1	2				

Outbound Message

Decoded from Instruments

Indications from Fixtures

Fixture Centric Testing

- System Current Level Stability– Stability of circuit current when intensity changes
- System/ Load Stability at application of Power– Check Circuit current when power is applied to check for Stable Operation
- Crest Factor ASK– Simulates Reduced conduction time of Thyristor CCR
- Sensitivity to Varied Current- Test increased and decreased circuit current for stable and correct operation
- FSK Crosstalk Test– Simulate cross-talking frequencies adding to the circuit to determine impact to operation
- Transient Test– simulates sudden intermittent load changes, similar to arcing
- Message Error Test– Forces various messages errors on the circuit to determine that the protocol's error checking does not accept incorrect information
- Insulation faults– Add short to ground and another ground fault to determine tolerance for poor insulation on a circuit

Fixture Centric Testing Summary

Details will be in report

Test	Significant Anomalies Found	Comment
System Current Level Stability at Application of Power	No	Stable in 160mS.
Current Level Stability	No	Stable operation
System Open Secondary Resistive/Reactive Loading	No	Simulated 30% open secondaries with correct operation
Fixture Sensitivity to Varied Current	No	FSK- ran 50% higher and 50% lower current, correct operation ASK-ran 50% higher and 50% lower current, correct operation with the exception of fixture 3 at 2.2 and 2.0 amps Missed messages due to ASK “0” bits at less than 2 amps below fixture 3’s delivered design limit In production this would be part of the design.
System Sensitivity to Crosstalk (FSK only)	No	25% crosstalk did not cause missed messages from fixtures

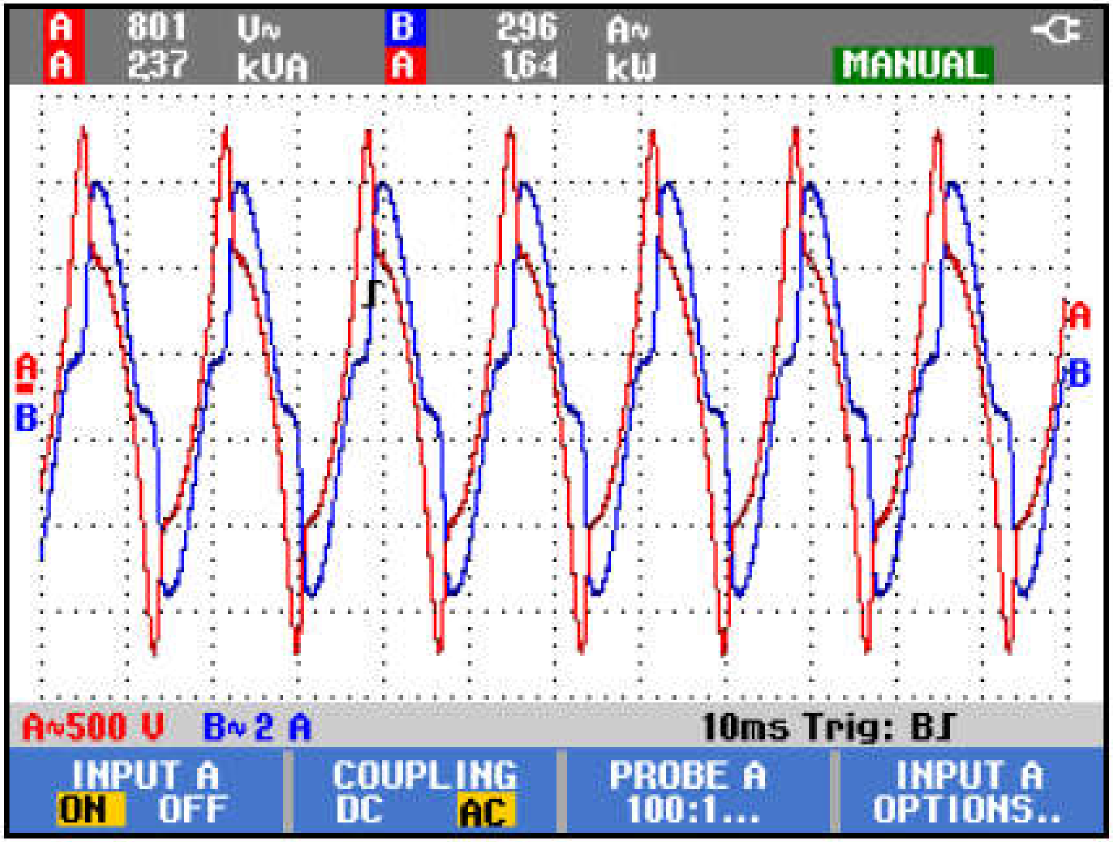
Fixture Centric Testing Summary

Test	Significant Anomalies Found	Comment
Fixture-level Sensitivity to Crest Factor (ASK only)	No	Reduced conduction time from 100% in 10% increments down to 40 % Fixture 2 was delivered for full conduction, missed some messages at 50% and 40% conduction
Fixture Sensitivity to Transients	No	ASK and FSK not impacted by induced transients
System Susceptibility to Message Framing Error	No	Forced ,message errors– framing, short messages, CRC errors All tests operated properly except fixture 1 for short EOM. This case was not covered by the fixture firmware. A production fixture would not have this issue
System Sensitivity to Insulation Faults	No	No problems found with added ground faults

JN1

FSK/ ASK Reactive Load Test

Red is Voltage – Blue is Current



Load with simulated 30% opens

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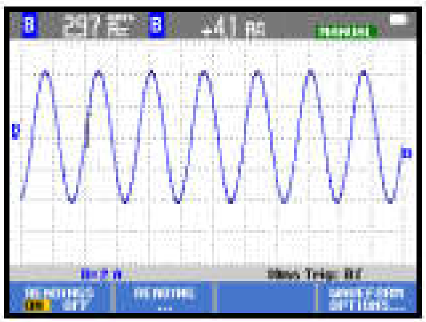
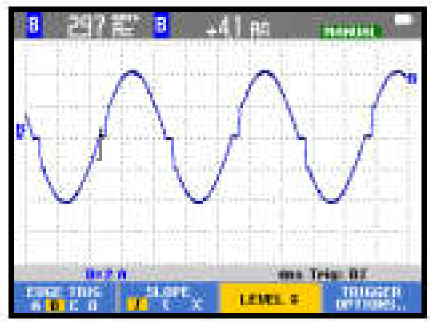
JN1 Jess, 7/15/2018

