Conducted Electrical Emissions From Type L-858 Style 2 and 3 Airfield Signs

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16. Abstract

This study investigated the conducted electrical emissions from Type L-858 style 2 and 3 airfield signs that cause the signs to flicker on and off. These emissions are caused by the internal power supply of the style 2 and 3 signs. These signs are designed to operate at a constant intensity on a series circuit with other lighting equipment that operates with either a three- or five-step intensity constant current regulator.

The test setup consisted of an airfield sign power supply and three subsystems: (1) a circuit current control that provided constant current to the power supply, (2) a line impedance stabilization network that provided a 60-hertz sign wave to the sign power supply, and (3) a data acquisition system.

For style 2 and 3 signs that include internal power supplies, the level of emissions should not exceed -6 decibel milliamperes (dBmA) for proper operation. Circuits that include style 2 or 3 signs should be run in separate conduits to prevent operational problems if the emissions exceed -6 dBmA. The practice of “double-circuiting” should be used when the circuit’s outbound and return cables are in the same conduit with no single-conductor runs. This will reduce the potential for crosstalk. The use of line filters should be considered for these signs if no other means is practical.

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LIST OF SYMBOLS AND ACRONYMS

dB	Decibel
dBA	Decibel amperes
dBmA	Decibel milliamperes
dBµA	Decibel microamperes
Hz	Hertz
mH	Milli-Henry
MHz	Megahertz
Ω	Ohm
AC	Advisory Circular
CCR	Constant current regulator
EUT	Equipment under test
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
kHz	Kilohertz
LISN	Line impedance stabilization network
MIL-STD	Military Standard
NI	National Instruments
RMS	Root mean squared
V	Volt

EXECUTIVE SUMMARY

This study investigated the conducted electrical emissions from the Type L-858 style 2 and 3 airfield signs that cause the signs to flicker on and off. These emissions are caused by the internal power supply of the style 2 and 3 signs. These signs are designed to operate at a constant intensity on a series circuit with other lighting equipment that operates with either a three- or five-step intensity constant current regulator.

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INTRODUCTION

PURPOSE.

The Federal Aviation Administration (FAA) Office of Aviation Research and Development Airport Safety Technology Branch, in response to a request from the Office of Airport Engineering Division, was tasked to investigate the conducted electrical emissions from the Type L-858 style 2 and 3 airfield signs that cause the signs to flicker on and off. These signs are designed to operate at a constant intensity on a series circuit with other lighting equipment that operate with either a three- or five-step intensity constant current regulator (CCR).

BACKGROUND.

Many terms and conversions are used with emissions measurements. Generally, decibel (dB) measurements are used when testing emissions. The use of dB, which is a logarithmic scale, allows the very small signals to be suitably compared to very large signals. The units of decibel amperes (dBA), decibel milliamperes (dBmA), or decibel microamperes (dBμA) were used for this application.

The formula for dBA is $dBA = 20\log(i)$, where dBA is decibel amperes and i is current in amperes. This means that 0 dBA is 1 amp, or that a measurement of 6 dBA is approximately 2 amps. As a general rule, an increase of 6 dB is about twice the regular magnitude of the current. Considering the formula, a signal that is 20 dB stronger than another signal is 10 times the amplitude. Alternatively, a signal that is weaker than another signal by -40 dB is 100 times weaker in magnitude.

The use of dBmA or dBμA simply changes the reference, such that 0 dBmA is 1 milliamp and 0dBμA is 1 microamp. These are used for convenience to better fit the scaling to the application.

Table 1 presents a conversion table that can be used to convert current to dBmA.

Table 1. Conversions of Decibel Amps to Amps

dBµA	dBmA	dBA	µA	dBµA	dBmA	dBA	µA	dBµA	dBmA	dBA	mA	dBµA	dBmA	dBA	Amps
0	-60	-120	1	40	-20	-80	100	80	20	-40	10	120	60	0	1
1	-59	-119	1.11	41	-19	-79	112.2	81	21	-39	11.22	121	61	1	1.12
2	-58	-118	1.25	42	-18	-78	125.9	82	22	-38	12.59	122	62	2	1.25
3	-57	-117	1.41	43	-17	-77	141.3	83	23	-37	14.13	123	63	3	1.41
4	-56	-116	1.58	44	-16	-76	158.5	84	24	-36	15.85	124	64	4	1.58
5	-55	-115	1.77	45	-15	-75	177.7	85	25	-35	17.78	125	65	5	1.77
6	-54	-114	1.99	46	-14	-74	199.5	86	26	-34	19.95	126	66	6	1.99
7	-53	-113	2.23	47	-13	-73	223.9	87	27	-33	22.39	127	67	7	2.23
8	-52	-112	2.51	48	-12	-72	251.2	88	28	-32	25.12	128	68	8	2.51
9	-51	-111	2.81	49	-11	-71	281.8	89	29	-31	28.18	129	69	9	2.81
10	-50	-110	3.16	50	-10	-70	316.2	90	30	-30	31.62	130	70	10	3.16
11	-49	-109	3.54	51	-9	-69	354.8	91	31	-29	35.48	131	71	11	3.51
12	-48	-108	3.98	52	-8	-68	398.1	92	32	-28	39.81	132	72	12	3.98
13	-47	-107	4.47	53	-7	-67	446.7	93	33	-27	44.67	133	73	13	4.46
14	-46	-106	5.01	54	-6	-66	501.2	94	34	-26	50.12	134	74	14	5.01
15	-45	-105	5.62	55	-5	-65	562.3	95	35	-25	56.23	135	75	15	5.62
16	-44	-104	6.31	56	-4	-64	631	96	36	-24	63.1	136	76	16	6.31
17	-43	-103	7.07	57	-3	-63	707.9	97	37	-23	707.9	137	77	17	7.07
18	-42	-102	7.94	58	-2	-62	794.3	98	38	-22	79.43	138	78	18	7.94
19	-41	-101	8.93	59	-1	-61	891.3	99	39	-21	89.13	139	79	19	8.91
20	-40	-100	10	60	0	-60	1	100	40	-20	100	140	80	20	10
21	-39	-99	11.22	61	1	-59	1.12	101	41	-19	112.2				
22	-38	-98	12.5	62	2	-58	1.25	102	42	-18	125.9				
23	-37	-97	14.13	63	3	-57	1.41	103	43	-17	141.3				
24	-36	-96	15.85	64	4	-56	1.58	104	44	-16	158.5				
25	-35	-95	17.78	65	5	-55	1.77	105	45	-15	177.8				
26	-34	-94	19.95	66	6	-54	1.99	106	46	-14	199.5				
27	-33	-93	22.39	67	7	-53	2.23	107	47	-13	223.9				
28	-32	-92	25.12	68	8	-52	2.51	108	48	-12	251.2				
29	-31	-91	28.18	69	9	-51	2.81	109	49	-11	281.8				
30	-30	-90	31.62	70	10	-50	3.16	110	50	-10	316.2				
31	-29	-89	35.48	71	11	-49	3.54	111	51	-9	354.8				
32	-28	-88	39.81	72	12	-48	3.98	112	52	-8	397.1				
33	-27	-87	44.67	73	13	-47	4.46	113	53	-7	446.7				
34	-26	-86	50.12	74	14	-46	5.01	114	54	-6	501.2				
35	-25	-85	56.23	75	15	-45	5.62	115	55	-5	562.3				
36	-24	-84	63.1	76	16	-44	6.31	116	56	-4	631				
37	-23	-83	70.79	77	17	-43	7.07	117	57	-3	707.9				
38	-22	-82	79.43	78	18	-42	7.94	118	58	-2	794.3				
39	-21	-81	89.13	79	19	-41	8.91	119	59	-1	891.3				

Formula for dBA: dBA = 20 *log (Current)

As listed in Advisory Circular (AC) 150/5345-44G, “Specification for Runway and Taxiway Signs,” there are six types of airfield signs. These six types of signs are specified in any of five sizes, five styles, and two classes. The electrical characteristics of airfield signs are categorized by style, as shown in table 2.

Table 2. Airfield Sign Styles From AC 150/5345-44G

Style	Description
1	Powered from a 120 volt alternating current power source
2	Powered from a series lighting circuit of 4.8 to 6.6 amps
3	Powered from a series lighting circuit of either 2.8 to 6.6 amps or 8.5 to 20 amps
4	Unlighted signs
5	Powered from a series lighting circuit of 5.5 amps

This study investigated the conducted electrical emissions of the Type L-858 style 2 and 3 airfield signs. Conducted emissions are caused by switching components within style 2 and 3 signs that are not present in the constant power sources of style 1 and 5 signs.

Style 2 and 3 airfield signs are designed to operate on a series circuit that has other lighting components that require a three- or five-step CCR. With a circuit current of 4.8 to 6.6 A (style 2) or 2.8 to 6.6 A (style 3), the sign must drive the lamps to a constant brightness regardless of the input current. In some designs, this is done by using a switching power supply in the sign to compensate for current variations on its input while supplying the same current to the sign lamps at its output. Using a switching supply results in conducted emissions that affect other airfield circuits by inductance, a process referred to as coupling. Coupling these conducted emissions to the series circuit can produce crosstalk into other cables on the airfield sign. Crosstalk makes it challenging for certain components to operate, including addressable controls that are used in low-visibility lighting systems.

Measurements were taken of the airfield sign emissions so the magnitude and frequencies could be understood.

SCOPE.

This study was conducted at the FAA William J. Hughes Technical Center, where measurements were taken, and at Consultant Services International, Inc., where the test process was developed. A conducted emissions test bed was set up for a representative Type L-858 style 3 airfield sign. This style was chosen since the current requirements for a style 3 airfield sign is 2.8 to 6.6 A, which is inclusive of the current range that style 2 airfield signs encompass.

For this test, only the conducted spectral emissions were considered. Any harmonic measurements taken from a thyristor CCR, such as power systems used to regulate the sign current, would have emissions that are dominated by the power system.

OBJECTIVES.

