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**Federal Railroad
Administration**

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Summary of AEM-7 Electromagnetic Emission Measurements

Office of Research
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Washington, D.C. 20590

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Interim Report

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Daniel J. O'Neill

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15. Supplementary Notes

This is the third in a series of interim reports documenting measurements of locomotive emission levels. A final report documenting analysis of the data and presenting characterizations of locomotive emission levels will be published tentatively in FY 82.

16. Abstract

Results of electromagnetic emission measurements performed on an AEM-7 at the Transportation Test Center near Pueblo, Colorado, are presented. A brief description of the measurements and methodology employed is included.

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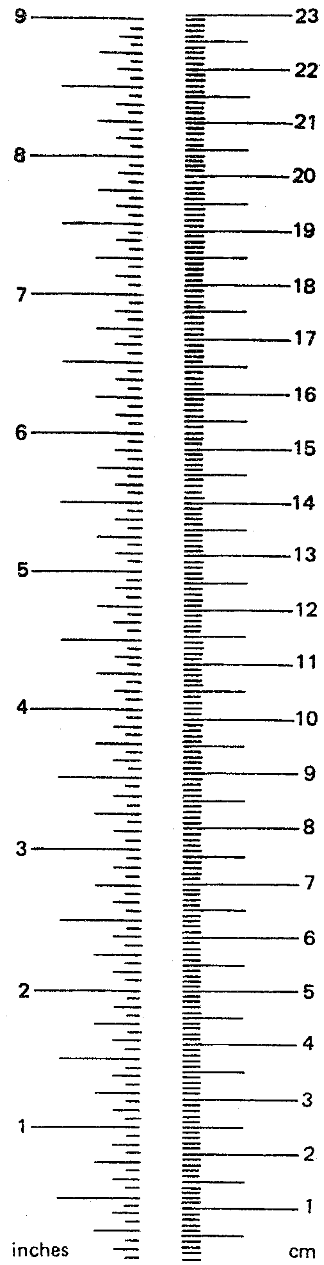
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

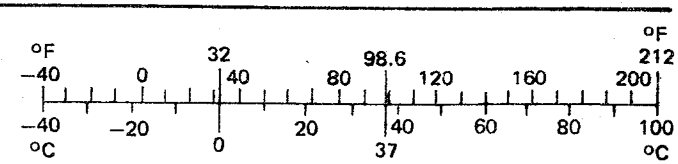
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in. = 2.54 cm (exactly). For other exact conversions and more detail tables see NBS Misc. Publ. 286. Units of Weight and Measures. Price $2.25 SD Catalog No. C13 10 286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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SECTION 1
INTRODUCTION

BACKGROUND

Since April 1977, the Electromagnetic Compatibility Analysis Center (ECAC) has been conducting an ongoing measurement and analysis program to assess the electromagnetic compatibility of various aspects of the United States railroad system. This work has been sponsored by the Federal Railroad Administration, Office of Research and Development (FRA/OR&D), Freight Systems. As part of this program, ECAC has sampled the electromagnetic emission levels of two types of electric locomotives -- the E-60 CP and the AEM-7.

The E-60 measurements were performed during Fiscal Year 1979 at AMTRAK's Wilmington, Delaware, maintenance facility, as well as during a revenue-service run from Washington, DC, to New Haven, Connecticut. Results of these measurements are documented in two ECAC reports.[1,2]

The AEM-7 emission measurements were performed during the month of August 1980 at the United States Department of Transportation, Transportation Test Center (TTC) in Pueblo, Colorado. These measurements entailed sampling emission levels on board the AEM-7 under steady-state and simulated revenue-run conditions, as well as wayside under the same conditions. Results of these measurements are presented in this report.

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[1] O'Neill, D.J., Railroad Electromagnetic Compatibility: Locomotive - Volume 1, Summary of E-60 CP Electromagnetic Emission Yard Measurements, FRA 80/66.1, Electromagnetic Compatibility Analysis Center, Annapolis, MD, October 1980,

[2] O'Neill, D.J., Railroad Electromagnetic Compatibility : Locomotive - Volume 2, Summary of E-60 CP Electromagnetic Emission Road Test Measurements, FRA-80/66.2, Electromagnetic Compatibility Analysis Center, Annapolis, MD, January 1981 ,

The data obtained from these measurements will be analyzed, and characterizations of the electromagnetic emission levels for both the AEM-7 and E-60 locomotives will be developed. These characterizations, along with a characterization to be developed for a diesel-electric locomotive, will be documented in a final report on locomotive electromagnetic emissions scheduled to be published in FY 82.

OBJECTIVE

The objective of this task was to measure and document AEM-7 emission data to be used later in the characterization of the electromagnetic emission levels of the AEM-7 electric locomotive.

APPROACH

From a study of the AEM-7 locomotive wiring diagrams, locomotive subsystems that appeared to be potential sources or propagators of electromagnetic interference (EMI) were identified. In addition, ECAC engineers made a preliminary trip to Wilmington, Delaware, to meet with AMTRAK and General Motors Electromotive Division (EMD) engineers to discuss technical aspects of the locomotive operation and to identify potential measurement locations. From information gathered, ECAC engineers wrote a test plan[3] for review and approval by engineers from TTC and FRA OR&D.

The measurements taken were classified into one of two general categories -- real-time[a] or recorded measurements[b] (see TABLE 1). The real-

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[3]Freeman, T., AEM-7 Electromagnetic Emissions Test Plan, Electromagnetic Compatibility Analysis Center, Annapolis, MD, June 1980.

[a]The term real-time measurements refers to photographs taken off the CRT display at the time the emission was being sampled at TTC.

[b]The term recorded measurements refers to emissions recorded on magnetic tape and later played back and analyzed.

time measurements entailed collecting data by photographing CRT displays of emission waveforms and/or spectra. Data was collected in this manner on board the locomotive with the engine idling (steady state) and also wayside with the engine idling as well as with the engine passing the test location. The recorded measurements entailed recording emission levels on board the locomotive using a reel-to-reel magnetic tape recorder, while the locomotive ran track profiles.

Upon completion of the measurements, the tapes were evaluated and photographs of CRT displays of emission time waveforms and frequency spectra were taken. This data, along with the real time photographs taken at TTC, will be used to develop a characterization of the electromagnetic emissions of the AEM-7 locomotive.

TABLE 1

AEM-7 EMISSION MEASUREMENTS PERFORMED

	Moving	Idling
On Board		
Real Time	X	X
Recorded	X	-
Wayside		
Real Time	X	X
Recorded	-	-

X= Measurements were taken

-= No measurements were taken.

SECTION 2

SYSTEM DESCRIPTION AND MEASUREMENT METHODOLOGY

SYSTEM DESCRIPTION

In Figure 1, a block diagram of the major electrical systems of the AEM-7 locomotive is displayed. Power for the locomotive is supplied through an overhead catenary system operating either at 25 Hz with a nominal voltage rating of 11 kV or at 60 Hz and a nominal voltage level of 25 kV.

The secondary of the main transformer is composed of 11 separate windings. Five of these windings are dedicated to supplying power to the four traction motors (one secondary winding for each traction-motor armature and one secondary winding used to excite all four traction-motor fields). In addition, three secondary windings supply power to the Head End Power (HEP) converter which, in turn, supplies 480-volt, 3-phase, 60-Hz power to the consist. The final three secondary windings supply power to the Static Power Converter which, in turn, supplies 440-volt, 3-phase, 60-Hz power to various electrical devices housed in the locomotive (e.g., blower motors, oil pump motor, and equipment room fan).

Motive power for the AEM-7 locomotive is derived from four separately excited dc traction motors (using either 25- or 60-Hz rectified power). Figure 2 is a simplified motoring diagram of one of the motors. Referring to Figure 2, as the locomotive accelerates from standstill, the thyristors in the upper bridge begin to conduct. As the locomotive continues to accelerate, the thyristors continue conducting until they are fully advanced. At this time, the thyristors in the lower bridge begin to conduct and do so up to desired speed.

The AEM-7 is equipped with two types of brakes -- service (air) and dynamic. Service brakes (shoe-type braking mechanisms) are used when the locomotive is traveling at very slow speeds (a few miles per hour) or, along with dynamic brakes, under emergency stop conditions. In dynamic braking, the traction motor leads are interchanged, and the motors become generators that act as a braking mode. The generated power is then dissipated as I^2R losses.

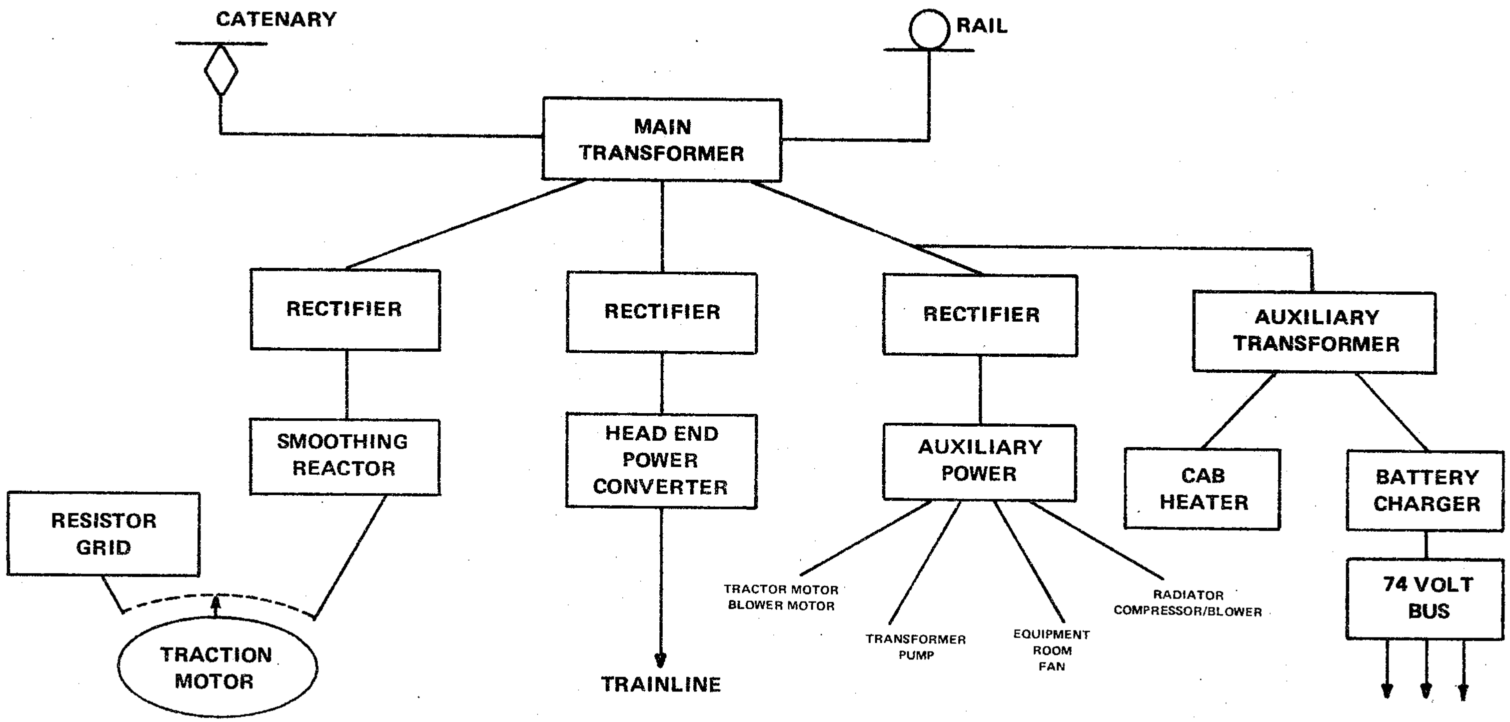

Figure 1. Block diagram of the major electrical systems on an AEM-7 locomotive.

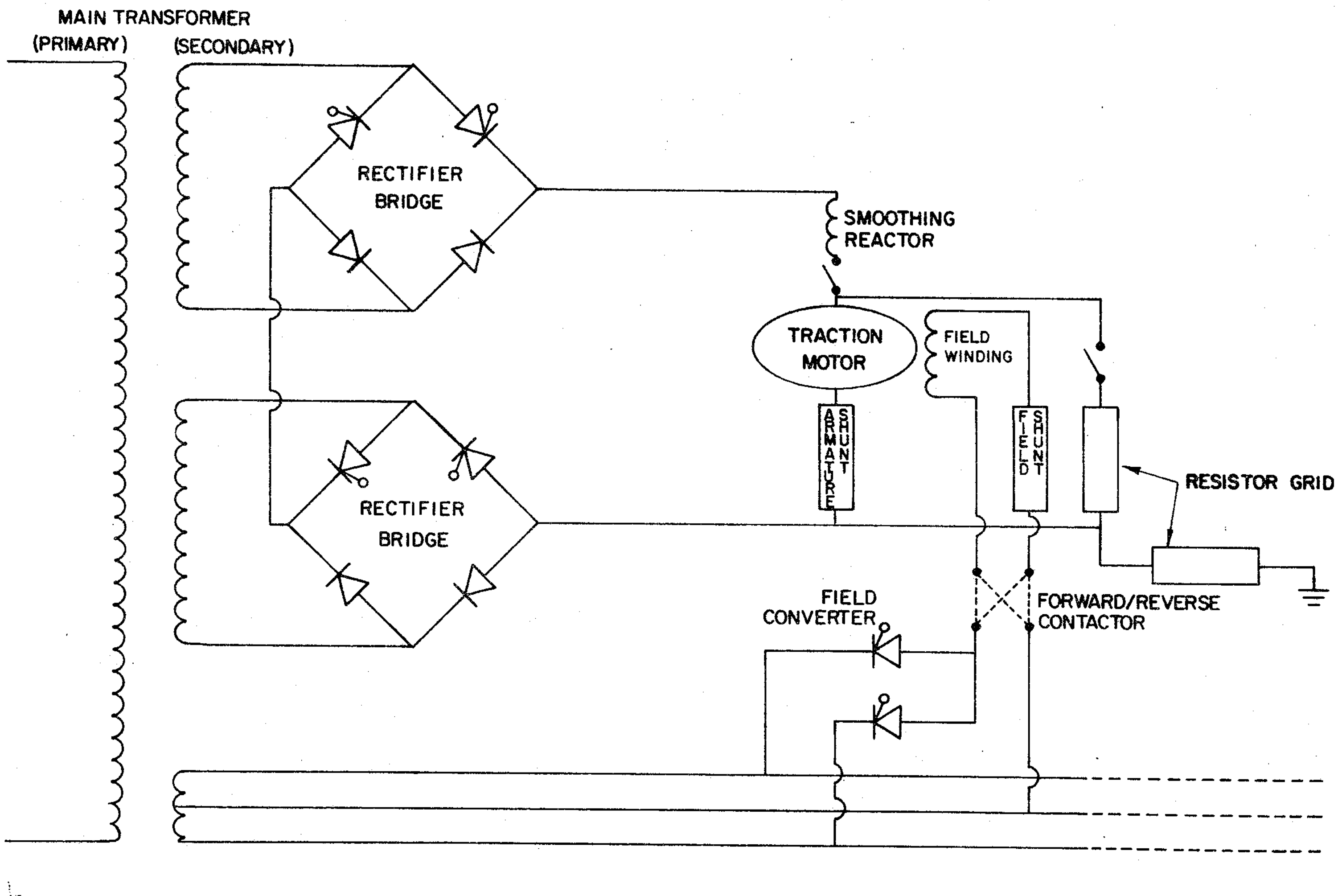

Figure 2. Simplified diagram of one traction motor circuit.

Figure 3 is a diagram of the general layout of TTC's Railroad Test Track (RTT). This track, shown along with TTC's other test tracks, is the largest track at TTC, measuring 14.7 miles (including the Balloon Track). The RTT is made up of 136-lb continuously welded and jointed rail on wood crossties. Electric power is supplied by a substation with variable-voltage capabilities of 12.5, 25, or 50 kV.

DISCUSSION OF MEASUREMENT METHODOLOGY

The measurement instrumentation and their respective functions are given in TABLE 2. The probes used to sample the emissions included an AMPROBE current probe to measure levels of current on the ground side of the main transformer primary as well as at the output of the HEP converter. An ECAC current/magnetic field probe[a] was used to measure levels of current in the number 2 traction-motor armature, as well as levels of magnetic field strength around and under the locomotive. Other probes used included: 1) the Tektronix P6201 probe set to measure levels of voltage across the 74-volt bus and the Trigger Pulse generator voltage levels, 2) the Tektronix P6202 probe set to measure voltage levels across the cab signal pickup and catenary voltage, as well as the main-transformer primary current (high side) levels, 3) a Tektronix P6022 probe set to measure levels of current in the cab signal pickup, and 4) a 41-inch whip antenna (along with the Tektronix P6201) and an Empire VA-105 antenna set to measure levels of electric field strength around and away from the locomotive.[b]

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[a] For a discussion of the ECAC current/magnetic field strength probe, see pages 7-9 in Reference 1.

[b] For validation purposes, the above probes were calibrated both before and after the tests were performed.

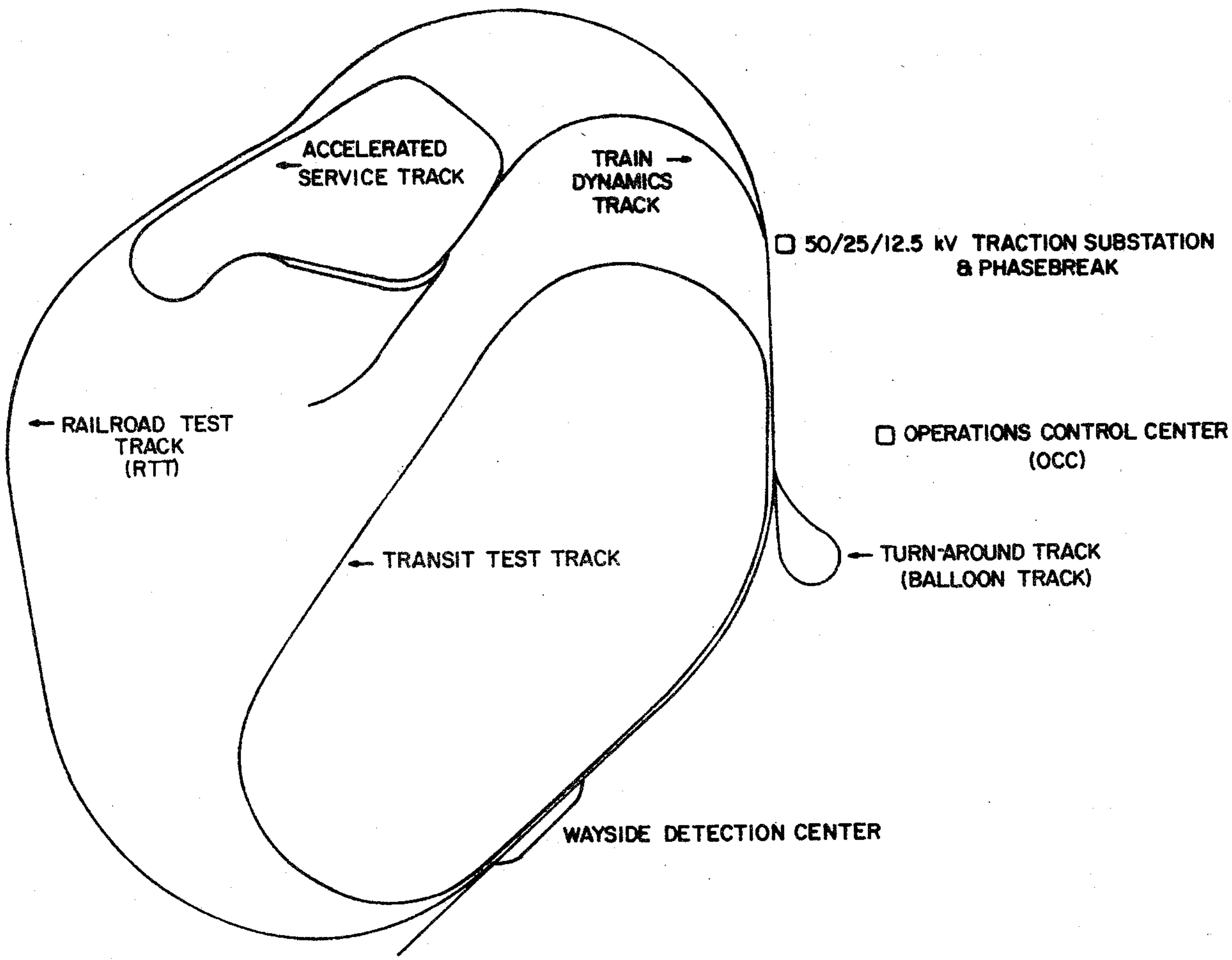


Figure 3. Layout of RTT.

TABLE 2

TEST EQUIPMENT AND RESPECTIVE FUNCTIONS

(Page 1 of 2)

Equipment	Function and Test Parameter
AMPROBE current/voltage probe	To measure levels of current in the main transformer primary winding (ground side) within the frequency range of 60 Hz to 300 kHz.
ECAC Current/Magnetic Field Probe	To measure levels of current in armature cable of traction motor number 2 and also magnetic field strength around the locomotive within frequency range of 60 Hz to 1 MHz.
Tektronix P6201 Probe Set	To measure levels of voltage across 74-volt dc bus and Trigger pulse generator voltage levels (frequency range of dc to 900 MHz).
Tektronix 1101 Probe Power Supply	To provide power for the Tektronix P6201 probe set.
Tektronix P6202 Probe Set	To measure levels of voltage across cab signal pickup and levels of TTC catenary voltage and main transformer probes (dc to 500 MHz).
Tektronix P6022 Current Probe	To measure levels of current in cab signal pickup (from 60 Hz to 10 kHz).
41" whip (along with Tektronix P6201) and Empire VA-105 antennas	To measure levels of electric field strength within frequency range of interest (60 Hz to 5 MHz).

