Improving Airfield Lighting Power Infrastructure for LED Lighting Components

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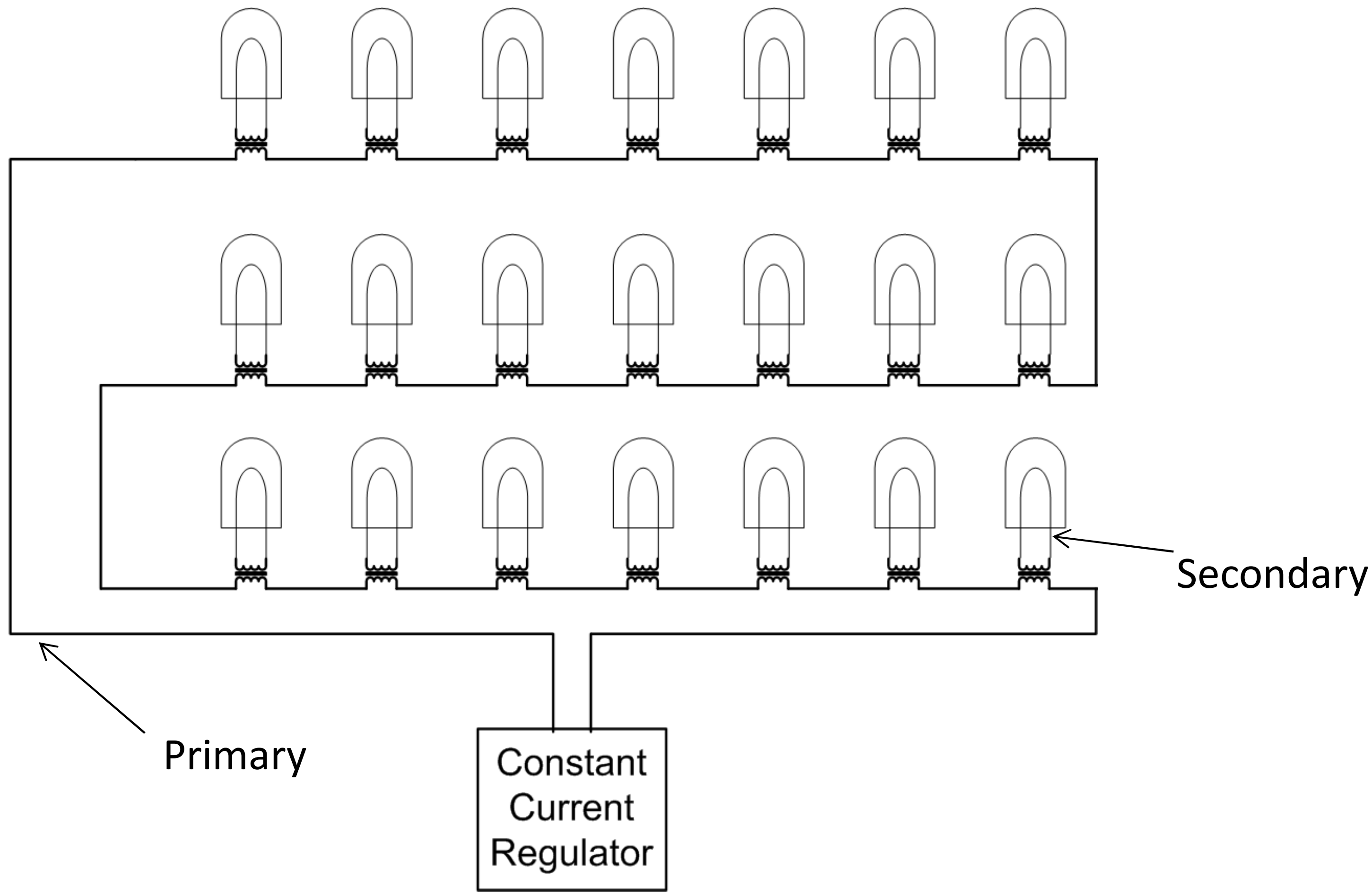
Summary of Discussion

- Legacy Circuit Architecture
- LED Components on Existing Circuits
- Elements of Airfield Lighting Infrastructure
- Research Highlights
- Current status
- Research Outlook
- Questions

Legacy Circuit Architecture

- Present airfield infrastructure based on a series circuit current loop, RMS Current is controlled on the loop
- Primary Current = Secondary Current, (more or less)



Legacy Circuit Architecture

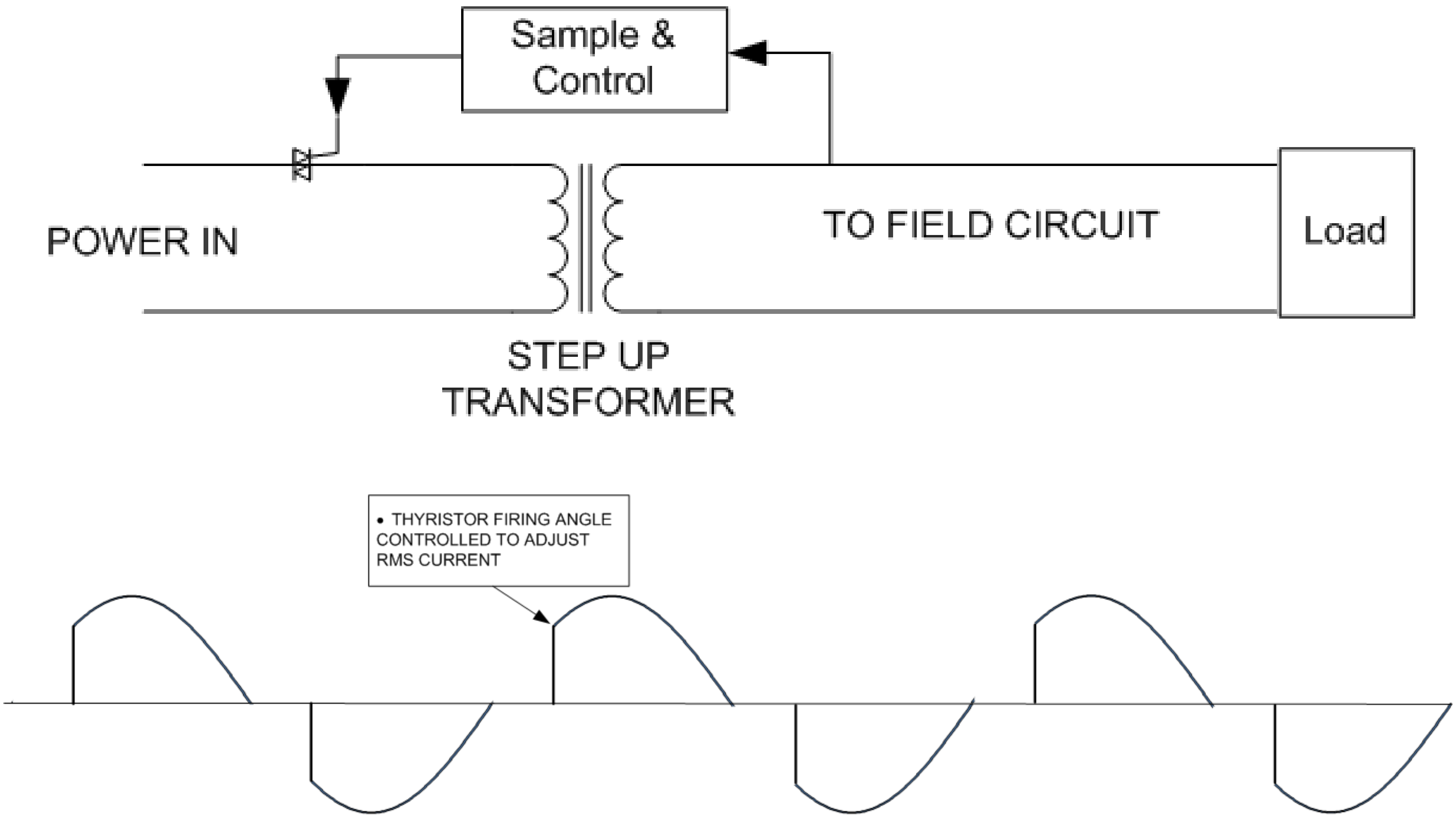
- For Incandescent lamps, current in the filament determines intensity
- Lamps are designed for 6.6 amps is its nominal maximum light intensity.
- Lower steps provide intensities listed independent of lamp wattage

Step,(5Step)	Step, (3 Step)	Fixture Current, Amps (6.6 amp Circuit) (=/- 0.1 amp)	Nominal Light Output, % of Max
B5	B100	6.6	100
	B30	5.5	30
B4		5.2	25
	B10	4.8	10
B3		4.1	5
B2		3.4	1.2
B1		2.8	0.15

Power for Legacy Circuits

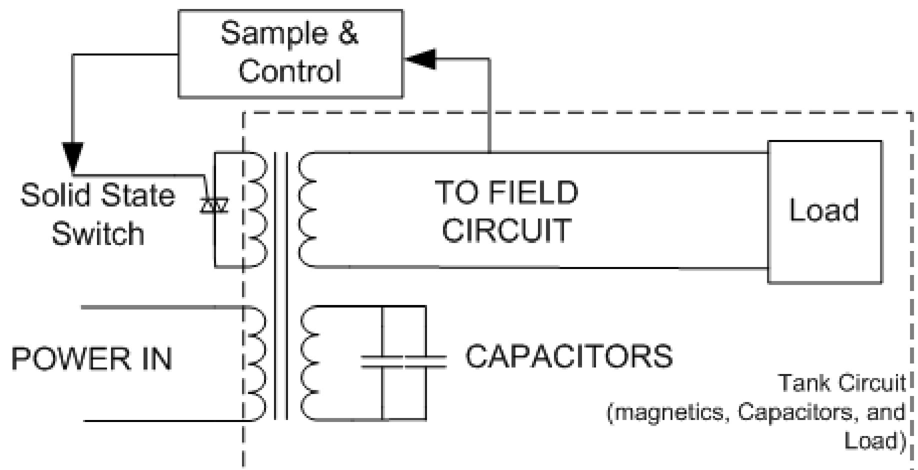
- Constant Current Regulators (CCR)
- Two Major categories:
  - Thyristor (or SCR)
  - Ferroresonant

Thyristor CCR



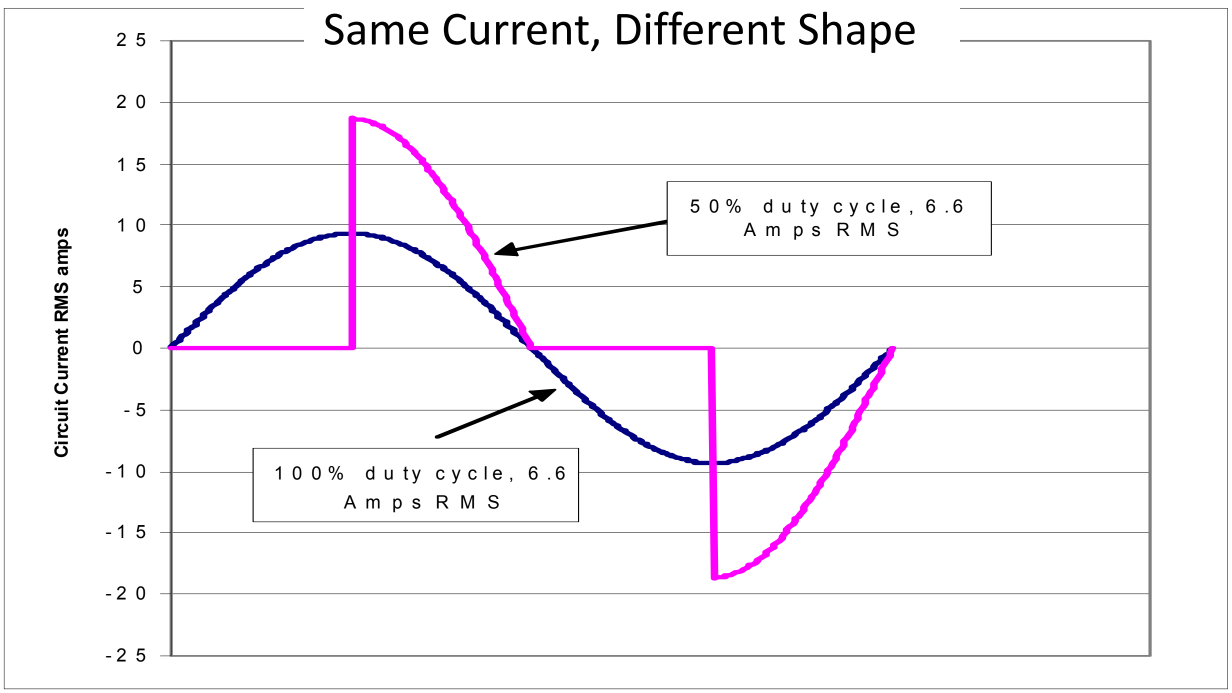
Ferroresonant CCR

- Tank circuit resonance regulates current for small changes in circuit load, Higher impedance (more load) results in more voltage to compensate
- Control circuit handles larger circuit load changes by allowing or inhibiting tank circuit current