The specific objectives of this research effort were to

- measure conducted emissions from a representative Type L-858 style 3 airfield sign, and describe reasons for and implications of those conducted emissions if present.
- develop recommendations for additional electrical performance testing criteria and measurement methodology.
- establish reasonable standards for the level of emissions allowable in testing criteria.
- develop recommendations to describe the design guidelines for airfield signs used, when possible compatibility with airfield components may be an issue.

RELATED DOCUMENTS.

Related documents dealing with this project are:

- AC 150/5340-30A, “Design and Installation Details for Airport Visual Aids,” April 11, 2005.
- AC 150/5345-10F, “Specification for Constant Current Regulators and Regulator Monitors,” June 24, 2005.
- AC 150/5345-44G, “Specification for Runway and Taxiway Signs,” August 8, 2004.
- Military Standard (MIL-STD)-461E, “Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment,” August 20, 1999.
- Federal Communications Commission (FCC): Title 47 Part 15, “Radio Frequency Devices,” January 2005.

EVALUATION APPROACH

EVALUATION METHOD.

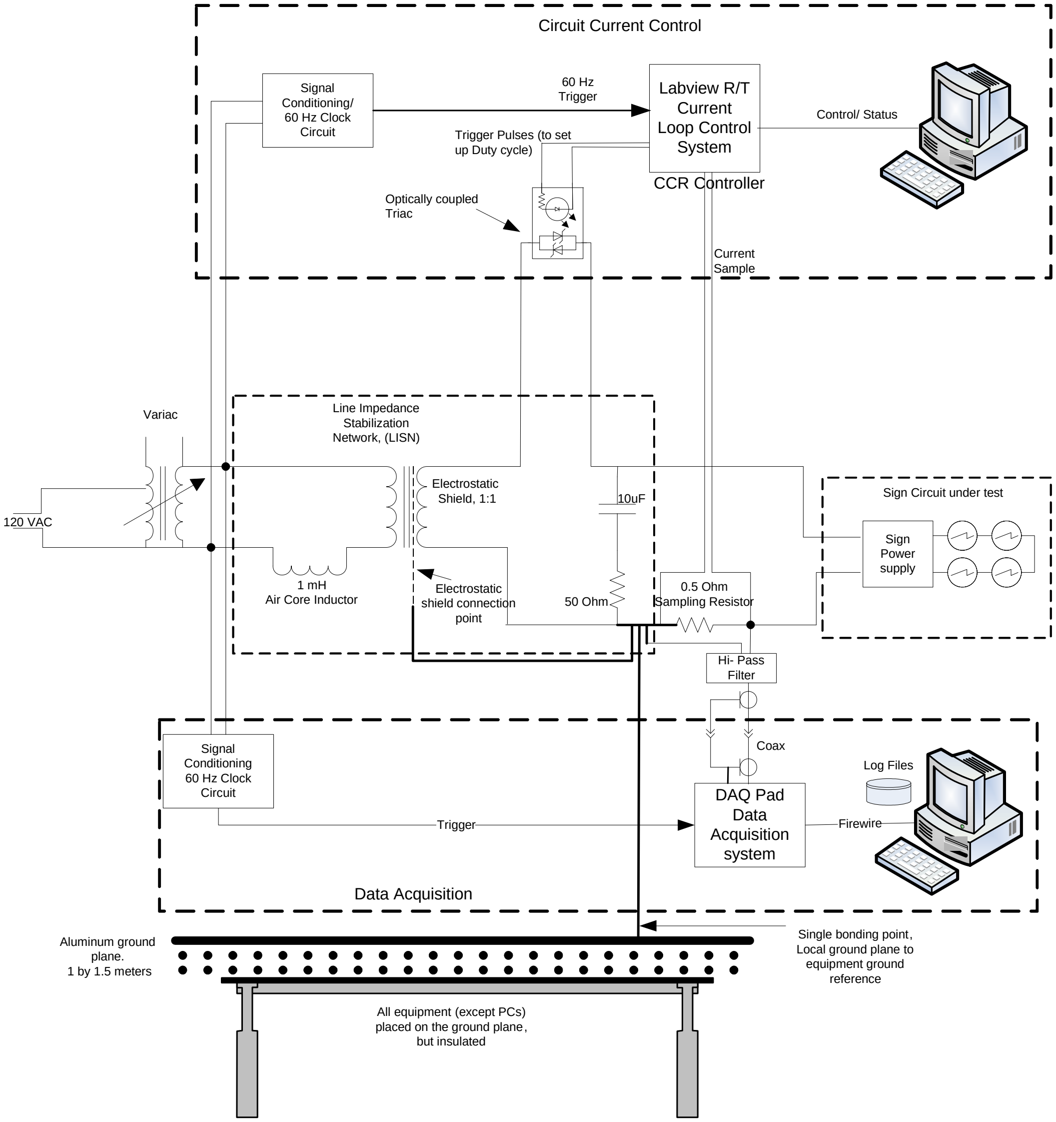
Figure 1 shows the test equipment setup that was used to test the airfield sign power supply circuit, which will be referred to as the equipment under test (EUT). Three subsystems were used to conduct the tests.

1. The circuit current control, which provided constant current to the EUT.

2. The line impedance stabilization network (LISN), described in the section detailing circuit current control.

3. The data acquisition subsystem, which recorded the measurements used for the analysis.

These subsystems and the EUT are shown in the dashed areas of figure 1.



R/T = Receive/Transmit

Figure 1. Diagram of the Project Test Setup

RESISTIVE LOAD REFERENCE. An incandescent lamp was used as a reference load to observe the characteristics of the underlying spectral noise floor, which is the noise present in the system prior to testing. The spectral floor was in the range of -30 to -40 dBmA.

TEST CONDITIONS. For this test, the sign circuit was supplied at the nominal CCR steps with some exceptions. The 2.8 and 3.4-A steps were not tested due to voltage limitations of the test system and because the emissions are present at the higher steps. The nominal CCR steps are listed in table 3.

Table 3. Nominal Current Steps for 6.6-amp Circuit

System	Nominal Brightness (%)	Step	Nominal Output (RMS-A)
3 Step	100	3	6.6
	30	2	5.5
	10	1	4.8
5 Step	100	5	6.6
	25	4	5.2
	5	3	4.1
	1.2	2	3.4
	0.15	1	2.8

RMS = Root mean squared

THE LISN. A 120-volt (V), 60-hertz (Hz) power was fed into the LISN system. The voltage was controlled with a Variac (variable transformer). After passing through a 1-milli-Henry (mH) air core inductor and an isolation transformer, 120 to 130 V was available for the test circuit. A high degree of isolation from line noise was provided by using an electrostatically shielded transformer designed for that purpose. The 1-mH inductor provided the important functionality of isolating the impedance of the power system from the impedance derived from the 50-ohm (Ω) resistor and 10-micro-Farad capacitor high-pass network shown in figure 1.

This high-pass network provides a known impedance characteristic that is presented to the EUT so that current measurements were made across the 0.5-Ω resistor. The impedance characteristics of the LISN are shown in figure 2.

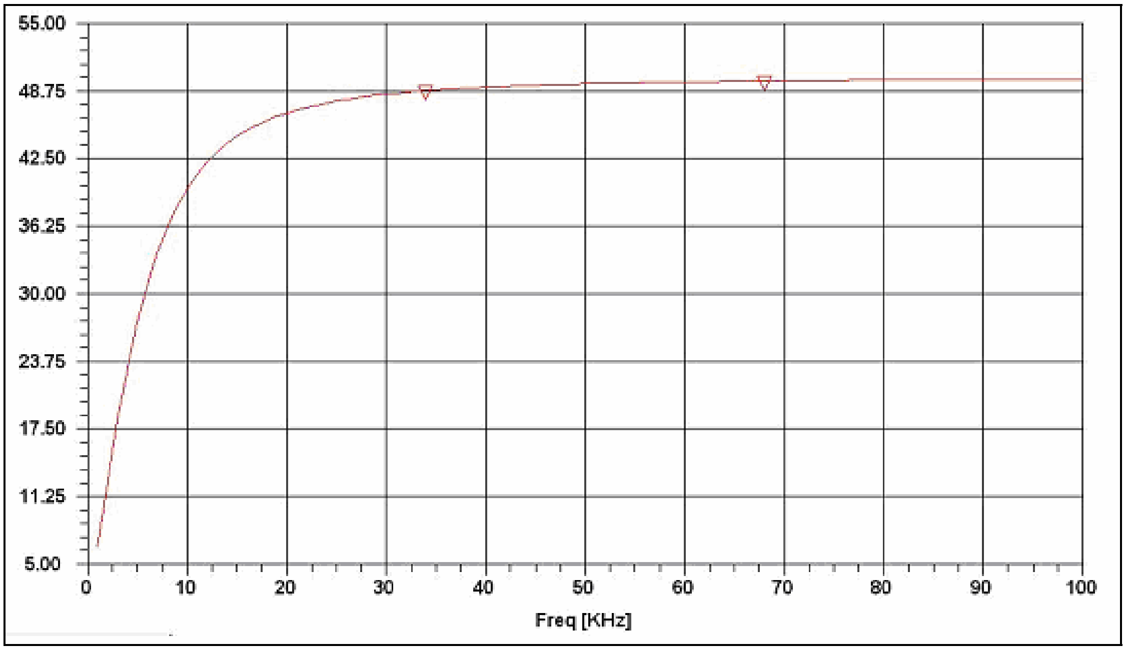


Figure 2. The LISN Impedance Curve

Voltage from the Variac was converted into a stream of clock pulses by a 60-Hz clock circuit. One clock pulse was created for each positive and negative zero crossing the voltage. This was used to synchronize the timing of the control loop application. A 0.5-Ω sampling resistor was used to develop circuit current for the control loop application, which was measured in true root mean squared (RMS) current. The control loop application calculated the RMS current, then measured and compared it to the desired RMS current setting. The control loop provided the triac, which is a silicon bi-directional rectifier, with a trigger pulse for each half cycle of current. These pulses provided the proper conduction time duty cycle for the system to maintain the circuit current to the desired level.