ASK Crest Factor Test

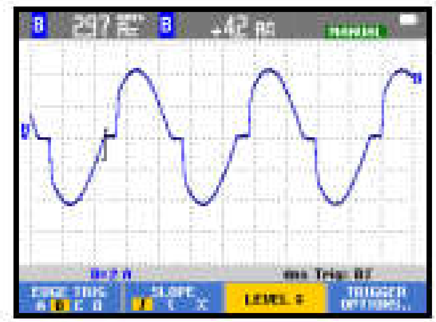
Circuit Current, 100% to 40% Conduction



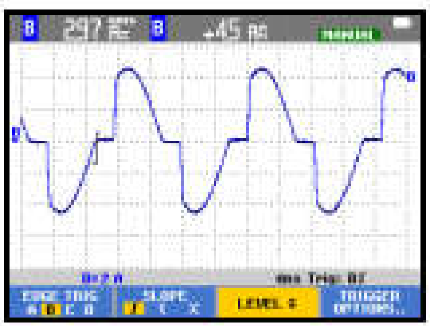
100%



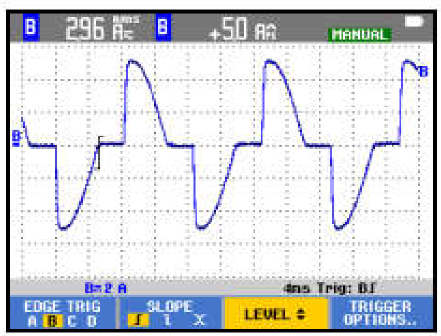
90%



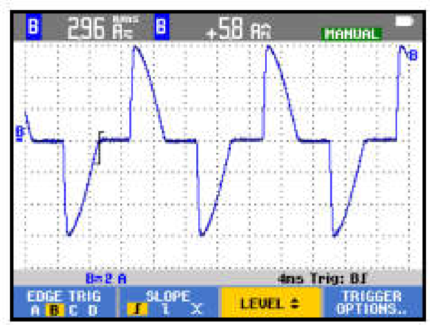
80%



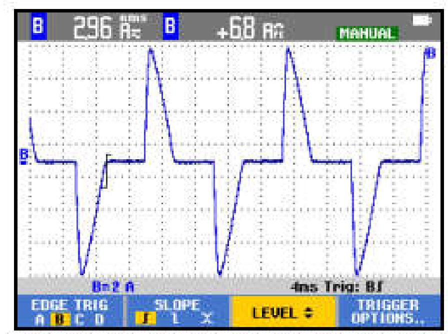
70%



60%



50%

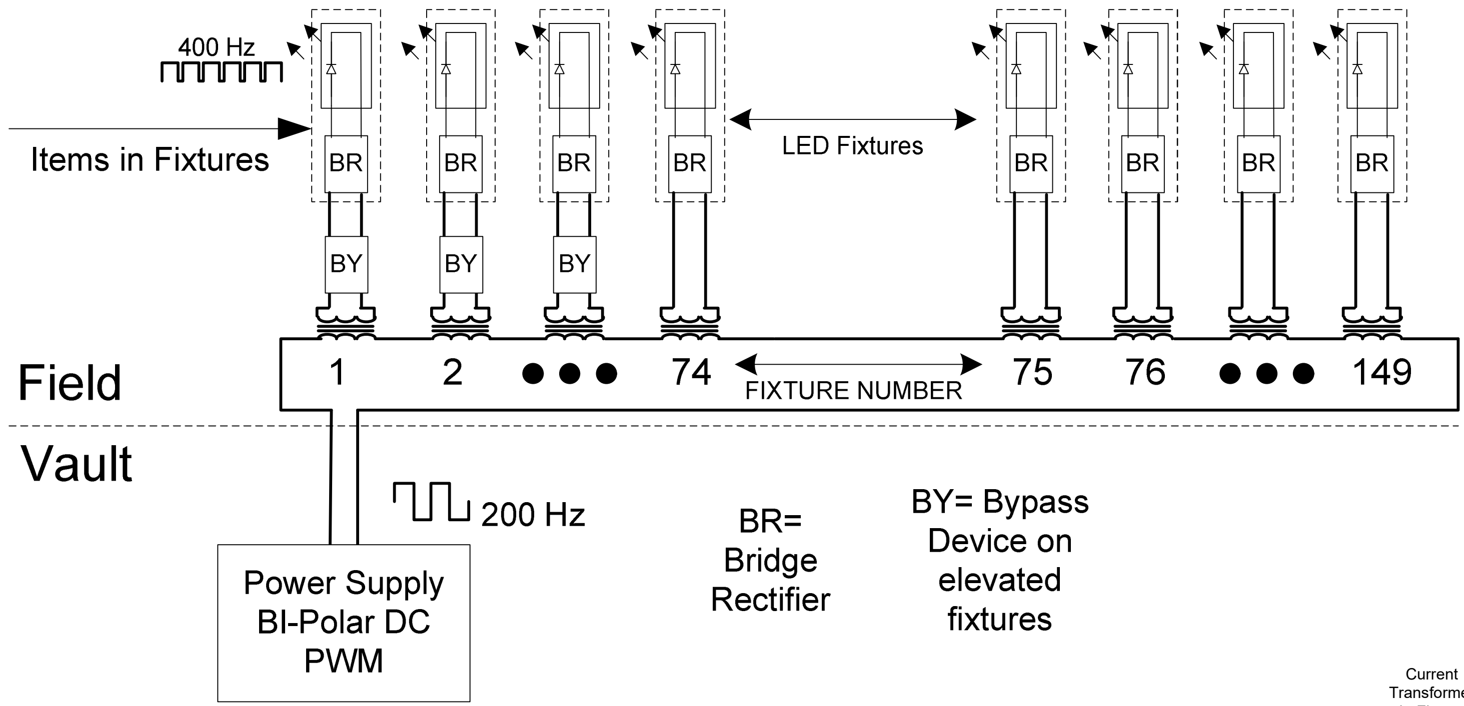


40%

Vault Centric Architectural Characteristics

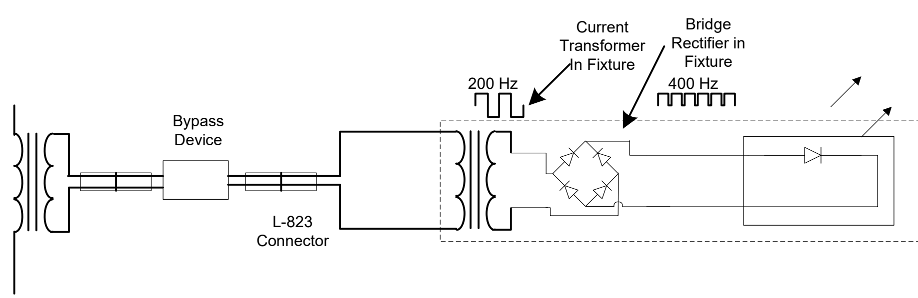
- Very low power consumption
- Operates at 2 amps
- Simple passive fixture electronics
- Uses existing infrastructure of cables and transformers

Vault Centric, PWM Pulse Drive



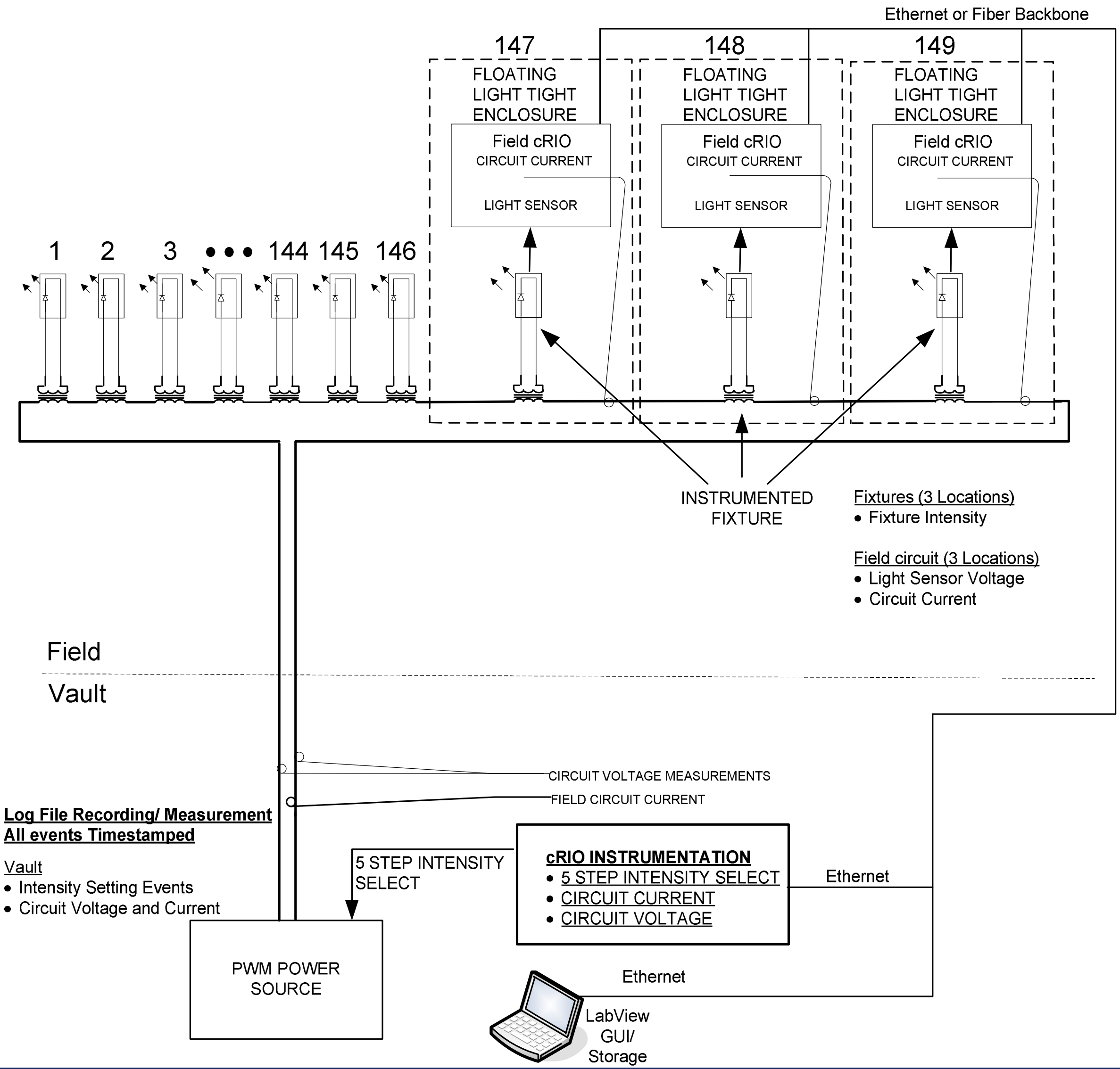
Vault Centric

- Intensity is based on Circuit Current
- Simplified passive fixture



Cape May Vault Centric Setup

ENCLOSURES CAN BE RE-LOCATED AS NEEDED

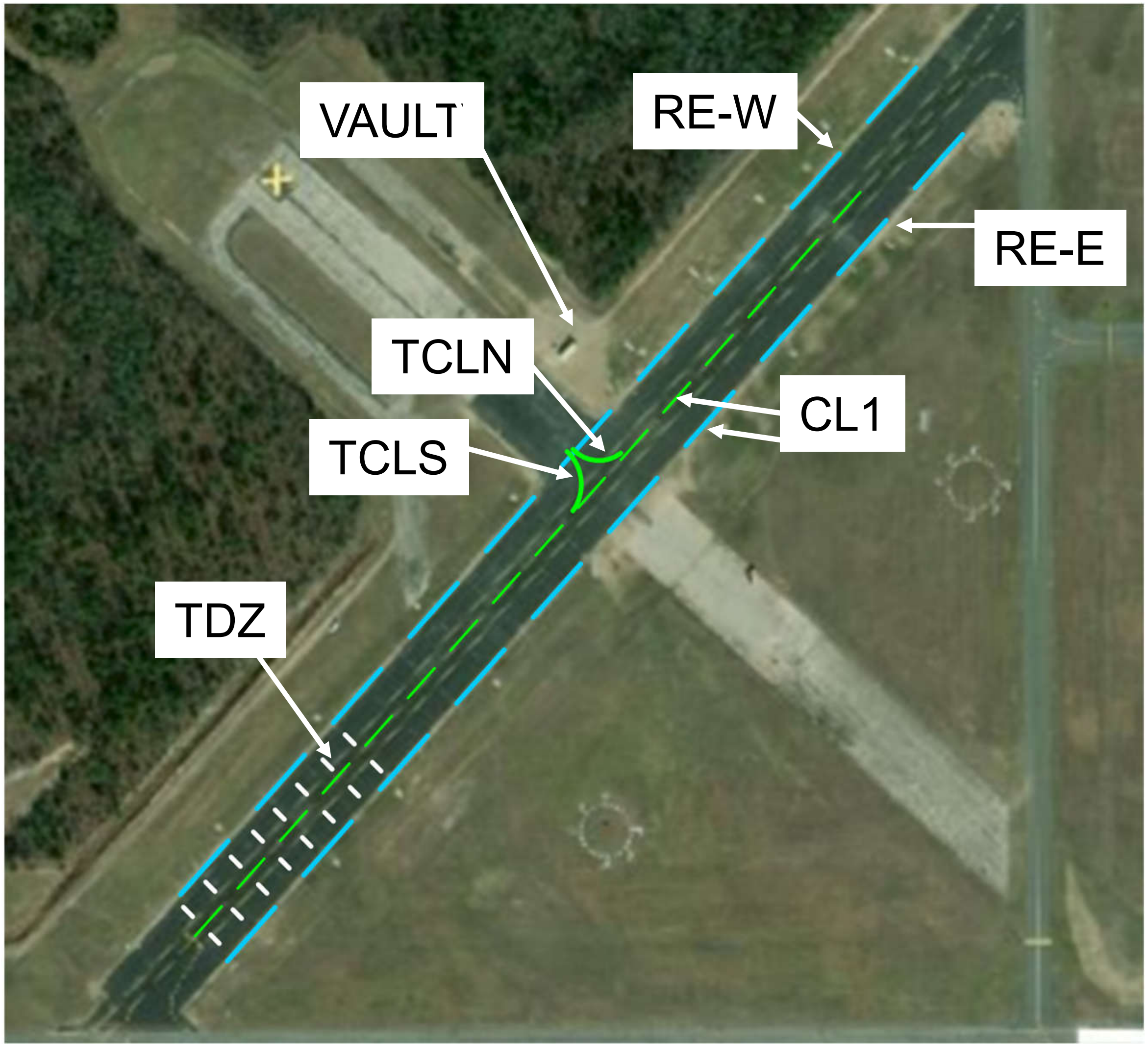


Vault Centric Installation, Cape May

TYPE	Location	QTY	Description	CIRCUIT	Fixture Spacing, feet
TCL	CL1	45	TW C CL LIGHTS	CL1	50
TCL	TCLN	13	RADIUS Near Vault, North	TCLN	12.5
TCL	TCLS	16	RADIUS Near Vault, South	TCLS	12.5
TCL	TDZ	49	TDZ SOUTH BARETTES	TDZ	5 / 72/ 100
MIRL	REW	11	ELEVATED EDGE, West Side	RE-W	200
MIRL	REE	12	ELEVATED EDGE, East Side	RE-E	200
TCL	V1	1	INSTRUMENTED FIXTURE	Floating	
TCL	V2	1	INSTRUMENTED FIXTURE	Floating	
TCL	V3	1	INSTRUMENTED FIXTURE	Floating	
	Total	149	TOTAL CIRCUIT LENGTH		8,100