TABLE 2

(Page 2 of 2)

Equipment	Function and Test Parameter
Honeywell 5600C Reel-to-Reel Tape Recorder	To record various current and voltage data.
Tektronix 7L13 Spectrum Analyzer	To display emission levels versus frequency from 1 kHz to 1.8 GHz (used from 100K up to 10 MHz).
Nicolet 444A FFT Spectrum Analyzer	To display emission levels versus frequency in real-time (used for frequency range from 60 Hz to 100 kHz).
Tektronix 7834/7A26/7B53 Mainframe/Oscilloscope	To display emission levels versus time.
Tektronix C-53 Scope Camera	To photograph spectrum analyzer and oscilloscope displays.
Bishop 6-dB Signal Splitters	To allow recording of one signal on two channels of the tape recorder (1 FM and 1 direct channel).
AEL AFA-10, 10-dB Pads	To provide 10-dB attenuation to a signal.
Various Lengths of RG214 and RG223 Cable	To connect probes to recorder/ oscilloscope/spectrum analyzers.

During the recorded measurement phase (locomotive running a track profile), the signals sampled were recorded on a Honeywell 5600C reel-to-reel tape recorder. The Honeywell recorder is able to record in two modes -- FM and direct. In the FM mode, the input signal is used to frequency modulate a carrier, which is then recorded on tape. The frequency response of the recorder in this mode extends from dc to 5 kHz (flat $\pm$ 3 dB). In the direct mode, the input signal is recorded on tape without any modulation. In this mode, the frequency response of the recorder extends from 400 Hz to 75 kHz (flat $\pm$ 3 dB).

During real-time measurements, data was collected using a Tektronix 7834/7A26/7B53 oscilloscope, a Nicolet 444A Fast Fourier Transform (FFT) spectrum analyzer, a Tektronix 7L13 swept-type spectrum analyzer, and a Tektronix C-53 scope camera. Since the probes, spectrum analyzers, and oscilloscope all had bandwidths greater than that of the tape recorder, data taken during these sequences represents samples over a larger frequency range than the recorded measurements.

In Figures 4, 5, and 6, the equipment setups used for recorded and real-time measurements, respectively, are given. The setup shown in Figure 4 was used to perform the recorded measurements; eight circuit emissions were sampled. Emission data collected from these circuits was recorded on four, 7-inch diameter reels of tape using the Honeywell recorder operating at 15 inches per second (ips). The recorder was equipped with 16 channels (4 direct and 12 FM). The main transformer primary current (sampled on the ground side) and the 74-volt dc bus voltage levels were recorded on both direct and FM channels to extend the frequency range of the recorded emission data. In addition, a voice channel, exclusive of the 16 data channels, was used for voice recording of pertinent information such as location markings, speed, etc.

The equipment setup for real-time on board measurements is presented in Figure 5. During these measurements, the emission levels of five circuits were sampled. Data was recorded on photographs using a Tektronix C-53 oscilloscope camera. In addition, other pertinent information was noted. The

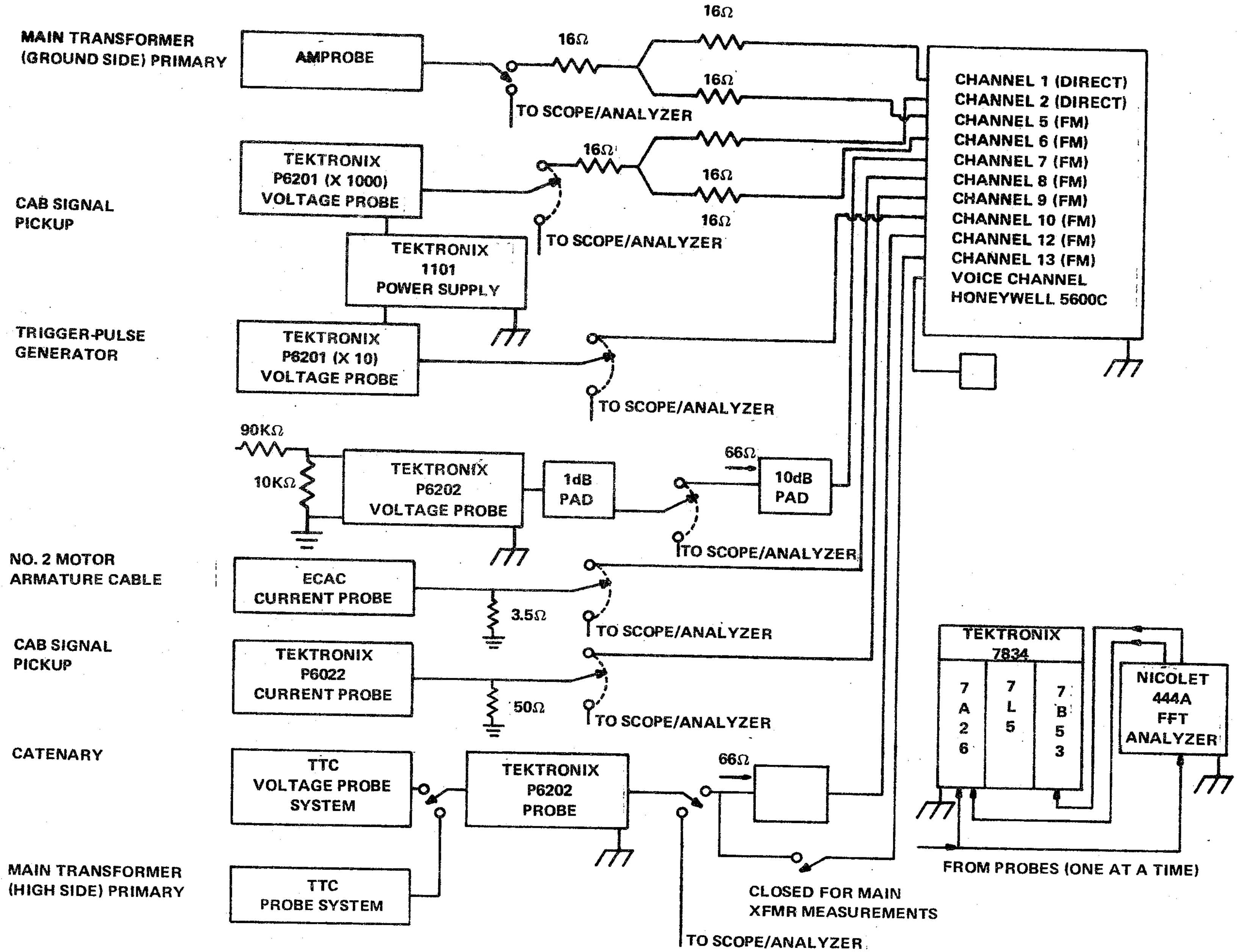


Figure 4. On board recorded measurement setup.

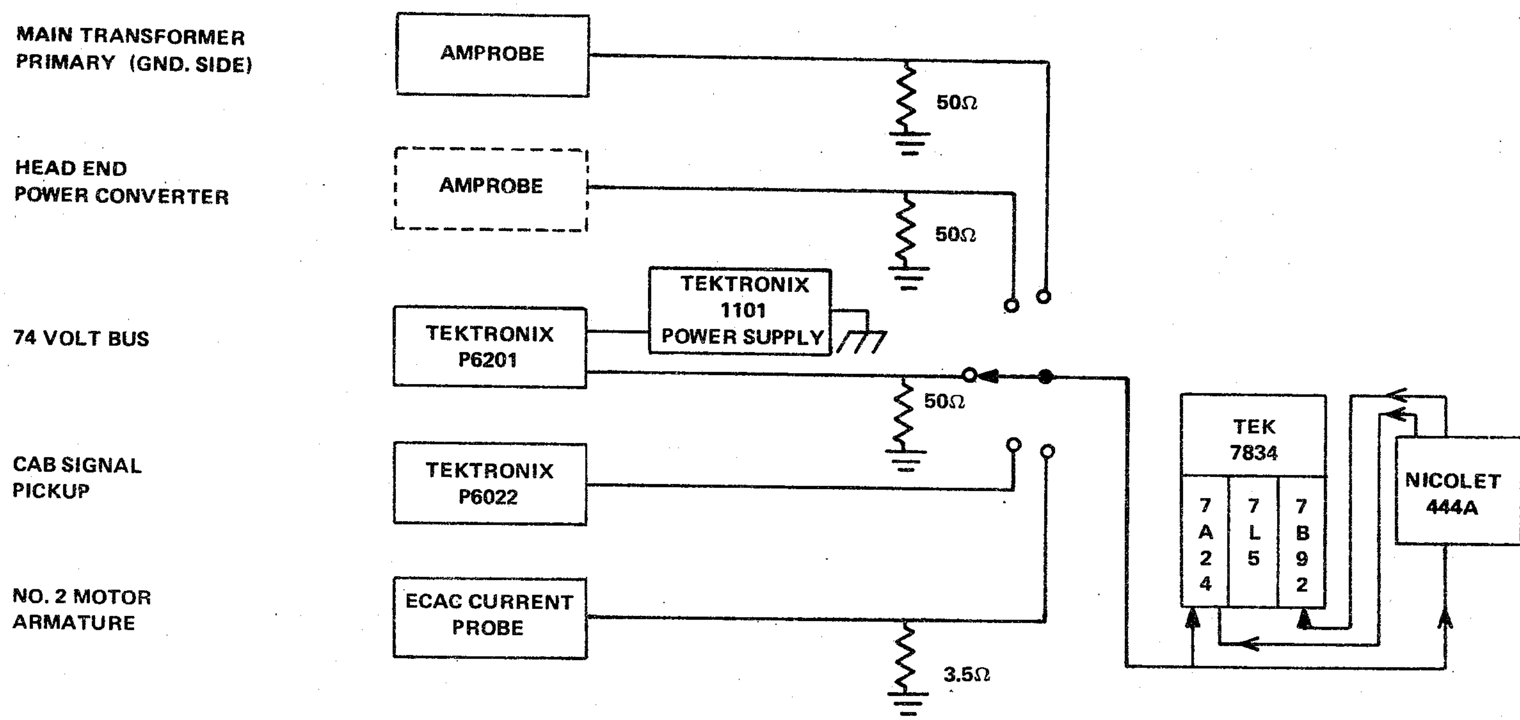


Figure 5. Real-time on board measurement equipment setup.

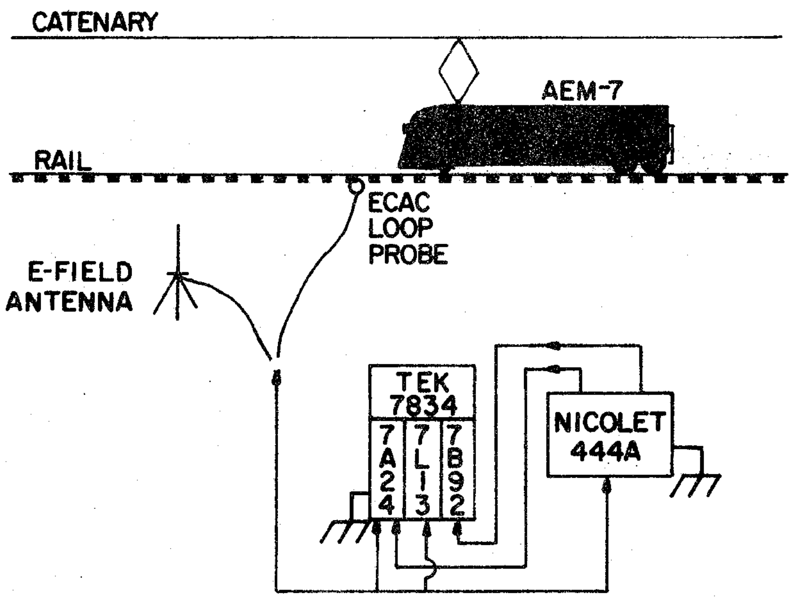


Figure 6. Real-time wayside measurement equipment setup.

real-time wayside equipment setup is illustrated in Figure 6. During these measurements, the current in the rails as well as the magnetic and electric field strengths produced by the locomotive were sampled. Again, data was recorded on photographs in conjunction with notes.

SECTION 3
DATA PRESENTATION

GENERAL

The AEM-7 emission data has been divided into two major categories -- real-time and recorded data. The real-time data has been further subdivided into on board and wayside data. During the on board real-time measurements, data was collected to be used as a baseline for comparison purposes with recorded data collected while the train was running a track profile. The wayside real-time measurements were made to characterize the magnetic and electric field strengths and rail currents produced by the locomotive.

The recorded measurements were taken while the locomotive, operating at 60 Hz with the catenary energized to a nominal voltage of 25 kV, ran track profiles. In all, approximately 11,500 seconds of data were recorded. As a first step in reviewing the data, the tapes were replayed and photographs of the various emission waveforms were taken. This data was then reviewed and photographs showing detailed information regarding the time waveforms and frequency spectra were taken. The basis for selection of data for in-depth investigation was somewhat subjective; however the selection attempted to include what appeared to be typical data collected under various locomotive conditions, as well as any atypical phenomena that were observed.

In the following subsections, results of the real-time and recorded measurements are presented.[a] In addition, a listing of all figures to be presented are tabulated with respect to type of measurement in TABLE 3.

REAL-TIME MEASUREMENTS

The real-time measurements performed included sampling emissions on board the locomotive as well as wayside with the locomotive stationary and passing by. In the following subsections, data collected from these measurements is presented.

Main Transformer Primary Winding (Ground Side)

Initially, measurements were performed on the ground side of the main transformer primary winding with the pantograph down and all electrical devices off in order to obtain a baseline for other measurements to follow.[b] Time waveform and frequency spectrum results of these samplings are presented in Figure 7. In this figure, a sinusoidal waveform is observed in the noise. The amplitude of the waveform is approximately 0.63 ampere peak-to-peak with a period of approximately 16.5 milliseconds (60 Hz). Referring to the spectrum, 60-Hz and 90-Hz levels of -18 dBA and -24 dBA, respectively (0.125 and 0.062 amperes rms, respectively) are observed. This energy sampled is presumed due to capacitive coupling between the energized catenary and the main transformer.

---

[a]Data illustrated on the curves is presented as envelopes of peak emission amplitudes. In many cases, both odd and even harmonic envelopes of 60 Hz up to 1 kHz are illustrated. These envelopes were generated by connecting a straight line between the odd peaks for one envelope and the even peaks for the second envelope. Caution should be taken not to assume that the non-harmonically related frequency levels would be as high as indicated on the curves. Above 1 kHz, the levels depicted are equivalent to those measured for all frequencies.

[b]Power for the test equipment during this and all other measurements was supplied by diesel generators situated in a trailing car and dedicated for test instrument use.

TABLE 3

LIST OF FIGURE NUMBERS FOR RESPECTIVE MEASUREMENTS

Circuit/Emission Measurement	Type of Measurement		
	Real-Time On Board (Figure)	Real-Time Wayside	Recorded On Board (Figure)
Main Transformer Primary (ground side)	7,8,9, and 10		46,47,48,49,50 and 51
Main Transformer Primary (high side)			52 and 53
Catenary Voltage			54
Traction-motor armature	11,12,13,14 and 15	55,56, and 57	
Cab-Signal Pickup - voltage			61, 62, and 63
Cab-signal Pickup - current	16		64 and 65
74-volt dc bus	17,18,19, 20 and 21		59 and 60
Head-End Power Converter	22,23, and 24		
Rail Current		26,27, and 28	
Electric Field Strength		31,32,33,34, 35,36, and 37	
Magnetic Field Strength		39,40,41,42, 43,44, and 45	
Trigger Pulse Generator			58

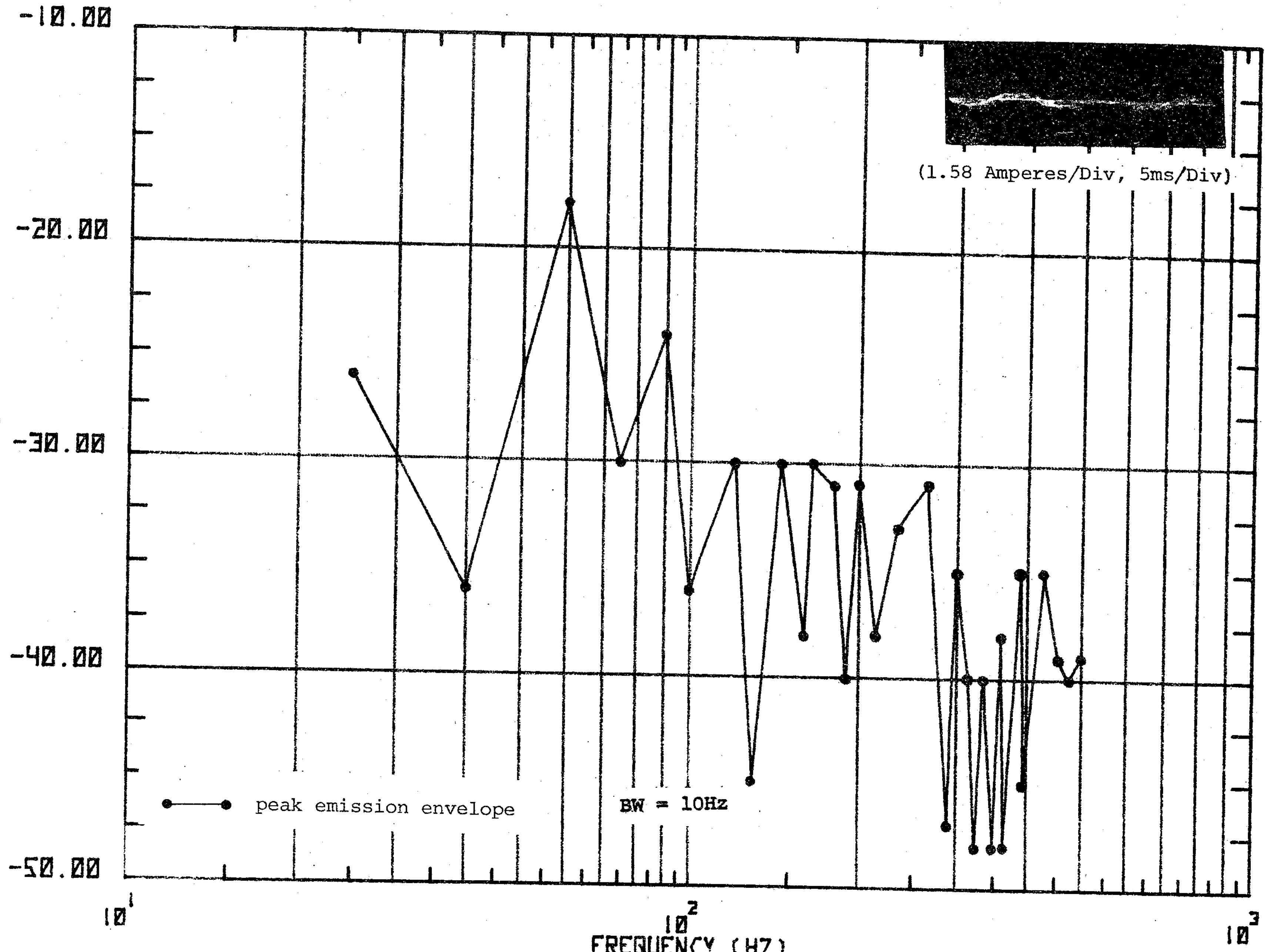


Figure 7. Waveform and spectrum of current in main transformer primary (ground side) with the pantograph down.

The spectrum of the current in the main transformer primary with the pantograph up and the engine idling is displayed in Figure 8. The 60-Hz fundamental sampled at this time was 14 dBA (5.01 amperes rms), while the 180-Hz third harmonic was 7 dBA (2.24 amperes rms).

Next, the current spectra were sampled while the locomotive was traveling at a slow speed, approximately 30 miles per hour (mph), and at high speed, approximately 95 mph, with only traction motors 3 and 4 on. These results are given in Figures 9 and 10, respectively. In comparing Figures 9 and 10, it is observed that the 60-Hz components sampled were 14 dBA (5.01 amperes rms) for the slow speed and 37 dBA (70.8 amperes rms) for the high speed.

Traction Motor Armature

The ac current in one of three cables leading to the armature of the number 2 traction motor was sampled. Initial samplings of the current spectra were made with the pantograph down and all electrical devices in the locomotive off. Results of these samplings are shown in Figure 11. From this figure, three noticeable emissions are present (at 60, 180, and 360 Hz, respectively). The 60-Hz component sampled was -27 dBA (approximately 44.7 milliamperes rms), while the 180- and 360-Hz emission levels were -43 and -47 dBA, respectively (approximately 7.1 and 4.5 milliamperes rms, respectively). Again, it is assumed that this energy is present due to capacitive coupling between the catenary and the locomotive.

After the measurements noted above were taken, the pantograph was raised and the blower motors, power converters, traction motors (idling), and various small electrical units in the locomotive were turned on. The time waveform of the current in the armature was then sampled (see Figure 12). The maximum amplitude of the waveform recorded is approximately 13.6 amperes peak-to-peak (4.81 amperes rms), with a period of approximately 17.5 milliseconds (corresponding to a frequency of roughly 60 Hz).