In appendix A, figure A-1 shows a screen capture of the control panel for the circuit current control application. The circuit current control application ran on a National Instruments (NI) 8187 PXI controller, which is a single-board computer. This controller resides in an instrumentation chassis and controls an NI 6259 multifunction data acquisition board, which provides a sampling of current for the control loop. An NI 6602 counter/timer module, also in the instrumentation chassis, was used to provide timing functions for the control loop and created the trigger pulses for the optically coupled triac. The control application was developed using LabView™ software to provide the performance needed to operate the control loop. This system provided complete flexibility to set the parameters of the control loop for laboratory use, as well as to provide duty-cycle data in real time.

<u>DATA ACQUISITION</u>. For this application, an analog data acquisition system was used in conjunction with computer-based spectrum analysis software. The NI 6052E data acquisition system had a sampling rate of 333,333 samples per second, allowing measurements up to 166,667 Hz. The analog-to-digital converter had a resolution of 16 bits, resulting in a dynamic range of greater than 90 dB (1 part in 65536, or 2^{16}). This data acquisition system provided

samples to a software analysis package that ran on a personal computer. For this project, LabView, with a signal processing toolkit, was used to develop the data acquisition and analysis applications. The sample files were processed by the application to extract the frequency characteristics of the measurements.

The test equipment was set-up on a suitable aluminum ground plane, which was the only ground connection to the instrumentation. The ground plane is shown in the lowermost portion of figure 1.

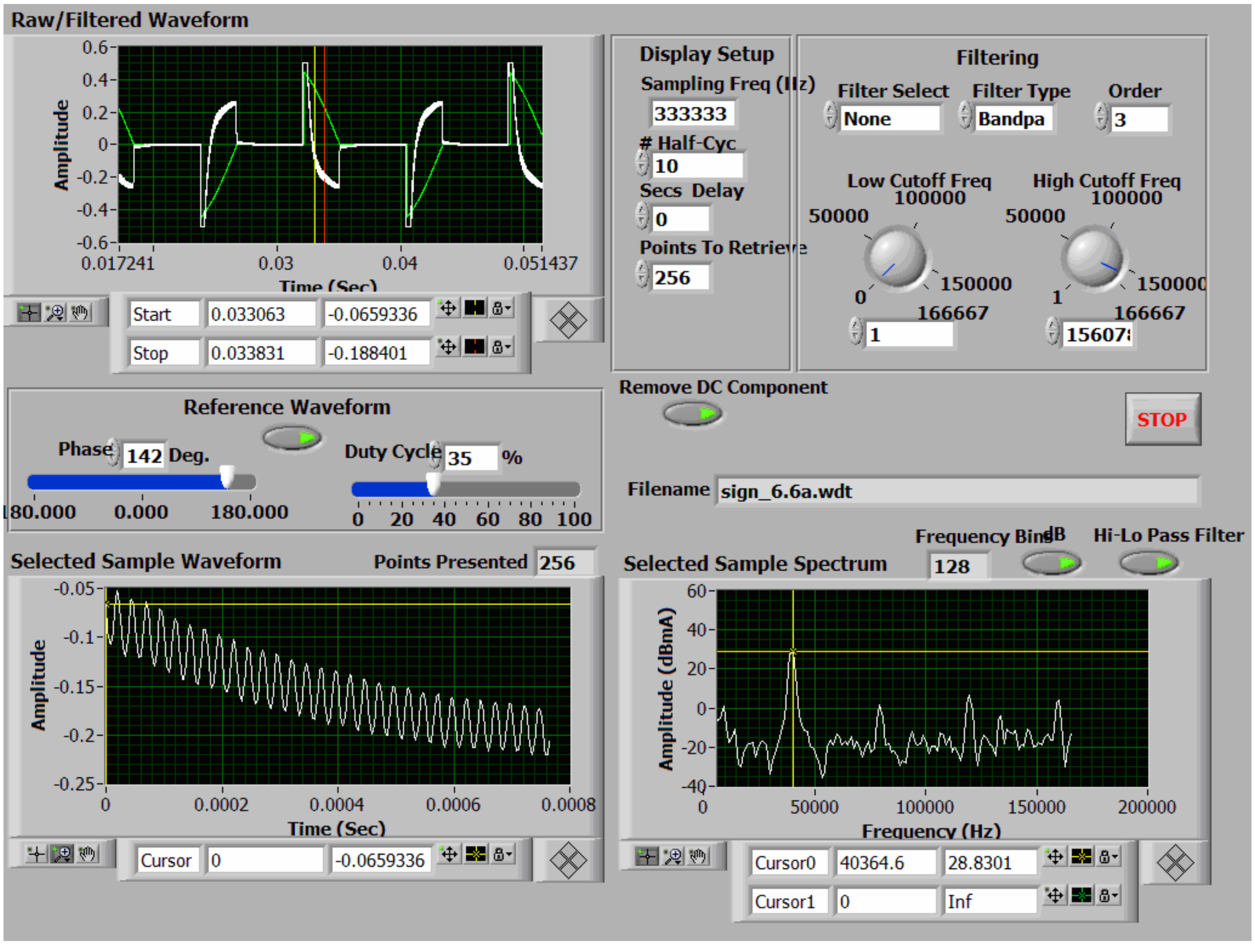
The resistive sampling is shown in differential four-terminal form. The voltage developed across the 0.5-Ω resistor in volts represents the circuit current in amperes. This approach had the additional benefit of directly connecting to one side of the EUT circuit to a local ground plane through the sampling resistor, thus permitting current sampling with virtually zero common mode voltage.

A high-pass filter was placed in between the sampling resistor and the data acquisition system. The purpose of the filter was to reduce the 60-Hz signal by a factor of 100, or -40 dB, and therefore, to allow the data acquisition system input circuitry to operate with higher gain. This has the benefit of increasing the sensitivity of the smallest high-frequency signal by about the same factor of 100, or 40 dB, while preventing overload of the data acquisition system input circuitry with excessively large 60-Hz signal levels.

A means to consistently trigger the data acquisition at a known time was also provided. The same signal conditioning and triggering hardware box was used for the data acquisition system as for the current control system shown in figure 1. This provided a stable phase coherent trigger source to ensure that the captured waveforms started at the same place and prevented jitter from noise.

When energized, conducted emission levels were captured by test equipment and analyzed for their characteristics. The sign uses four lamps in series that are fed by the sign’s power supply. The EUT was provided with regulated circuit current. For this test, the lamps and supply were removed from the sign assembly, as shown in figure 1. This had no impact on measurements, but allowed the relatively small electronics and lamps to be conveniently placed on the test bed table.

<u>SPECTRAL MEASUREMENT SCREEN</u>. A screen capture of the application, which provided the detail for emissions of frequencies, is shown in figure 3. These emissions are not necessarily harmonically related to 60-Hz frequency. In the upper-left graph of figure 3, the white trace represents the sign current waveform that was high-pass filtered. Generally, only the high-frequency components are visible, which accounts for distortion. The green trace in the same graph is a simulated waveform used as a reference so the 60-Hz current could be visualized, which had no effect on the measurement. The flat portion of the white trace is when there is no current flow, and then the turn-on step is clearly seen.



Raw/Filtered Waveform

Start 0.033063 -0.0659336

Stop 0.033831 -0.188401

Reference Waveform

Phase 142 Deg.

Duty Cycle 35 %

Display Setup

Sampling Freq (Hz) 333333

Half-Cyc 10

Secs Delay 0

Points To Retrieve 256

Filtering

Filter Select None

Filter Type Bandpa

Order 3

Low Cutoff Freq 1

High Cutoff Freq 15607

Remove DC Component

Filename sign_6.6a.wdt

Selected Sample Waveform

Points Presented 256

Cursor 0 -0.0659336

Selected Sample Spectrum

Frequency Bins 128

Cursor0 40364.6 28.8301

Cursor1 0 Inf

Figure 3. Sample Measurement Screen

The region between the yellow and red lines in the upper-left graph of figure 3 was used to locate a selected sample area with which to perform spectrum analysis. This allowed specific spectrum characteristics to be identified during specific intervals of time. In this example, the region is placed in a location where there is an emission of relatively high strength. These emissions appear on the white waveform during a time when there is current flowing from the power supply.

The lower-left graph of figure 3 shows a selected sample waveform that is an enlarged area of the region defined between the yellow and red bars in the upper-left graph. Depending on the waveform, this was additionally enlarged both in time and amplitude to allow a close look at the signal when necessary. The selected simple waveform, and vertical axis is labeled amplitude measured in amperes, and the horizontal axis is labeled time measured in seconds. The lower-right graph of figure 3 shows the exported signal spectrum and the frequencies present in the selected sample waveform.

There is compensation in the magnitude of the frequencies displayed to account for the roll-off characteristics of the high-pass filter used for this measurement. The strength of the frequencies is shown in dBmA, where a signal of 0 dBmA is equal to 1 milliamp. In figure 3, there is a signal frequency at 40,364 Hz at an amplitude of 28 dBmA, followed by harmonics at 80,728, 121,092, and 161,456 Hz.

RESULTS

The sign circuit behavior was similar at all five steps, with some minor exceptions noted at 6.6 amps of circuit current, shown in figures A-2, A-3, and A-4 of appendix A. There were high-conducted emissions present, which are characterized differently during conduction, just after conduction, and just before the conduction starts in the next half cycle.

In figure A-2, the measurements were made during conduction. It can be observed that the frequency is about 40 kilohertz (kHz), with harmonics at about 80, 120, and 160 kHz. The 40 kHz fundamental frequency is approximately 29 dBmA, or the equivalent of about 28 mA of current. In figure A-3, the measurements were taken just after the circuit conduction stops, but the sign fixture was still generating emissions. These generated emissions are at the same fundamental frequency though at a lower 15 dBmA, or about 5 mA. The emissions present at this time in the cycle also contain similar harmonics of the fundamental frequency 40 kHz. Figure A-4 shows the state of the EUT current waveform just before conduction returns. In this state, the characteristic of the emission changes to a fundamental frequency of approximately 80 kHz at about 10 dBmA, or 3 mA. These emissions can be seen as containing less harmonic content. Higher harmonics of these frequencies past 80 kHz were evident up to 2 megahertz (MHz), but at lower levels of amplitude.

