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(143 Pages)

NAVAL AIR WARFARE CENTER AIRCRAFT DIVISION
PATUXENT RIVER, MARYLAND

TECHNICAL REPORT

REPORT NO: NAWCADPAX/TR-2000/33

BOEING 747-100 FUEL QUANTITY INDICATION SYSTEM (FQIS) SUSCEPTIBILITY TO INDUCED ENERGY FROM CAPACITIVE AND INDUCTIVE CABLE COUPLING

12 June 2000

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DEPARTMENT OF THE NAVY
NAVAL AIR WARFARE CENTER AIRCRAFT DIVISION
PATUXENT RIVER, MARYLAND

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BOEING 747-100 FUEL QUANTITY INDICATION SYSTEM (FQIS) SUSCEPTIBILITY TO INDUCED ENERGY FROM CAPACITIVE AND INDUCTIVE CABLE COUPLING

by

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

An electrical ground test was conducted to evaluate the Boeing 747-100 aircraft's fuel quantity indication system (FQIS) susceptibility to induced energy from capacitive and inductive coupling, and to measure voltage harmonics on the Captain's channel of the cockpit voice recorder for various electrical load conditions. The test was conducted to support the National Transportation Safety Board's investigation of the TWA 800 accident. Electrical loads were identified that were candidates for coupling energy from cables that are corouted with the FQIS wiring of the center wing tank. These electrical load cables were moved directly adjacent to the FQIS wiring for the length of corouting. A simulated center wing tank was connected to the FQIS. Aircraft systems were powered using aircraft generators and the FQIS was energized. Voltage and current measurement were taken at fuel probes of the simulated center wing tank while aircraft electrical loads were cycled. Additional measurements were taken with conductive debris placed either across terminals of a fuel probe or from a terminal of a fuel probe to the simulated center wing tank in an attempt to create and calculate the energy dissipation through the debris. The maximum energy of a debris transient was 125 μJ.

15. SUBJECT TERMS

Boeing 747-100; TWA Flight 800; Fuel Quantity Indication System (FQIS); Electrical Power System Test; Capacitive and Inductive Coupling; Harmonics; Cockpit Voice Recorder (CVR)

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SUMMARY

An electrical ground test was conducted to evaluate the Boeing 747-100 aircraft's fuel quantity indication system (FQIS) susceptibility to induced energy from capacitive and inductive coupling, and to measure voltage harmonics on the Captain's channel of the cockpit voice recorder (CVR) for various electrical load conditions. The testing was conducted at AAR Aircraft Services, Inc., facilities in Roswell, New Mexico, from 10-19 November 1999. The tests were conducted to support the National Transportation Safety Board's investigation of the TWA 800 accident. Electrical loads were identified that were candidates for coupling energy from cables that are corouted with the FQIS wiring of the center wing fuel tank. These electrical load cables were moved directly adjacent to the FQIS wiring for the length of corouting. A simulated center wing tank was connected to the FQIS. Aircraft systems were powered using aircraft generators and the FQIS was energized. Voltage and current measurement were taken at fuel probes of the simulated center wing tank while aircraft electrical loads were cycled. Additional measurements were taken with conductive debris placed either across terminals of a fuel probe or from a terminal of a fuel probe to the simulated center wing tank in an attempt to create and calculate energy dissipation through the debris. The potential capability to ignite fuel was evaluated against the flammability properties of aircraft fuels, reference 1. As stated in reference 1, the minimum electric spark ignition energy of Jet A fuel is 200 μJ.

The maximum energy calculated for a transient through debris was 125 μJ. The debris was a few strands of aluminum wool placed between the HiZ terminal and the shield terminal of fuel probe F44 during a turn off of the Engine No. 1 Hydraulic Valve. The transient lasted a duration of 207 μsec. The maximum voltage transient recorded for the no debris condition was 175 V peak measured on fuel probe F40 between the Shield terminal of the fuel probe and the simulated center wing tank during a turn off of the Engine No. 1 Hydraulic Valve.

The Total Harmonic Distortion (THD) of the base load condition of the voltages measured at the CVR Captain's channel input was approximately 33%. The electrical load conditions that resulted in a reduction in THD of the voltages measured at the CVR Captain's channel were: immediately after closing all generator circuit breakers; breaker pulled for transformer rectifier unit (TRU) 2; Essential Power Selector to BUS 3; Essential Power Selector to BUS 2; Essential Power Selector to BUS 1; and all TRU breakers pulled.

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INTRODUCTION

BACKGROUND

1. An aircraft electrical system ground test of a Boeing 747-100 aircraft, G-AWNF, line number 111, was conducted at AAR Aircraft Services, Inc., facilities in Roswell, New Mexico, from 10-19 November 1999. This test was in support of the National Transportation Safety Boards (NTSB) investigation of the TWA 800 accident. On 17 July 1996, at 2031 eastern daylight time, a Boeing 747-131, N93119 crashed into the Atlantic Ocean shortly after takeoff from John F. Kennedy International Airport, about 8 miles south of East Moriches, New York. The NTSB has determined that a potential cause of the accident was the explosion of the center wing fuel tank. A possible ignition source under investigation is an abnormal event in the Fuel Quantity Indication System (FQIS). NTSB contracted with the NAVAIRSYSCOM, Electrical Power Systems Division (EPSD), to determine if electrical power transients could induce sufficient energy into the FQIS through capacitive and inductive cable coupling to ignite fuel in a Boeing 747-131 center wing fuel tank. The potential capability to ignite fuel was evaluated against the flammability properties of aircraft fuels, reference 1. As stated in reference 1, the minimum electric spark ignition energy of Jet A fuel is 200 μJ. Additional tests were conducted to measure the voltage harmonics of the Captain's channel of the cockpit voice recorder (CVR) for various electrical load conditions.

2. The FQIS uses a combination of different voltages in its operation. The wiring for the FQIS also runs in bundles with other cables having various voltages. These bundles run from the center wing fuel tank up to the flight deck of the aircraft. Previous tests conducted by Boeing Aircraft Company characterized the electrical transients induced onto the FQIS wiring entering the center wing fuel tank. Most of the testing conducted by Boeing was performed with the FQIS deenergized. The tests of this investigation were conducted with the FQIS energized. This investigation did not address abnormal electrical short circuits between the FQIS cables and other cables within the wire bundle. This investigation did address if sufficient energy can be coupled to the FQIS during short circuits occurring on wire bundles running near the FQIS cabling.

3. Voltage harmonic spectrums of the Captain's channel of the CVR were measured for various electrical loading conditions of the aircraft. The CVR is located in the tail of the aircraft. The wiring for the CVR's channels is corouted with numerous cables. Many of these cables are powered by 400 Hz, 115 V of the electrical system. The inductive and capacitive coupling between the power cables and the wiring for CVR channels creates what is known as "noise" or background 400 Hz "hum" and can be detected on the audio information of the CVR. During the development of the transcript of the TWA 800 audio recording, the CVR group identified two segments of the recording that contained a change in the background 400 Hz "hum". These abnormalities in the background 400 Hz "hum" occurred during the last second of the recording on the Captain's channel. The voltage harmonic spectrum measurements of this investigation were taken for comparison to the background 400 Hz "hum" of the TWA 800 recordings.

PURPOSE

4. The purpose of the electrical ground test was to determine if electrical power transients could induce sufficient energy into the FQIS through capacitive and inductive cable coupling to ignite fuel in a Boeing 747-131 center fuel tank and to measure the voltage harmonic spectrum of the CVR's Captain's channel for various electrical load conditions. The testing did not address abnormal electrical short circuits between the FQIS wiring and other wiring. The test did address if sufficient energy can be coupled to the FQIS during short circuits occurring near the FQIS cabling.

DESCRIPTION OF AIRCRAFT

GENERAL

5. The 747 is a commercial transport aircraft manufactured by Boeing Aircraft Company. There are 15 models of the 747. These include all-passenger, passenger and cargo, and all-cargo models. The oldest model is the 100 series. The aircraft is a four turbofan cantilever low wing monoplane aircraft with a semi-monocoque fuselage. The maximum passenger load is up to 490. However, a typical passenger load is 374. The maximum takeoff weight of the 747-100 aircraft is 710,000 lb. The test aircraft was owned by AAR and is a retired 747-136, RA-318 located at the AAR Aircraft Service, Inc., facility in Roswell, New Mexico. Upon completion of the test, the aircraft was to be disassembled by AAR and salvaged. A detailed description of the 747 aircraft is provided in reference 2.

FUEL SYSTEM

6. The fuel storage areas are divided into four main tanks, two reserve tanks, and a center wing fuel tank. Located within the fuel tanks are fuel lines, pumps, valves, vents, drains, and sensing equipment required for the monitoring of the fuel system. An electronic FQIS is provided to indicate the amount of fuel contained within the tanks. All pump and valve controls along with the fuel quantity indicators and indicating lights are located on the flight engineer's panel in the cockpit. The center wing tank contains seven fuel probes (F38, F39, F40, F41, F42, F43, and F44) and one compensator probe (F36). The compensator and fuel probes are submerged in fuel. On each fuel probe there are three terminals (HiZ, LoZ, and SH). The capacitance across the HiZ and LoZ terminals change proportionally to the amount of fuel within the probe. The compensator probe is used to compensate the dielectric constant for different types of aircraft fuel. The center wing tank FQIS wiring is contained within wire bundles W480 and W350. The W480 wire bundle is routed along side many other wire bundles between the center wing fuel tank and the flight engineer's panel. A pictorial representation of the FQIS wiring and the terminal connections on each fuel probe are presented in appendix A. A complete description of the fuel system is contained in reference 2.

ELECTRICAL SYSTEM

7. The aircraft electrical system consisted of four 60 kVA rated generators for three-phase 115/200 V, 400 Hz primary AC power; one 90 kVA auxiliary power unit (APU) generator for three-phase 115/200V, 400 Hz secondary AC power; one 500 VA rated inverter for backup single-phase 115 V, 400 Hz AC power; three 75-amp transformer-rectifiers for 28 V primary DC power; and two 36 amp-hr nickel cadmium batteries for 24 V backup DC power, APU start power, and bus/switching logic for power distribution. The aircraft has receptacles for external AC power. The APU generator control unit functions as an AC external power monitor and prevents abnormal quality power from being applied externally to the aircraft. During normal operation, the four 60 kVA generators supply power to four main AC buses. The generators are synchronized and connected together by the closing bus tie and split bus breakers. The inverter provides power to flight critical equipment when primary AC power is not available. Step-down transformers are used to provide 28 VAC power. Three separate transformer-rectifier units supply power to the main 28 VDC buses. These buses are connected to together through isolation relays. A complete description of the electrical system is contained in reference 2.

SCOPE OF TEST

8. Aircraft ground tests of a Boeing 747-100 aircraft were conducted to determine if electrical power transients could induce sufficient energy into the center wing tank via the wiring and fuel probes of the FQIS, and to measure the voltage harmonics on the Captain's channel of the CVR. The tests were conducted primarily with electrical power applied from the No. 1 and No. 4 generators, and sometimes with power from all four generators. The FQIS was energized for the test.

AIRCRAFT CONFIGURATION

9. The aircraft was fleet representative with the external power, APU power, and all main electrical power generating systems fully functional. The aircraft discrepancy book (ADB) was reviewed to evaluate the effect aircraft system discrepancies would have on the performance of the test. No discrepancies were found in the ADB that would have any adverse effect on the tests. The landing gear and remotely actuated access doors were pined. Any radiating sources (Weather Radar, HF1, HF2, VHF1, VHF2, and VHF3 radios) located near the instrumentation vehicle or near personnel access doors/panels on the aircraft were secured and/or inhibited. The FQIS wiring harnesses were disconnected from the center fuel tank and connected to the Boeing simulated center wing fuel tank. The FQIS was powered for the test. Measurement instrumentation was installed and monitored by EPSD. Representatives from AAR, NTSB, FAA, Honeywell, and Boeing were present to assist EPSD during the instrumentation installation and testing. Inspection of the installation and verification of electrical and mechanical workmanship was performed by AAR and the NTSB.

METHOD OF TEST

GENERAL

10. Testing followed a minimum risk buildup method starting with instrumentation checks; aircraft system checks; normal electrical power; bus transfers and aircraft system operation; followed by FQIS energy coupling test for bus transfers and electrical load switching; short circuit/bundle crush tests; and parametric FQIS wiring separation testing. Steady state and transient data were recorded to characterize the electrical performance of the FQIS during these tests. An additional test was performed to measure the voltage harmonics of the Captain's channel of the CVR for various electrical load conditions.

TEST CONFIGURATION

11. The FQIS wiring to the onboard center wing fuel tank was disconnected from the aircraft and connected to the Boeing simulated center wing fuel tank located on the ground beneath the rear left wheel well. Shorting plugs were connected to FQIS connectors of the onboard center wing fuel tank. The simulated center wing tank was electrically bonded to the aircraft structure. The EPSD electrical instrumentation was temporarily installed in the aircraft to monitor various test points on the aircraft and on the fuel probes within the simulated center wing tank. Signal cables from this instrumentation were routed to the data acquisition equipment located in a test van at the nose of the aircraft. Appendix B shows the location of personnel, equipment, and safety zones in relation to the aircraft. To prevent the possibility of igniting the fuel, nitrogen gas was continuously pumped into the onboard fuel tanks through the left wing pressure-refueling receptacle in accordance with the inerting procedures of appendix C. The inertness of the onboard tanks was continuously monitored throughout the test by measuring the oxygen content from the outflow vents at the tip of each wing.

BOEING SIMULATED CENTER WING TANK

12. A simulated center wing tank was fabricated by Boeing to conduct a FQIS electromagnetic compatibility test. Seven fuel probes were mounted on a Plexiglas sheet and a production wire harness connected all the fuel probes to the FQIS wiring harness. For this test, the Boeing simulated center wing fuel tank was used to access the fuel probes. The simulated center wing tank was placed beneath the left wheel well. The simulated wing tank was electrical bonded to the aircraft structure for the test. A complete description of the Boeing simulated center wing fuel tank is contained in reference 3.

INSTRUMENTATION FOR FQIS COUPLING TEST

13. The instrumentation for the induced energy from capacitive and inductive coupling to the FQIS wiring consisted of a multichannel digital oscilloscope, voltage probe sensors, current sensors, and instrumentation cables to bring the signals from the sensors to the inputs of the digital oscilloscope. The measurement locations for a given test consisted of voltage and current

measurements at a fuel probe within the simulated center wing tank, voltage and current measurements for the load that was cycled (whose load wires were adjacent to the FQIS wiring), and voltage and current measurements of the aircraft's electrical distribution system including 400 Hz AC systems and the 28 VDC systems.

Digital Oscilloscope

14. A Nicolet Odyssey multichannel digital oscilloscope was used to record the signals from instrumentation sensors located throughout the aircraft. As configured, the Odyssey had two OD-200 acquisition cards and two OD-100 acquisition cards. This gave the Odyssey 8 channels with a sample rate of up to 10 MS/s (Mega-Samples per second) at 14 bit resolution and 16 channels with a sample rate of up to 100 kS/s (kilo-Samples per second) at 16 bit resolution. The Nicolet Odyssey oscilloscope has the capability of dual sample rates. The oscilloscope can record continuously at a lower sample rate and record at a higher rate when triggering criteria is met. The OD-200 acquisition cards were set to a high sample rate of 10 MS/s and lower sample rate of 100 kS/s. The OD-100 acquisition cards were set to a continuos sample rate of 100 kS/s. The dual sample capability allowed a large number of transients to be recorded over hundreds of seconds. The triggering levels were set to slightly above the nominal voltages and current measured at the fuel probe and the channel triggers were "or-ed" (i.e., any transient occurring on any voltage or current at the fuel probe would trigger the OD-200 acquisition card to record at the 10 MS/s rate). To prevent aliasing, the built-in filters of the Odyssey were set to 5 MHz for the OD-200 acquisition card and to 25 kHz for the OD-100 acquisition cards.

Fuel Probe Measurements

15. The following instrumentation was used for the fuel probe measurements:

a. Tektronix P5200 active differential voltage probes

b. Pearson 4997 current transformer

c. Pearson 411 current transformer

The voltage sensors used for the fuel probe measurements were the Tektronix P5200 active differential voltage probes set to a 500 to 1 voltage attenuation factor (Note: the Tektronix P5200 voltage probes were used for all voltage measurements for this tests). The Tektronix P5200 voltage probes have a bandwidth of DC to 25 MHz (-3 dB) and input impedance of 8 MΩ. The signal cable for the voltage probes was 120 ft of RG-58 coaxial cable. The voltage measurements for the fuel probes were alternated between measuring the terminals to simulated center wing tank and measuring across the terminals as follows:

HiZ terminal of the fuel probe to simulated center wing tank
LoZ terminal of fuel probe to simulated center wing tank
Shield terminal of fuel probe to simulated center wing tank

or

HiZ terminal to LoZ terminal of the fuel probe
HiZ terminal to shield terminal of the fuel probe
LoZ terminal to shield terminal of the fuel probe

The current sensors used for the fuel probe measurement were Pearson 4997 or Pearson 411 current transformers. The Pearson 4997 current transformer has an attenuation factor of 100 amp to 1 V and a bandwidth of 20 MHz (-3 dB). The Pearson 4997 current transformers measured the HiZ with shield and LoZ currents. The Pearson 411 current transformer has an attenuation factor of 10 amp to 1 V and a bandwidth of 20 MHz (-3 dB). The Pearson 411 current transformer was used for the debris current measurements on all tests except the Bus Transfer test and the Scavenge Pump Cycling test where a Pearson 4997 current transformer was used. The signal cable for the current transformers was 120 ft of RG-58 coaxial cable.

<u>Other Measurements throughout the Aircraft</u>

16. For the other measurements throughout the aircraft, the instrumentation listed below was used:

a. Tektronix P5200 active differential voltage probes

b. Pearson 4997 current transformer (AC)

c. Pearson 1330 current transformer (AC)

d. LEM LT-2000S hall effect current transformer (DC)

e. LA-100P hall effect current transformer (DC)

The signal cables for other measurements were 50 to 120 ft of RG-58 coaxial cable. The other measurements included voltages and currents of loads that were cycled, select points within the electrical distribution system, and other points of interest for the test. All voltage sensors were Tektronix P5200 active differential probes set to a 500 to 1 voltage attenuation factor or set to a 50 to 1 voltage attenuation. The Tektronix P5200 voltage probes have a bandwidth of DC to 25 MHz (-3 dB) and input impedance of 8 MΩ. The signal cables for the voltage probes were 50 to 120 ft of RG-58 coaxial cable. For the 400 Hz AC measurement, the current sensors were Pearson 1330 current transformers or Pearson 4997 current transformers. The Pearson 1330 current transformer has an attenuation factor of 100 amp to 1 V and a bandwidth of 1.5 MHz (-3 dB), and was only used for channels of the OD-100 acquisition cards. The Pearson 4997 current transformer has an attenuation factor of 100 amp to 1 V and a bandwidth of 20 MHz (-3 dB). For the DC measurement, the current transformers were LEM LT-2000S hall effect current transformers or LA-100P hall effect current transformers. These hall effect current transformers required ±15 V voltage source, which was supplied via 60 ft of a three-conductor AWG-20 103A-3/C cable from a power supply. The precision burden resistor for the LEM LT-2000S current transformer was sized for an attenuation factor of 250 amp to 1 V. The precision burden resistor for the LA-100P current transformer was sized for an attenuation factor of 10 amp to 1 V.

CALIBRATION OF INSTRUMENTATION

17. In addition to the standard calibrations required by the instrumentation, calibration tests were performed on the instrumentation as a system. For the voltage probes, known voltage signals of various frequencies including DC, 400 Hz, 10 kHz, and 5 MHz were applied to the input leads of the probes. The signals recorded on the instrumentation were compared to the known signal. This calibration was performed with the voltage probes connected to the Nicolet Odyssey digital oscilloscope via the same cables used for the aircraft tests. For the current sensors, known currents were passed through the current transformers at various frequencies including 400 Hz, 10 kHz, 5 MHz, and DC (for the hall effect transformer only). The signals recorded on the instrumentation were compared to the known signal. This calibration was performed with the current transformers connected to the Nicolet Odyssey digital oscilloscope via the same cables used for the aircraft tests.

18. Calibration tests were also performed with a Solar Model 8282-1 transient pulse generator and with the voltage and current sensors connected to a Honeywell fuel probe P/N FG420A18. The voltage and current sensors were connected to the fuel probe in exactly the same manner as they were for the aircraft test, including the same instrumentation cable. Transient voltage spikes from 50 V up to 600 V of 0.15, 5, and 10 μsec durations were applied across the respective terminals of the fuel probe, and from the fuel probe terminals to ground. A high-speed (150 MHz) Hewlett Packard 54602A digital oscilloscope with Hewlett Packard voltage probes (100 to 1) impedance and bandwidth matched to the oscilloscope were used to measure the pulses. The traces from the Hewlett Packard oscilloscope were compared to the traces recorded on the Nicolet Odyssey oscilloscope. These calibration tests were repeated with aluminum wool debris and Joslyn arc-gaps placed across the respective terminals of the fuel probe, and from the fuel probe terminals to ground. The debris current was passed through a Pearson 4997 current transformer connected to the Hewlett Packard oscilloscope with a 5 ft coaxial cable, and another Pearson 4997 current transformer (and repeated with a Pearson 411 current transformer) connected to the Nicolet Odyssey oscilloscope via the 120 ft cable used for the aircraft test. The traces from the Hewlett Packard oscilloscope were compared to the traces recorded on the Nicolet Odyssey oscilloscope. All these calibration tests were repeated with only the instrumentation used for the aircraft test. The measurements without calibration equipment connected were consist with the measurements taken with the calibration instrumentation connected.

ENERGY CALCULATION

19. The energy dissipated across the simulated debris was calculated using the following formula:

$$H(t) = \int_0^T V(t)I(t)dt$$

where,

H(t) is the dissipated energy, V(t) is the voltage across the simulated debris in Volts, I(t) is the current through the simulated debris in amperes, and 0 to T is the time period of interest.

20. A qualitative judgement was made to assess the waveforms recorded on the Nicolet Odyssey digital oscilloscope for energy calculations. The waveforms for the current passing through the debris and for the voltage across the debris were examined. The primary factor for determining if the waveforms were valid for energy calculations was comparing the magnitude of the transient debris currents against the noise level. Currents whose magnitudes exceeded a 10 to 1 signal-to-noise ratio were used. The voltage waveform was then examined. Comparing the magnitude of the transient voltage to the noise level on the voltage waveforms was difficult because of the task of distinguishing between nontransient electrical systems coupling to the FQIS wiring and the noise level inherent in the instrumentation wiring. Voltages whose magnitudes exceeded the combined nontransient coupling to the FQIS and the noise level by greater than four were used. Using ProView software version 3.31, a power waveform was obtained by multiplying the voltage waveform V(t) by the current waveform I(t). The power waveform was in Watts (Joules per second). The absolute value of the power waveform was calculated, and for the time period of the transient through the simulated debris (0 to T), the energy was calculated by finding the area under the curve. The energy was in Joules. The calculated dissipated energy and the duration of the transient were recorded.

INSTRUMENTATION FOR COCKPIT VOICE RECORDER HARMONIC VOLTAGE MEASUREMENTS TEST

21. A Hewlett Packard 35670A spectrum analyzer was used for the CVR Harmonic Voltage Measurements Test. The input from the CVR Captain's channel was connected directly to the input of the spectrum analyzer via a 6-ft twisted pair cable.

FUEL QUANTITY INDICATION SYSTEM ENERGY COUPLING TEST

22. The candidate electrical loads that could cause coupling were selected prior to testing based on coupling lengths, type and size of load, and prior Boeing testing. Aircraft wiring that powered the respective systems was moved adjacent to the FQIS cabling. The length of coupling was measured and recorded. Fuel probes were instrumented, aircraft systems for the respective load were instrumented, aircraft systems were energized, and the FQIS was energized. The respective load was cycled on and off (Bus transfer performed for the Bus transfer tests) and the transient data recorded. In the interest of time and based on the results of these no debris tests, a decision

was made to continue with the debris conditions. For the debris conditions, aluminum wool and/or nonintrusive arc-gap-voltage-transient-suppression devices were connected from a selected terminal of a fuel probe or across selected terminals of a fuel probe within the simulated center fuel tank and the respective load cycling repeated. The aluminum wool/arc-gap-voltage-transient-suppression devices were intended to simulate the inadvertent contact of conductive debris with the terminals and fuel tank or across the fuel probe terminals.

BUS TRANSFERS

23. The Bus Transfer tests were performed before the aircraft load cycling tests. No wires were moved for the Bus Transfer test. Smiths gauges and totalizer were installed in the Flight Engineer's Instrumentation Panel. Aircraft Generators No. 1 and No. 4 powered the electrical system of the aircraft. The Bus Transfer tests were accomplished by using the following procedure:

a. Ensured No. 4 generator circuit breaker (GCB) was closed.

b. Ensured No. 1 bus transfer breaker (BTB), No. 2 BTB, No. 3 BTB, and No. 4 BTB were closed.

c. Ensured No. 1 GCB, No. 2 GCB, and No. 3 GCB were open.

d. Ensured Split System Breaker (SSB) was closed.

e. Opened SSB.

f. Closed No. 1 GCB breaker.

g. Opened No. 1 GCB breaker.

h. Closed SSB.

SCAVENGE PUMP

24. The Scavenge Pump test was the first test in which an aircraft load was cycled. For the cycling of the Scavenge Pump test, wires W644-Q66-20, W644-Q67-20, W644-Q68-20, and W644-W442-20 were moved directly adjacent to the FQIS wires within wire bundle W480. The first three wires provided 115 V, 400 Hz, three-phase power to the scavenge pump mounted on the aft bulkhead of the center wing tank. The last wire provided Scavenge Pump pressure indication. There was 21 ft 10 in. of coupling length between these wires and the FQIS wires. The coupling was from station 1000 to station 1265 of the wiring tray located below the main cabin floorboards. These tests were performed first with Smiths gauges and totalizer installed in the Flight Engineer's Instrumentation Panel and repeated after Honeywell gauges and totalizer were installed. Aircraft Generators No. 1 and No. 4 powered the electrical system of the aircraft. The

Scavenge Pump Switch, located on the Flight Engineer's Instrumentation Panel was toggled between ON and Off, energizing and deenergizing the Scavenge Pump Relay. The contacts of the Scavenge Pump Relay in turn energized and deenergized the Scavenge Pump.

ENGINE NO. 1 HYDRAULIC VALVE

25. The Engine No. 1 Hydraulic Valve test was the second test in which an aircraft load was cycled and produced the highest energy. For the cycling of the Engine No. 1 Hydraulic Valve test, Wire W528-1M270-18 was moved directly adjacent to the FQIS wires within wire bundle W480. Wire W528-1M270-18 powers the hydraulic depressurization valve of Engine No. 1, which is powered by 28 VDC. There was 39 ft 10 in. of coupling length between wire W528-1M270 and the FQIS wires. The coupling was from station 400 at the sidewall of the upper deck to station 920 in the ceiling of the main cabin. Honeywell gauges and totalizer were installed in the Flight Engineer's Instrumentation Panel. Aircraft Generators No. 1 and No. 4 powered the electrical system of the aircraft. The Engine Driven Pump Control Switch, located on the M171 System No. 1 Hydraulic Control Module in the Flight Engineer's Instrumentation Panel was toggled between Normal and Depressurize/Off.

AUXILIARY POWER UNIT FUEL BOOST PUMP AND AUXILIARY POWER UNIT FUEL SHUTOFF VALVE

26. The APU Boost Pump was the third test in which an aircraft load was cycled. For the cycling of the APU Boost Pump test, wires W644-Q686-18, W644-Q99-18, W644-Q100-18, and W644-W75-20 were moved directly adjacent to the FQIS wires within wire bundle W480. The first wire provided 28 VDC power to the APU Fuel Boost Pump. The next two wires provided 28 VDC power for closing and opening of the APU Fuel Shutoff Valve, respectively. The last wire provided APU Fuel Pump pressure indication. There was 19 ft 0 in. of coupling length between these wires and the FQIS wires. The coupling was from station 1040 to station 1265 of the wiring tray located below the main cabin floorboards. Honeywell gauges and totalizer were installed in the Flight Engineer's Instrumentation Panel. Aircraft Generators No. 1 and No. 4 powered the electrical system of the aircraft. The APU Master Control Switch, located on the M176 APU Control Module in the Flight Engineer's Instrumentation Panel was toggled between On/Start and Off.

NO. 1 FUEL CROSSFEED VALVE

27. The No. 1 Fuel Crossfeed Valve was the fourth test in which an aircraft load was cycled. For the cycling of the No. 1 Fuel Crossfeed Valve test, wires W292-1Q28-18 and W292-1Q28-18 were moved directly adjacent to the FQIS wires within wire bundle W480. These two wires provided 28 VDC power for opening and closing of the No. 1 Fuel Crossfeed Valve, respectively. There was 52 ft 10 in. of coupling length between these wires and the FQIS wires. The coupling was from station 400 at the ceiling of the flight deck to station 920 in the ceiling of the main cabin. Honeywell gauges and totalizer were installed in the Flight Engineer's Instrumentation Panel. Aircraft Generators No. 1 and No. 4 powered the electrical system of the aircraft. The

No. 1 Fuel Crossfeed Valve Switch located on the M154 Fuel Control Module on the Flight Engineer's Instrument Panel was turned between Open and Close.

LAVATORY FLUSH MOTORS

28. The Lavatory Flush Motors for lavatory M and N were the fifth test in which an aircraft load was cycled. For the cycling of the Lavatory Flush Motors, wire W880-M515-18 was moved directly adjacent to the FQIS wires within wire bundle W480. This wire provided 115 V, 400 Hz, power for phase A of the motors. There was 19 ft 6 in. of coupling length between these wires and the FQIS wires. The coupling was from station 1040 to station 1265 of the wiring tray located below the main cabin floorboards. Honeywell gauges and totalizer were installed in the Flight Engineer's Instrumentation Panel. Aircraft Generators No. 1 and No. 4 powered the electrical system of the aircraft. The Lavatory Flush Motors for lavatory M and N were activated by pressing the flush switch in the appropriate lavatories.

OTHER AIRCRAFT LOADS

29. The following loads were cycled and the voltages at fuel probe F36 checked. This was done without moving wires directly adjacent to the FQIS wiring in the interest of saving time.

a. Aft Galley Ovens

b. No. 1 Main Aft Boost Pump

c. No. 2 Main Aft Boost Pump

d. No. 3 Main Forward Boost Pump

e. No. 4 Main Forward Boost Pump

f. Center Wing Tank Left Override/Jettison Pump

g. Reserve Tank Transfer Valve No. 1

h. Left Outflow Valve

i. Left Aileron Trim Motor

CABLE CUTS/CRUSHES

30. There were three cable cuts/crushes performed. Honeywell gauges and totalizer were installed in the Flight Engineer's Instrumentation Panel. Aircraft Generators No. 1, No. 2, No. 3, and No. 4 powered the electrical system of the aircraft and the simulated wire bundle via a load distribution panel connected at BUS No. 1 in the P14 panel of the aircraft. The distribution panel was added for safety and to have representative aircraft circuit breakers feeding the simulated aircraft loads. The size of the wires, circuit breaker sizes feeding the load, and the load connected to the simulated aircraft bundle wires are listed in appendix D. The simulated wire bundle was place next to the FQIS wiring from station 1000 to station 1265 of the wiring tray located below the main cabin floorboards. There was 19 ft 10 in. of coupling length between the wires of the simulated wire bundle and the FQIS wires. The simulated wire bundles were run out a window of the left wing down to the tarmac. The simulated wire bundle was placed in a cable cutter. An EPSD electrical power feeder harness protected by EPSD and aircraft circuit breakers was connected to aircraft power-generating systems within the aircraft. The EPSD electrical power feeder harness was installed along side the FQIS cabling. External load banks provided by the FAA and Boeing were used to energize the EPSD electrical power feeder harness during the simulated short circuit and wire bundle-crush tests. A portion of the EPSD electrical power feeder harness was routed outside the aircraft to an EPSD cable cutter/crusher mechanism located on the ground. The EPSD electrical power feeder harness was cut and crushed utilizing sharp and dull blades, respectively. The cable cutter/crusher was activated by a mechanism that dropped a weight onto these cable-cutter blades. The cable cutting/crusher mechanism was electrically grounded to the aircraft and electrically isolated from the operator.

PARAMETRIC SPACING TESTS

31. For the Parametric Spacing test, a simulated aircraft load was used. The simulated aircraft load was a three phase network of inductors connected in wye of 3.12 milliHenries per phase and feed via six cables, three 12 AWG and three 14 AWG. The simulated aircraft load was cycled by a relay provided by Boeing P/N 58657-9126. For this test, the load was cycled with the load wires directly adjacent to the FQIS wires within wire bundle W480 and with the load wires spaced at set distances of ¼ in., ½ in., 1 in., 2 in., and 4 in. from the FQIS wiring. There was 19 ft 8 in. of coupling length between these wires and the FQIS wires. The coupling is from station 1000 to station 1240 of the wiring tray located below the main cabin floorboards. Honeywell gauges and totalizer were installed in the Flight Engineer's Instrumentation Panel. Aircraft Generators No. 1 and No. 4 powered the electrical system of the aircraft. The simulated aircraft load was powered from the AC Bus No. 1 via the installed relay.

COCKPIT VOICE RECORDER VOLTAGE HARMONICS

32. Voltage harmonic spectrum measurements were taken at the input to the Captain's channel of the CVR for various electrical load conditions. The input pins to the Captain's channel were confirmed by keying the Captain's microphone and confirming the change in voltage at the pins. Generators No. 1, No. 2, No. 3, and No. 4 powered the electrical systems of the aircraft. The

electrical load conditions of the aircraft were varied and harmonic spectrum recorded. The electrical load conditions are as follows:

a. Base Load Case

b. Storm Lights On

c. Overhead Panel Lights Off

d. Instrument Lights Captain-side Off

e. Upper Deck Light Breaker Pulled

f. Upper Deck Galley Equipment On

g. Keying the Passenger Address Microphone

h. Passenger Address Pressed on Captain's Audio

i. Open Split System Breaker

j. Open GCB 3 and GCB 4

k. All GCB's Open, No Emergency Lights

l. All GCB's Closed, No Emergency Lights (Spectrum taken immediately after closing GCB's)

m. All GCB's Open, with Emergency Lights

n. All GCB's Closed (Spectrum taken immediately after closing GCB's)

o. GCB 1 and GCB 2 Open

p. Breaker Pulled for transformer rectifier unit (TRU) 1

q. Breaker Pulled for TRU2

r. Breaker Pulled for TRU3

s. Essential Power Selector to BUS 3

t. Essential Power Selector to BUS 2

u. Essential Power Selector to BUS 1

v. All TRU Breakers Pulled

RESULTS AND EVALUATION

GENERAL

33. The maximum energy calculated for a transient through debris was 125 μJ. The debris was a few strands of aluminum wool placed between the HiZ terminal and the shield terminal of fuel probe F44 during a turn off of the Engine No. 1 Hydraulic Valve. The transient lasted a duration of 207 μsec. The maximum voltage transient recorded for the no debris condition was 175 V peak measured on fuel probe F40 between the Shield terminal of the fuel probe and the simulated center wing tank during a turn off of the Engine No. 1 Hydraulic Valve.

34. The Total Harmonic Distortion (THD) of the base load conditions of the voltages measured at the CVR Captain's channel input were approximately 33%. The electrical load conditions that resulted in a reduction in the THD voltages measured at the CVR Captain's channel were, immediately after closing all GCB's, Breaker Pulled for TRU2, Essential Power Selector to BUS 3, Essential Power Selector to BUS 2, Essential Power Selector to BUS 1, and all TRU Breakers Pulled.

ENGINE NO. 1 HYDRAULIC VALVE

35. The results of cycling the Engine No. 1 Hydraulic Valve test are shown in tables E-1 through E-4. Table 1 summarizes the maximum peak voltages for the no debris conditions. The maximum voltage transient recorded for the no debris condition was 175 V peak measured on fuel probe F40 between the Shield terminal of the fuel probe and the simulated center wing tank. Figure 1 shows the waveform for the voltage at the switch and the current waveforms for the Engine No. 1 Hydraulic Valve during a turn-off. Figure 2 shows the voltage for the terminal to simulated center wing tank at fuel probe F44 for a turn-off of the Engine No. 1 Hydraulic Valve. Table 2 summarizes the maximum energies calculated for the debris conditions. The maximum energy calculated for a transient through debris was 125 μJ and lasted a duration of 207 μsec. The debris was a few strands of aluminum wool placed between the HiZ terminal and the shield terminal of fuel probe F44. This was the maximum energy calculated for any debris condition for this investigation. Figure 3 shows the waveform for the voltage at the switch and the current waveforms for the Engine No. 1 Hydraulic Valve during the turn-off for this debris transient. Figure 4 shows the voltage waveform from HiZ terminal to Shield off fuel probe F44, the current waveform for the current passing through the debris, the voltage and current waveforms for the Engine No. 1 Hydraulic Valve during the turn-off for this debris transient.

Table 1: Engine No. 1 Hydraulic Valve Maximum Peak Voltages on Fuel Probes for No Debris Conditions

Fuel Probes	HiZ Terminal of Fuel Probe to SCWT[1] (V Peak)	LoZ Terminal of Fuel Probe to SCWT (V Peak)	Shield Terminal of Fuel Probe to SCWT (V Peak)	HiZ Terminal to Shield Terminal of Fuel Probe (V Peak)	LoZ Terminal to Shield Terminal of Fuel Probe (V Peak)	HiZ Terminal to LoZ Terminal of Fuel Probe (V Peak)
F 36	157	137	170	10	27	31
F 40	164	124	175	12	79	76
F 42	154	143	157	11	40	44
F 44	158	130	163	13	69	69

NOTE: (1) SCWT - Simulated Center Wing Tank.

Table 2: Maximum Energy and Duration Calculated for the Debris Conditions of Aluminum Wool Placed between Terminal and Probe as Debris

Fuel Probes	Aluminum Wool Debris from HiZ Terminal of Fuel Probe to SCWT[1]	Aluminum Wool Debris from LoZ Terminal of Fuel Probe to SCWT	Aluminum Wool Debris from Shield Terminal of Fuel Probe to SCWT	Aluminum Wool Debris from HiZ Terminal to Shield Terminal of Fuel Probe	Aluminum Wool Debris from LoZ Terminal to Shield Terminal of Fuel Probe	Aluminum Wool Debris from HiZ Terminal to LoZ Terminal of Fuel Probe
F 36	87 μJ / 446 μsec	71 μJ / 250 μsec	23 μJ / 187 μsec	28 μJ /189 μsec	N/A	98 μJ /221 μsec
F 40	36 μJ /249 μsec	51 μJ /200 μsec	19 μJ / 199 μsec	16 μJ / 182 μsec	28 μ / 256 μsec	26 μJ / 181 μsec
F 42	17 μJ / 106 μsec	11 μJ / 18 μsec	25 μJ / 166 μsec	28 μJ / 227 μsec	24 μJ / 180 μsec	7 μJ / 27 μsec
F 44	74 μJ / 171 μsec	78 μJ / 214 μsec	24 μJ / 198 μsec	125 μJ / 207 μsec	N/A	23 μJ / 182 μsec

NOTE: (1) SCWT - Simulated Center Wing Tank.

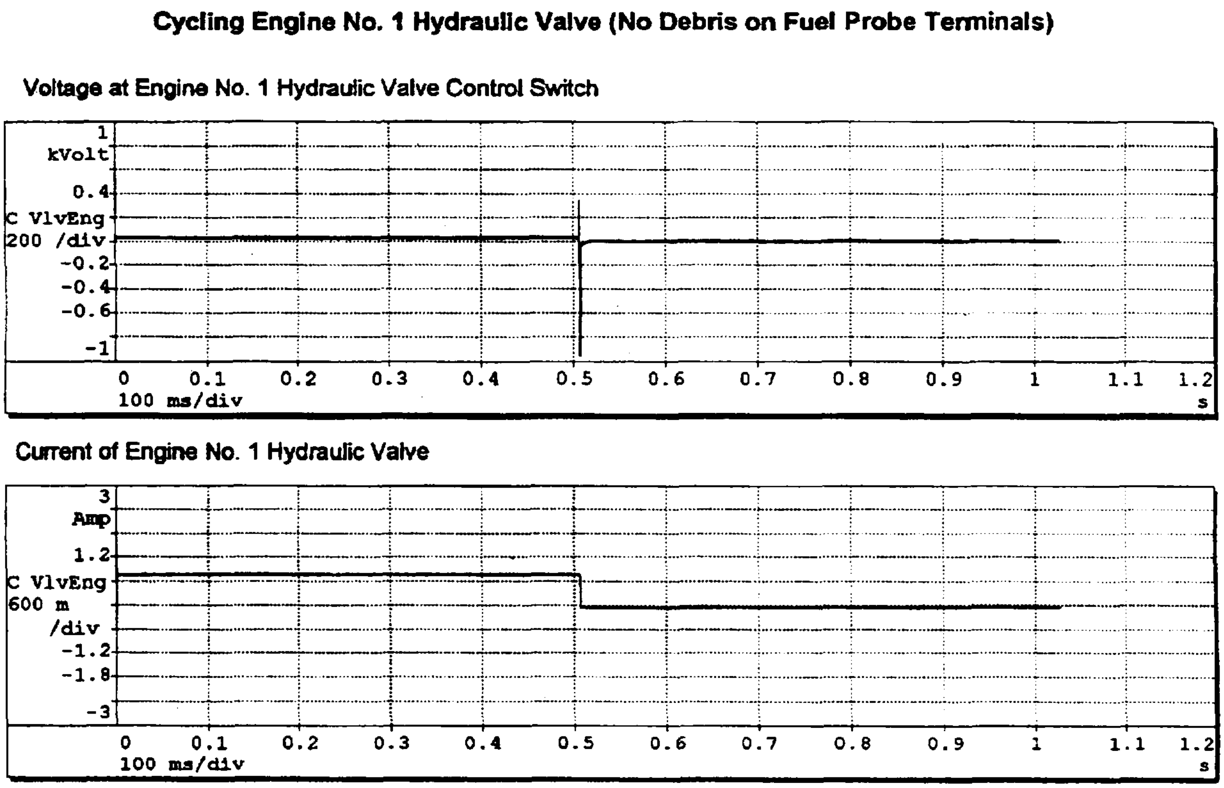
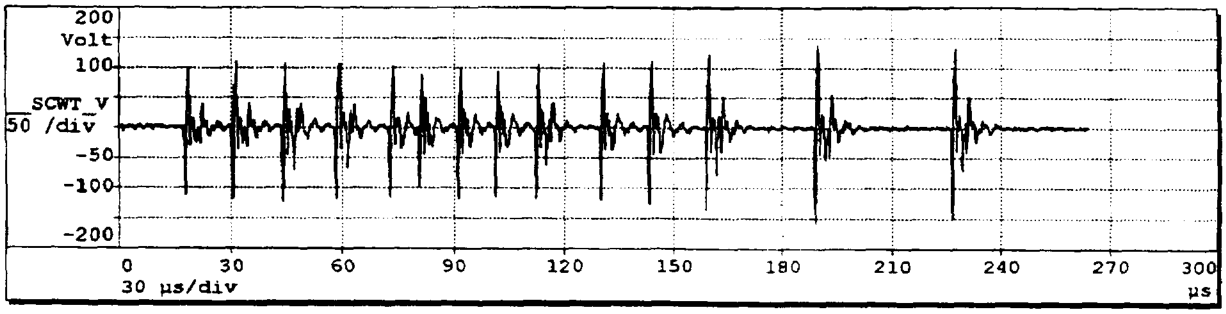


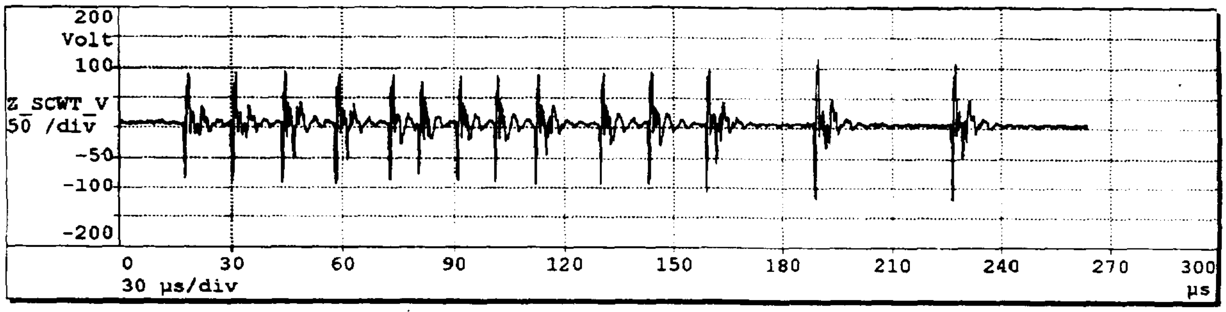
Figure 1: Voltage and Current at Control Switch during a Turn-Off of Engine No. 1 Hydraulic Valve

Switching Off of Engine No. 1 Hydraulic Valve (No Debris)

Voltage from HiZ to Simulated Center Wing Tank for Fuel Probe F44



Voltage from LoZ to Simulated Center Wing Tank for Fuel Probe F44



Voltage from Shield to Simulated Center Wing Tank for Fuel Probe F44

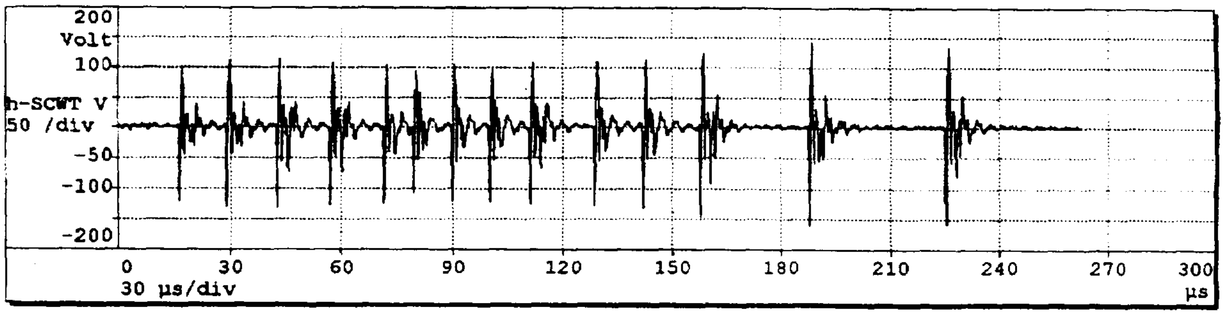


Figure 2: Voltages from Fuel Probe F44 Terminals to Simulated Center Wing Tank during a Turn-Off of Engine No. 1 Hydraulic Valve

Switching Of Engine No. 1 Hydraulic Valve

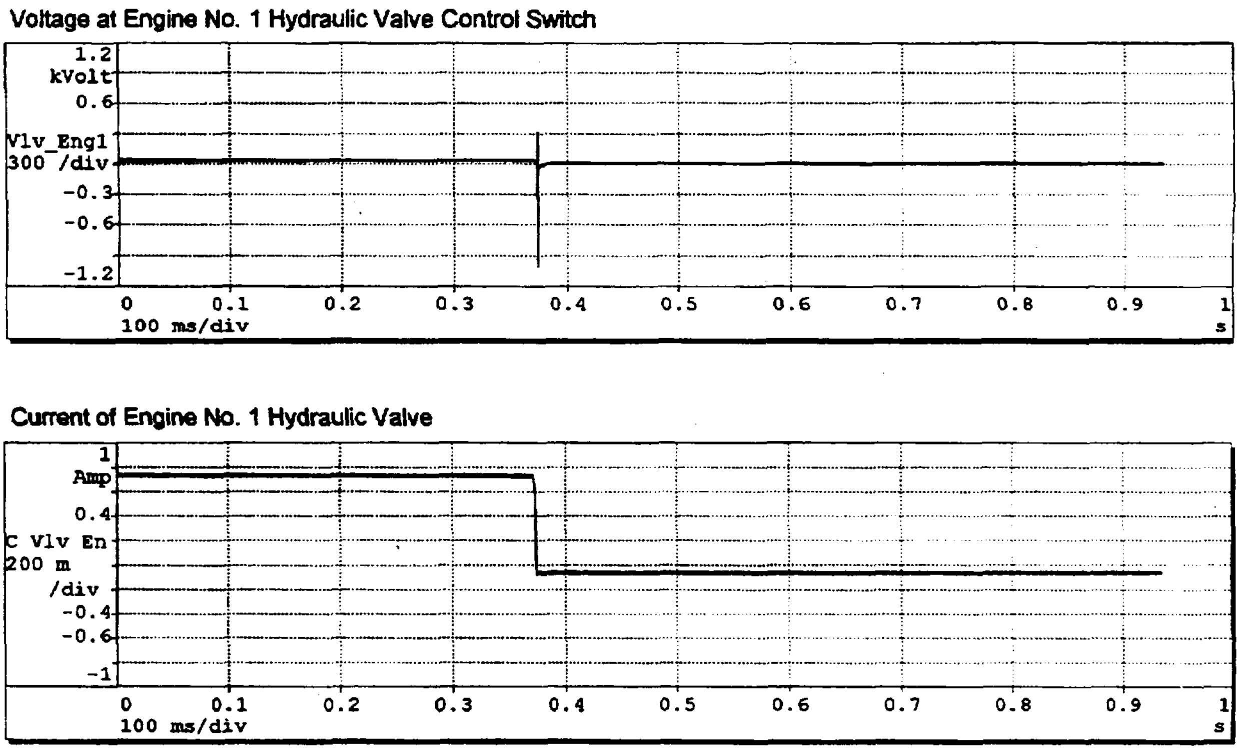


Figure 3: Voltage and Current at Control Switch during Turn-Off of Engine No. 1 Hydraulic Valve with Debris from HiZ Terminal to Shield of Fuel Probe 44

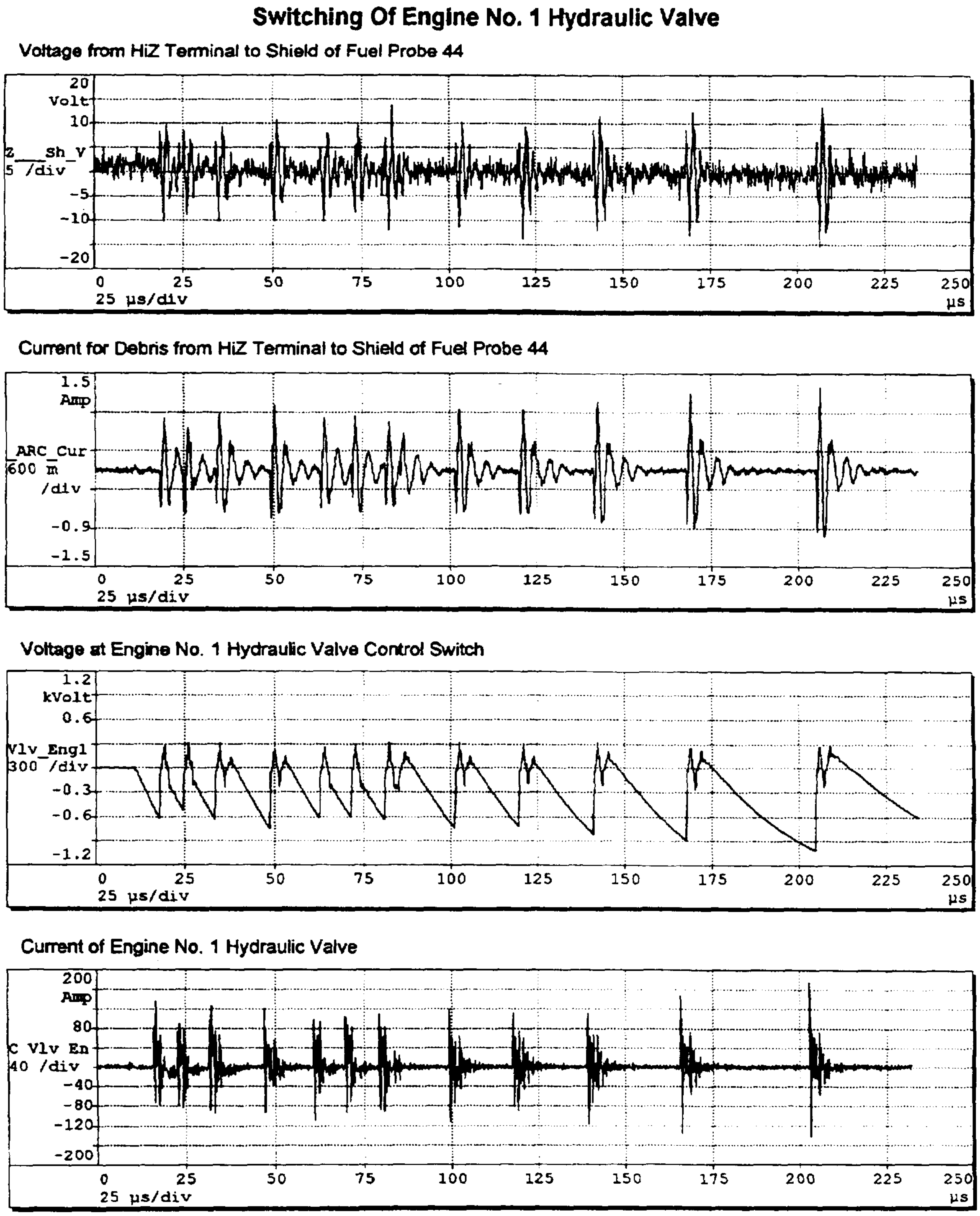


Figure 4: Voltage from HiZ Terminal to Shield of Fuel Probe F44, Current through Debris Placed between HiZ Terminal and Shield of Fuel Probe F44, Voltage at Control Switch of Engine No. 1 Hydraulic Valve, and Current of Engine No. 1 Hydraulic Valve during Turn-Off of Engine No. 1 Hydraulic Valve

AUXILIARY POWER UNIT FUEL BOOST PUMP AND AUXILIARY POWER UNIT FUEL SHUTOFF VALVE

36. The results of cycling the APU Boost Pump test are shown in tables E-5 and E-6. The maximum voltage transient recorded for the no debris condition was 68 V peak measured on fuel probe F44 between the LoZ terminal of the fuel probe and the simulated wing tank. The maximum energy calculated for a transient through debris was 73 μJ and lasted a duration of 390 μsec. The debris was a few strands of aluminum wool placed between the HiZ terminal and the Shield terminal of fuel probe F44.