CCR Waveform

- Crest Factor allowed is up to 3.4 with peaks of 22.4 amps (AC 150/5345-10)
- Incandescent fixture intensity is not sensitive to waveform
- Intensity is determined by the area under the curve

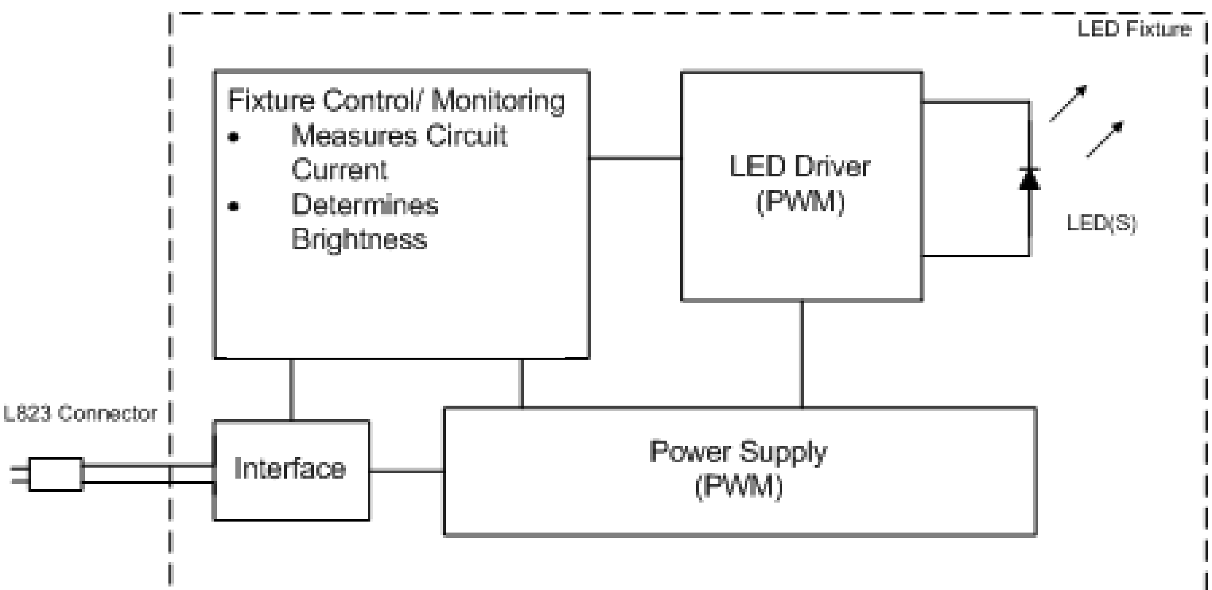


Factors influencing current into the fixture

- Transformer loading
- Transformer manufacturing tolerances
- Insulation quality
- Crest factor (from 1.4 up to 3.4)
- Allowable CCR tolerance (+/- 0.1 amps)
- Out of tolerance CCRs in the field

LED Components on Existing Circuits

- Initial approach was to have intensity of LED fixtures match the legacy infrastructure
- The emphasis was primarily on intensity behavior
- At the time, the assumption was that electrical compatibility would follow



LED Components on Existing Circuits

Example Power Comparison		
Fixture	Quartz	LED, pf .95 more or less
L-861 T Taxiway Edge	45W	15- 20 VA
L852D, Bidirectional Taxiway Centerline Light	60W	20- 30 VA
L-850A , Bidirectional Runway Centerline Light	96W	30-40 VA

LED Components on Existing Circuits

Advantages

- Plug and play operation
- Power systems could remain more or less the same
- Installation and maintenance was similar

Disadvantages

- Loss in the cables and transformers as a result of currents higher than required for power delivery to LED fixtures
- Compatibility issues arose as numbers of installed fixtures was increased
- Over time, mixing of LED and incandescent was not allowed

LED Components on Existing Circuits

- Circuit and transformer losses could be at least 2.5 KVA, for a runway edge circuit at high step.
- LED Compatibility issues included:
  - Dependency of LED fixture intensity to duty cycle
  - Unexpected behavior of fixture when selected current was influenced by CCR tolerances, calibration, insulation and transformer tolerances.
  - On some LED fixtures, voltage is over double at start up compared to operational voltage.
  - Conducted emissions from LED electronics that can interfere with addressable components using power line carrier

Electrical Infrastructure Research Team (EIRT)

- Team was formed by Don Gallagher and Alvin Logan who are co-chairs for the team
- Team consists of experts from FAA, industry, airport maintenance, design consultants
- An EIRT Test Team chaired by Robert Bassey was also formed to test and evaluate experimental architectures, and report to the EIRT
- The Test Team consists of FAA, product development experts, and consultants with appropriate background in airfield lighting design

Electrical Infrastructure Research Team (EIRT)

- EIRT Scope:
  - Investigate, Discuss, and Resolve These Issues With Respect to Infrastructure
  - Test and Evaluate New Systems and Design Elements
  - Develop Basis for Standards for Infrastructure that resulted in improved performance, and interoperability of components
- <u>Entire Systems Level Approach that addresses the electrical behavior of the components, and allows some level of infrastructure degradation as it does in the real world</u>

Electrical Infrastructure Research Team (EIRT)

Infrastructure Desirable Characteristics

- Provide the support for the fixtures to meet photometric and radiometric output requirements.
- Support standardized system operations so equipment manufacturers can produce interoperable products
- High system availability and reliability.
- Suitable capability for airport electrical designers to implement a design and appropriate constructability for contractors to build.
- Safety considerations for maintainers of the systems
- Account for real world circuit conditions, so there are large operating margins.
- Lower system life cycle costs in terms of initial equipment outlay, maintenance costs, and energy consumption.

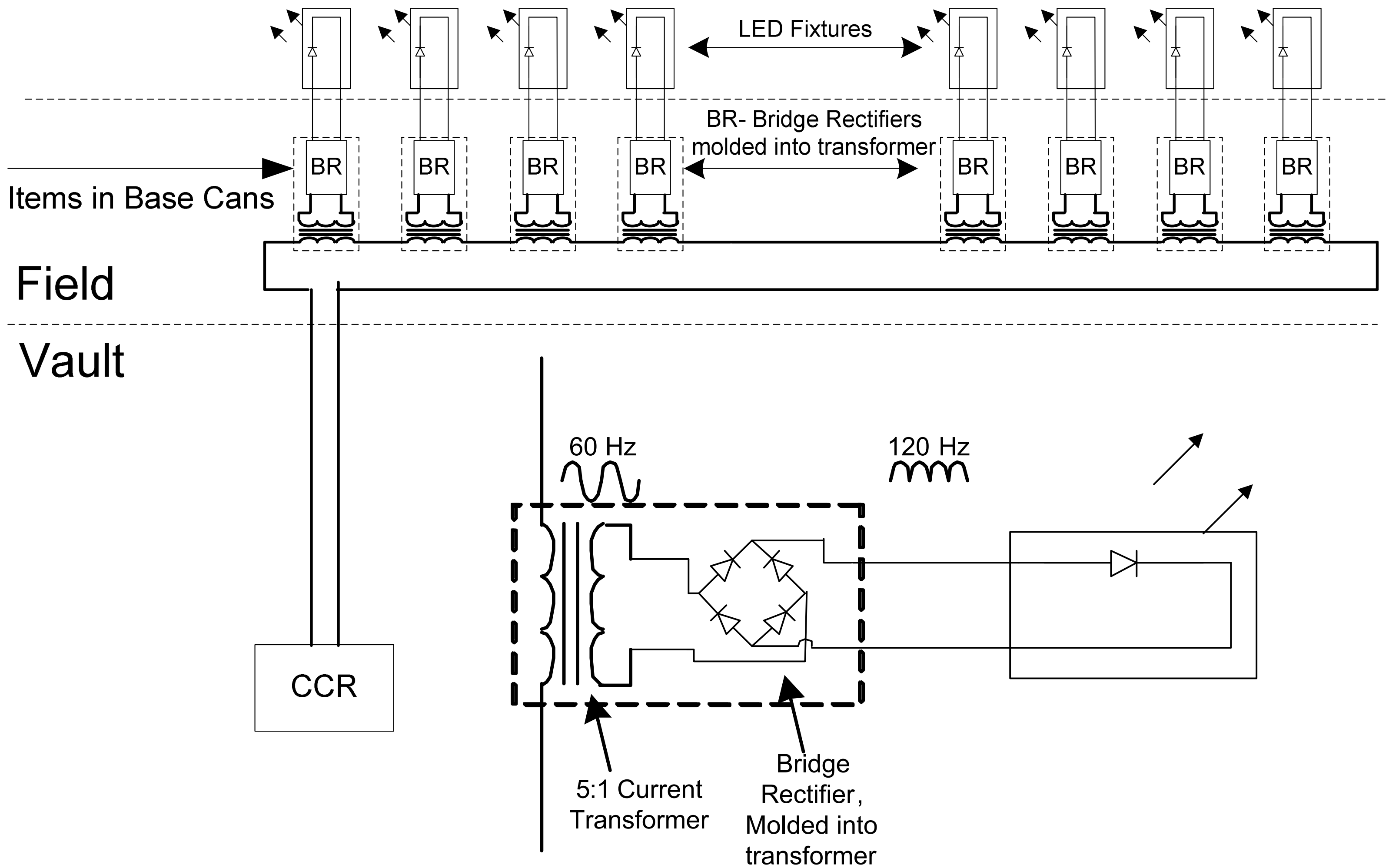
Research Highlights

- Investigations of existing alternative Infrastructures
- Objective is to identify desirable elements of experimental architectures to best suit the application
- Experimental infrastructures considered included:
  - Low Current, Series Powered, LED Driver in the Vault, Sinusoidal Drive
  - Low Current, Series Powered, LED Driver in the Vault, Pulse Drive
  - Parallel Powered, Power line Carrier
  - Low Current Series Powered, Power line Carrier
- FAA proof of concept architectures
  - Low Current Series Powered, Amplitude Shift Keying (ASK)
  - Low Current Series Powered, Frequency Shift Keying (FSK)