The remaining steps that were measured in figures A-5 through A-16 show a similar characteristic frequency-versus-time profile, but with slightly reduced levels. There was an exception shown in figure A-14 where, at this step of 4.1 amps and the emissions measured during conduction, the frequency was elevated to about 45 kHz.

The measured conducted emissions of this sign circuit reveal a typical level ranging of from about 10 to 29 dBmA at frequencies of 40 to 80 kHz, as well as the higher-order harmonics of those frequencies. This occurs for currents of about 3 to 28 mA for each sign on the circuit.

SUMMARY

A sign circuit generates emissions during conduction time as well as during nonconduction times within each half cycle. It is likely that these continued emissions are due to the internal power supply, or because the pulse width modulation driver of the sign lamps is continuing to regulate the voltage to the lamps during a period of time in each half cycle when the sign input circuitry is not in conduction.

The characteristics of the frequency during the “off” time of the series circuit current are likely a result of the energy that is stored in the sign power supply being depleted during each half cycle; and the switching characteristics change as the available stored energy decays. On a typical airfield, many signs with these characteristics can share a circuit. There is a potential for interaction of the emissions on the circuit, which can result in even higher levels in some locations on the circuit loop.

Emissions of these levels and frequencies can easily couple into other cables sharing conduits due to the capacitance between conductors. The implications of these conducted emissions can be negative for airfield components, such as Surface Movement Guidance Control Systems (SMGCS), or other applications in which the communications can be challenged or even made nonfunctional. The levels of the emissions measured for this study are similar to, or stronger than, the levels these systems use to communicate. Power line carrier products used on the airfield manage crosstalk between circuits within their own system in order to operate, but the emissions from these signs are not under the control of the power line carrier system. There are other systems that can be impacted by this level and frequency of emissions, which include radio navaids or beacons, depending on the frequencies generated by specific sign products. Any digital control cabling on the airfield that is in proximity to sign circuit cables for long linear runs or shares a conduit may also be affected by these emissions.

There are no standards for emissions in AC 150/5345-44G for signs covering Type L-858 style 2 or 3 signs. Other style 2 or 3 signs may show different frequencies of emissions or at higher or lower levels.

CONCLUSIONS

The following conclusions were reached during the course of the evaluation.

1. Conducted emissions of a typical Type L-858 style 3 airfield sign were measured to be approximately up to 29 dBmA, or about 28 mA per sign in the 40-kHz range, and short-duration emissions were observed and harmonics up to 2 MHz.

    a. The reason for these emissions, as implied by their characteristics and profile, are the switching components within the sign that remain active during times of no circuit current being supplied to the sign power supply.

    b. The implication of these high levels of emissions lies in the possibility of their coupling into other airfield circuits in the same conduit system due to capacitance between conductors. An additional implication is that since short-duration emissions reoccurred at a line rate of 120 Hz, the possibility of a negative impact on airfield system communication exists.

2. Conducted emission characteristics are not currently addressed by Advisory Circular (AC) 150/5345-44G or included as part of the qualification testing. The following are recommendations to address this issue

    a. MIL-STD-461E methodology is recommended with a customization for the measurement of emissive current through the sign circuit, rather than voltages with respect to a ground, in contrast to Federal Communications Commission Part 15. The testing system should include the following subsystems: the airfield sign power supply circuitry, also known as the equipment under test; circuit current control; line impedance stabilization network; and a data acquisition system.

  b. Emissions levels should be measured while observing the full waveform, sample of the full waveform at a specific interval of time within each 60-Hz half cycle, and the spectral content of that sample during, that interval. Emission levels should be measured at periods in time before, during, and after conduction within each half cycle, instead of a simple averaging technique, to capture short-duration emissions.

  c. A test requirement based on the methodologies of this report should be placed in section 4 of AC 150/5345-44G.

3. Based on the results of this research, the following emission limits and requirements are recommended.

  a. For style 2 and 3 signs that include internal power supplies, the level of conducted emissions should not exceed -6 dBmA.

  b. The emission requirement should be included in AC 150/5345-44G section 3.2.5.8.

4. Additional design- and installation-related measures can be taken by designers, engineers, and maintenance personnel to reduce the likelihood of conducted emissions-related anomalies with other airfield equipment.

  a. Circuits that include style 2 or 3 signs should be run in separate conduits to minimize the potential for crosstalk onto other circuits.

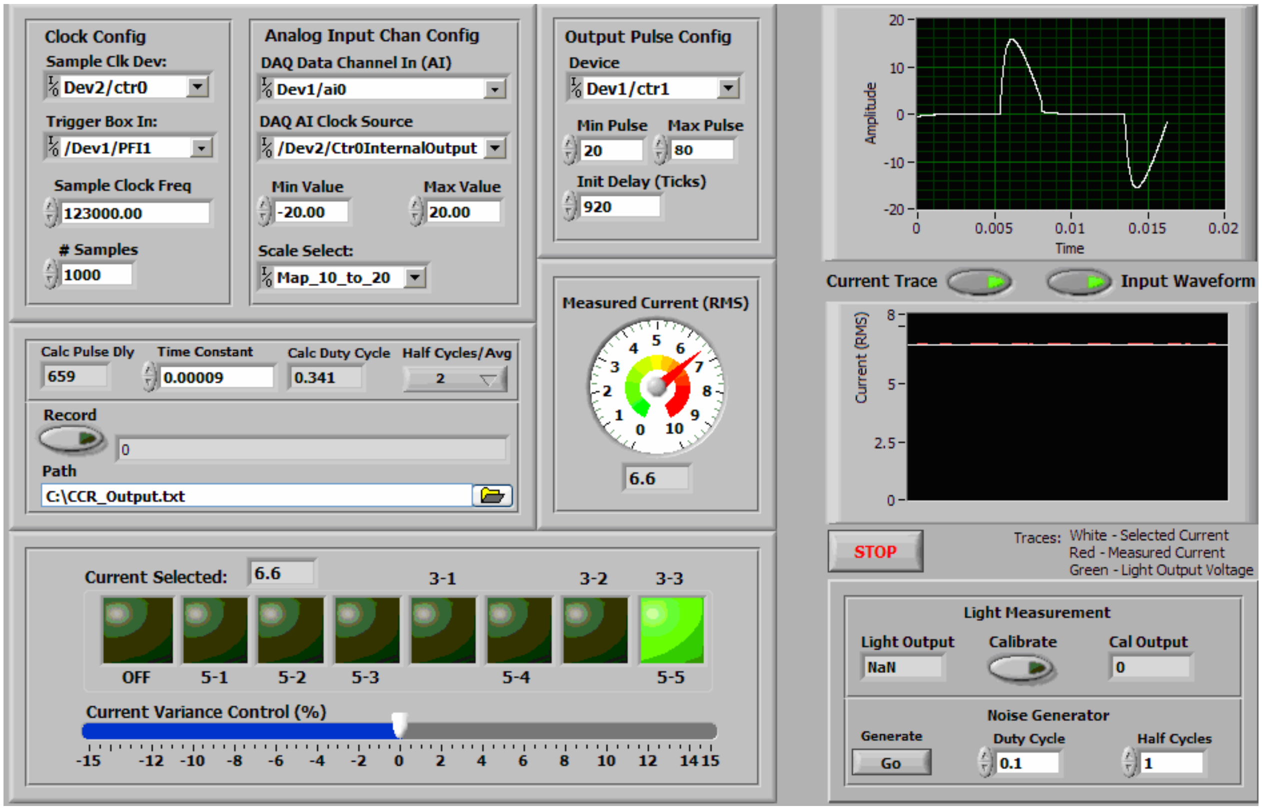
  b. Designers, engineers, and maintenance personnel should use “double-circuiting,” meaning the outbound and return cables for the circuit should always be in the same conduit with no single-conductor runs. This will help reduce the potential for crosstalk.

  c. Keeping the sign circuits physically separated as practical within duct banks will also help to reduce the potential for emissions-related issues.

  d. The designer should discuss the specifics of the installation with the manufacturers of these signs and with the manufacturer of any power line carrier products used to reduce the potential for emissions-related issues. Consideration must be given to switching frequencies used by the signs, and communications frequencies used by the power line carrier products or other airfield equipment.

  e. Using line filters may be considered for the signs if other means are not practical. However, using line filters adds to the complexity and cost of the system.