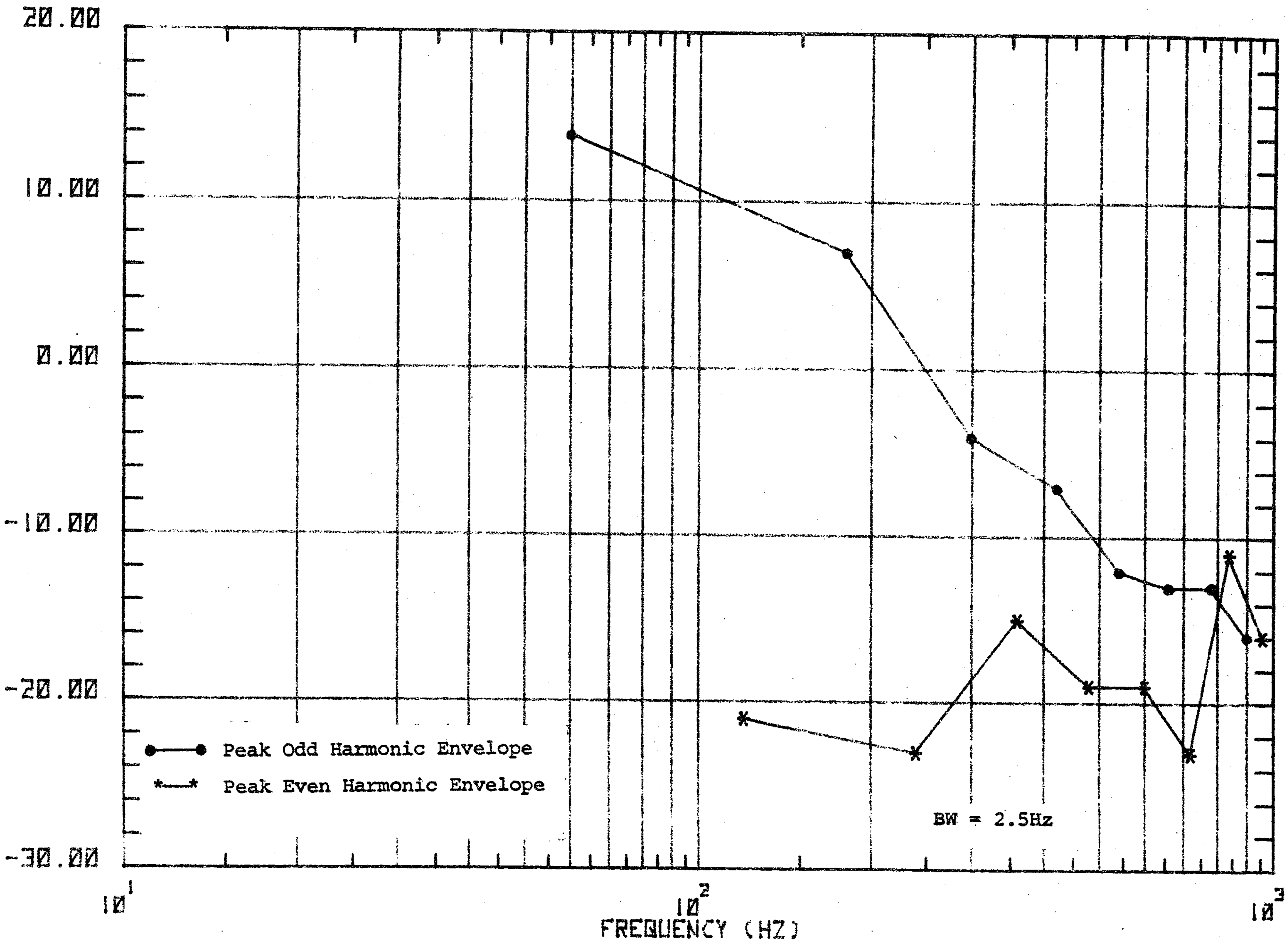


Figure 8. Spectrum of current sampled on ground side of the main transformer primary with the pantograph up.

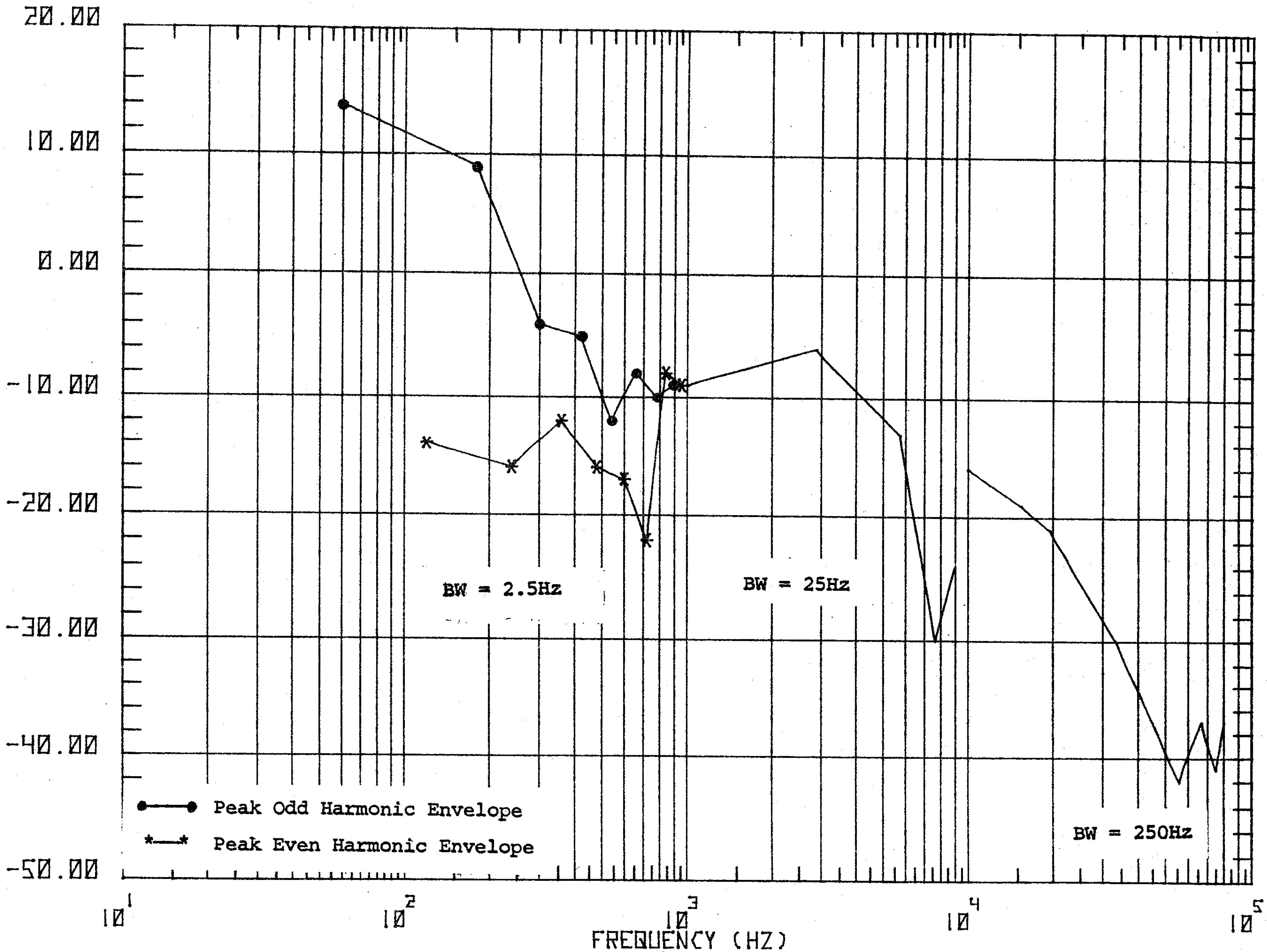


Figure 9. Spectrum of ground side primary current sampled while locomotive was traveling at slow speed.

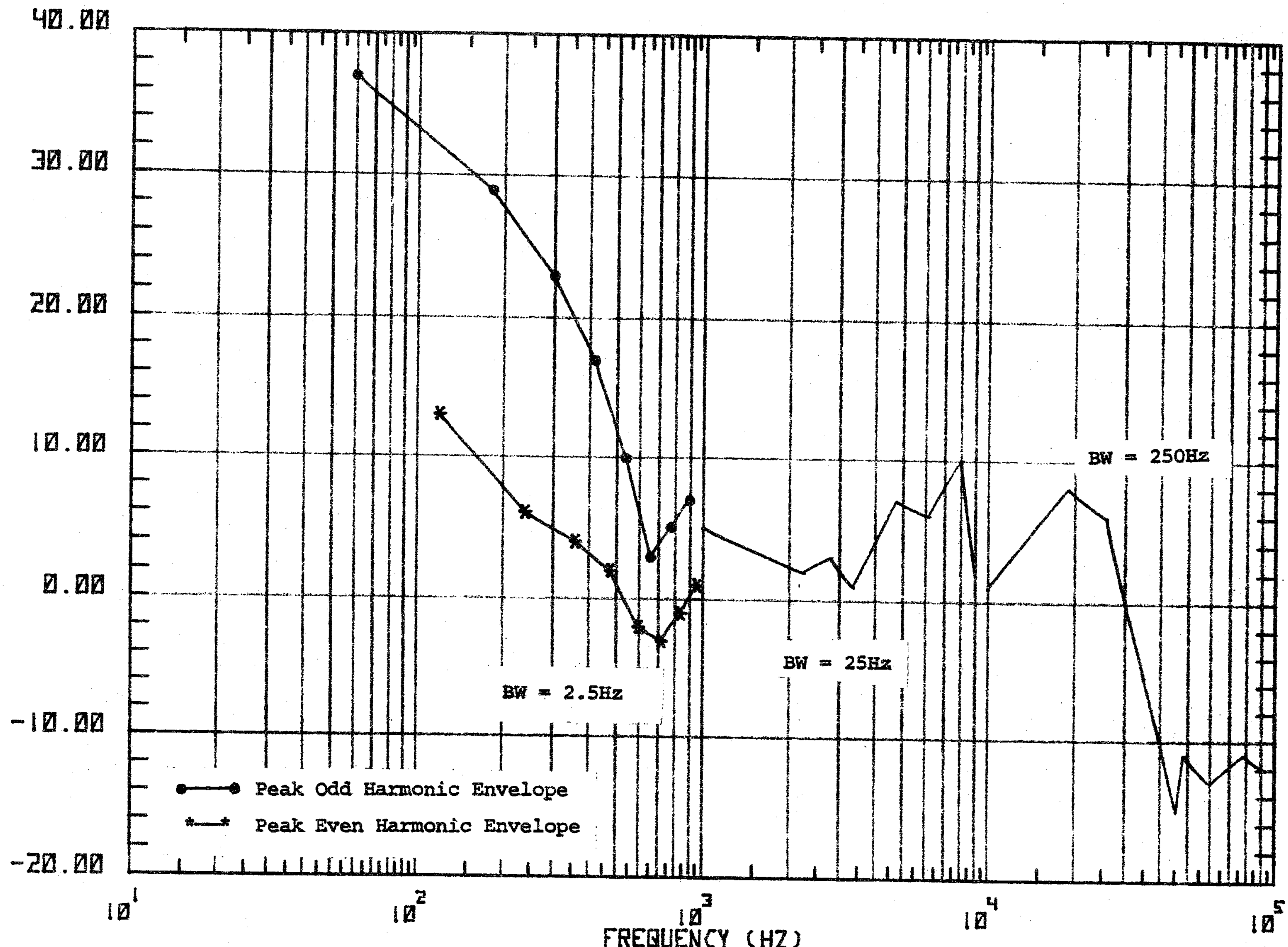


Figure 10. Spectrum of primary current sampled while locomotive was traveling at high speed.

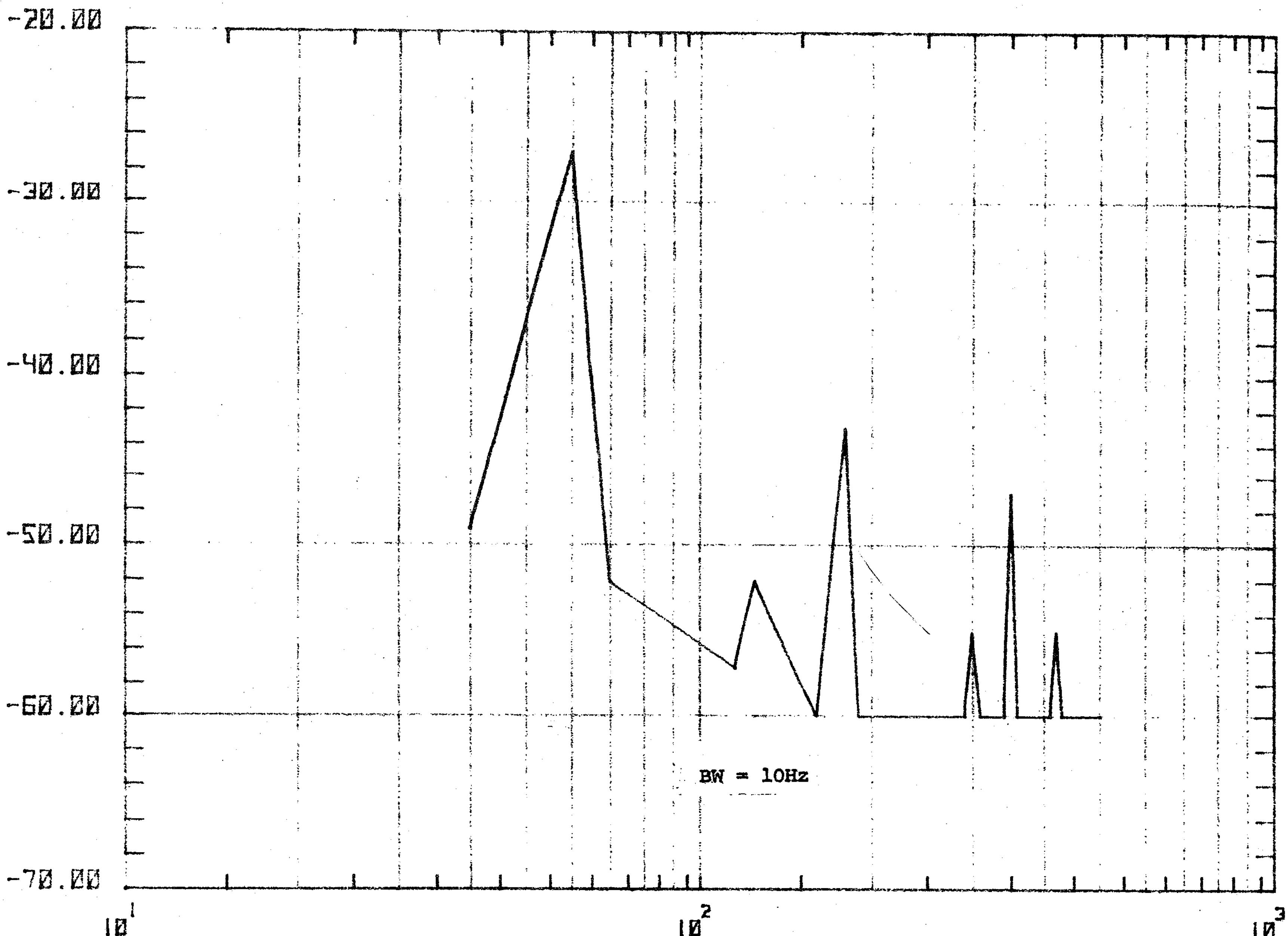
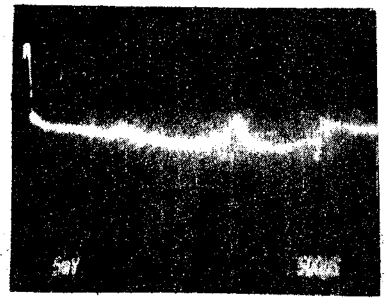


Figure 11. Spectrum of current in traction motor armature, pantograph down.



(3.9 amperes/div., 5 ms/div.)

Figure 12. Waveform of current in traction motor armature, locomotive idling.

Next, as the locomotive traveled around the track, the waveforms of the ac current in the number 2 traction motor (one of three cables) and the ground side of the primary winding of the main transformer were sampled simultaneously and are shown in Figure 13.[a] These two waveforms were each recorded at two different points along the track. In Figure 13a (the first location), the amplitude of the armature and primary currents were 186.24 and 1391.5 amperes peak-to-peak (65.8 and 492 amperes rms), respectively.

At the second location (Figure 13b), the armature and primary current amplitudes sampled were 356.5 and 2213.4 amperes peak-to-peak, (126 and 782.6 amperes rms), respectively. The primary current amplitude presented here appears excessively large. Resolution or confirmation of this level will be made during further analysis of the data.

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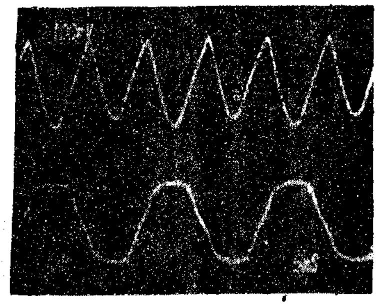
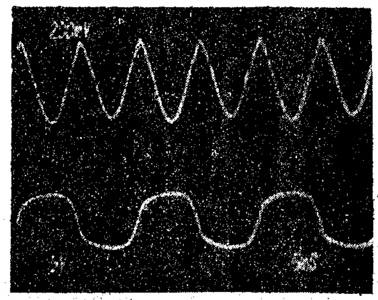
[a] In presenting the data, any known speed information is noted. At times where it is not noted, the speed was not ascertainable.



a. Location 1: armature = 77.6 A/div., primary = 632.5 A/div., 5 ms/div.



b. Location 2: armature = 155 A/div., primary = 1581 A/div., 5 ms/div.

Figure 13. Waveforms of main transformer primary and traction motor armature currents.

Next, the spectrum of the current in one cable leading to the armature winding of traction motor 2 was sampled while the locomotive was traveling over 100 miles per hour (all four traction motors running). This spectrum is presented in Figure 14. The 60-Hz component recorded was 52 dBA (398 ampere rms), while the third and fifth harmonics were 32 and 23 dBA (39.8 and 14.13 amperes rms), respectively.

As a final example, the spectrum of the current in one of the cables leading to the traction motor 2 armature (with traction motors 1 and 2 off and traction motors 3 and 4 on) while the train traveled around the track was measured and is displayed in Figure 15. The 60-Hz component in this case was 7 dBA (2.2 amperes rms). The 180-Hz third harmonic recorded was -2 dBA (0.79 ampere rms).

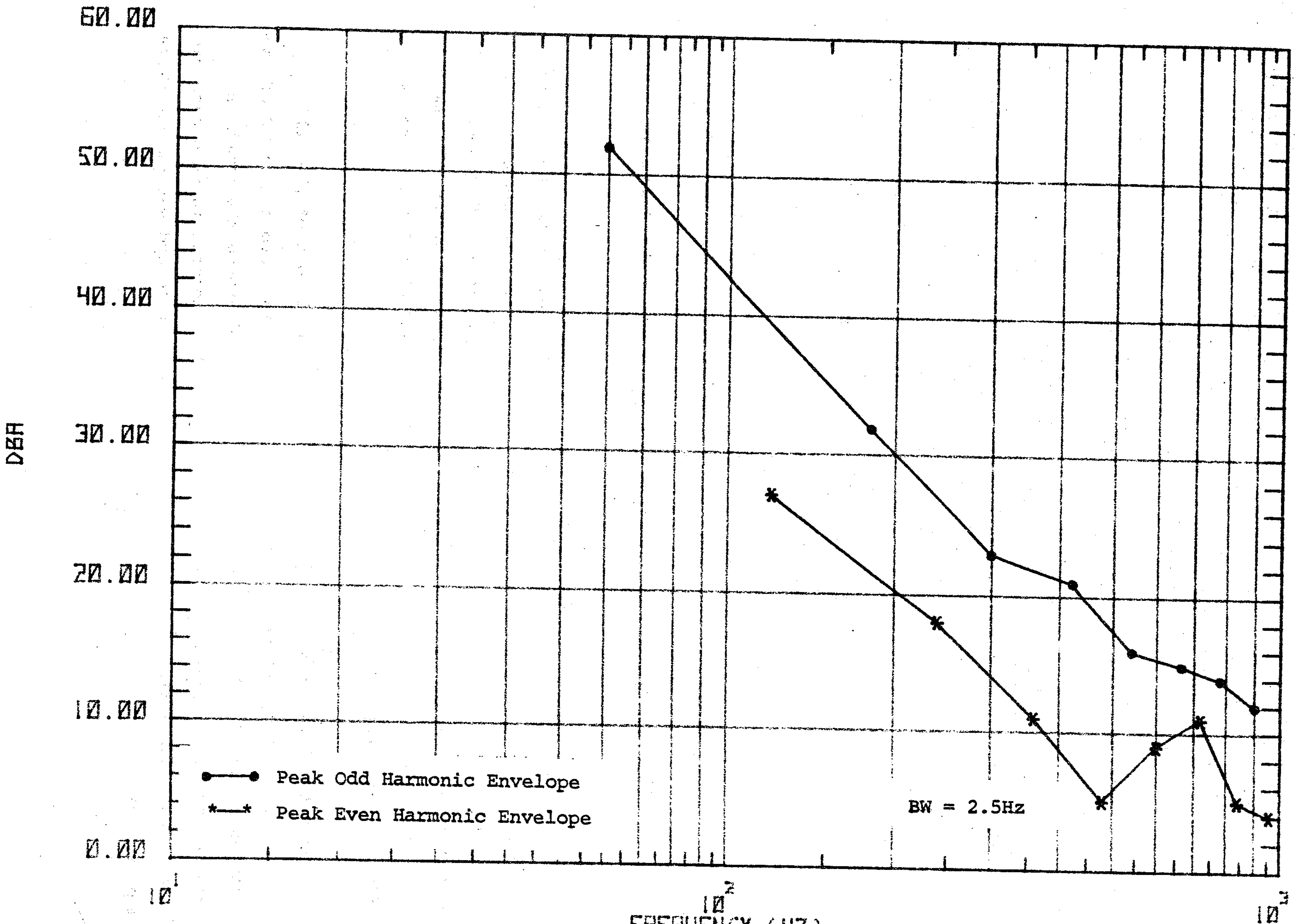


Figure 14. Spectrum of the current in one of three cables leading to armature, locomotive traveling at over 100 mph.