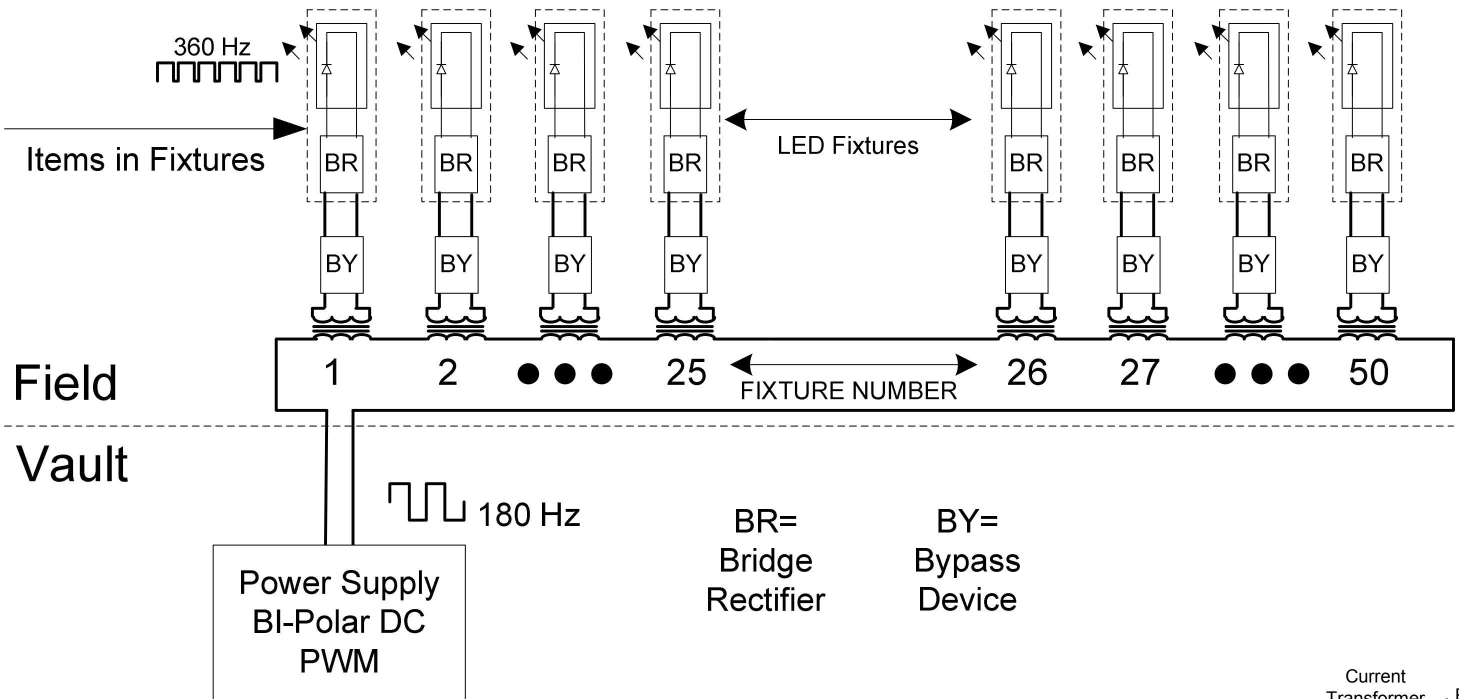
Research Highlights

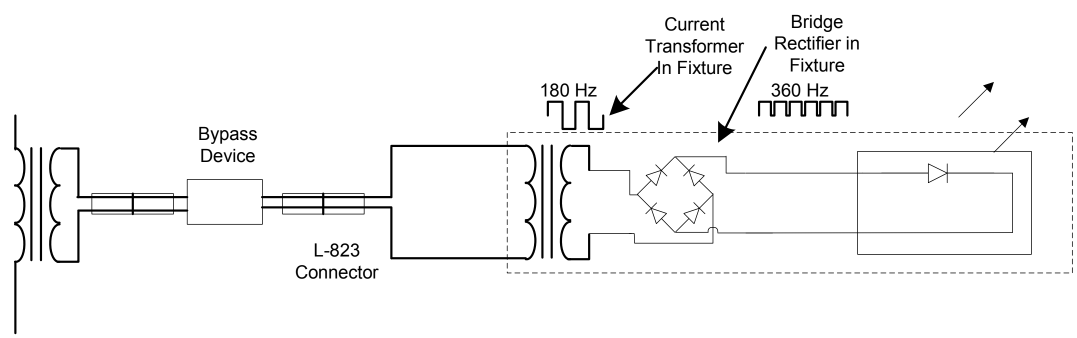
- DC architectures are not optimal for isolation of components
- Parallel architecture has load limitations and is not well suited for dealing with circuit configuration changes