APPENDIX A—SCREEN CAPTURES OF DATA AND CONTROL SYSTEMS


Clock Config
Sample Clk Dev: Dev2/ctr0
Trigger Box In: /Dev1/PFI1
Sample Clock Freq: 123000.00
Samples: 1000

Analog Input Chan Config
DAQ Data Channel In (AI): Dev1/ai0
DAQ AI Clock Source: /Dev2/Ctr0InternalOutput
Min Value: -20.00
Max Value: 20.00
Scale Select: Map_10_to_20

Output Pulse Config
Device: Dev1/ctr1
Min Pulse: 20
Max Pulse: 80
Init Delay (Ticks): 920

Calc Pulse Dly: 659
Time Constant: 0.00009
Calc Duty Cycle: 0.341
Half Cycles/Avg: 2
Record: 0
Path: C:\CCR_Output.txt

Measured Current (RMS): 6.6

Current Selected: 6.6

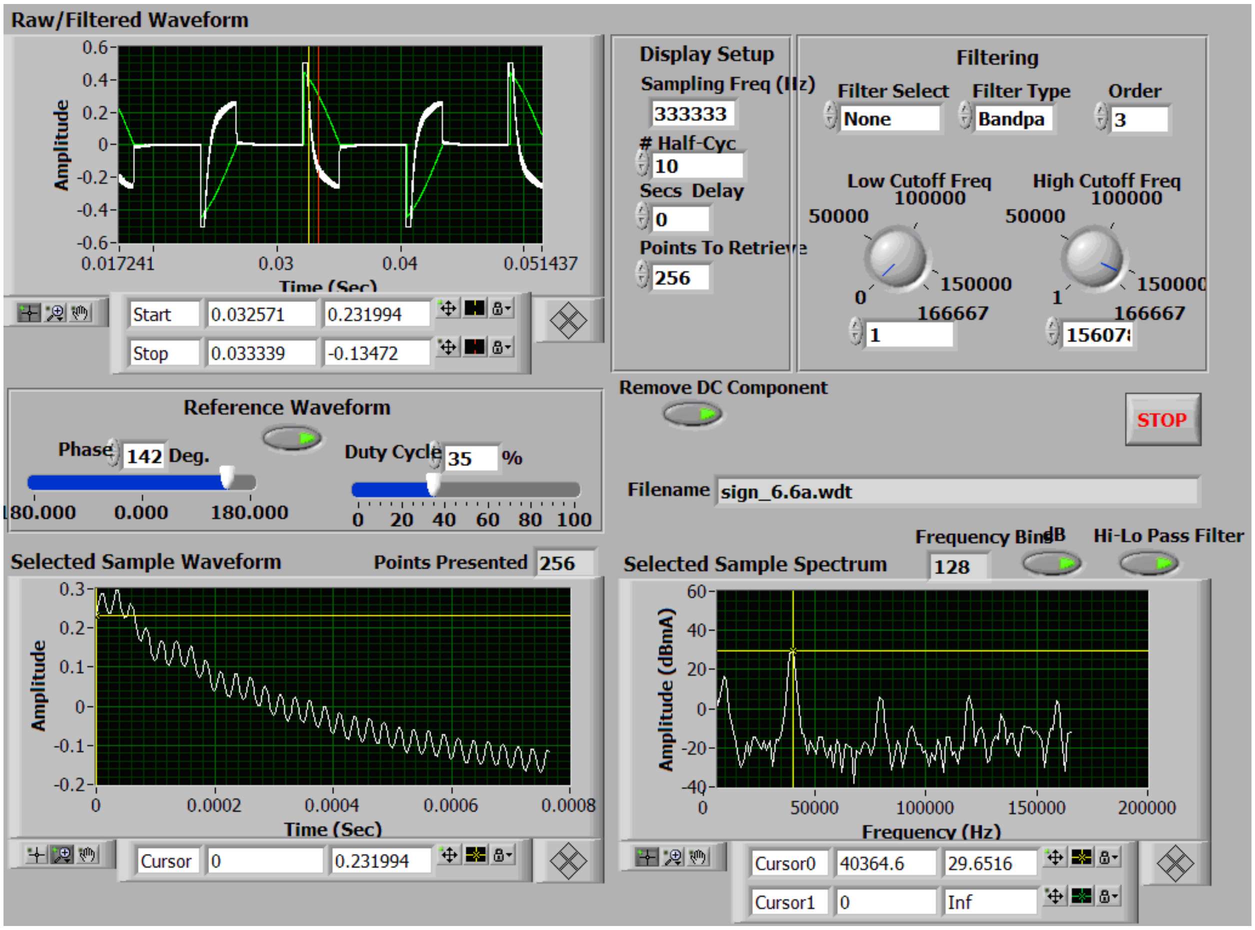
Current Variance Control (%)

Traces: White - Selected Current
Red - Measured Current
Green - Light Output Voltage

Light Measurement
Light Output: NaN
Calibrate
Cal Output: 0

Noise Generator
Generate: Go
Duty Cycle: 0.1
Half Cycles: 1

Figure A-1. Circuit Control Loop Screen



Start 0.032571 0.231994

Stop 0.033339 -0.13472

Sampling Freq (Hz) 333333

Half-Cyc 10

Secs Delay 0

Points To Retrieve 256

Filter Select None

Filter Type Bandpa

Order 3

Low Cutoff Freq 1

High Cutoff Freq 15607

Phase 142 Deg.

Duty Cycle 35 %

Filename sign_6.6a.wdt

Points Presented 256

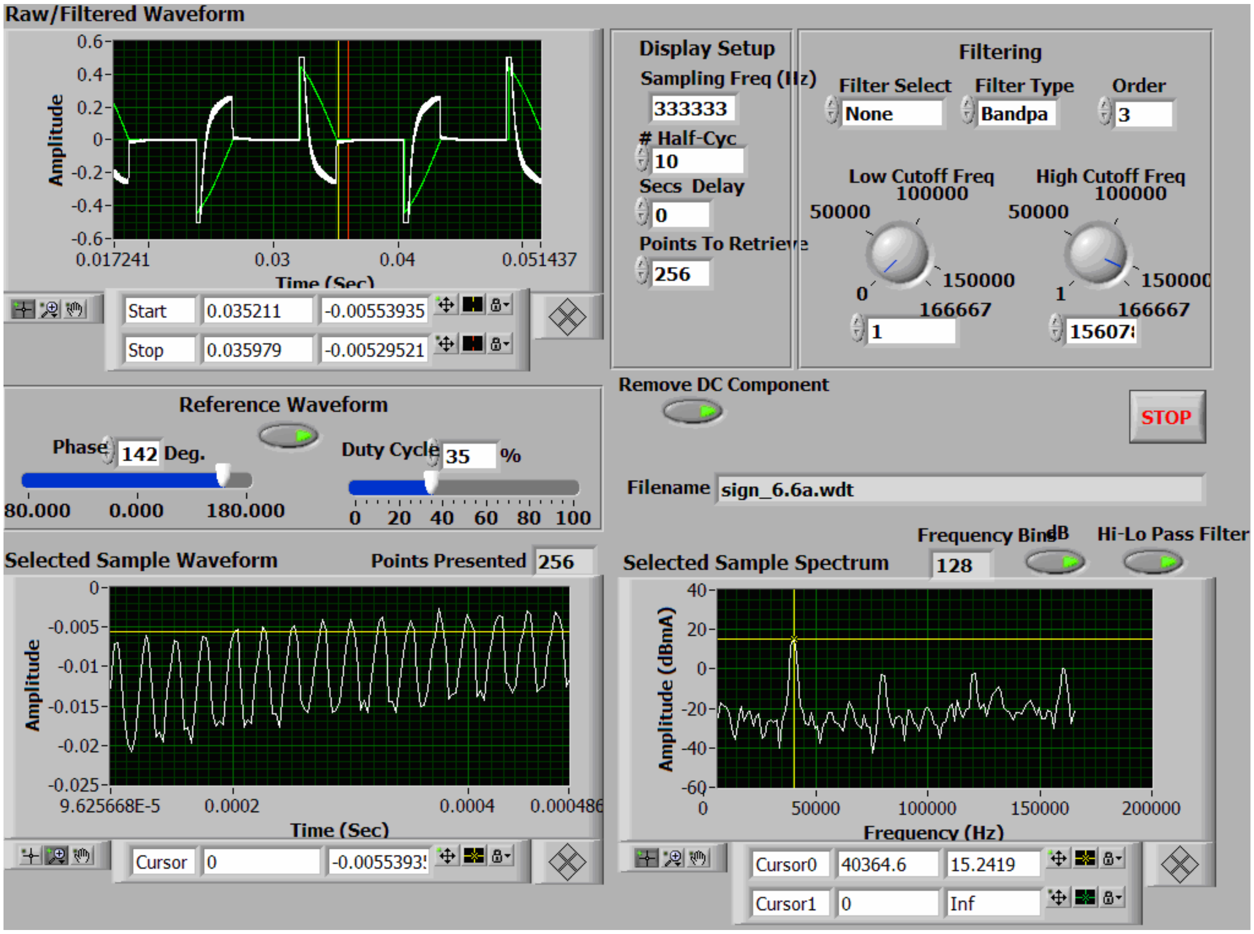
Frequency Bins 128

Cursor 0 0.231994

Cursor0 40364.6 29.6516

Cursor1 0 Inf

Figure A-2. Spectrum at 6.6 amps During Conduction



Start 0.035211 -0.00553935

Stop 0.035979 -0.00529521

Display Setup

Sampling Freq (Hz) 333333

Half-Cyc 10

Secs Delay 0

Points To Retrieve 256

Filtering

Filter Select None

Filter Type Bandpa

Order 3

Low Cutoff Freq 1

High Cutoff Freq 15607

Phase 142 Deg.