NO. 1 FUEL CROSSFEED VALVE

37. The results of cycling No. 1 Fuel Crossfeed Valve test are shown in table E-7. The maximum voltage transient recorded for the no debris condition was 142 V peak measured on fuel probe F44 between the Shield terminal of the fuel probe and the simulated wing tank. The maximum energy calculated for a transient through debris was 21 μJ and lasted a duration of 29 μsec. The debris was a few strands of aluminum wool placed between the HiZ terminal of fuel probe F44 and the simulated center wing tank.

SCAVENGE PUMP

38. The results of cycling the Scavenge Pump test are shown in tables E-8 and E-9. The maximum voltage transient recorded for the no debris conditions was 88 V peak measured on fuel probe F44 between the Shield terminal of the fuel probe and the simulated wing tank. No significant differences were noted in the transients produced by either Smiths gauges and totalizer or Honeywell gauges and totalizer. The maximum energy for transients through debris could not be calculated due to the high background noise of the current measurement. Instrumentation was changed subsequent to the Scavenge Pump test to eliminate these problems. The longest transient for the Scavenge Pump test lasted 563 μsec.

BUS TRANSFERS

39. The results of the Bus Transfer are shown in table E-10. The maximum voltage transient recorded for the no debris condition was 18 V peak measured on fuel probe F36 between the LoZ terminal of the fuel probe and the simulated wing tank. The maximum energy for transients through debris could not be calculated due to the high background noise of the current measurement. Instrumentation was changed subsequent to the Scavenge Pump test to eliminate these problems. The longest transient for the Bus Transfer tests lasted 1,040 μsec.

LAVATORY FLUSH MOTORS

39. The results of cycling the Lavatory Flush Motors for lavatory M and N test are shown in table E-11. The maximum voltage transient recorded for the no debris condition was 10 V peak measured on fuel probe F36 between the Shield terminal of the fuel probe and the simulated

center wing tank. The debris conditions and thus the energy calculation were not performed because of the low voltage levels in the no debris tests. The longest transient for the Lavatory Flush Motors test lasted 114 μsec.

OTHER AIRCRAFT LOADS

41. None of the aircraft loads listed below resulted in voltage transient large enough to trigger event markers on the digital oscilloscope.

a. Aft Galley Ovens

b. No. 1 Main Aft Boost Pump

c. No. 2 Main Aft Boost Pump

d. No. 3 Main Forward Boost Pump

e. No. 4 Main Forward Boost Pump

f. Center Wing Tank Left Override/Jettison Pump

g. Reserve Tank Transfer Valve No. 1

h. Left Outflow Valve

i. Left Aileron Trim Motor

CABLE CUTS/CRUSHES

42. The maximum current for the cable cuts/crush tests was 660 amps on phase B of the bundle for the second cut/crush test. The maximum voltage transient recorded was 33 V peak measured on fuel probe F44 between the LoZ terminal of the fuel probe and the simulated wing tank.

PARAMETRIC SPACING TESTS

43. The maximum peak voltage transients recorded for the Parametric Spacing test on fuel probe F44 for the various spacing between the load wire and the FQIS wiring are listed below. All the maximum voltages for the fuel probe occurred from the HiZ terminal to the simulated center wing tank.

a. 0 in. 124 V peak

b. 1/4 in. 71 V peak

c. 1/2 in. 73 V peak

d. 1 in. 52 V peak

e. 2 in. 48 V peak

f. 4 in. 46 V peak

COCKPIT VOICE RECORDER VOLTAGE HARMONICS

44. The results of CVR Voltage Harmonic Spectrum measurements taken at the input to the Captain's channel are listed in table F-1. The spectrum plots are shown in figures F-1 through F-85. The THD of the base load condition of the voltages measured at the CVR Captain's channel input were 33.13% and 33.78%. The electrical load conditions that resulted in a reduction in the THD voltages measured at the CVR Captain's channel input are listed below.

a. All GCB's Closed, No Emergency Lights (Spectrum taken immediately after closing GCB's), THD 12.25%

b. All GCB's Closed (Spectrum taken immediately after closing breakers), THD 12.09%

c. Breaker Pulled for TRU2, THD 12.30% and THD 12.09%

d. Essential Power Selector to BUS 3, THD 11.98%

e. Essential Power Selector to BUS 2, THD 12.48%

f. Essential Power Selector to BUS 1, THD 12.51%

g. All TRU Breakers Pulled, THD 18.72% and THD 18.86%

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REFERENCES

1. Typical Flammability and Ignition Properties of Aircraft Fuels, Aviation Fuel Properties Handbook, of 1983.

2. Boeing 747 Maintenance Manual for Trans World Airlines, Inc., Boeing Doc No. DG-30002, of 25 Apr 1993.

3. Boeing Aircraft Company Letter No: B-B600-16330-ASI, "FQIS EMC Transient Test, TWA 747-100, N93119 Accident off Long Island, New York – 17 July 1996", of 19 Jan 1998.

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GLOSSARY

A	ampere
AC	alternating current
ADB	Aircraft Discrepancy Book
Amp-hr	amp-hour
APU	auxiliary power unit
AWG	american wire gauge
BTB	bus transfer breaker
CVR	cockpit voice recorder
CWT	center wing tank
DC	direct current
dB	decibel
EPSD	Electrical Power Systems Division
FAA	Federal Aviation Administration
FQIS	Fuel Quantity Indication System
ft	feet
GCB	generator circuit breaker
HF	high frequency
Hz	hertz (cycles per second)
in.	inch(es)
kHz	kilohertz
kS/s	kilo-Samples per second
kV	kilovolt
kVA	kilovolt Amp
MHz	megahertz
μJ	micro-Joules
μsec	microseconds
MΩ	megaohms
Ms	millisecond
MS/s	Mega-Samples per second
NAWCAD	Naval Air Warfare Center Aircraft Division
NTSB	National Transportation Safety Board
SCWT	simulated center wing tank
SH	shield
SSB	split system breaker
THD	total harmonic distortion
TRU	transformer rectifier unit
TWA	Trans World Airlines, Inc.
V	volt(s)
VA	volt ampere
VAC	volts alternating current
VDC	volts direct current
VHF	very high frequency

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APPENDIX A
FUEL QUANTITY INDICATION SYSTEM WIRING

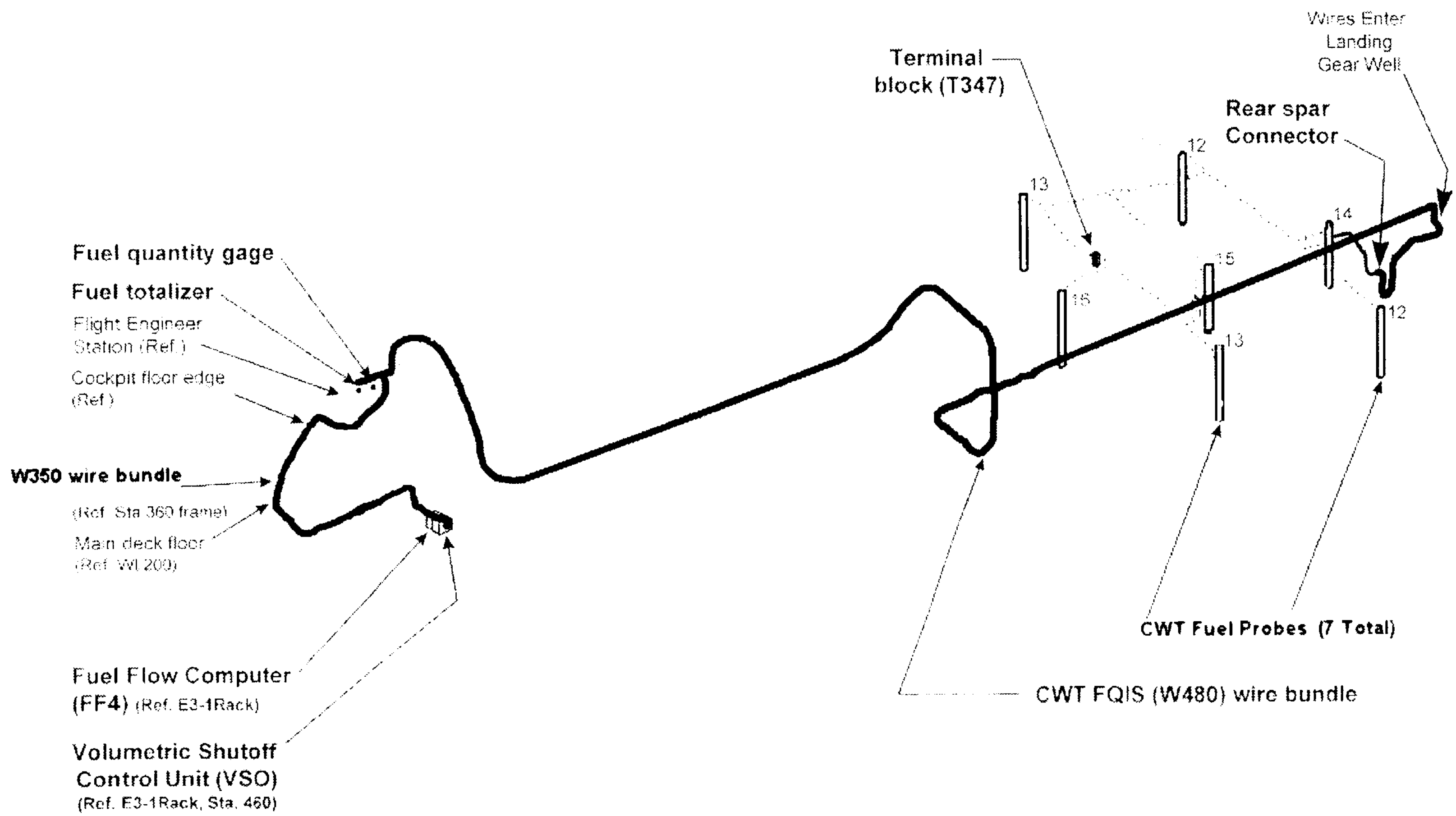

Figure A-1: FQIS Wiring Locations

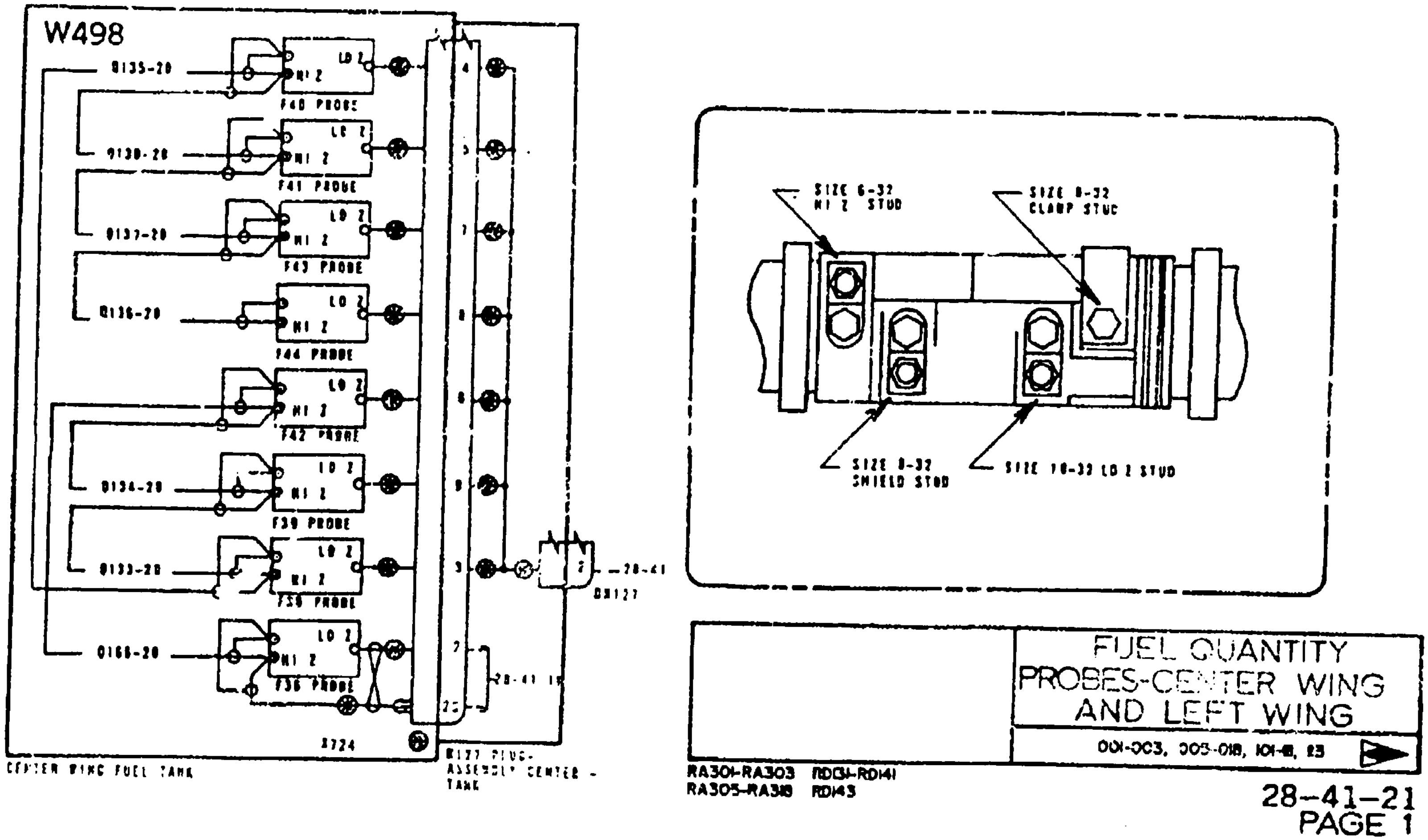

Figure A-2: Center Wing Tank Fuel Probe Connections and Terminals

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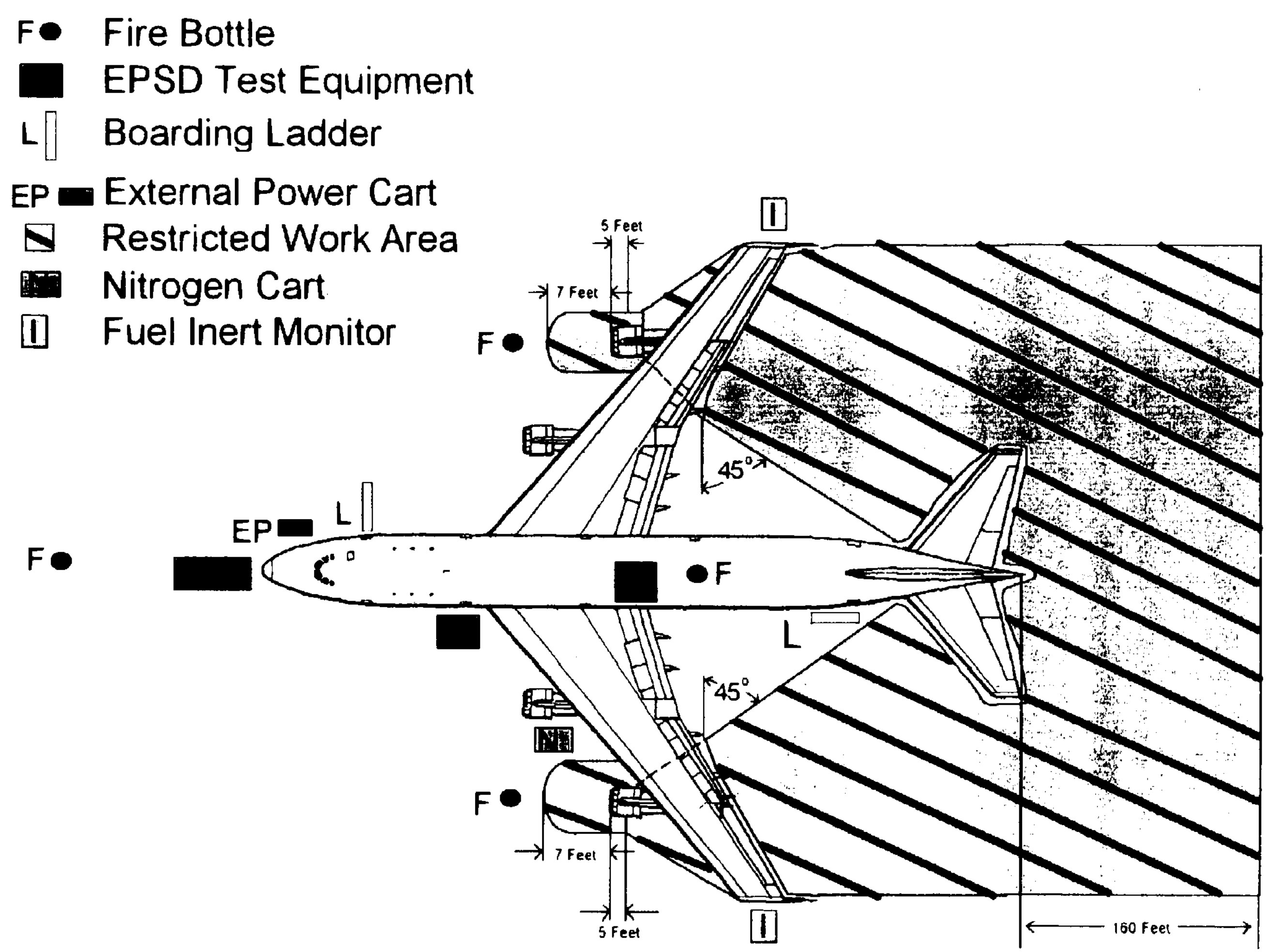
APPENDIX B
EQUIPMENT AND PERSONNEL TEST LOCATIONS



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APPENDIX C
FUEL TANK INERTING PROCEDURE

PROCEDURE OVERVIEW

The fuel tank inerting procedure is designed to render all of the test aircraft's fuel tanks inert to lower the potential for explosions. The procedure will use the pressure refueling lines to deliver the gaseous nitrogen to each fuel tank.

A standard refueling nozzle has been adapted to accept a pressurized nitrogen line. The refueling nozzle will be connected to the refueling receptacle in the aircraft, and the nitrogen will flow through the refueling lines in the tanks in the same fashion as fuel does during normal refueling. The gaseous nitrogen will be delivered at a pressure of approximately 1.5 psig.

Manual override of the refueling valves will be used in the system to allow for refueling a specific tank while excluding the others. These valves will be used to direct nitrogen to each tank individually during the initial inerting, and also to direct nitrogen to all of the tanks during the tests. As the nitrogen is delivered to the fuel tanks, the fuel/air vapors will be driven out of the tanks through the aircraft's vent system. The vent lines for each tank run to a surge tank where they combine to exit the aircraft through a single line. The output for this line is on the underside of the wing, near the wingtip. There is a vent system output port at each wingtip. The flow coming out of this vent system output port will be monitored for oxygen content, and the tanks will be considered to be inert once the oxygen concentration drops below 9% (it is desired to lower the oxygen level to 5%). In addition, the total volume of nitrogen put into the tank will be measured, and it is expected that 1 to 1.5 complete, empty tank volumes of nitrogen will be required for each tank to reach the 5% oxygen concentration level.

The tanks will be continuously inerted during the tests by a continuous flow of nitrogen into the tanks. The continuous flow will be metered to provide the volume necessary to make up for the fuel burned while the engines are running. A minimum flow calibration procedure will be performed to calibrate each refueling valve's minimum flow condition. A member of the test team will be designated the "inerting system monitor" and will be tasked with monitoring the oxygen concentration in the vent system output ports prior to each test.

GENERAL SYSTEM DESCRIPTION: PRESSURE FUELING SYSTEM

(Note: This is the general system description of the pressure fueling system. It discusses aspects of the system as they relate to normal pressure fueling. In most cases, changing the context from Jet-A refueling to nitrogen inerting will lead to the proper system description.)

The pressure fueling system provides a rapid means of filling the fuel tanks in the airplane. The system distributes fuel under pressure from a fueling station in each wing to the tanks through manifolds and refuel valves. The refuel valves allow fuel to flow from the main distribution manifold into the tanks. Refuel valves are installed as follows: one in each reserve and outboard tank; two in each of the inboard main and the center wing tanks.

The fueling station is equipped with two fueling receptacles coupled together to a manifold that extends through the outboard main tank to the main distribution manifold. Each receptacle incorporates a manual shutoff valve. The fueling station in the left wing is provided with a control panel consisting of fueling quantity (repeater) indicators, refuel valve control switches, valve position indicator lights, a refuel power switch, and a test switch for the volumetric shutoff control unit, and indicators. A proximity switch is actuated by the door to cut off all power to the panel when the door is closed.

The fueling receptacles provide a means of connecting ground refueling hose nozzles to the pressure fueling system. Two receptacles at each fueling station are mounted on the front spar forward face. Each receptacle consists of a fueling nozzle adapter, a cast aluminum elbow, a cap, a spring-loaded check valve and a manual shutoff valve attached to the spar and connected to the manifold. The fueling nozzle adapter has mating lugs that couple with and secure the fueling hose.

When the hose nozzle is coupled to the adapter, the spring-loaded check valve is lifted to a position that allows the hose nozzle to lock in place. During pressure fueling, the check valve opens only when nozzle fuel pressure is greater than receptacle manifold pressure. (Depending on the cracking pressure for this valve, it may or may not open during inerting operations at relatively low pressures. If the nitrogen delivery pressure is insufficient to open the check valve, the receptacle may be put in the defuel configuration (lift lever on popet up), and the check valve will be open as soon as the refuel nozzle is inserted. Care must be taken, however, since this means that if the tank fuel level is above the height of the refuel valve, fuel back flow can occur. The fuel levels in the individual tanks must be monitored to make sure that they do not exceed the level of the refuel valve to prevent back flow.)

The refueling manifold distributes fuel to all tanks during a pressure fueling operation. The manifold consists of two crossover manifolds and main distribution manifold; the main distribution manifold is also used as the fuel jettison manifold. The crossover manifolds extend from the fueling receptacles at the front spar through outboard main tanks to the main distribution manifold. The main distribution manifold is routed inside the fuel tank area with solenoid-controlled refuel valves installed in each tank. Manual override of the valve is provided in the event of valve failure during fueling operation. The refuel valve can be opened or closed manually by turning the valve override screw up to 10 - 13 complete revolutions in the direction indicated on the override screw retainer (clockwise to close/counterclockwise to open). Note that fuel pressure should be removed from the fuel manifold during the opening/closing of the refueling valves in manual override.

MINIMUM FLOW CALIBRATION TESTS

This test is required to document the minimum number of turns on the manual override of the refueling valves that are required to achieve a minimum flow condition. The minimum flow condition is important for the continuous inerting phase of the inerting operations. Each refueling valve will be opened individually, and flow will be checked to determine if nitrogen will flow. The actual flow rate demonstrated in that condition will be recorded.

The procedure is as follows:

a. Remove fueling receptacle caps.

b. Connect test fueling nozzle to fueling receptacles at left wing station.

c. Open test fueling nozzle manual shutoff valve

d. Open manual shutoff valve at fueling receptacles.

e. Note: All BA airplanes are equipped with a refuel system left to right isolation valve. This valve will need to be opened prior to inerting fuel tanks on the opposite side of whichever refuel receptacle is used.

f. Manually open (or increase the opening of the) applicable refuel valve.

    (1) Verify fueling manifold has been depressurized.

    (2) Remove lockwire from knurled knob of valve override screw (if applicable). Note: Do not remove retainer plate lockwire, screws, or retainer plate.

    (3) Turn override screw (knurled knob) 1 (or one additional, as applicable) complete revolution in counterclockwise direction. Note: Pliers may be required to initially loosen override screw and to overcome increasing poppet spring pressure.

g. Start flow of nitrogen.

h. Note: Nitrogen will also flow through the manifold drain lines into the inboard main tanks

i. Monitor nitrogen supply flow meter. If nitrogen is flowing, test is complete for that valve. Record flow rate. If nitrogen is not flowing, turn off nitrogen supply and return to step f.

j. Stop flow of nitrogen.

k. Manually close applicable refuel valve.

(1) Verify fueling manifold has been depressurized.

(2) Turn override screw (knurled knob) as required in clockwise direction. Note: Pliers may be required to initially loosen override screw and to overcome increasing poppet spring pressure.

(3) Lockwire knurled knob of valve override screw. (May be omitted if further inerting operations are planned).

l. Move to the next applicable refuel valve. Continue repeating the procedure until all of the tanks have been inerted.

m. Close manual shutoff valves.

n. Disconnect fueling hose nozzles.

o. Install fueling receptacle caps.

GENERAL INERTING PLANS

The aircraft will be inerted during several discrete operations:

a. Initial inerting - conducted to get the tanks to an initial level of inerting. This procedure will be accomplished the night before testing is scheduled to begin.

b. Follow-up inerting - conducted each morning prior to the resumption of testing.

c. Continuous inerting - conducted while the tests are ongoing.

The procedures for each of these operations are as follows:

Note: To minimize the potential for static buildup, standard grounding procedures will be followed for inerting operations. The aircraft, nitrogen source, and nitrogen supply lines will all be grounded and bonded to each other as if it were an actual refueling operation.

a. Inerting Procedures:

(1) Initial inerting procedure.

(a) Remove fueling receptacle caps.

(b) Connect test fueling nozzle to fueling receptacle at left wing station.

(c) Open test fueling nozzle manual shutoff valve.

(d) Open manual shutoff valves at fueling receptacles.

(e) Note: All BA airplanes are equipped with a refuel system left to right isolation valve. This valve will need to be opened prior to inerting fuel tanks on the opposite side of whichever refuel receptacle is used.

(f) Manually open applicable refuel valve.

1. Verify fueling manifold has been depressurized.

2. Remove lockwire from knurled knob of valve override screw. Note: Do not remove retainer plate lockwire, screws, or retainer plate.

3. Turn override screw (knurled knob) 10-13 complete revolutions in counterclockwise direction. Note: Pliers may be required to initially loosen override screw and to overcome increasing poppet spring pressure.

(g) Start flow of nitrogen.

(h) Monitor oxygen concentration of vent outflow ports.

(i) When oxygen concentration falls below 9%, continue flow for an additional 10 min or until the oxygen concentration falls below 5%. Note that the amount of nitrogen introduced into the tank should equal 1-1.5 times the empty volume of the tank. (Note: Some of this nitrogen flow will be going to the inboard main tanks through the refuel manifold drain lines.

(j) Stop flow of nitrogen.

(k) Manually close applicable refuel valve.

1. Verify fueling manifold has been depressurized.

2. Turn override screw (knurled knob) 10-13 complete revolutions in clockwise direction. Note: Pliers may be required to initially loosen override screw and to overcome increasing poppet spring pressure.

3. Lockwire knurled knob of valve override screw. (May be omitted if further inerting operations are planned).

(l) Note: All BA airplanes are equipped with a refuel system left to right isolation valve. This valve will need to be opened prior to inerting fuel tanks on the opposite side of whichever refuel receptacle is used.

(m) Move to the next applicable refuel valve. Continue repeating the procedure until all of the tanks have been inerted.

(n) Close manual shutoff valves.

(o) Disconnect fueling hose nozzles.

(p) Install fueling receptacle caps.

b. Follow-up Inerting Procedures:

(1) Remove fueling receptacle caps.

(2) Connect test fueling nozzles to fueling receptacle at left wing station.

(3) Open test fueling nozzle manual shutoff valve.

(4) Open manual shutoff valves at fueling receptacles.

(5) Note: All BA airplanes are equipped with a refuel system left to right isolation valve. This valve will need to be opened prior to inerting fuel tanks on the opposite side of whichever refuel receptacle is used.

(6) Manually open applicable refuel valve.

(a) Verify fueling manifold has been depressurized.

(b) Remove lockwire from knurled knob of valve override screw (if applicable). Note: Do not remove retainer plate lockwire, screws, or retainer plate.

(c) Turn override screw (knurled knob) 10-13 complete revolutions in counterclockwise direction. Note: Pliers may be required to initially loosen override screw and to overcome increasing poppet spring pressure.

(7) Start flow of nitrogen.

(8) Monitor oxygen concentration of vent outflow ports.

(9) Continue flow of nitrogen until oxygen concentration falls below 5% desired, 9% required.

(10) Stop flow of nitrogen.

(11) Manually close applicable refuel valve.

(a) Verify fueling manifold has been depressurized.

(b) Turn override screw (knurled knob) 10-13 complete revolutions in clockwise direction. Note: Pliers may be required to initially loosen override screw and to overcome increasing poppet spring pressure.

(c) Lockwire knurled knob of valve override screw. (May be omitted if further inerting operations are planned).

(12) Move to the next applicable refuel valve. Continue repeating the procedure until all of the tanks have been inerted.

(13) Prepare for continuous inerting procedure.

c. Continuous Inerting Procedures:

(1) Ensure that the manual shutoff valve at fueling receptacle is in the open position.

(2) Manually open each refuel valve.

(a) Verify fueling manifold has been depressurized.

(b) Remove lockwire from knurled knob of valve override screw (if applicable). Note: Do not remove retainer plate lockwire, screws, or retainer plate.

(c) Turn override screw (knurled knob) in counterclockwise direction to achieve minimum flow condition as found in minimum flow calibration tests. Note: Pliers may be required to initially loosen override screw and to overcome increasing poppet spring pressure.

(3) Note: All BA airplanes are equipped with a refuel system left to right isolation valve. This valve will need to be opened prior to inerting fuel tanks on the opposite side of whichever refuel receptacle is used.

(4) Start flow of nitrogen.

(5) Monitor oxygen concentration of vent outflow ports.

(6) Ensure that oxygen concentration stays below 9%. If oxygen concentration increases above 9%, stop tests. Since the oxygen monitors are only registering the oxygen concentration in the combined vent system output, all of the tanks must be rechecked to ensure total inerting of the aircraft. Repeat follow-on inerting procedure until the oxygen concentration in all tanks has been lowered below 9%. As a precaution, when oxygen concentration reaches 7%, increase the flow of nitrogen by increasing the supply pressure.

(7) Once testing is complete, stop flow of nitrogen.

(8) Manually close applicable refuel valves.

(a) Verify fueling manifold has been depressurized.

(b) Turn override screw (knurled knob) as required in clockwise direction. Note: Pliers may be required to initially loosen override screw and to overcome increasing poppet spring pressure.

(c) Lockwire knurled knob of valve override screw. (May be omitted if further inerting operations are planned).

(9) Close manual shutoff valves.

(10) Disconnect fueling hose nozzle.

(11) Install fueling receptacle caps.

BOEING 747
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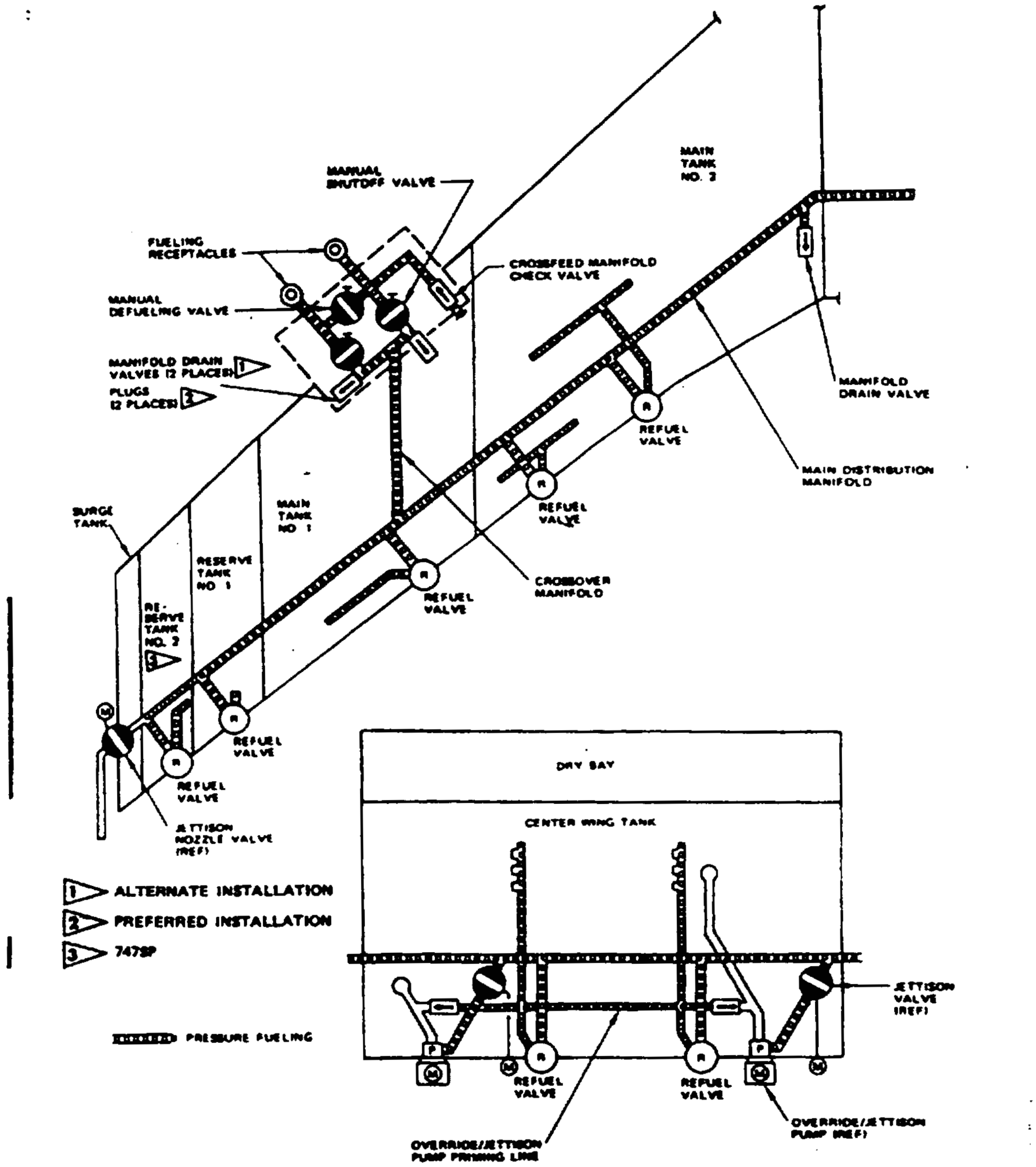

Pressure Fueling Flow Diagram
Figure 6

EFFECTIVITY ALL

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LEFT WING FUEL PRESSURE FILLING SYSTEM DIAGRAM

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APPENDIX D
LOADS FOR CABLE CUT/CRUSH TESTS

Wire No.	Wire Size	Circuit Breaker Rating	Power	Phase	Load Current	Low Impedance Ohms	Resistance/Reactance	Watts or VA
1	12			A	8.65 A	13.3 Ohms	5.29 mH	995 VA
2	12	3-phase 20 amp	3-phase 115 VAC	B	8.65 A	13.3 Ohms	5.29 mH	995 VA
3	12			C	8.65 A	13.3 Ohms	5.29 mH	995 VA
4	14			A	6.00 A	19.2 Ohms	7.63 mH	690 VA
5	14	3-phase 10 amp	3-phase 115 VAC	B	6.00 A	19.2 Ohms	7.63 mH	690 VA
6	14			C	6.00 A	19.2 Ohms	7.63 mH	690 VA
7	16			A	4.50 A	25.6 Ohms	10.17 mH	518 VA
8	16	3-phase 7.5 amp	3-phase 115 VAC	B	4.50 A	25.6 Ohms	10.17 mH	518 VA
9	16			C	4.50 A	25.6 Ohms	10.17 mH	518 VA
10	16	7.5 amp	Single 115 VAC	A	2.95 A	39.0 Ohms	39.0 Ohms	339 W
11	16	7.5 amp	28 VDC	+	2.80 A	10.0 Ohms	10.0 Ohms	322 W
12	16	7.5 amp	28 VDC	+	Unk	Relay	Relay	Unknown
13	18			A	3.00 A	38.3 Ohms	15.25 mH	345 VA
14	18	3-phase 7.5 amp	3-phase 115 VAC	B	3.00 A	38.3 Ohms	15.25 mH	345 VA
15	18			C	3.00 A	38.3 Ohms	15.25 mH	345 VA
16	18			A	2.00 A	57.5 Ohms	22.88 mH	230 VA
17	18	3-phase 5 amp	3-phase 115 VAC	B	2.00 A	57.5 Ohms	22.88 mH	230 VA
18	18			C	2.00 A	57.5 Ohms	22.88 mH	230 VA
19	18	5 amp	Single 115 VAC	A	2.50 A	46.0 Ohms	18.30 mH	288 VA
20	18	5 amp	Single 115 VAC	B	2.45 A	47.0 Ohms	47.0 Ohms	281 W
21	18	5 amp	Single 115 VAC	C	0.00 A	Open	Open	N/A
22	18	5 amp	28 VDC	+	2.80 A	10.0 Ohms	10.0 Ohms	322 W
23	18	2.5 amp	28 VDC	+	Unk	Relay	Relay	Unknown
24	18	2.5 amp	28 VDC	+	0.00 A	Open	Open	N/A
25	20			A	2.00 A	57.5 Ohms	22.88 mH	230 VA
26	20	3-phase 3 amp	3-phase 115 VAC	B	2.00 A	57.5 Ohms	22.88 mH	230 VA
27	20			C	2.00 A	57.5 Ohms	22.88 mH	230 VA
28	20	2.5 amp	Single 115 VAC	A	2.00 A	57.5 Ohms	22.88 mH	230 VA
29	20	2.5 amp	Single 115 VAC	B	1.00 A	115.0 Ohms	45.76 mH	115 VA
30	20	2.5 amp	Single 115 VAC	C	0.96 A	120.0 Ohms	120.0 Ohms	110 W
31	20	1 amp	Single 115 VAC	A	0.51 A	225.0 Ohms	225.0 Ohms	59 W
32	20	1 amp	Single 115 VAC	B	0.00 A	Open	Open	N/A
33	20	2.5 amp	28 VDC	+	0.50 A	Relay	Relay	Unknown
34	20	2.5 amp	28 VDC	+	0.50 A	Relay	Relay	Unknown
35	20	2.5 amp	28 VDC	+	0.00 A	Open	Open	N/A
36	20	1 amp	28 VDC	+	0.00 A	Open	Open	N/A

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APPENDIX E
ENERGY MEASUREMENTS AT FUEL PROBES FOR LOAD SWITCHINGS

Table E-1: Engine No. 1 Hydraulic Valves, Load Switching Event 3

Generators 1 and 4 - Honeywell Gauges

Fuel Probe F36	No Debris	Debris HiZ-to-SCWT[(1)]	Debris LoZ-SCWT	Debris Shield-SCWT	Debris HiZ-Shield	Debris LoZ-Shield	Debris HiZ-LoZ
Maximum Peak Voltage at Fuel Probe (V)	170	47	106	37	41	10	31
Location of Maximum Peak Voltage	Shield-SCWT	LoZ-SCWT	LoZ-SCWT	LoZ-SCWT	HiZ-LoZ	HiZ-LoZ	HiZ-LoZ
Maximum Peak Current at Debris (mAmp)	N/A	1072	1302	1218	498	502	598
Maximum Energy Dissipated at Debris (μJ)	N/A	87	71	23	N/A	28	98
Maximum Duration (μsec)	370	390	267	185	224	192	1,720
Minimum Duration (μsec)	147	156	153	185	84	59	105
Maximum Peak Voltage across Load Switch (V)	1,050	406	1,189	1,102	1,090	350	1,146
Maximum Peak Current of Load (amp)	10	134	161	134	179	76	167

NOTE (1) SCWT - Simulated Center Wing Tank

Table E-2: Engine No. 1 Hydraulic Valve, Load Switching Event 3

Generators 1 and 4 - Honeywell Gauges

Fuel Probe F40	No Debris	Debris HiZ-to-SCWT[(1)]	Debris LoZ-SCWT	Debris Shield-SCWT	Debris HiZ-Shield	Debris LoZ-Shield	Debris HiZ-LoZ
Maximum Peak Voltage at Fuel Probe (V)	175	58	122	54	62	14	11
Location of Maximum Peak Voltage	Shield-SCWT	LoZ-SCWT	HiZ-SCWT	LoZ-SCWT	HiZ-LoZ	HiZ-LoZ	HiZ-LoZ
Maximum Peak Current at Debris (mAmp)	N/A	992	1328	998	528	882	762
Maximum Energy Dissipated at Debris (μJ)	N/A	36	51	19	28	25	16
Maximum Duration (μsec)	202	248	739	206	163	232	161
Minimum Duration (μsec)	111	29	32	108	11	65	13
Maximum Peak Voltage across Load Switch (V)	1,196	1,137	1,051	109	1,075	1,078	1,027
Maximum Peak Current of Load (amp)	152	163	178	159	165	169	187

NOTE (1) SCWT - Simulated Center Wing Tank

Table E-3: Engine No. 1 Hydraulic Valve, Load Switching Event 3

Generators 1 and 4 - Honeywell Gauges

Fuel Probe F42	No Debris	Debris HiZ-to-SCWT(1)	Debris LoZ-SCWT	Debris Shield-SCWT	Debris HiZ-Shield	Debris LoZ-Shield	Debris HiZ-LoZ
Maximum Peak Voltage at Fuel Probe (V)	157	42	92	38	49	11	20
Location of Maximum Peak Voltage	Shield-SCWT	LoZ-SCWT	-	LoZ-SCWT	HiZ-LoZ	LoZ-shld	LoZ-Shield
Maximum Peak Current at Debris (mAmp)	N/A	1,035	1,112	1,195	530	1,037	797
Maximum Energy Dissipated at Debris (μJ)	N/A	17	11	25	28	24	7
Maximum Duration (μsec)	220	59	38	28	216	182	27
Minimum Duration (μsec)	69	29	29	28	83	119	15
Maximum Peak Voltage across Load Switch (V)	1,090	1,036	1,137	1,077	1,037	985	1,112
Maximum Peak Current of Load (amp)	200	168	109	157	162	143	171

NOTE (1) SCWT - Simulated Center Wing Tank

Table E-4: Engine No. 1 Hydraulic Valve, Load Switching Event 3

Generators 1 and 4 - Honeywell Gauges

Fuel Probe F44	No Debris	Debris HiZ-to-SCWT(1)	Debris LoZ-SCWT	Debris Shield-SCWT	Debris HiZ-Shield	Debris LoZ-Shield	Debris HiZ-LoZ
Maximum Peak Voltage at Fuel Probe (V)	163	197	114	48	69	127	27
Location of Maximum Peak Voltage	Shield-SCWT	Shield-SCWT	HiZ-SCWT	LoZ-SCWT	LoZ-Shield	LoZ-Shield	LoZ-Shield
Maximum Peak Current at Debris (mAmp)	N/A	773	1,300	953	150	1	N/A
Maximum Energy Dissipated at Debris (μJ)	N/A	197	78	32	7	125	23
Maximum Duration (μsec)	596	631	205	219	227	218	225
Minimum Duration (μsec)	168	187	155	187	153	167	149
Maximum Peak Voltage across Load Switch (V)	1,105	1,179	1,088	1,019	1,046	1,087	1,140
Maximum Peak Current of Load (amp)	174	182	164	172	165	177	166

NOTE (1) SCWT - Simulated Center Wing Tank

Table E-5: APU Boost Pump - Turn "On", Load Switching Event 4

Fuel Probe F44	No Debris	Debris HiZ-to-SCWT(1)	Debris LoZ-to-SCWT	Debris Shield-to-SCWT	Debris HiZ-to-Shield	Debris LoZ-Shield	Debris HiZ-LoZ
Maximum Peak Voltage at Fuel Probe (V)	68	42	31	34	42	11	15
Location of Maximum Peak Voltage	LoZ-SCWT	Loz-SCWT	Hiz-SCWT	Loz-SCWT	Hiz-Loz	LoZ - Shield	HiZ-Shield
Maximum Peak Current at Debris (mAmp)	N/A	480	507	507	933	907	987
Maximum Energy Dissipated at Debris (μJ)	N/A	20	42	19	61	N/A	N/A
Maximum Duration (μsec)	352	198	385	396	320	N/A	N/A
Minimum Duration (μsec)	352	198	385	396	320	N/A	N/A
Maximum Peak Voltage across Load Switch (V)	98	86	71	84	94	98	92
Maximum Peak Current of Load (amp)	153	149	153	154	158	170	172

NOTE (1) SCWT - Simulated Center Wing Tank

Table E-6: APU Boost Pump - Turn "Off", Load Switching Event 4

Generators 1 and 4 - Honeywell Gauges

Fuel Probe F44	No Debris	Debris HiZ-to-SCWT(1)	Debris LoZ-to-SCWT	Debris Shield-to-SCWT	Debris HiZ-to-Shield	Debris HiZ-Shield	Debris LoZ-Shield	Debris HiZ-LoZ
Maximum Peak Voltage at Fuel Probe (V)	15	14	13	15	15	24	9	14
Location of Maximum Peak Voltage	LoZ-SCWT	Loz-SCWT	Hiz-SCWT	Loz-SCWT	Loz-Shield	HiZ-LoZ	LoZ-Shield	HiZ-Shield
Maximum Peak Current at Debris (mAmp)	N/A	147	133	173	933	960	N/A	933
Maximum Energy Dissipated at Debris (μJ)	N/A	N/A	N/A	27	9	N/A	N/A	N/A
Maximum Duration (μsec)	N/A	N/A	N/A	1580	55	N/A	N/A	N/A
Minimum Duration (μsec)	N/A	N/A	N/A	1580	55	N/A	N/A	N/A
Maximum Peak Voltage across Load Switch (V)	22	11	19	47	45	75	54	46
Maximum Peak Current of Load (amp)	14	16	14	26	29	24	24	28

NOTE (1) SCWT - Simulated Center Wing Tank

Table E-7: No. 1 Fuel Crossfeed Valve, Load Switching Event 5

Generators 1 and 4 - Honeywell Gauges

Fuel Probe F44	No Debris	Debris HiZ-SCWT[1]	Debris HiZ - SCWT	Debris HiZ-SCWT	Debris HiZ-SCWT	Debris LoZ-SCWT	Debris Shield-SCWT
Maximum Peak Voltage at Fuel Probe (V)	142	N/A	272	15	31	47	32
Location of Maximum Peak Voltage	Shield-SCWT	HiZ - SCWT	LoZ-SCWT	LoZ-SCWT	LoZ-SCWT	Shield-SCWT	LoZ-SCWT
Maximum Peak Current at Debris (mAmp)	N/A	N/A	172	165	378	562	445
Maximum Energy Dissipated at Debris (μJ)	N/A	5	12	N/A	21	5	3
Maximum Duration (μsec)	69	40	34	N/A	29	38	27
Minimum Duration (μsec)	7	35	34	N/A	29	20	14
Maximum Peak Voltage across Load Switch (V)	389	101	110	82	256	292	283
Maximum Peak Current of Load (amp)	162	81	19	19	86	99	82

NOTE (1) SCWT - Simulated Center Wing Tank

Table E-8: Load Switching Event 2 Scavenge Pumps

Generators 1 and 4 - Smith Gauges

Fuel Probe F36	No Debris	Debris HiZ-to-Shield
Maximum Peak Voltage at Fuel Probe (V)	26	37
Location of Maximum Peak Voltage	LoZ-SCWT[1]	HiZ-Shield
Maximum Peak Current at Debris (mAmp)	N/A	N/A
Maximum Energy Dissipated at Debris (μJ)	N/A	N/A
Maximum Duration (μsec)	246	29
Minimum Duration (μsec)	115	58
Maximum Peak Voltage across Load Switch (V)	490	746
Maximum Peak Current of Load (amp)	10	10

NOTE (1) SCWT - Simulated Center Wing Tank

Table E-9: Load Switching Event 2 Scavenge Pumps

Generators 1 and 4 - Honeywell Gauges

Fuel Probe F40	No Debris	Debris HiZ-to-SCWT(1)	Debris LoZ-SCWT	Debris Shield-SCWT	Debris HiZ-Shield	Debris LoZ-Shield	Debris HiZ-LoZ
Maximum Peak Voltage at Fuel Probe (V)	36	38	41	36	12	7	12
Location of Maximum Peak Voltage	HiZ-LoZ	LoZ-SCWT	Shield-SCWT	LoZ-SCWT	LoZ-Shield	HiZ-Shield	LoZ-Shield
Maximum Peak Current at Debris (mAmp)	N/A	9,133	9,000	8,600	9,533	8,867	9,533
Maximum Energy Dissipated at Debris (μJ)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Maximum Duration (μsec)	130	128	191	78	N/A	N/A	N/A
Minimum Duration (μsec)	58	127	50	22	N/A	N/A	N/A
Maximum Peak Voltage across Load Switch (V)	737	727	716	662	522	829	486
Maximum Peak Current of Load (amp)	11	11	10	10	10	10	10

NOTE (1) SCWT - Simulated Center Wing Tank

Noise on arc current channel was too high for energy calculations.