Low Current, Series Powered, LED Driver in the Vault, Sinusoidal Drive

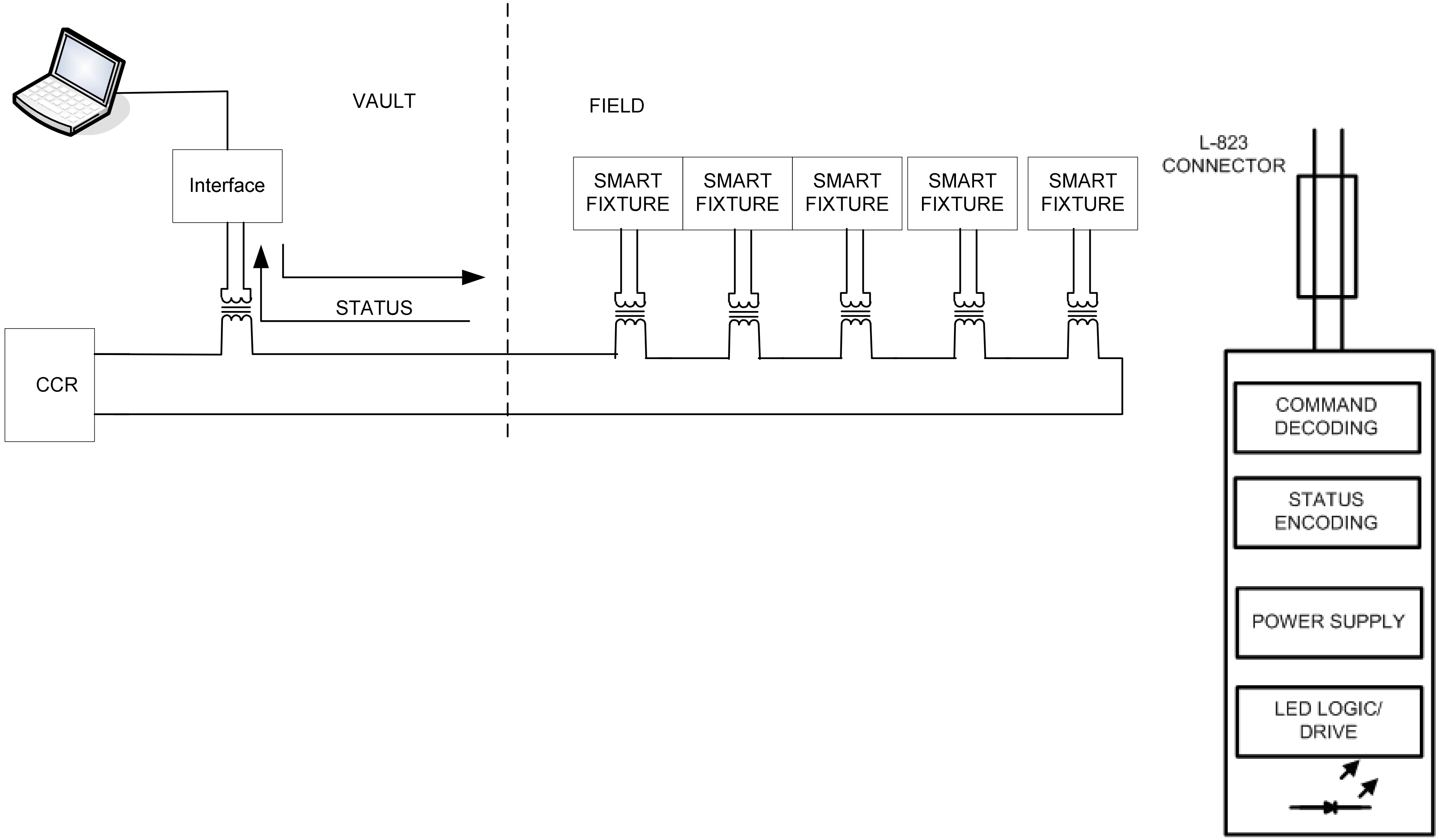


Low Current, Series Powered, LED Driver in the Vault, PWM Pulse Drive

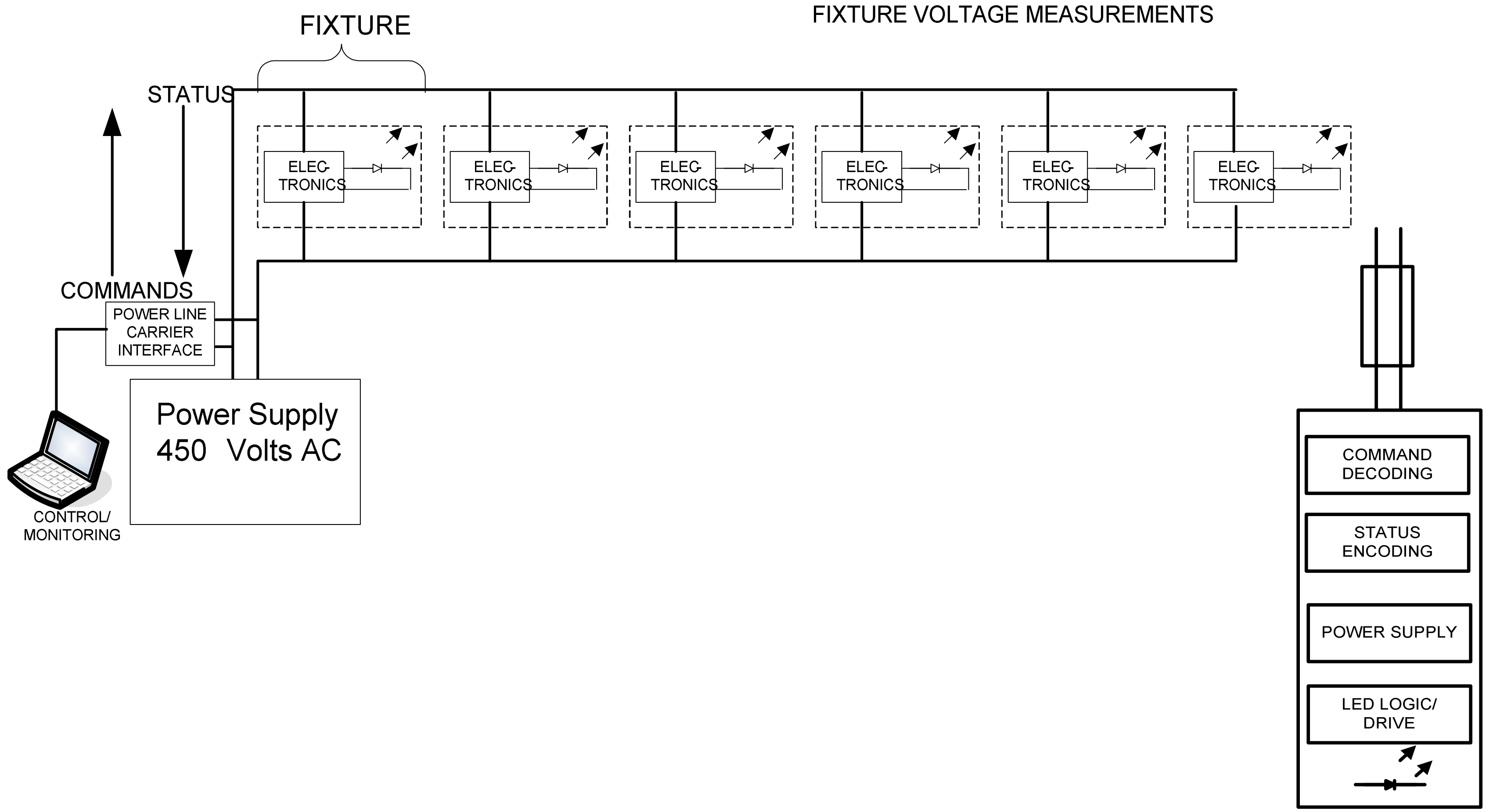




Low Current Series Powered, Power line Carrier

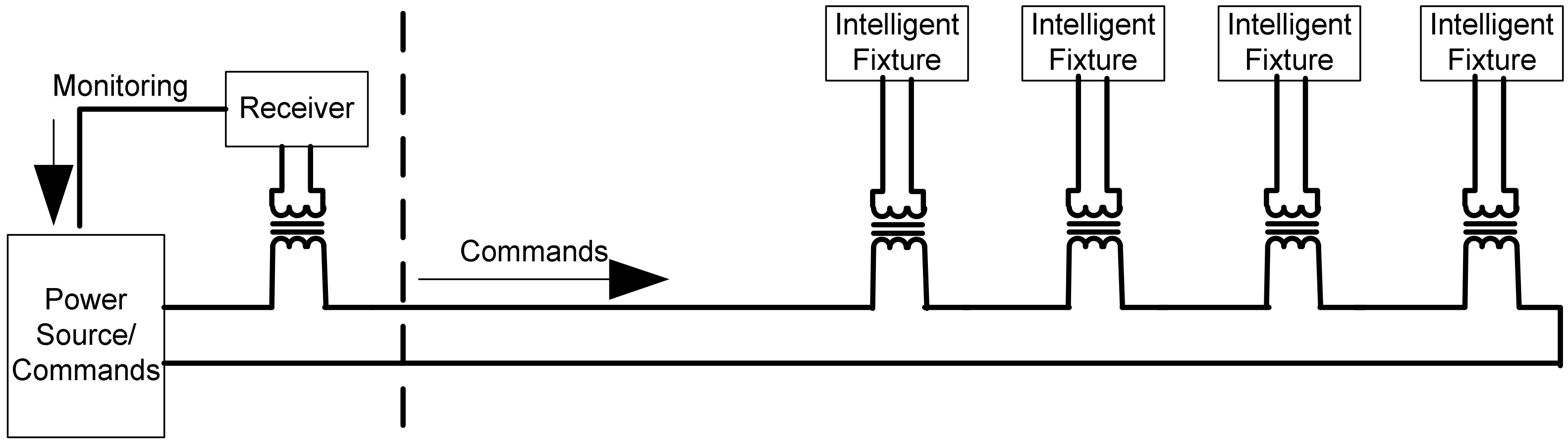


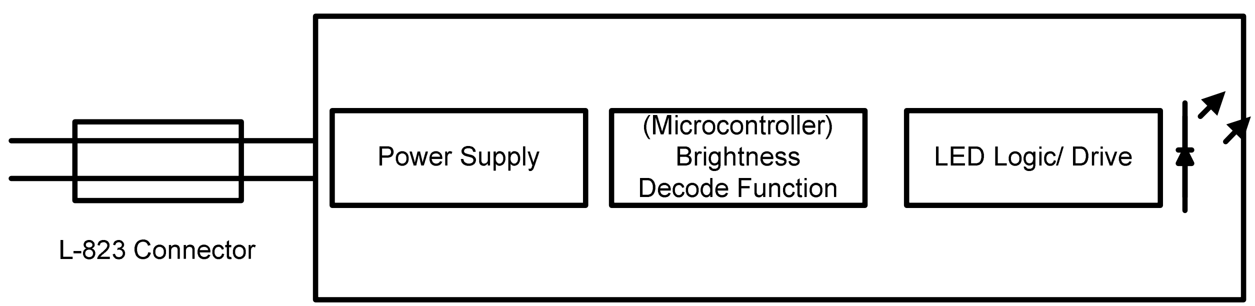
Parallel Powered, Power Line Carrier



Fixture Detail

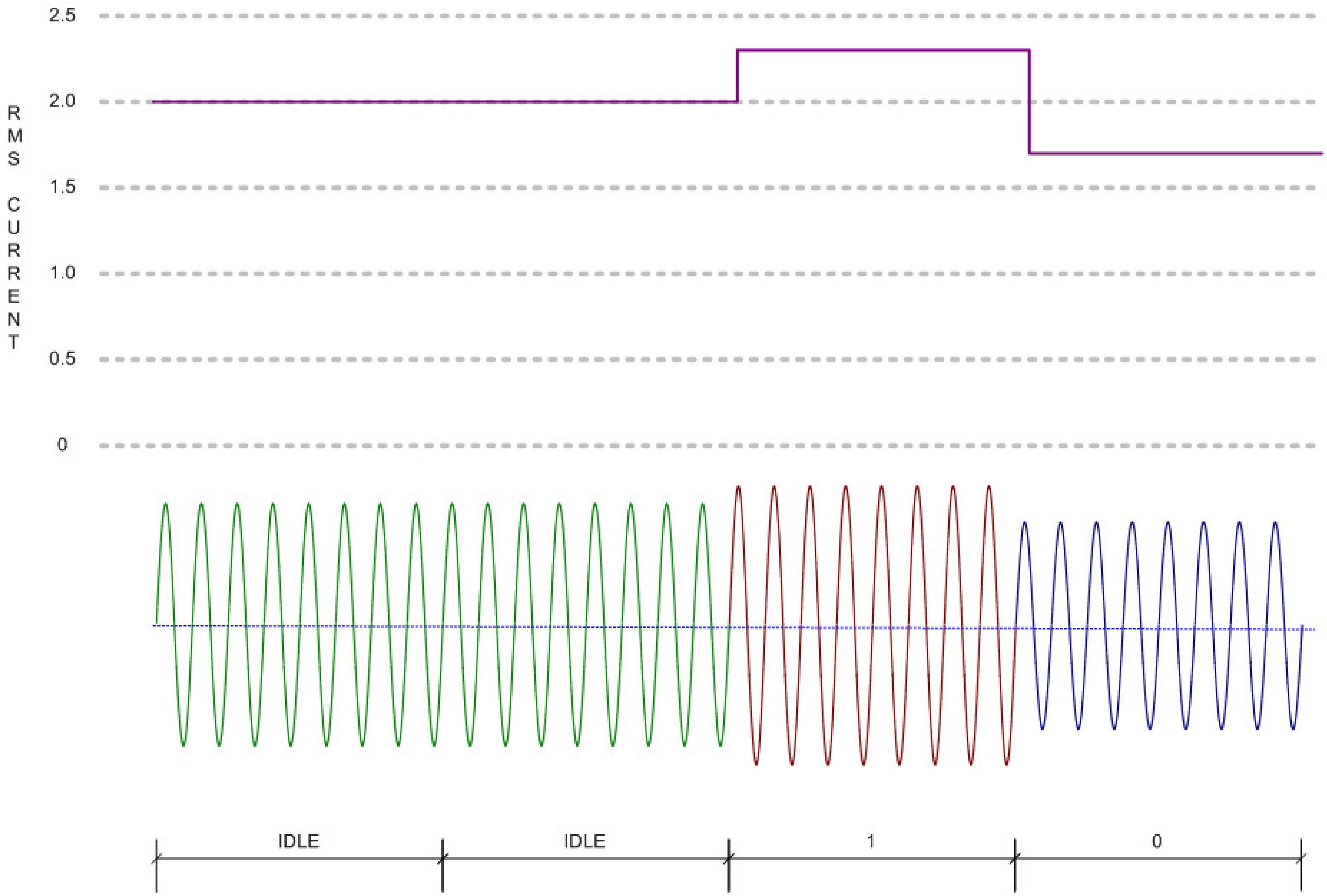
Low Current Series Powered, Amplitude Shift Keying (ASK) and Frequency Shift Keying (FSK)



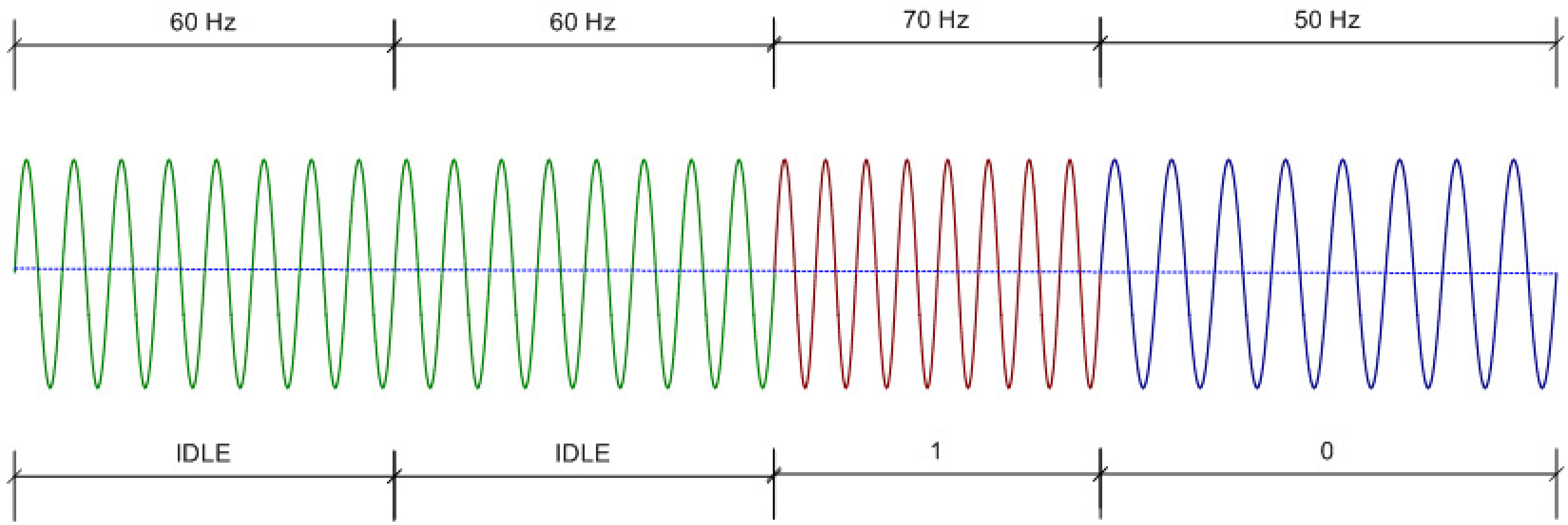


Fixture Detail, same as 6.6 amp Fixture

ASK Symbols



FSK Symbols



Tale of Two Architectures

- Investigation and testing revealed two fundamental architectural characteristics
- **Vault Centric-** where intensity is controlled by a power source for the entire circuit. The fixture directly tracks circuit current
- Advantage –
  - Least expensive,
  - Lowest power
- Disadvantage –
  - All infrastructure elements (power source, cables transformers, cable layout, insulation leakage and crosstalk) influence fixture intensity.
  - Lower intensities may not provide predictable intensity performance suitable for standardization
  - Heater options not practical
  - PWM version is a source of emissions on the circuit
  - Will not readily support add on capability for SMGCS

Tale of Two Architectures cont.

- **Fixture Centric** - Fixture controls its intensity level after intensity information is conveyed to it.
- Advantage-
  - Discrete intensity step information is sent to the fixture
  - Fixture intensity dimming- virtually any desired level at any pulse rate
  - Lights in groups can be independently controlled (for example bidirectional fixtures)
  - Fixture intensity not dependant or impacted on infrastructure. Tolerances in circuit current or voltage, transformers, and leakage do not impact intensity
  - Fixture can compensate for its own changes in performance such as temperature. Compensation is on the fixture level.
  - Heater or other loads are supported and can be independently controlled
  - The allowance for infrastructure related manufacturing tolerances and with less dependence on circuit layout and field conditions, provides suitability for standardization.
  - FSK/ ASK not proprietary
  - FSK/ ASK allow SMGCS add on capability to be supported
- Disadvantages
  - Cost is similar to conventional 6.6 amp LED fixture
  - Consumes more power than Vault Centric, on the order of 1.5 to 2 watts per fixture without the LED energized.

Testing Philosophy

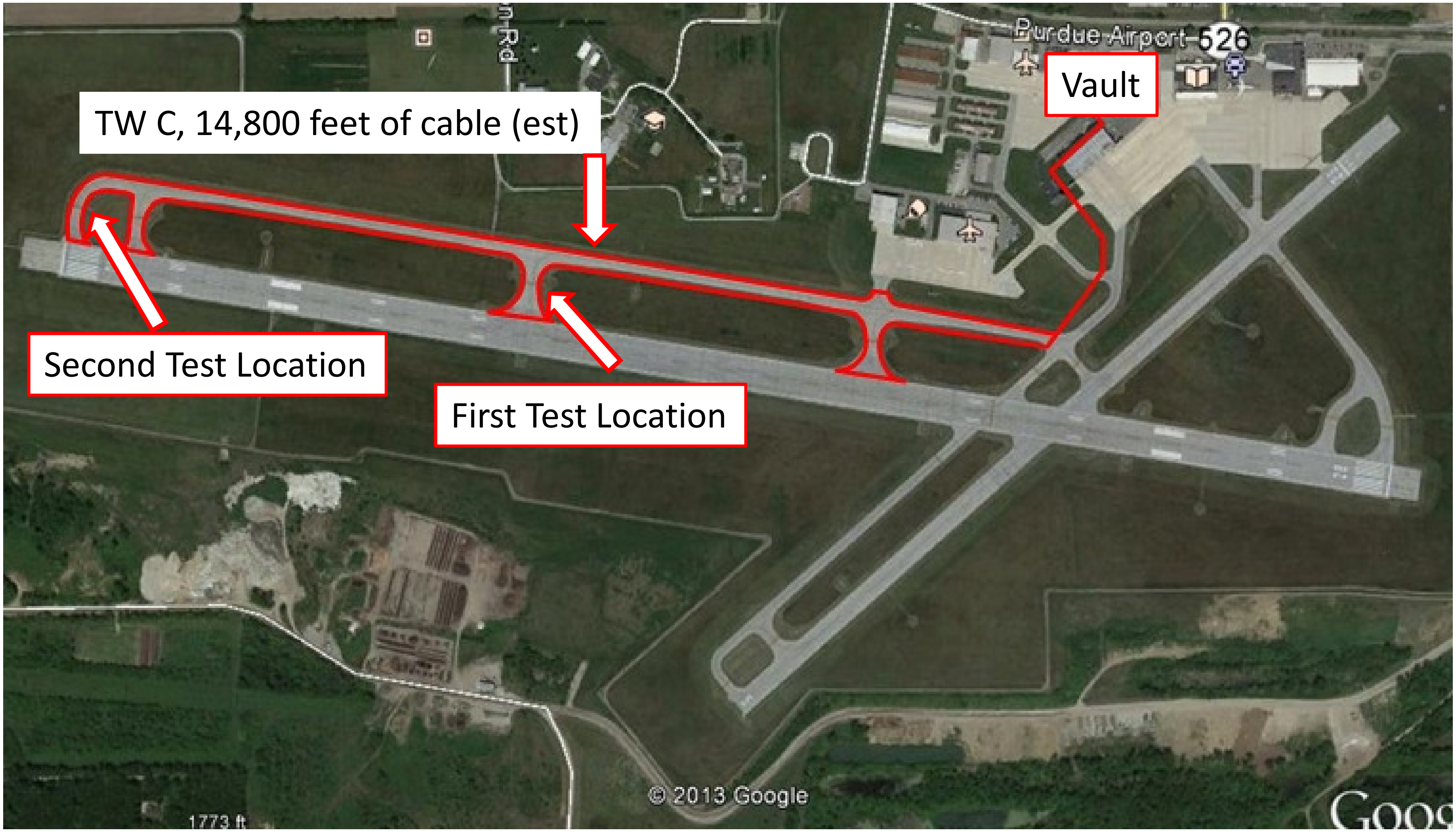
Build a little, Test a little.