JN2

Vault Centric Topology



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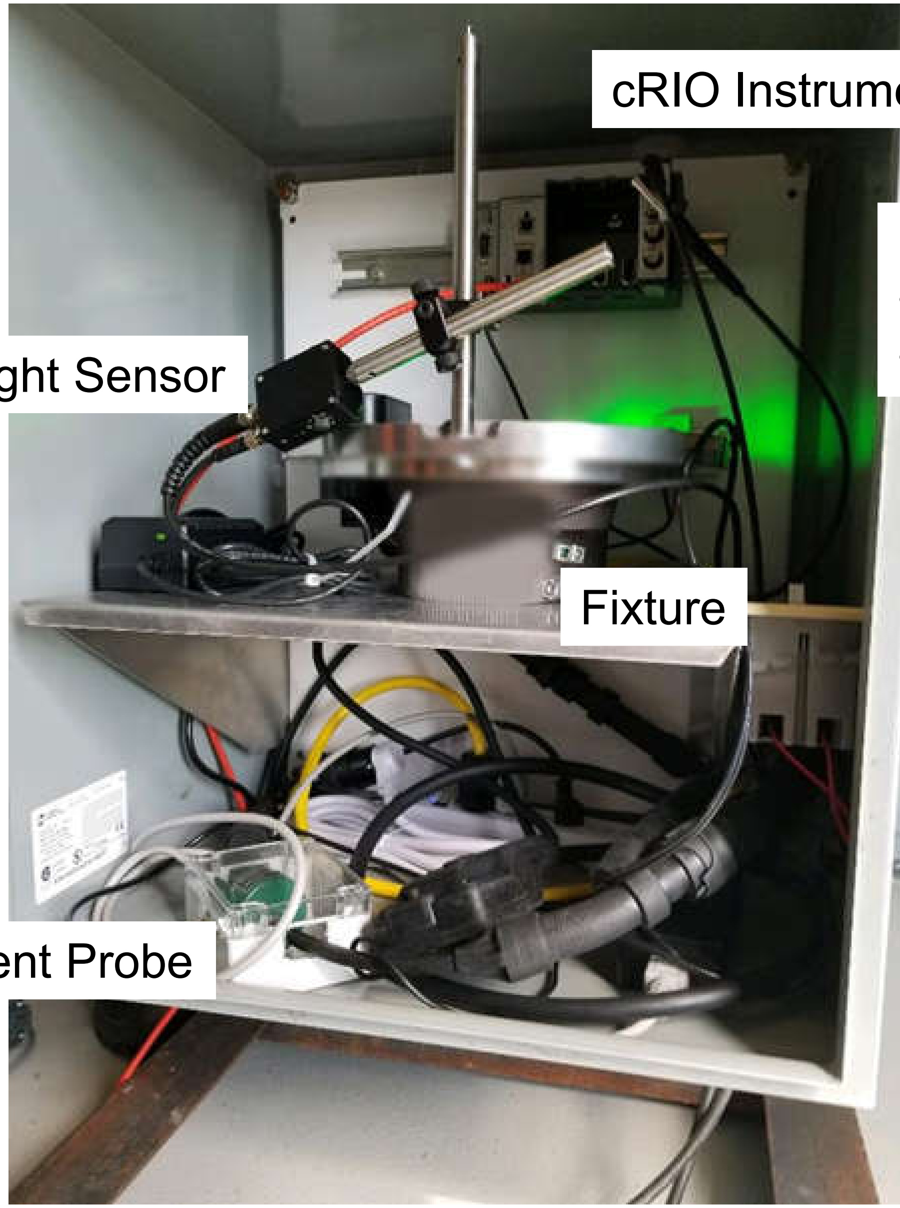
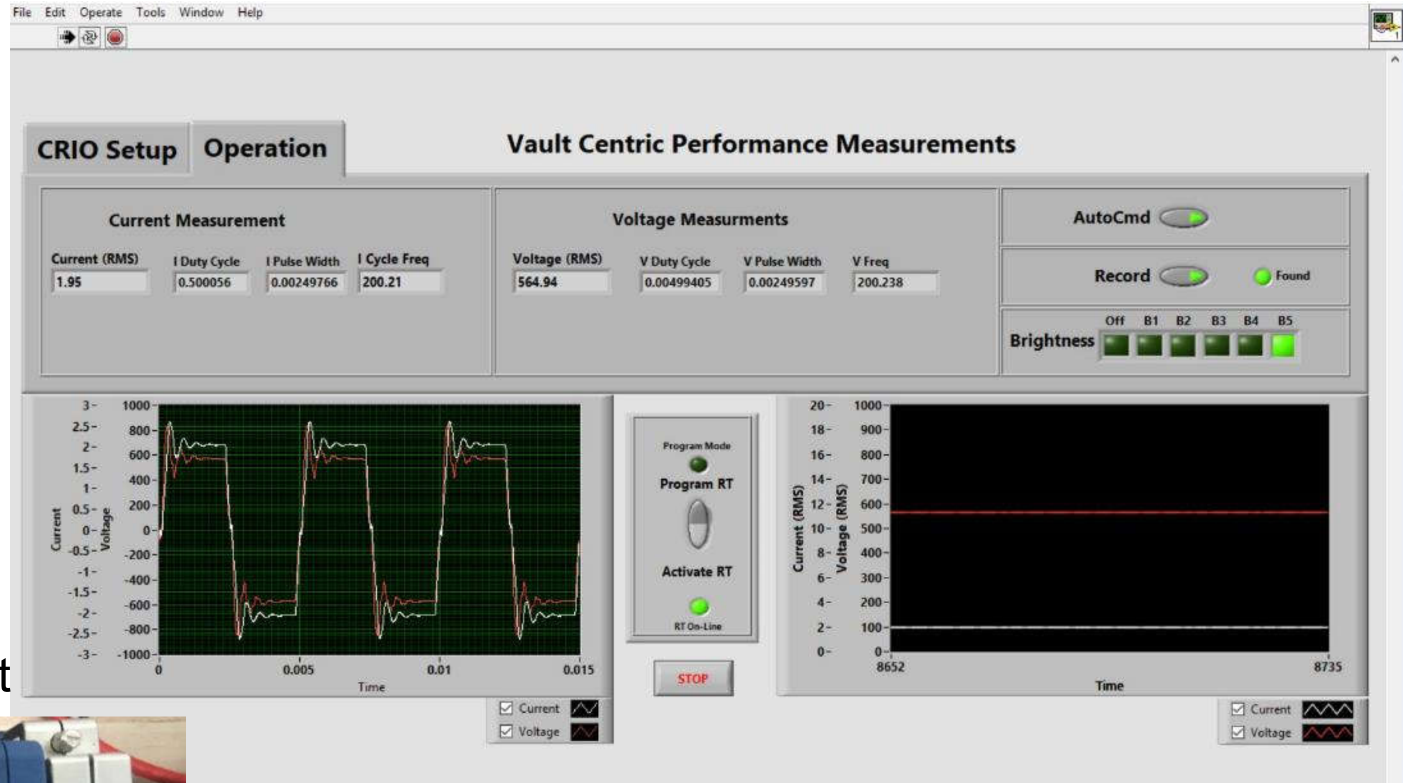
JN2 Jess, 7/22/2018


C-12
Box #1
F2



Measures and Reports
- Circuit Current
- Light Sensor Voltage

Vault Centric Instrumentation



cRIO instrument target

Control Screen

Target Provides:

- Intensity Select Control
- Circuit Current Measurement
- Circuit Voltage Measurement
- Sends Data onto Network

Data Collection Operation

- The Vault cRIO is interfaced to the intensity selection digital input on power supply, and can select intensities automatically
- When intensity is selected, a log file entry is stored on the laptop with a timestamp
- The vault cRIO is measuring circuit current and voltage. It sends these measurements every 2 seconds to the log file and it is stored with a timestamp
- The 3 monitored fixture cRIO targets sample circuit current, and light sensor output voltage. These measurements are reported every two seconds, and stored with a timestamp on the vault laptop
- The log file is stopped after a test with the file stored and later analyzed

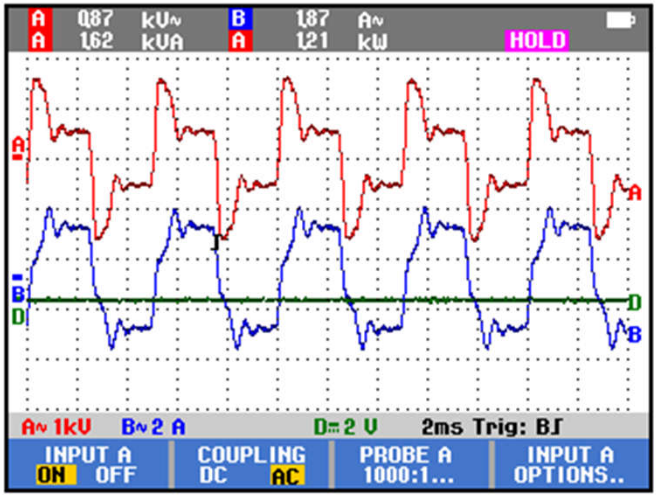
Vault Centric Testing

- **Current Level Stability– Stability when different intensities are selected**
- **Stability on application of Power– Stable operation at power up.**
- **Reactive Load Test– Behavior with a large number of open secondary isolation transformers**
- **Fixture Performance– Intensity Step Compliance and influence to circuit current across the circuit with different topologies**
- **Insulation Test-- Operation when circuit leakage is present**