Table E-10: Bus Transfers, Load Switching Event 1

Generators 1 and 4 Smith Gauges

Fuel Probe F36	No Debris	Debris HiZ-to-SCWT(1)	Debris LoZ-to-SCWT	Debris Shield-to-SCWT	Debris HiZ-to-Shield	Debris LoZ-to-Shield	Debris HiZ-LoZ
Maximum Peak Voltage at Fuel Probe (V)	18	35	6	14	15	6	16
Location of Maximum Peak Voltage	LoZ-SCWT	Loz-SCWT	Loz-SCWT	LoZ-SCWT	LoZ-Shield	Hiz-Shield	HiZ-Shield
Maximum Peak Current at Debris (mAmp)	N/A	13	13	11	10	9	9
Maximum Energy Dissipated at Debris (μJ)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Maximum Duration (μsec)	N/A	131	N/A	N/A	1040	N/A	141
Minimum Duration (μsec)	N/A	131	N/A	N/A	43	N/A	127
Maximum Peak Voltage across Load Switch (V)	169	193	169	169	165	166	165
Maximum Peak Current of Load (amp)	469	300	418	302	227	545	397

NOTE (1) SCWT - Simulated Center Wing Tank

Table E-11: Lavatory Flush Motors, Load Switching Event 6

Generators 1 and 4 - Honeywell Gauges

	Fuel Probe F44 No Debris	Fuel Probe F36 No Debris
Maximum Peak Voltage at Fuel Probe (V)	9	10
Location of Maximum Peak Voltage	LoZ-SCWT[(1)]	Shield-SCWT
Maximum Peak Current at Debris (mAmp)	N/A	N/A
Maximum Energy Dissipated at Debris (µJ)	N/A	N/A
Maximum Duration (µsec)	N/A	114
Minimum Duration (µsec)	N/A	114
Maximum Peak Voltage across Load Switch (V)	N/A	N/A
Maximum Peak Current of Load (amp)	4	5

NOTE (1) SCWT - Simulated Center Wing Tank

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APPENDIX F
VOLTAGE HARMONIC'S ON CAPTAIN'S CHANNEL OF COCKPIT VOICE RECORDER

Electrical Load Condition	Total Harmonic Distortion (% THD)	RMS Voltage Level of the Fundamental mV	Spectrum Trace
Base Load Case	33.13	110.4	Trace 1
Base Load Case	33.78	105.3	Trace 2
Storm Lights On	32.72	106.2	Trace 3
Overhead Panel Lights Off	33.03	107.4	Trace 4
Instrument Lights Captain-side Off	31.03	114.2	Trace 5
Upper Deck Light Breaker Pulled	37.23	96.2	Trace 6
Upper Deck Galley Equipment On	33.00	103.5	Trace 7
Keying the Passenger Address Microphone	76.87	73.9	Trace 8
Keying the Passenger Address Microphone	81.02	70.4	Trace 9
Passenger Address Pressed on Captain's Audio	80.47	67.0	Trace 10
Open Split System Breaker	64.35	67.7	Trace 11
Open GCB 3 and GCB 4	31.54	115.5	Trace 12
All GCB's Open, No Emergency Lights	48.76	11.4	Trace 13
All GCB's Open, No Emergency Lights	46.20	12.4	Trace 14
All GCB's Closed, No Emergency Lights (Spectrum taken immediately after closing GCB's)	12.25	294.5	Trace 15
All GCB's Open, with Emergency Lights	47.58	12.0	Trace 16
All GCB's Closed (Spectrum taken immediately after closing GCB's)	12.09	344.8	Trace 17
GCB 1 and GCB 2 Open	32.06	106.5	Trace18
Breaker Pulled for TRU1	58.66	99.9	Trace 19
Breaker Pulled for TRU2	12.30	329.8	Trace 20
Breaker Pulled for TRU2	12.09	327.7	Trace 21
Breaker Pulled for TRU3	31.96	100.8	Trace 22
Essential Power Selector to BUS 3	11.98	322.8	Trace 23
Essential Power Selector to BUS 2	12.48	328.2	Trace 24
Essential Power Selector to BUS 1	12.51	298.1	Trace 25
All TRU Breakers Pulled	18.72	336.0	Trace 26
All TRU Breakers Pulled	18.86	322.6	Trace 27

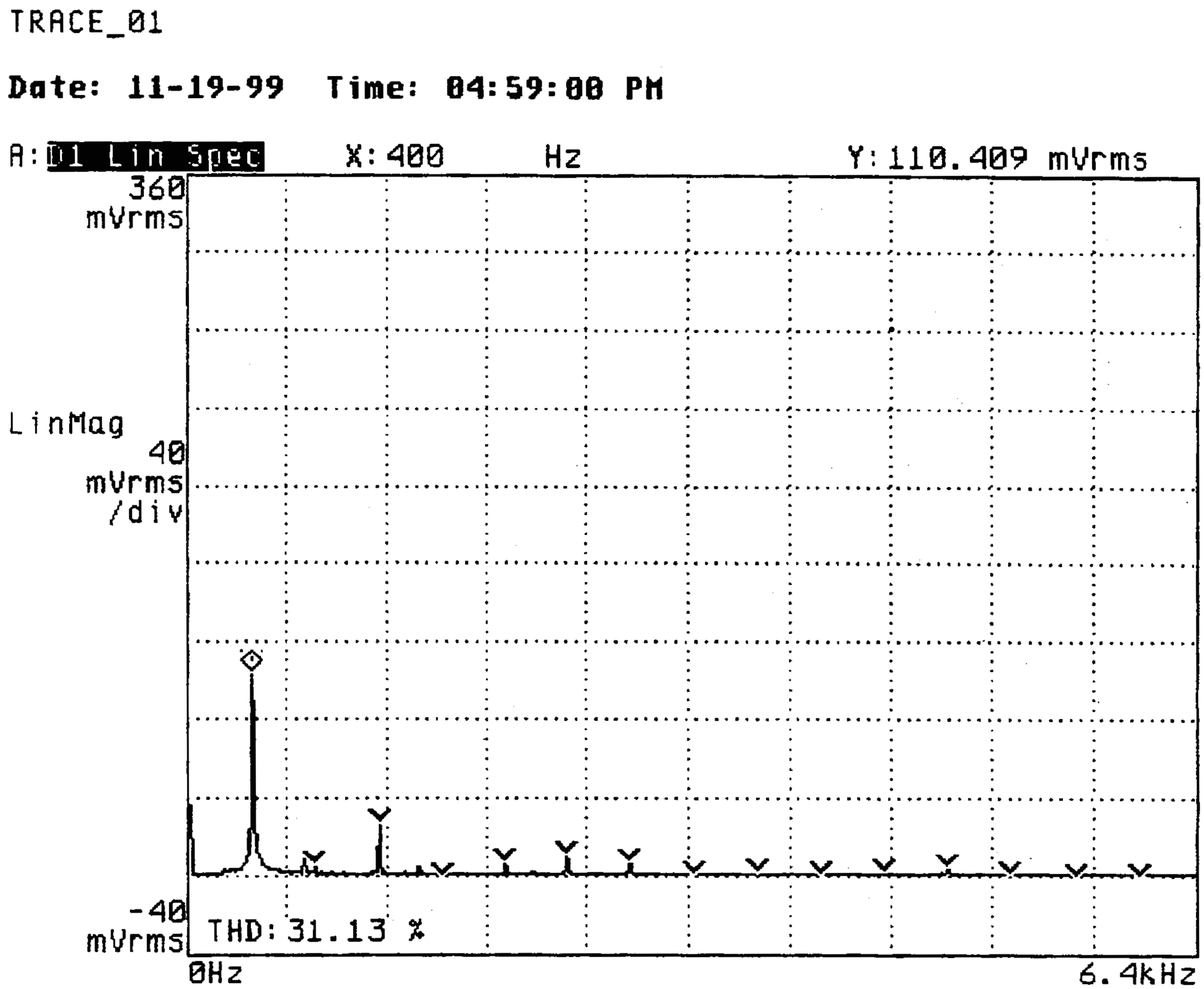

Figure F-1A: Spectrum for Base Load Case

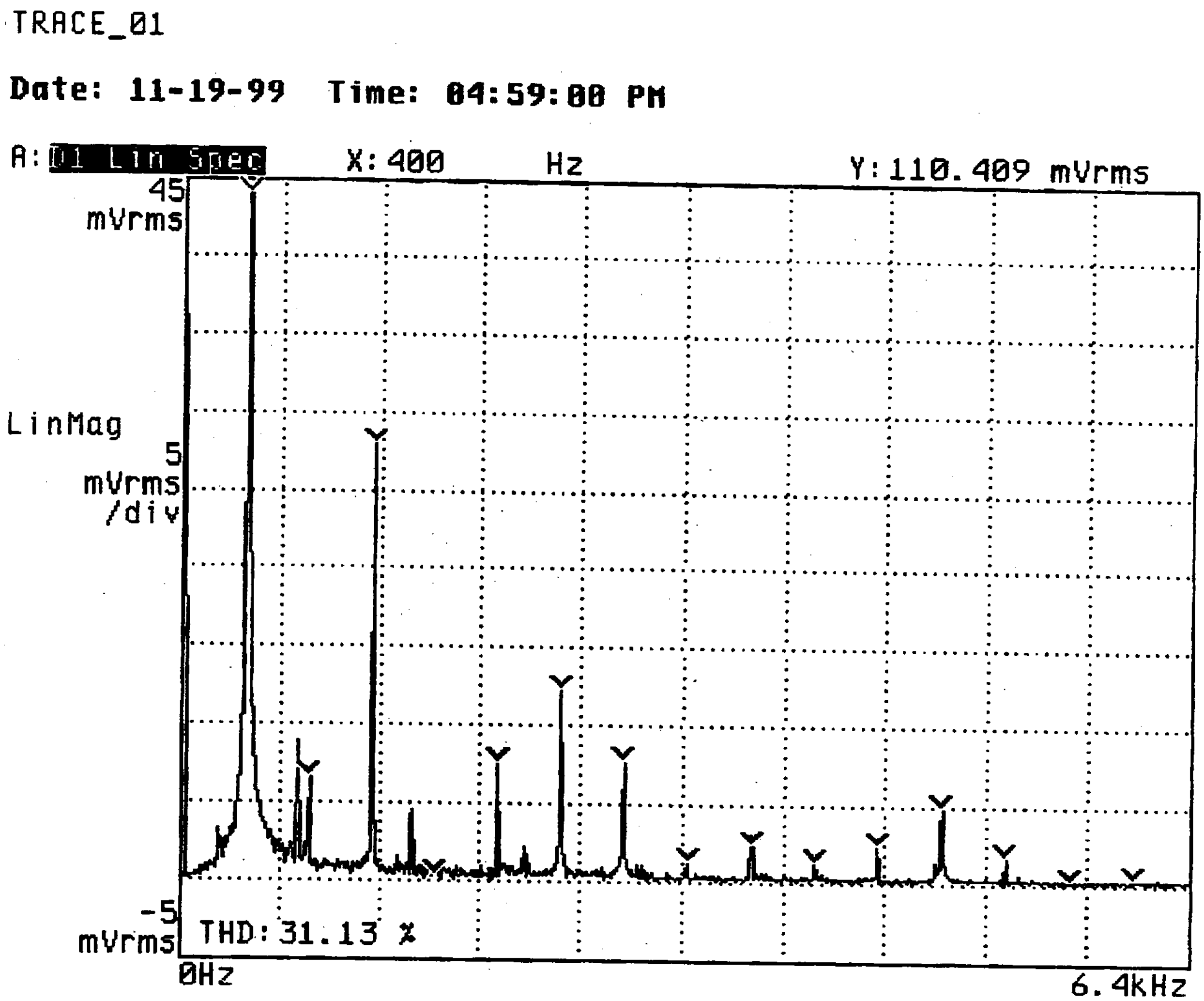

Figure F-1B: Spectrum for Base Load Case (Cont'd)

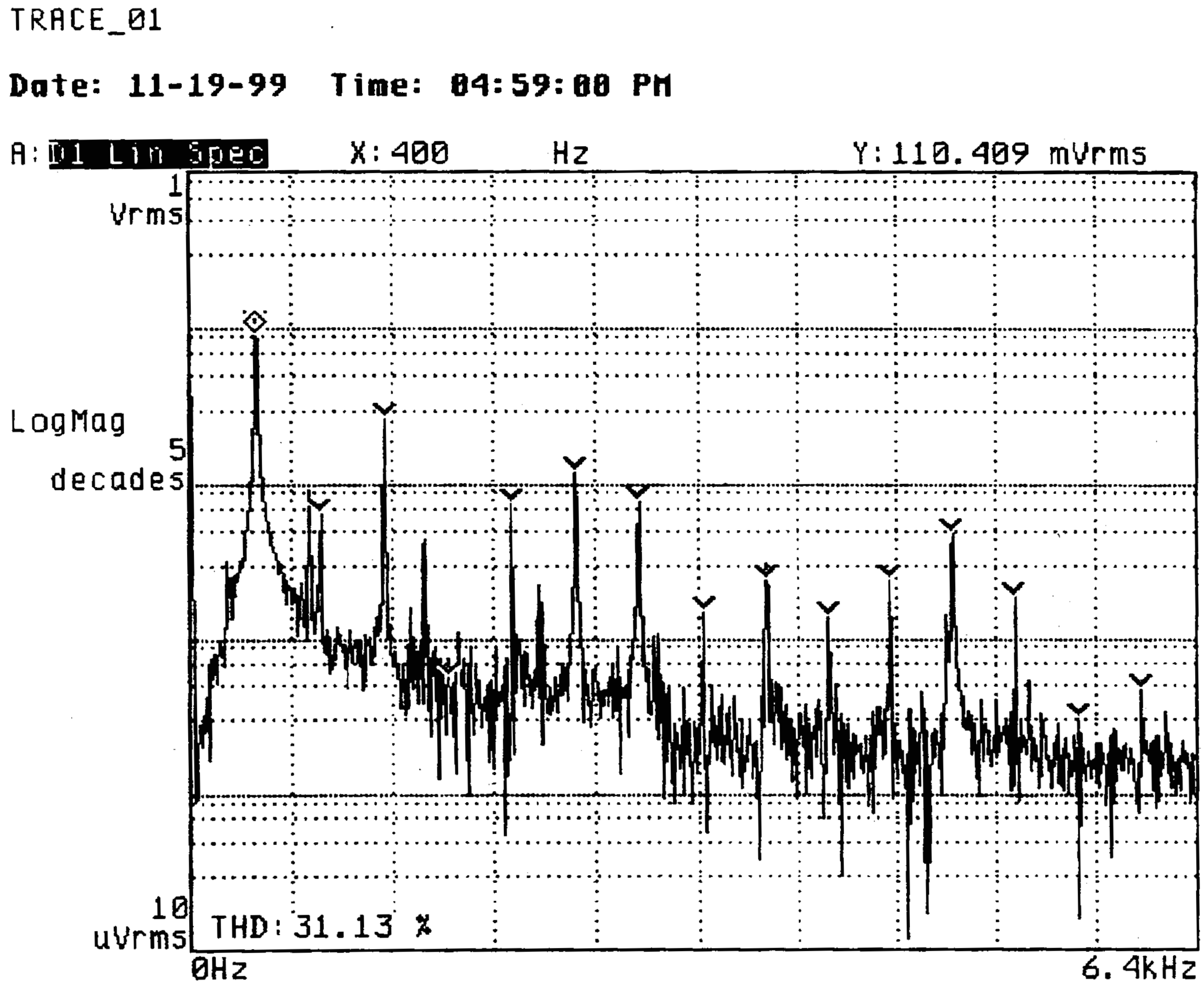

Figure F-1C: Spectrum for Base Load Case (Cont'd)

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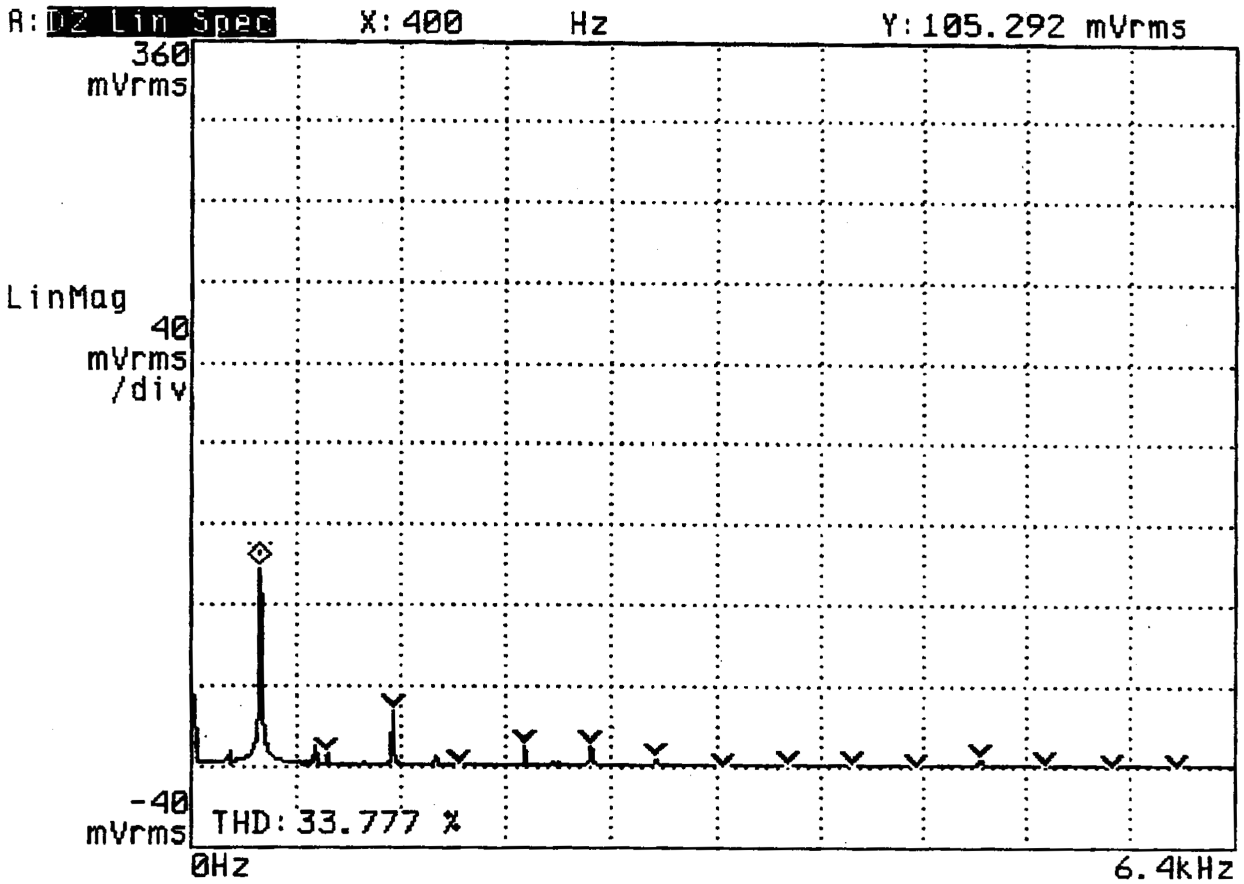

Figure F-2A: Spectrum for Base Load Case (Repeated)

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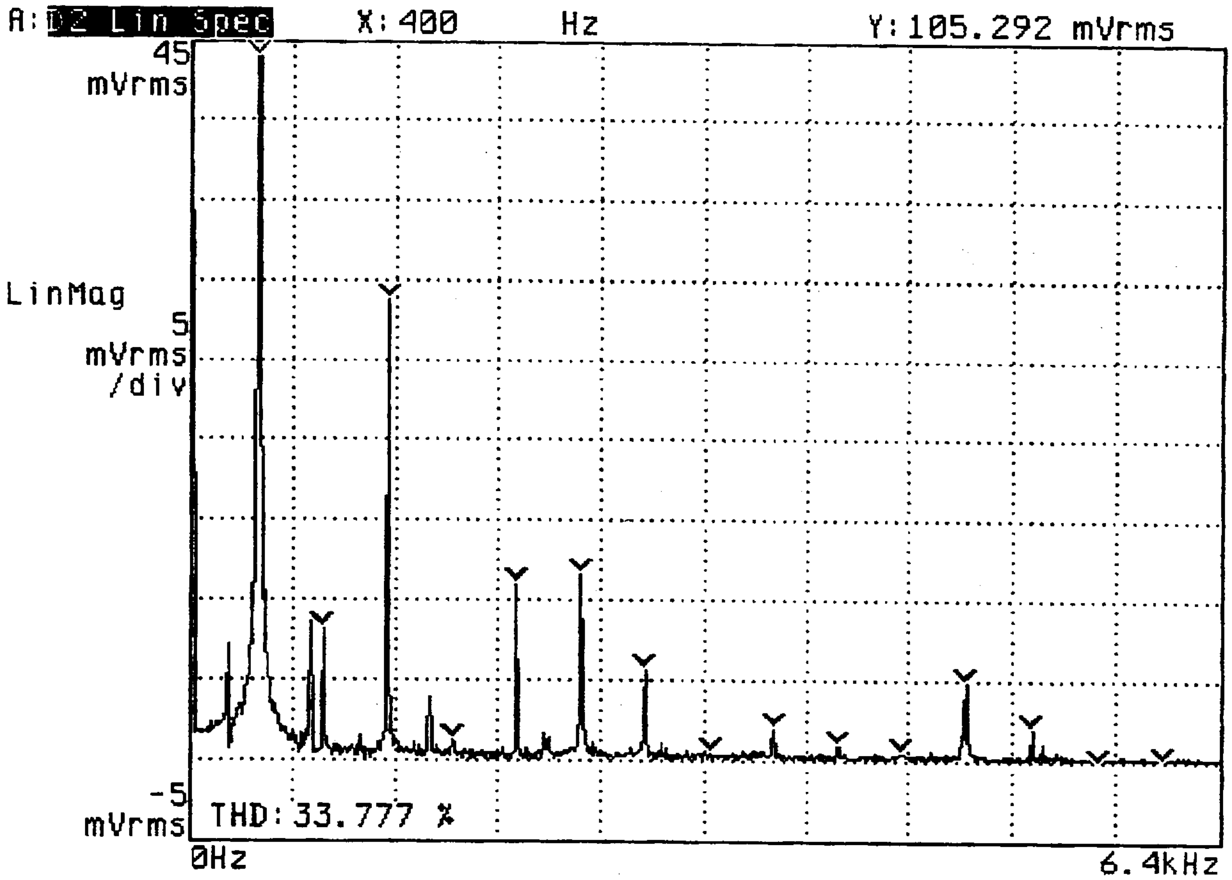

Figure F-2B: Spectrum for Base Load Case (Repeated) (Cont'd)

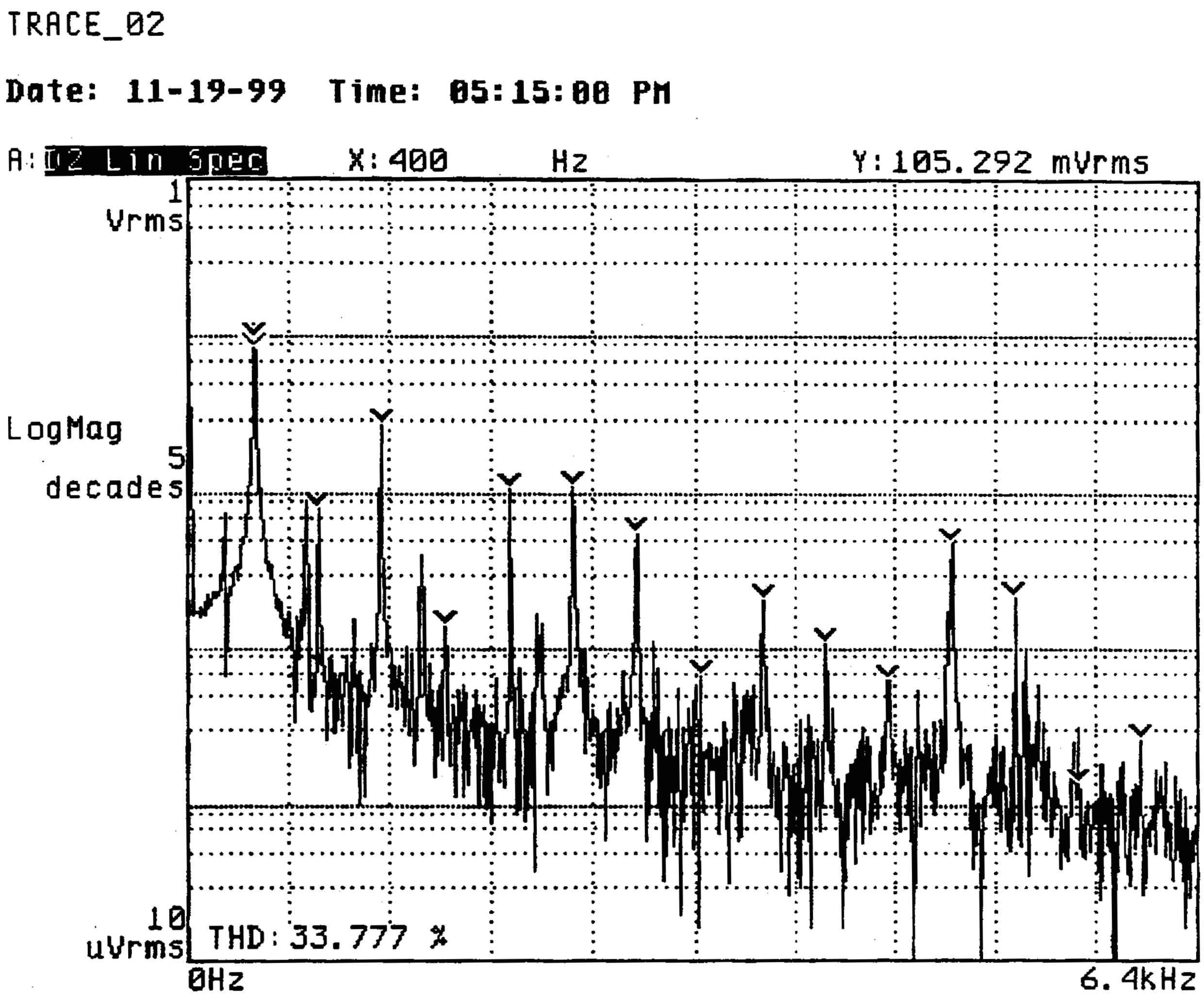

Figure F-2C: Spectrum for Base Load Case (Repeated) (Cont'd)

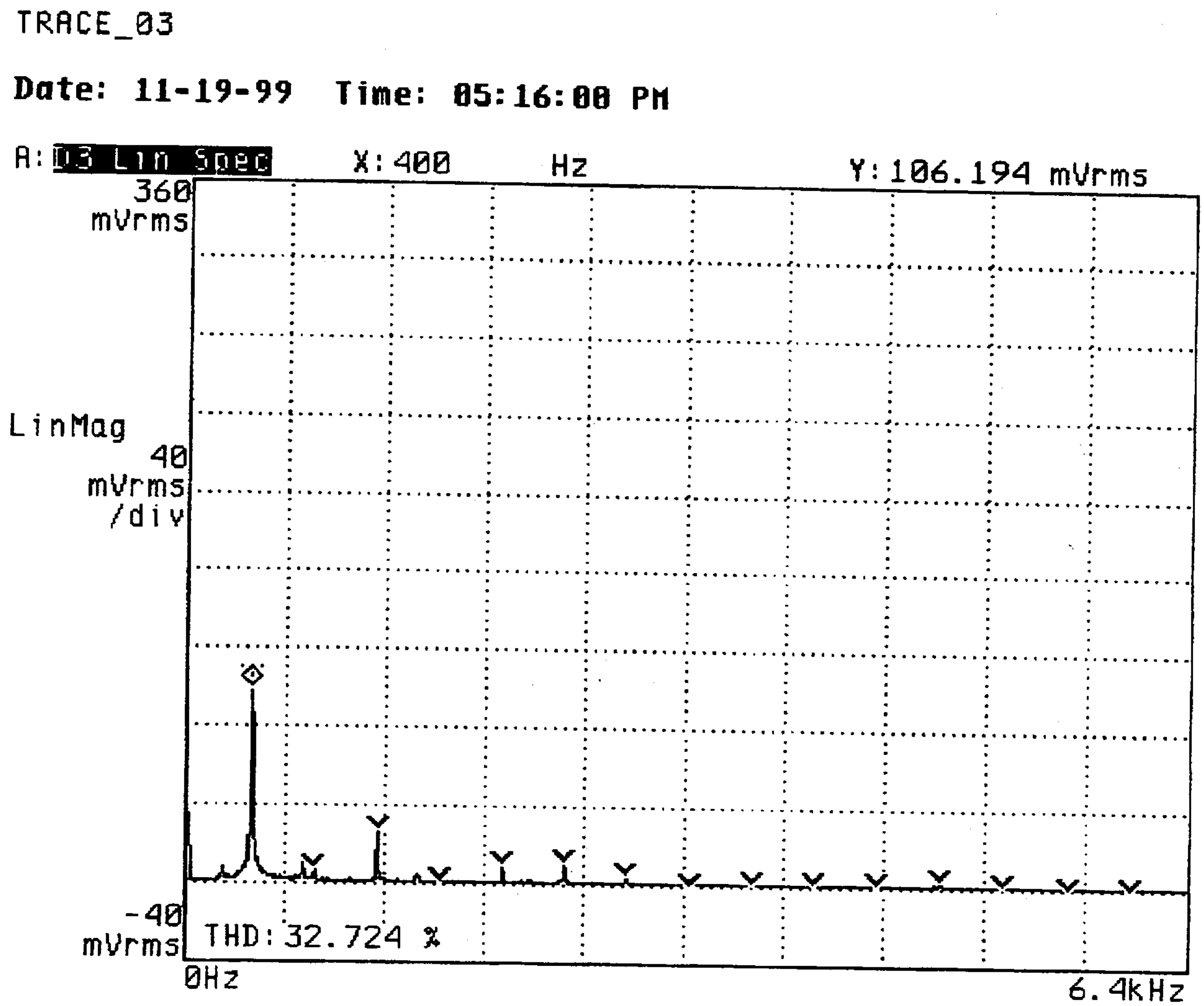

Figure F-3A: Spectrum for Storm Lights On

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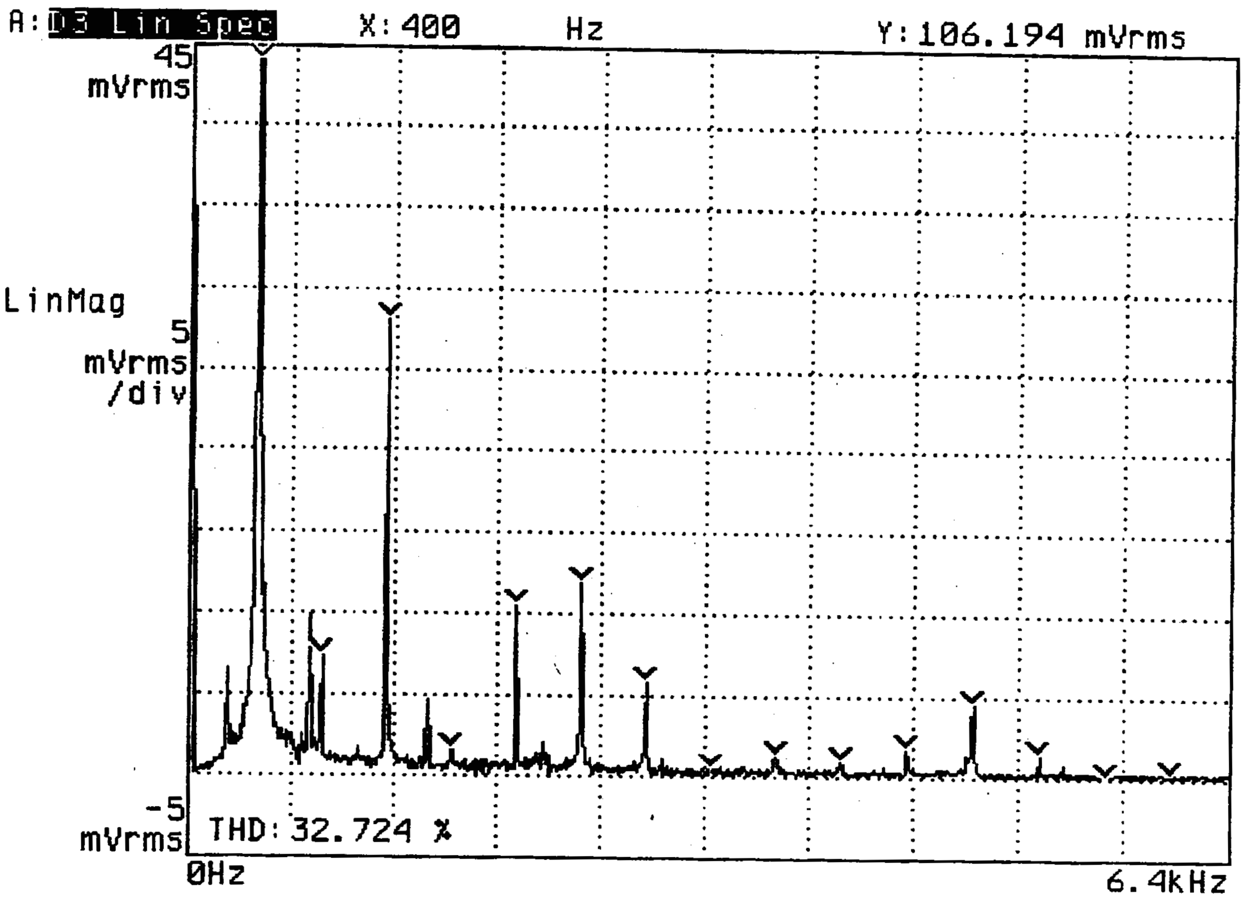

Figure F-3B: Spectrum for Storm Lights On (Cont'd)

TRACE_03

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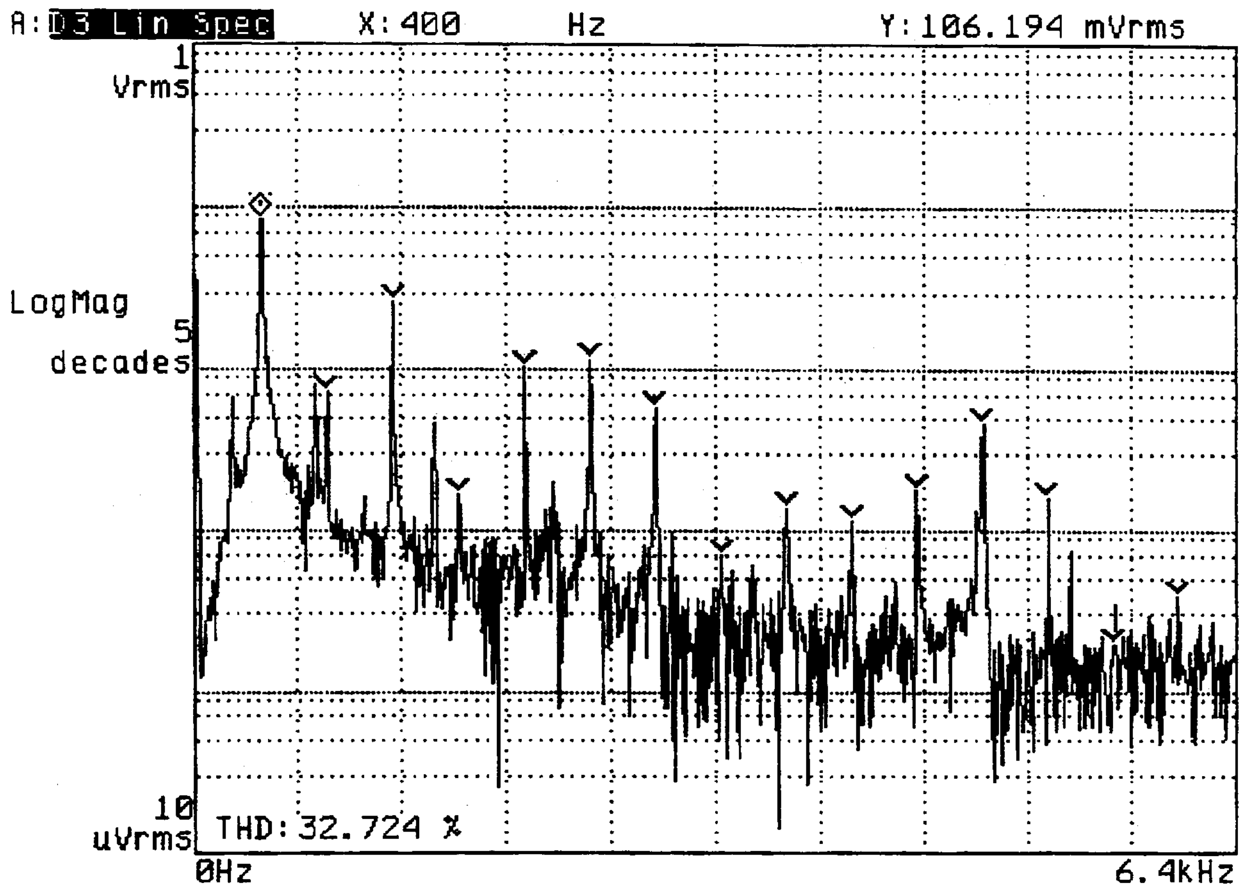

Figure F-3C: Spectrum for Storm Lights On (Cont'd)

TRACE_04

Date: 11-19-99 Time: 05:18:00 PM

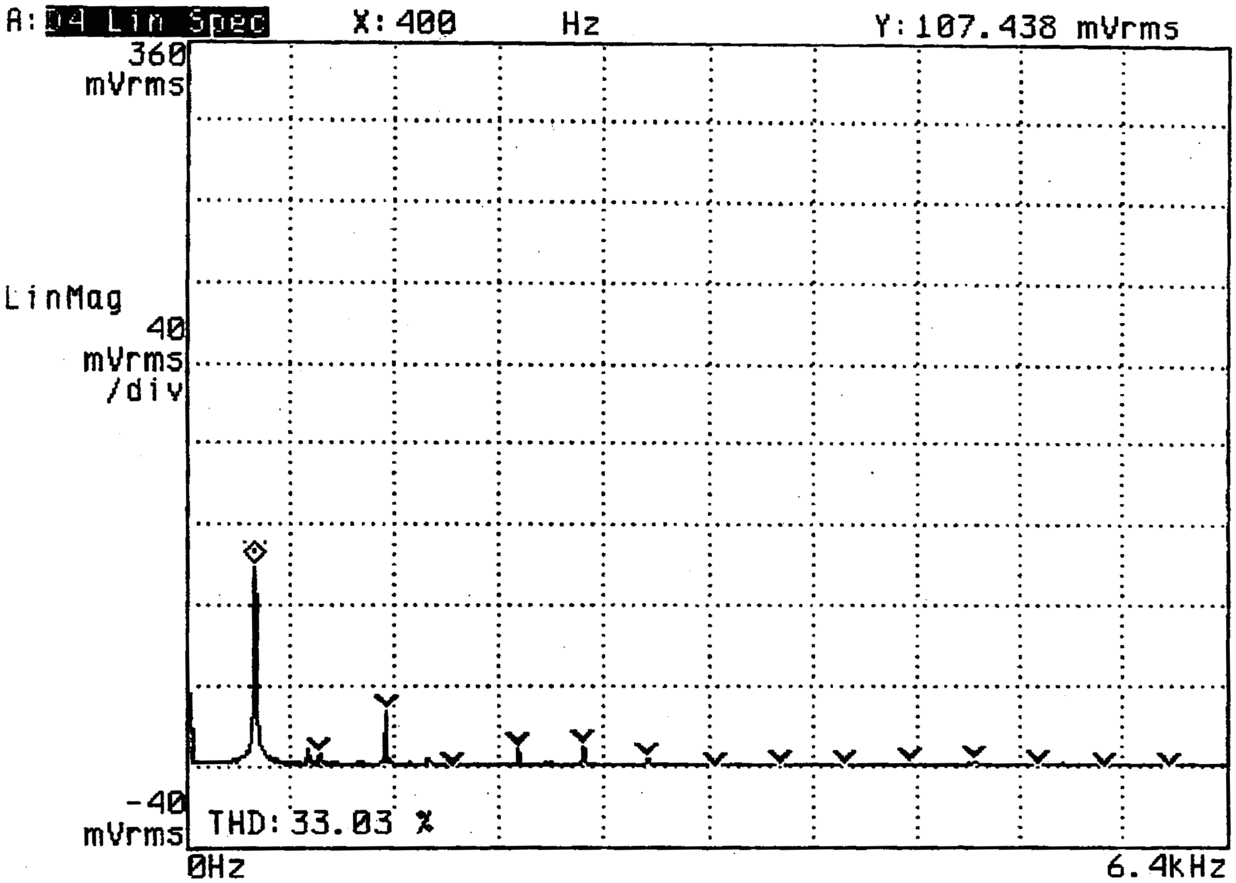

Figure F-4A: Spectrum for Overhead Panel Lights Off

TRACE_04

Date: 11-19-99 Time: 05:18:00 PM

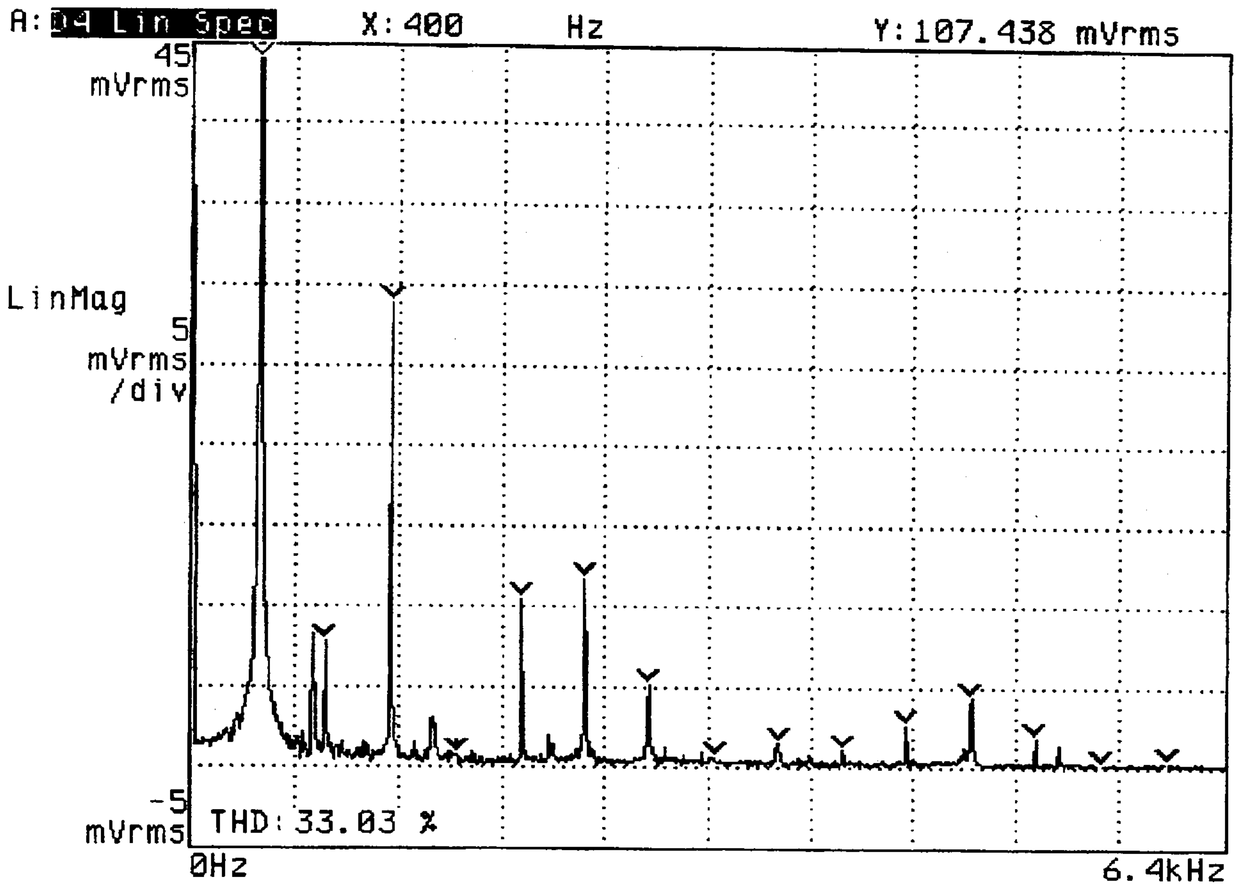

Figure F-4B: Spectrum for Overhead Panel Lights Off (Cont'd)

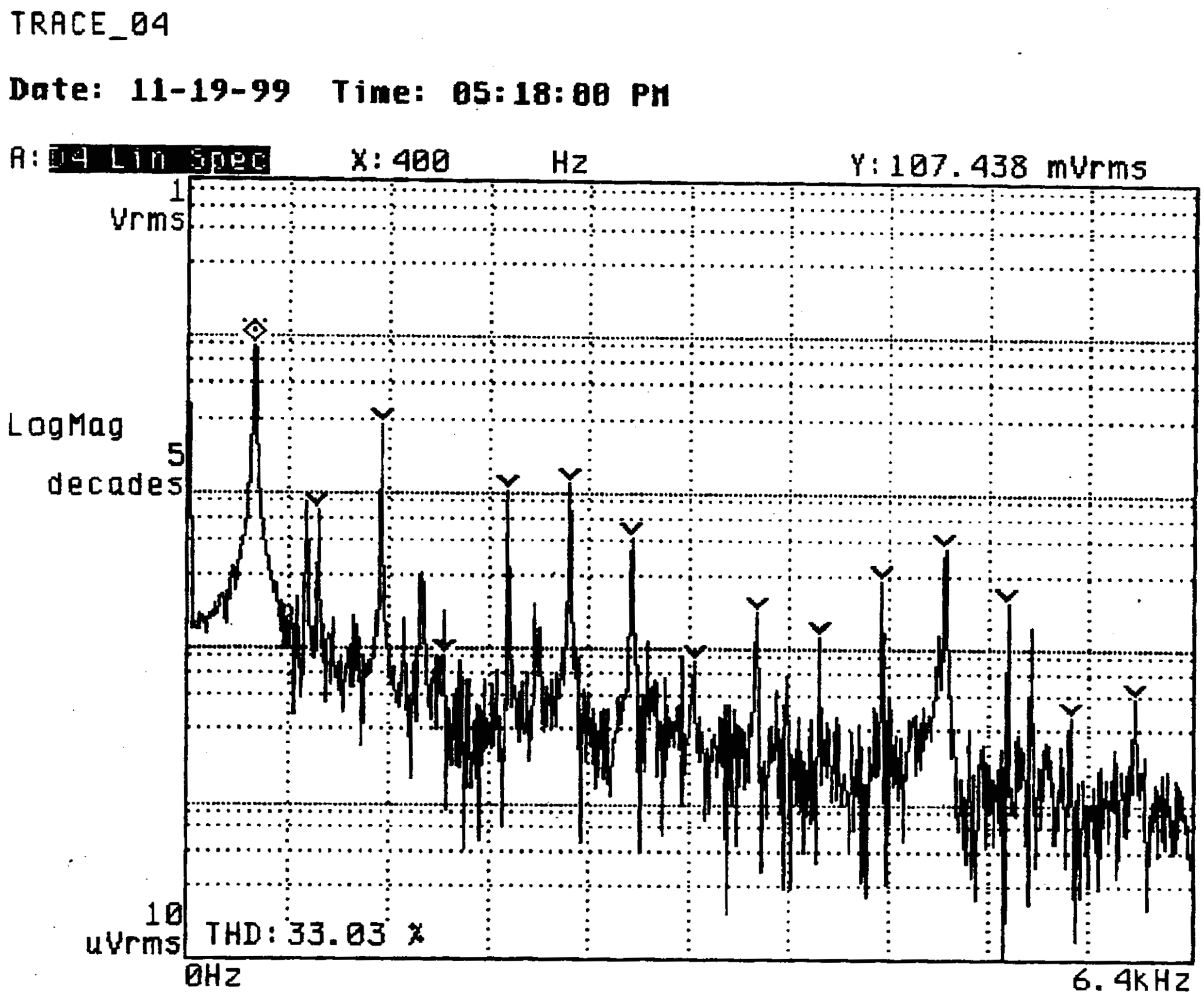

Figure F-4C: Spectrum for Overhead Panel Lights Off (Cont'd)