- ASK and FSK are new infrastructures that required some proof of concept work to be done
- Lab proof of concept used a transmitting unit and receiving unit to demonstrated that information can easily be conveyed
- FAA test bed was used with 50 transformers about 2,000 feet of cable to further provide some information of proof of concept
- The test team developed a strawman protocol that is representative of how ASK and FSK might work (24 bits, intensity, direction, message error detection)
- 3 manufactures developed ASK and FSK fixtures from existing 6.6 amp products with modified firmware and successfully decoded intensity step messages in the lab
- All parties gained experience and a few issues regarding power stability came into focus and was addressed.

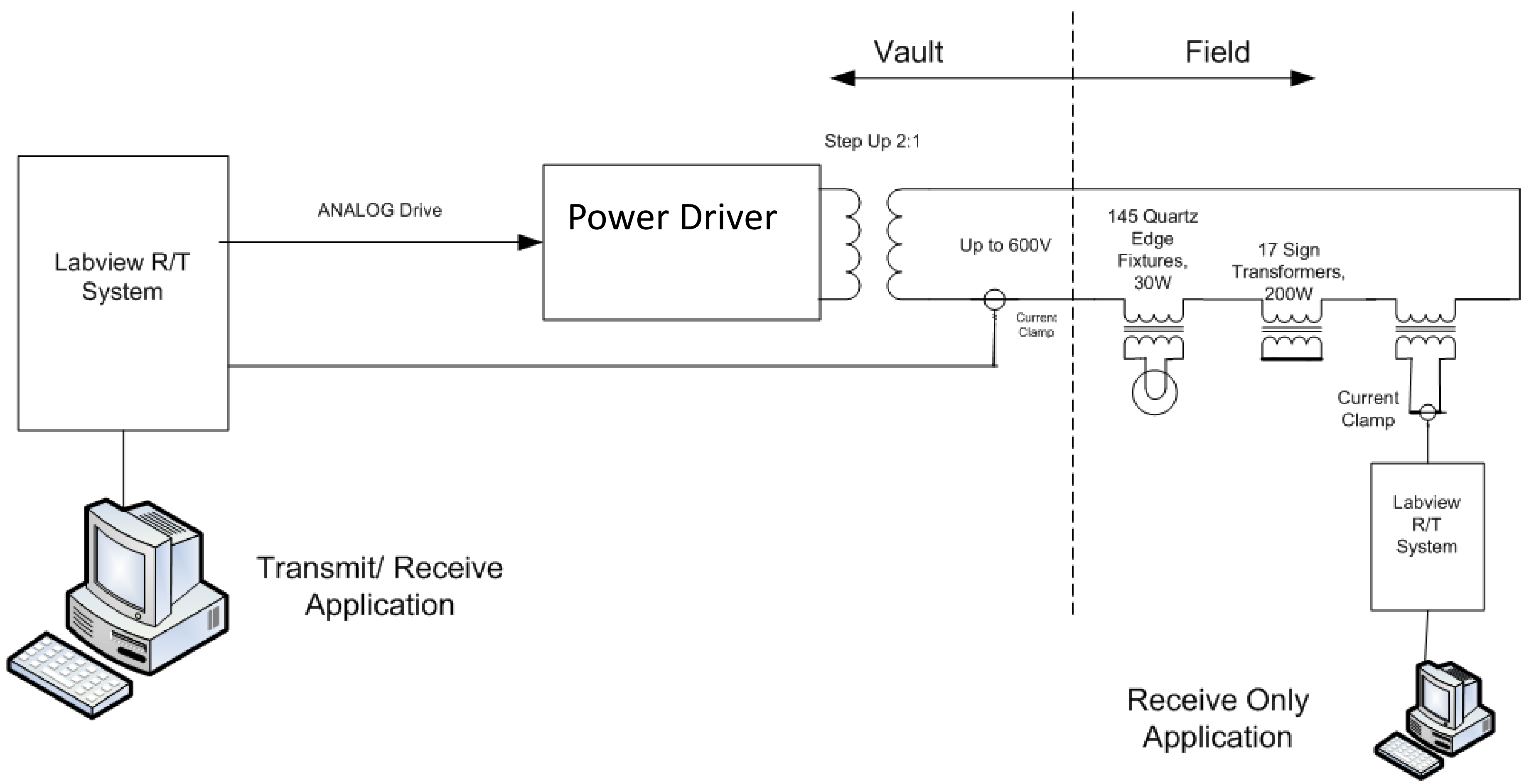
Purdue Initial Checkout

- Purpose – to gain an understanding of ASK and FSK behavior on a large circuit with poor electrical conditions.
- Circuit length about 14,800 feet
- 145 L830 30/45 watt transformers with MITL 30 watt incandescent fixtures
- 17 Signs with 200 W L830 Transformers, with shorting plugs
- Tested at several levels of current between 0.25 and 3.5 amps
- Insulation Resistance of the circuit: Less than 100 Ohms, Basically shorted to ground. (Should be at least 10 megohms) Measured at 1000 and 250 V
- Second receive location was losing about 0.2 amps of current due to insulation losses

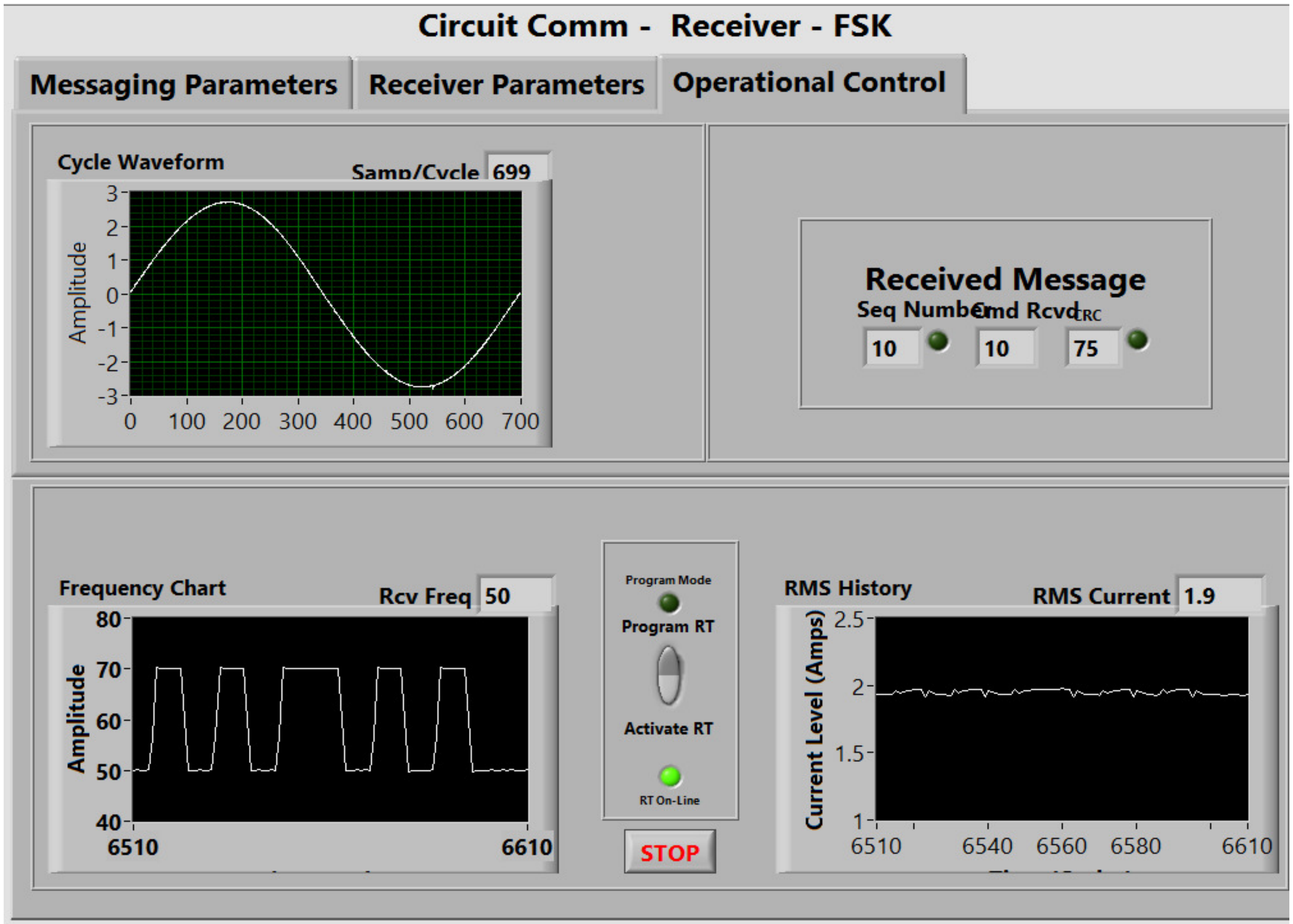
Airport at Purdue (LAF)