Duty Cycle 35 %

Filename sign_6.6a.wdt

Points Presented 256

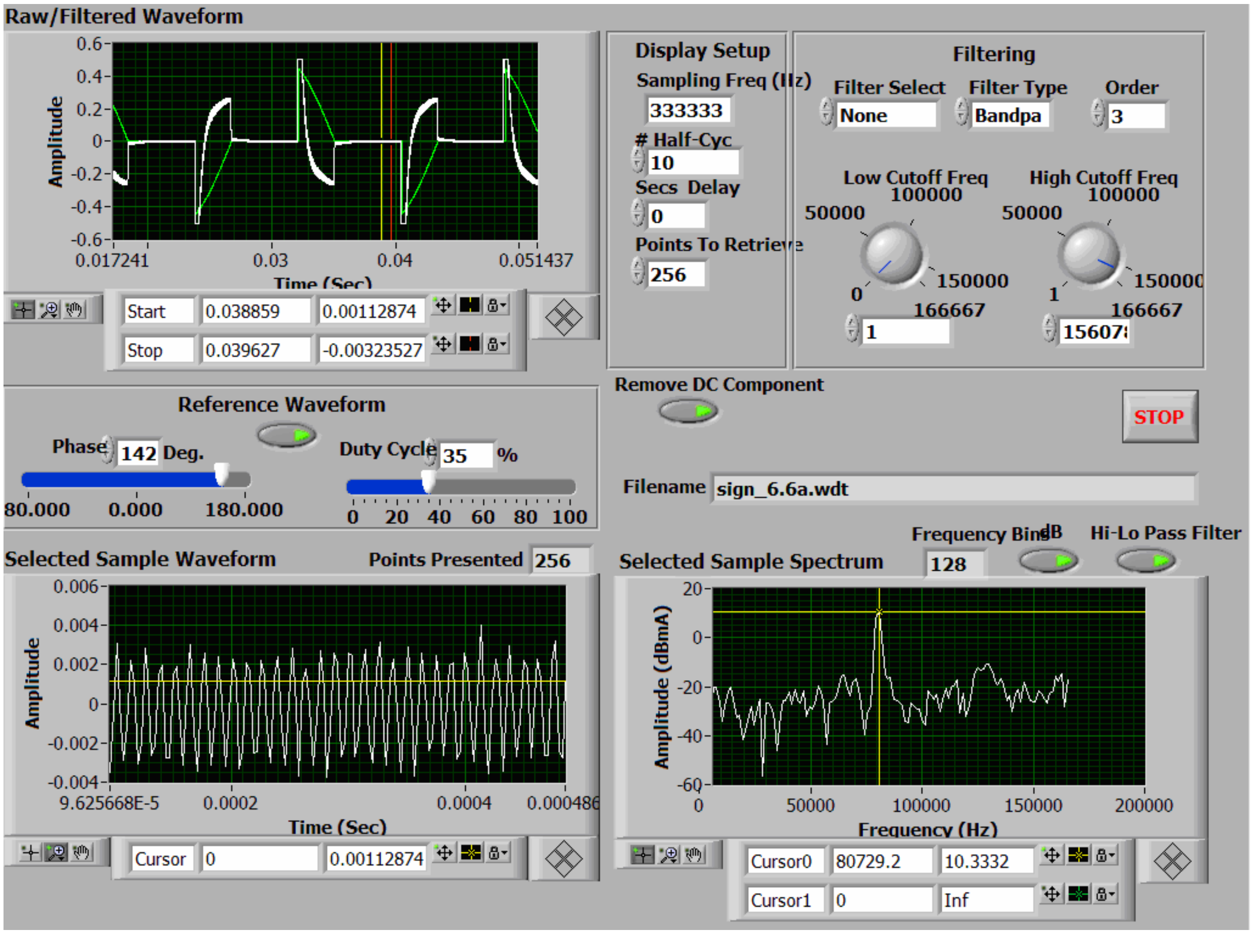
Frequency Bins 128

Cursor 0 -0.0055393

Cursor0 40364.6 15.2419

Cursor1 0 Inf

Figure A-3. Spectrum at 6.6 amps Just After Conduction



Start 0.038859 0.00112874

Stop 0.039627 -0.00323527

Sampling Freq (Hz) 333333

Half-Cyc 10

Secs Delay 0

Points To Retrieve 256

Filter Select None

Filter Type Bandpa

Order 3

Low Cutoff Freq 1

High Cutoff Freq 15607

Phase 142 Deg.

Duty Cycle 35 %

Filename sign_6.6a.wdt

Points Presented 256

Frequency Bins 128

Cursor 0 0.00112874

Cursor0 80729.2 10.3332

Cursor1 0 Inf

Figure A-4. Spectrum at 6.6 amps Just Before Conduction

Sampling Freq (Hz) 333333

Half-Cyc 10

Secs Delay 0

Points To Retrieve 256

Filter Select None

Filter Type Bandpa

Order 3

Low Cutoff Freq 1

High Cutoff Freq 15607

Phase 148 Deg.

Duty Cycle 33 %

Filename sign_5.5a.wdt

Points Presented 256

Frequency Bins 128

Start	0.032766	0.120617
Stop	0.033534	-0.196903
Cursor	0	0.120617
Cursor0	40364.6	29.227
Cursor1	0	Inf

Figure A-5. Spectrum at 5.5 amps During Conduction

Start 0.035469 -0.00424519

Stop 0.036237 0.00092753

Sampling Freq (Hz) 333333

Half-Cyc 10

Secs Delay 0

Points To Retrieve 256

Filter Select None

Filter Type Bandpa

Order 3

Low Cutoff Freq 1

High Cutoff Freq 15607

Phase 148 Deg.

Duty Cycle 33 %

Remove DC Component

Filename sign_5.5a.wdt

Points Presented 256

Frequency Bins 128

Cursor 0 -0.0042451

Cursor0 40364.6 11.9547

Cursor1 0 Inf

Figure A-6. Spectrum at 5.5 amps Just After Conduction

Start 0.039333 0.00257549

Stop 0.040101 -0.00114766

Phase 148 Deg.

Duty Cycle 33 %

Sampling Freq (Hz) 333333

Half-Cyc 10

Secs Delay 0

Points To Retrieve 256

Filter Select None

Filter Type Bandpa

Order 3

Low Cutoff Freq 1

High Cutoff Freq 15607!

Filename sign_5.5a.wdt

Points Presented 256

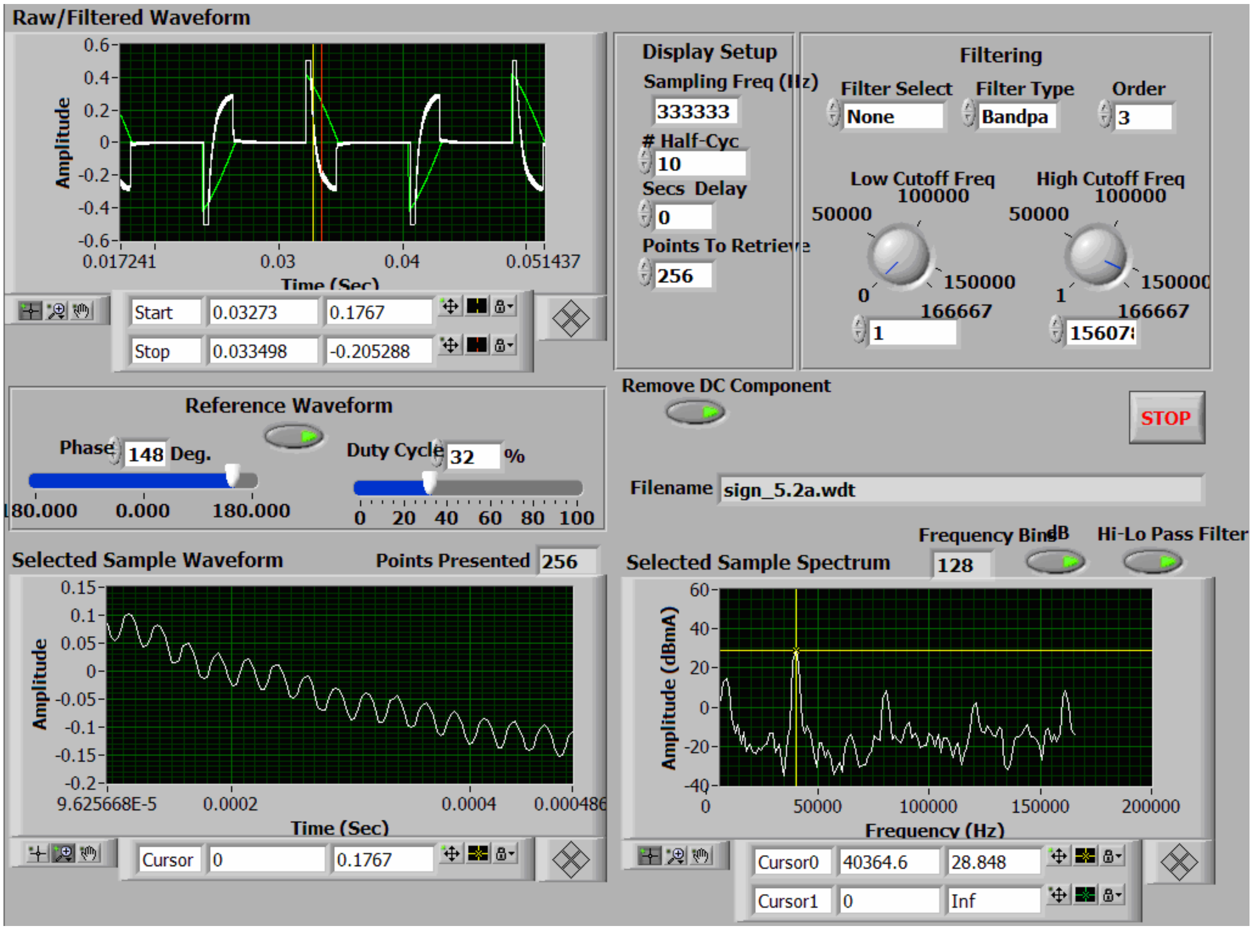
Frequency Bins 128

Cursor 0 0.00257549

Cursor0 80729.2 10.156

Cursor1 0 Inf

Figure A-7. Spectrum at 5.5 amps Just Before Conduction



Start 0.03273 0.1767

Stop 0.033498 -0.205288

Phase 148 Deg.