Test	Significant Anomalies Found	Summary
Current Stability at Application of Power	No	Stable Operation
Current Level Stability	No	Stable Operation
Fixture Performance	Yes	Position Dependency related to Pulse shape
System Open Secondary/Reactive Loading Test	Yes	Open Secondary results in much higher VA loading at 200 Hz than at 60 Hz
System Sensitivity to Insulation Faults	Yes	High Pulse rate and higher order harmonics resulted in significant Impact on insulation fault sensitivity

Vault Centric Reactive Load Test

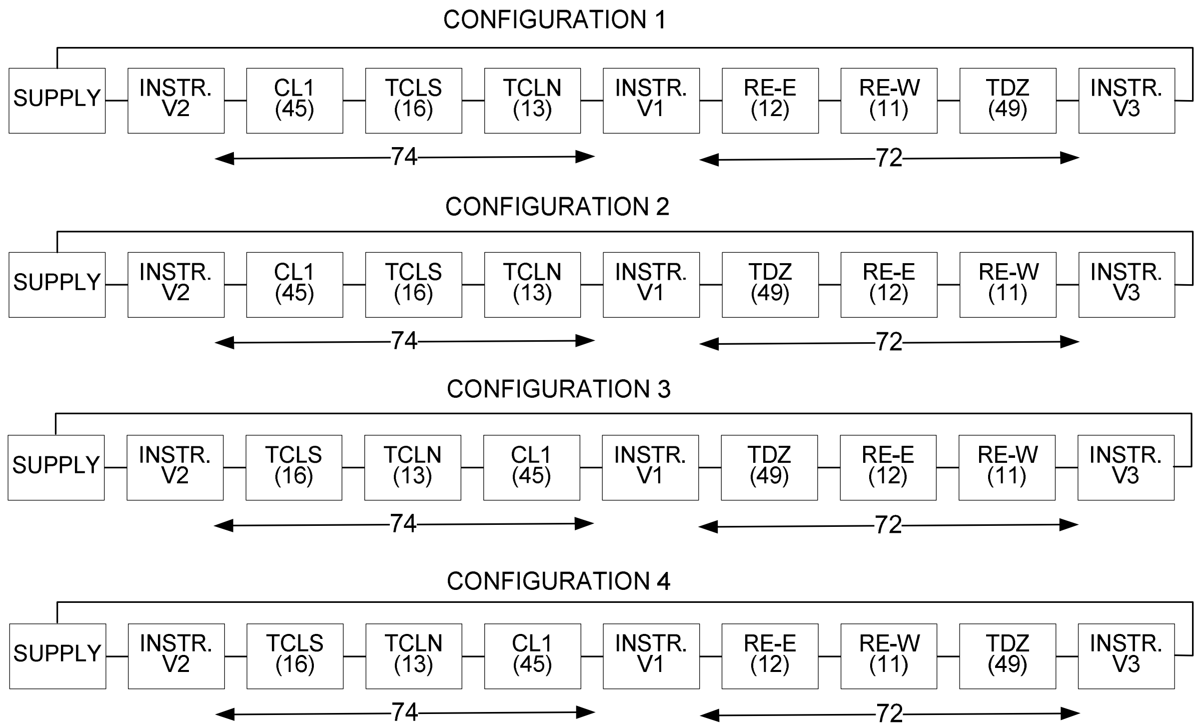
- The test requirement would require the rating of the power source to be much higher.
- The requirement from the incandescent circuit should be re-evaluated for LED circuits.
- The higher frequencies used results in much higher VA load from an open secondary compared to 60 Hz
- The test had to be curtailed as the supply was beginning to fold back its current and voltage limit with this load



Red is Voltage – Blue is Current

Vault Centric Fixture Performance Test

Four Basic Circuit Configurations



Vault Centric Fixture Performance Test

- **Configuration 1– V1 is in the middle of the circuit; V2 and V3 are on the ends**
- **Variance in circuit current appears at V1, in the circuit center**
- **Currents at V2 and V3 stayed generally at nominal**
- **Current at V1– slightly higher for B5, B4, and B2 than V2 and V3**
- **But Substantially Higher at B3**
- **Substantially lower At B1**

	Configuration 1 Current, Amps			Percent change in V1 Current vs average of V2 and V3
	V1	V2	V3	V1
B1	0.0884	0.1235	0.1236	-28.47%
B2	0.2540	0.2464	0.2464	3.07%
B3	0.5519	0.4892	0.4893	12.80%
B4	1.0079	0.9781	0.9783	3.03%
B5	1.9709	1.9477	1.9480	1.19%

Vault Centric Fixture Performance Test

- **For Position 1, Relative Intensity also different at V1**

Relative Intensity

	V1	V2	V3
B1	1.173%	1.787%	1.489%
B2	4.083%	4.985%	4.137%
B3	9.332%	10.360%	9.451%
B4	26.973%	27.909%	27.325%
B5	99.589%	99.558%	99.578%

Absolute difference to Baseline intensity

	V1	V2	V3
B1	-0.787%	-0.193%	-0.211%
B2	-0.937%	-0.055%	-0.083%
B3	-0.678%	+0.330%	+0.201%
B4	-0.707%	+0.179%	+0.115%
B5	-0.111%	-0.112%	-0.152%

B1 and B2 differences are large compared to the nominal intensity percentages

Vault Centric Fixture Performance Test

- For configuration 1, V1 and V2 were swapped, and the results followed the location.
- Other configurations tested:
- Middle of TDZ
- Middle of Centerline
- Different Currents were seen depending on the location, but intensity did not always go up or down following currents. This also could be higher order harmonic currents, that change with location

Vault Centric Insulation Test

- This test is to determine how ground faults impact the circuit behavior
- For this test, a single ground is placed on the circuit
- After checking operation with a single ground, resistance to ground is added at a different location

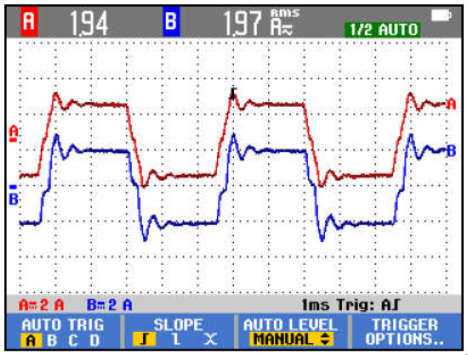
- When a single ground was installed, the circuit current was impacted.
- More impact was seen the lower the steps were selected
- The single ground was replaced with 100Ω and then with 1KΩ
- Similar results were seen.
- This appears to be related to the higher frequency components in the waveform after