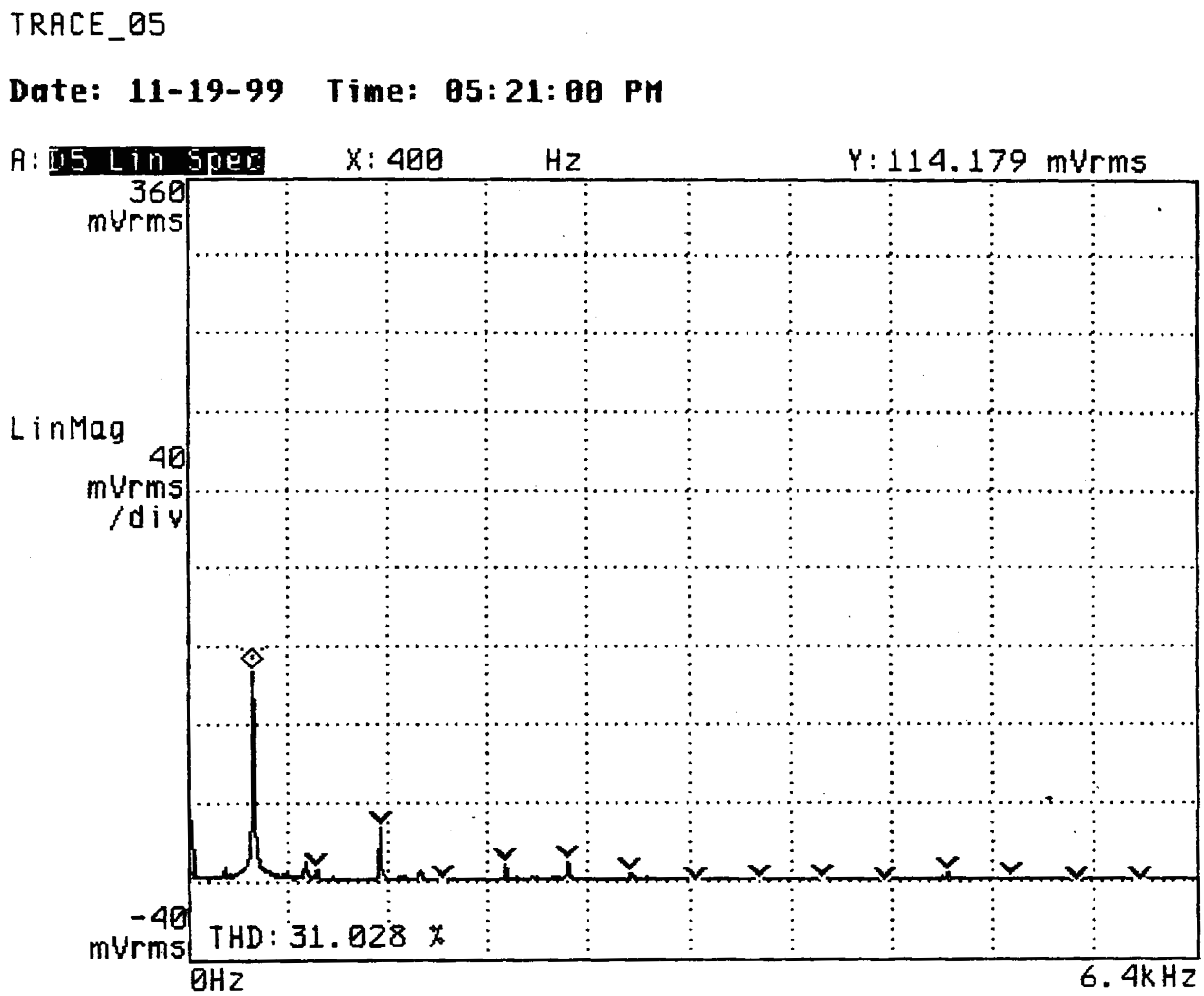

Figure F-5A: Spectrum for Instrument Lights Captain-side Off

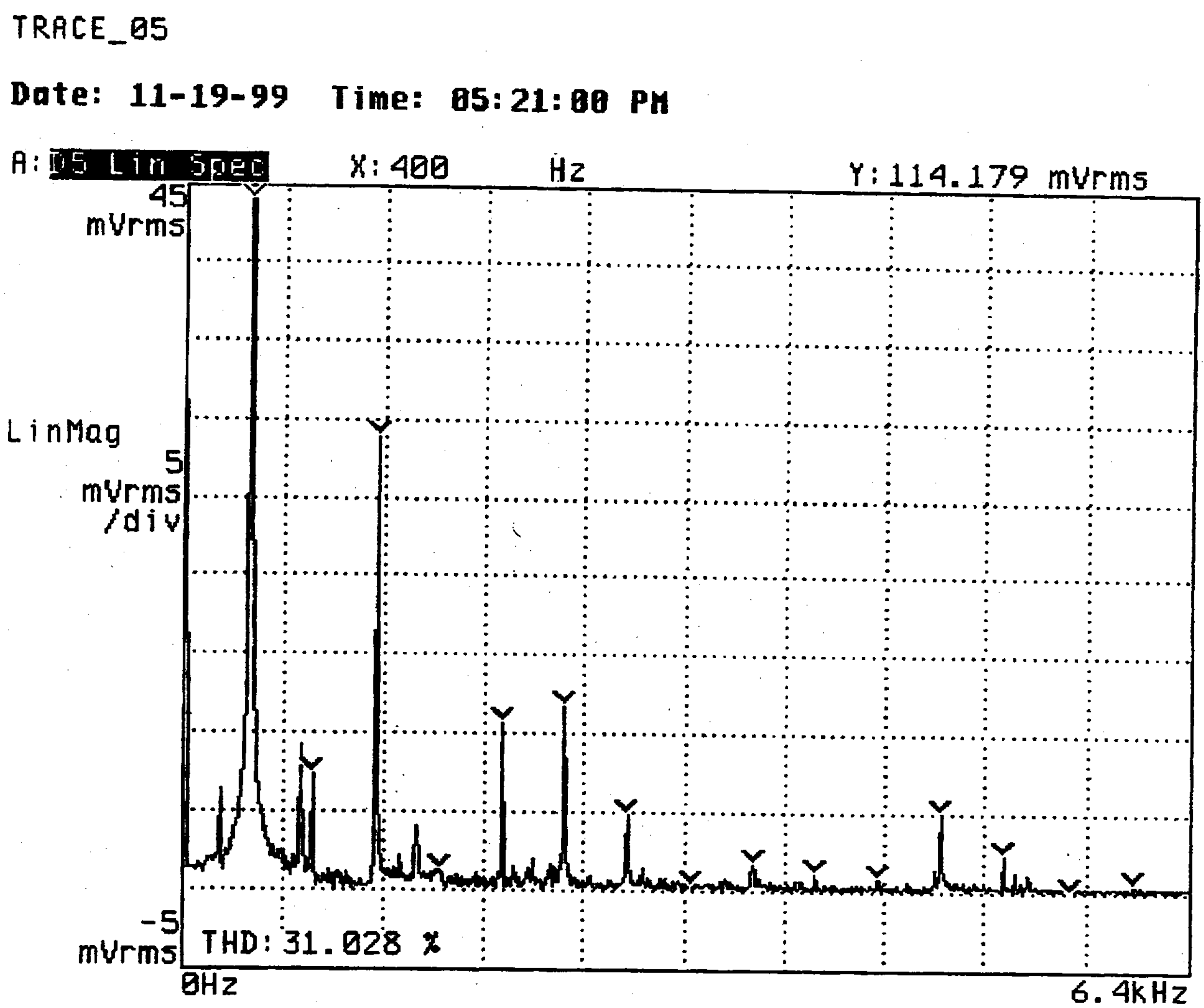

Figure F-5B: Spectrum for Instrument Lights Captain-side Off (Cont'd)

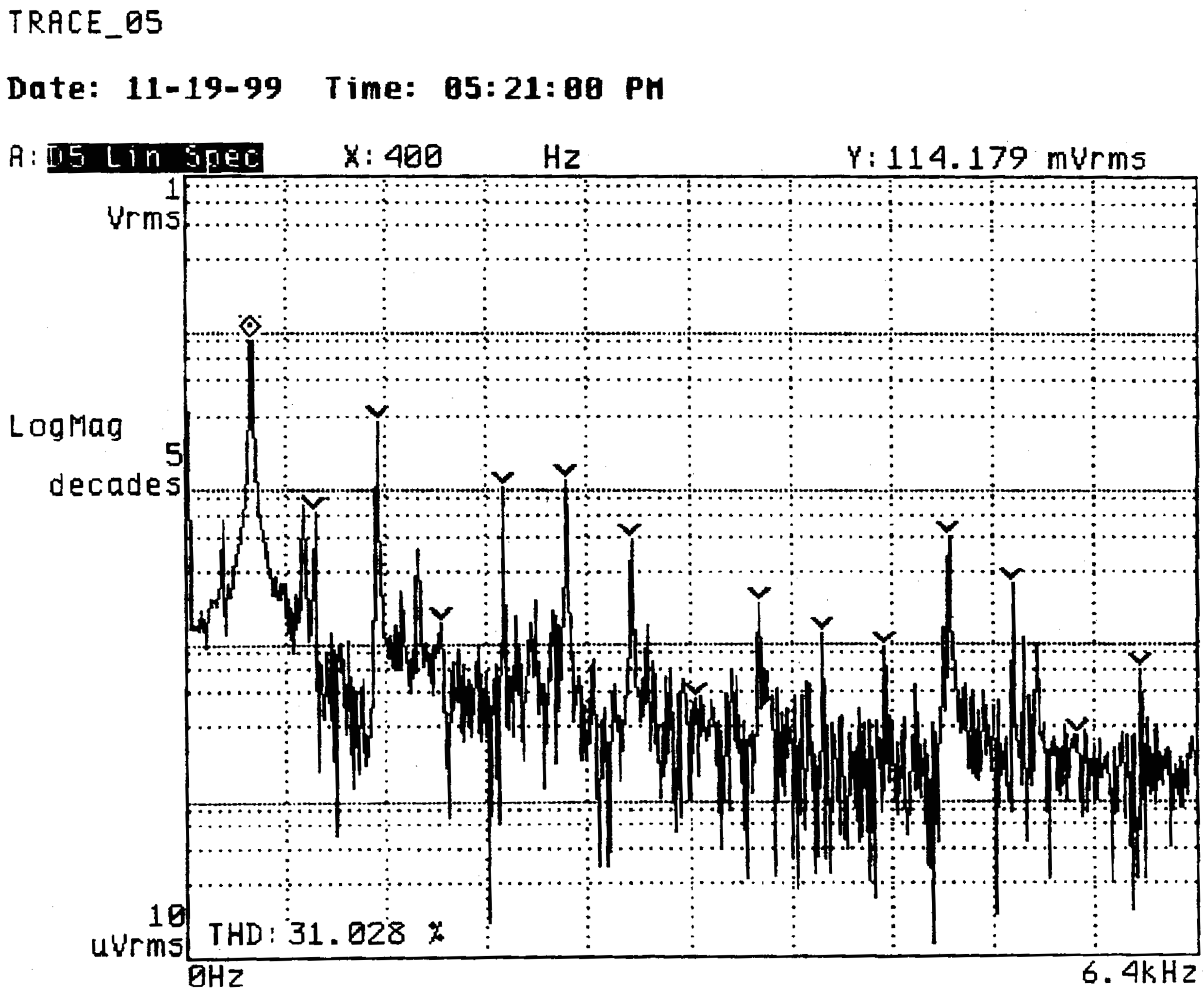

Figure F-5C: Spectrum for Instrument Lights Captain-side Off (Cont'd)

TRACE_06

Date: 11-19-99 Time: 05:25:00 PM

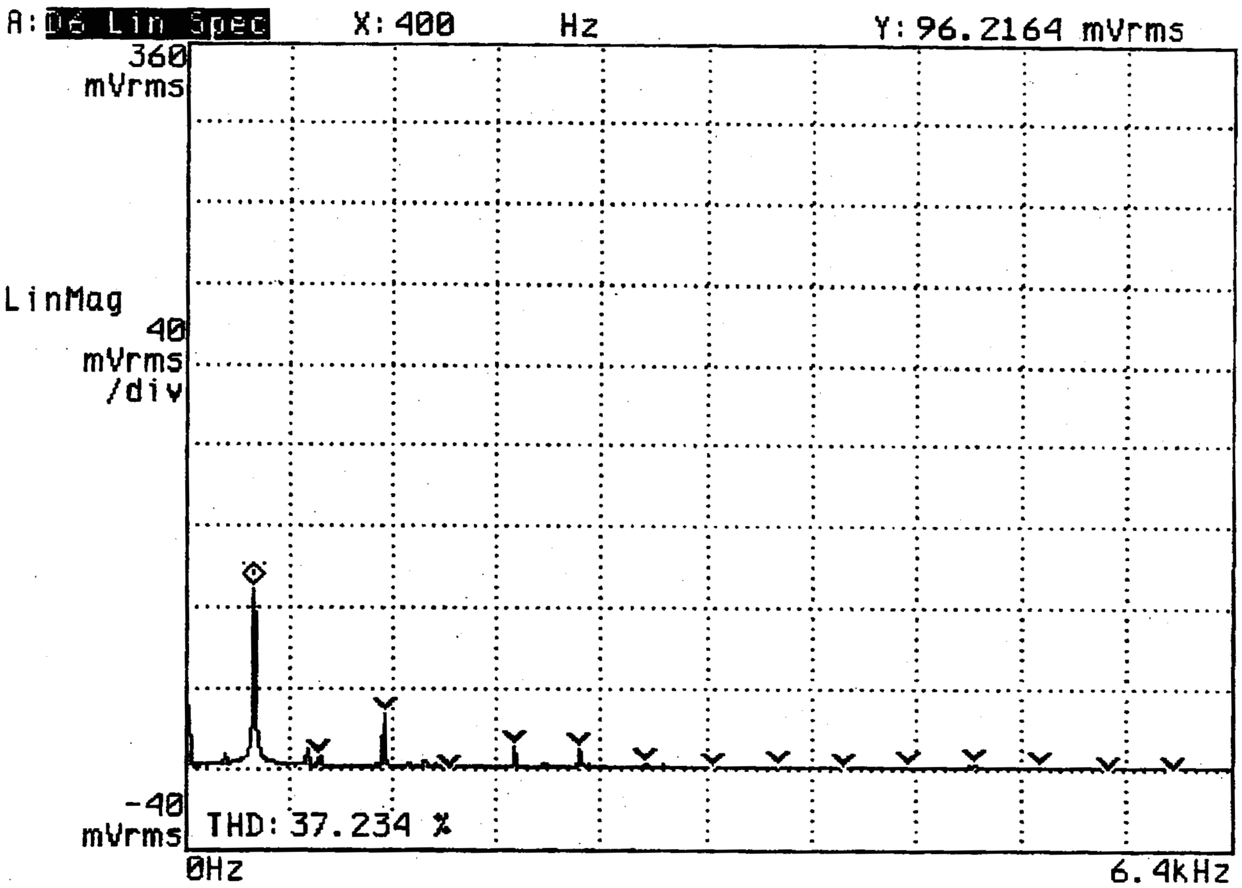

Figure F-6A: Spectrum for Upper Deck Light Breaker Pulled

TRACE_06

Date: 11-19-99 Time: 05:25:00 PM

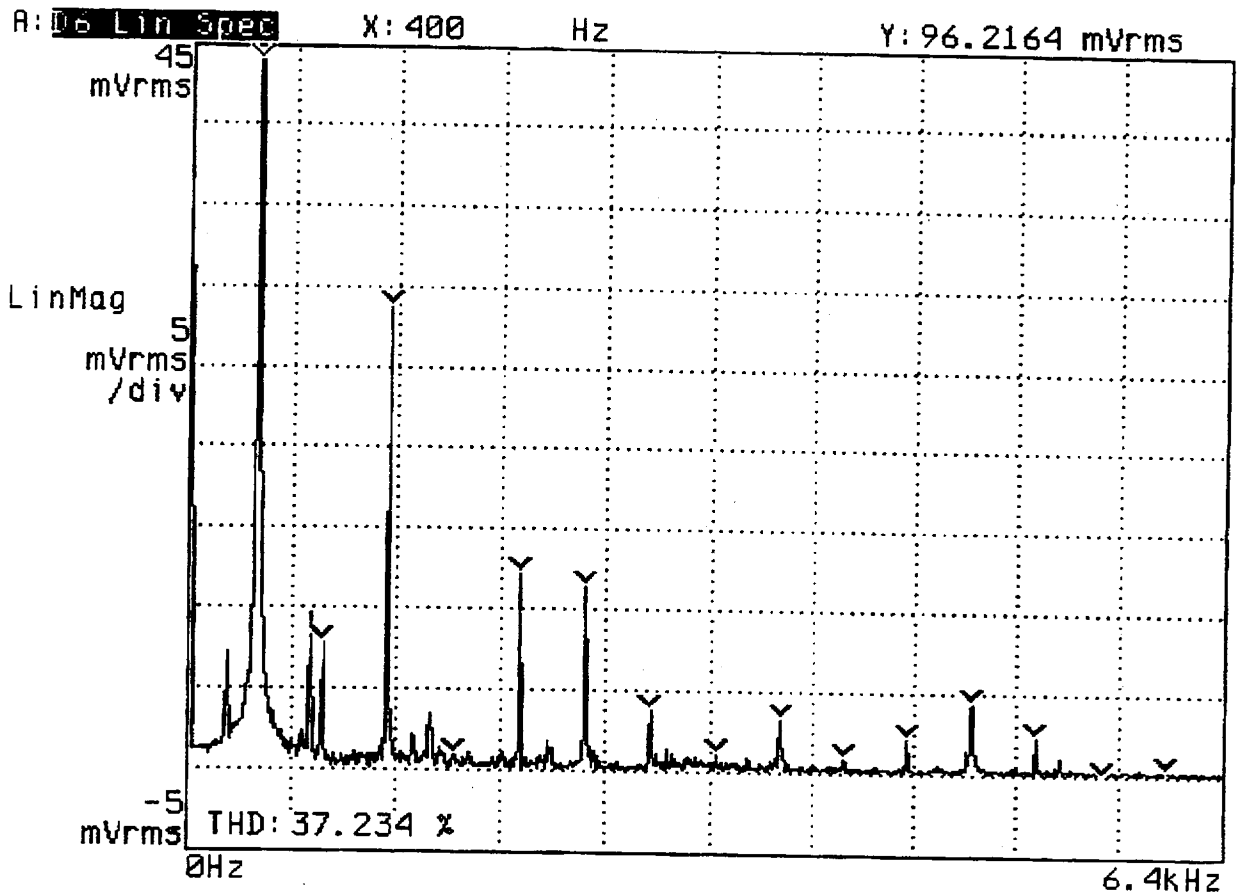

Figure F-6B: Spectrum for Upper Deck Light Breaker Pulled (Cont'd)

TRACE_06

Date: 11-19-99 Time: 05:25:00 PM

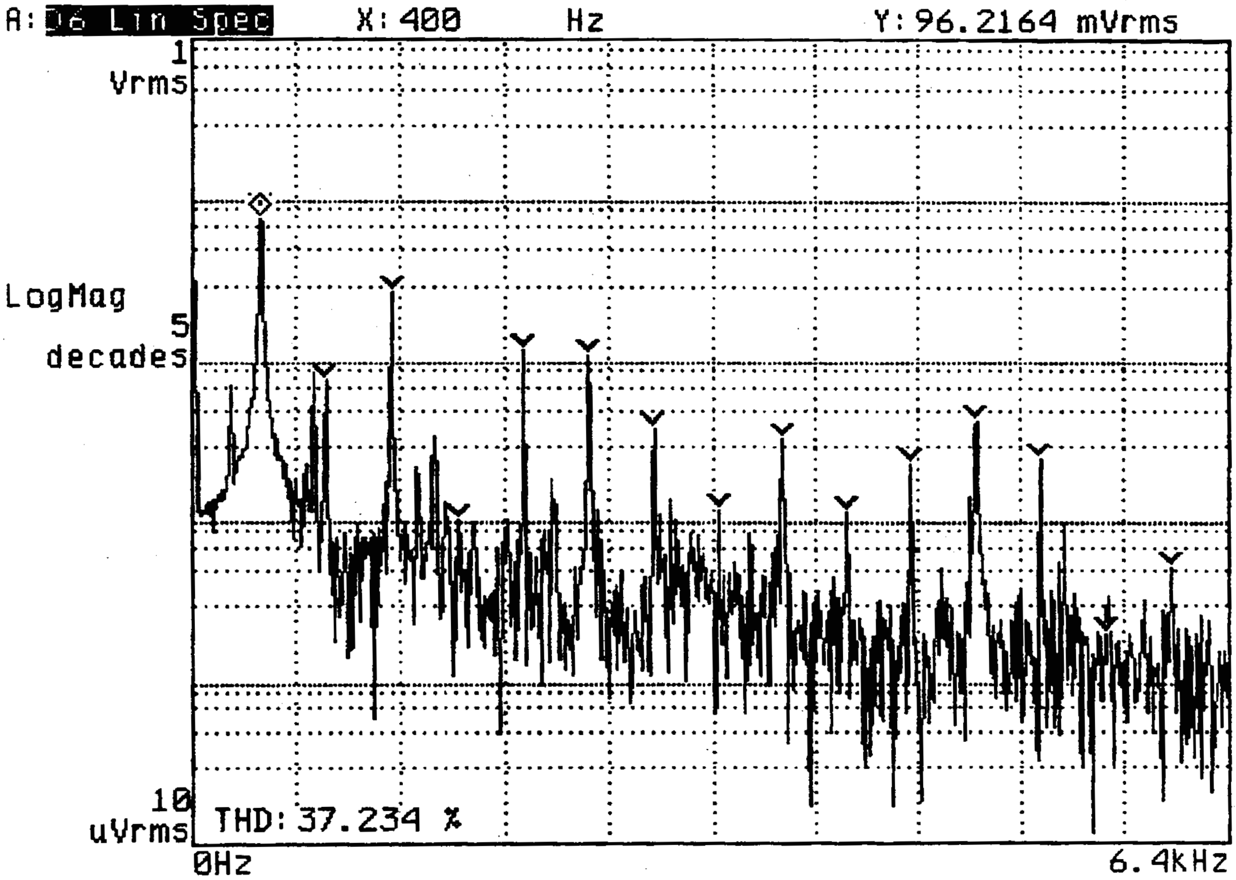

Figure F-6C: Spectrum for Upper Deck Light Breaker Pulled (Cont'd)

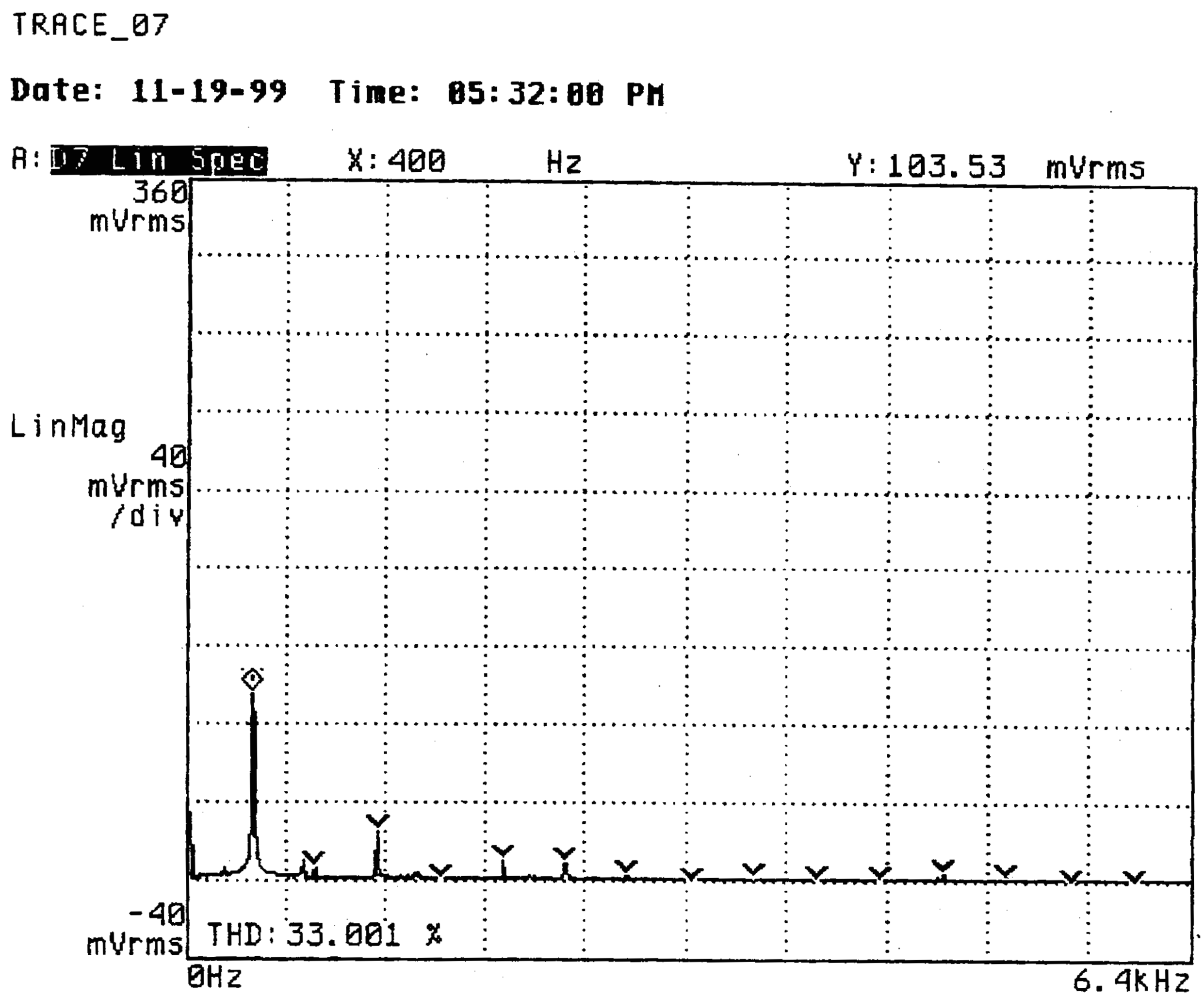

Figure F-7A: Spectrum for Upper Deck Galley Equipment On

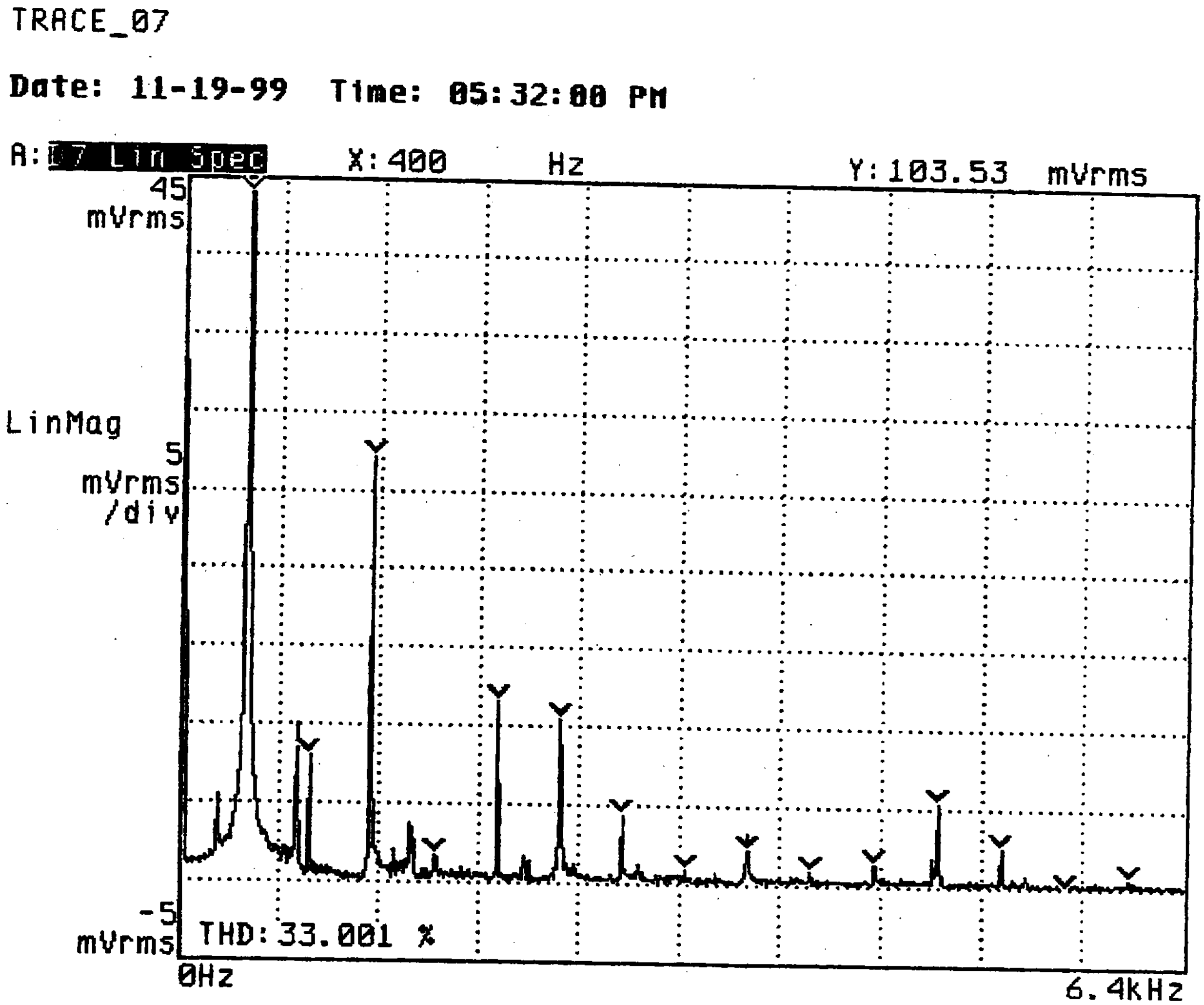

Figure F-7B: Spectrum for Upper Deck Galley Equipment On (Cont'd)

TRACE_07

Date: 11-19-99 Time: 05:32:00 PM

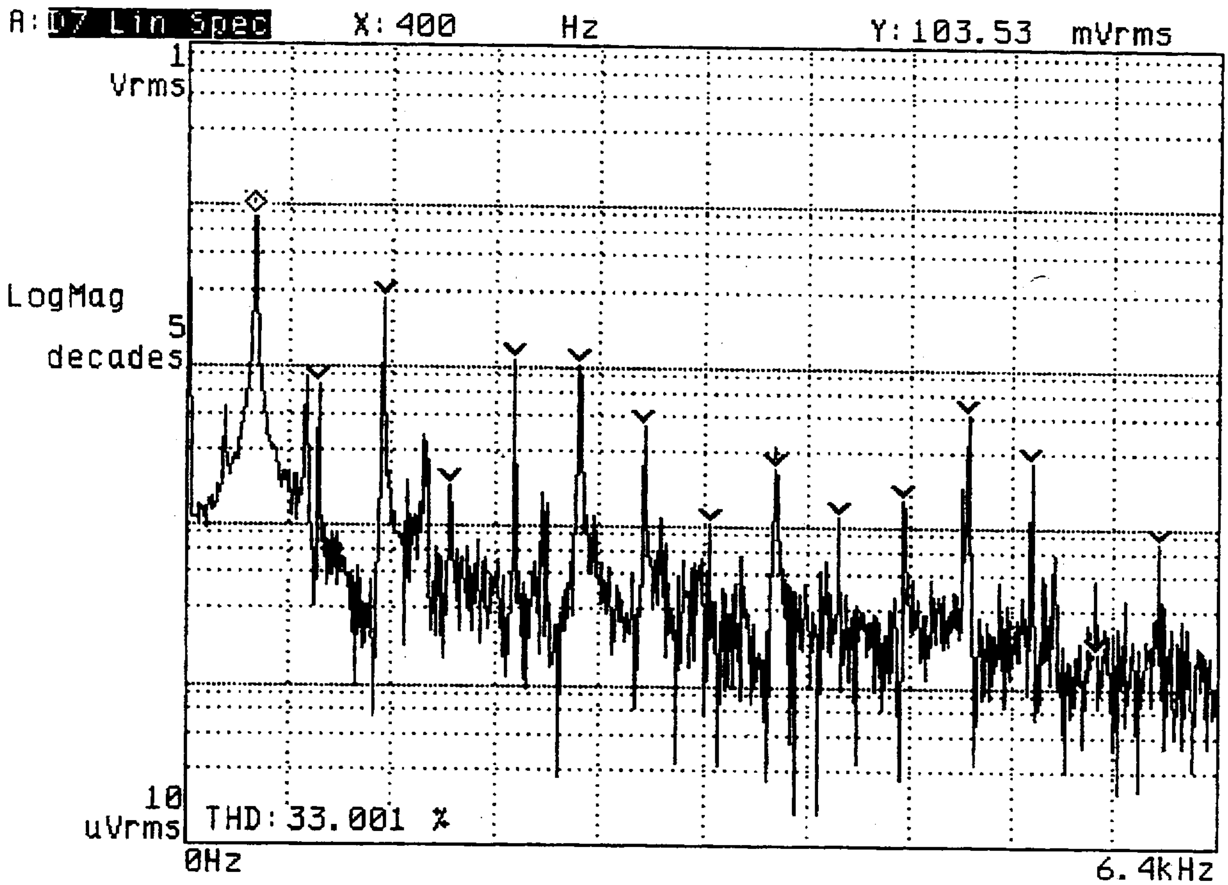

Figure F-7C: Spectrum for Upper Deck Galley Equipment On (Cont'd)

TRACE_08

Date: 11-19-99 Time: 05:37:00 PM

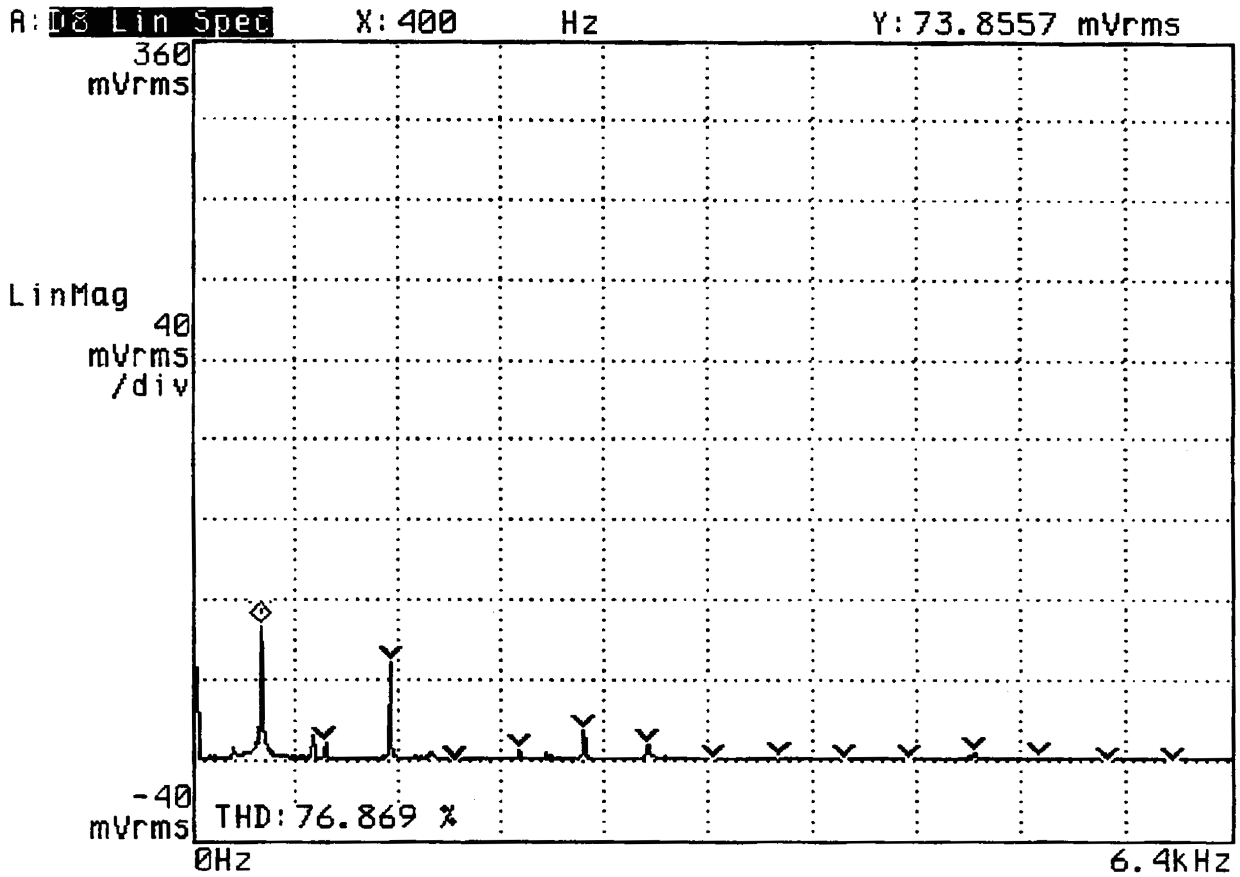

Figure F-8A: Spectrum for Keying the Passenger Address Microphone

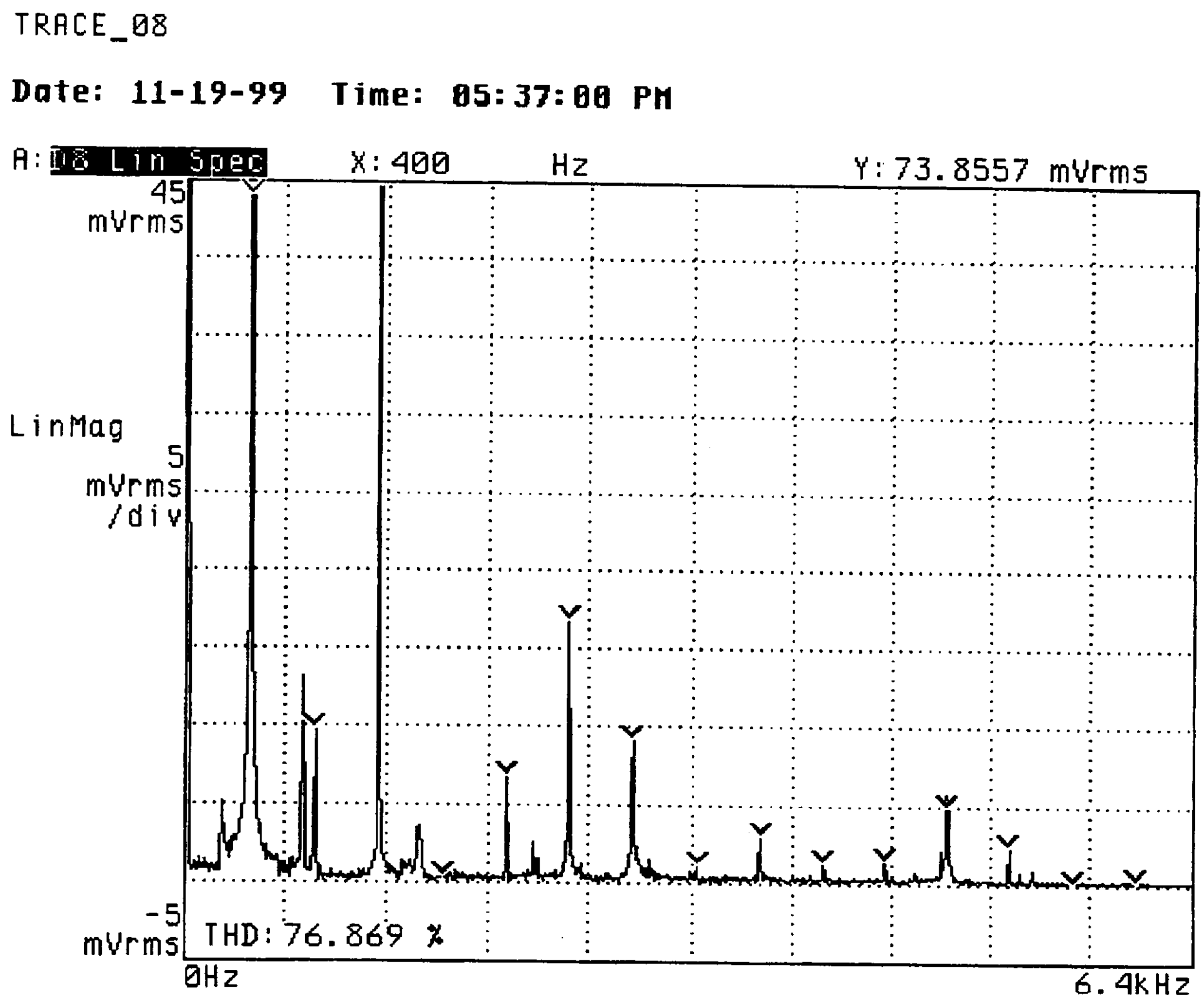

Figure F-8B: Spectrum for Keying the Passenger Address Microphone (Cont'd)

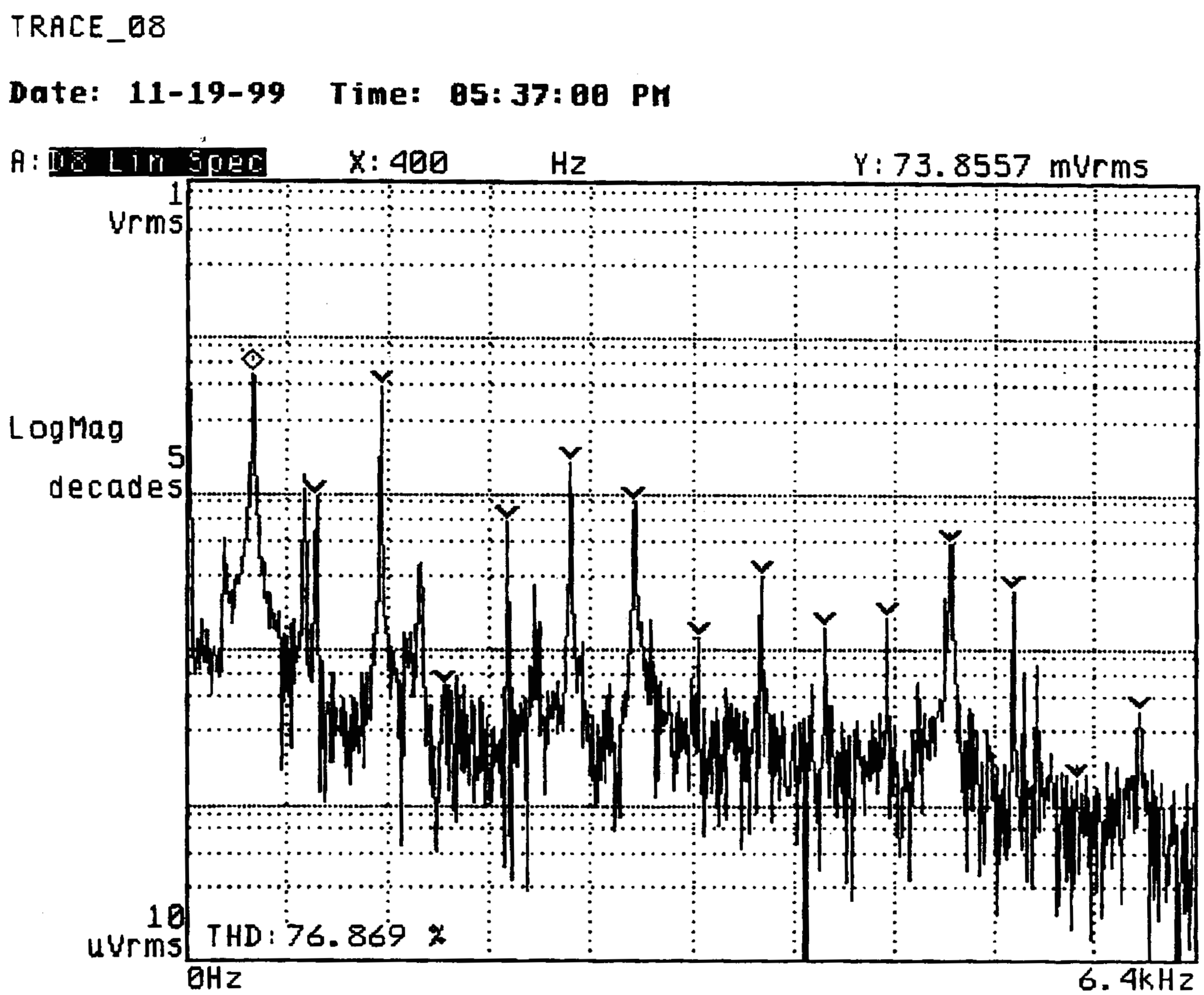

Figure F-8C: Spectrum for Keying the Passenger Address Microphone (Cont'd)

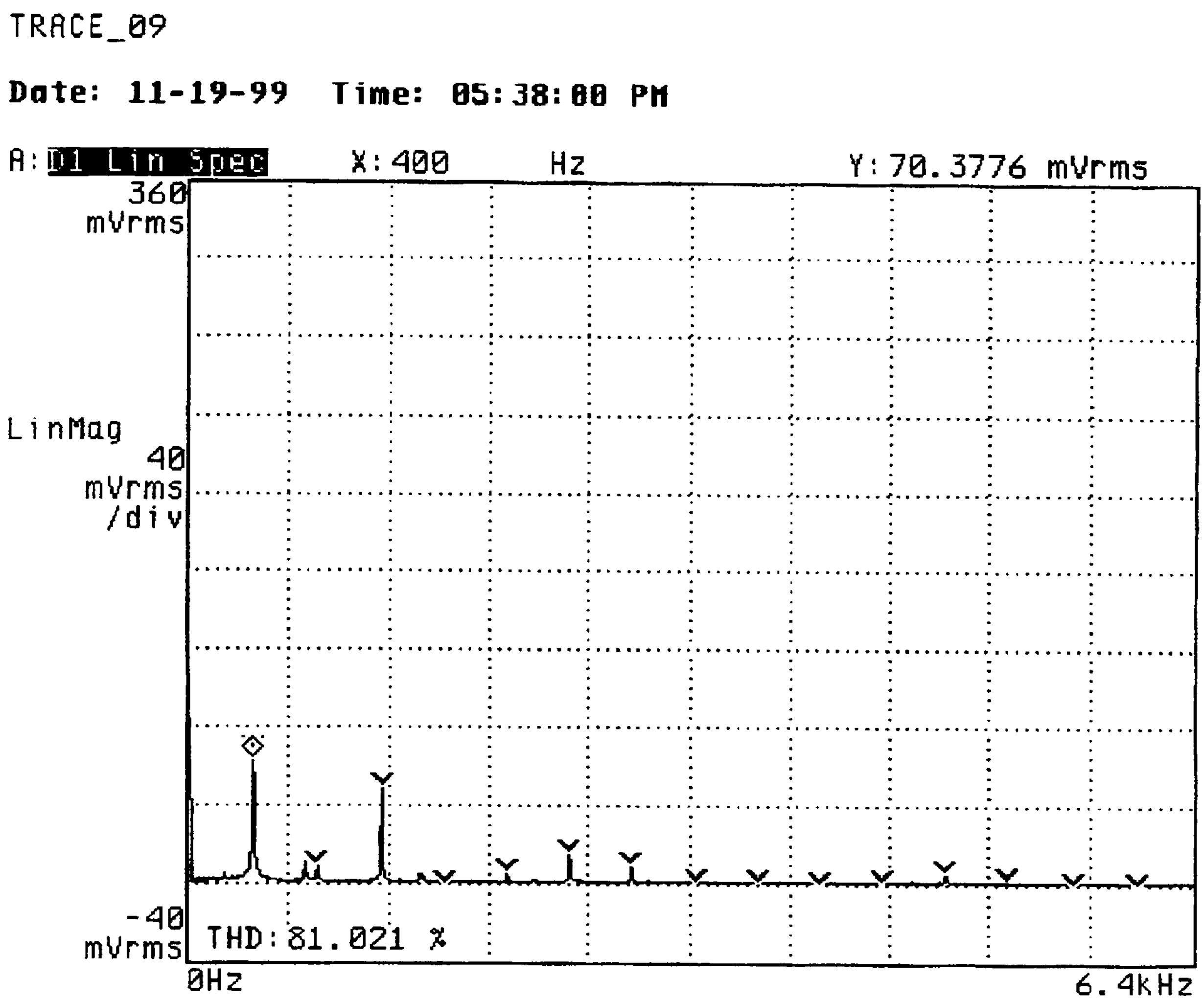

Figure F-9A: Spectrum for Keying the Passenger Address Microphone (Repeated)

TRACE_09

Date: 11-19-99 Time: 05:38:00 PM

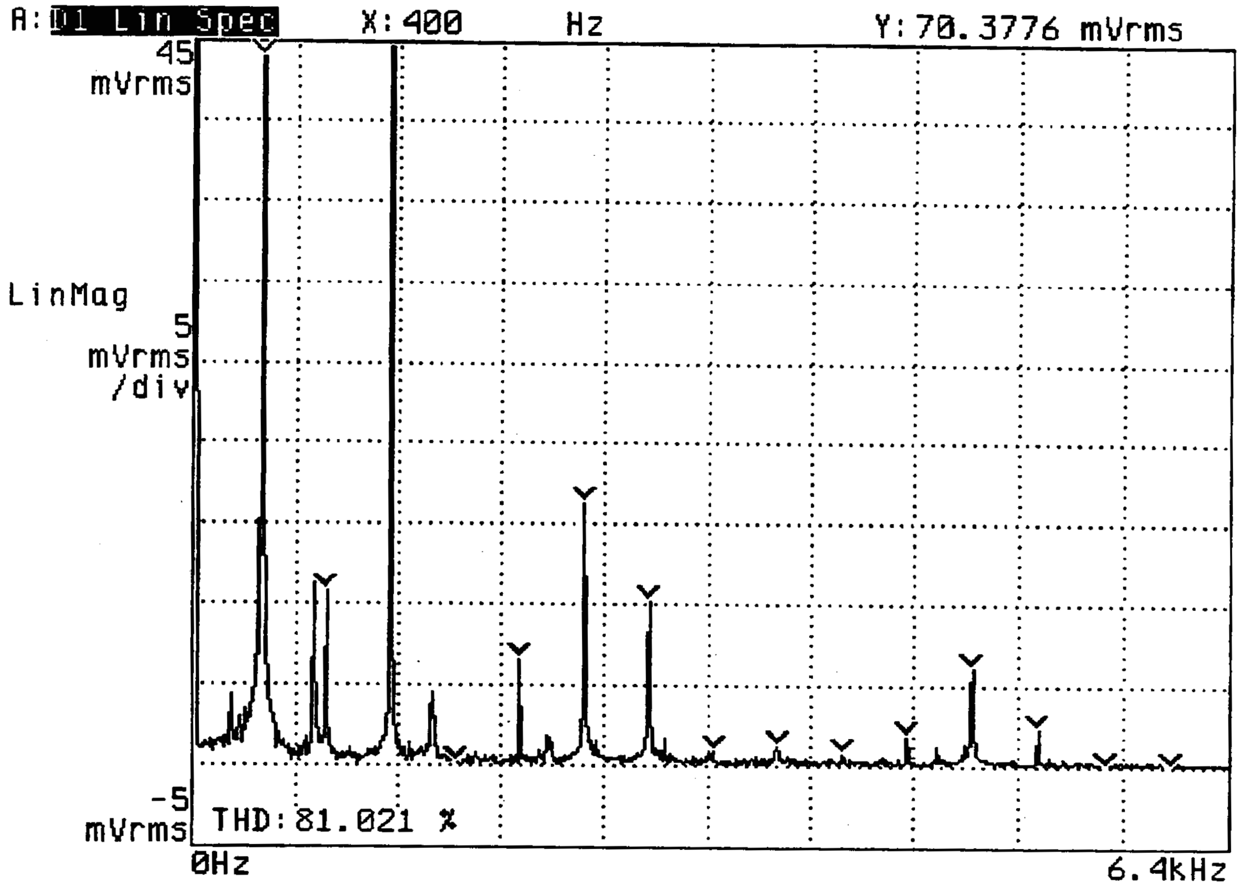

Figure F-9B: Spectrum for Keying the Passenger Address Microphone (Repeated) (Cont'd)