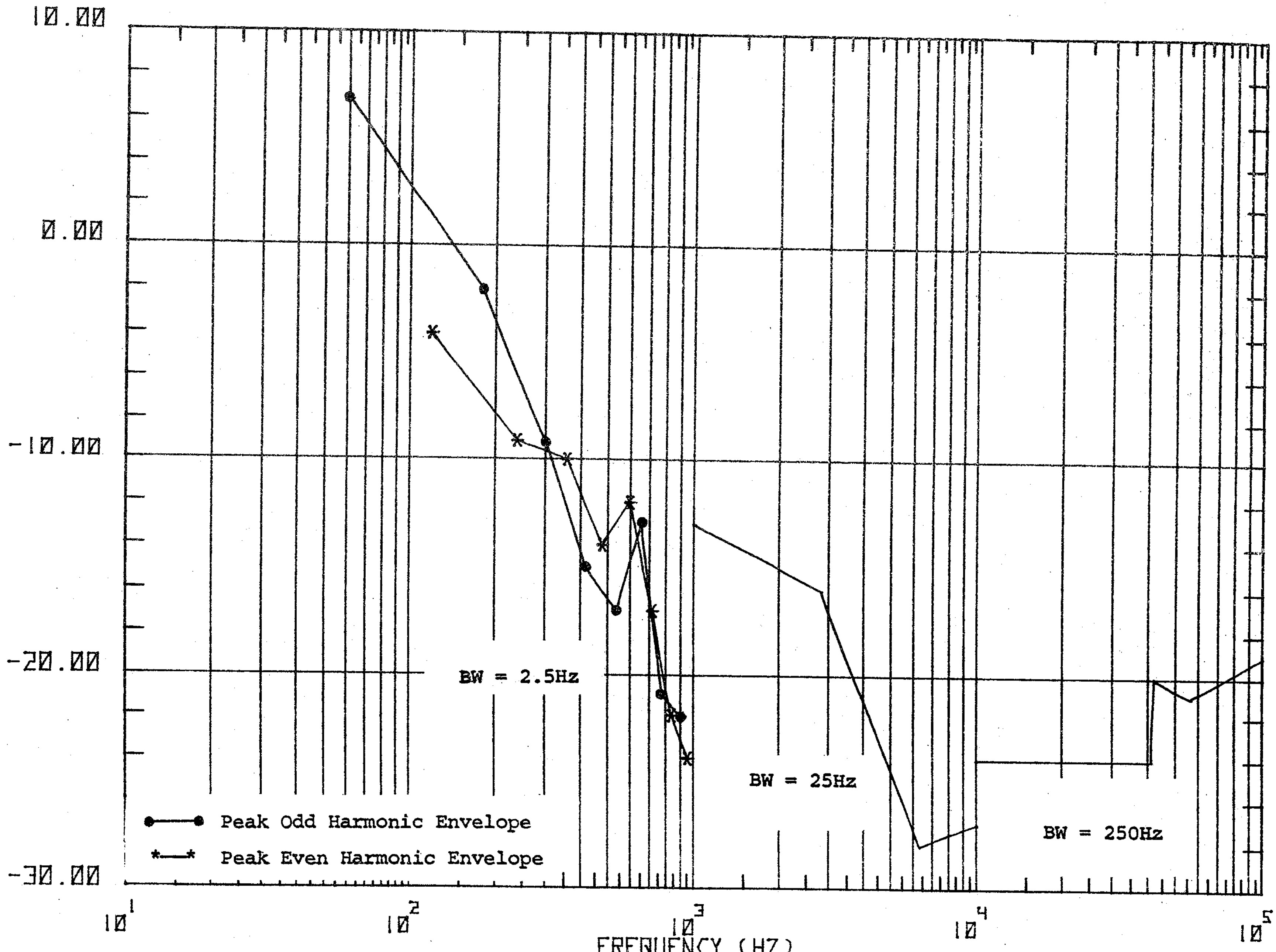


Figure 15. Spectrum of current in one of three cables leading to armature, traction motors off.

Cab Signal Pickup

The spectrum of the current in the cab signal pickup was sampled between 0 and 500 Hz with the catenary energized and the pantograph down. These measurements, as well as on board recorded cab signal measurements, were made on the rear cab signal pickup. This pickup was unterminated during the measurements. Results of this sampling are given in Figure 16. From this figure, the only distinguishable emissions are observed at 40 and 180 Hz. The noise levels recorded at these frequencies were -70 and -79 dBA (0.32 and 0.11 milliamperes rms), respectively.

74 Volt dc Bus

Measurements of levels of voltage across the 74-volt dc bus versus frequency and time were taken and recorded in real-time with the locomotive stationary. In Figure 17, the spectrum of the voltage across the bus, sampled between 0 and 500 Hz, with the pantograph down and all major electrical units in the locomotive off, is given. In this figure, the fundamental as well as the third, fifth, and seventh harmonics of 60 Hz are noticeable. The sampled levels of voltage for the 60-, 180-, 300-, and 420-Hz components were -23, -30, -34, and -34 dBV (70.8, 31.6, 19.95, and 19.95 millivolts rms), respectively.

The dc voltage across the 74-volt bus was then sampled with the pantograph up, the engine idling, and the batteries being charged. The waveform obtained under these conditions is given in Figure 18; the measured voltage level was 76 volts dc. In addition to the dc voltage, repetitive voltage pulses (20 volts peak-to-peak) occurring every 8.5 milliseconds are observed. These pulses are presumed to be caused by the battery charger.

Next, the ac voltage was sampled under the same conditions noted above. These waveforms are displayed in Figure 19. In Figure 19a, the ac waveform was sampled over a 50-millisecond time period. The amplitude of the waveform is approximately 22 volts peak-to-peak with a period of 17 milliseconds (~ 60

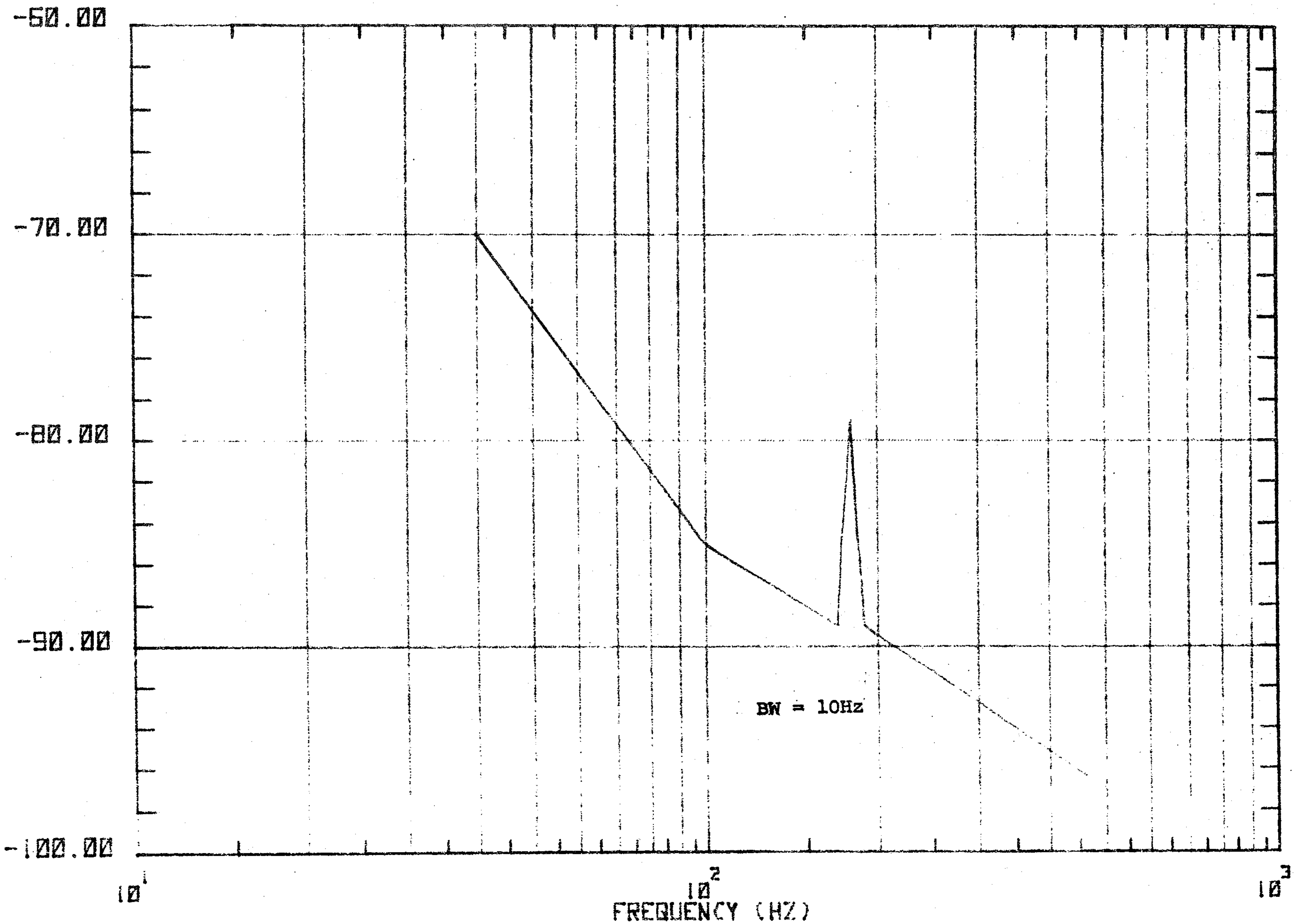


Figure 16. Spectrum of current in cab signal pickup, pantograph down.

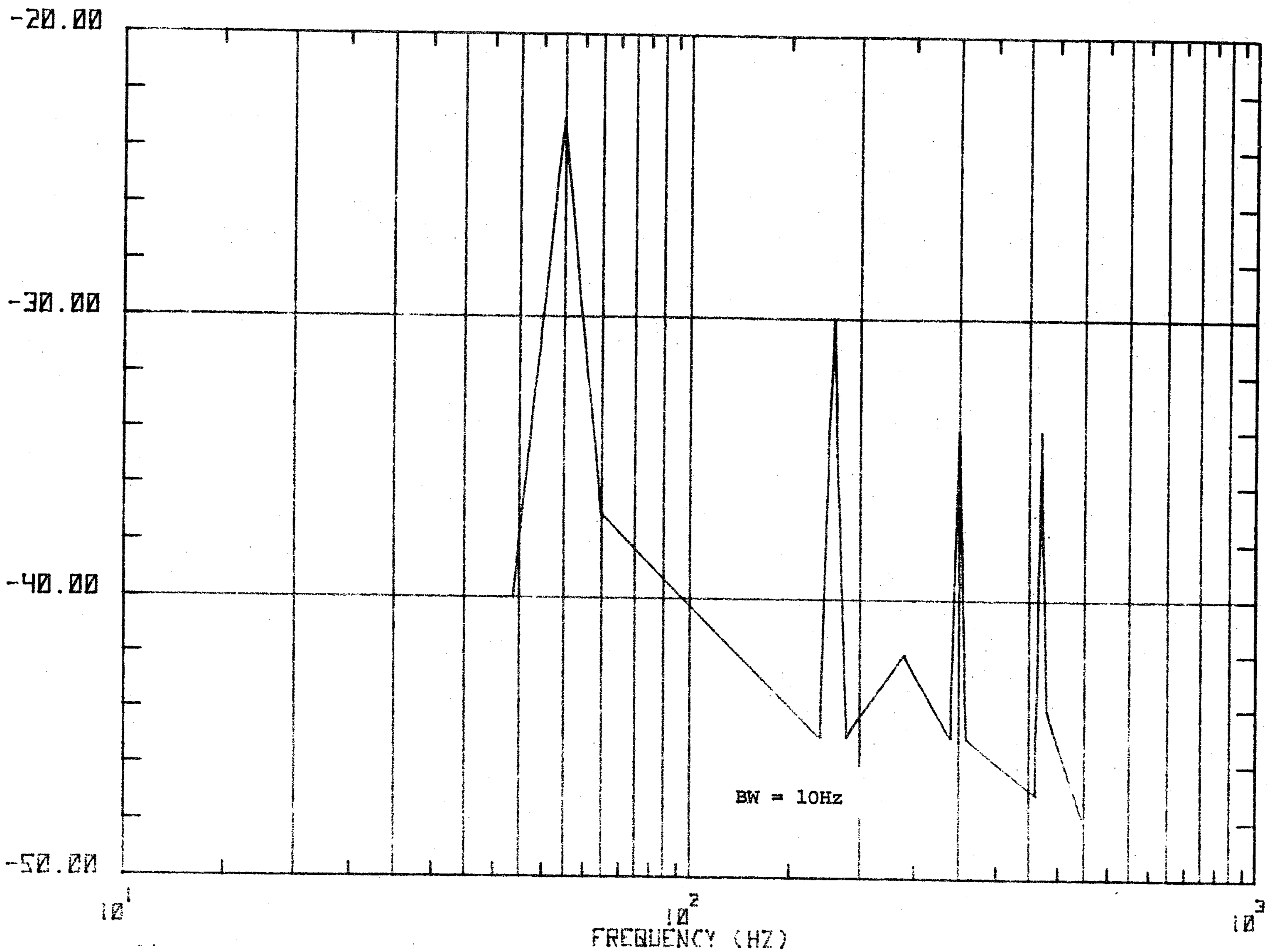
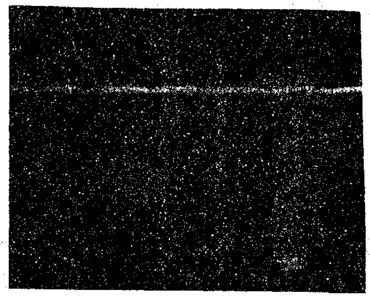


Figure 17. Spectrum of voltage across 74-volt bus with the pantograph down.

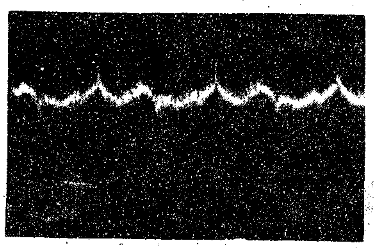


... 0-volts dc

(50 volts/div., 5 ms/div.)

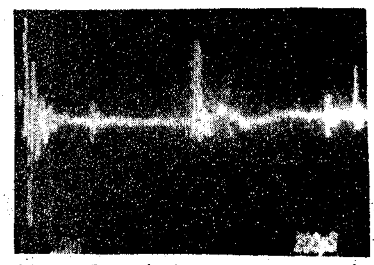
Figure 18. Waveform of dc voltage across 74-volt bus.

Hz). Again, this waveform is presumed to be caused by the battery charger. In Figures 19b and 19c, the ac waveform was sampled over a 2-millisecond and a 200-microsecond interval, respectively.



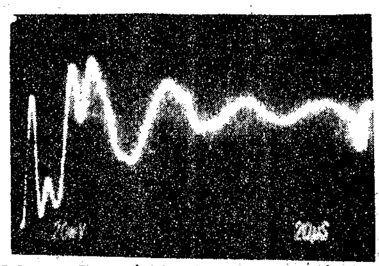
... 0-volts ac

a. 10 volts/div., 5 ms/div.



... 0-volts dc

b. 10 volts/div., 200 μs/div.



... 0-volts ac

c. 20 volts/div., 20 μs/div.

Figure 19. Waveform of ac voltage across 74-volt bus.

The spectrum of the voltage corresponding to the waveforms shown in Figure 19 is presented in Figure 20.

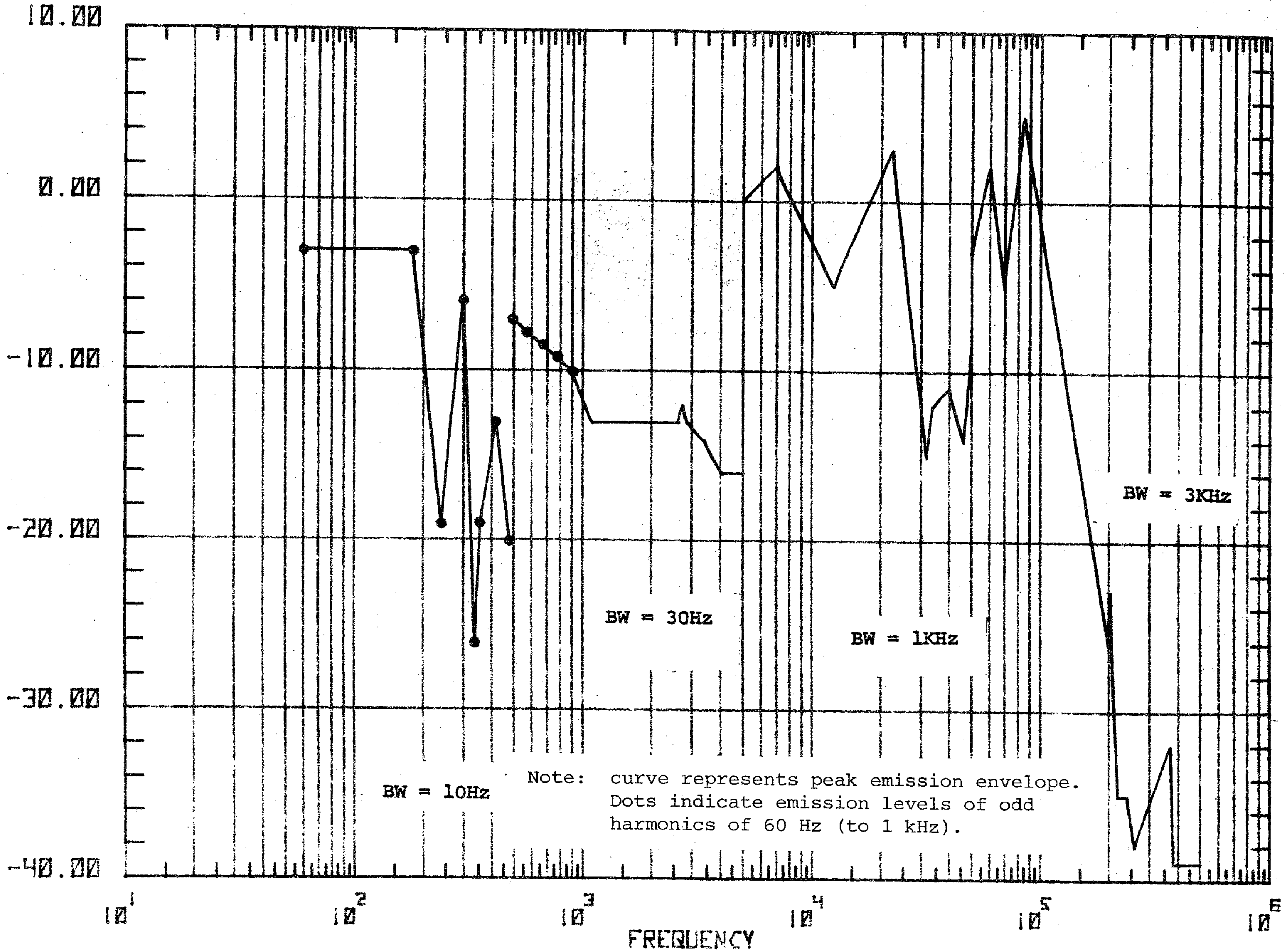


Figure 20. Spectrum of voltage across 74-volt bus (corresponding to Figure 19).

At a later time, the voltage across the 74-volt bus was again sampled. At this time, the engine was idling with all major electrical units (e.g., the blower motor, oil pump, etc.) as well as many small electrical units on. The batteries were not being charged at this time. The spectrum sampled between 0.5 and 5 MHz is presented in Figure 21. Referring to this figure, the most noticeable emission sampled was at 800 kHz where the level recorded was -26 dBV (0.05 volts rms).

Head End Power Converter

The outputs of the HEP converter were sampled using the AMPROBE current probe and the FFT spectrum analyzer. During these measurements, the locomotive was idling. For reporting purposes, the first output cable sampled was called phase 1, while the second and third cables sampled were called phases 2 and 3, respectively. The spectra of the three phase currents are presented in Figures 22, 23, and 24. Referring to these figures, the 60-Hz components sampled for phases 1, 2, and 3 were 26, 28, and 25 dBA (19.95, 25.1, and 17.8 amperes rms), respectively.

Approximately one half hour later, the currents were again sampled, this time using the AMPROBE's current meter. The rms values read off of the AMPROBE (bandwidth = 300 kHz) were 58, 37, and 36 amperes, respectively.

Rail Current

The levels of current in one rail were measured as a function of time and frequency using the ECAC current probe placed next to the rail as shown in Figure 25. Measurements were performed while the locomotive (with a 5-car consist) was idling next to the measurement location (marked as position 1 in Figure 25), and also while the locomotive was running a track profile. In the latter case, measurements were initiated as the locomotive approached and passed the point noted as position 2 in Figure 25, while the probe was placed at position 1.