Vault Centric Insulation Test

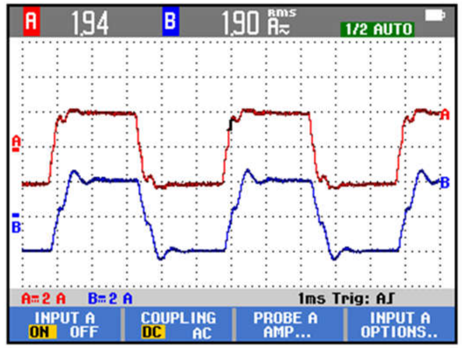
Red- Vault

Blue- At V1 location, mid circuit

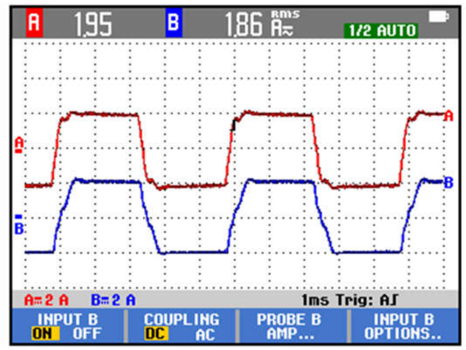
B5 and B4 Intensities



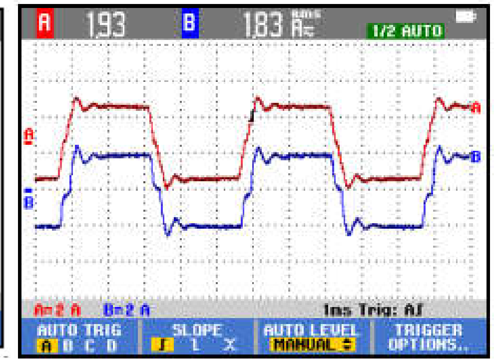
B5



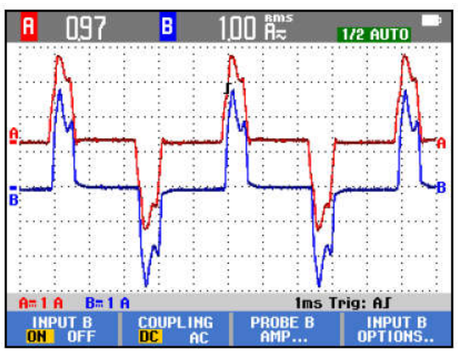
B5 SHORT



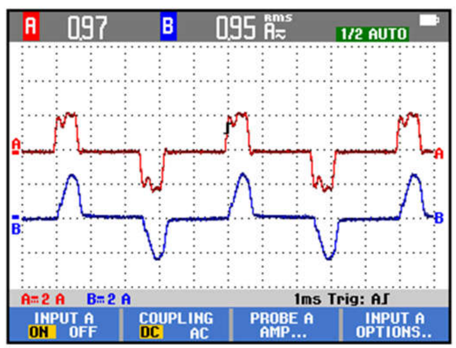
B5 100 Ω



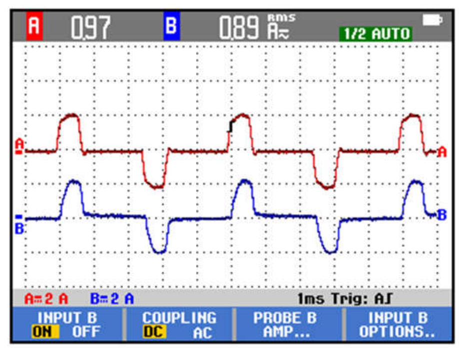
B5, 1K Ω



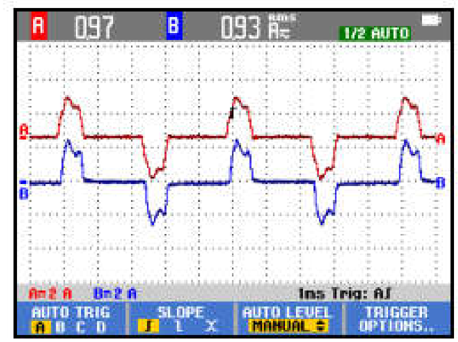
B4



B4 SHORT



B4 100 Ω



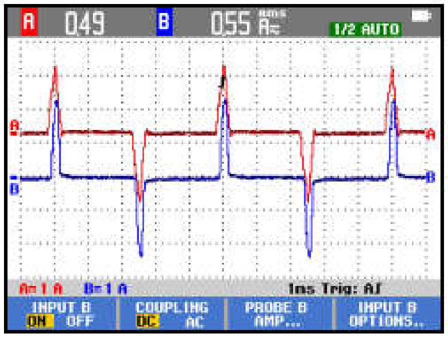
B4 , 1K Ω

Vault Centric Insulation Test

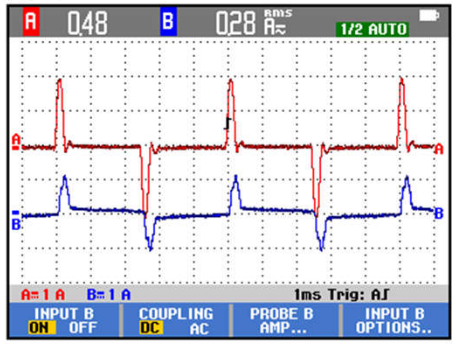
Red- Vault

Blue- At V1 location, mid circuit

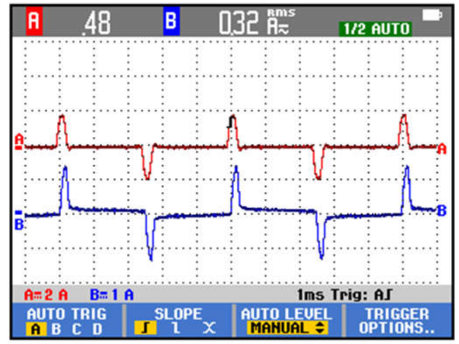
B3 and B2 Intensities



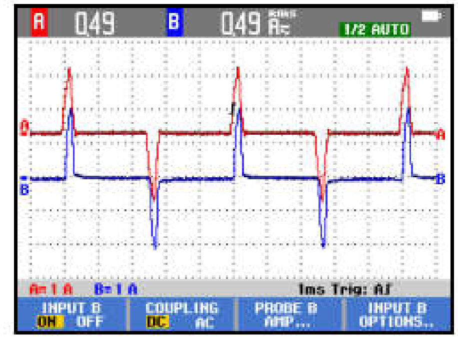
B3



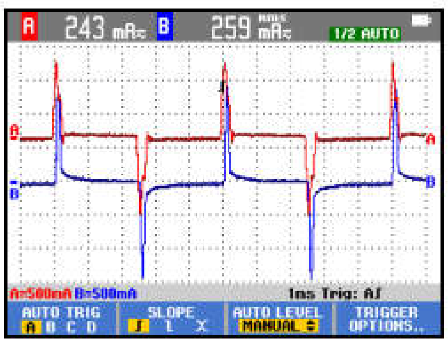
B3, SHORT



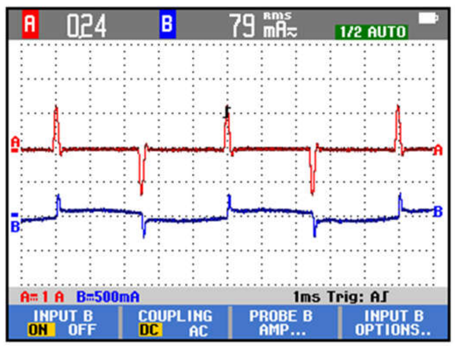
B3, 100 Ω



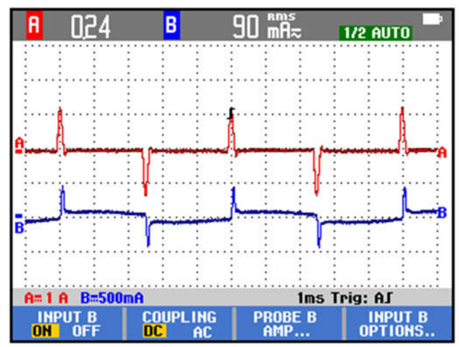
B3, 1K Ω



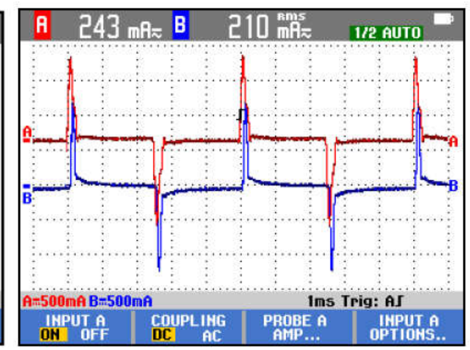
B2



B2, SHORT



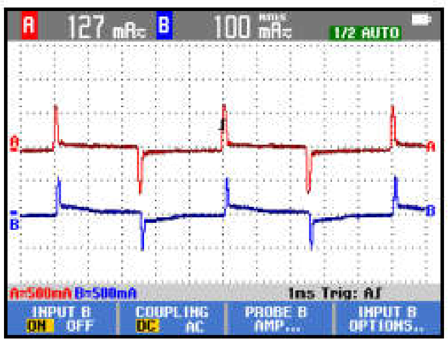
B2, 100 Ω



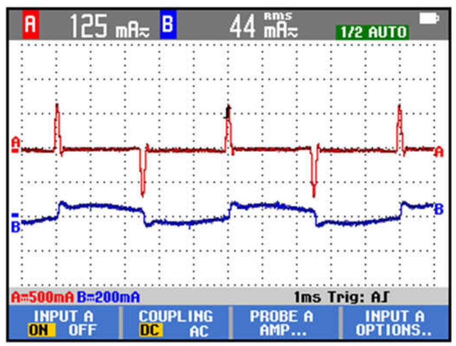
B2, 1K Ω

Vault Centric Insulation Test

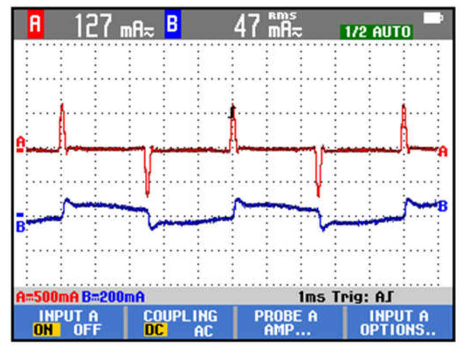
Red- Vault
Blue- At V1 location, mid circuit
B1 Intensity