TRACE_09

Date: 11-19-99 Time: 05:38:00 PM

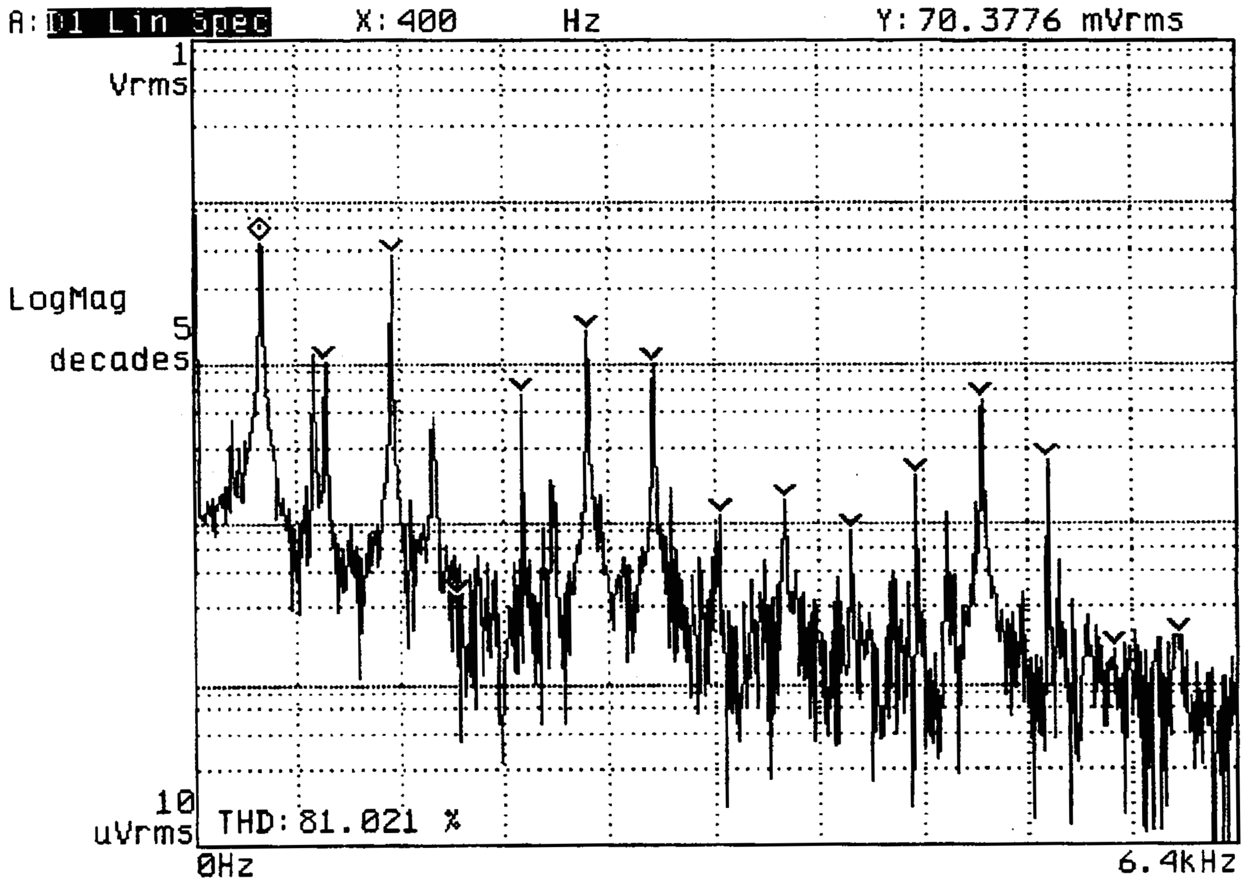

Figure F-9C: Spectrum for Keying the Passenger Address Microphone (Repeated) (Cont'd)

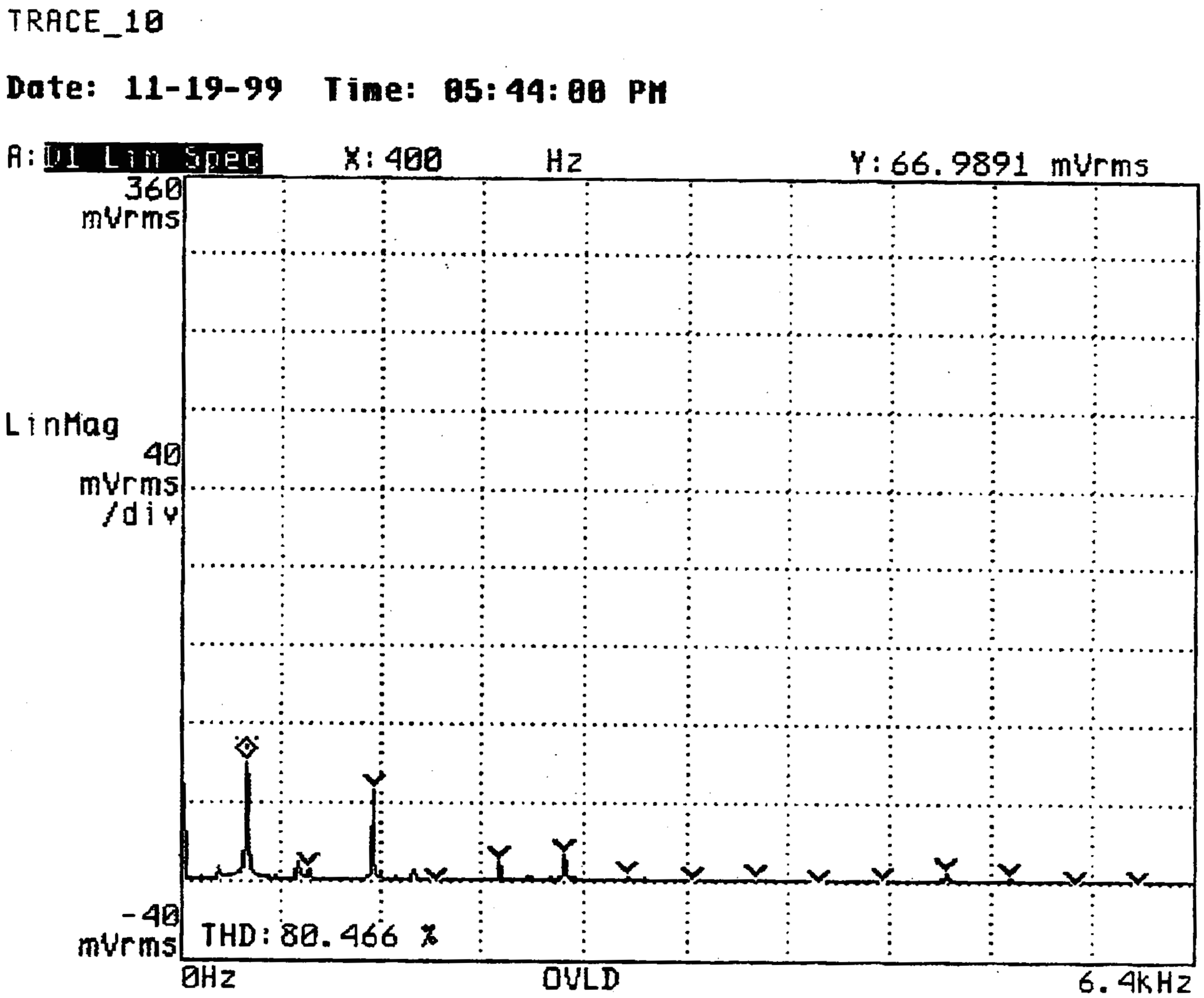

Figure F-10A: Spectrum for Passenger Address Pressed on Captain's Audio

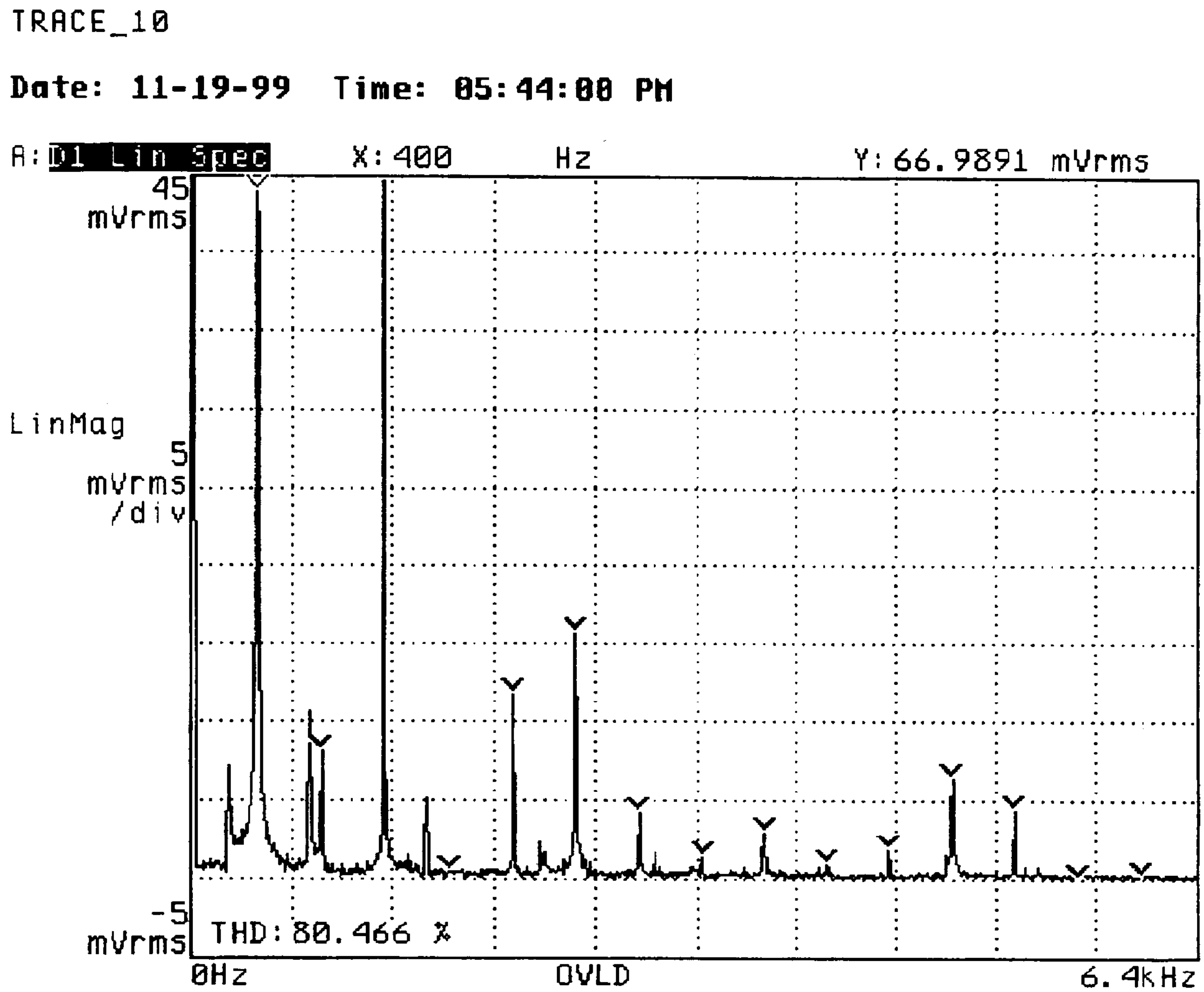

Figure F-10B: Spectrum for Passenger Address Pressed on Captain's Audio (Cont'd)

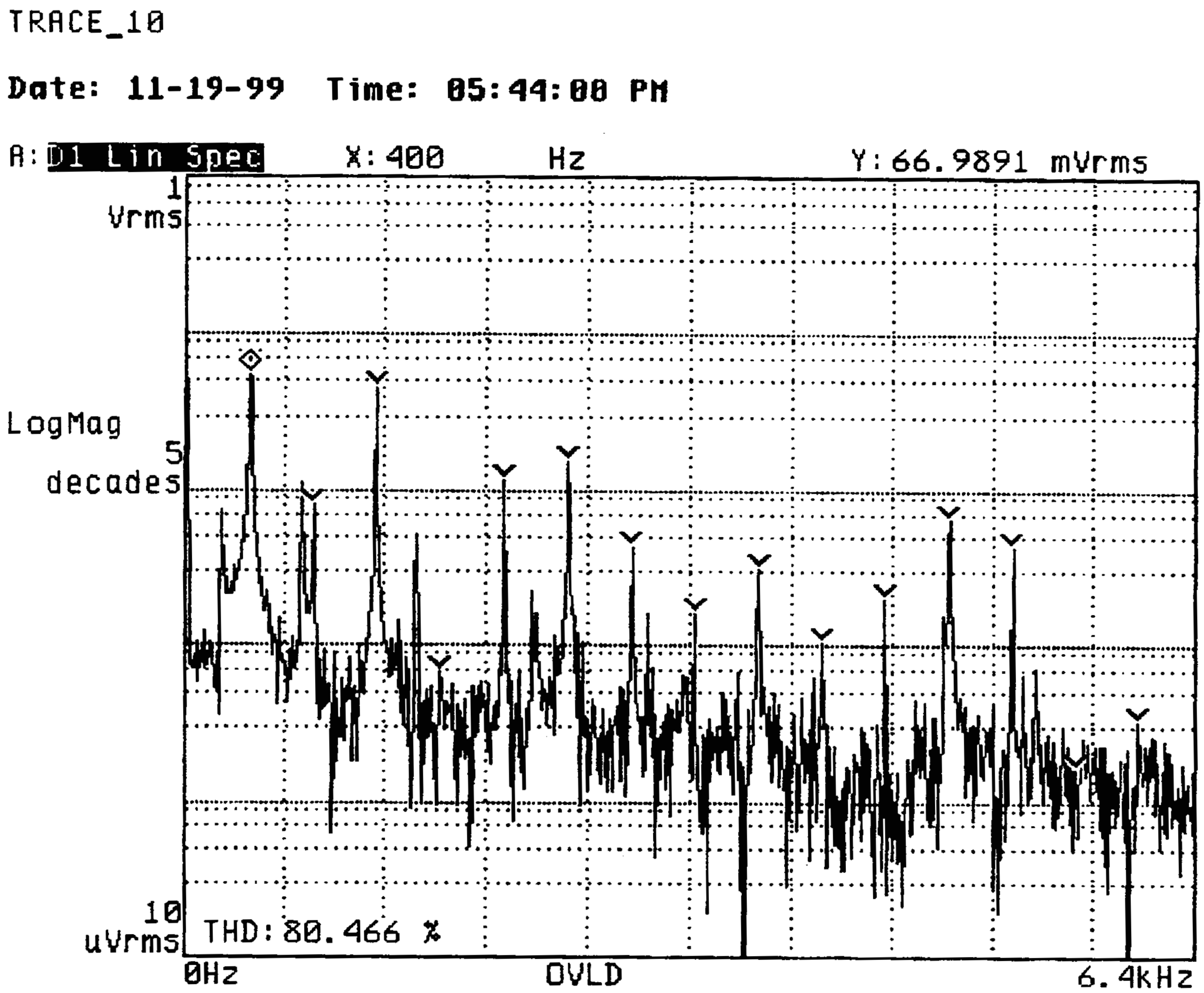

Figure F-10C: Spectrum for Passenger Address Pressed on Captain's Audio (Cont'd)

TRACE_11

'Date: 11-19-99 Time: 05:49:00 PM

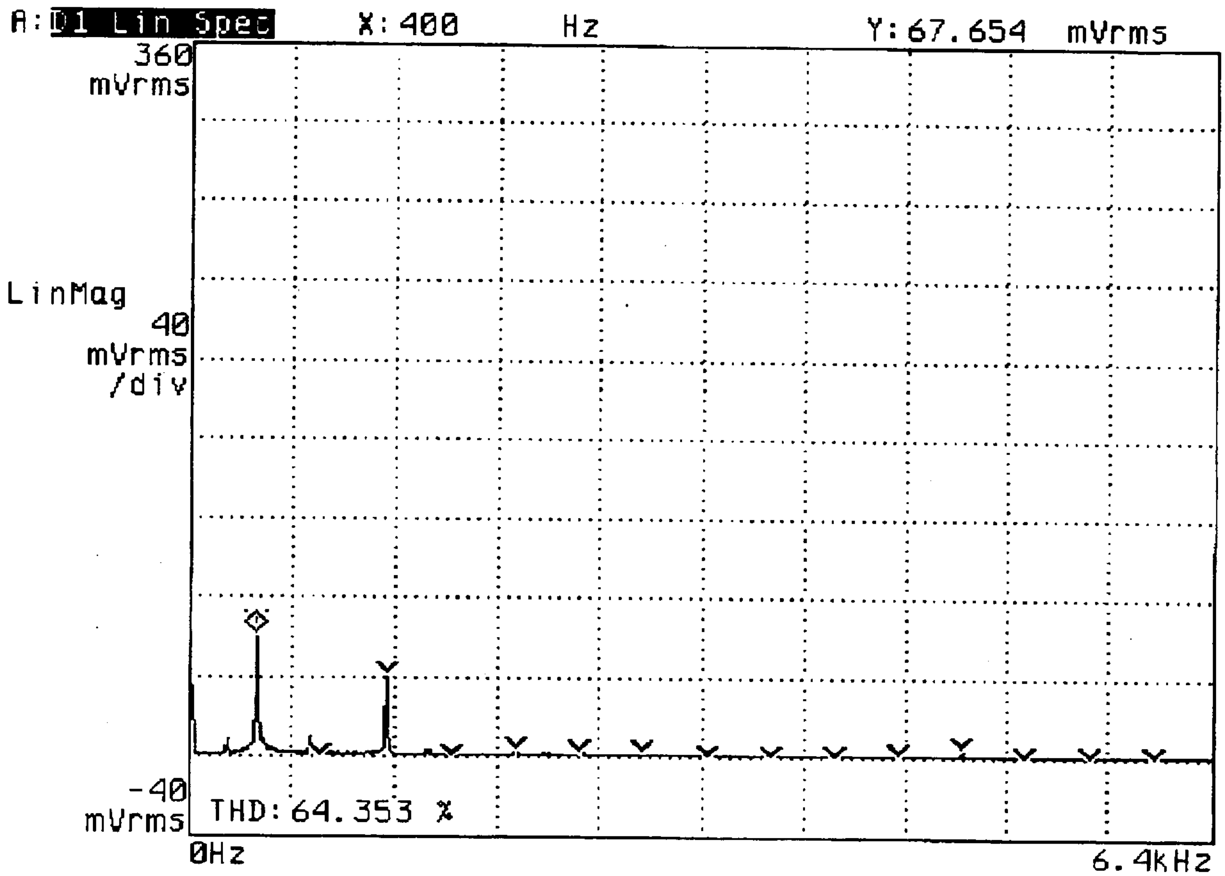

Figure F-11A: Spectrum for Open Split System Breaker

TRACE_11

Date: 11-19-99 Time: 05:49:00 PM

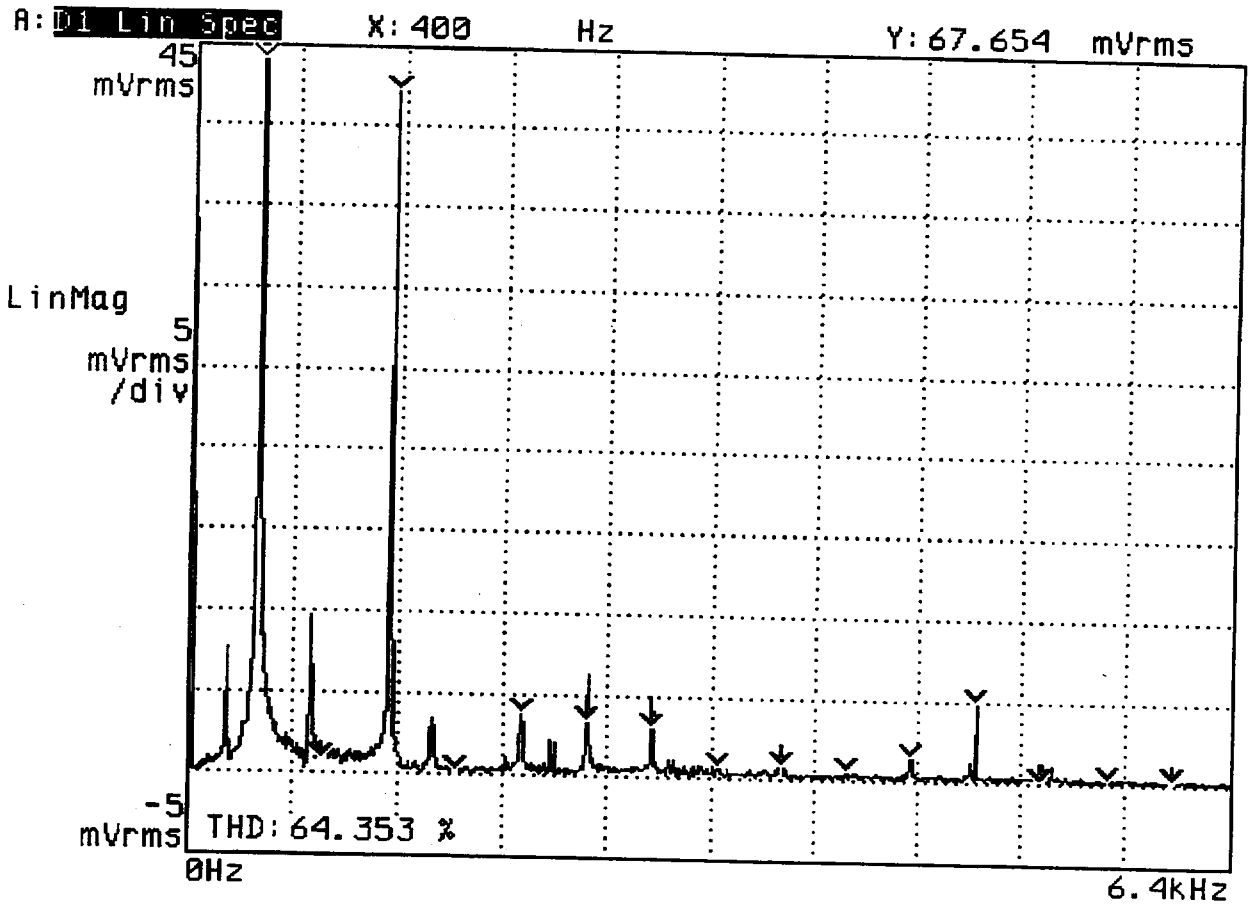

Figure F-11B: Spectrum for Open Split System Breaker (Cont'd)

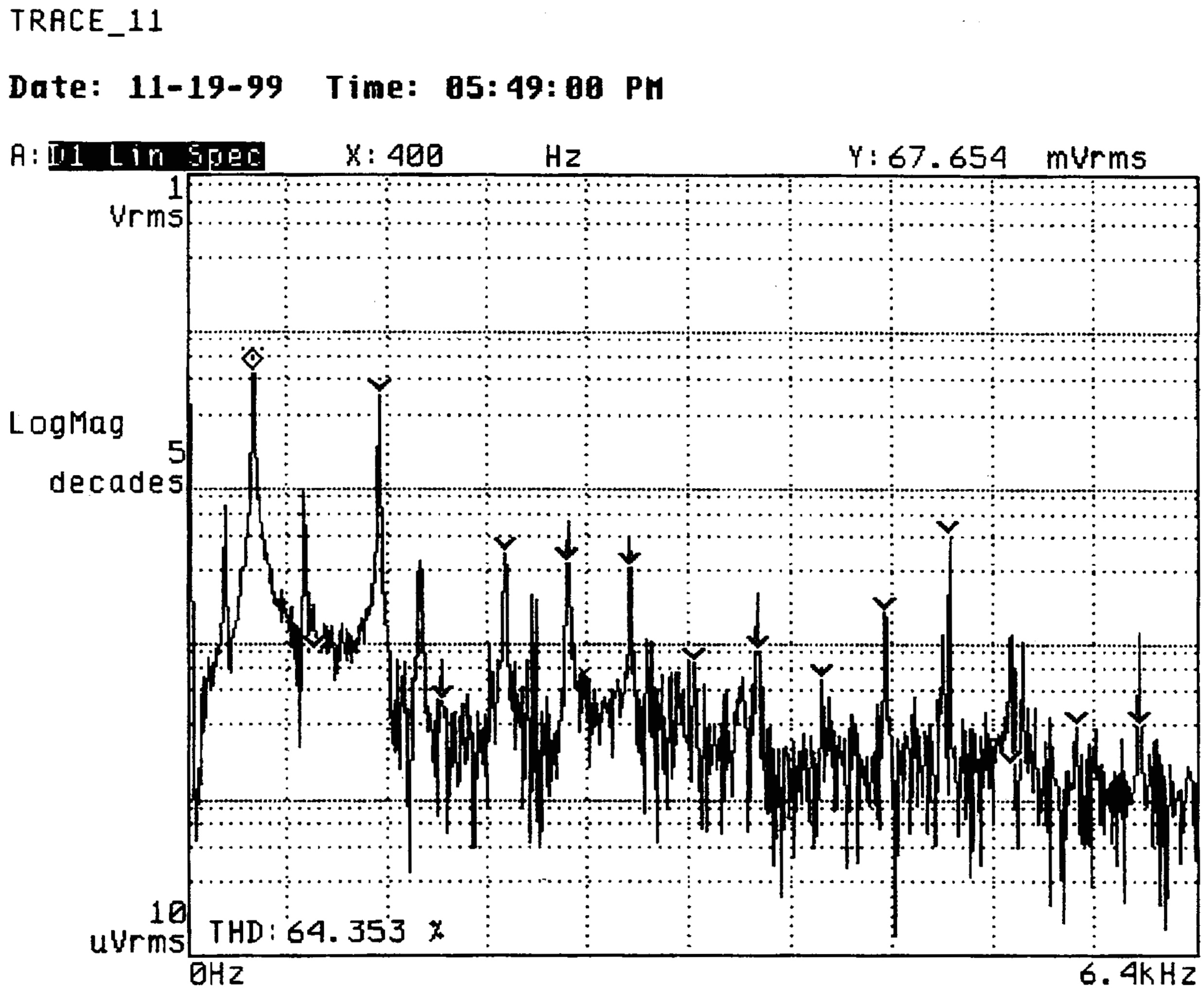

Figure F-11C: Spectrum for Open Split System Breaker (Cont'd)

TRACE_12

Date: 11-19-99 Time: 05:51:00 PM

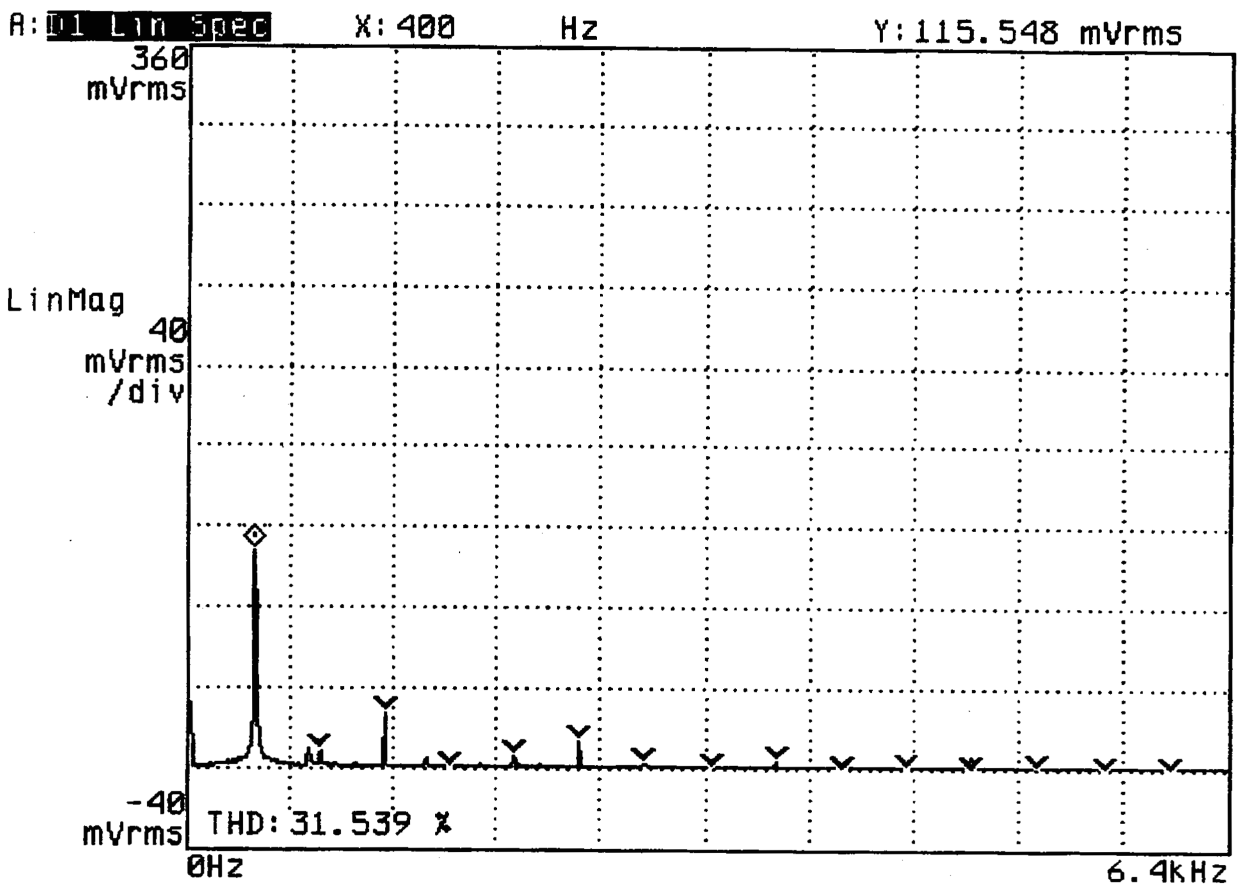

Figure F-12A: Spectrum for Open GCB 3 and GCB 4

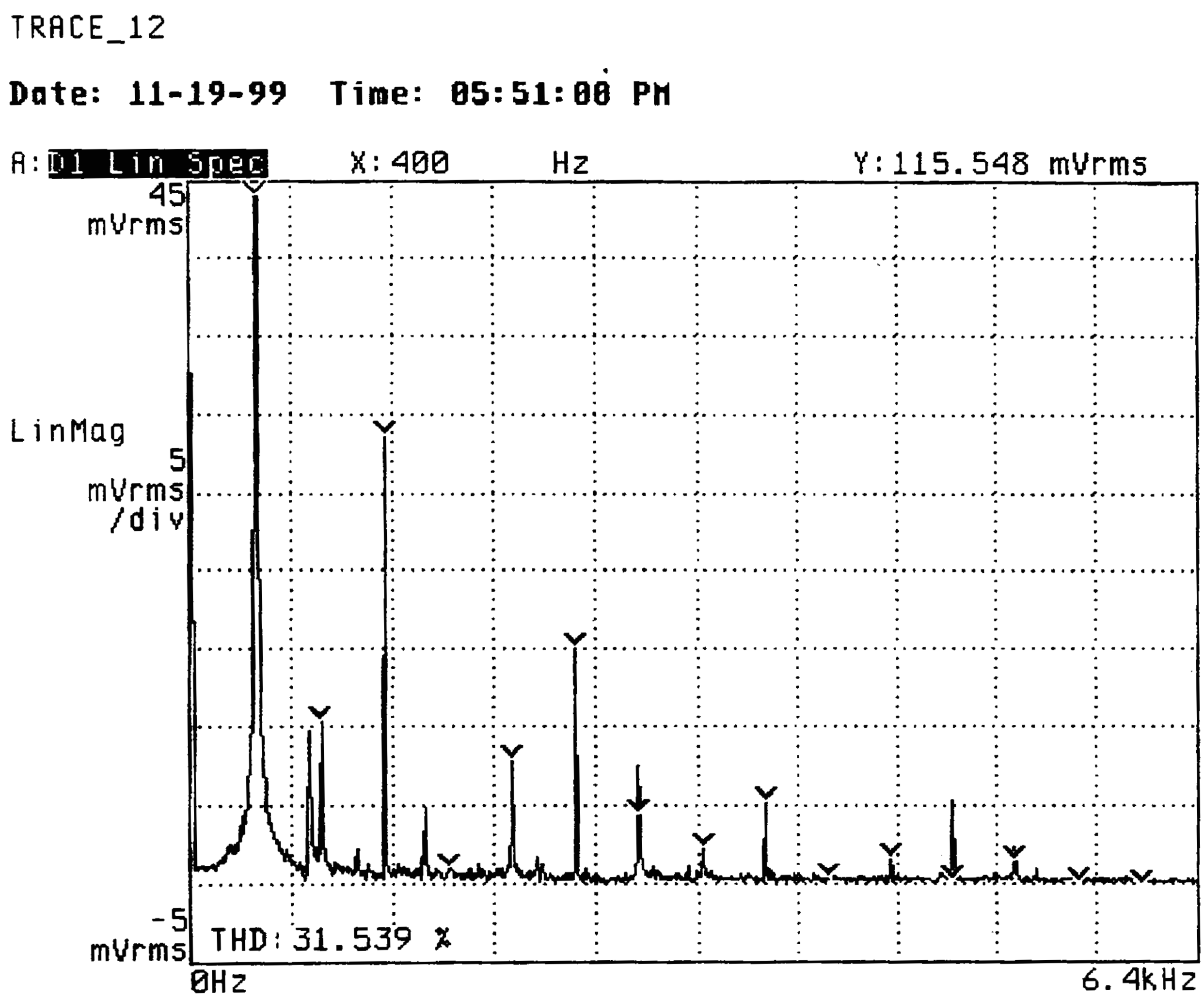

Figure F-12B: Spectrum for Open GCB 3 and GCB 4 (Cont'd)

TRACE_12

Date: 11-19-99 Time: 05:51:00 PM

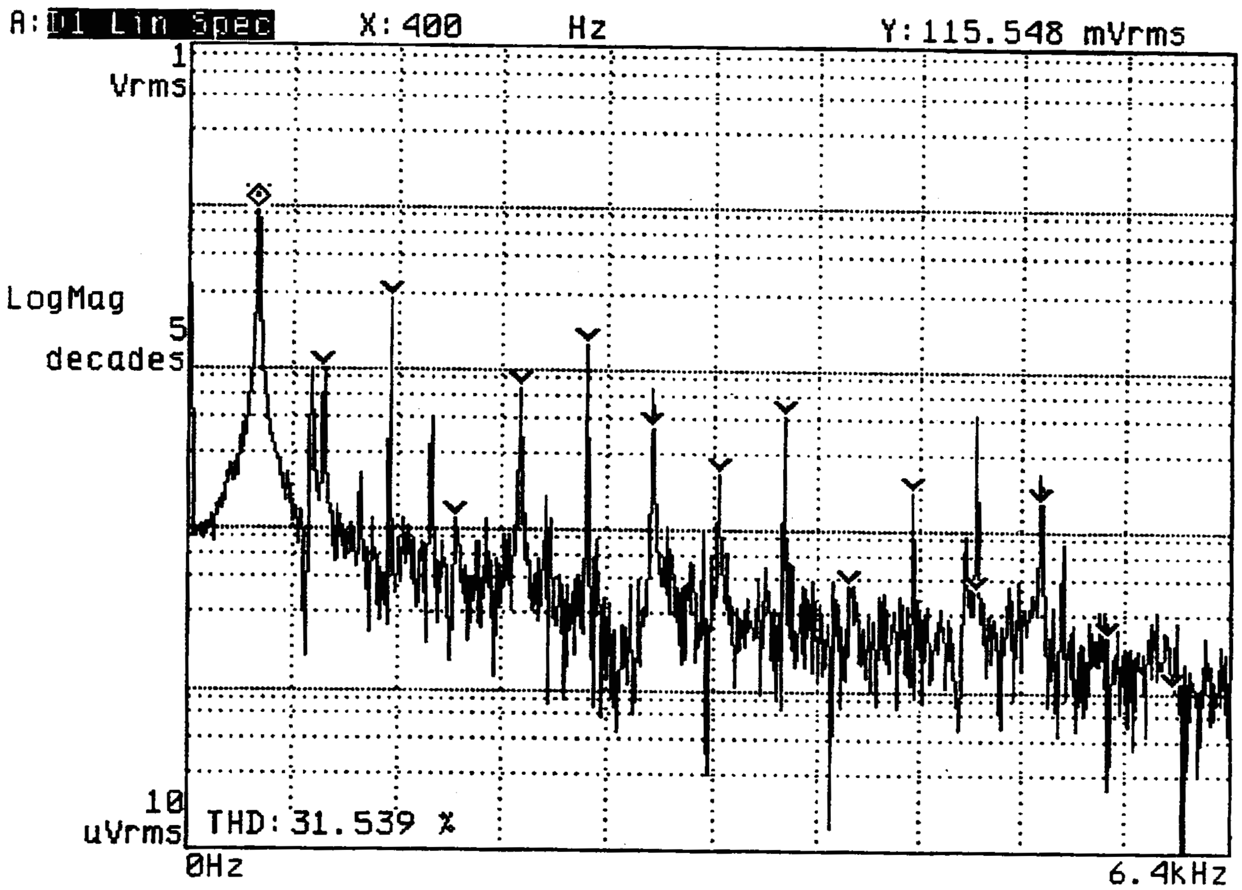

Figure F-12C: Spectrum for Open GCB 3 and GCB 4 (Cont'd)

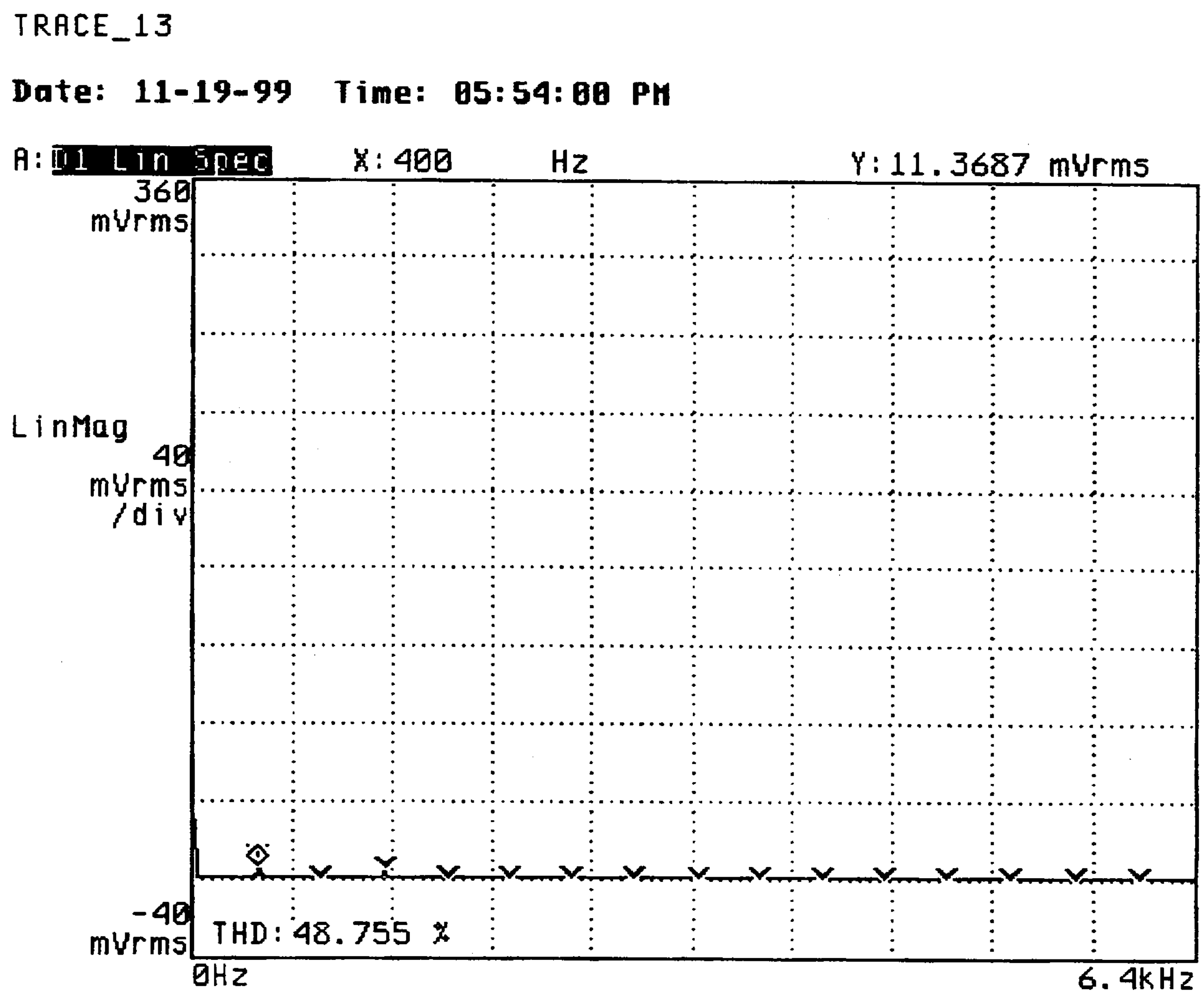

Figure F-13A: Spectrum for All GCB's Open, No Emergency Lights

TRACE_13

Date: 11-19-99 Time: 05:54:00 PM

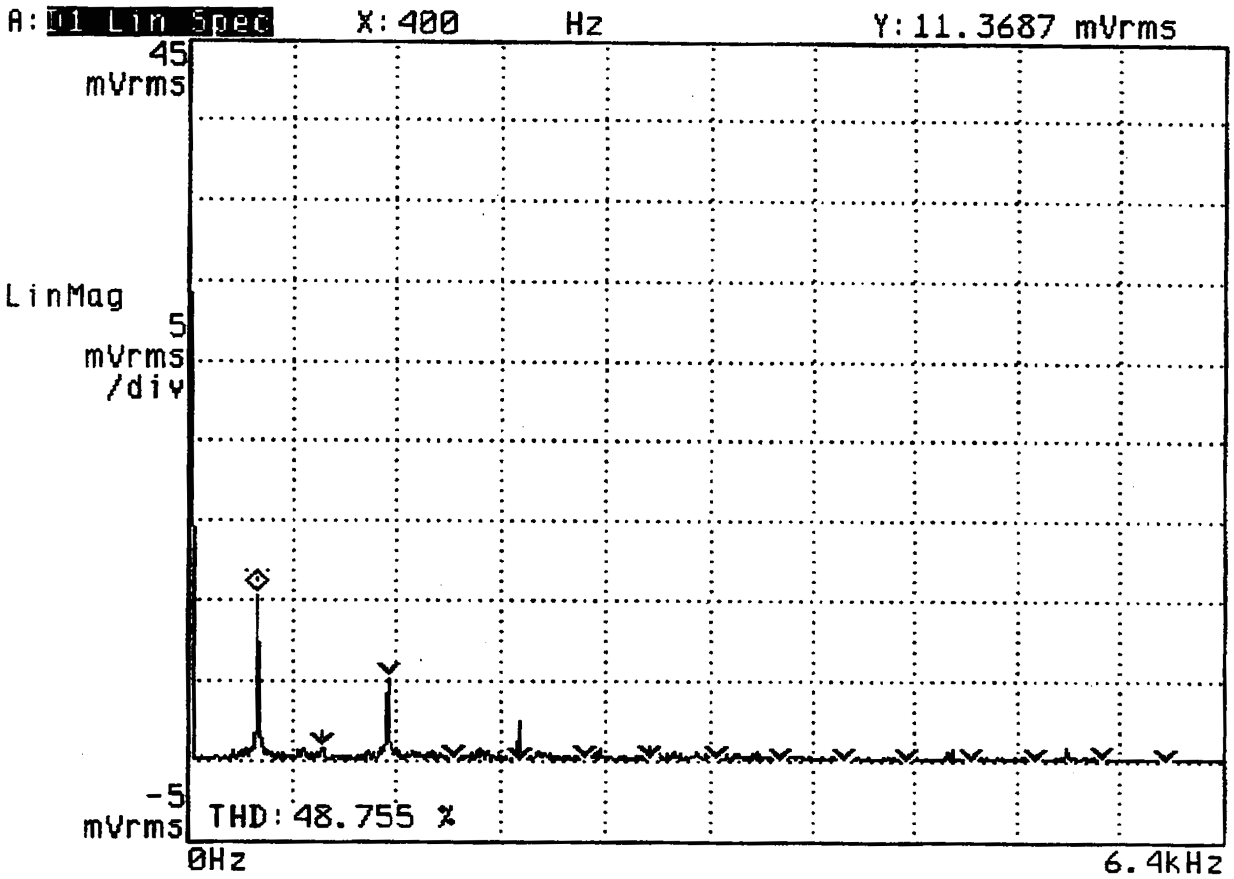

Figure F-13B: Spectrum for All GCB's Open, No Emergency Lights (Cont'd)

TRACE_13

Date: 11-19-99 Time: 05:54:00 PM

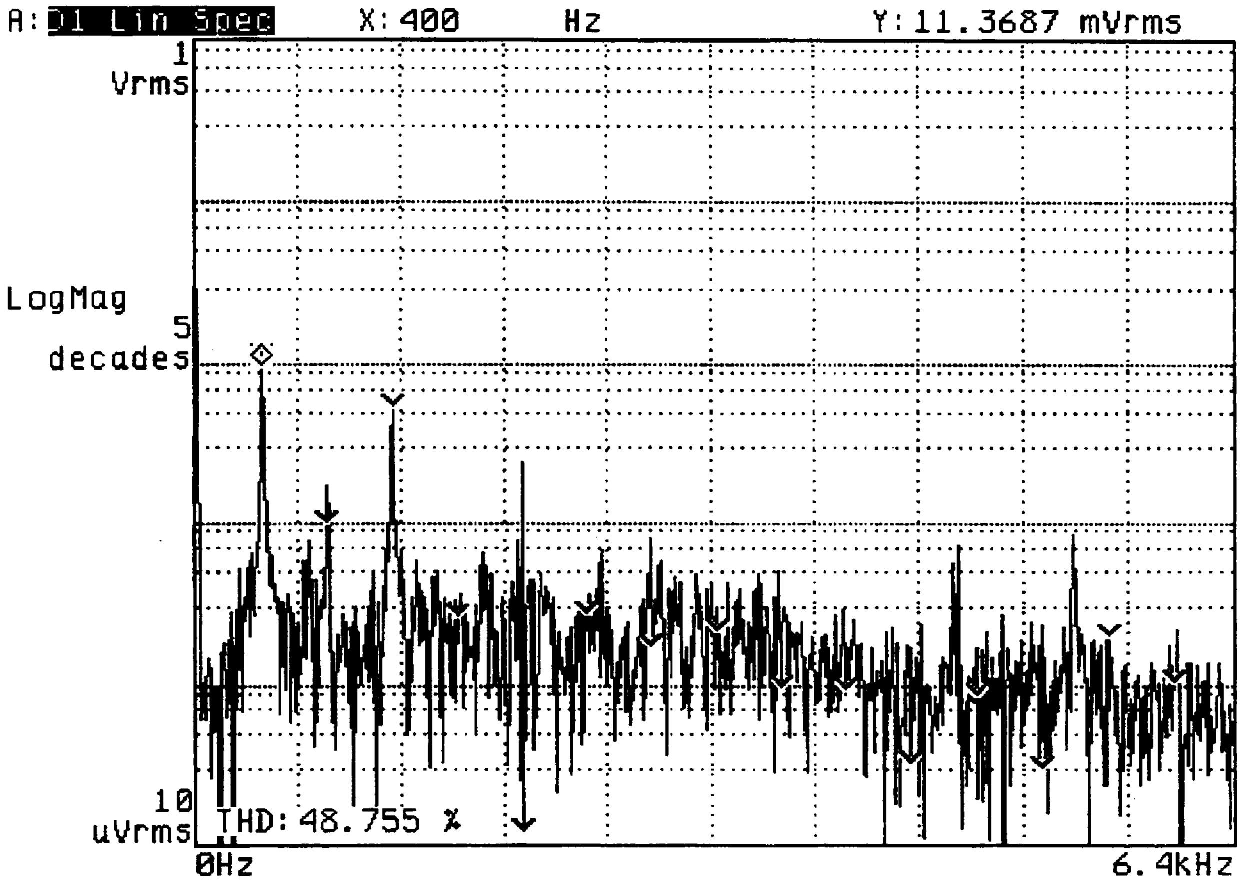

Figure F-13C: Spectrum for All GCB's Open, No Emergency Lights (Cont'd)

FOR OFFICIAL USE ONLY

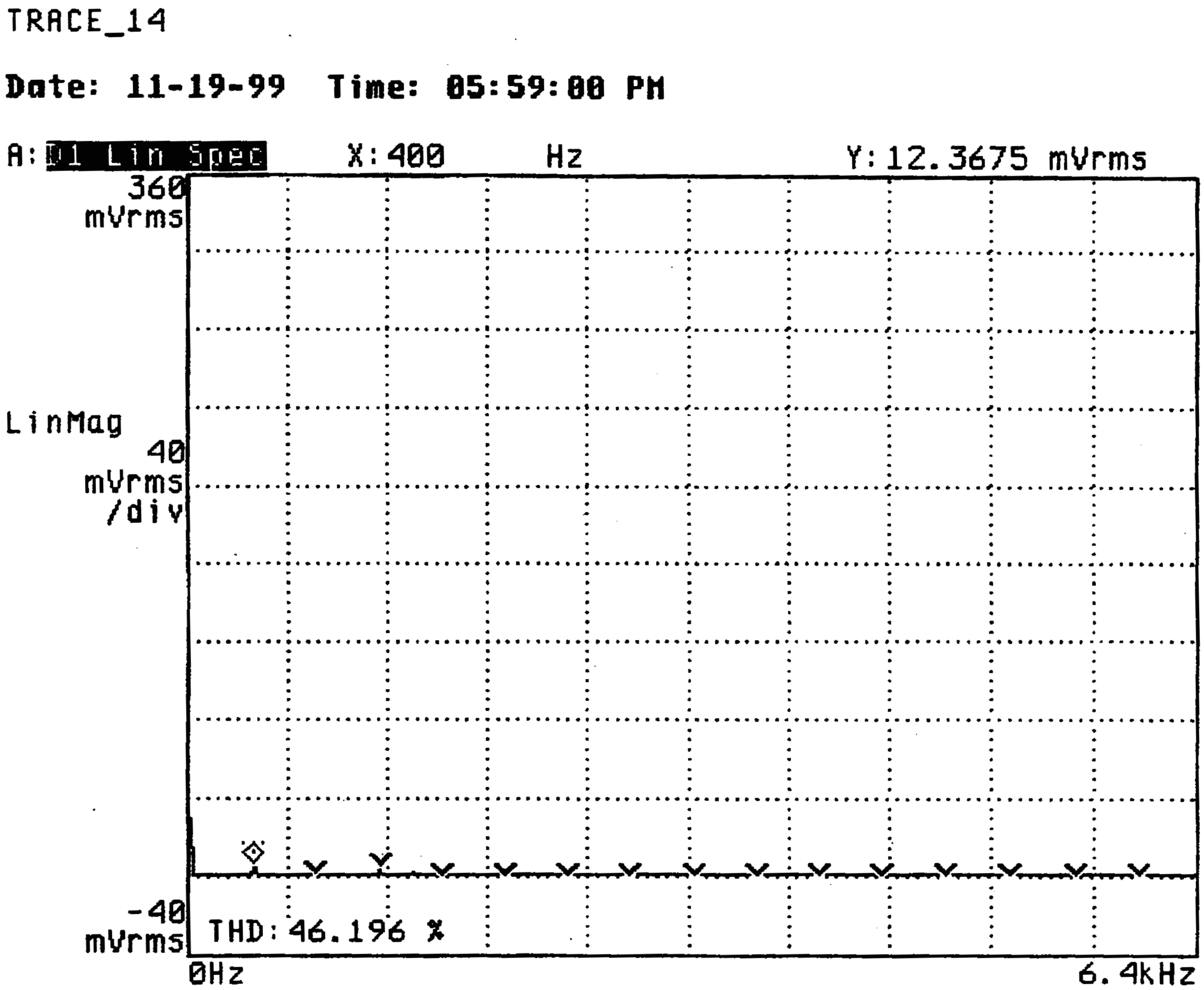

Figure F-14A: Spectrum for All GCB's Open, No Emergency Lights (Repeated)