Duty Cycle 32 %

Sampling Freq (Hz) 333333

Half-Cyc 10

Secs Delay 0

Points To Retrieve 256

Filter Select None

Filter Type Bandpa

Order 3

Low Cutoff Freq 1

High Cutoff Freq 15607

Filename sign_5.2a.wdt

Points Presented 256

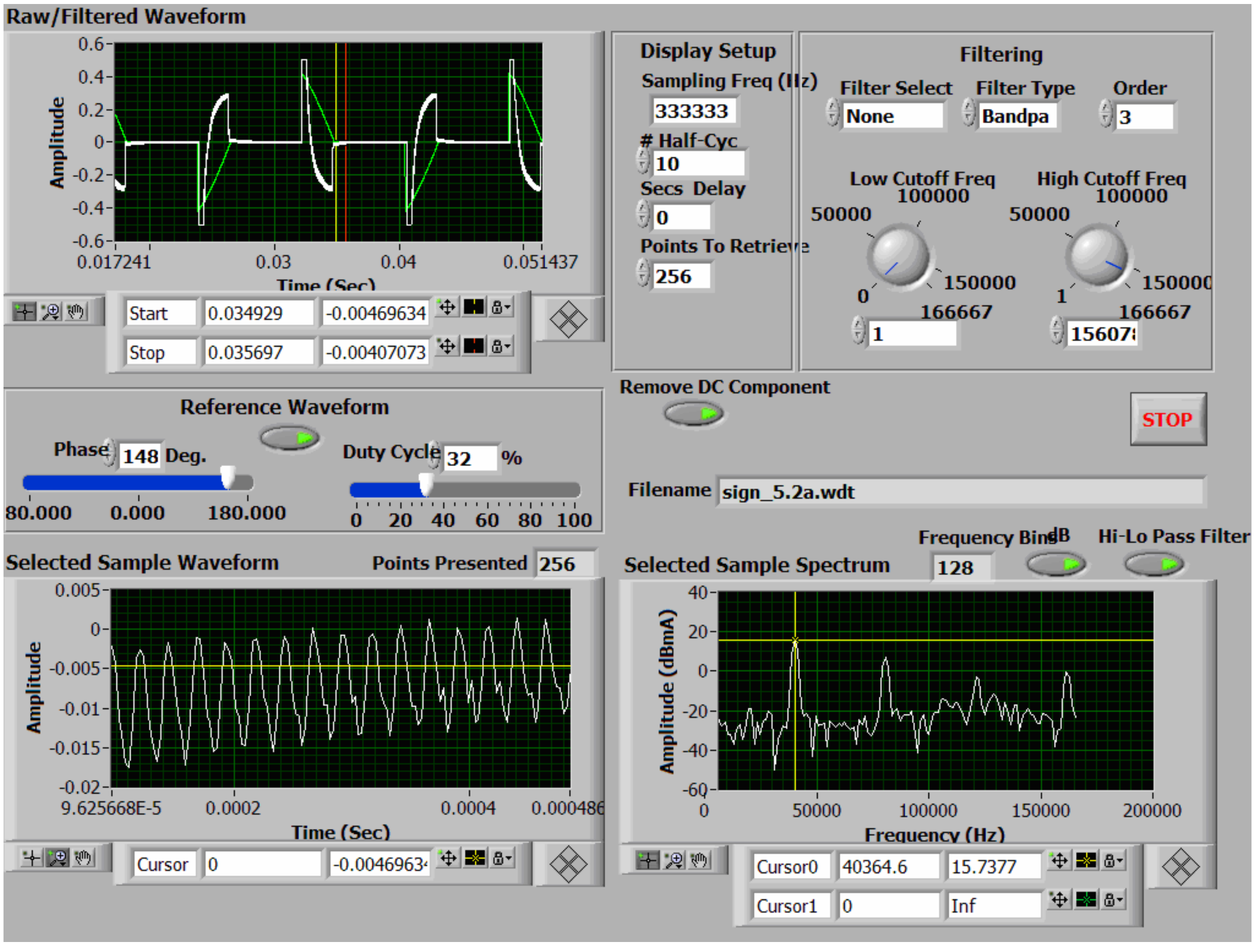
Cursor 0 0.1767

Frequency Bins 128

Cursor0 40364.6 28.848

Cursor1 0 Inf

Figure A-8. Spectrum at 5.2 amps During Conduction



Start 0.034929 -0.00469634

Stop 0.035697 -0.00407073

Display Setup

Sampling Freq (Hz) 333333

Half-Cyc 10

Secs Delay 0

Points To Retrieve 256

Filtering

Filter Select None

Filter Type Bandpa

Order 3

Low Cutoff Freq 1

High Cutoff Freq 15607

Phase 148 Deg.

Duty Cycle 32 %

Remove DC Component

Filename sign_5.2a.wdt

Points Presented 256

Frequency Bins 128

Cursor 0 -0.0046963

Cursor0 40364.6 15.7377

Cursor1 0 Inf

Figure A-9. Spectrum at 5.2 amps Just After Conduction

Start 0.03936 0.00108674
Stop 0.040128 -0.00216339

Display Setup
Sampling Freq (Hz) 333333
Half-Cyc 10
Secs Delay 0
Points To Retrieve 256

Filtering
Filter Select None
Filter Type Bandpa
Order 3
Low Cutoff Freq 1
High Cutoff Freq 15607

Phase 148 Deg.
Duty Cycle 32 %

Filename sign_5.2a.wdt

Points Presented 256
Frequency Bins 128

Cursor 0 0.00108674

Cursor0 80729.2 10.2291
Cursor1 0 Inf

Figure A-10. Spectrum at 5.2 amps Just Before Conduction

Start 0.032709 0.193701

Stop 0.033477 -0.196527

Display Setup

Sampling Freq (Hz) 333333

Half-Cyc 10

Secs Delay 0

Points To Retrieve 256

Filtering

Filter Select: None

Filter Type: Bandpa

Order: 3

Low Cutoff Freq 1

High Cutoff Freq 15607

Remove DC Component

Phase 148 Deg.

Duty Cycle 32 %

Filename sign_4.8a.wdt

Points Presented 256

Frequency Bins 128

dB

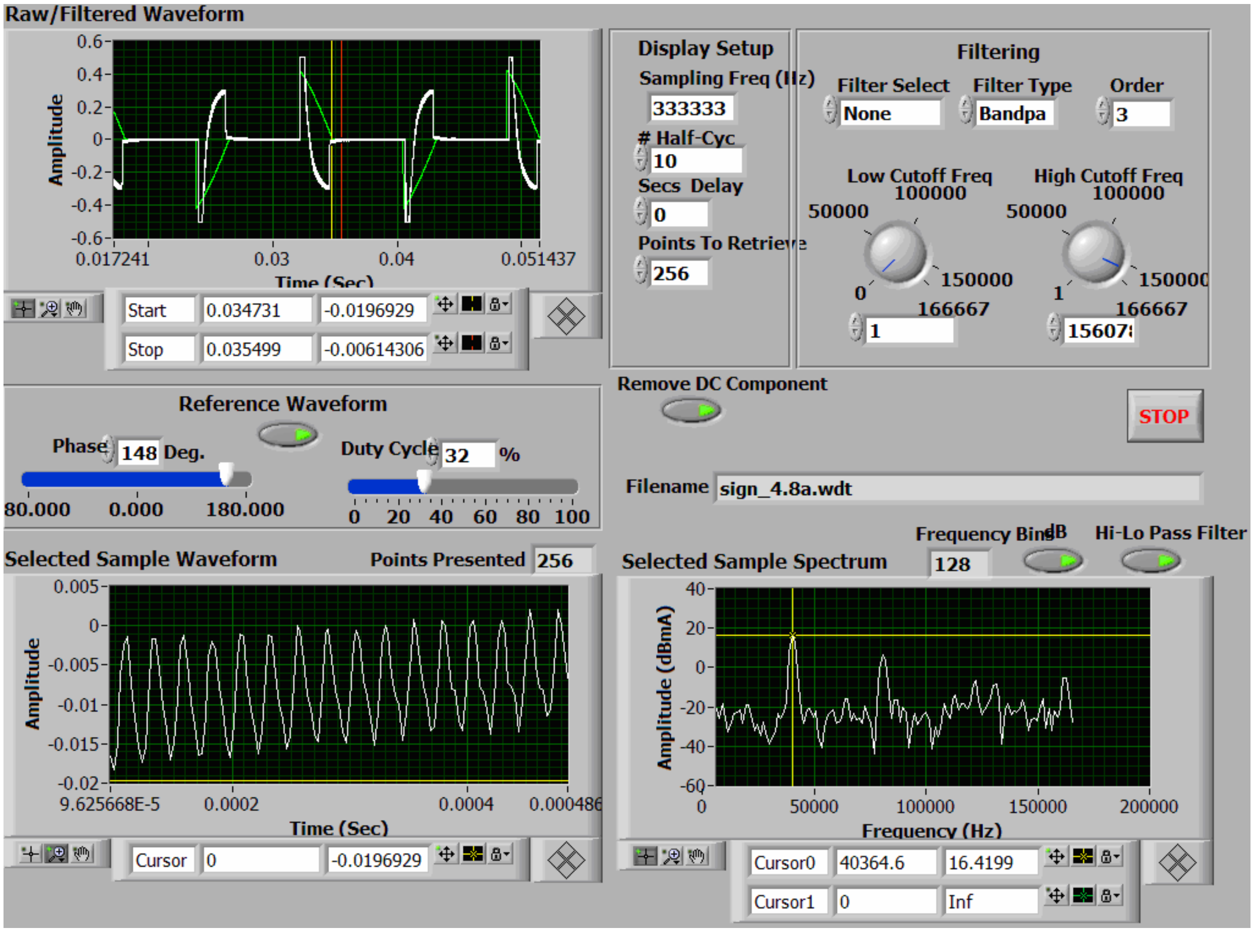
Hi-Lo Pass Filter

Cursor 0 0.193701

Cursor0 40364.6 27.4141

Cursor1 0 Inf

Figure A-11. Spectrum at 4.8 amps During Conduction



Start 0.034731 -0.0196929

Stop 0.035499 -0.00614306

Sampling Freq (Hz) 333333

Half-Cyc 10

Secs Delay 0

Points To Retrieve 256

Filter Select None

Filter Type Bandpa

Order 3

Low Cutoff Freq 100000 1

High Cutoff Freq 100000 15607

Phase 148 Deg.

Duty Cycle 32 %

Filename sign_4.8a.wdt

Frequency Bins 128

Points Presented 256

Cursor 0 -0.0196929

Cursor0 40364.6 16.4199

Cursor1 0 Inf

Figure A-12. Spectrum at 4.8 amps Just After Conduction

Start 0.039351 0.00331739

Stop 0.040119 0.00183729

Sampling Freq (Hz) 333333

Half-Cyc 10

Secs Delay 0

Points To Retrieve 256

Filter Select None

Filter Type Bandpa

Order 3

Low Cutoff Freq 1

High Cutoff Freq 15607

Phase 148 Deg.