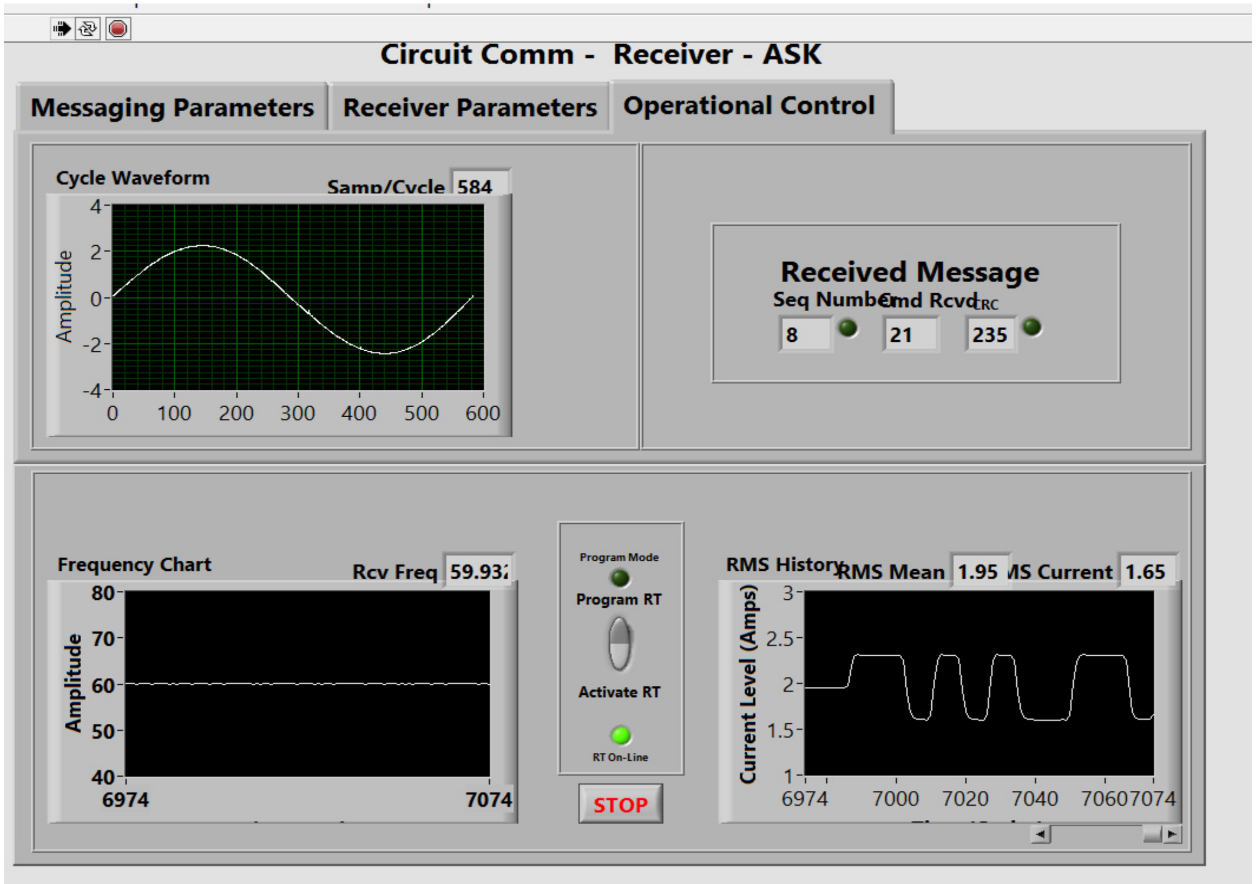
LAF TWY C Initial Test Setup 6/10/2014



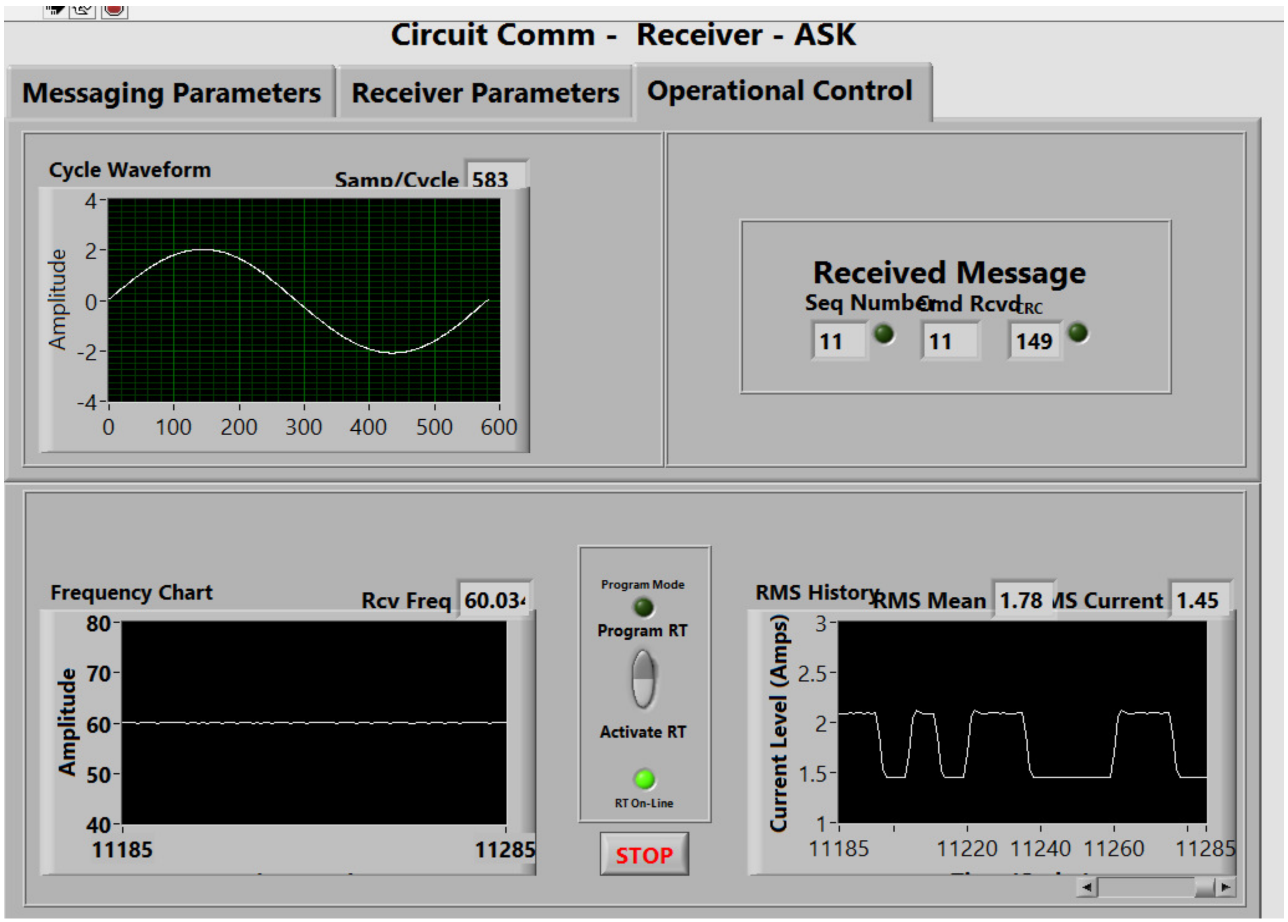
FSK Screen shot from the Field at 2 amps, 10 Hz Modulation TWY C2@10-28 hold sign (first test location)



ASK Screen shot from the Field at 2 amp, 0.3 amps Modulation TWY C2@10-28 hold sign (first test location)



ASK Screen shot from the Field at 2 amp, 0.3 amps Modulation TWY C4@10-28 hold sign (second test location)



Purdue Test 6-10-14 at LAF

- No message errors occurred
- Circuit was basically grounded at more than one location
- There was a reduction in current at the C4 sign location of about 0.18 amps, with no change in performance
- This was due to circuit leakage, resulting in uneven current distribution
- Two deliberately Interfering circuits did not impact performance

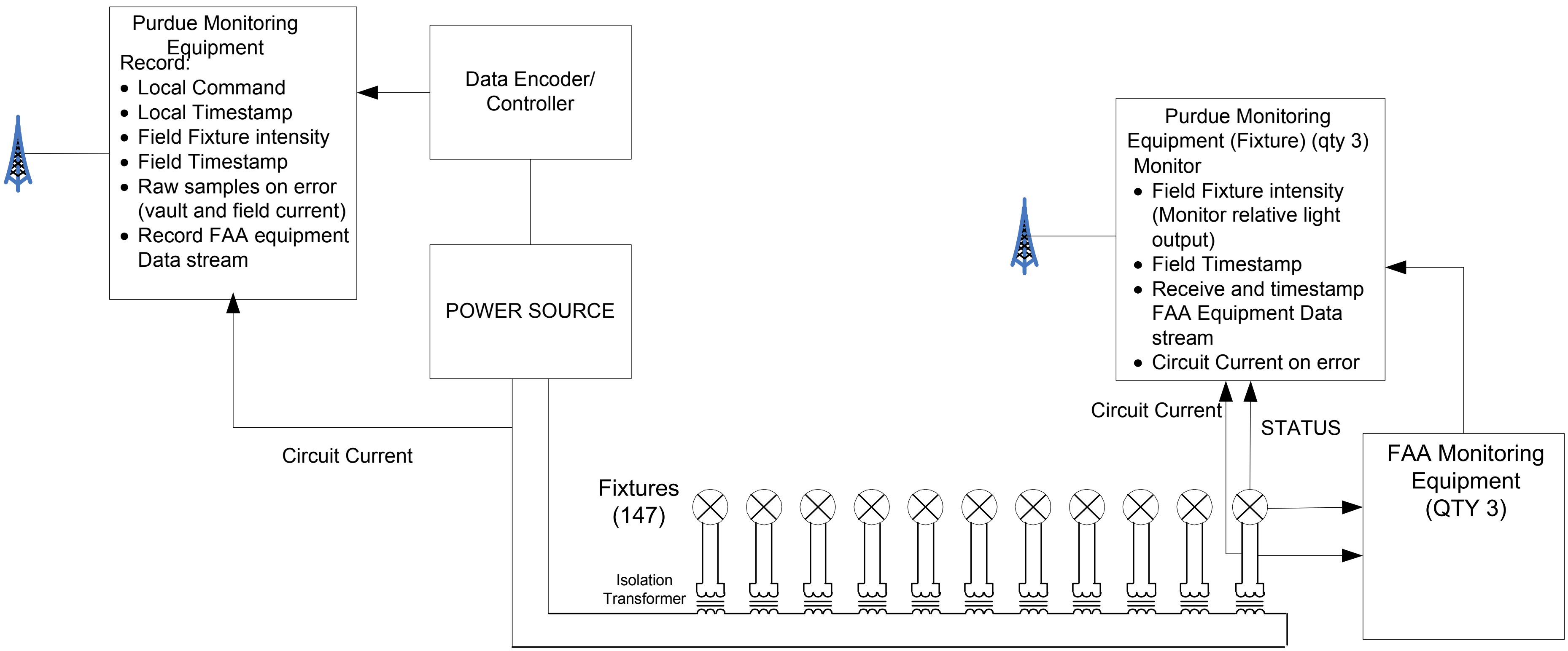
Alpha Test at The FAA Technical Center

- Purpose is to integrate ASK and FSK fixtures from 3 different manufacturers and FAA power and monitoring equipment
- Will include all equipment to be shipped to Purdue
- Adjustments and bug fixes can take place on a test bed with no access restrictions
- After testing, the Beta testing can begin at Purdue

Next Testing at the Purdue University Airport

- Support for testing and circuit simulation from Purdue University as part of the PEGASAS program with the FAA
- Purpose is to collect information on ASK and FSK architectures on a large scale circuit over a period of several months
- 147 ASK/ FSK capable fixtures will be installed, 49 from each manufacturer
- The large population of fixtures will provide data on any message related issues, and also power interactions that relate to stability
- Existing Taxiway C circuit will be used for testing
- 1 fixture from each manufacturer will be instrumented

Next Testing at the Purdue University Airport



Research Outlook

- Develop Long Term Data on ASK and FSK at Purdue
- Test Team will Prepare report to EIRT Team
- Decision on Architecture(s)
- Fully Detail Architecture(s) based on testing and simulations
- Report and recommendations
- Develop Fully Compliant Products
- Large Scale checkout
- Final report and recommendations to Airport Engineering

Summary

- The research had resulted in candidate architectures that can are a significant improvement on the 6.6 amp infrastructure and support present and future requirements while reducing energy use
- An important aspect of the present research effort is to define the infrastructure that will ensure compatibility and interoperability of components
- Infrastructure definition will include characteristics and interactions of the components that have been identified from the research to ensure compatibility, leaving no gaps between power source, cable and coupling and fixture.
- Initial testing has shown very positive results in both the lab and large circuit testing. The next steps will include a large number of components on a circuit in poor condition.
- The resulting work will allow a proposed improved architecture to be documented into a standard.

Questions

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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	