TRACE_14

Date: 11-19-99 Time: 05:59:00 PM

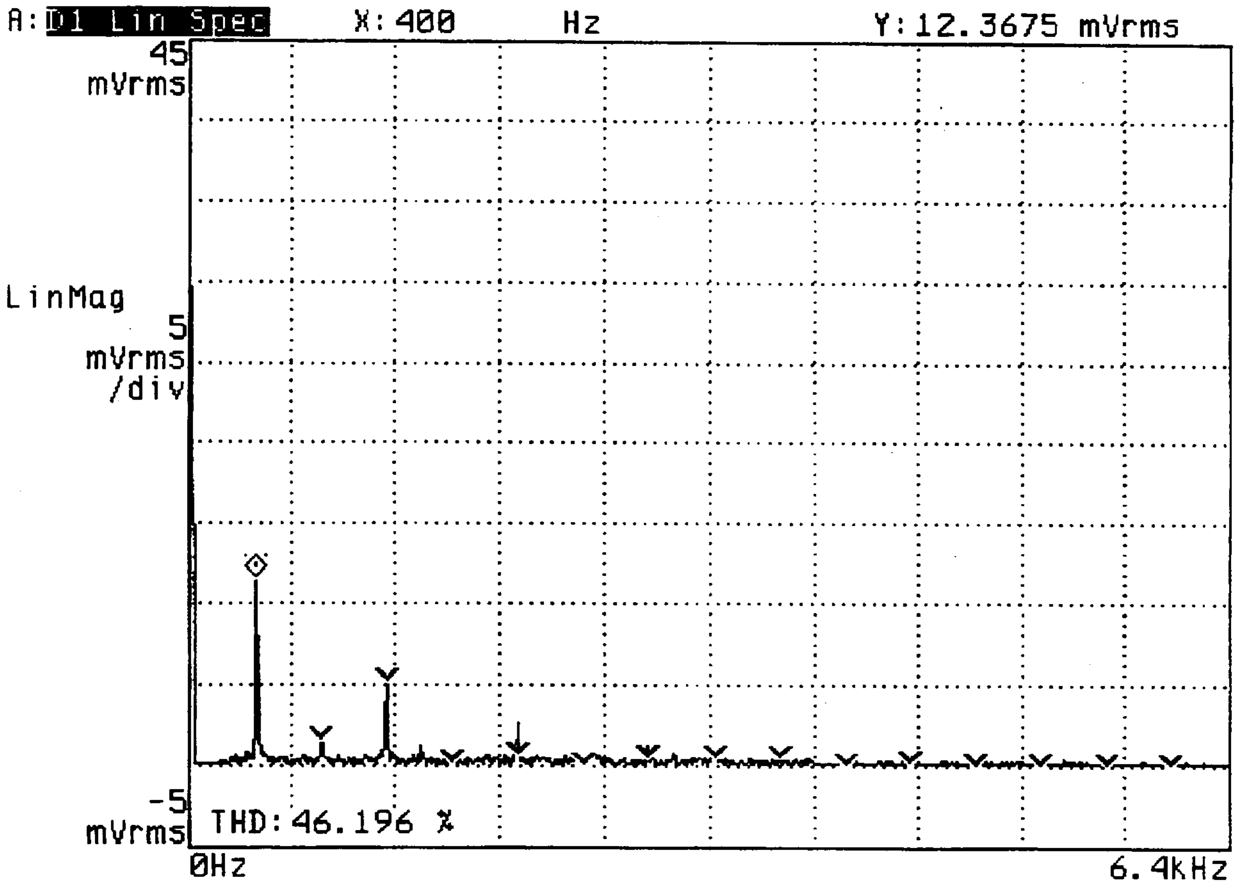

Figure F-14B: Spectrum for All GCB's Open, No Emergency Lights (Repeated) (Cont'd)

TRACE_14

Date: 11-19-99   Time: 05:59:00 PM

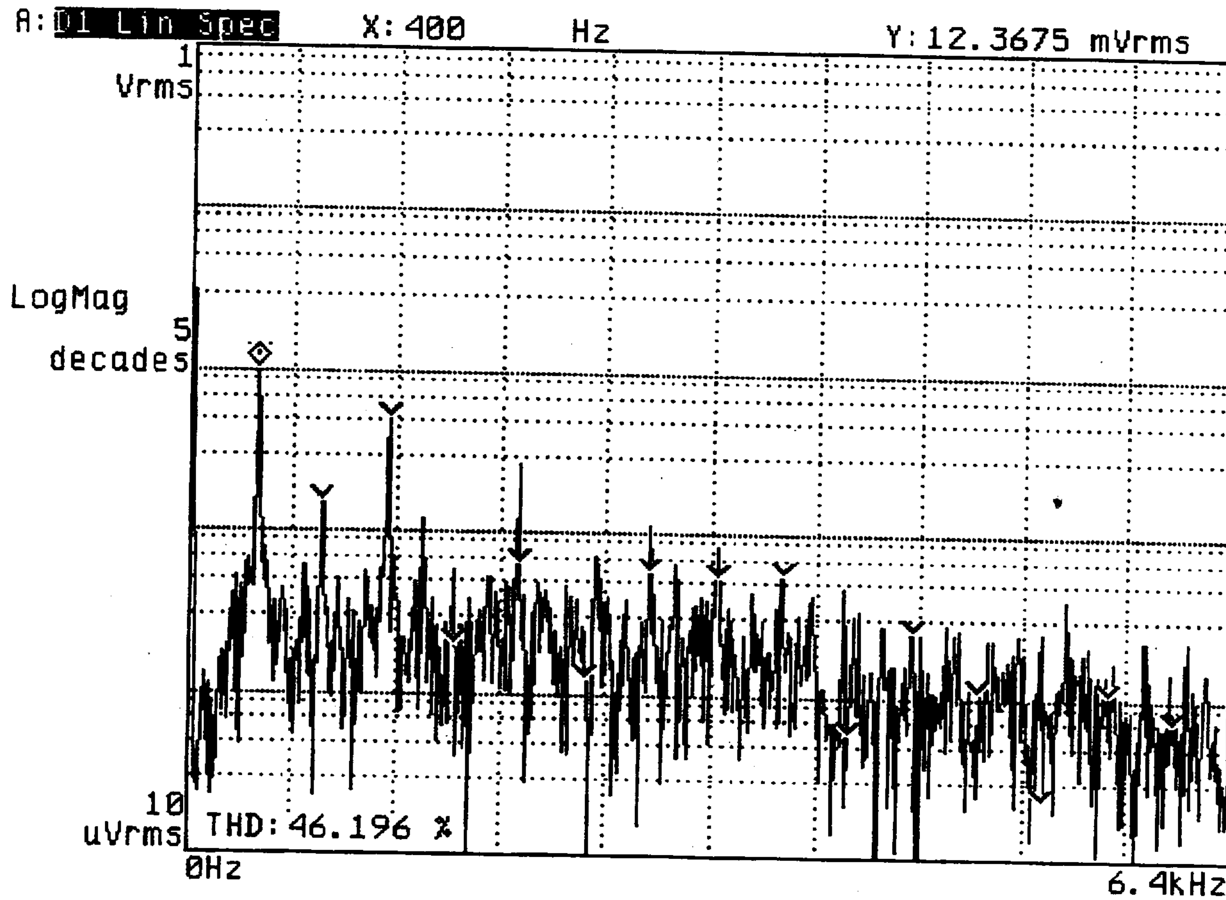

Figure F-14C: Spectrum for All GCB's Open, No Emergency Lights (Repeated) (Cont'd)

TRACE_15

Date: 11-19-99 Time: 06:00:00 PM

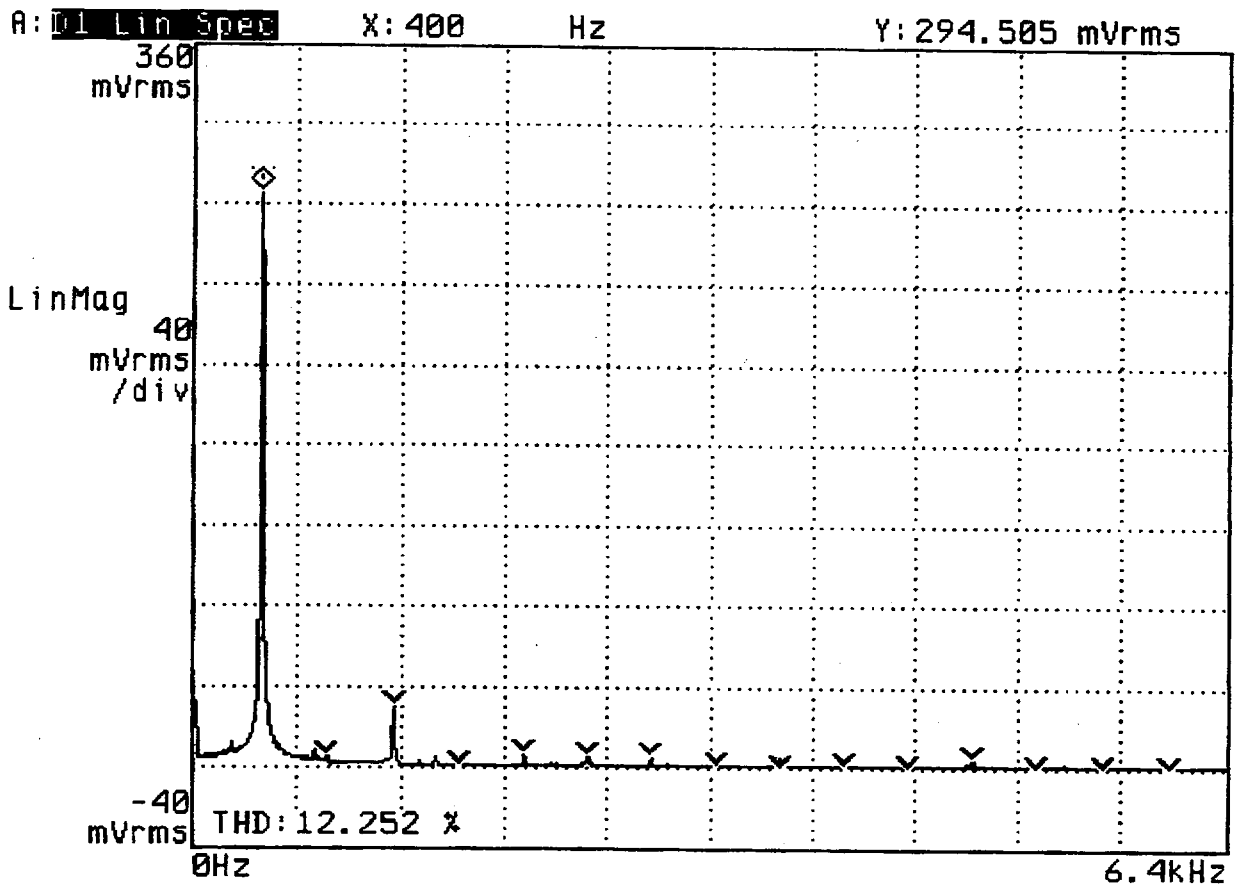

Figure F-15A: Spectrum for All GCB's Closed, No Emergency Lights
(Spectrum taken immediately after closing GCB's)

TRACE_15

Date: 11-19-99 Time: 06:00:00 PM

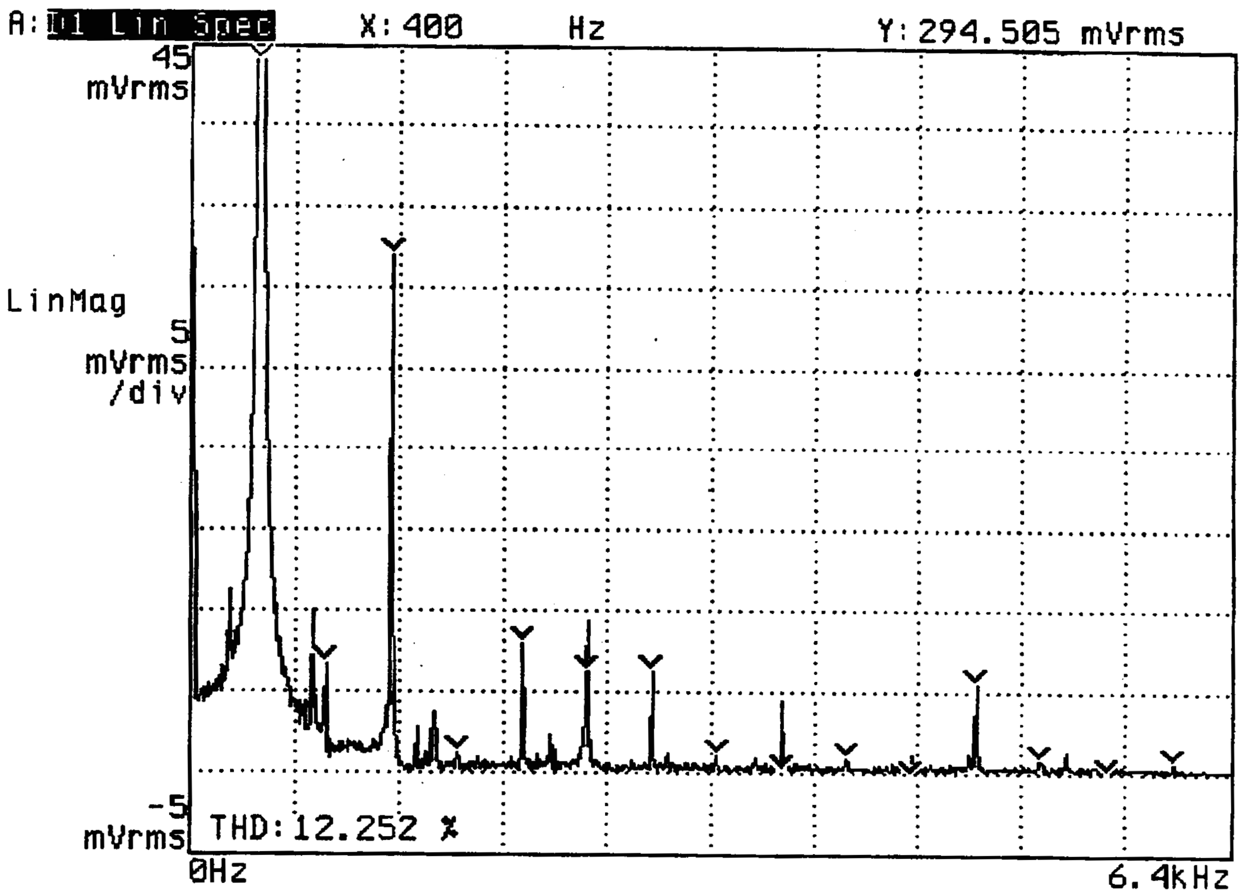

Figure F-15B: Spectrum for All GCB's Closed, No Emergency Lights (Cont'd)
(Spectrum taken immediately after closing GCB's)

TRACE_15

Date: 11-19-99 Time: 06:00:00 PM

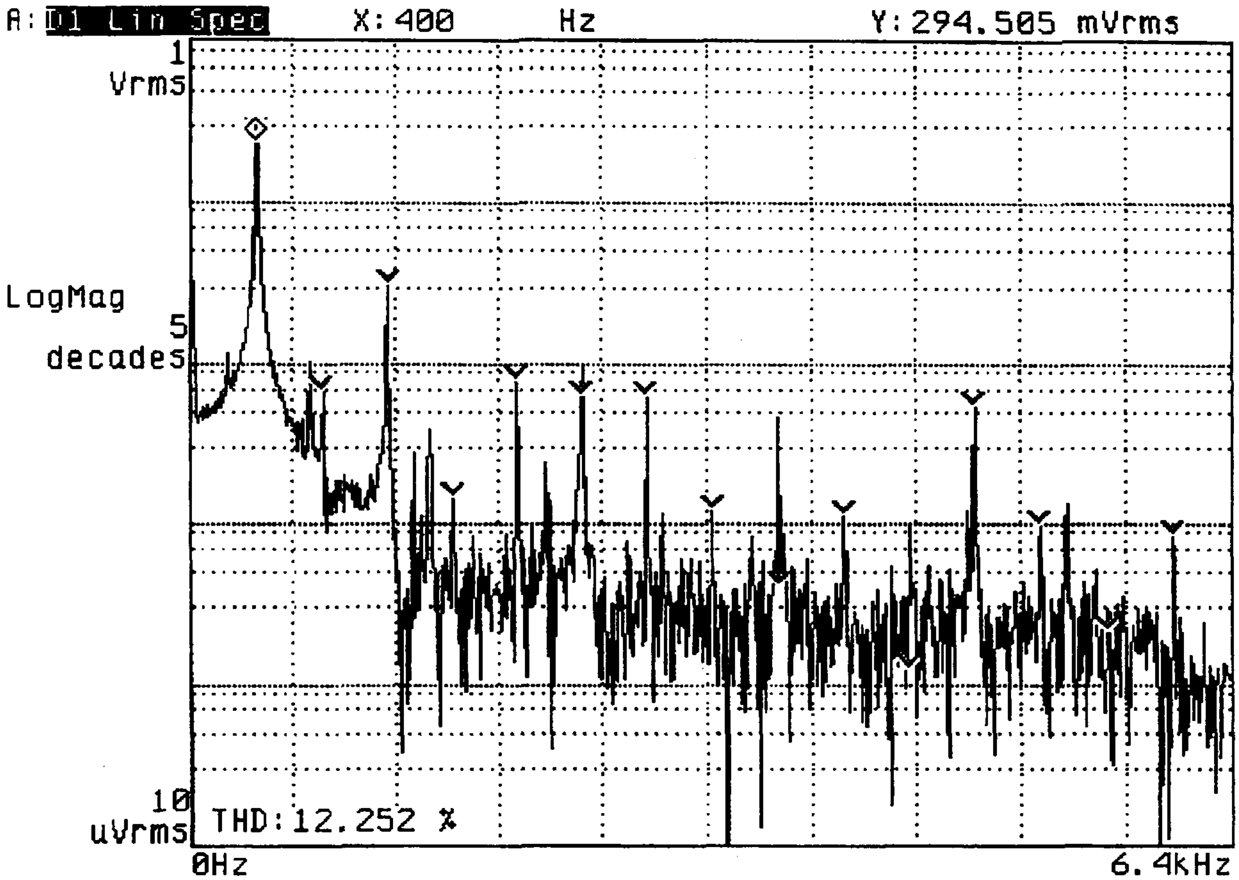

Figure F-15C: Spectrum for All GCB's Closed, No Emergency Lights (Cont'd)
(Spectrum taken immediately after closing GCB's)

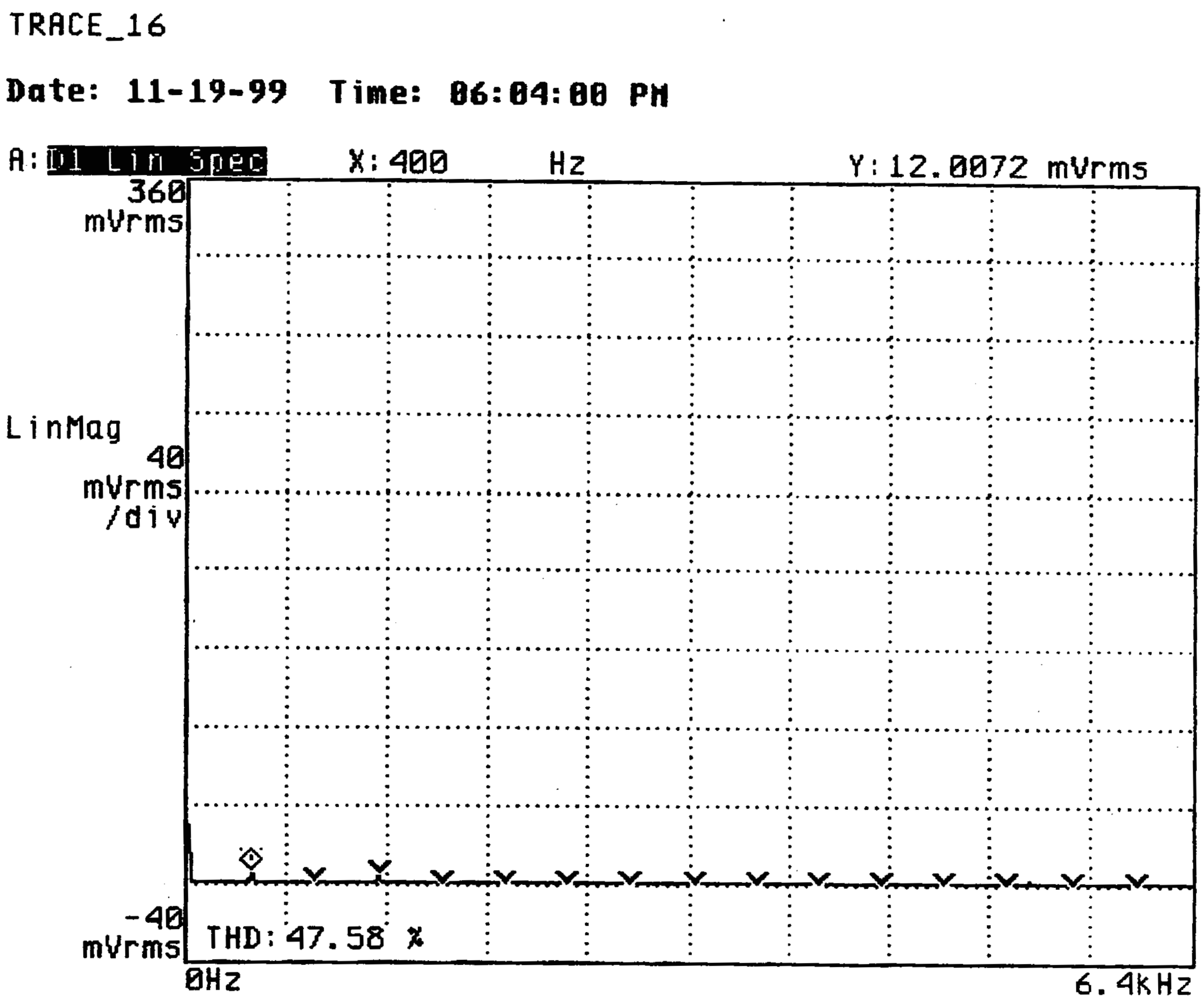

Figure F-16A: Spectrum for All GCB's Open, with Emergency Lights

TRACE_16

Date: 11-19-99 Time: 06:04:00 PM

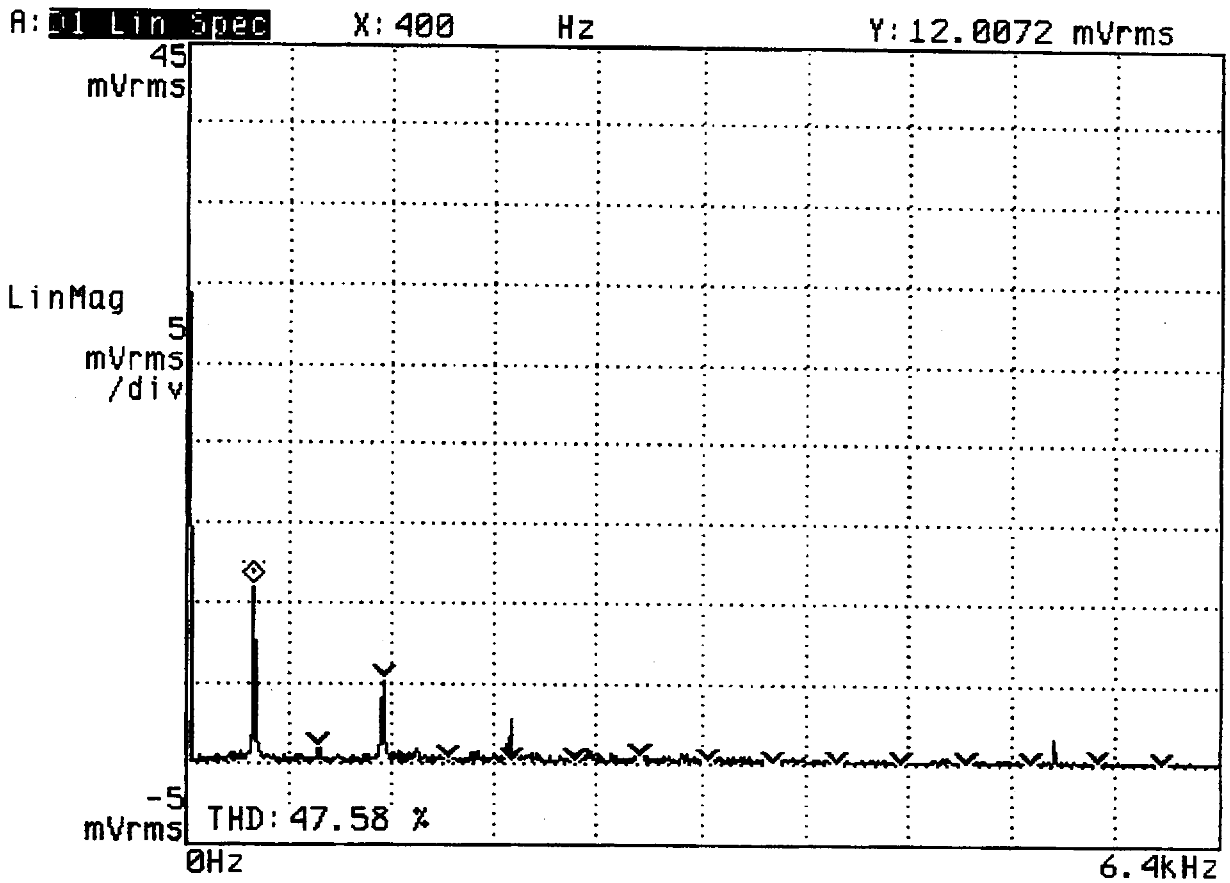

Figure F-16B: Spectrum for All GCB's Open, with Emergency Lights (Cont'd)

TRACE_16

Date: 11-19-99 Time: 06:04:00 PM

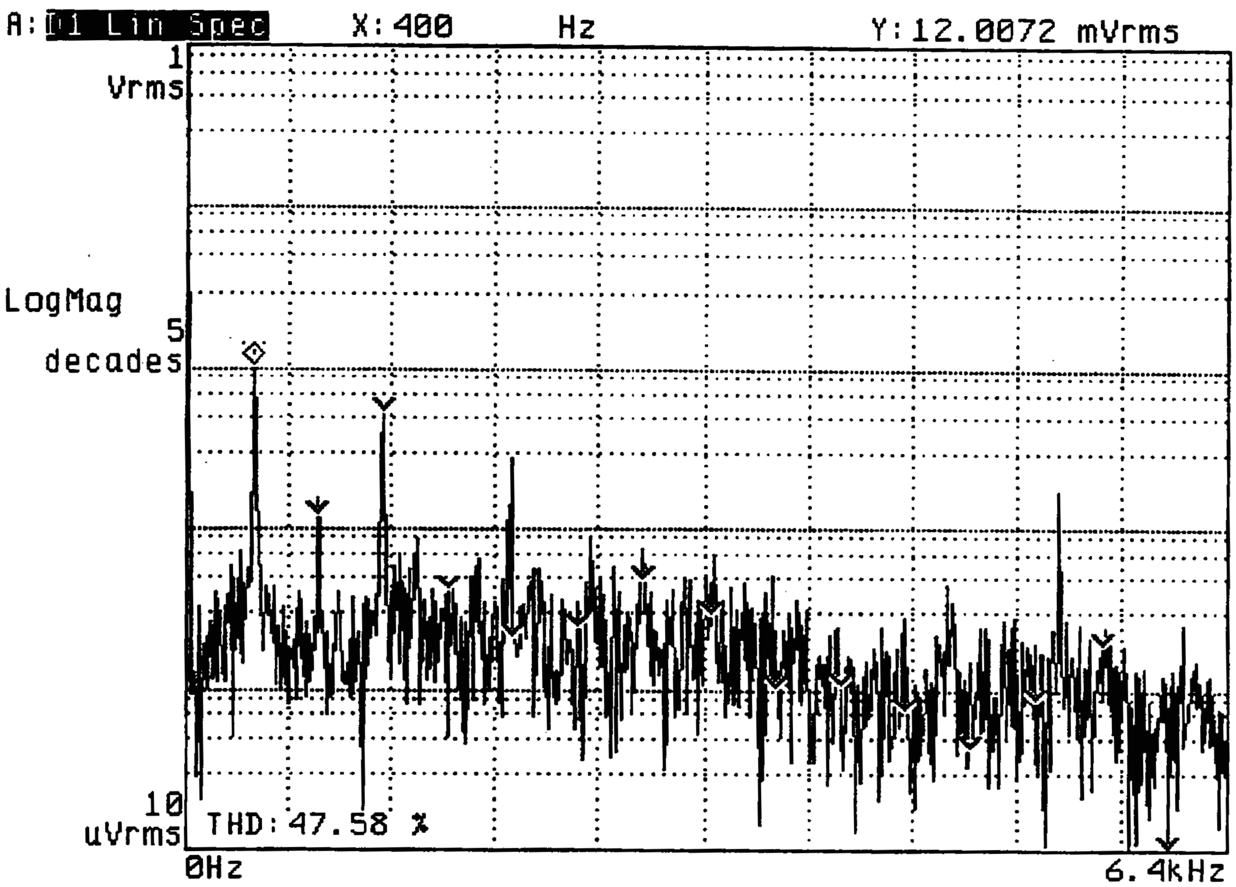

Figure F-16C: Spectrum for All GCB's Open, with Emergency Lights (Cont'd)

TRACE_17

Date: 11-19-99 Time: 06:05:00 PM

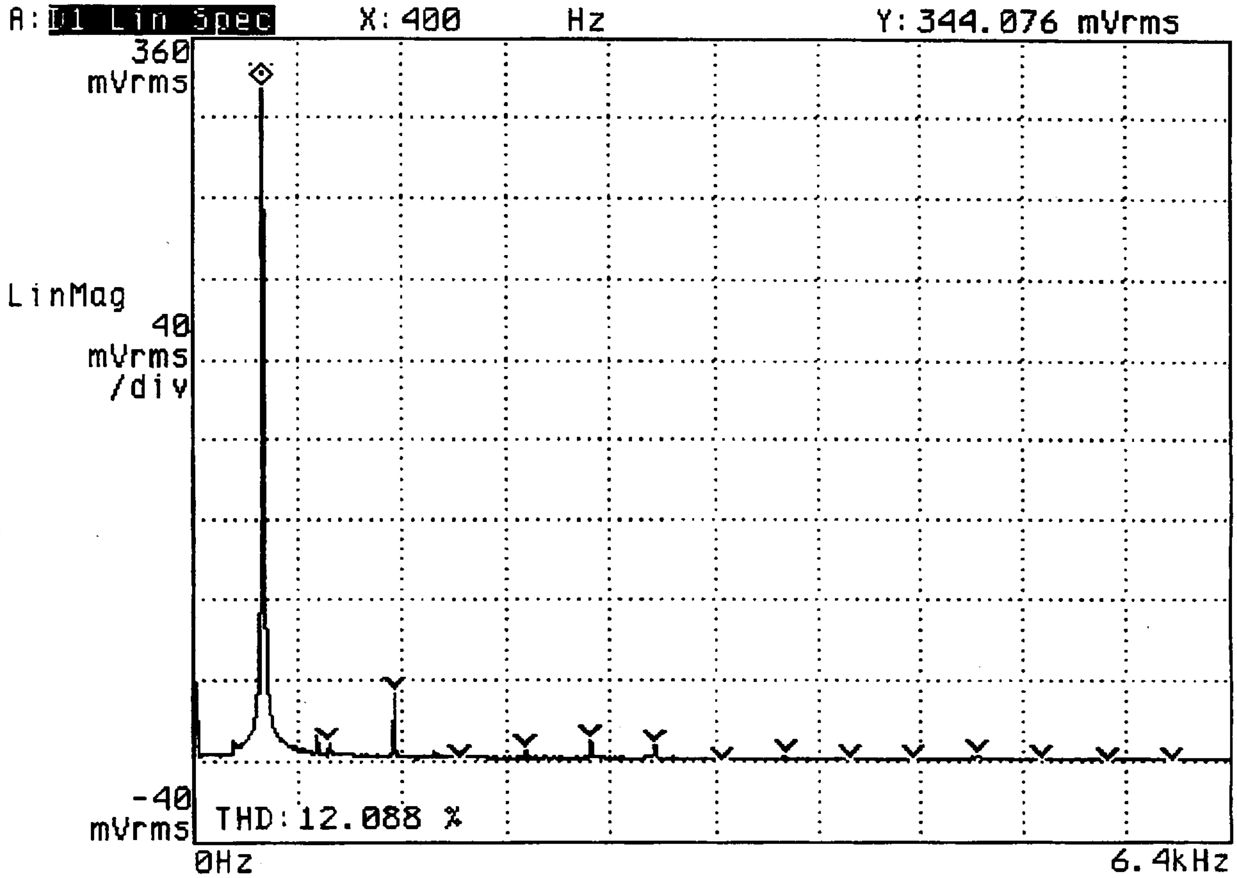

Figure F-17A: Spectrum for All GCB's Closed
(Spectrum taken immediately after closing GCB's)

TRACE_17

Date: 11-19-99 Time: 06:05:00 PM

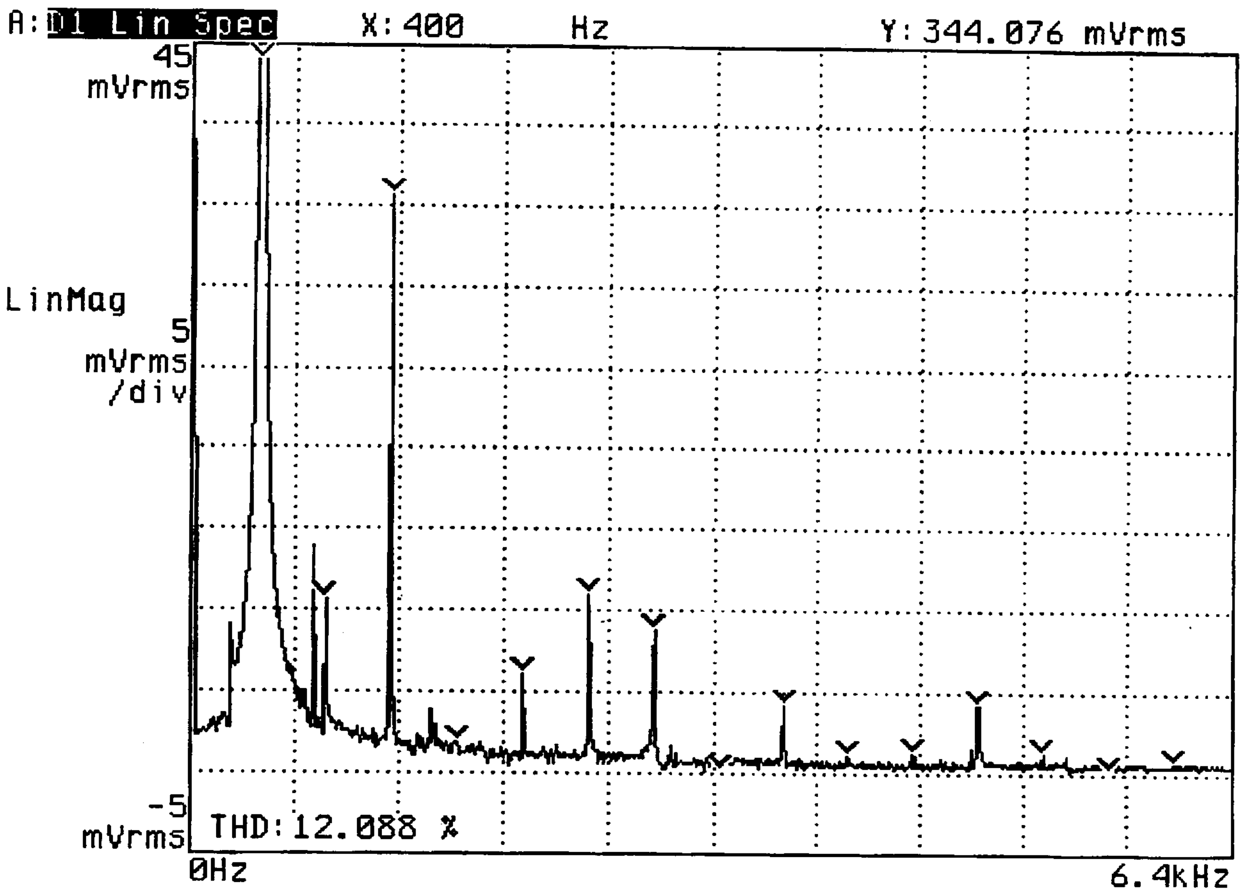

Figure F-17B: Spectrum for All GCB's Closed (Cont'd)
(Spectrum taken immediately after closing GCB's)

TRACE_17

Date: 11-19-99 Time: 06:05:00 PM

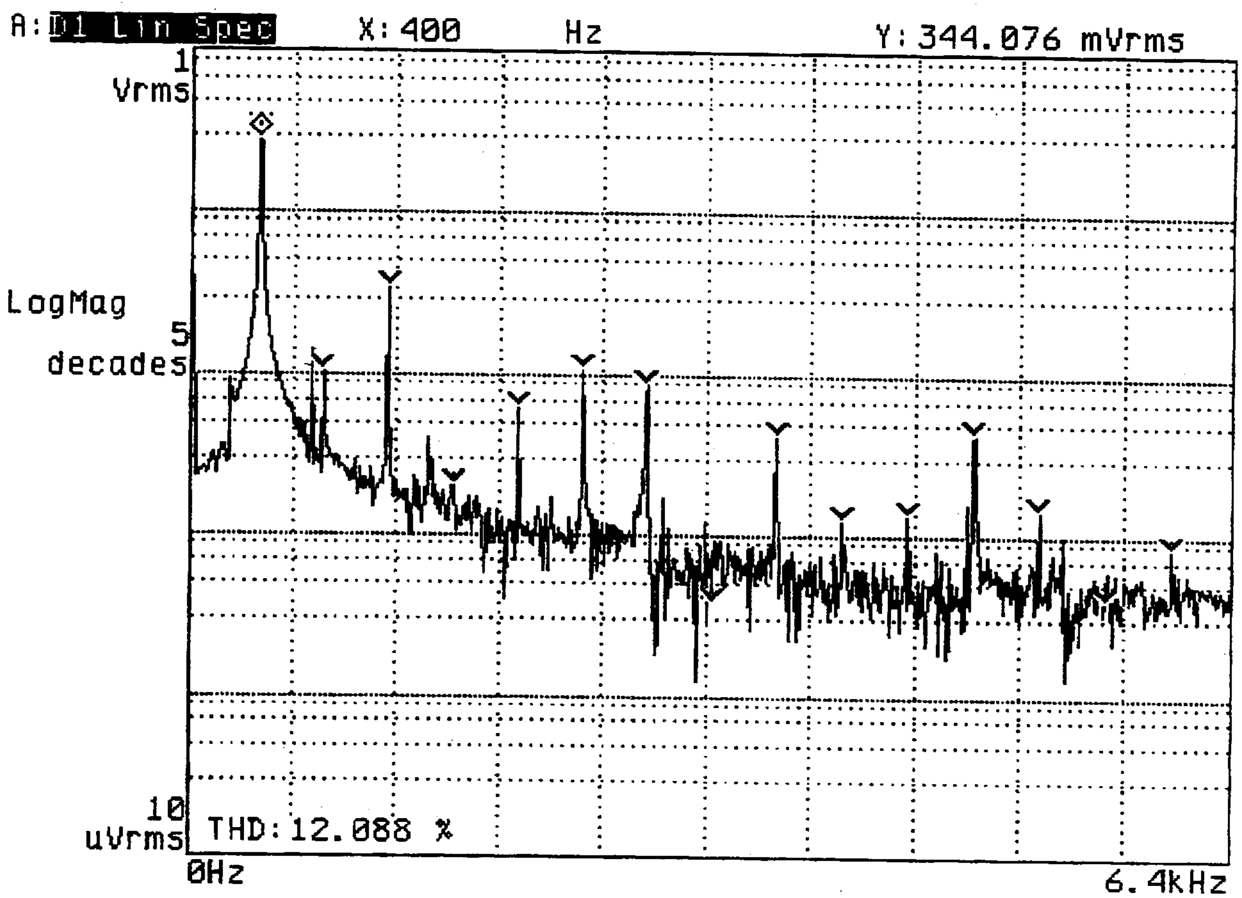

Figure F-17C: Spectrum for All GCB's Closed (Cont'd)
(Spectrum taken immediately after closing GCB's)

TRACE_18

Date: 11-19-99 Time: 06:07:00 PM

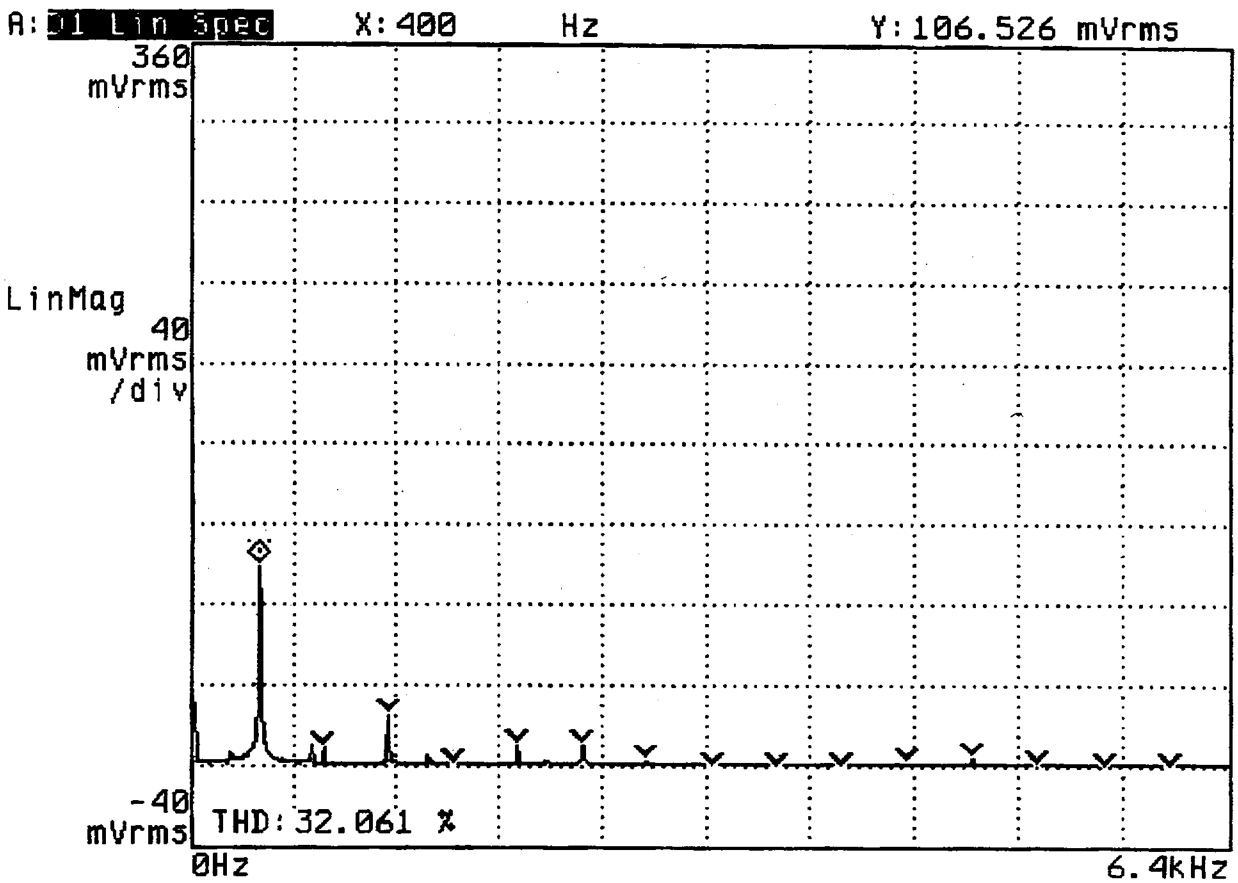

Figure F-18A: Spectrum for GCB 1 and GCB 2 Open

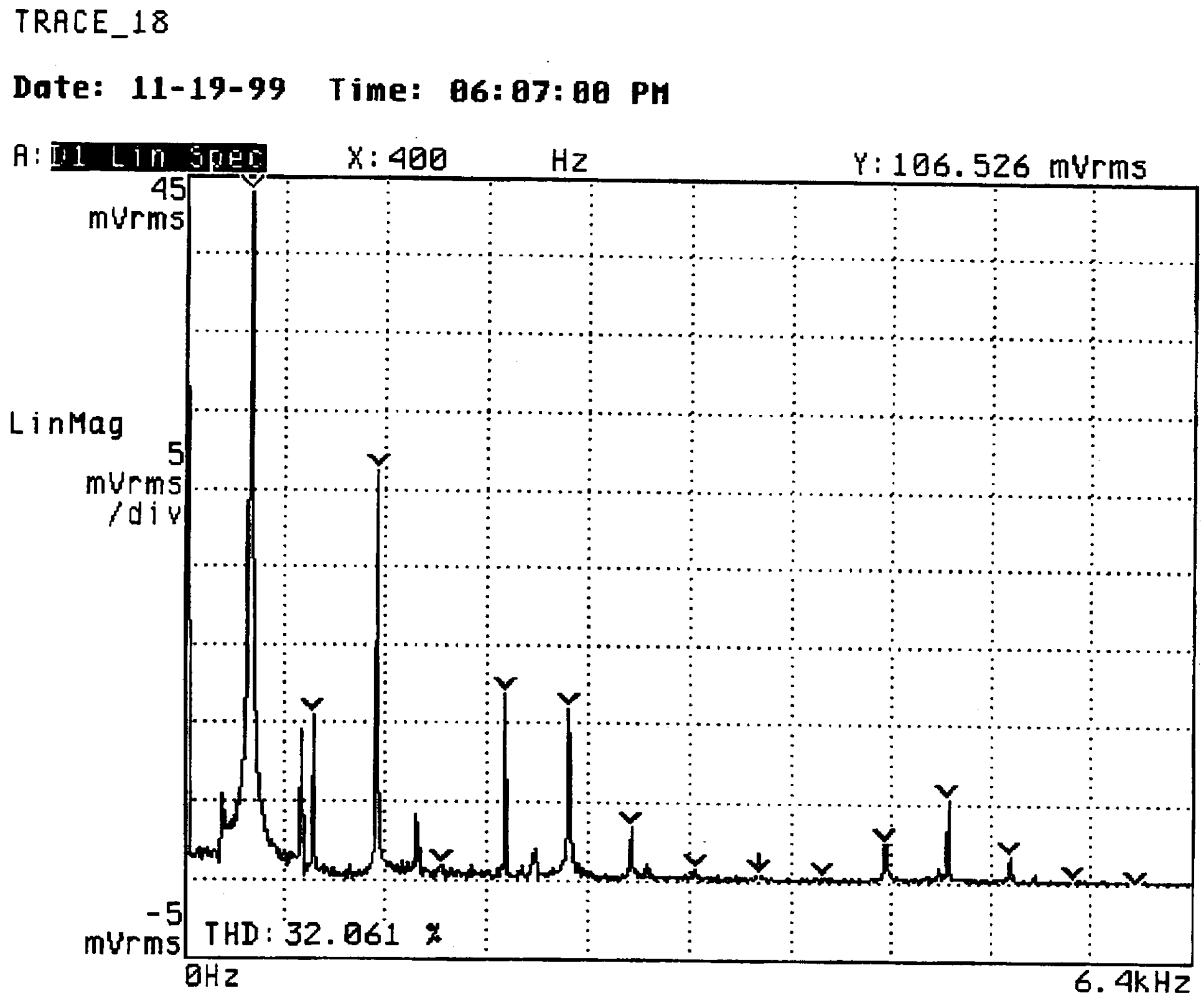

Figure F-18B: Spectrum for GCB 1 and GCB 2 Open (Cont'd)

TRACE_18

Date: 11-19-99 Time: 06:07:00 PM

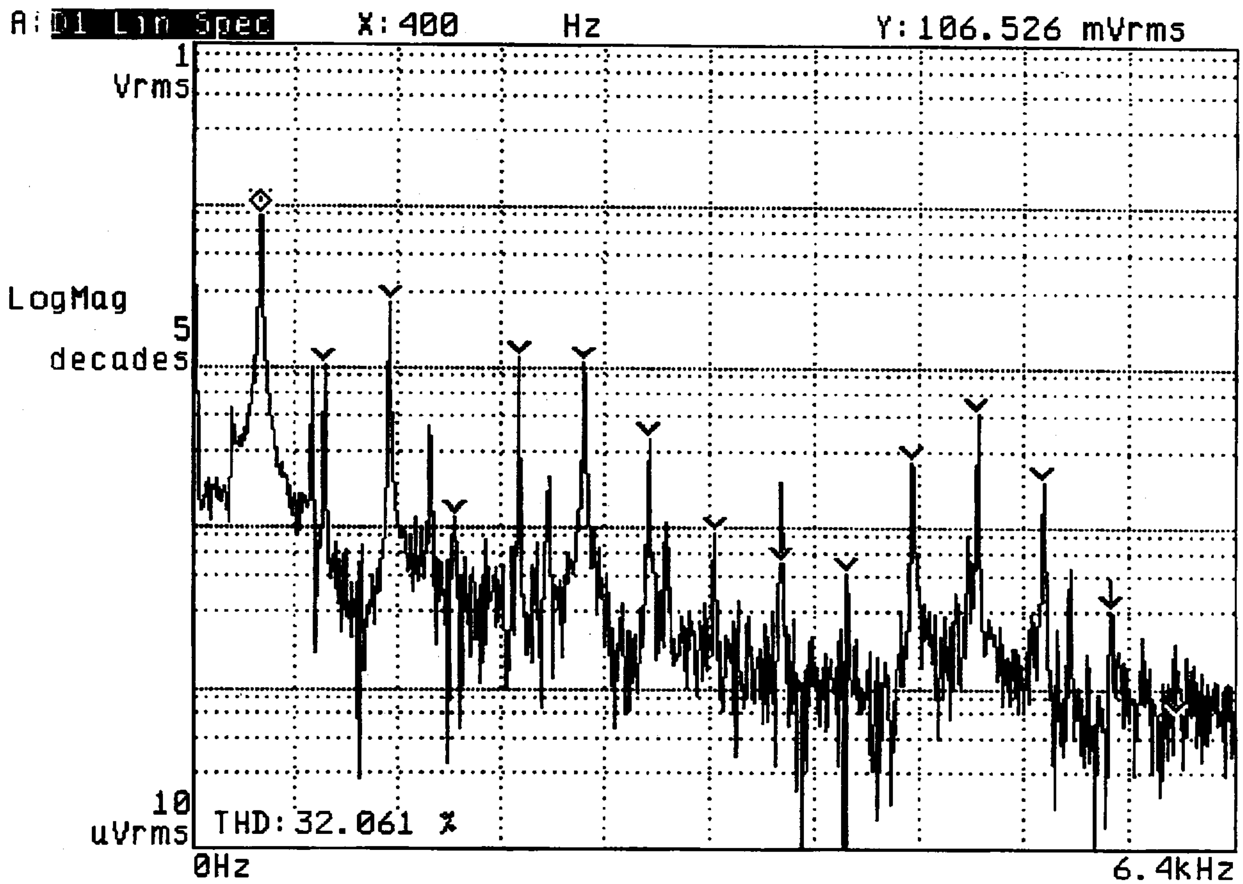

Figure F-18C: Spectrum for GCB 1 and GCB 2 Open (Cont'd)