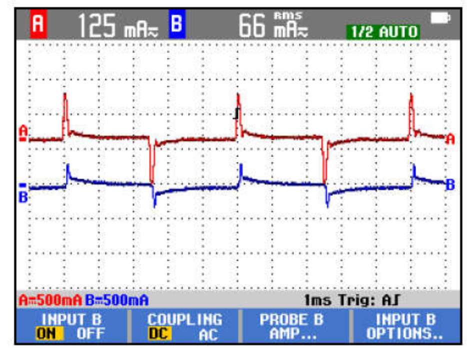
B1



B1, SHORT



B1, 100Ω



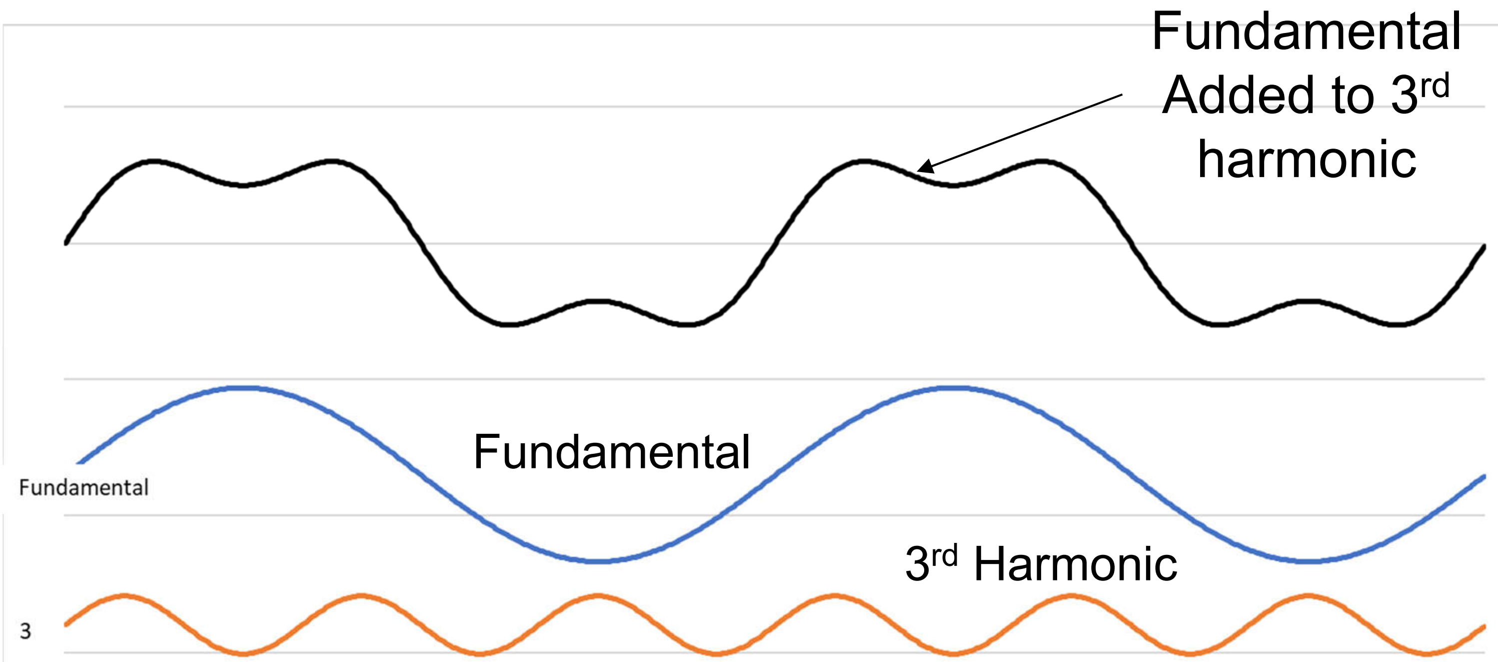
B1, I KΩ

Harmonics 101

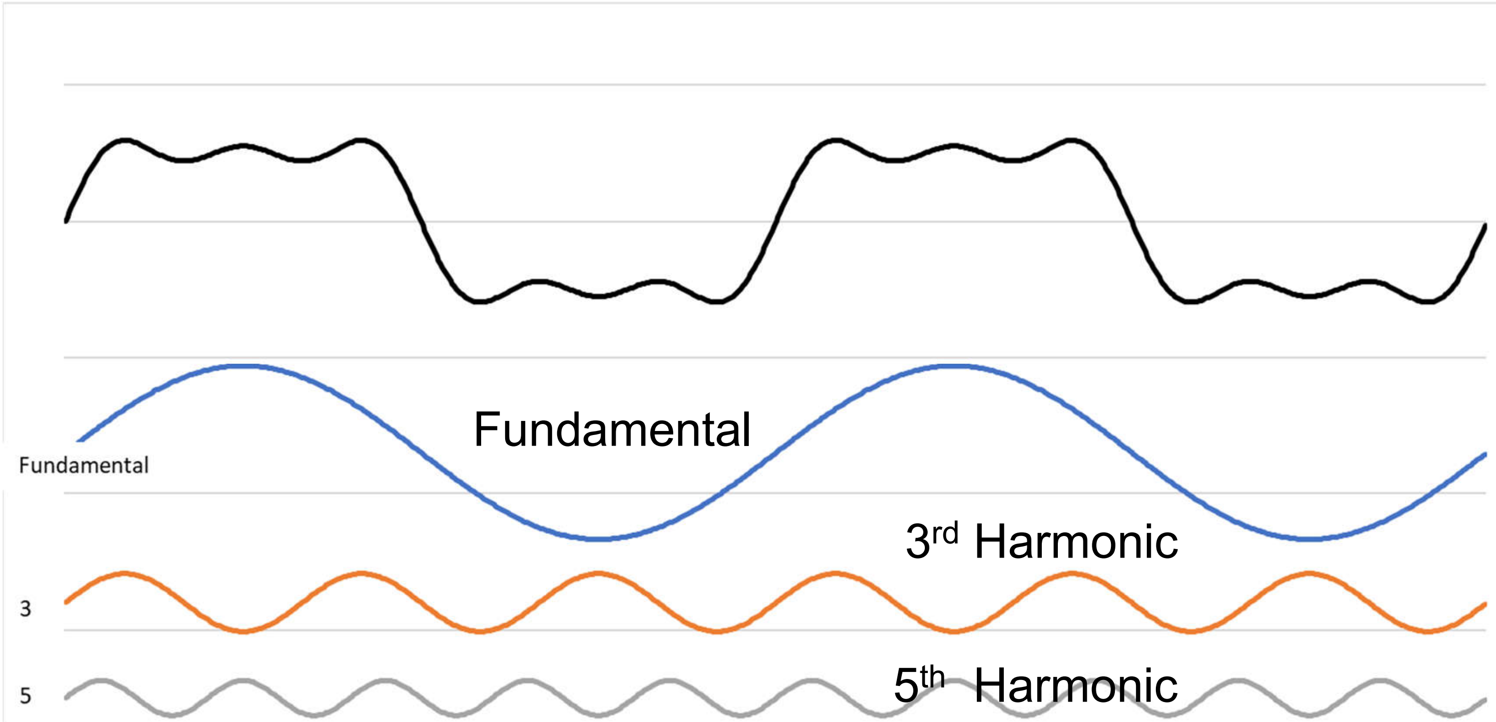
Square Wave

Square Wave is the sum of a series of
Odd Harmonics sine waveforms

Harmonics 101

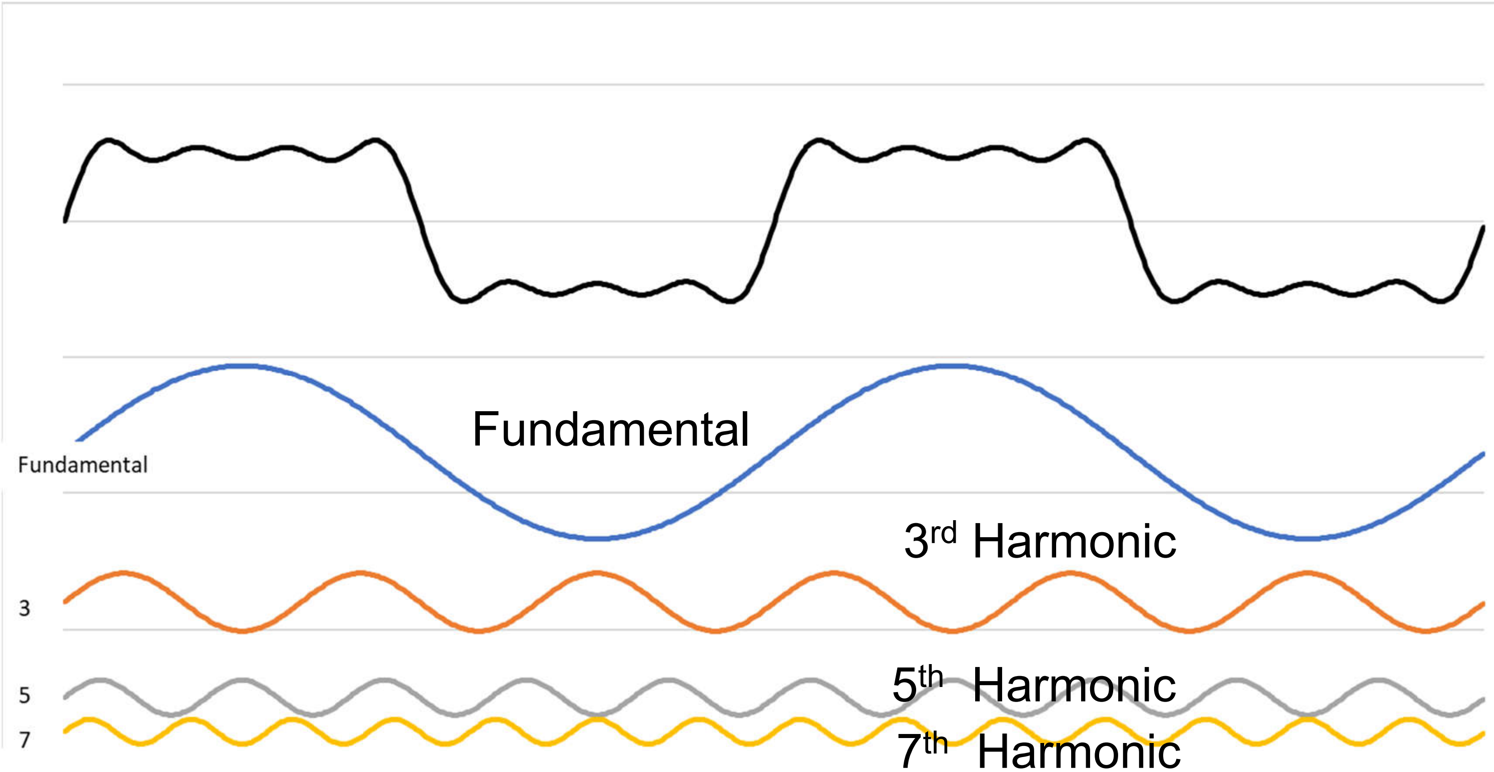


Harmonics 101



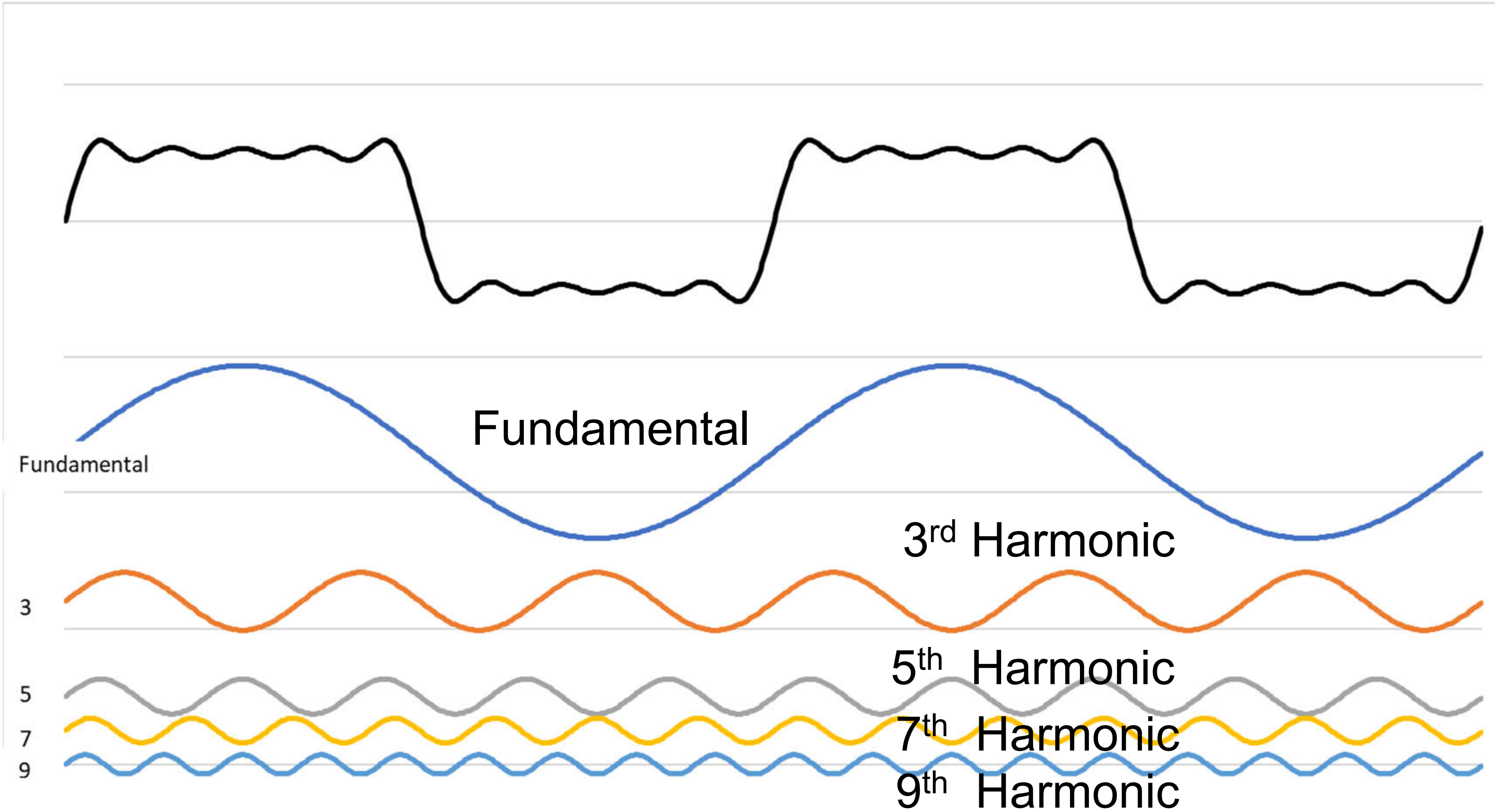
Fundamental Added to
3rd and 5th harmonic