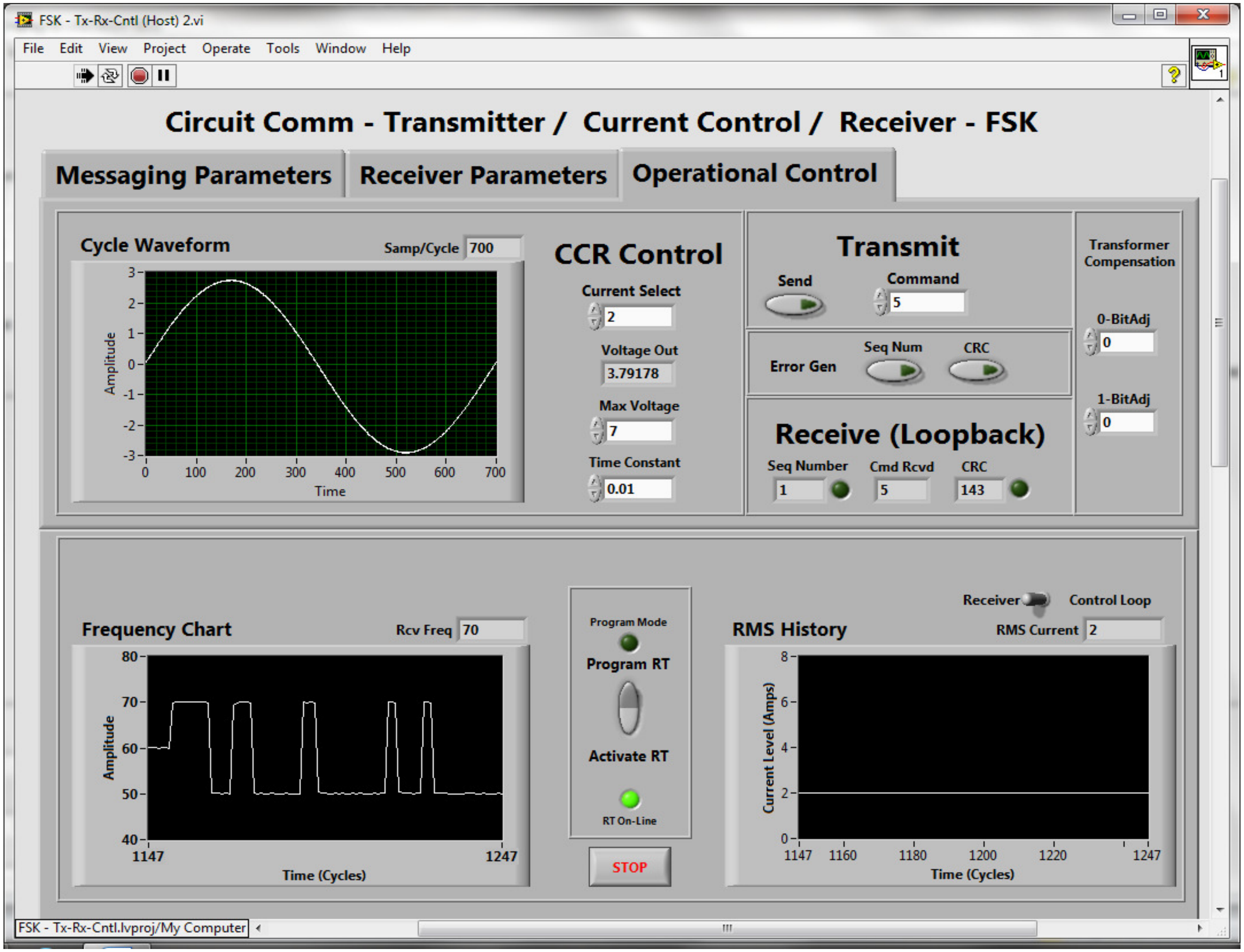
d4:d3 light

00	reserved
01	side A
10	side B
11	Both

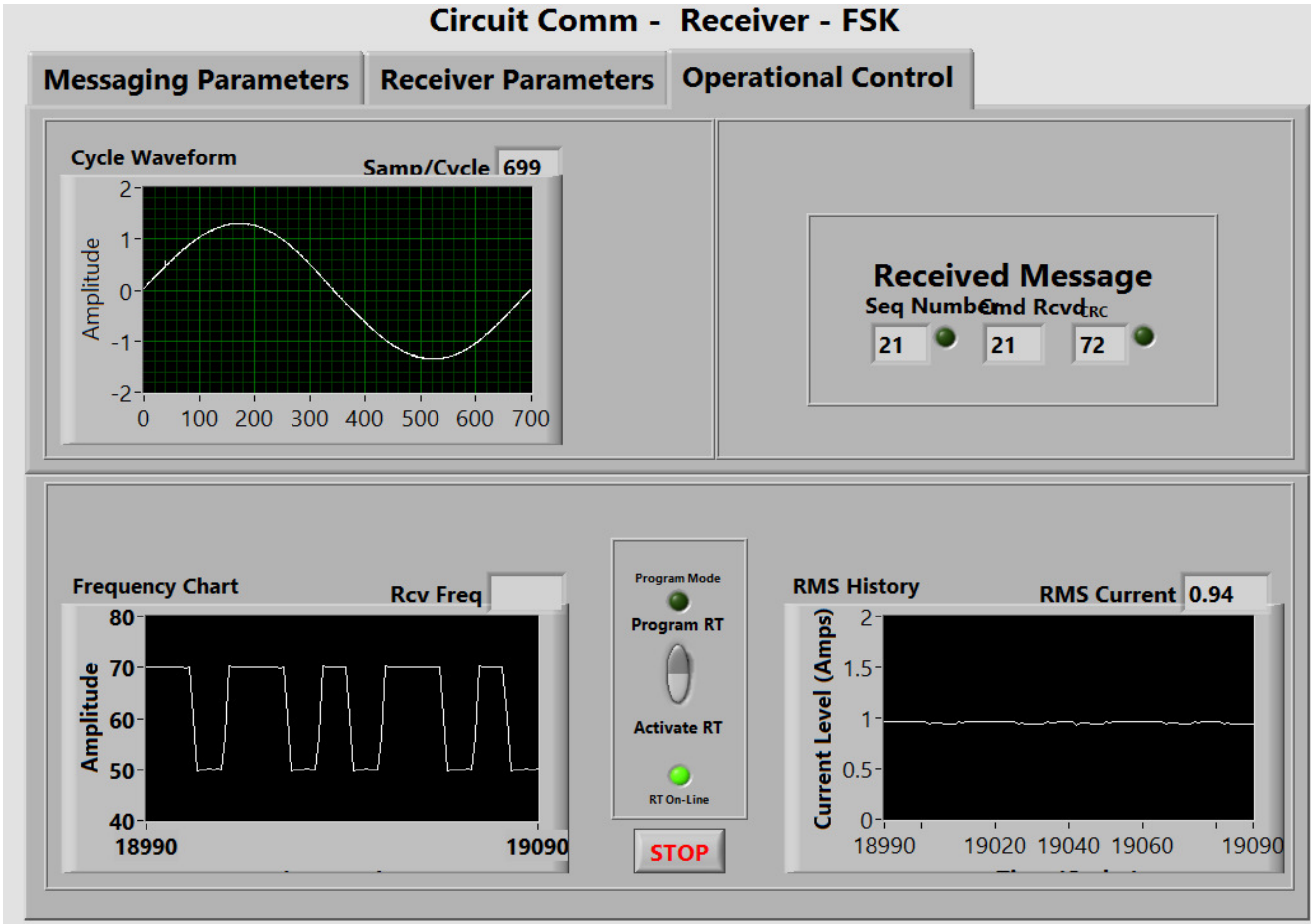
d2:d0 Intensity

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

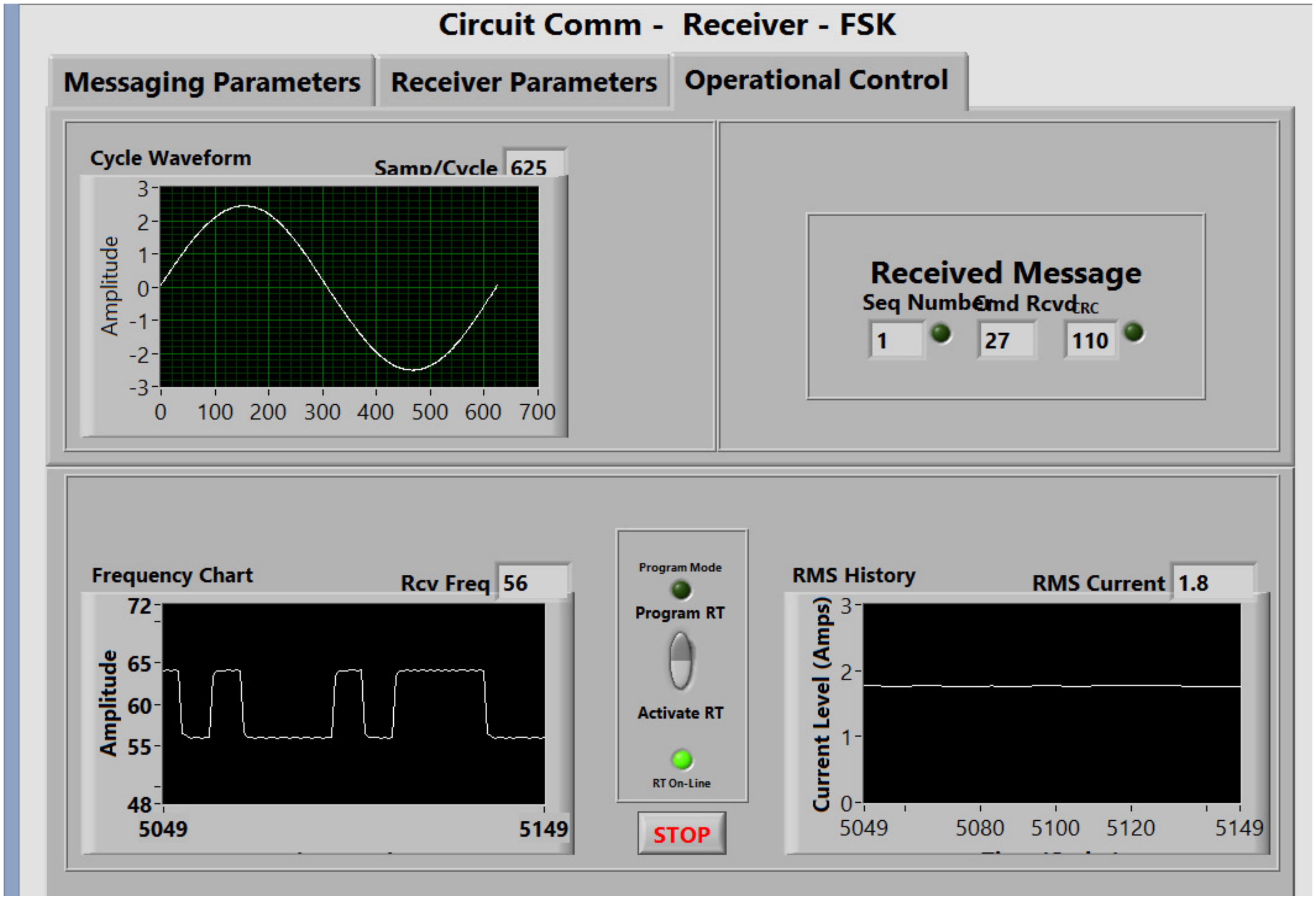
FSK Screen shot from the vault at 2 amps, 10 Hz Modulation



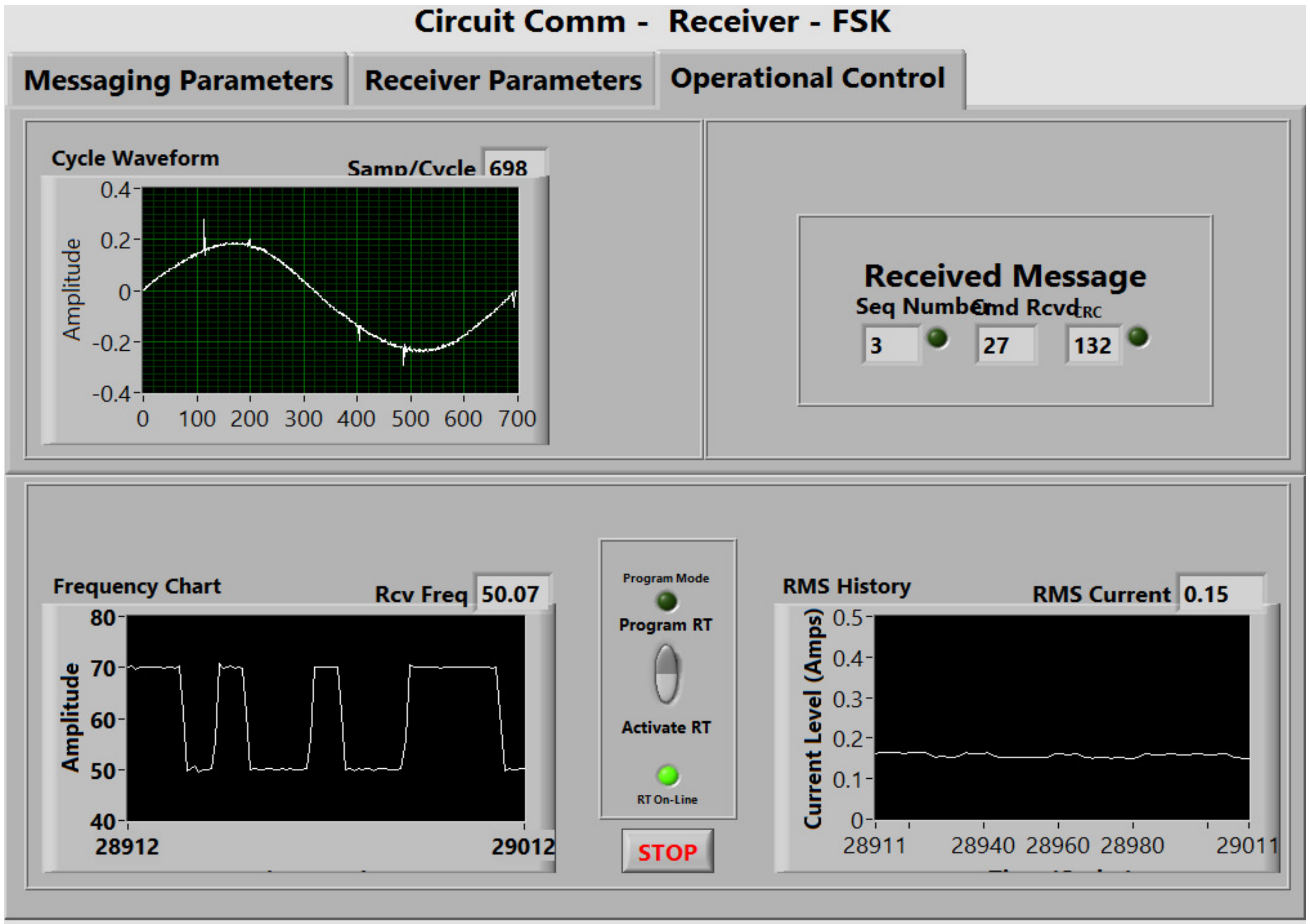
FSK Screen shot from the Field at 1 amp, 10 Hz Modulation
TWY C2@10-28 hold sign (first test location)