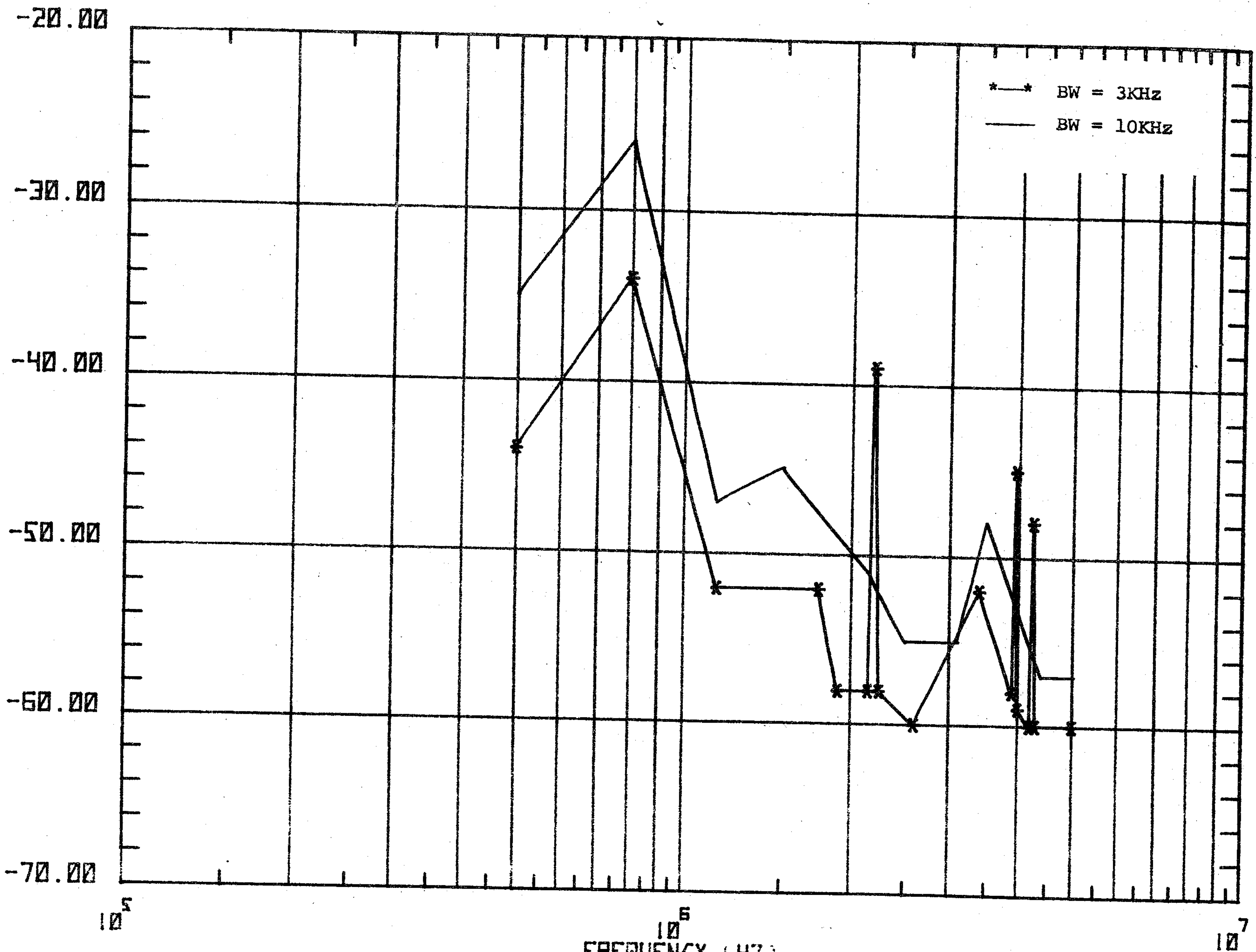


Figure 21. Spectrum of voltage across 74-volt bus, engine idling.

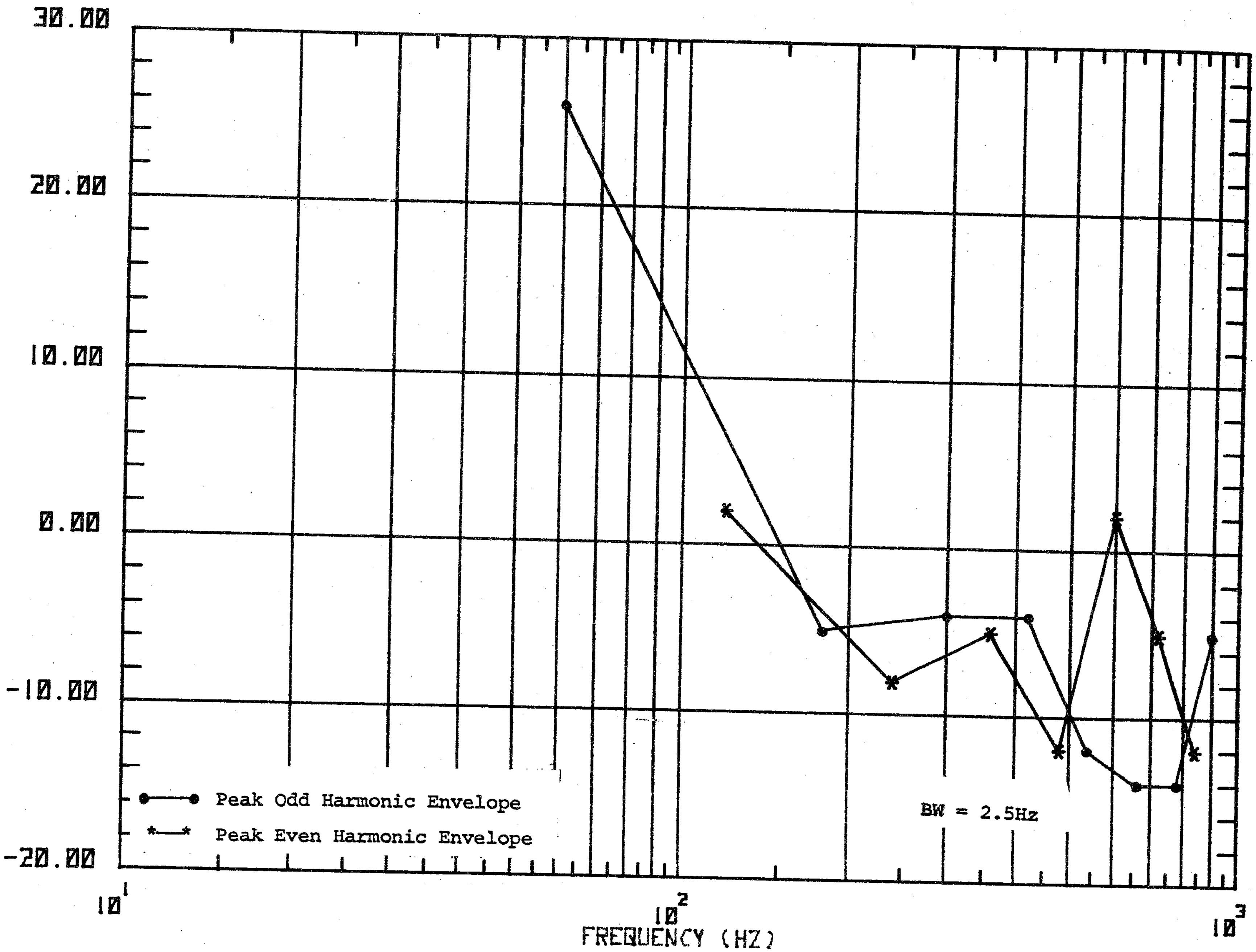


Figure 22. HEP phase-1 current spectrum.

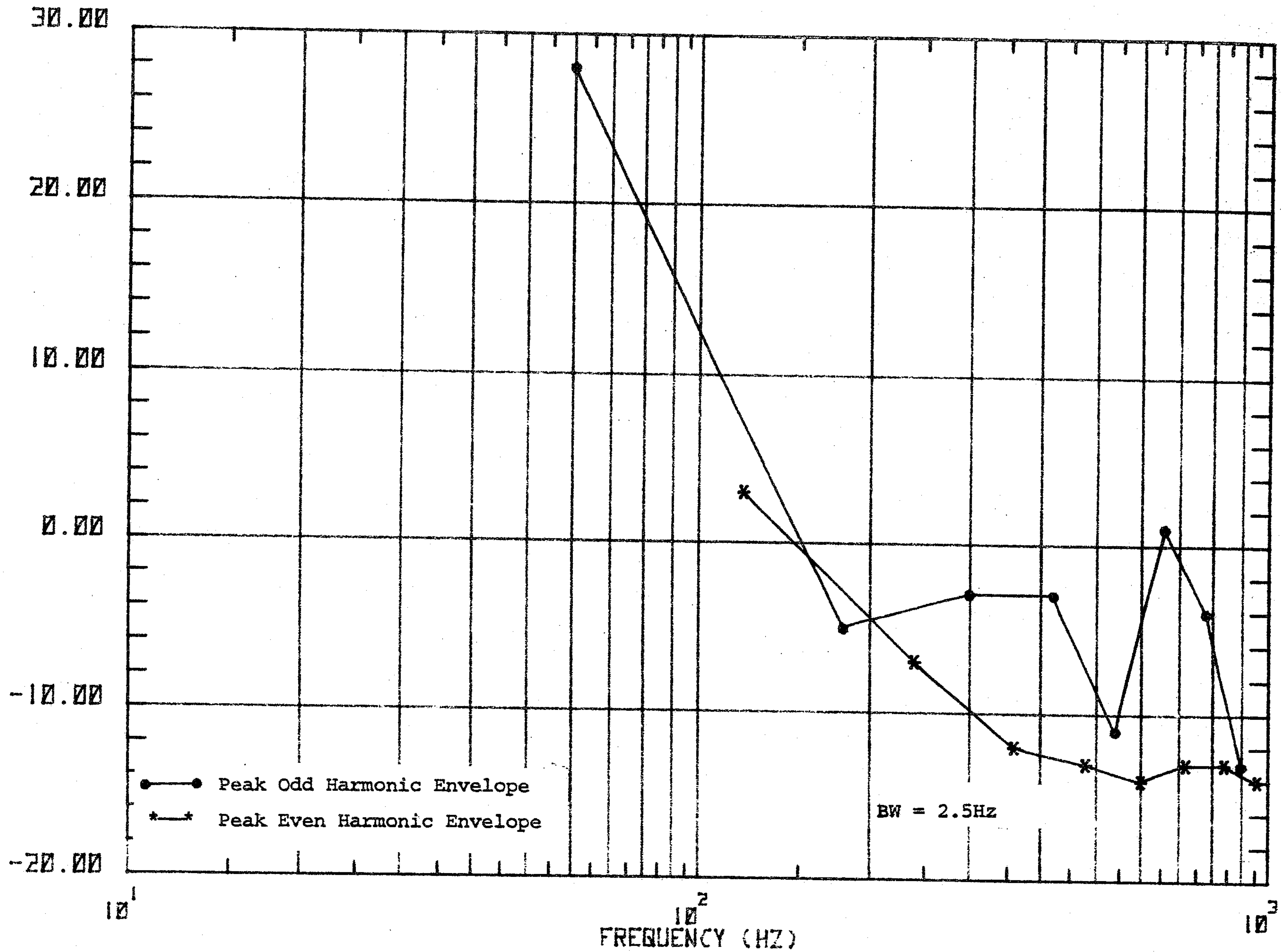


Figure 23. HEP phase-2 current spectrum.

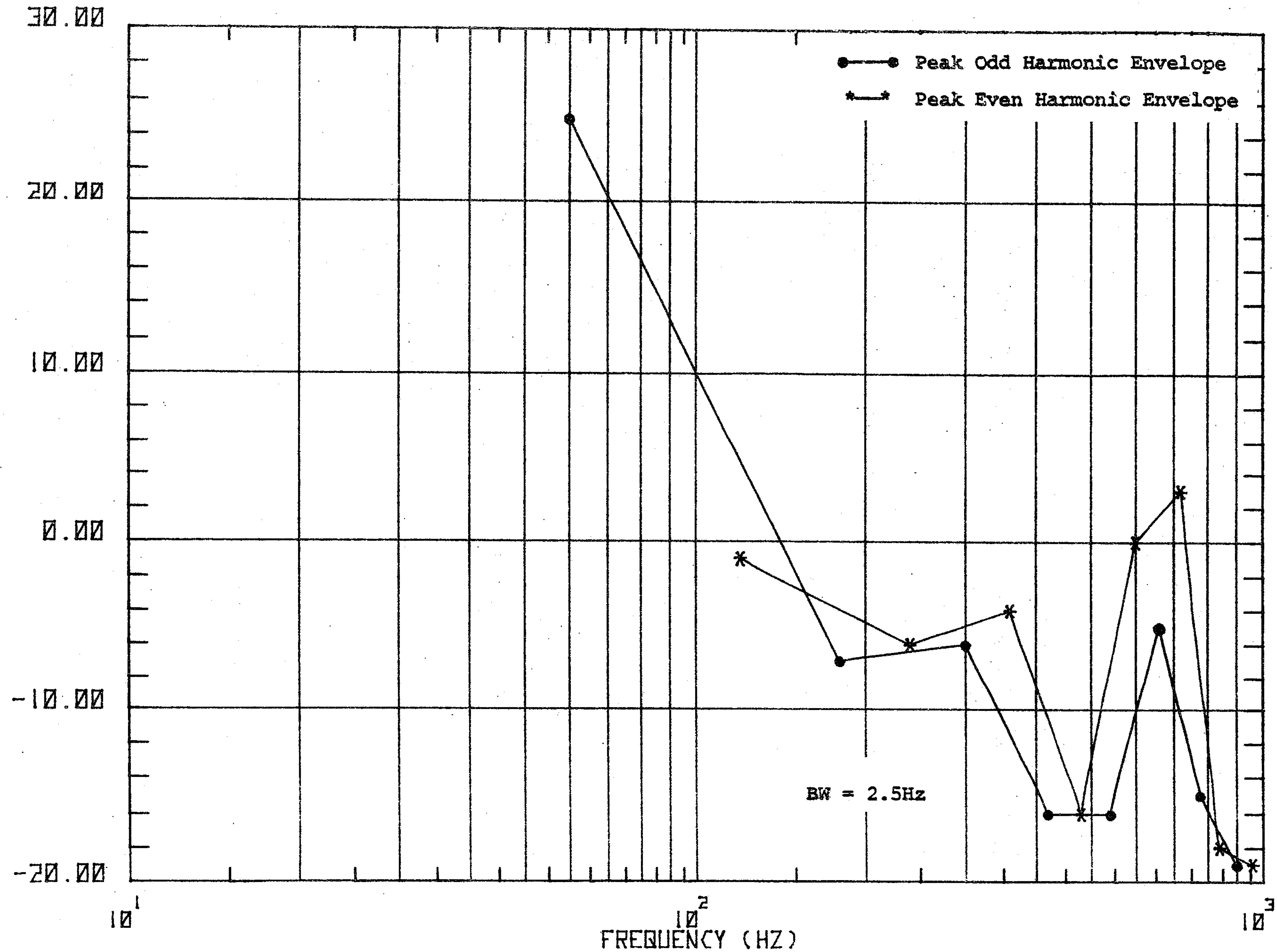


Figure 24. HEP phase-3 current spectrum.

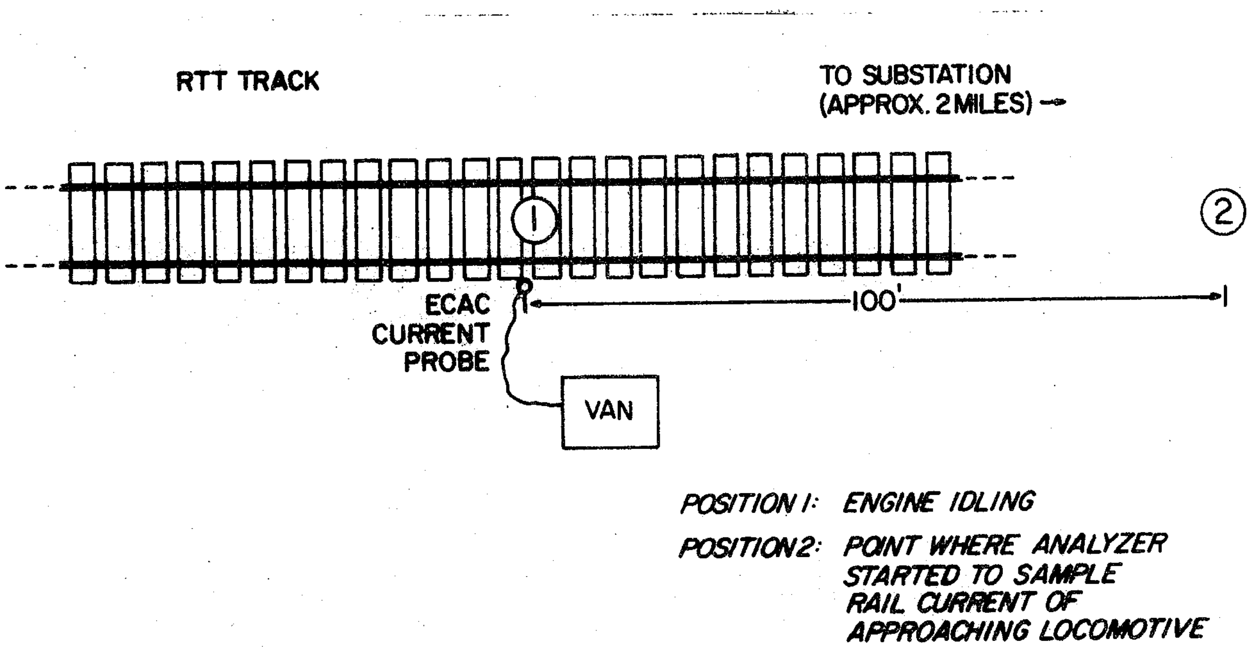
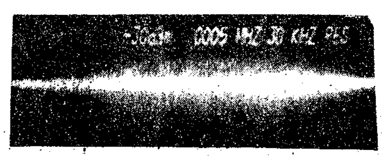


Figure 25. Rail current measurement location.

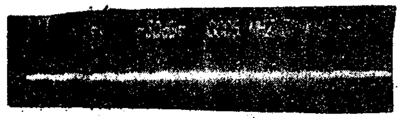
The waveform of the current sampled while the locomotive was stationary (position 1) is given in Figure 26. The amplitude of the current sampled at this time was 2.8 amperes peak-to-peak (0.98 ampere rms).



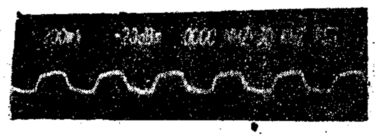
(6.9 A/div., 500 ms/div.)

Figure 26. Waveform of current in one rail, engine idling.

In Figure 27, two waveforms are presented. The first waveform (Figure 27a) was sampled while the locomotive was coasting as it approached the measurement location. The second waveform (Figure 27b) was sampled while the locomotive was accelerating past the measurement location. The current amplitude for the cases where the locomotive was coasting or accelerating was 27.6 and 138 amperes peak-to-peak, respectively.



a. Locomotive coasting (276 A/div., 200 ms/div.)



b. Locomotive accelerating (276 A/div., 100 ms/div.).

Figure 27. Waveforms of current in one rail as train approaches measurement location.

Next, the frequency spectrum of the current in one rail was sampled as the locomotive approached and passed the measurement location. This spectrum is illustrated in Figure 28. The 60-Hz component of the current recorded at this time was 33 dBA (44.7 amperes rms), while the 180-Hz third harmonic was 19 dBA (8.9 amperes rms).

Substation Ground Return

The traction return current in one of three ground-return cables from the test track was sampled at the substation using the AMPROBE current probe as shown in Figure 29. Initially, the 60-Hz component was sampled with no load except for the capacitance between the 25-kV catenary and ground. The level recorded for this condition was -6 dBA (0.5 ampere rms) for one of three cables. Next, the locomotive (without the consist) was placed on the track approximately 4 miles from the substation with the pantograph raised and the locomotive idling. The spectral levels recorded for this set of conditions are presented in TABLE 4. The 60-Hz component sampled with the train idling was

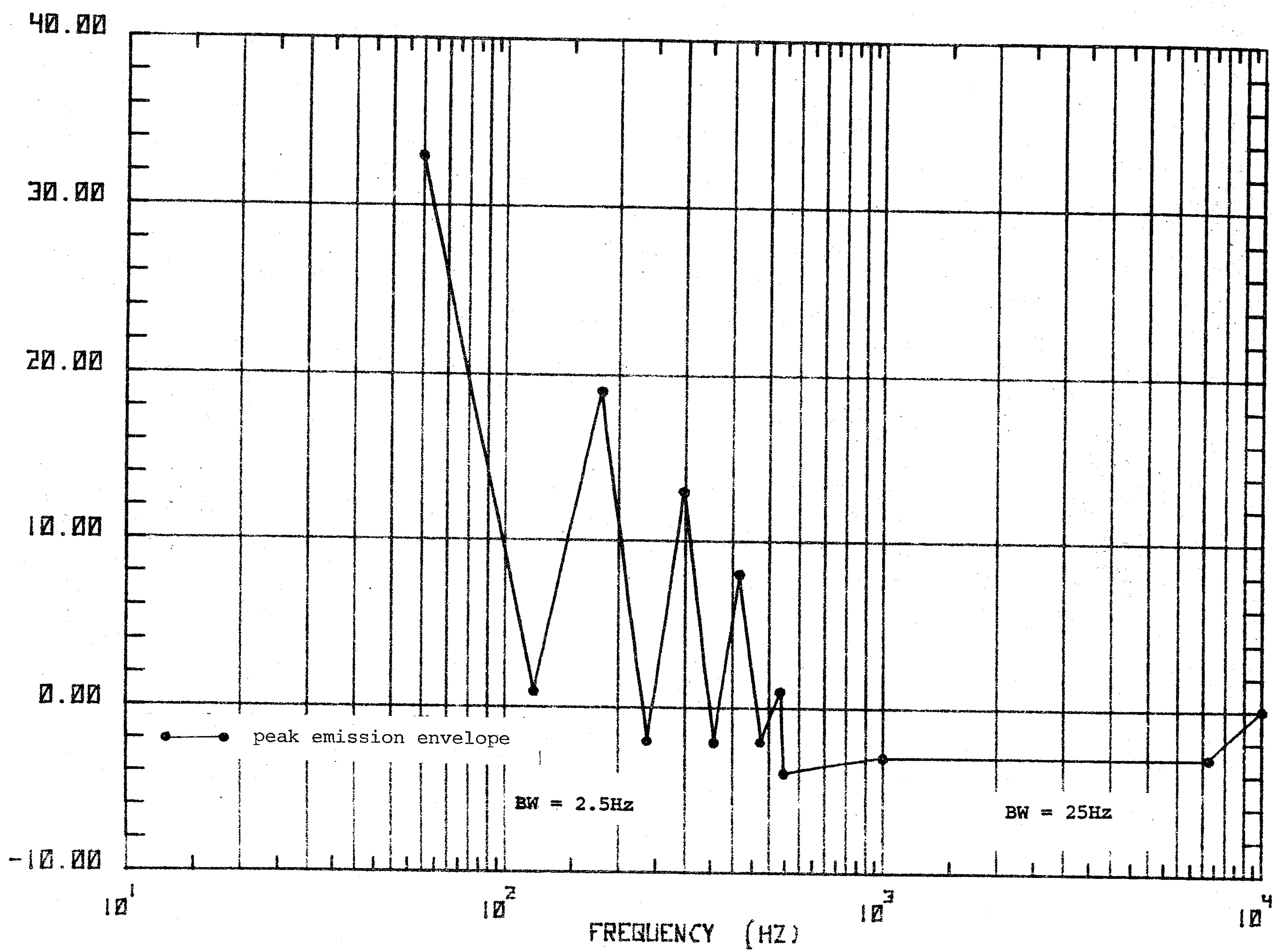


Figure 28. Spectrum of current in one rail as locomotive passes measurement location.