Harmonics 101



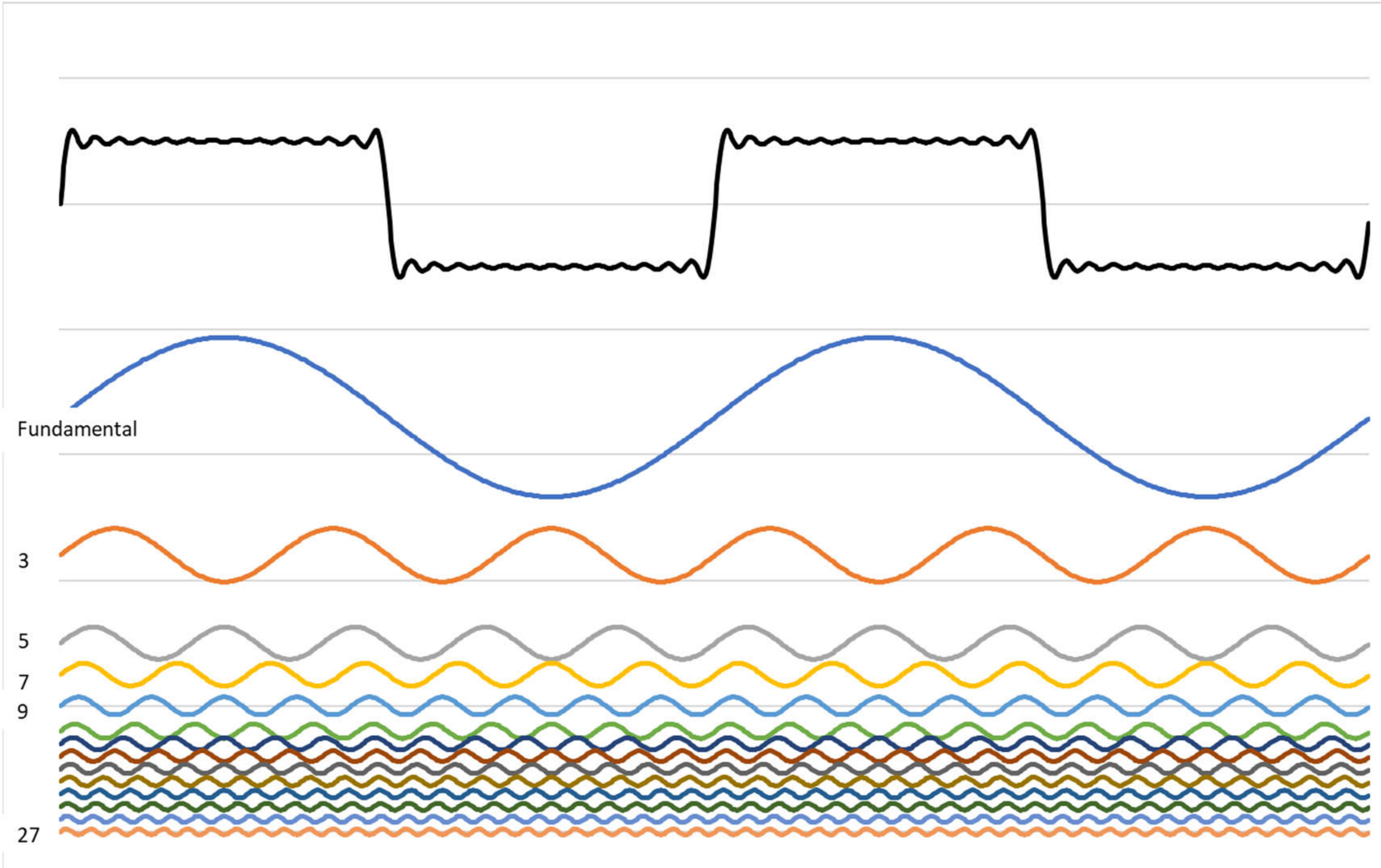
Fundamental Added to
3rd, 5th, and 7th harmonic