TRACE_19

Date: 11-19-99 Time: 06:13:00 PM

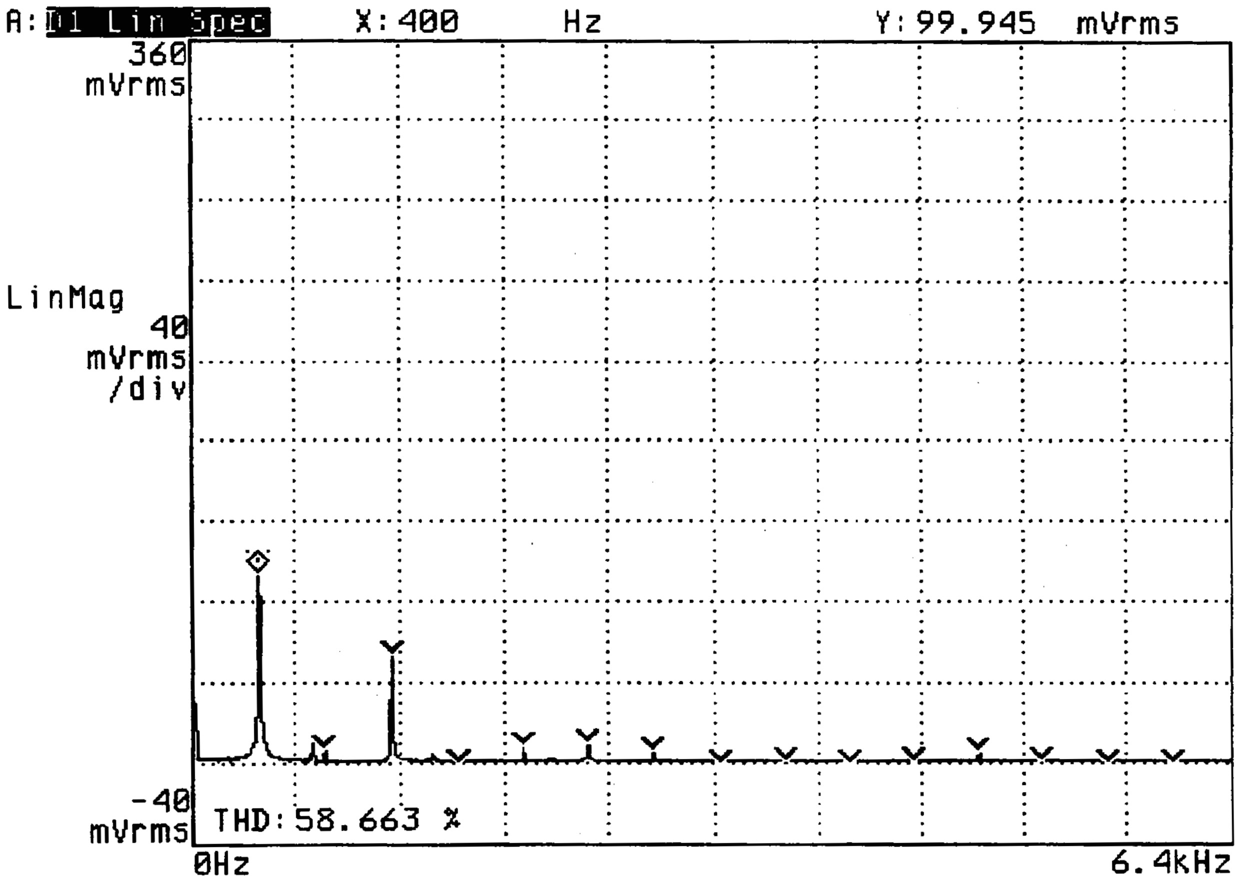

Figure F-19A: Spectrum for Breaker Pulled for TRU1

TRACE_19

Date: 11-19-99 Time: 06:13:00 PM

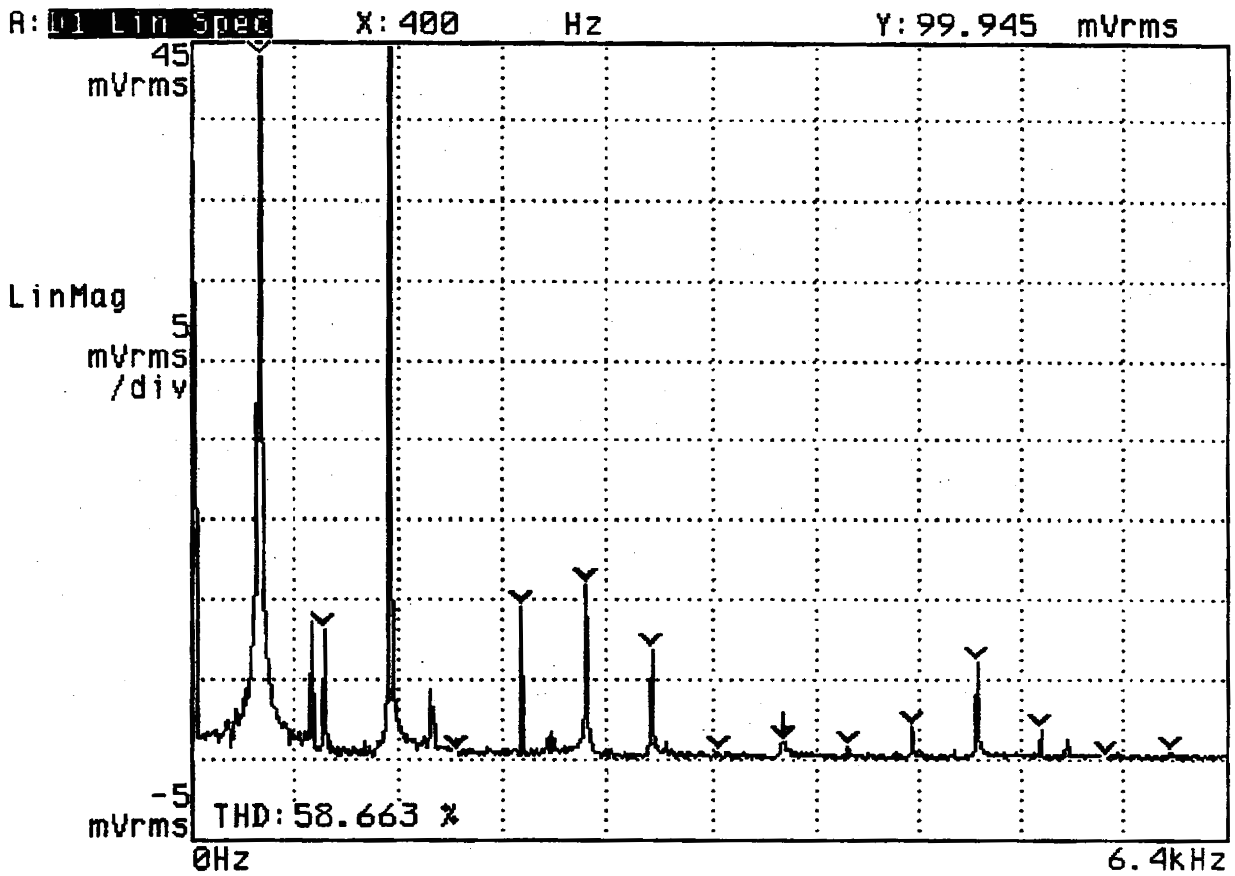

Figure F-19B: Spectrum for Breaker Pulled for TRU1 (Cont'd)

TRACE_19

Date: 11-19-99 Time: 06:13:00 PM

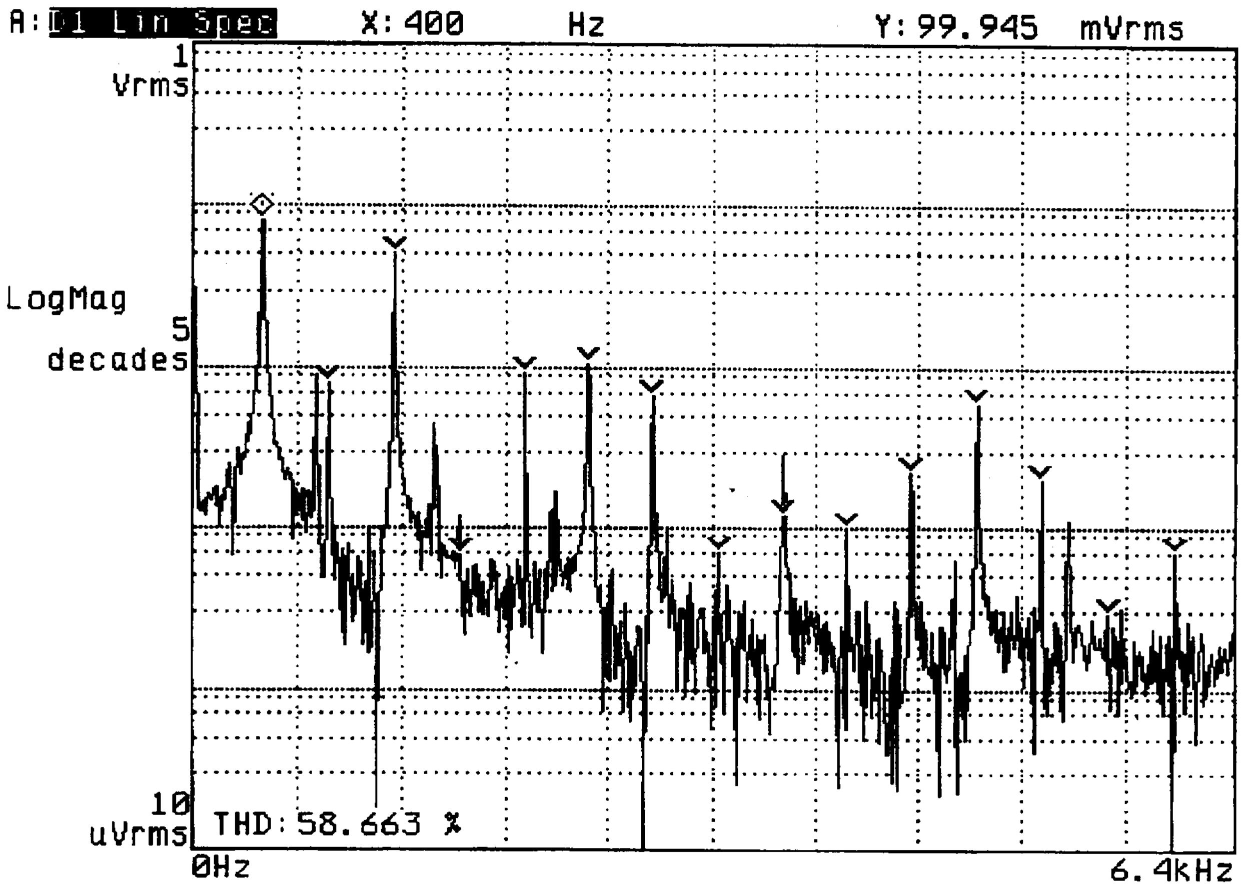

Figure F-19C: Spectrum for Breaker Pulled for TRU1 (Cont'd)

TRACE_20

Date: 11-19-99 Time: 06:15:00 PM

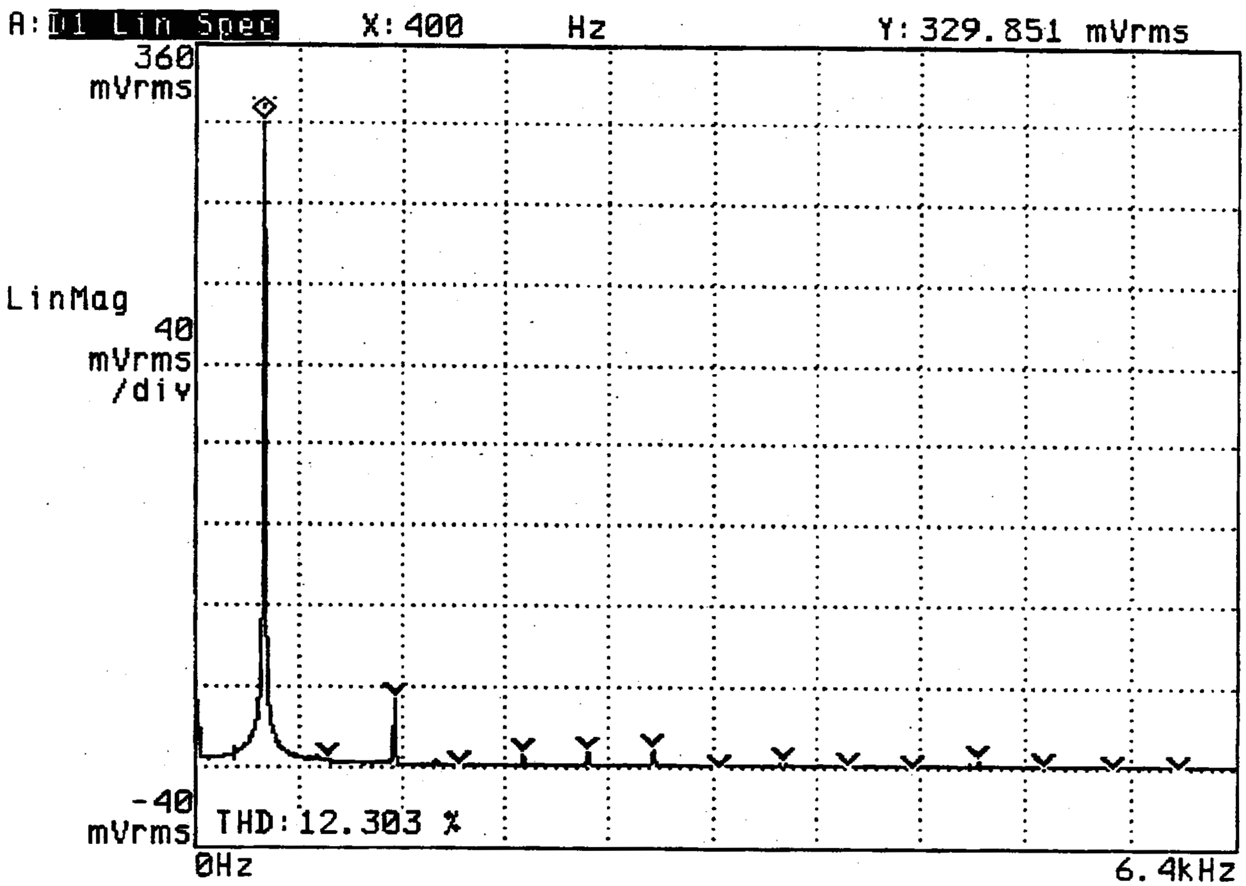

Figure F-20A: Spectrum for Breaker Pulled for TRU2

TRACE_20

Date: 11-19-99 Time: 06:15:00 PM

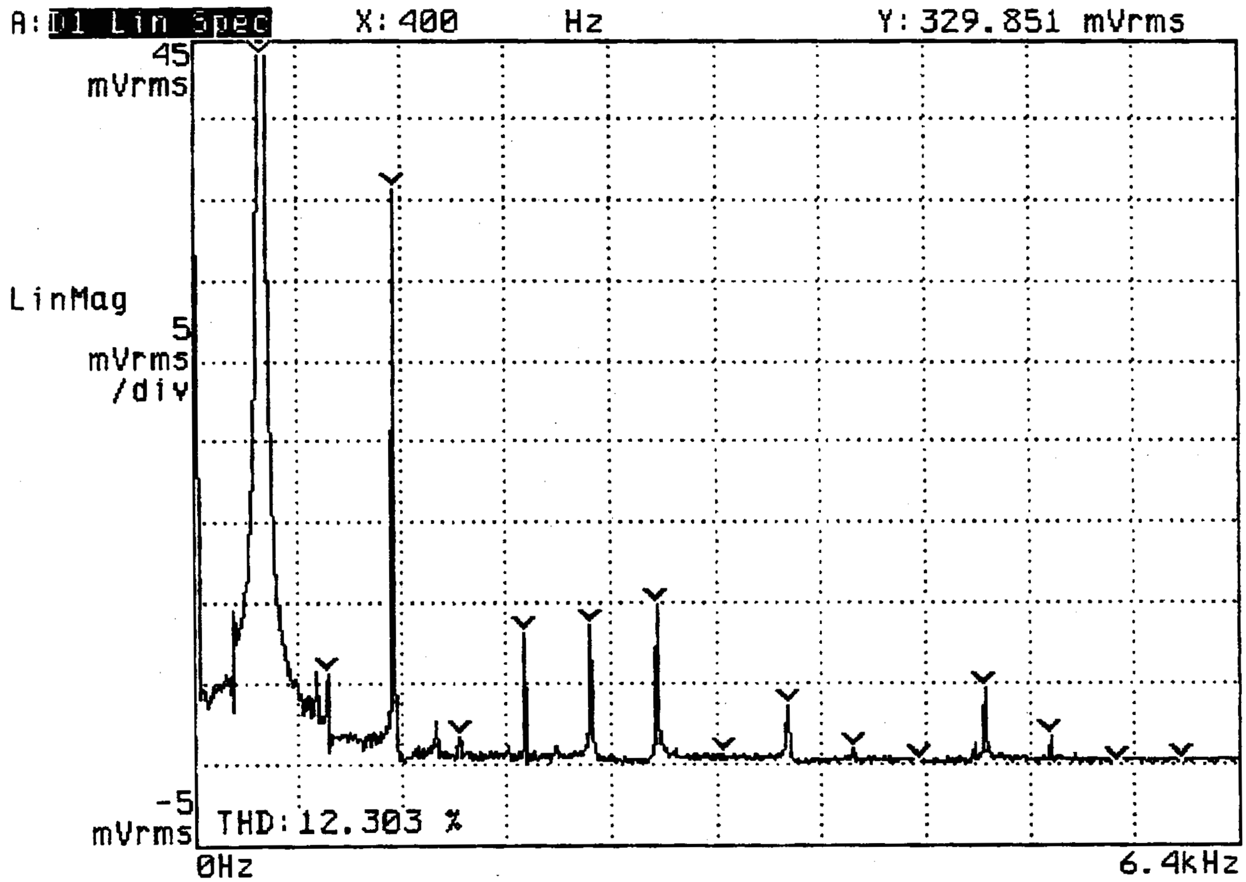

Figure F-20B: Spectrum for Breaker Pulled for TRU2 (Cont'd)

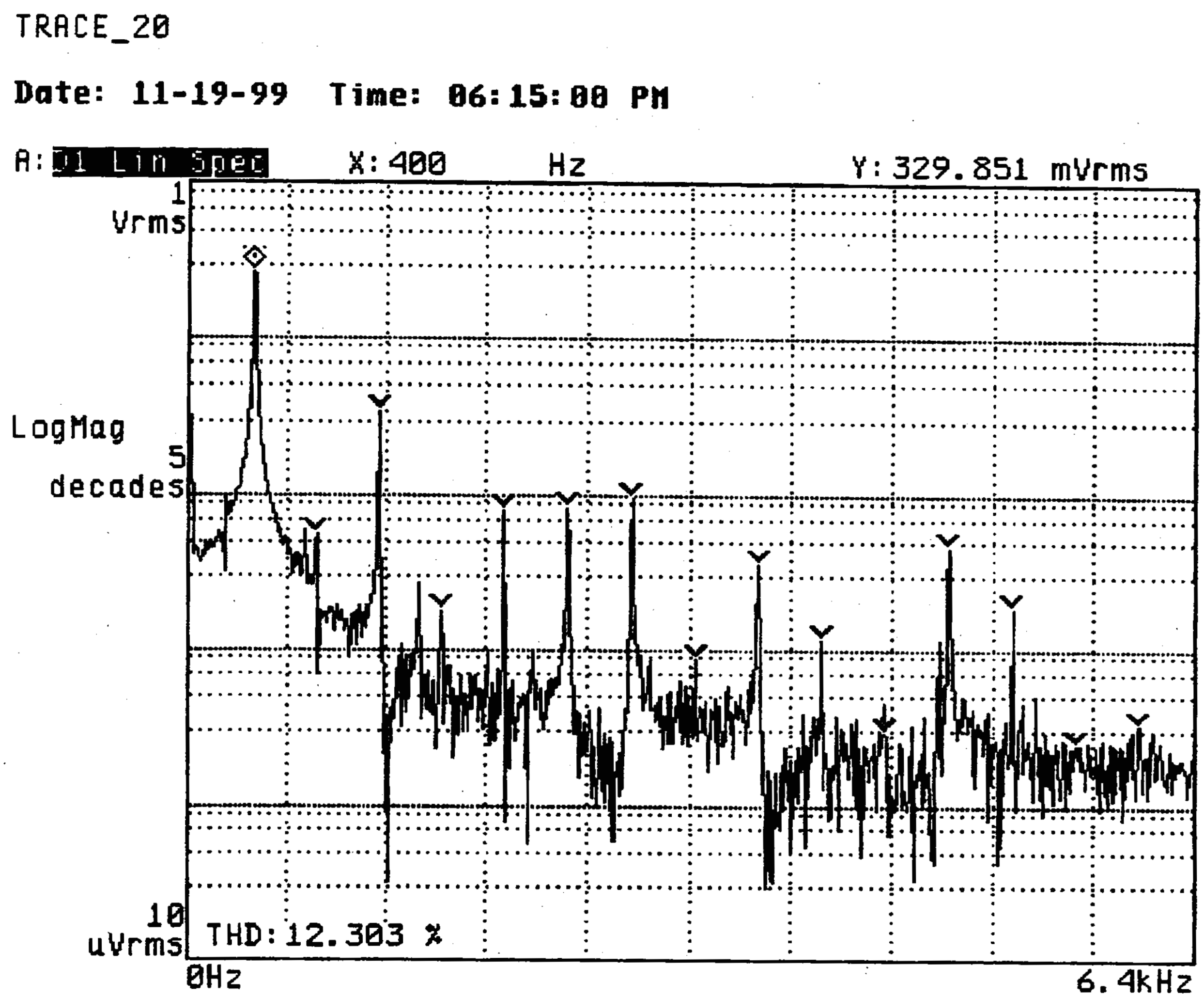

Figure F-20C: Spectrum for Breaker Pulled for TRU2 (Cont'd)

TRACE_21

Date: 11-19-99 Time: 06:19:00 PM

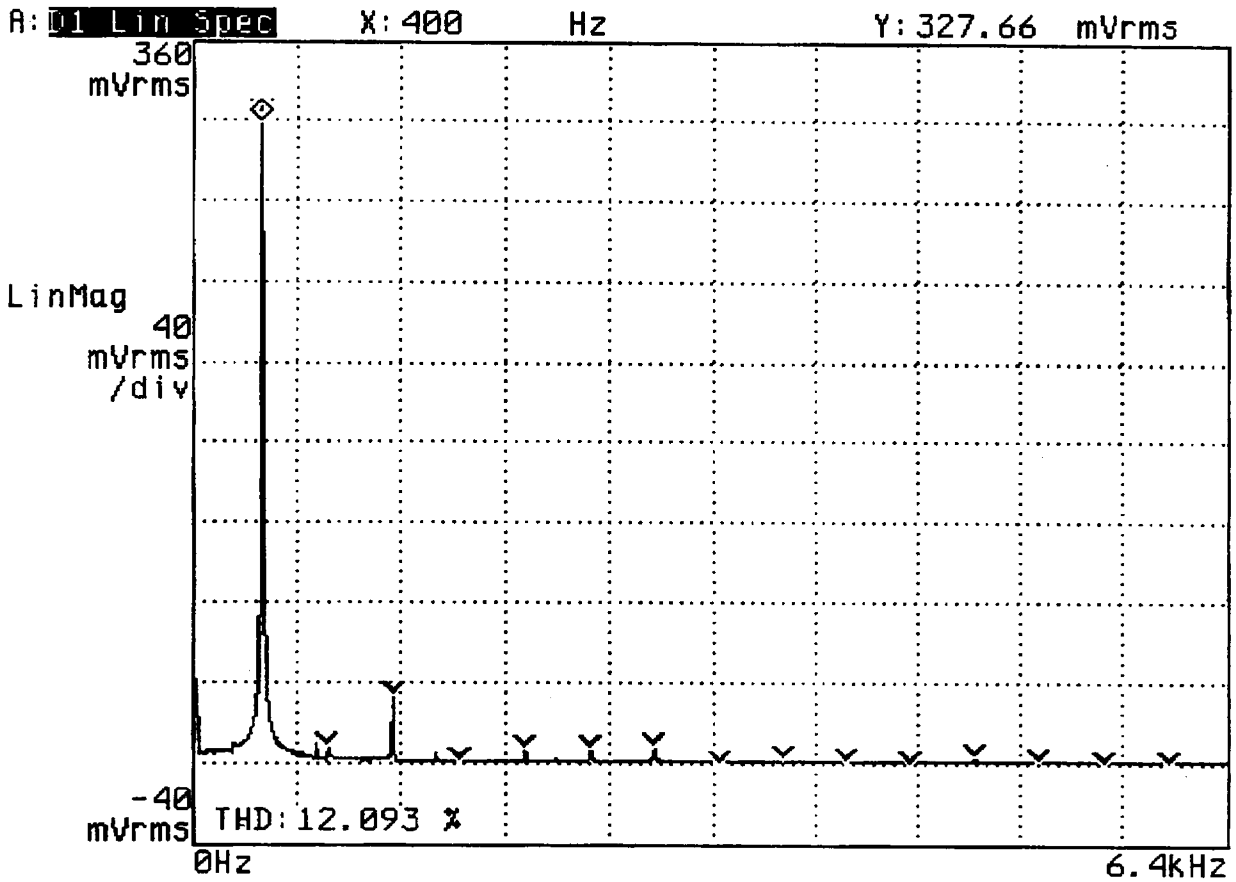

Figure F-21A: Spectrum for Breaker Pulled for TRU2 (Repeated)

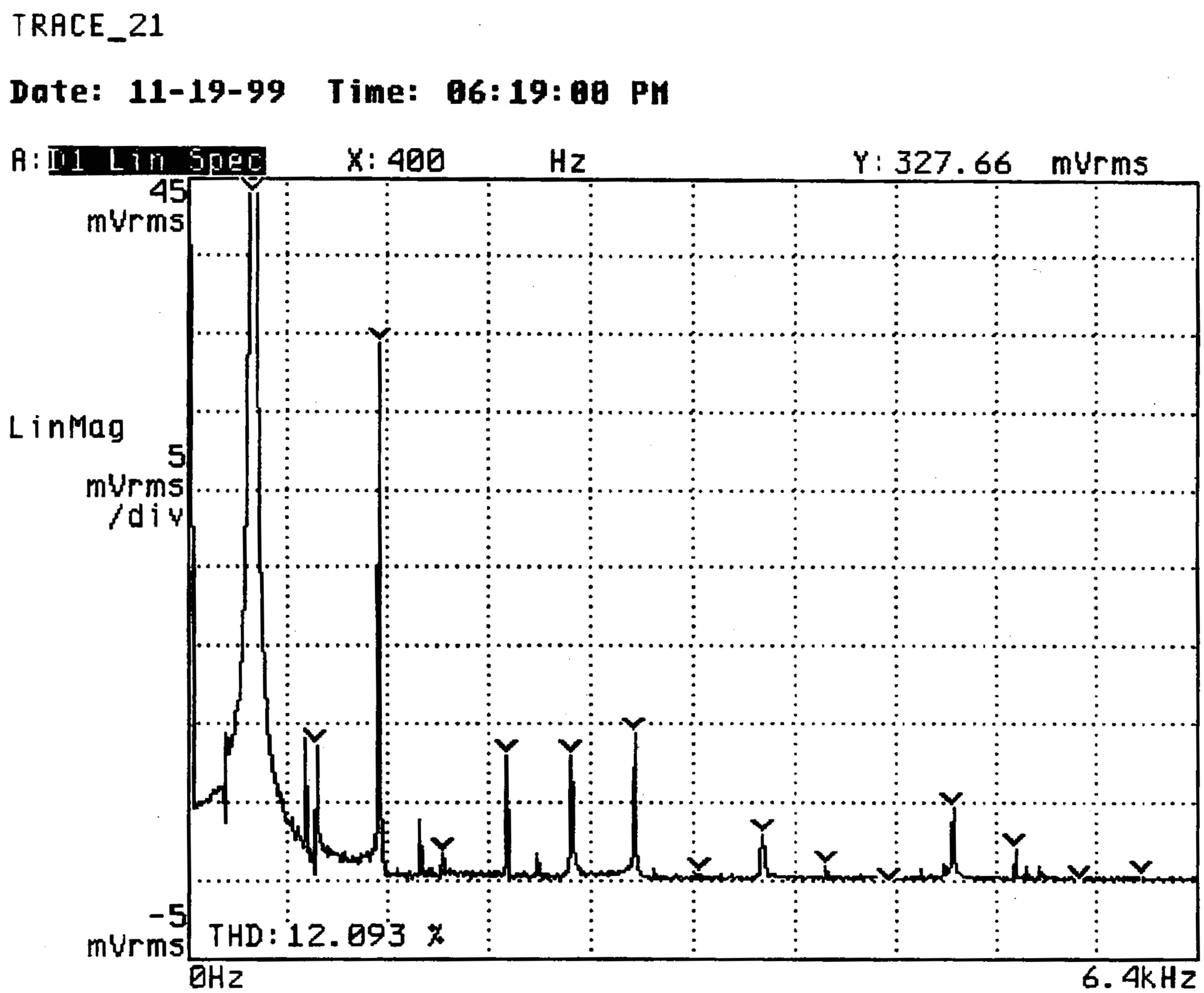

Figure F-21B: Spectrum for Breaker Pulled for TRU2 (Repeated) (Cont'd)

TRACE_21

Date: 11-19-99 Time: 06:19:00 PM

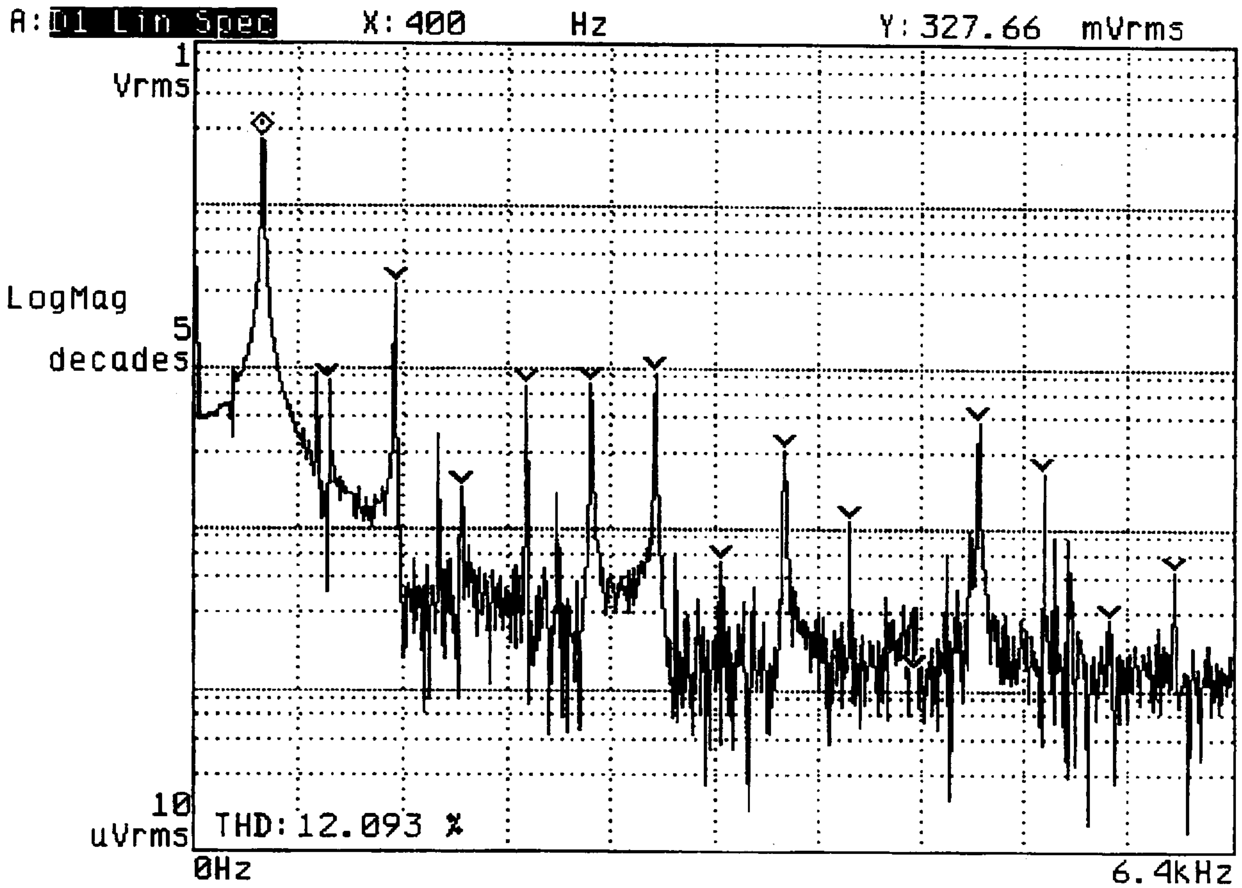

Figure F-21C: Spectrum for Breaker Pulled for TRU2 (Repeated) (Cont'd)

TRACE_22

Date: 11-19-99 Time: 06:25:00 PM

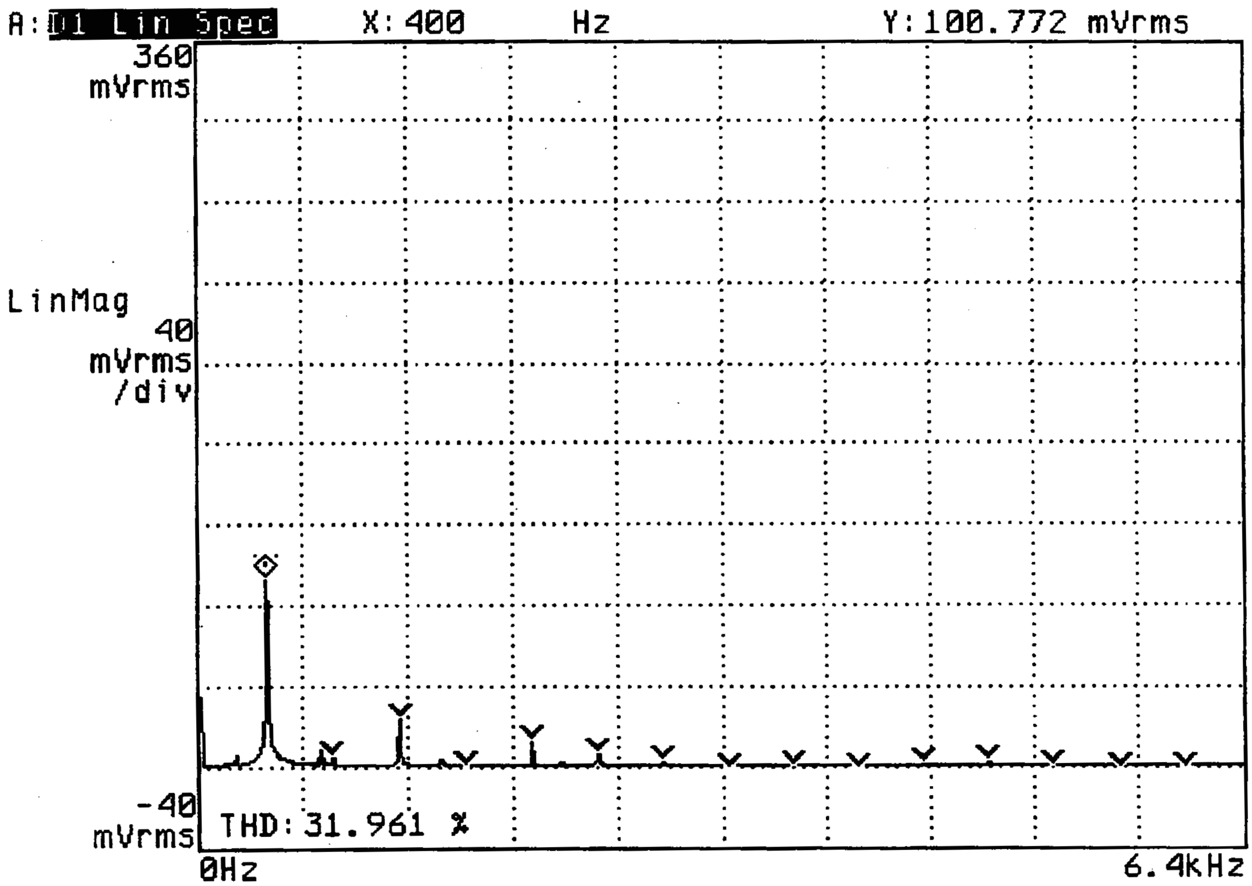

Figure F-22A: Spectrum for Breaker Pulled for TRU3

TRACE_22

Date: 11-19-99 Time: 06:25:00 PM

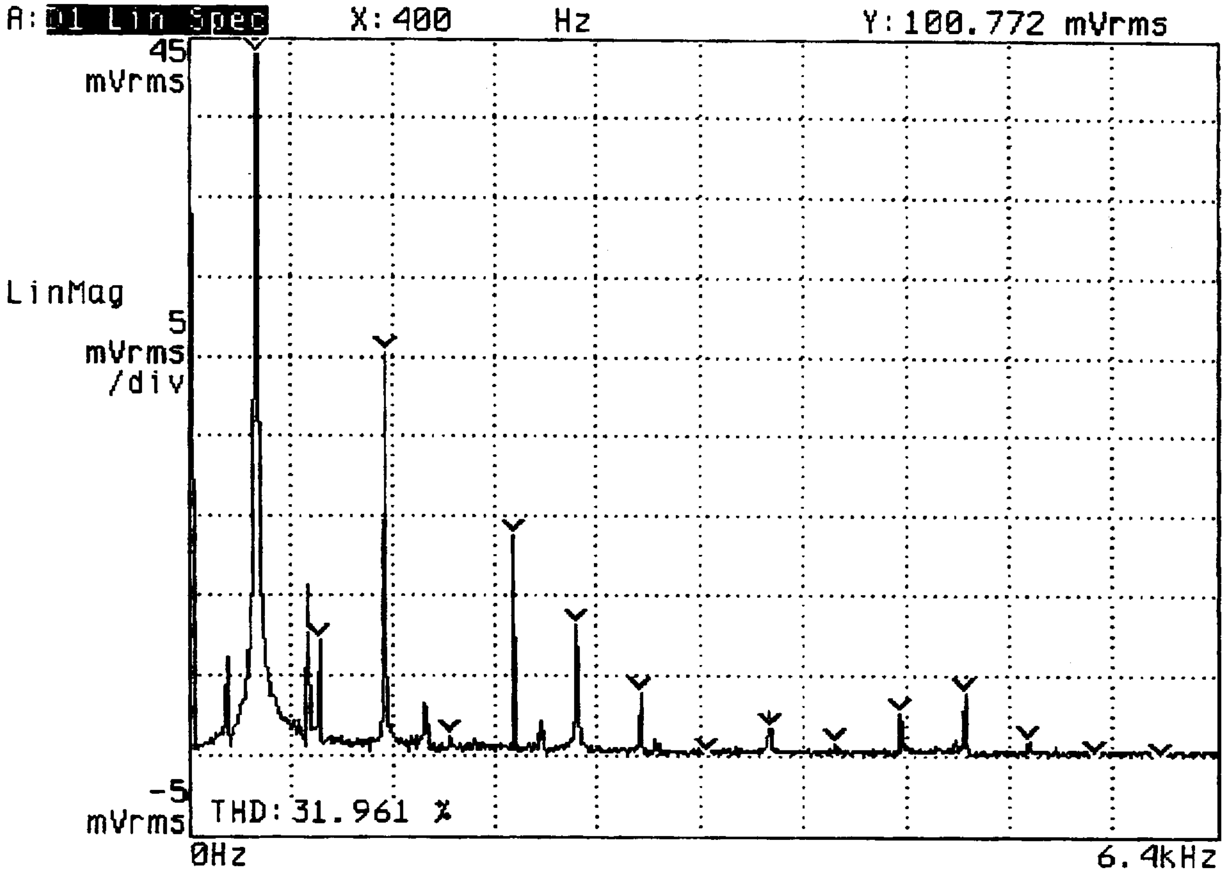

Figure F-22B: Spectrum for Breaker Pulled for TRU3 (Cont'd)

TRACE_22

Date: 11-19-99 Time: 06:25:00 PM

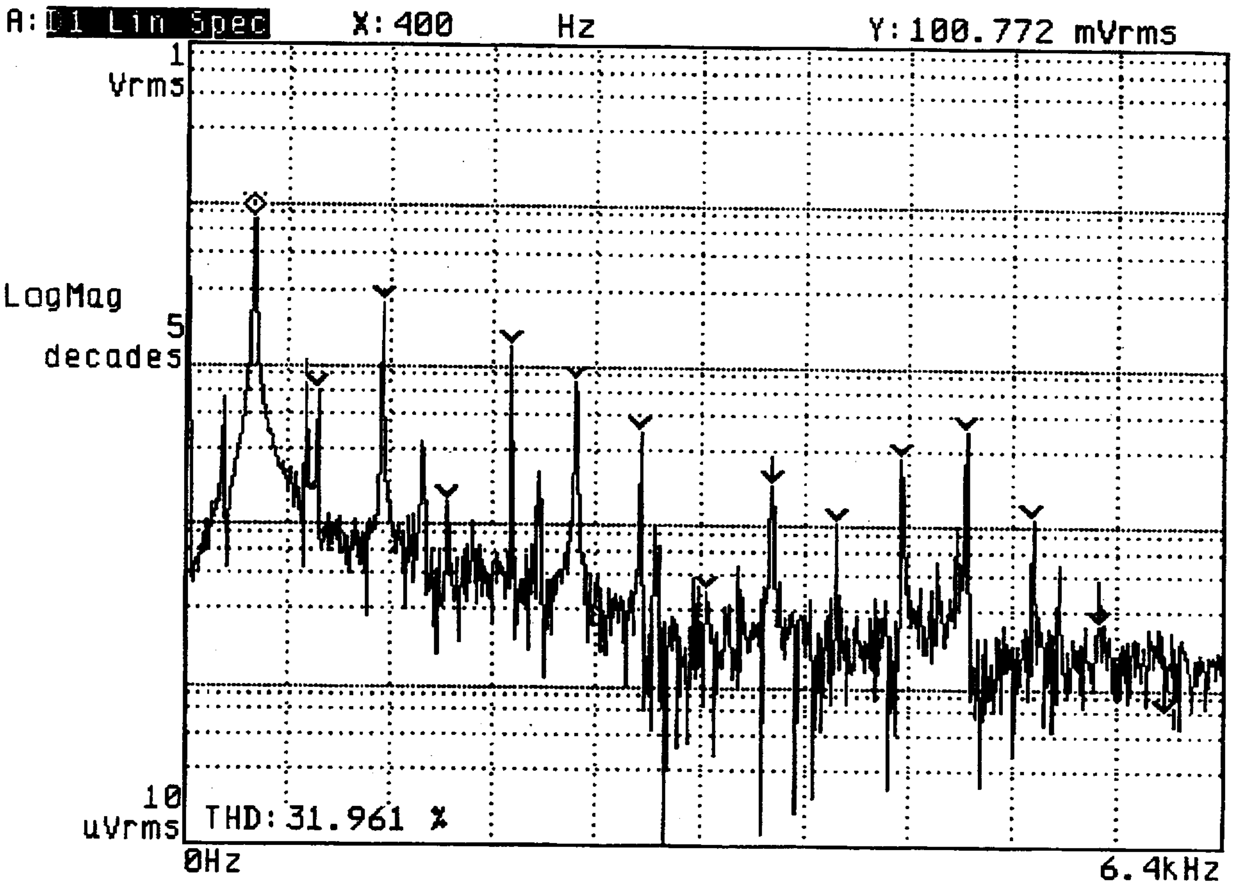

Figure F-22C: Spectrum for Breaker Pulled for TRU3 (Cont'd)

TRACE_23

Date: 11-19-99 Time: 06:28:00 PM

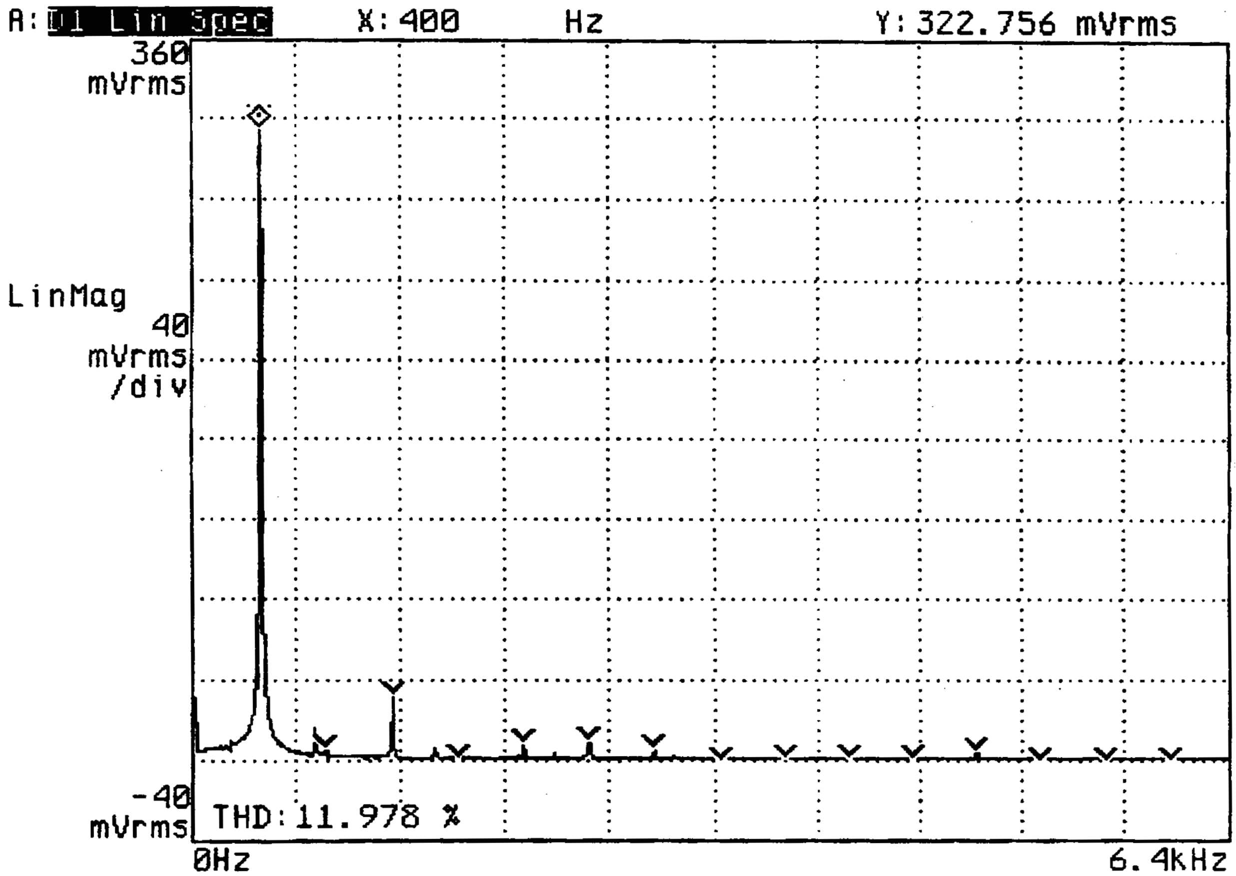

Figure F-23A: Spectrum for Essential Power Selector to Bus 3

TRACE_23

Date: 11-19-99 Time: 06:28:00 PM

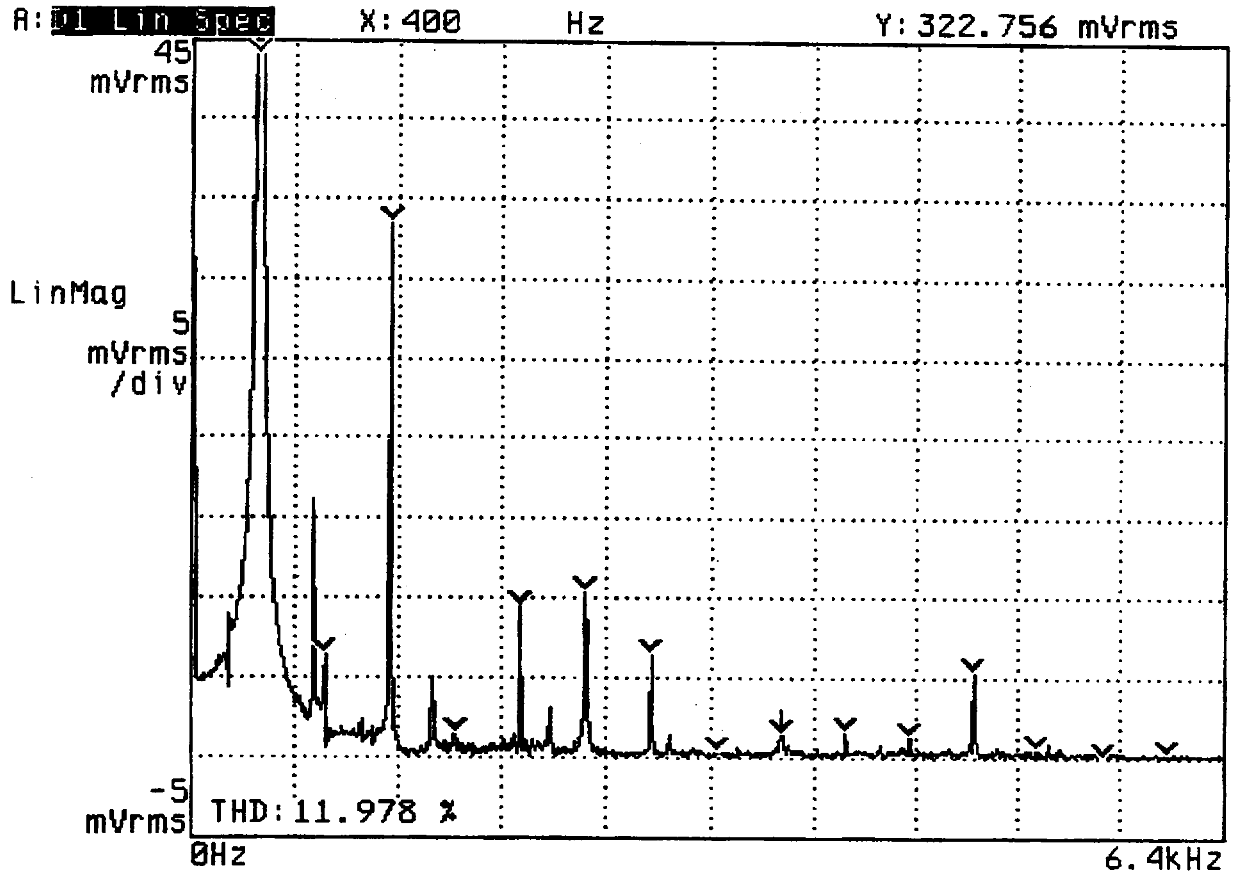

Figure F-23B: Spectrum for Essential Power Selector to Bus 3 (Cont'd)