Duty Cycle 32 %

Filename sign_4.8a.wdt

Points Presented 256

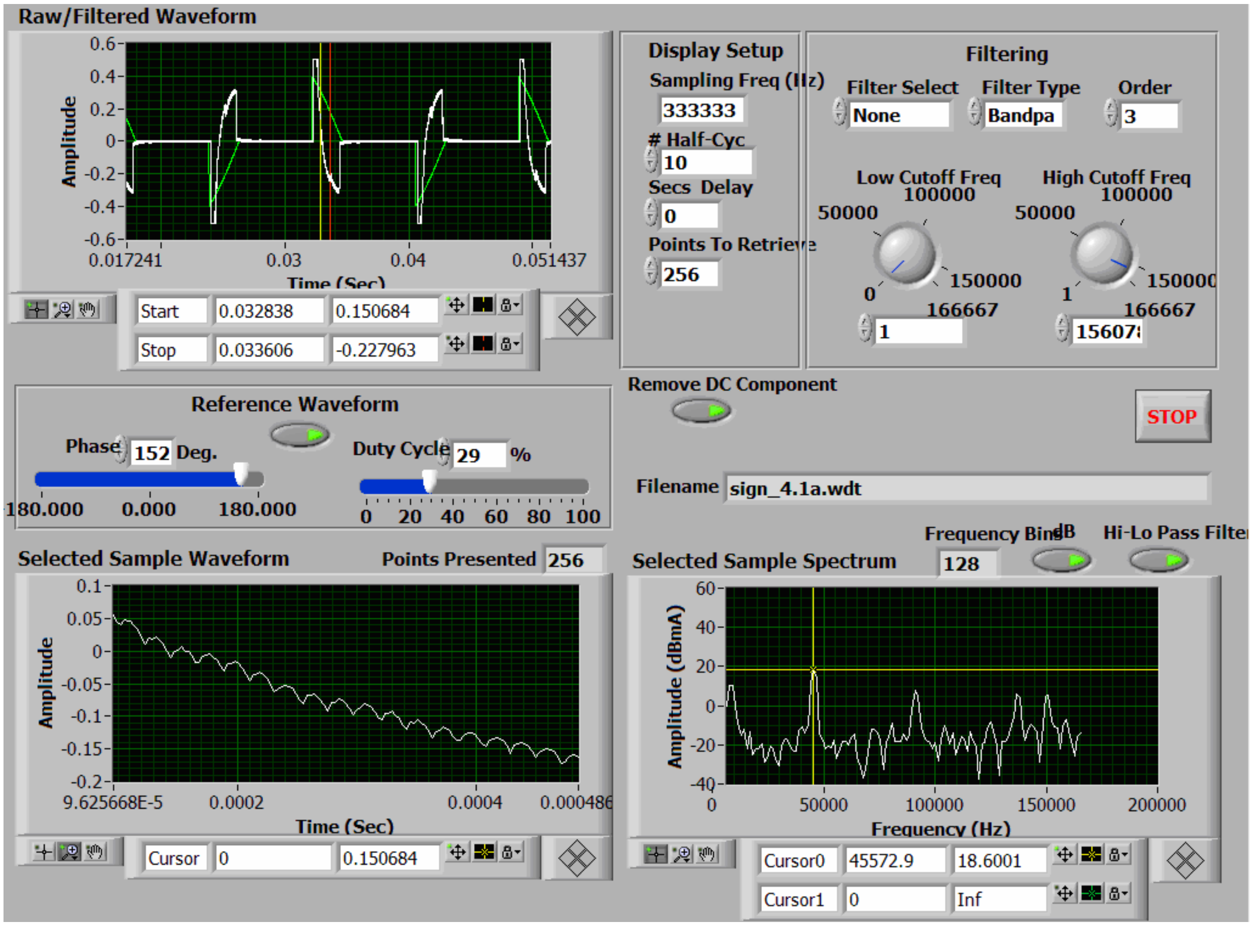
Frequency Bins 128

Cursor 0 0.00331739

Cursor0 80729.2 10.1764

Cursor1 0 Inf

Figure A-13. Spectrum at 4.8 amps Just Before Conduction



Start 0.032838 0.150684
Stop 0.033606 -0.227963

Sampling Freq (Hz) 333333
Half-Cyc 10
Secs Delay 0
Points To Retrieve 256

Filter Select None
Filter Type Bandpa
Order 3
Low Cutoff Freq 1
High Cutoff Freq 15607

Phase 152 Deg.
Duty Cycle 29 %

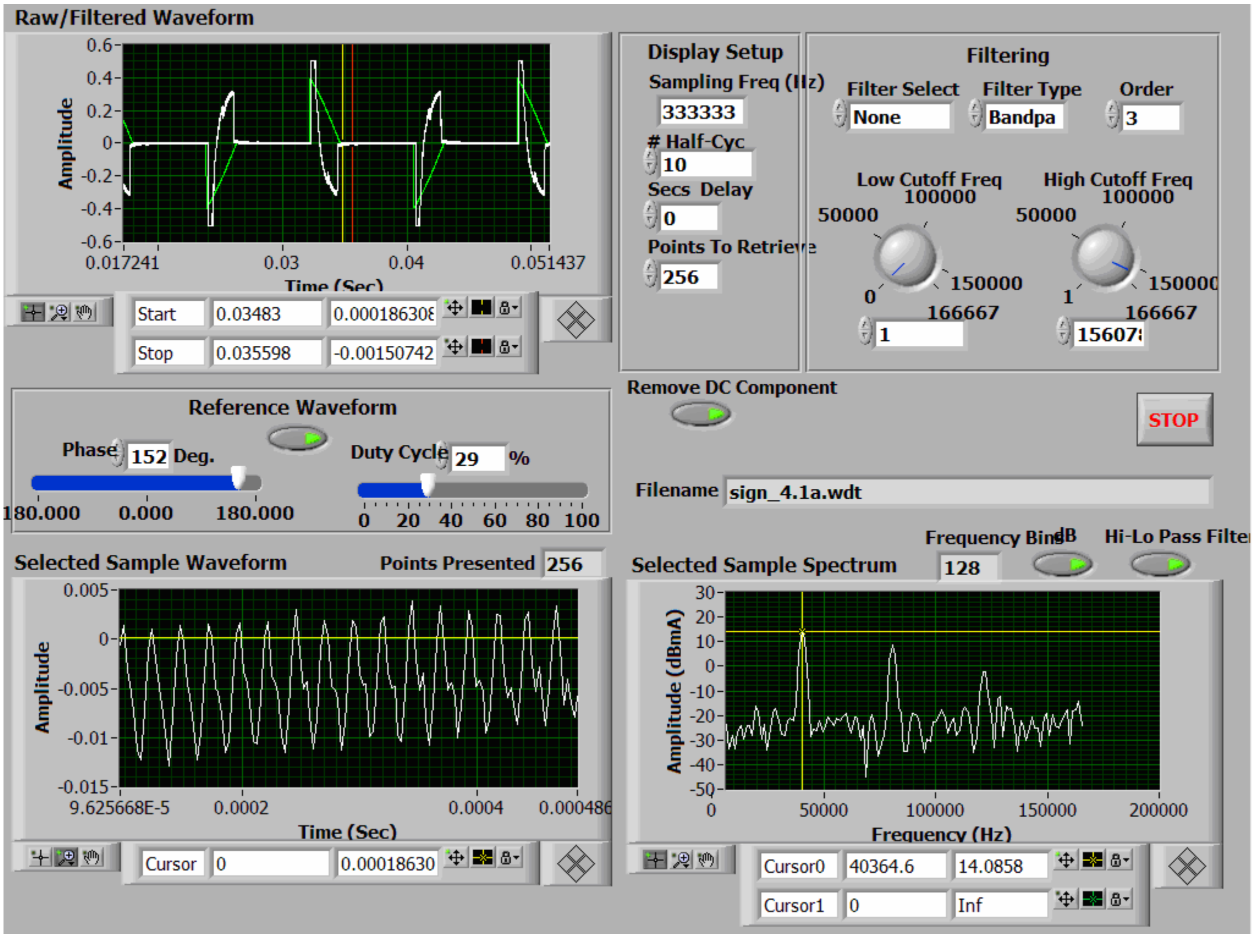
Filename sign_4.1a.wdt

Points Presented 256
Frequency Bins 128

Cursor 0 0.150684

Cursor0 45572.9 18.6001
Cursor1 0 Inf

Figure A-14. Spectrum at 4.1 amps During Conduction



Start 0.03483 0.000186308

Stop 0.035598 -0.00150742

Sampling Freq (Hz) 333333

Half-Cyc 10

Secs Delay 0

Points To Retrieve 256

Filter Select None

Filter Type Bandpa

Order 3

Low Cutoff Freq 1

High Cutoff Freq 15607

Phase 152 Deg.

Duty Cycle 29 %

Filename sign_4.1a.wdt

Points Presented 256

Frequency Bins 128

Cursor 0 0.00018630

Cursor0 40364.6 14.0858

Cursor1 0 Inf

Figure A-15. Spectrum at 4.1 amps Just After Conduction

Start 0.039645 -0.00362839

Stop 0.040413 -0.00123276

Sampling Freq (Hz) 333333

Half-Cyc 10

Secs Delay 0

Points To Retrieve 256

Filter Select None

Filter Type Bandpa

Order 3

Low Cutoff Freq 1

High Cutoff Freq 15607

Phase 152 Deg.

Duty Cycle 29 %

Filename sign_4.1a.wdt

Points Presented 256

Frequency Bins 128

dB

Hi-Lo Pass Filte

Cursor 0 -0.0036283

Cursor0 80729.2 10.2227

Cursor1 0 Inf

Figure A-16. Spectrum at 4.1 amps Just Before Conduction