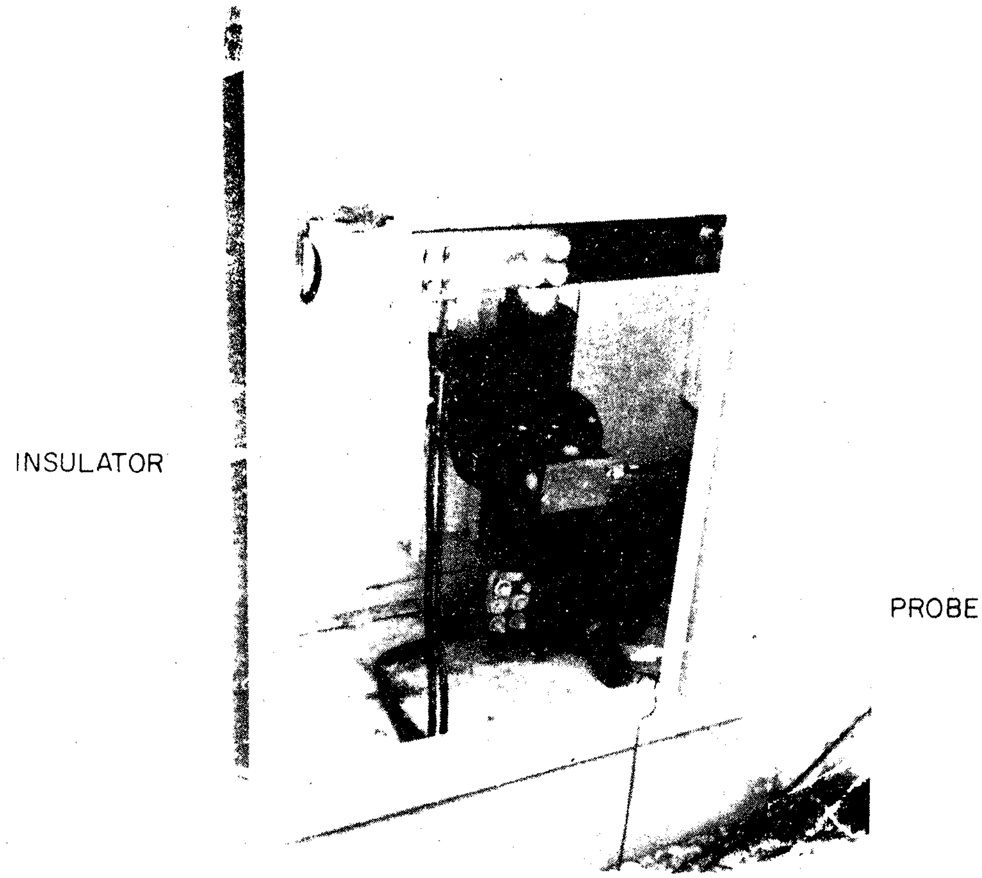


Figure 29. Probe placement for ground return samplings.

15 dBA or 5.6 amperes rms. The 180-Hz third harmonic sampled was 10 dBA (3.16 amperes rms).

After completing the mesurements with the engine idling, the locomotive was then driven around the track using traction motors 1, 2, and 3. The current in one of three of the ground-return cables was again sampled. Under these conditions, two samples of this current were made, both of which are presented in TABLE 3. In the first sample, the amount of dc current drawn by the traction motors was not able to be ascertained; however, during the second sampling, the locomotive traction motors were each drawing approximately 2300 amperes dc.

Comparison shows that the 60-Hz component increased from 15 dBA while idling to 18 dBA (7.9 amperes rms) in the first sampling, to 35 dBA (56.2 amperes rms) during the second sampling. The third harmonic (180 Hz) surprisingly dropped from 10 dBA while the locomotive was idling to 2 dBA (1.26 amperes rms) during the first sampling with the locomotive moving. During the second sampling, the 180-Hz third harmonic recorded increased to 21 dBA (11.22 amperes rms).

Electric Field Strength

To establish a baseline for the electric field strength measurements to follow, the ambient noise environment was first sampled with respect to frequency. During these measurements, the catenary was de-energized. However, two Urban Mass Transit Authority (UMTA) substations were on[a]

[a]One of these dc substations was located within 1 mile of the measurement location.

TABLE 4

LEVELS OF CURRENT IN ONE OF THREE GROUND RETURN WIRES AT SUBSTATION

Frequency	Pantograph Up, Engine Idling (4 miles away) in dBA (amperes rms)	Train Passing Substation in dBA (amperes rms)	Train Passing Substation, 3 motors on, 2300 A dc/motor in dBA (amperes rms)
60	15 (5.62)	18(7.94)	35 (56.23)
120	--[a]	--	-1 (0.89)
180	10 (3.16)	2 (1.26)	21 (11.22)
240	--	--	-2 (0.79)
300	-5 (0.56)	0 (1.0)	14 (5.01)
360	--	--	-3 (0.71)
420	-2 (0.79)	-2 (0.79)	8 (2.51)
480	--	--	-4 (0.63)
540	-9 (0.35)	-11 (0.28)	4 (1.58)
600	--	--	-3 (0.71)
660	-7 (0.45)	-9 (0.35)	0 (1.00)
720	--	--	-3 (0.71)
780	-10 (0.32)	-11 (0.28)	-1 (0.89)
840	--	--	-5 (0.56)
900	-12 (0.25)	-13 (0.22)	-2 (0.79)

[a]Blank spaces indicate a value less than -15 dBA (<0.178 ampere rms).

as well as a 115-kV power line (located approximately 1 to 2 miles from the measurement location). The location of the antenna with respect to the test track is shown in Figure 30, while the spectrum of the electric field strength recorded for this case is shown in Figure 31.

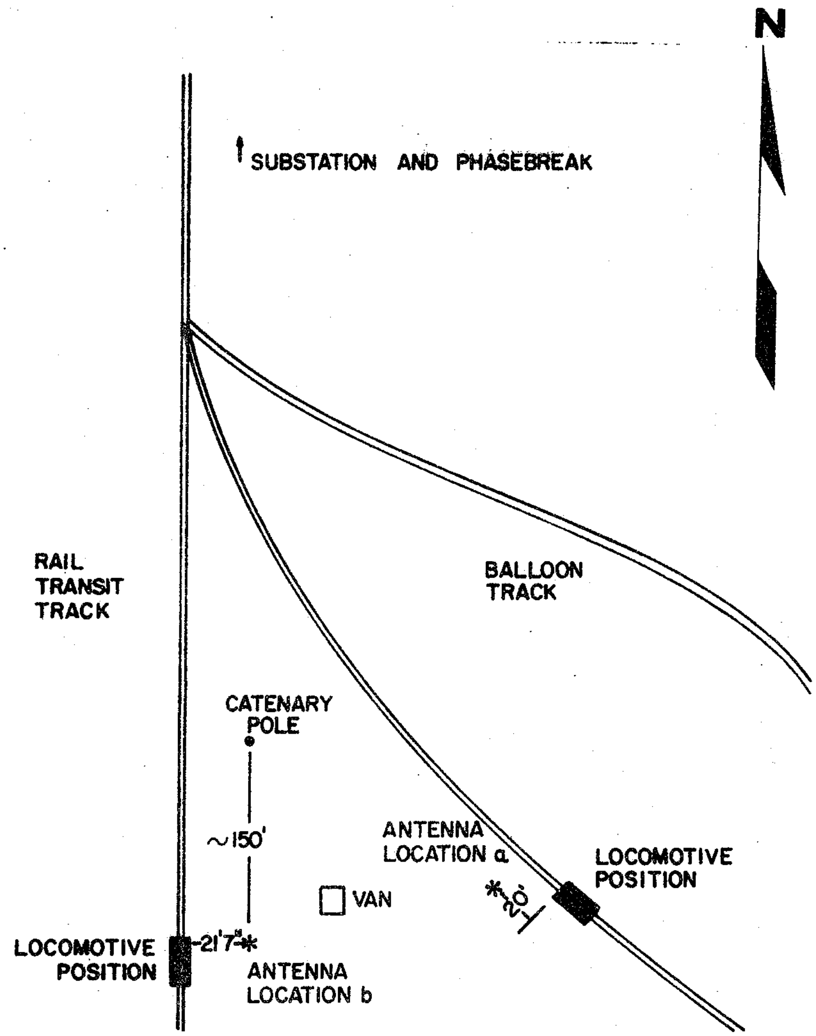


Figure 30. Electric field strength measurement locations.

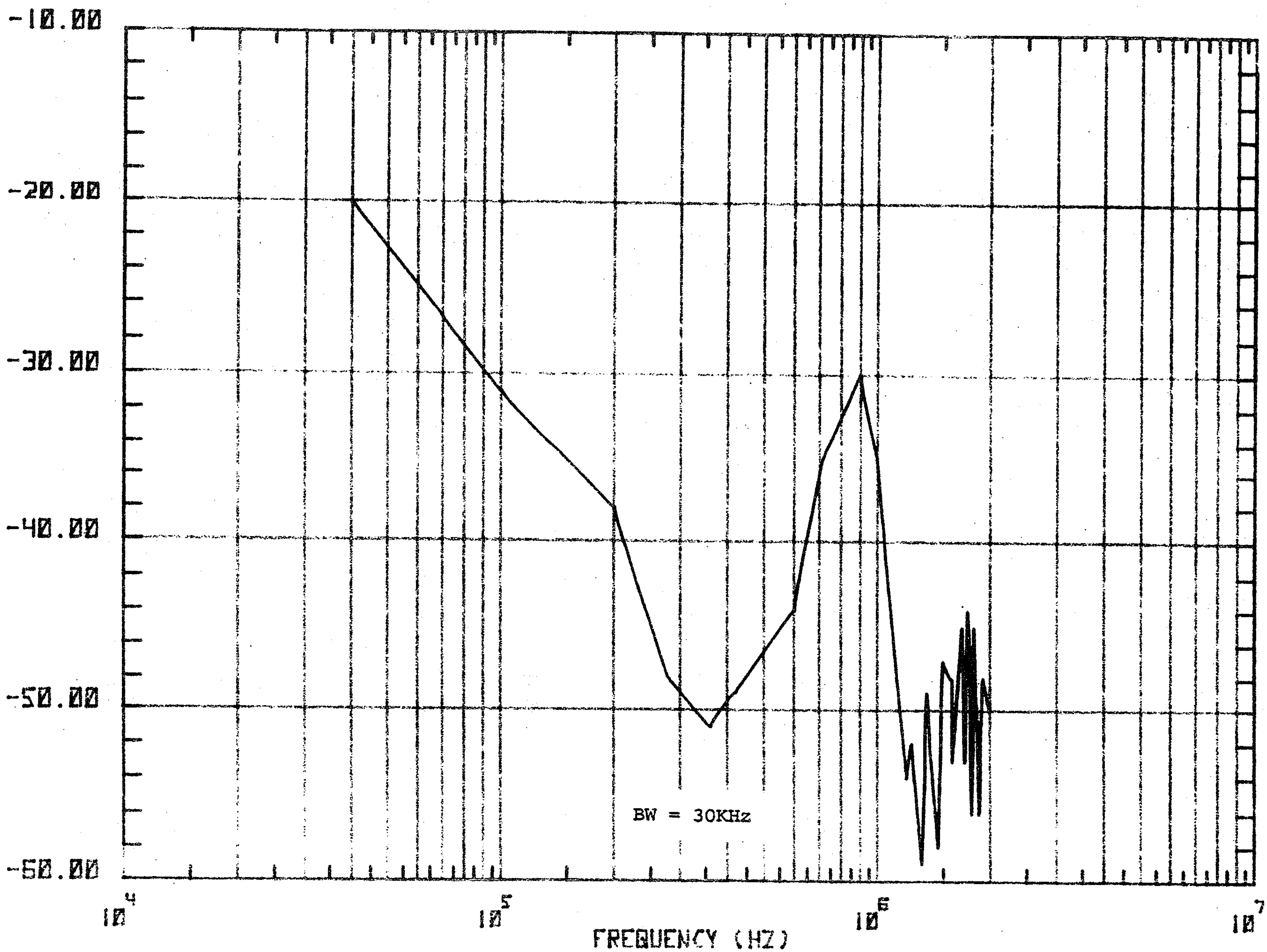


Figure 31. Spectrum of electric field strength of the ambient environment.

During the next set of measurements, the locomotive was placed on the balloon track facing the direction of the substation (see Figure 30). The locomotive (without a consist) was stationary and idling. The electric field strength antenna was then manually moved longitudinally back and forth alongside the fireman's side of the locomotive to find the point of maximum electric field strength. This location (noted as location a in Figure 30) was 20 feet in front of the locomotive and 3 feet away from the balloon track towards the test track. The catenary was then energized and electric field strength measurements were performed. The spectrum sampled at this time is illustrated in Figure 32.

Next, the pantograph was raised and two samples of the electric field strength were taken with the engine idling. The first sample, taken between 0 and 1 kHz, is presented in Figure 33. Results of the second sampling, taken between 60 Hz and 1 MHz, are shown in Figure 34. From Figure 33, the 60-Hz component of the electric field strength measured was 60 dBV/m (1,000 V/m rms), while the 120-Hz component was 21 dBV/m (11.2 V/m rms). A considerable amount of energy was found in the 240-Hz and 720-Hz components where levels of 18 and 13 dBV/m, (7.9 and 4.5 V/m rms) respectively, were recorded. From Figure 34, the emission level recorded at 60 Hz was also 60 dBV/m. However, in this sampling, the 120-Hz component dropped to 14 dBV/m (5 volts/m rms). Also in this figure, it is observed that a large amount of energy (10 dBV/m or 3.16 V/m rms) is present between 10 and 22 kHz.

Upon completion of the measurements shown in Figure 34, the locomotive was moved onto the RTT and readied for that night's track profile run. While the locomotive was being readied, more samplings of the electric field strength were taken. At this time, the locomotive and the antenna were positioned at location b as shown in Figure 30. Results of these samplings are presented in Figure 35. From this figure, the 60-Hz component of the electric field strength sampled was 52 dBV/m (398.1 volts/m rms), while the 180- and 300-Hz components were 23 and 15 dBV/m (14.1 and 5.6 volts/m rms), respectively.

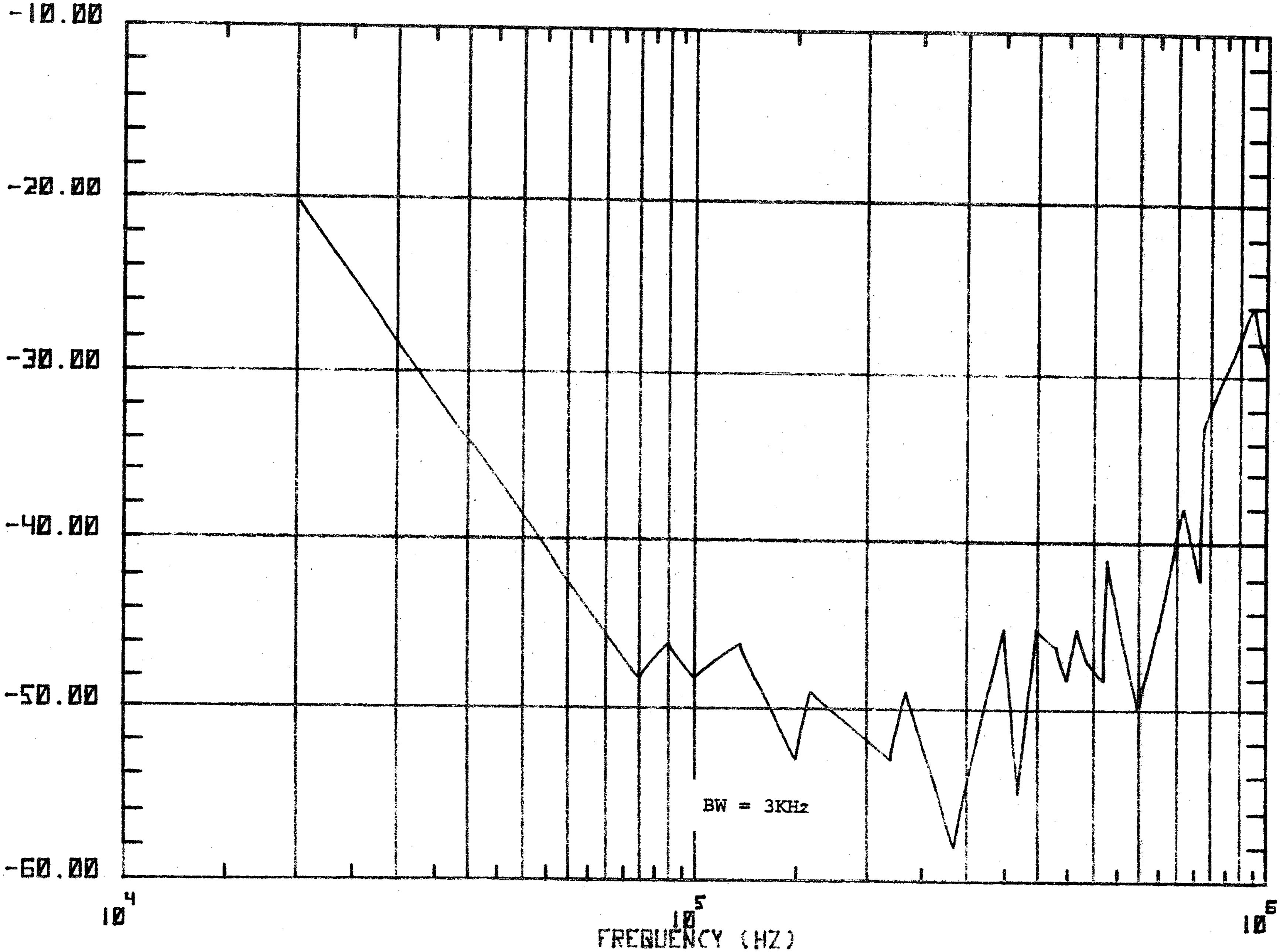


Figure 32. Spectrum of electric field strength of environment with catenary energized.