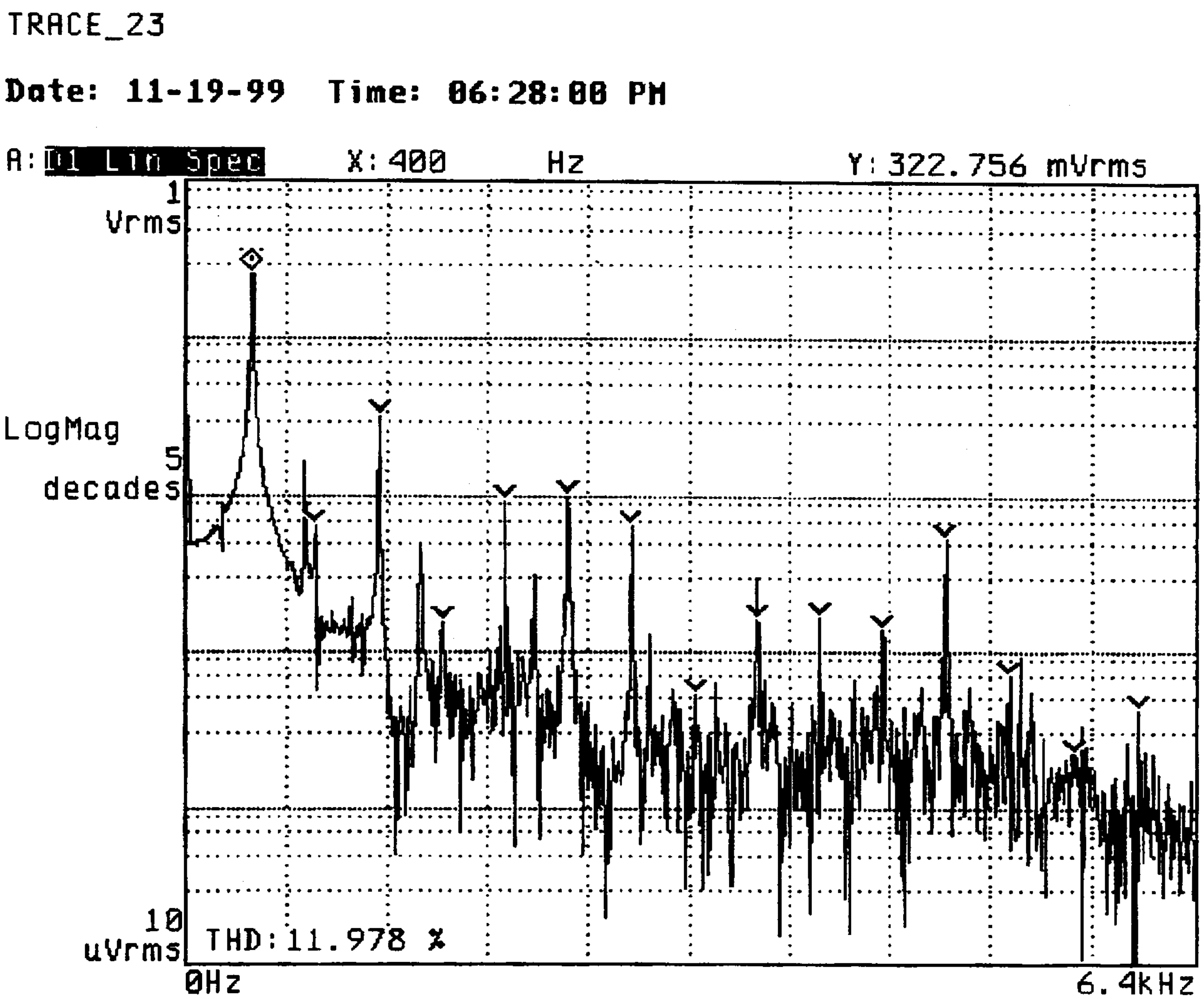

Figure F-23C: Spectrum for Essential Power Selector to Bus 3 (Cont'd)

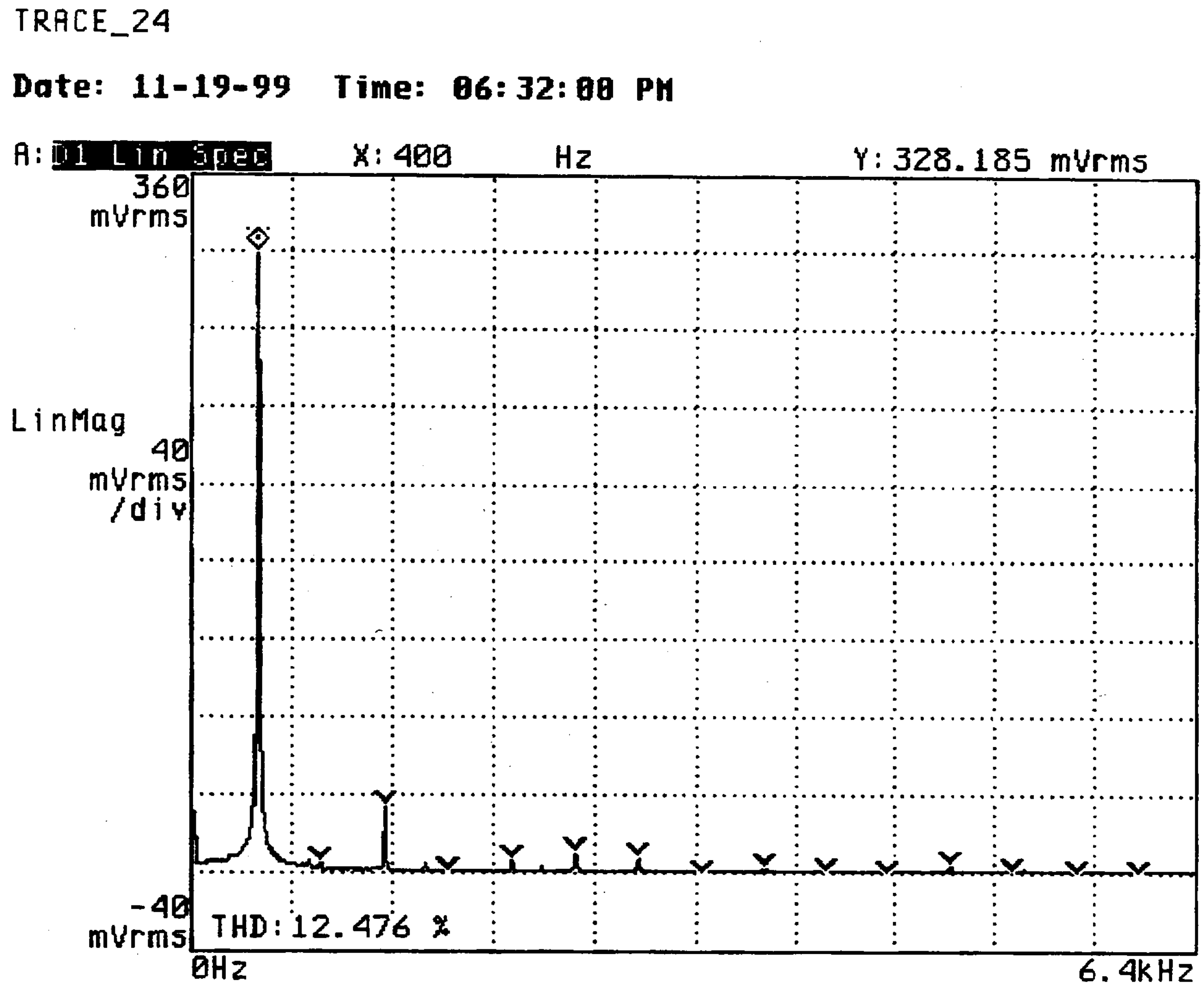

Figure F-24A: Spectrum for Essential Power Selector to Bus 2

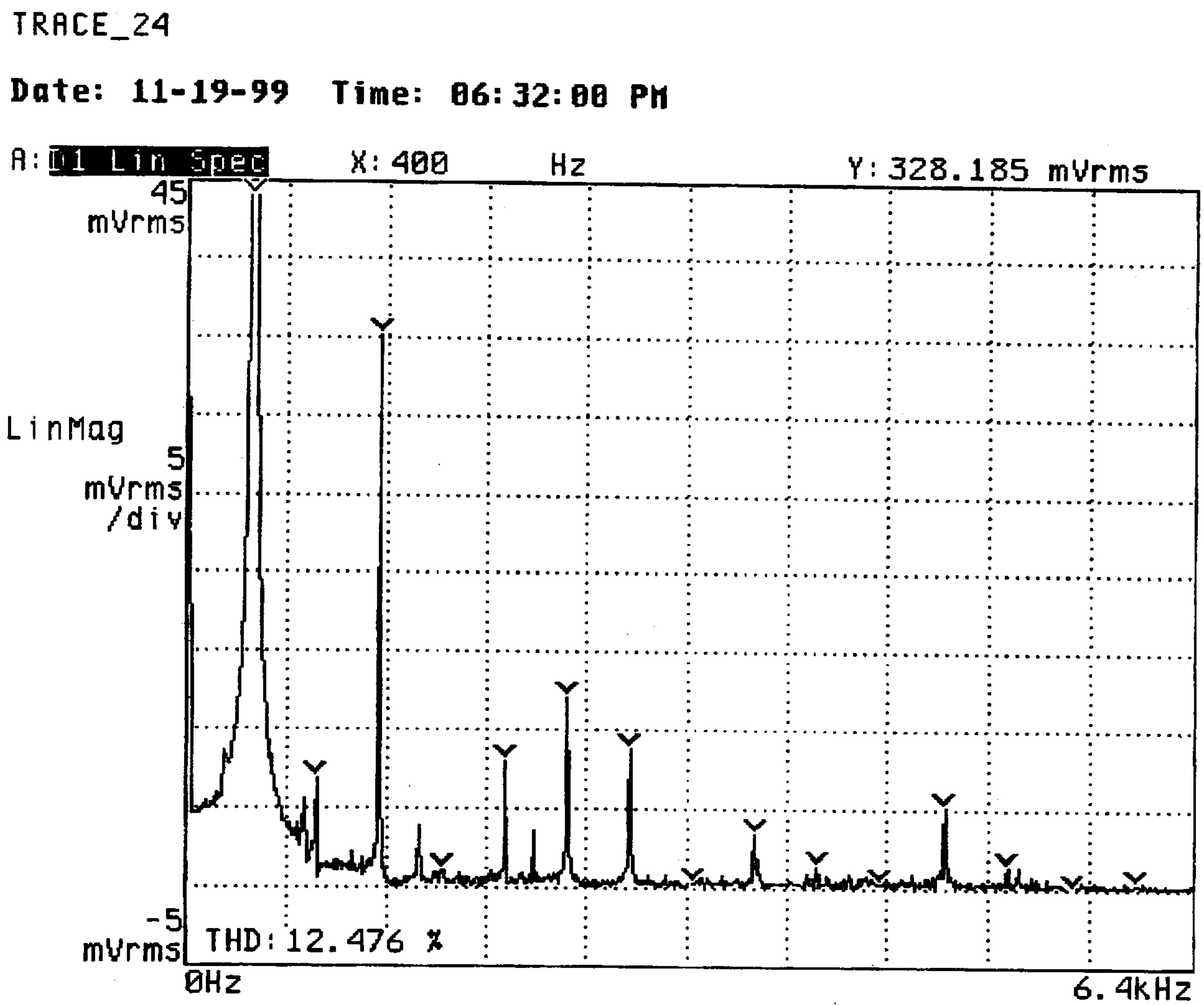

Figure F-24B: Spectrum for Essential Power Selector to Bus 2 (Cont'd)

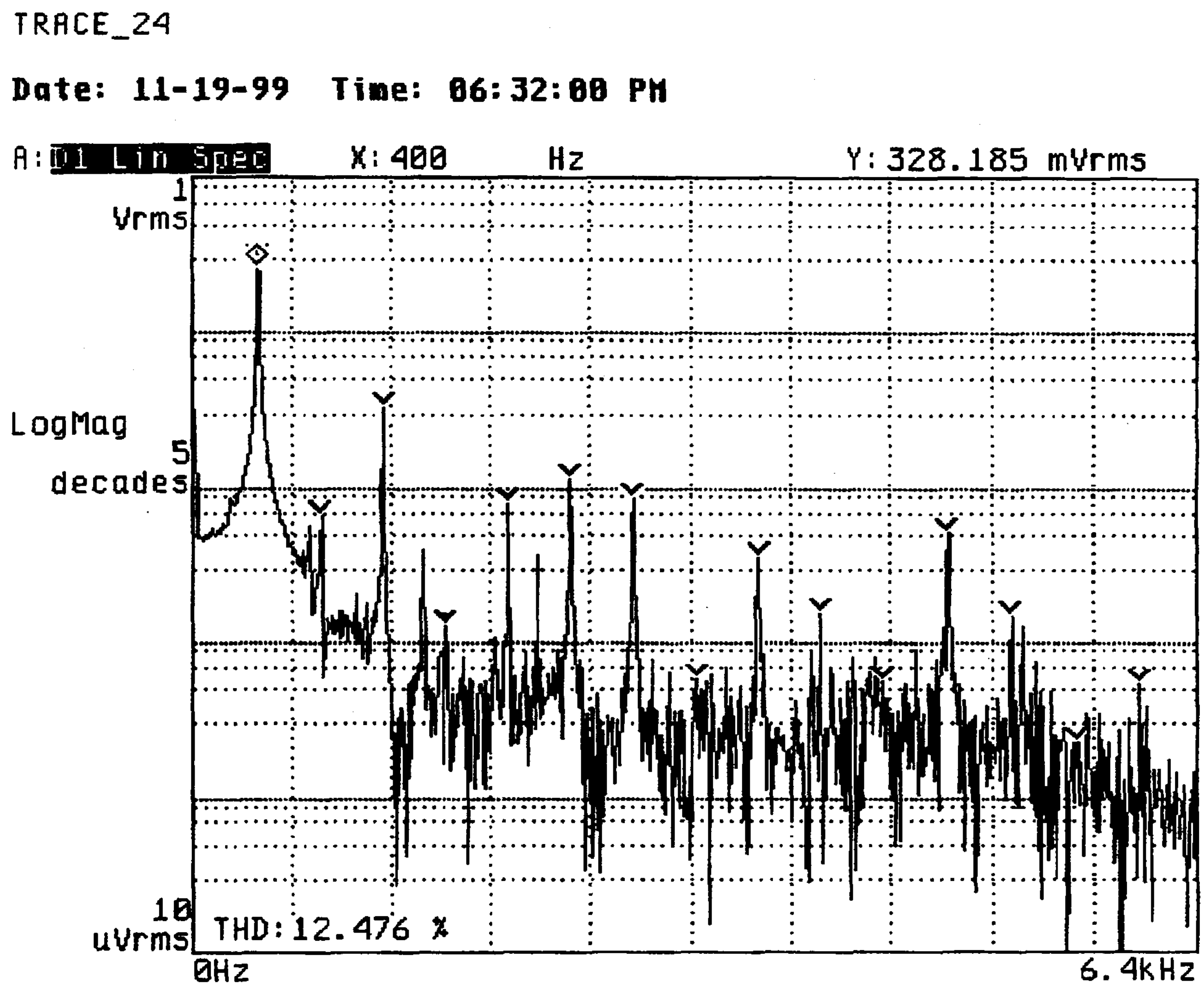

Figure F-24C: Spectrum for Essential Power Selector to Bus 2 (Cont'd)

TRACE_25

Date: 11-19-99 Time: 06:35:00 PM

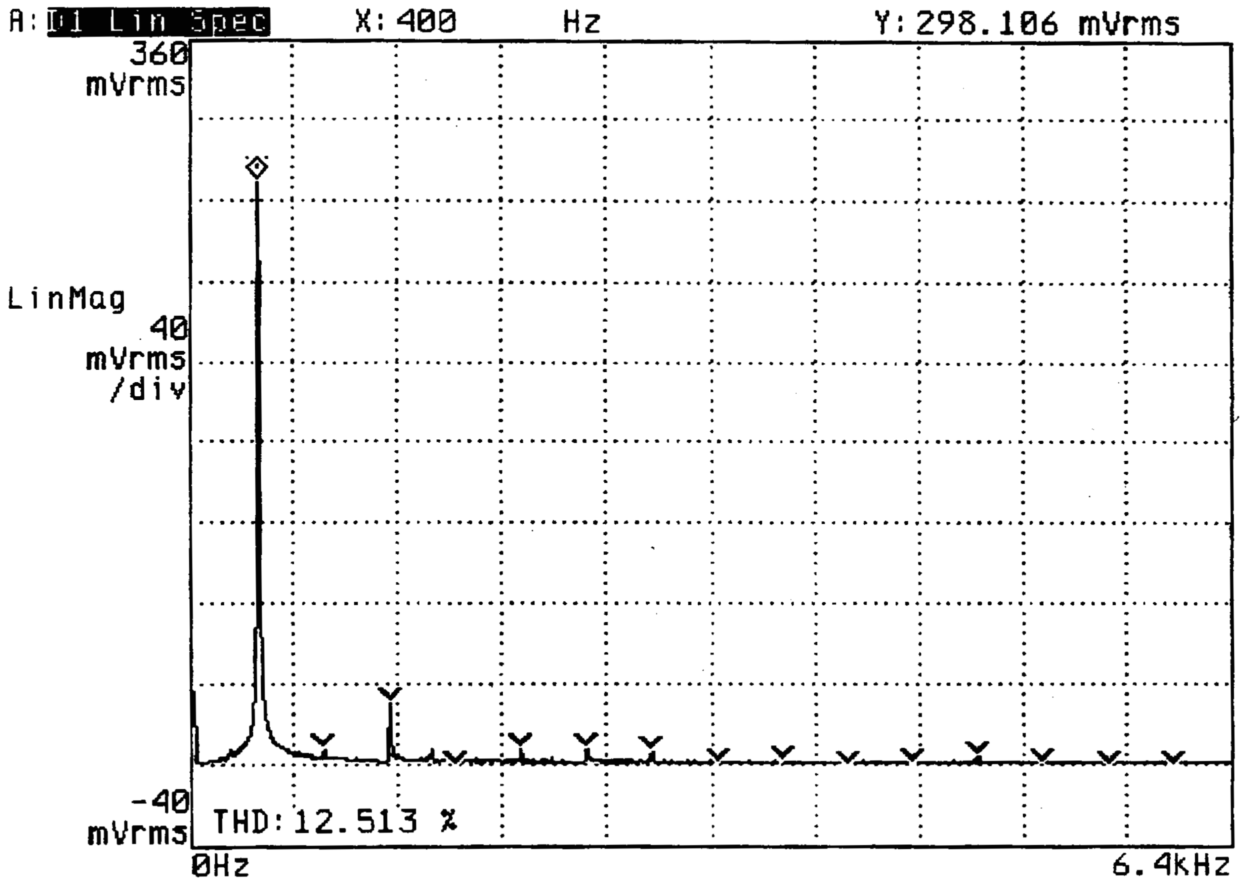

Figure F-25A: Spectrum for Essential Power Selector to Bus 1

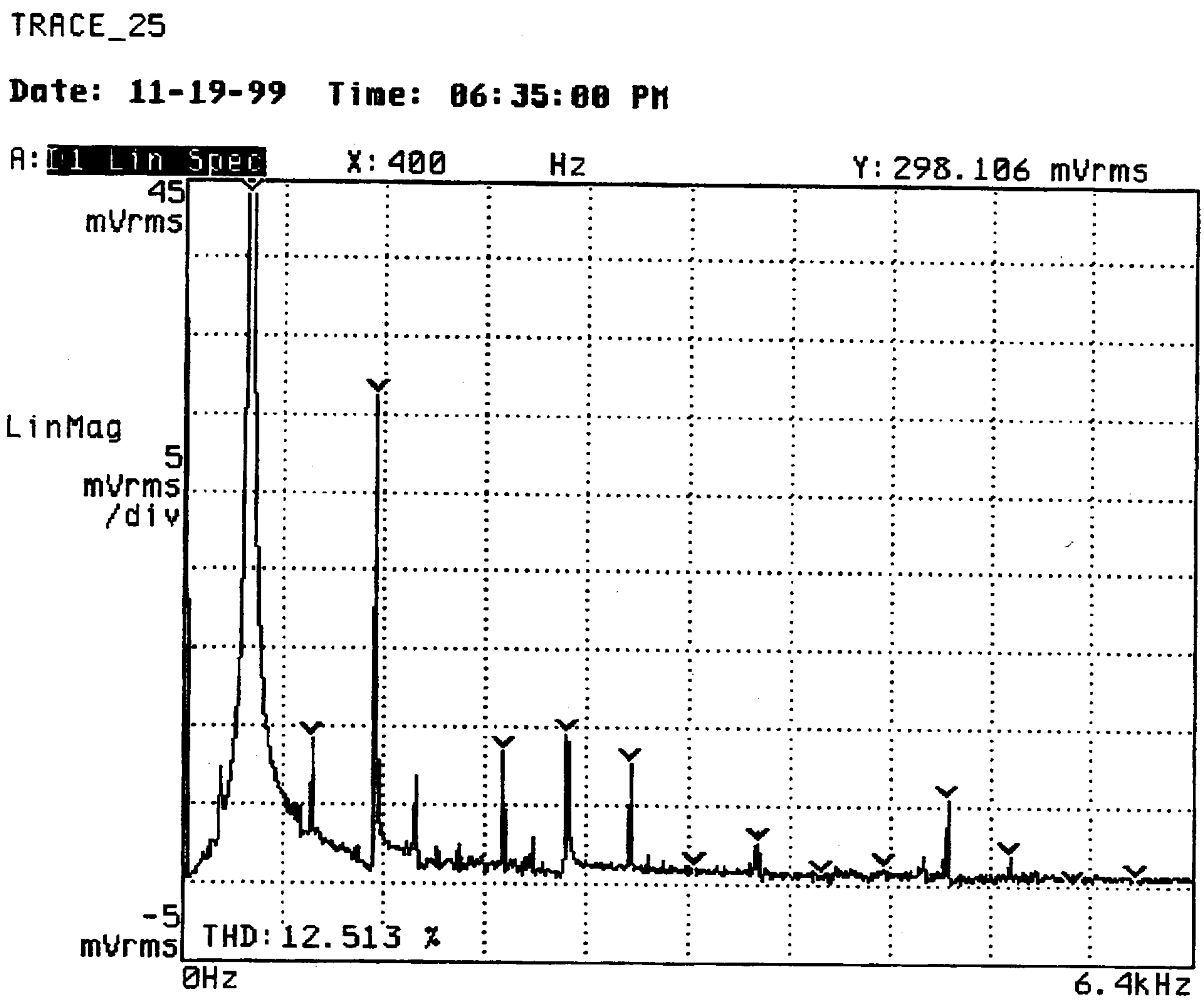

Figure F-25B: Spectrum for Essential Power Selector to Bus 1 (Cont'd)

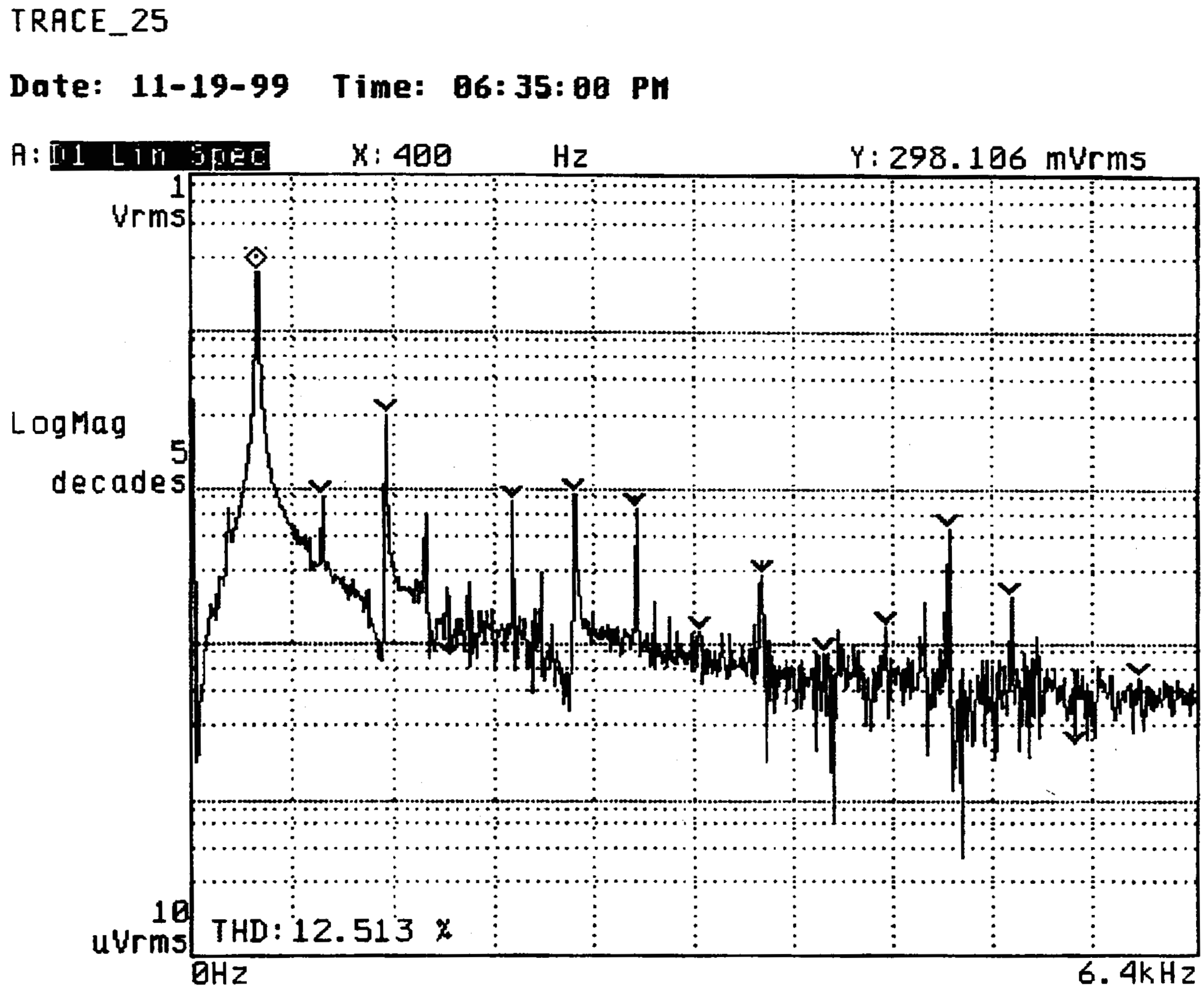

Figure F-25C: Spectrum for Essential Power Selector to Bus 1 (Cont'd)

TRACE_26

Date: 11-19-99 Time: 06:39:00 PM

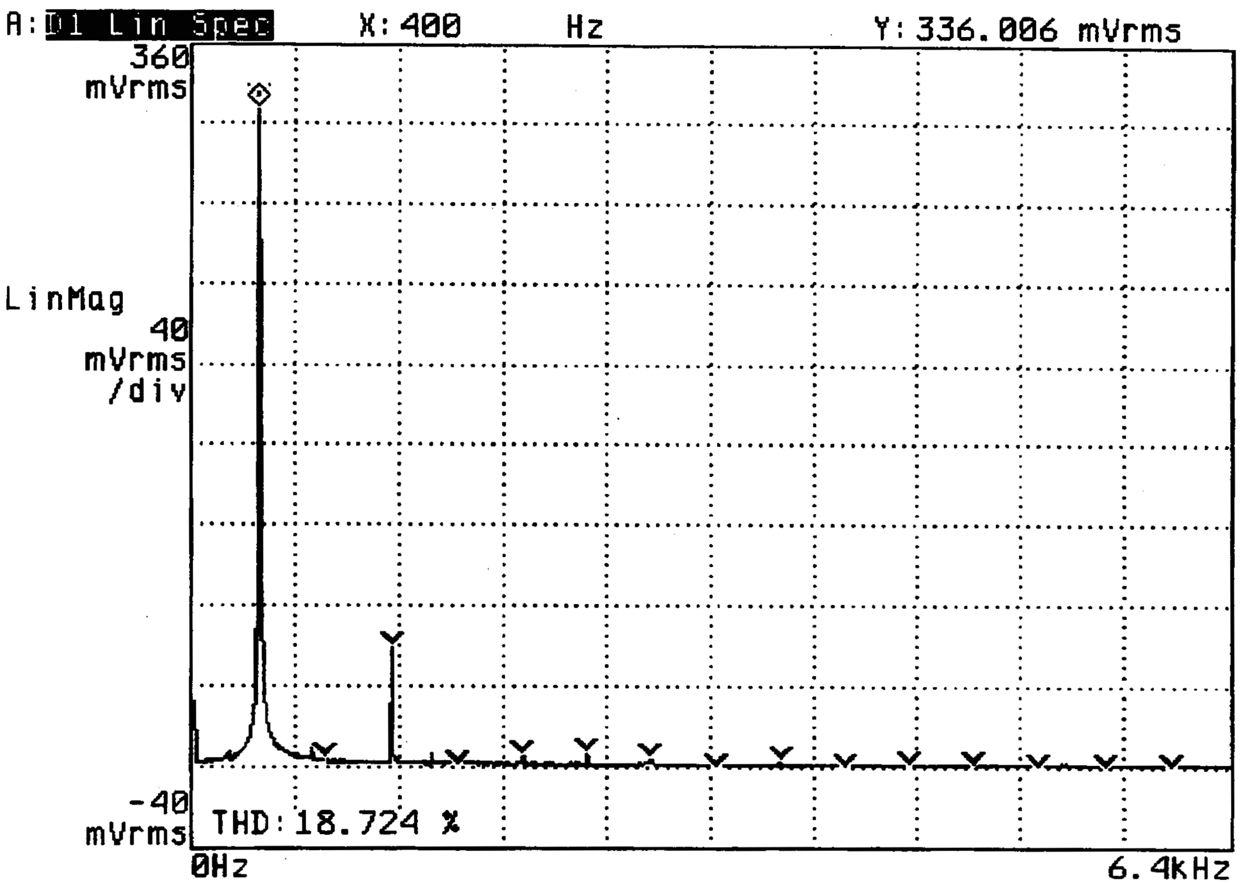

Figure F-26A: Spectrum for All TRU Breakers Pulled

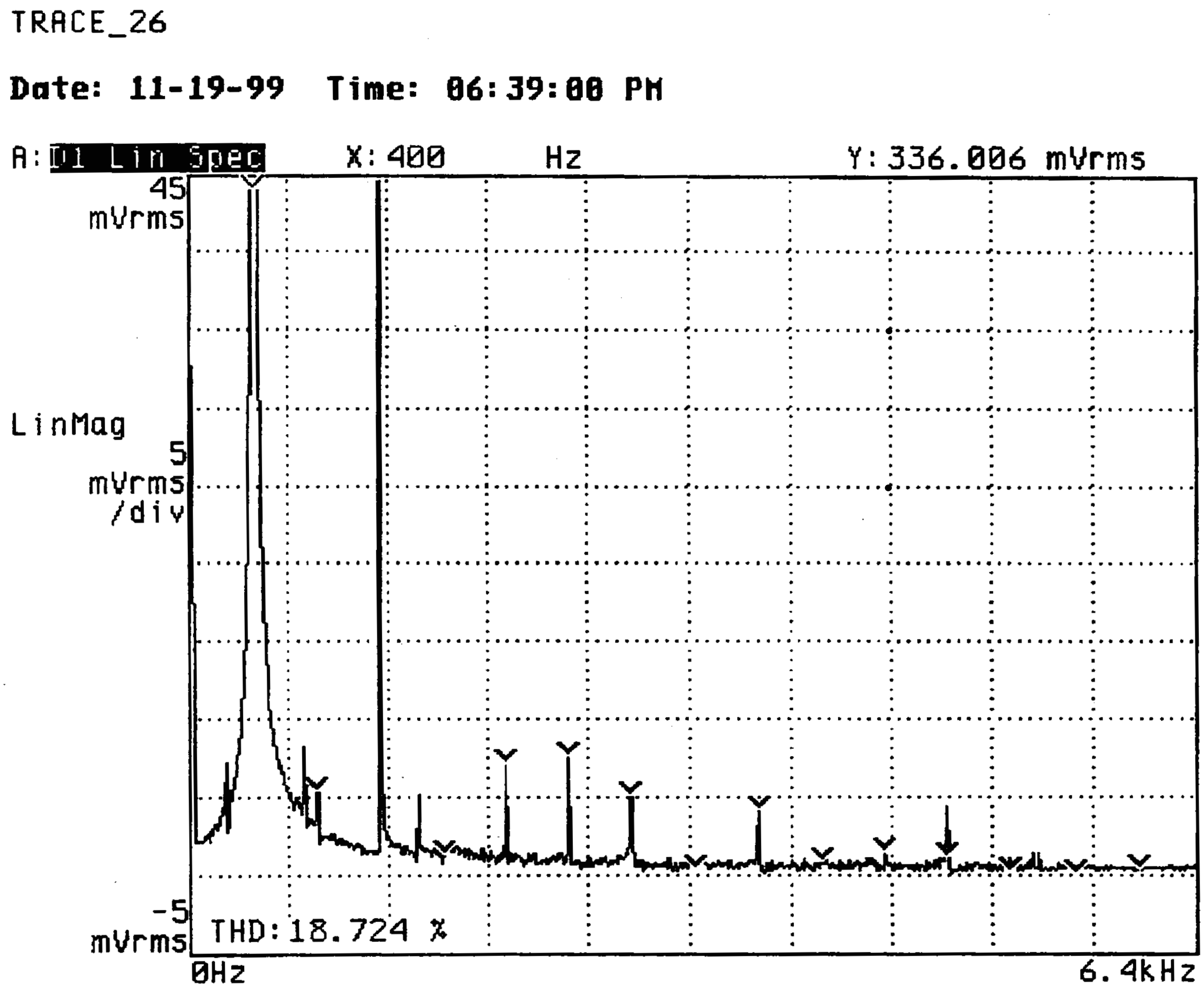

Figure F-26B: Spectrum for All TRU Breakers Pulled (Cont'd)

TRACE_26

Date: 11-19-99 Time: 06:39:00 PM

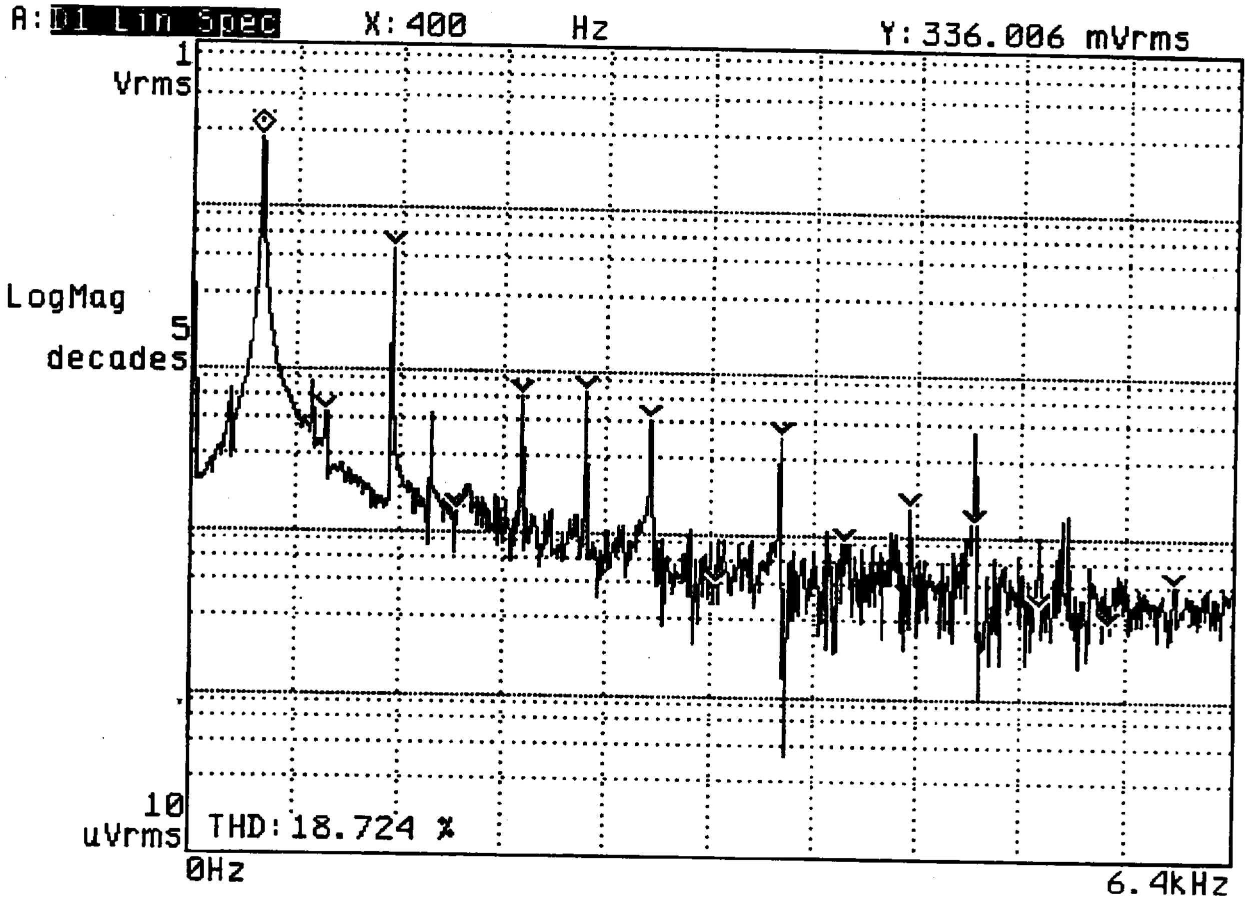

Figure F-26C: Spectrum for All TRU Breakers Pulled (Cont'd)

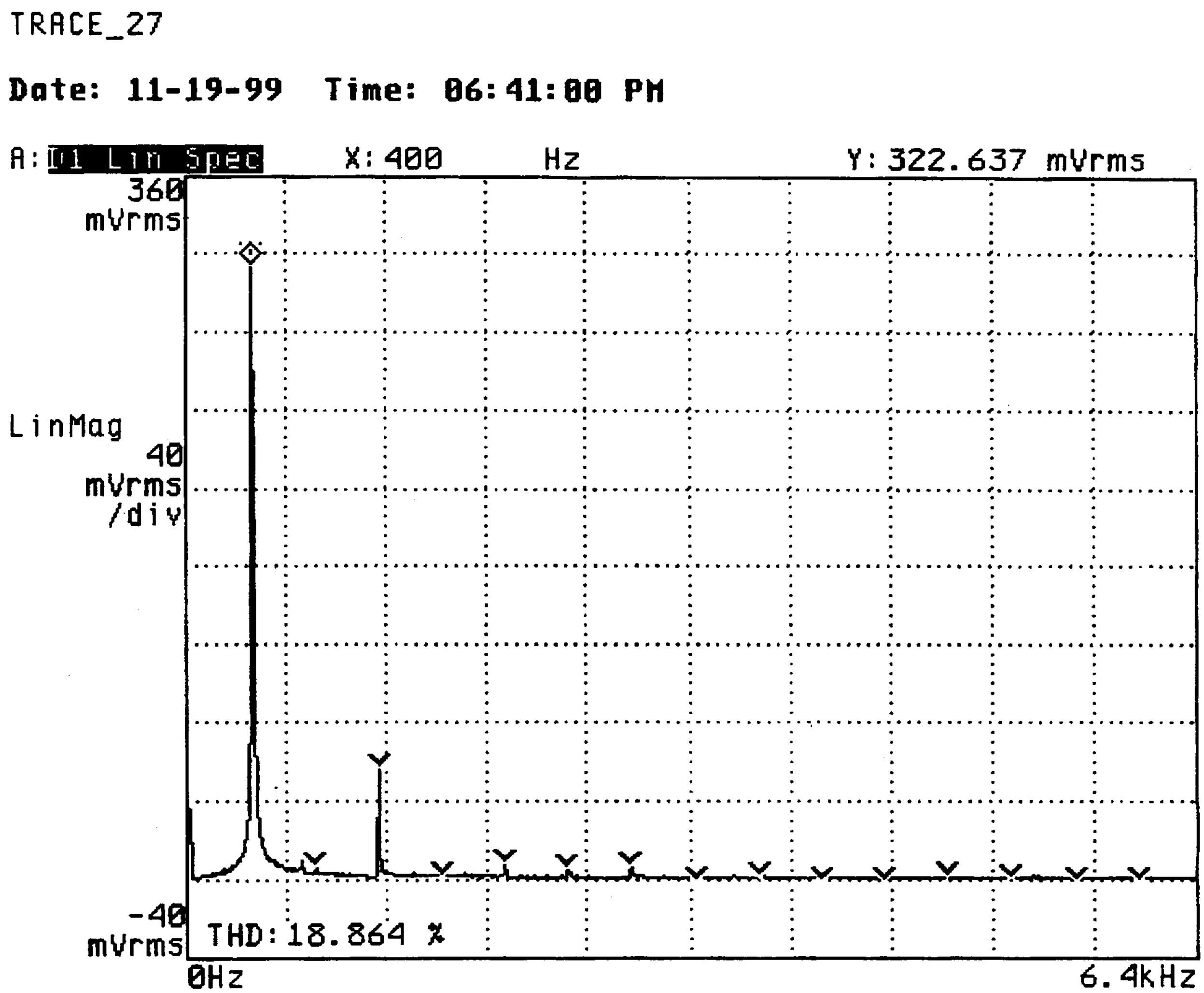

Figure F-27A: Spectrum for All TRU Breakers Pulled (Repeated)

TRACE_27

Date: 11-19-99 Time: 06:41:00 PM

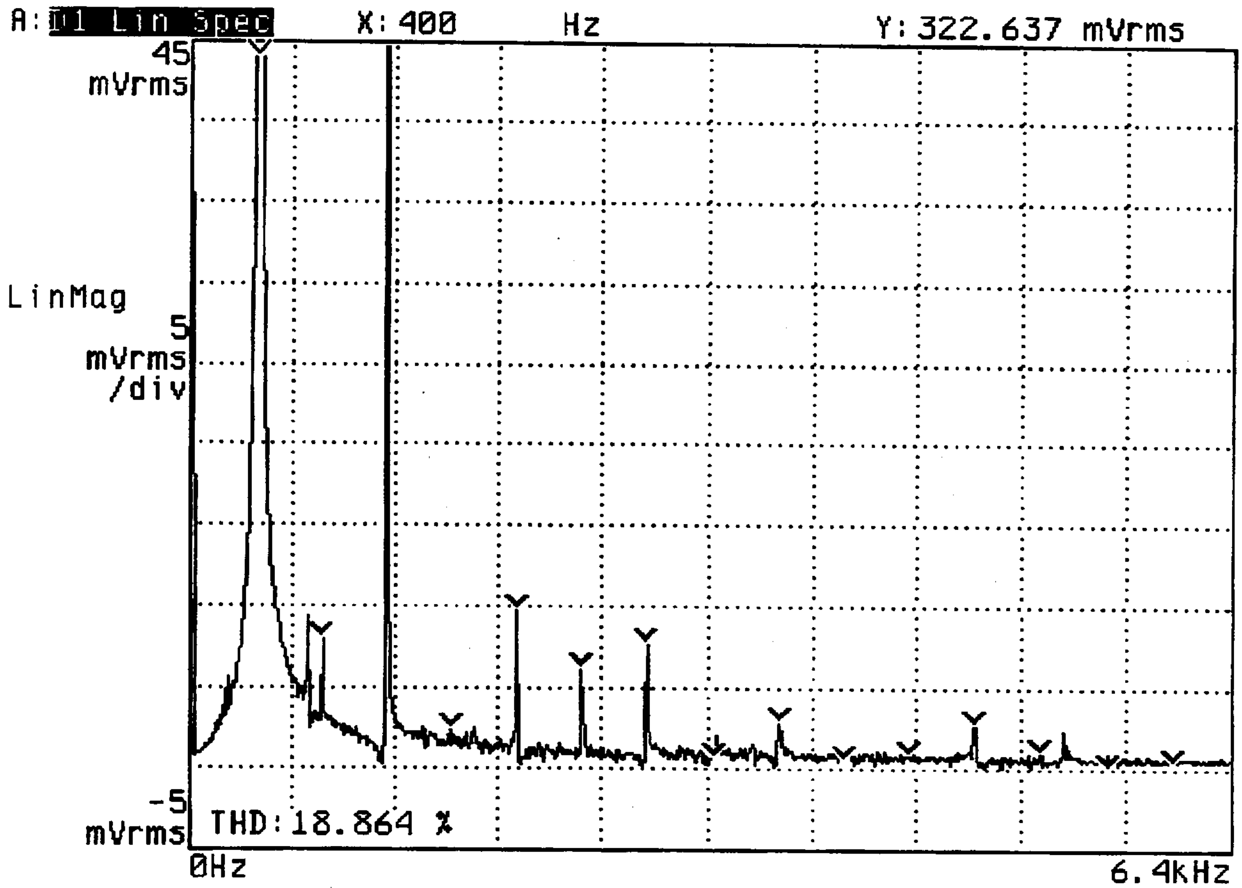

Figure F-27B: Spectrum for All TRU Breakers Pulled (Repeated) (Cont'd)

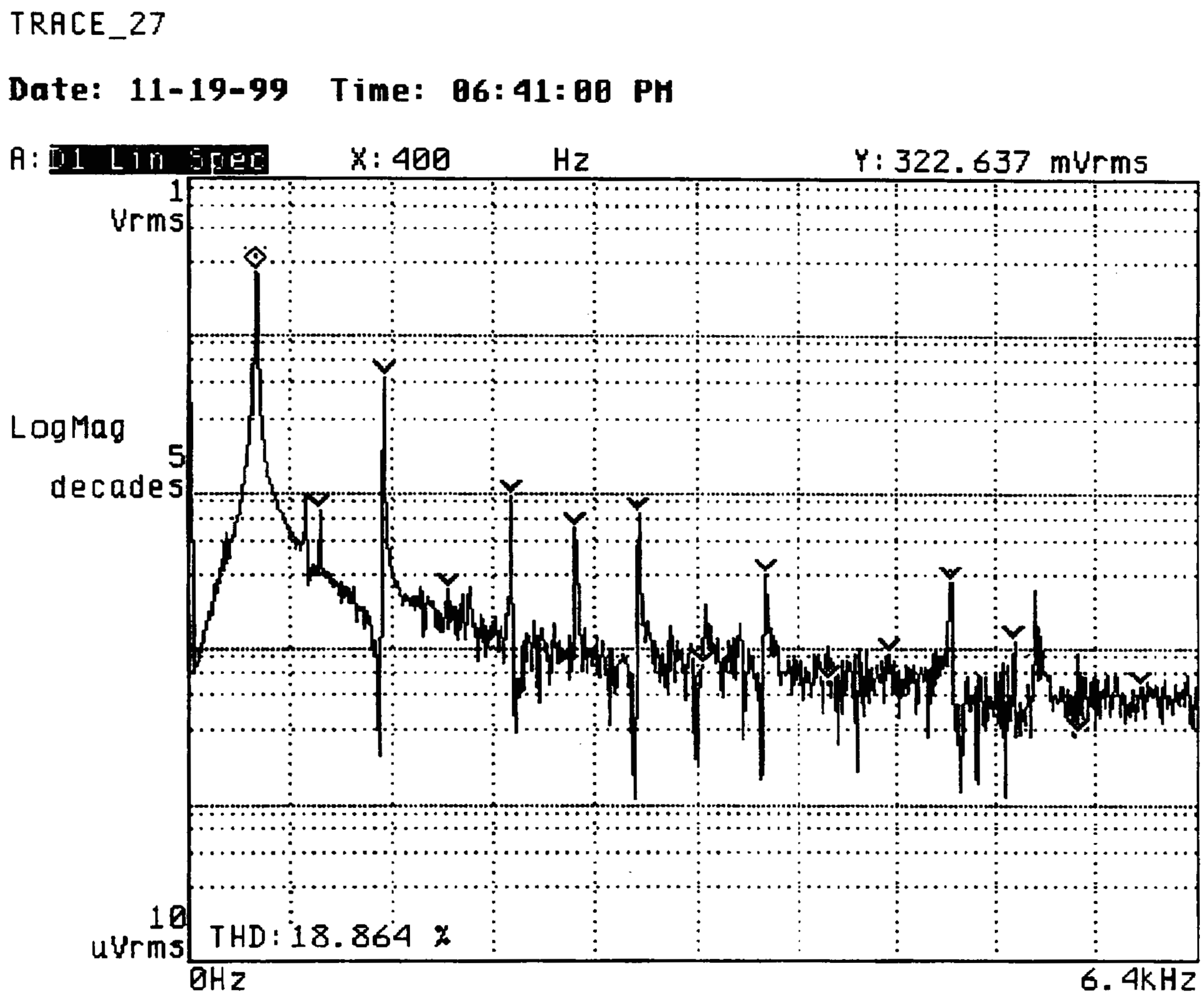

Figure F-27C: Spectrum for All TRU Breakers Pulled (Repeated) (Cont'd)

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