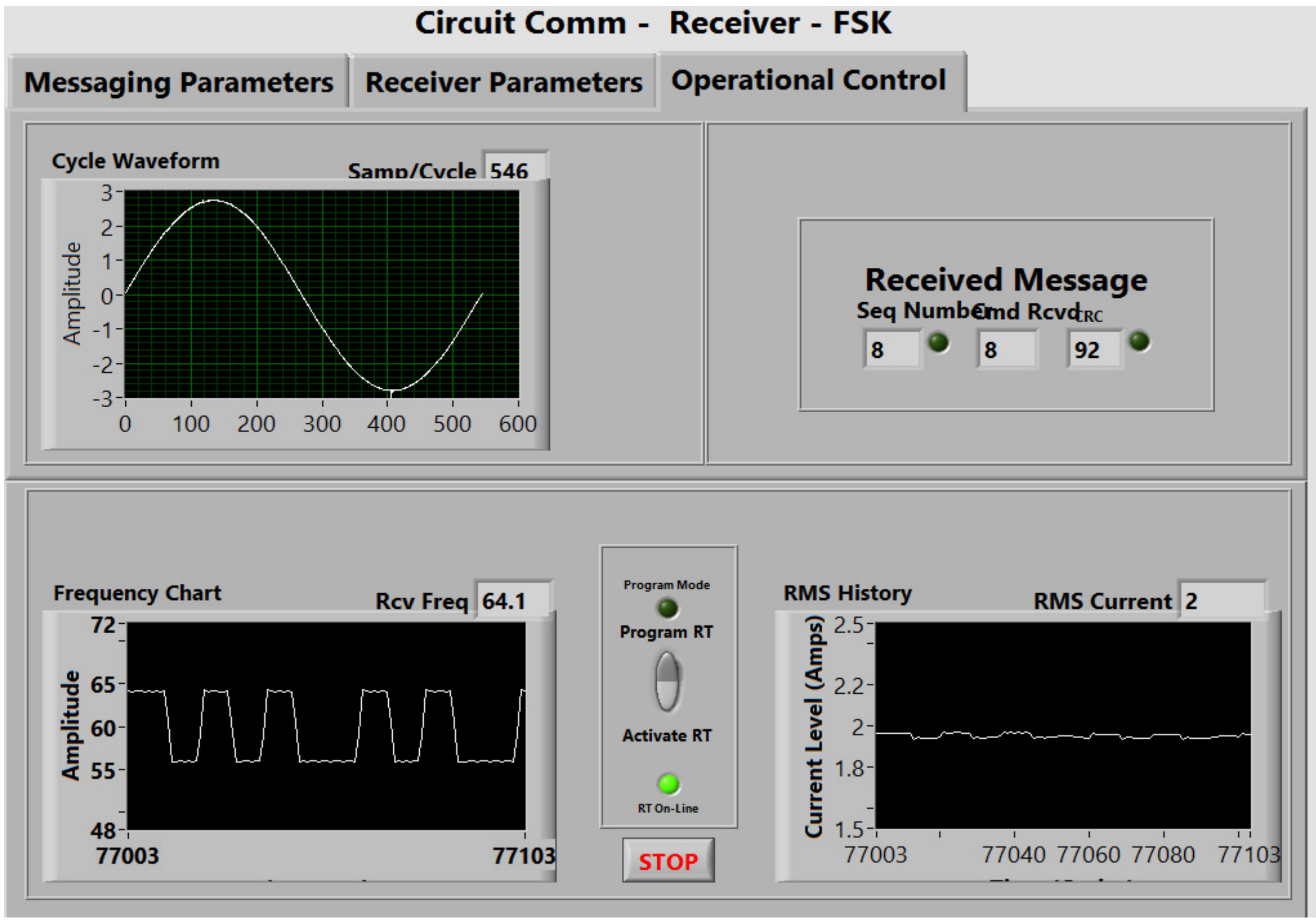
FSK Screen shot from the Field at 2 amps, 10 Hz Modulation
TWY C4@10-28 hold sign (Second test location)



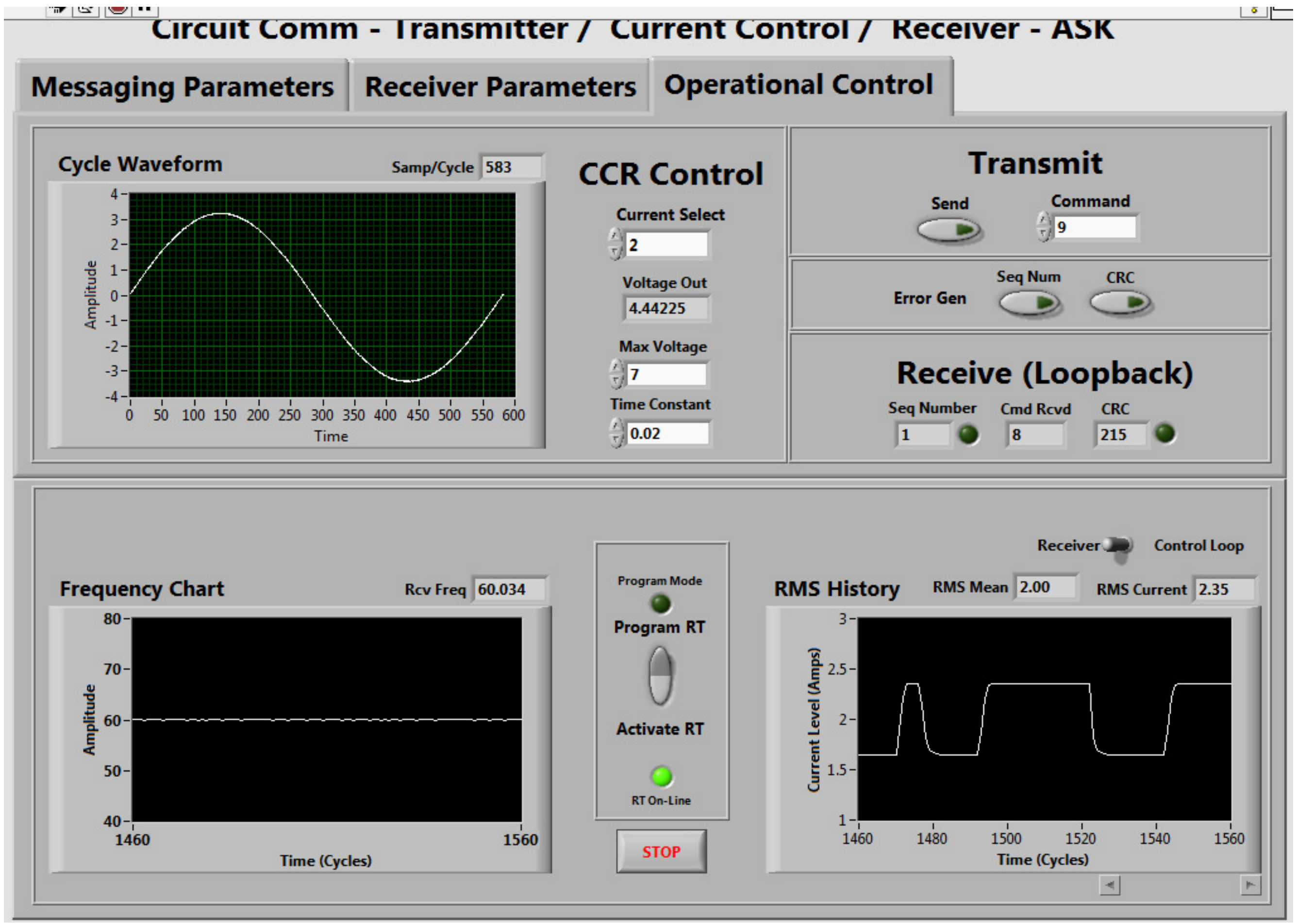
FSK Screen shot from the Field at 0.25 amp, 10 Hz Modulation TWY C2@10-28 hold sign (first test location)



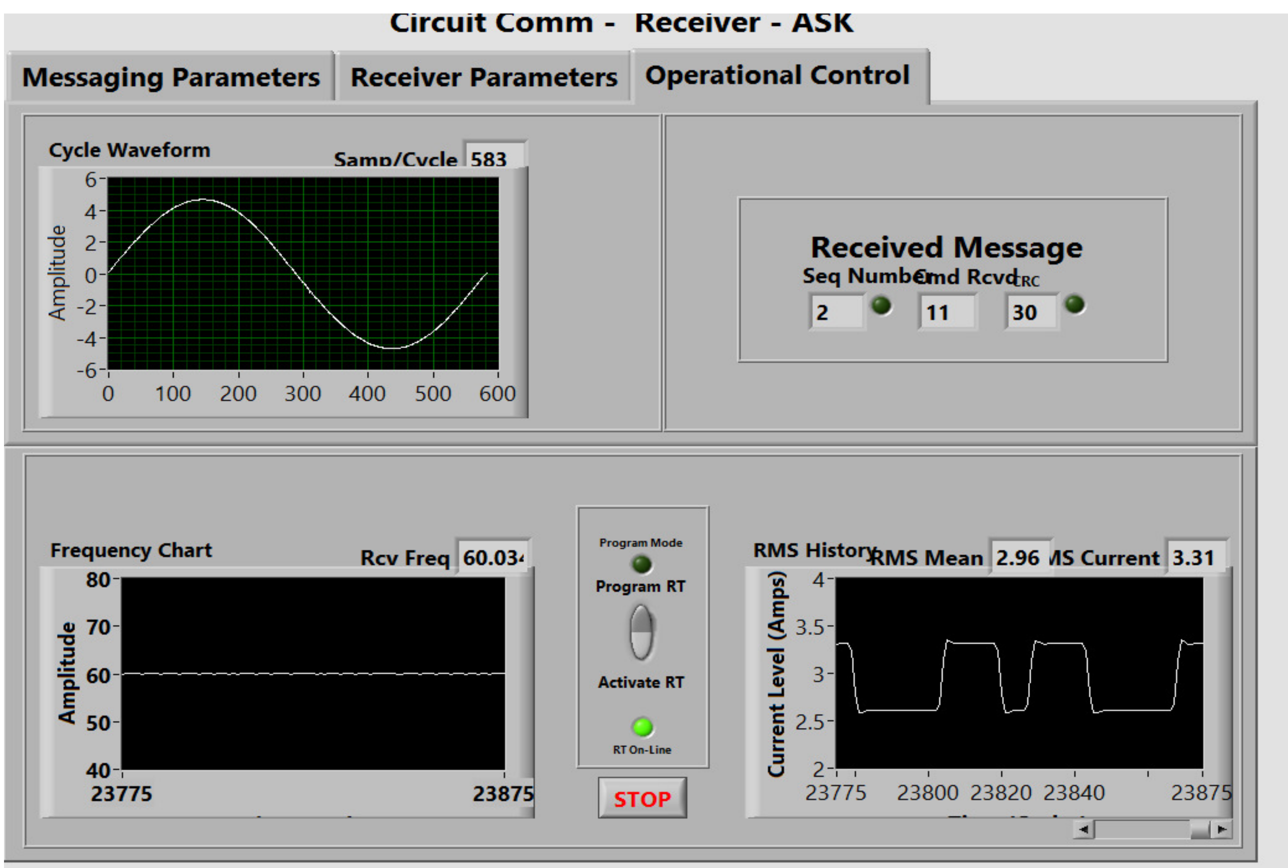
FSK Screen shot from the Field at 2 amp, 4 Hz Modulation
TWY C2@10-28 hold sign (first test location)



ASK Screen shot from the Vault at 2 amp, 0.3 amps Modulation



ASK Screen shot from the Field at 3 amp, 0.3 amps Modulation TWY C2@10-28 hold sign (first test location)



ASK Screen shot from the Field at 1 amp, 0.3 amps Modulation
TWY C2@10-28 hold sign (first test location)