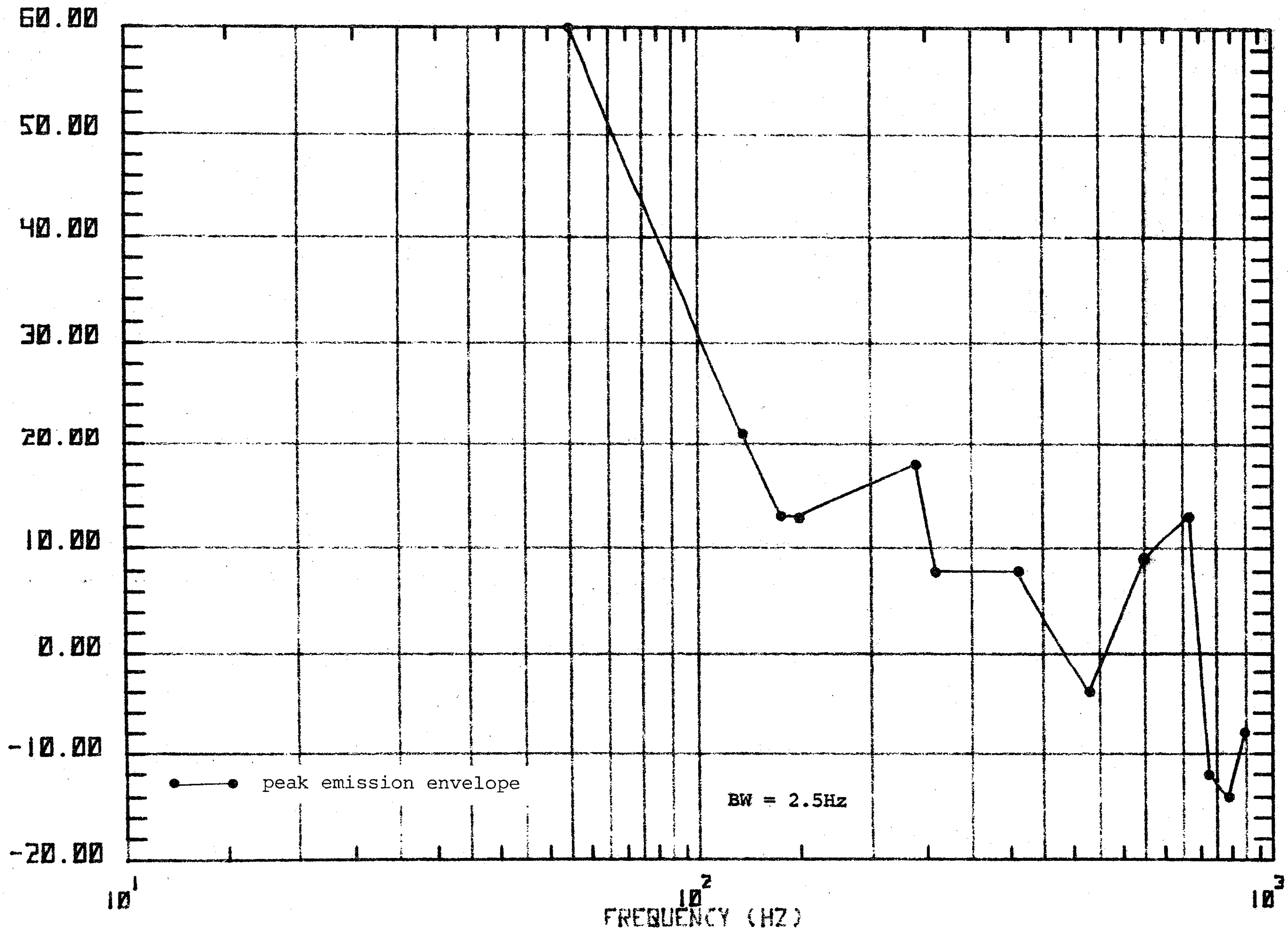


Figure 33. Spectrum of electric field strength, locomotive idling (sample 1).

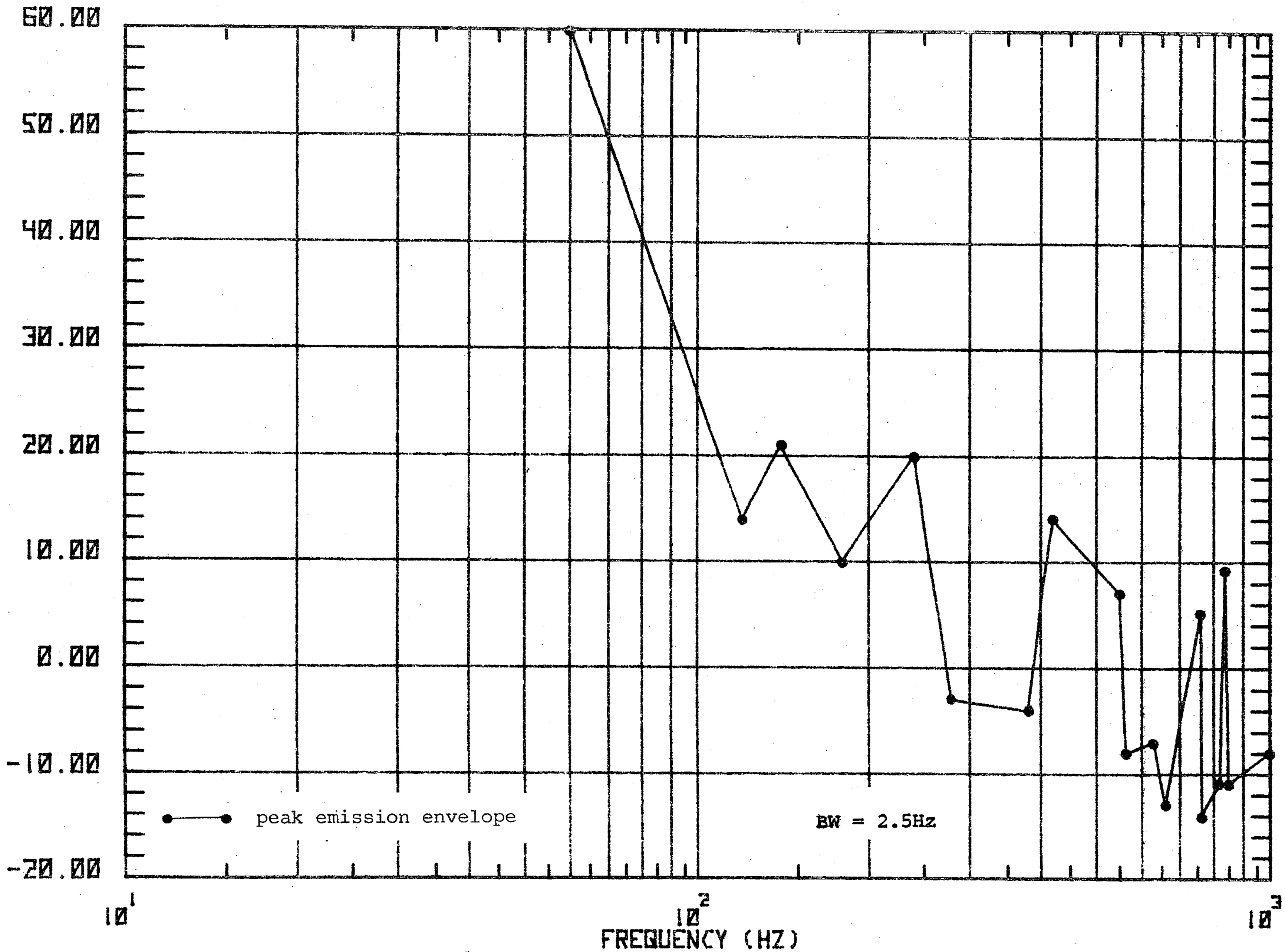


Figure 34. Spectrum of electric field strength, locomotive idling (sample 2).

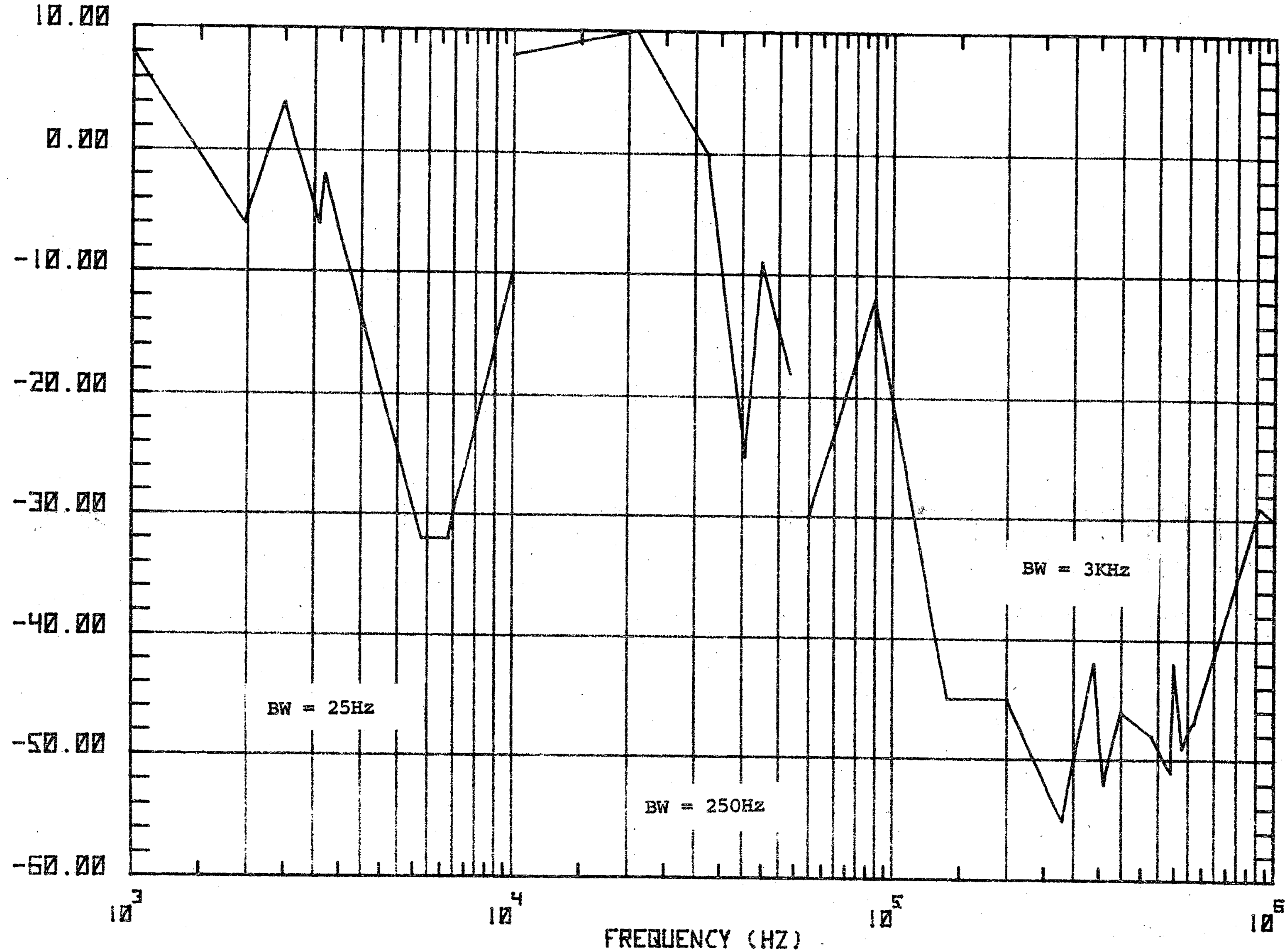


Figure 34. Spectrum of electric field strength, locomotive idling (sample 2) (Continued).

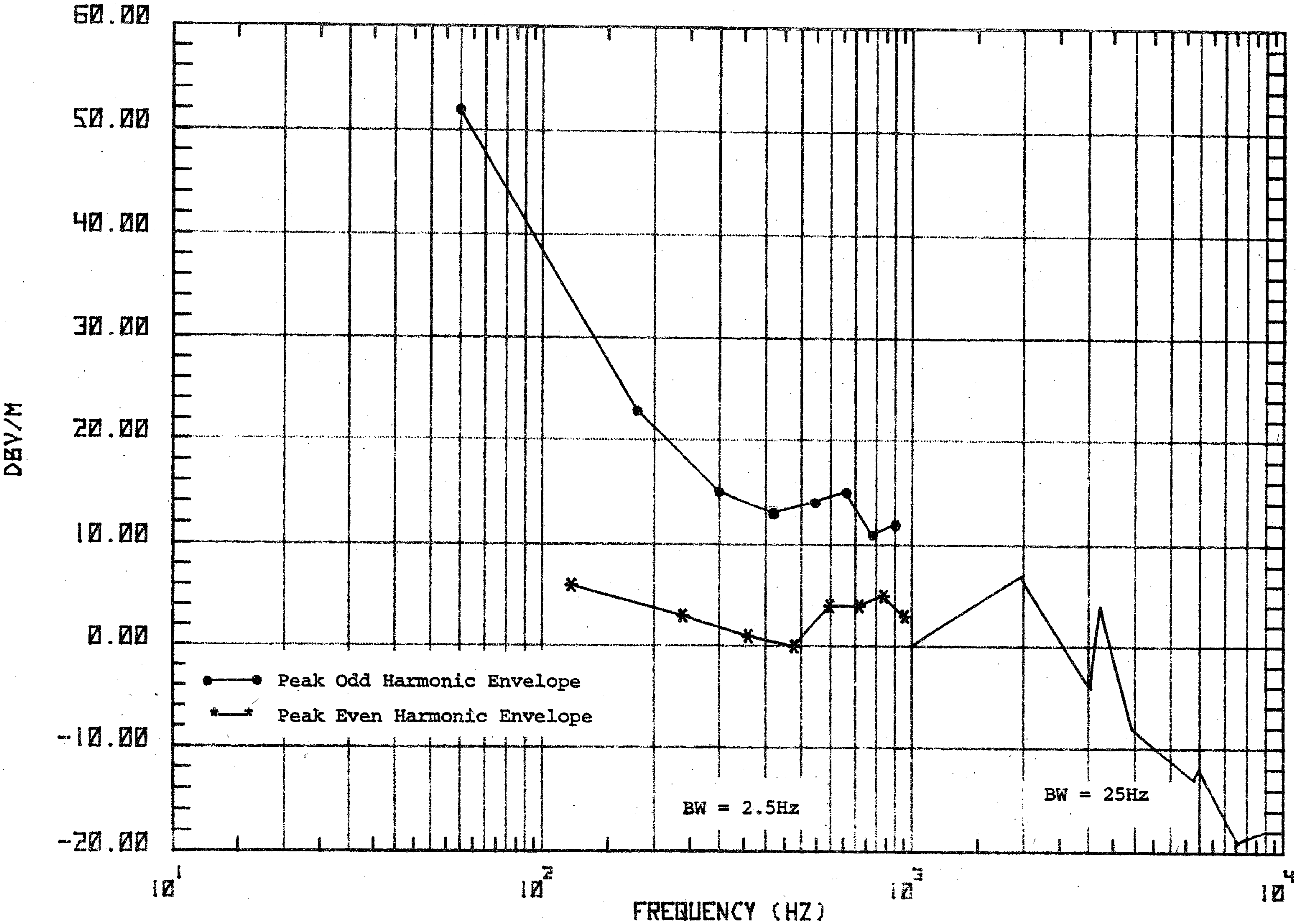


Figure 35. Spectrum of electric field strength sampled while locomotive was idling (locomotive on RTT).

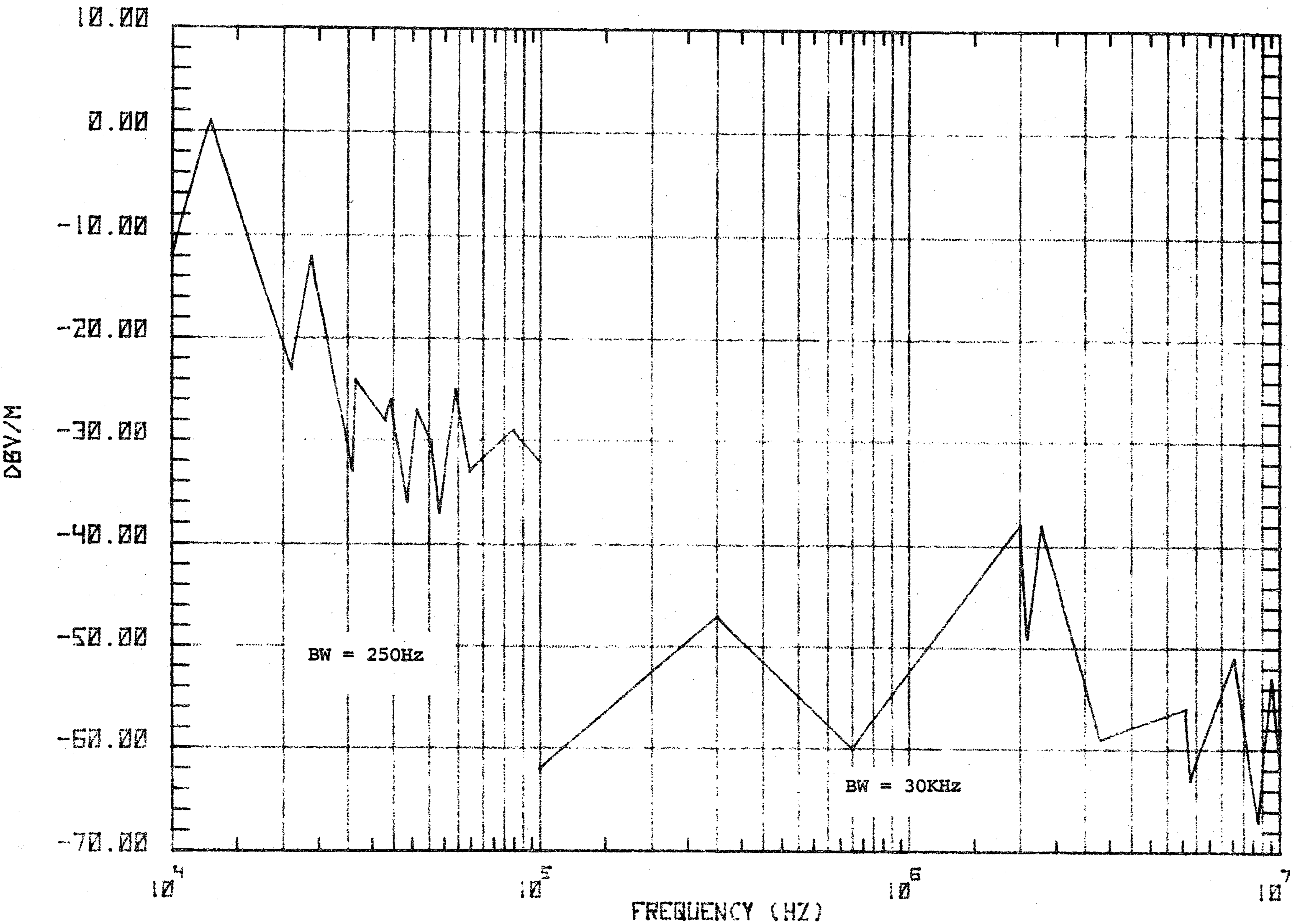


Figure 35. Spectrum of electric field strength sampled while locomotive was idling (locomotive on RTT) (Continued).

The next set of electric field strength measurements presented were taken while the train was running a track profile of the Northeast Corridor. In Figure 30, the train traveled in the direction from the substation toward ECAC's test setup (from north to south). A catenary pole was situated roughly 150 feet north of antenna location b. As the locomotive passed by this point, the spectrum analyzer(s) began sampling the electric field strength. The electric field strength spectrum sampled while the train was coasting by the measurement location is given in Figure 36.

The spectrum of the electric field strength, sampled while the locomotive accelerated past the test point, is given in Figure 37. The electric field strength spectrum shown in this figure was sampled in a 30-kHz analyzer resolution bandwidth. The emission levels presented in this figure varied from -59 dBV/m (0.001 V/m rms) at 360 kHz to -37 dBV/m (0.014 V/m rms) at 760 kHz to -66 dBV/m (5×10^{-4} V/m rms) at 1.72 MHz.

Magnetic Field Strength

The ECAC current/magnetic field strength probe was used to sample magnetic field strength emissions with respect to both time and frequency, produced by the locomotive. These measurements were performed wayside at the same location as the electric field strength samplings (see Figure 30). As in Figure 38a, the probe was placed between the rails at three different locations. The first probe location (noted as 1 in Figure 38a) was situated between the rails 6 inches towards the center of the track from the rail nearest the test van. The second probe location was in the center of the track, while the third location was 6 inches inward toward the center of the track from the outside rail. As in the case of the electric field strength measurements, a catenary pole, roughly 150 feet north of the test location, was used as the point from which emission samplings were initiated. During these measurements, the probe was placed in two different orientations (as shown in Figure 38b) -- parallel and perpendicular to the rails.

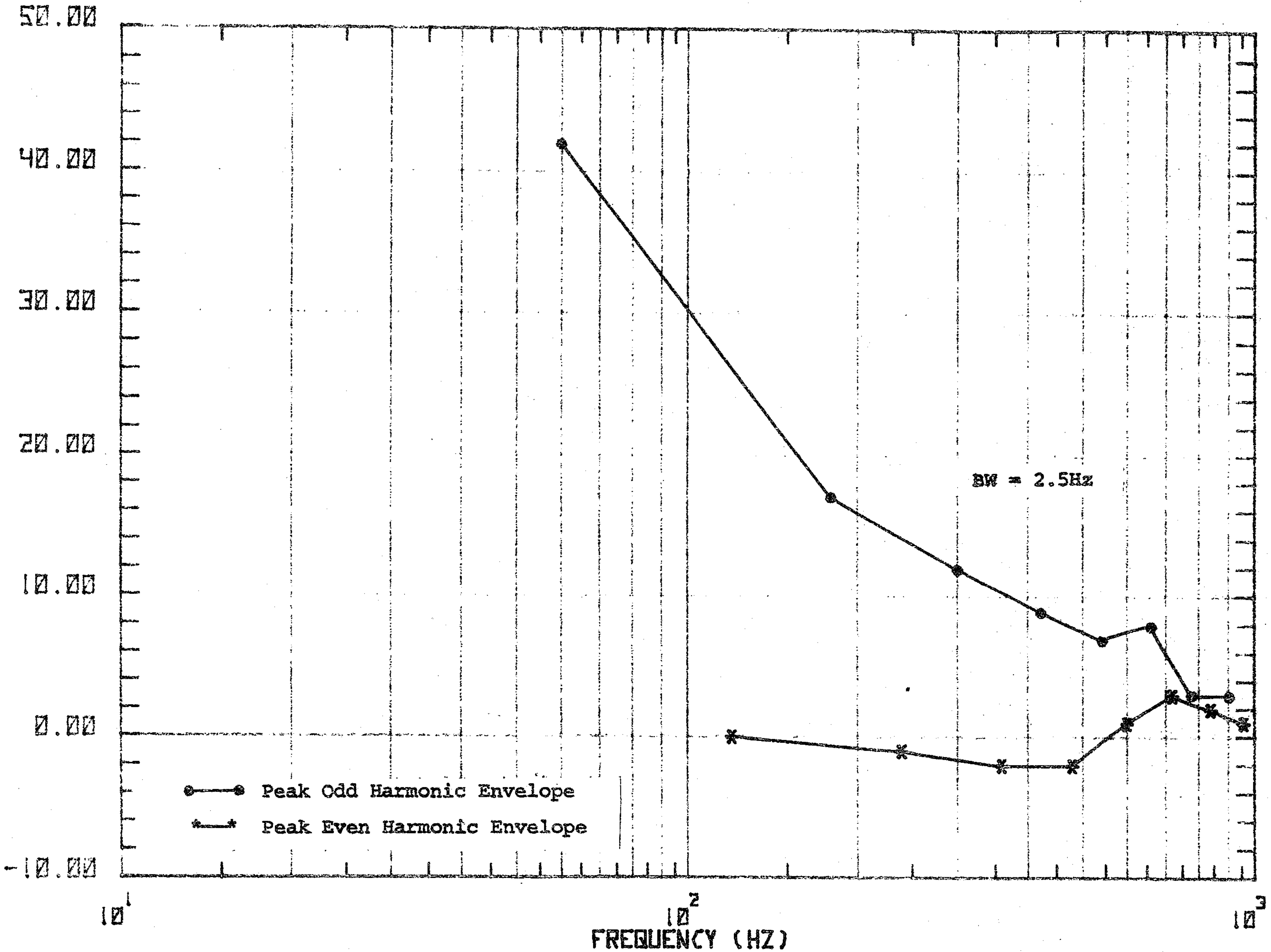


Figure 36. Spectrum of electric field strength sampled while locomotive coasted.