Harmonics 101

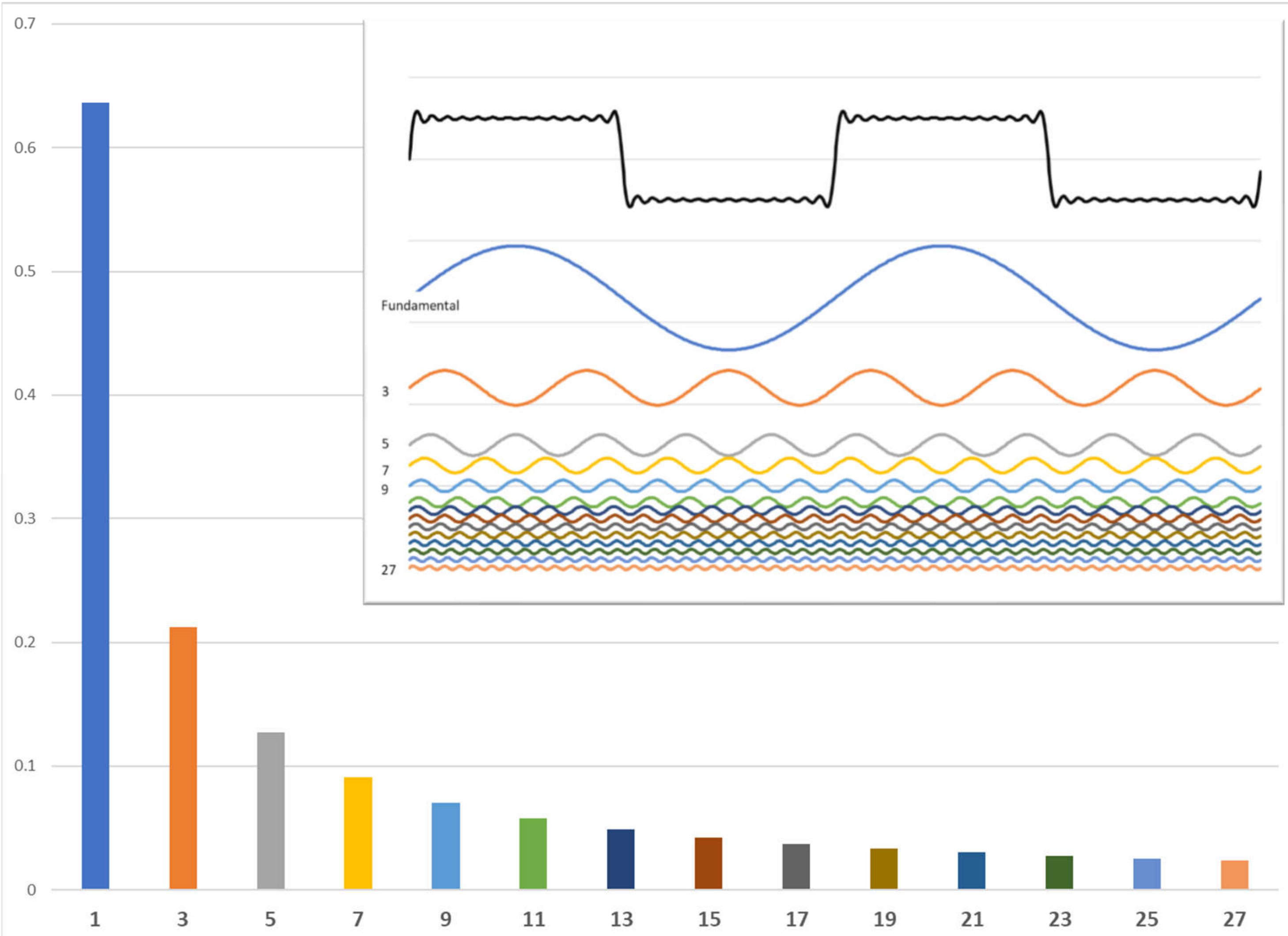


Fundamental Added to 3rd, 5th, 7th, and 9th harmonic

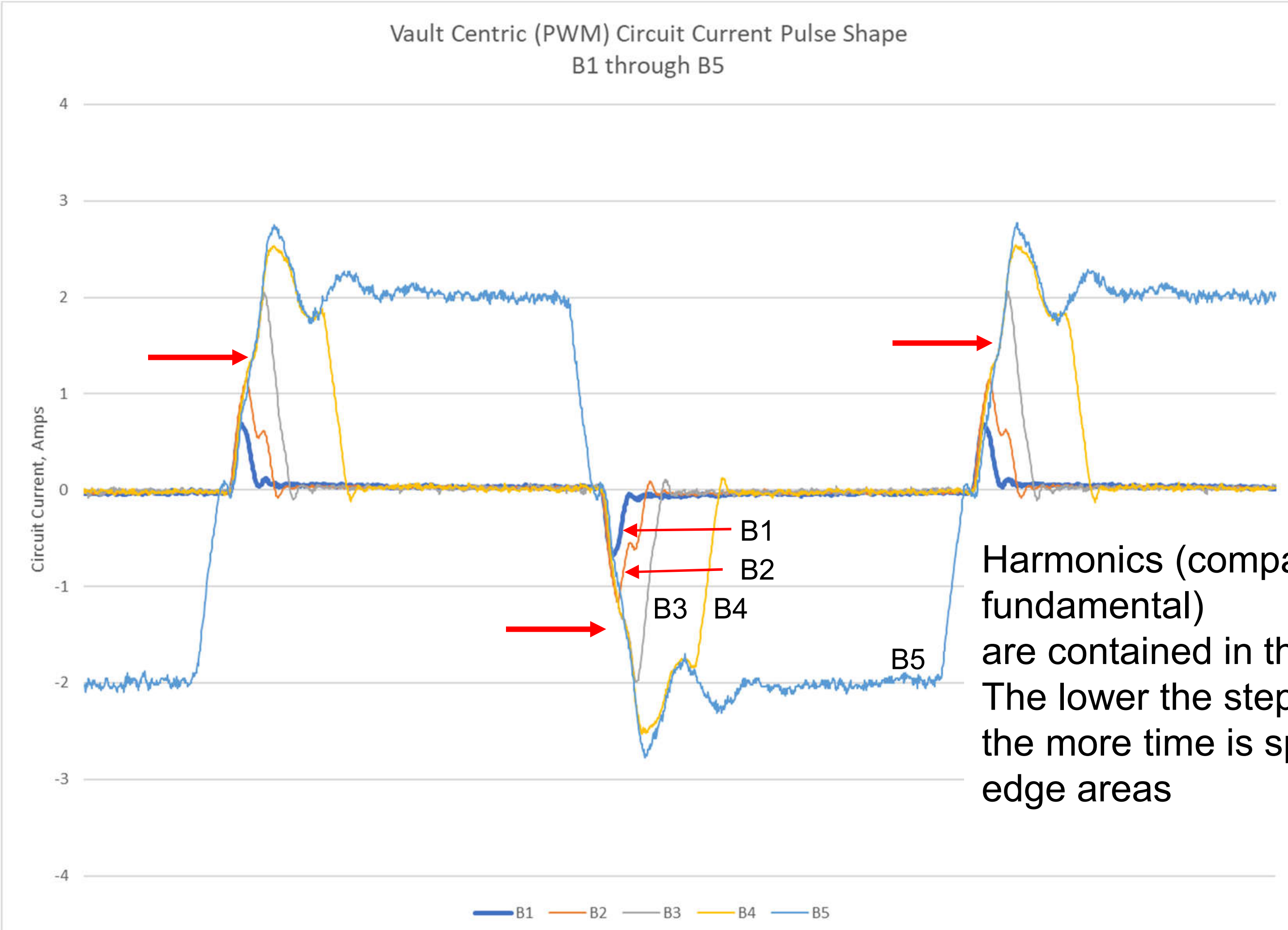
Harmonics 101



Harmonics 101

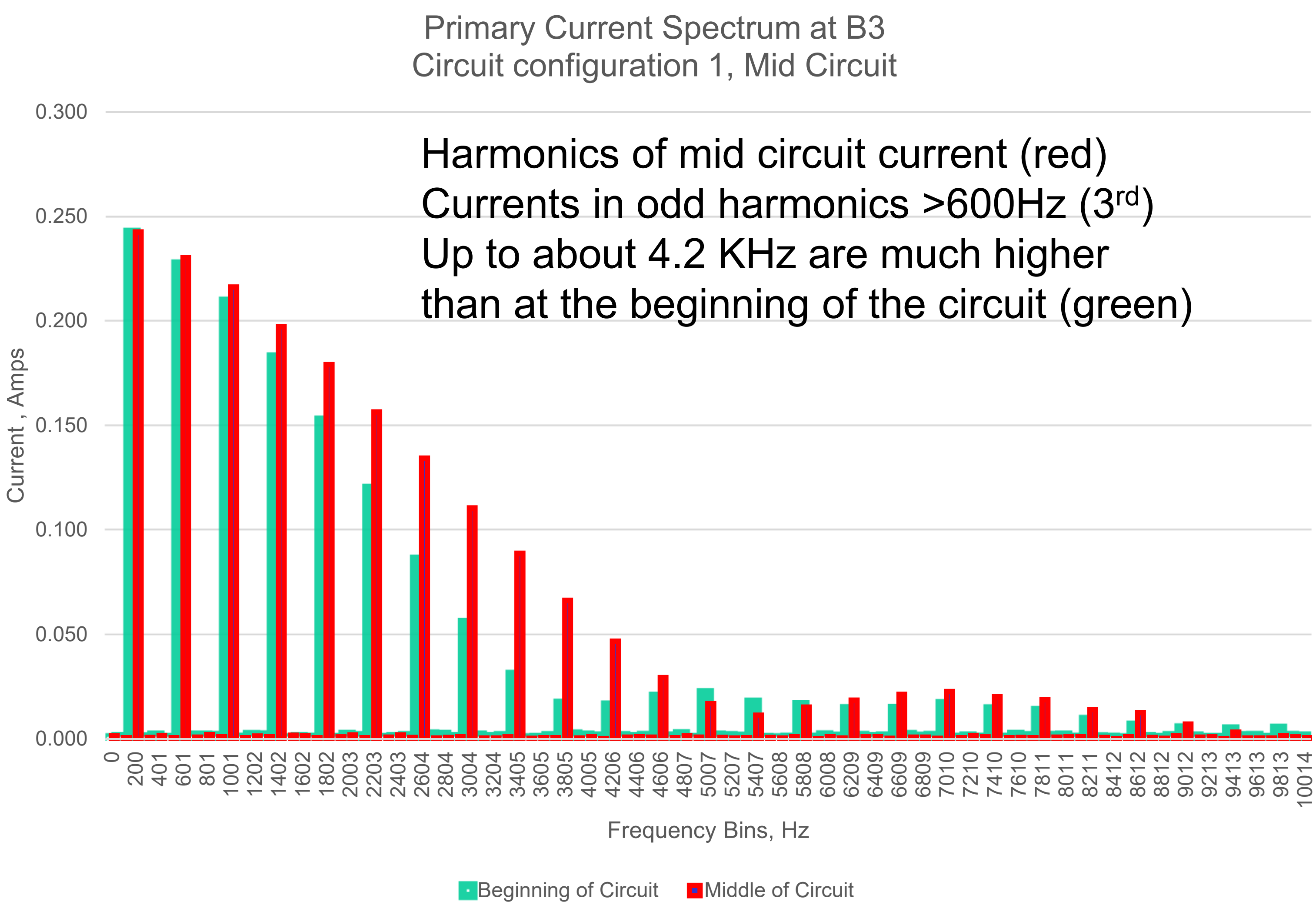


Vault Centric Fixture Performance Test



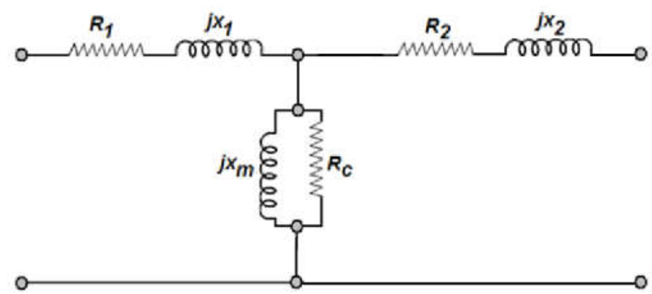
Harmonics (compared to fundamental) are contained in the edges. The lower the step, the more time is spent in edge areas

Vault Centric Fixture Performance Test

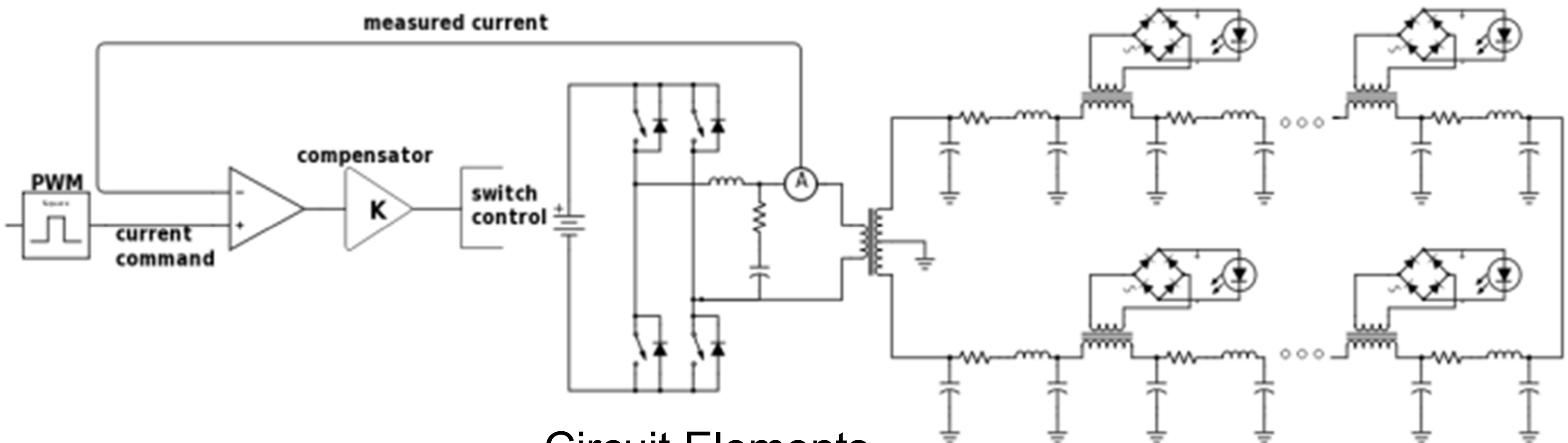


Modeling and Simulation

- Purdue University developed electrical models and ran simulations of the Vault Centric Circuit
- This was done to confirm testing results
- Purdue built an electrical model of the power source, cables, transformers and fixtures
- Based on this work, the simulation confirmed the measurements made.
- Reducing transformer leakage inductance reduces, but does not eliminate, some of the anomalies found



Fixture transformer



Circuit Elements

Vault Centric Summary

- Overall Loading is very low
- White light dimming will result in even lower dimming levels (Higher dimming ratios)
- Reactive loading requirement may be excessive for LED circuits
- Harmonic content of pulses is variable on circuit- this makes uniformity an issue, and specs a challenge
- Low inductance transformers may help in some areas of the circuit but change other areas. Other impacts would be likely, in driver stability and consistent current distribution.
- Insulation faults impact lower intensity settings most, indicating that the high frequencies coupling to ground is the issue

Conclusions, Vault Centric

- At this time, Vault centric PWM included issues with uniformity of current on circuit, and sensitivity to circuit insulation faults These are due to the higher frequencies and harmonics that result from the shape of the waveform. This fundamental characteristic of this architecture will make any specifications challenging.
- Style 2 or 3 signs or other constant VA loads on circuits at lower steps will be difficult to implement.
- Arctic Kits may not be a practical option.
- At this time, the EIRT is not recommending that the FAA pursue the development of performance standards based on this architecture.

Conclusions Fixture Centric

- Fixture centric architecture showed interoperability, and robust performance
- Fixture centric retains existing functionality and can support legacy 6.6 amp operation. This provides a migration path.
- Heater controls are independent of intensity
- Addressable components can select fixture direction or groups.

- The EIRT is recommending that the FAA develop performance standards based on this architecture.

Thank you!

Questions?

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