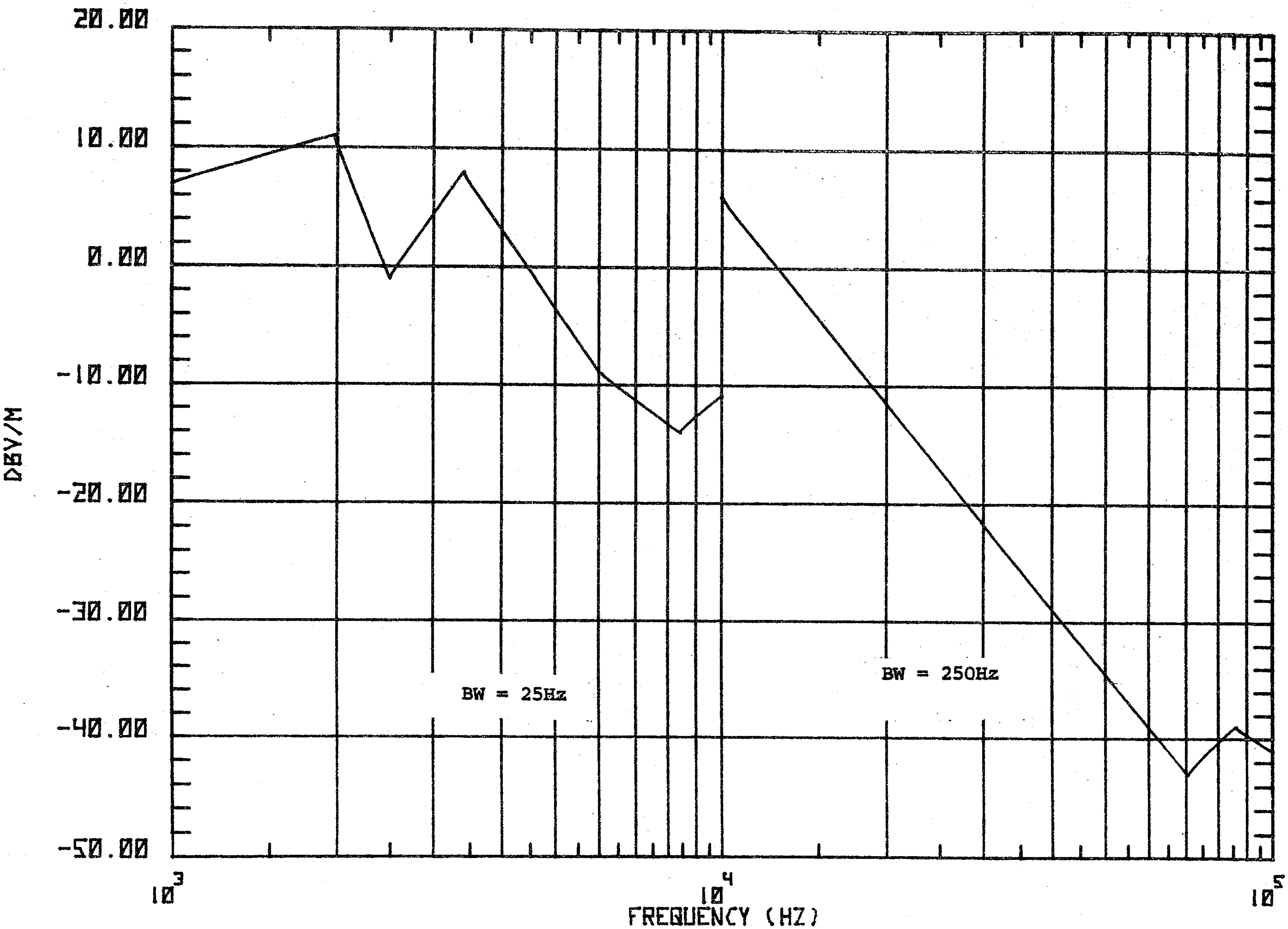


Figure 36. Spectrum of electric field strength sampled while locomotive coasted (Continued).

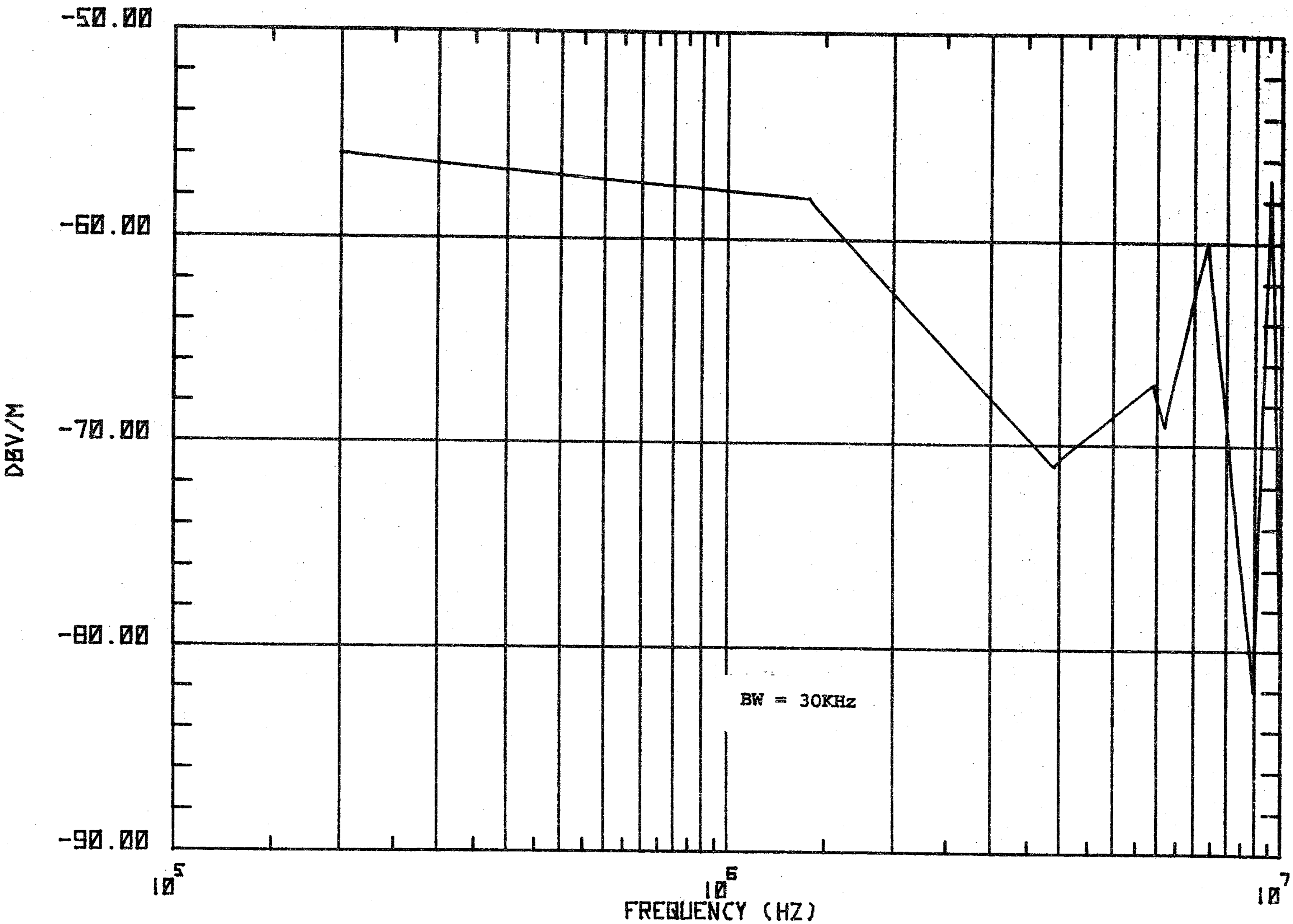


Figure 36. Spectrum of electric field strength sampled while locomotive coasted (Continued).

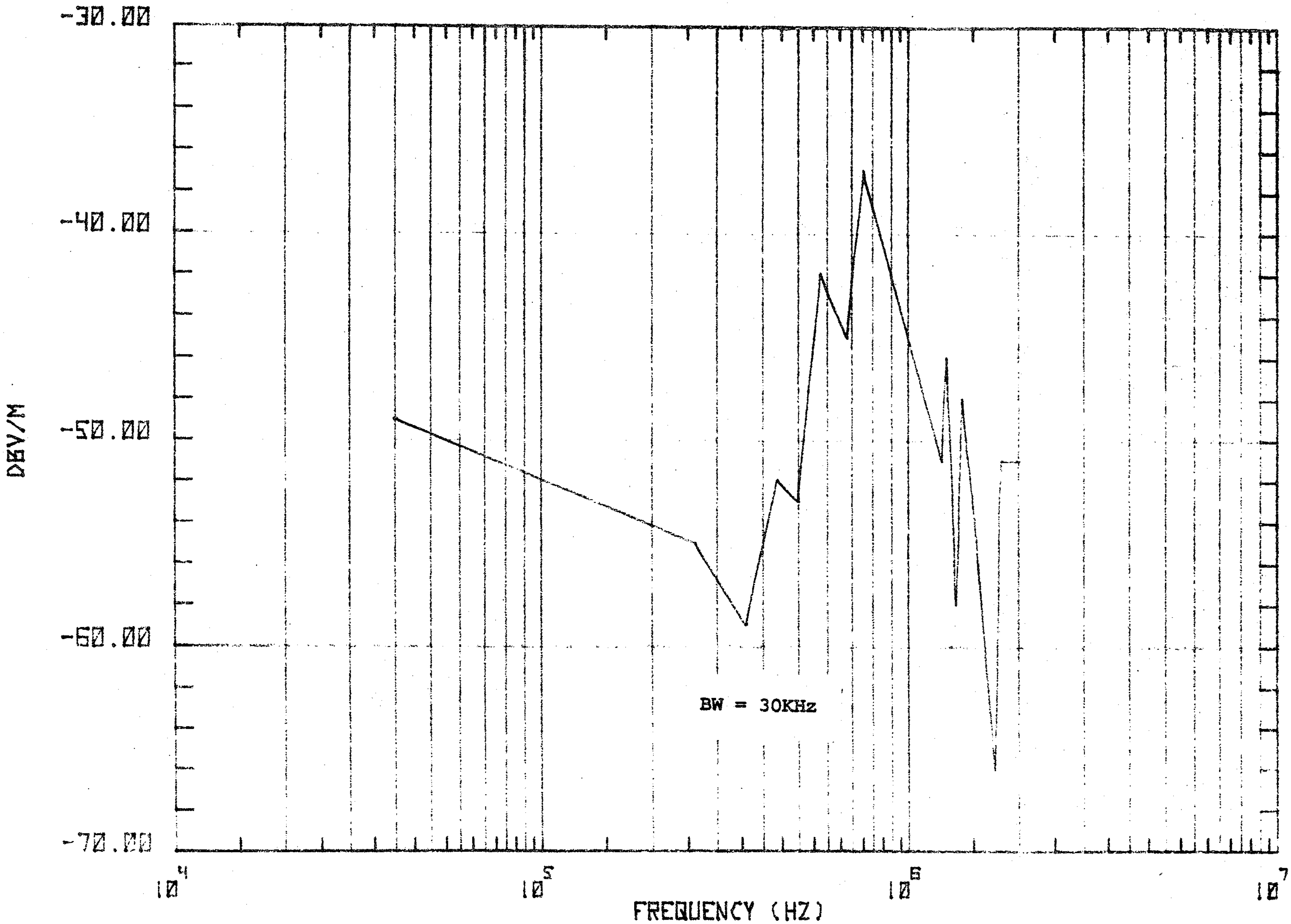
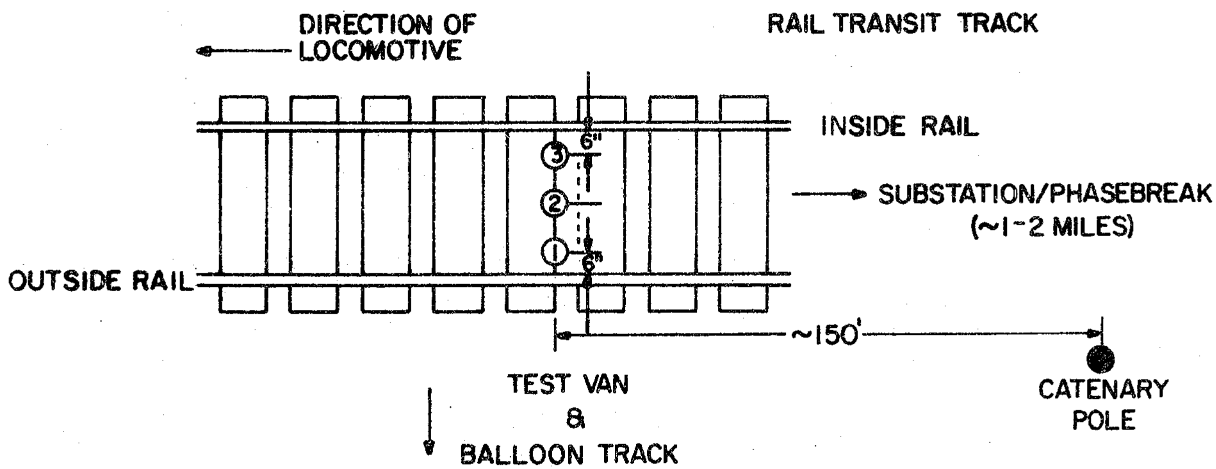
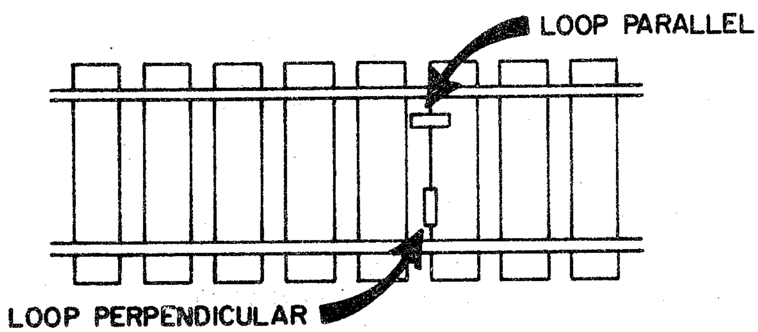


Figure 37. Spectrum of electric field strength sampled as locomotive accelerated passed the test point.



a. Three-probe locations.



b. Two-probe orientation.

Figure 38. Magnetic field strength probe placements.

In Figure 39, the time waveform and frequency spectrum of the magnetic field strength, sampled with the probe oriented parallel to the rails and located at position 1, are given. Referring to this figure, the transient amplitude of the time waveform was 24.8 A/m peak-to-peak (8.77 A/m rms). The 60-Hz component of the spectrum recorded was 2 dBA/m (1.26 A/m rms).

The time waveform and frequency spectrum, sampled with the probe perpendicular to the rails situated at location 1, are given in Figure 40. In this case, the amplitude of the time waveform recorded was approximately 36 A/m peak-to-peak (12.7 A/m rms), an increase of 11.2 A/m peak-to-peak. However, the 60-Hz component of the spectrum recorded was -1 dBA/m (0.89 A/m rms), a 3-dBA/m decrease from the spectrum shown in Figure 39. This would tend to indicate that the increase in magnetic field strength associated with the probe oriented perpendicular versus parallel to the rails is found at higher frequencies (above 1 kHz).[a]

The time waveforms and frequency spectra sampled with the probe situated at the second location, with the probe oriented parallel and perpendicular to the rails, are presented in Figures 41 and 42, respectively. At the time the magnetic field strength displayed in Figure 41 was sampled, the locomotive was drawing 1600 A/motor of dc current. The time waveform of the magnetic field strength recorded at this time was 31 A/m peak-to-peak or 10.96 A/m rms. The 60-Hz component of the spectrum was 16 dBA/m or 6.3 A/m rms. Other notable emission levels were recorded at 240, 360, and 420 Hz where the levels were 4, -3, and -10 dBA/m (1.58, 0.71, and 0.32 A/m rms), respectively.

Referring to Figure 42, the amplitude of the waveform sampled with the probe oriented perpendicular to the rails was 29.8 A/m peak-to-peak (10.52 A/m rms), a 1.2 A/m decrease from Figure 41. The amplitude of the 60-Hz signal recorded at this time was 0 dBA/m (1 A/m rms), a 16 dBA/m decrease from the measurements noted above.

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[a]In instances where the locomotive primary current is not indicated, the current amplitude was not known.

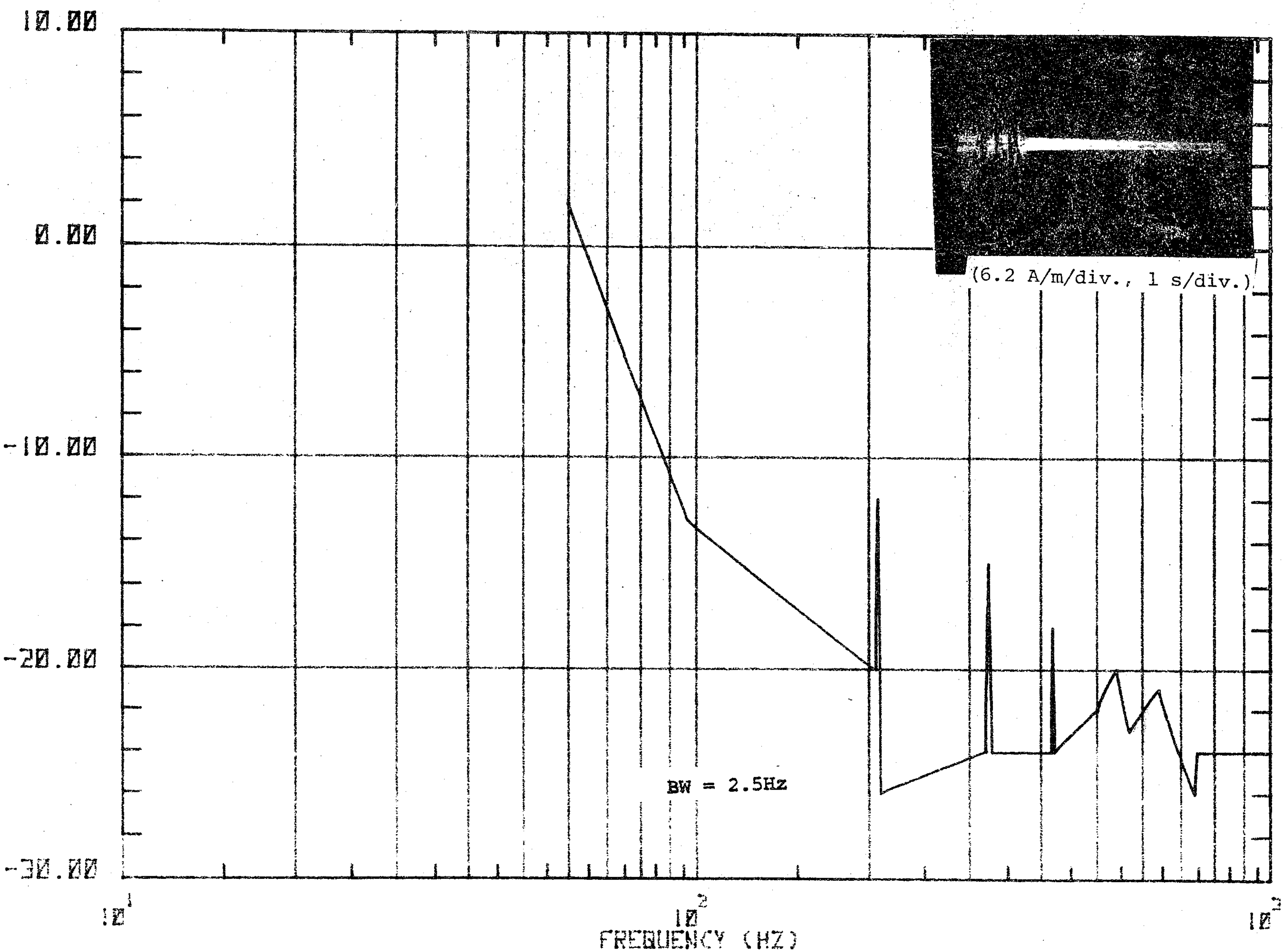

Figure 39. Waveform and spectrum of magnetic field strength with probe at location 1 and probe parallel to rails.

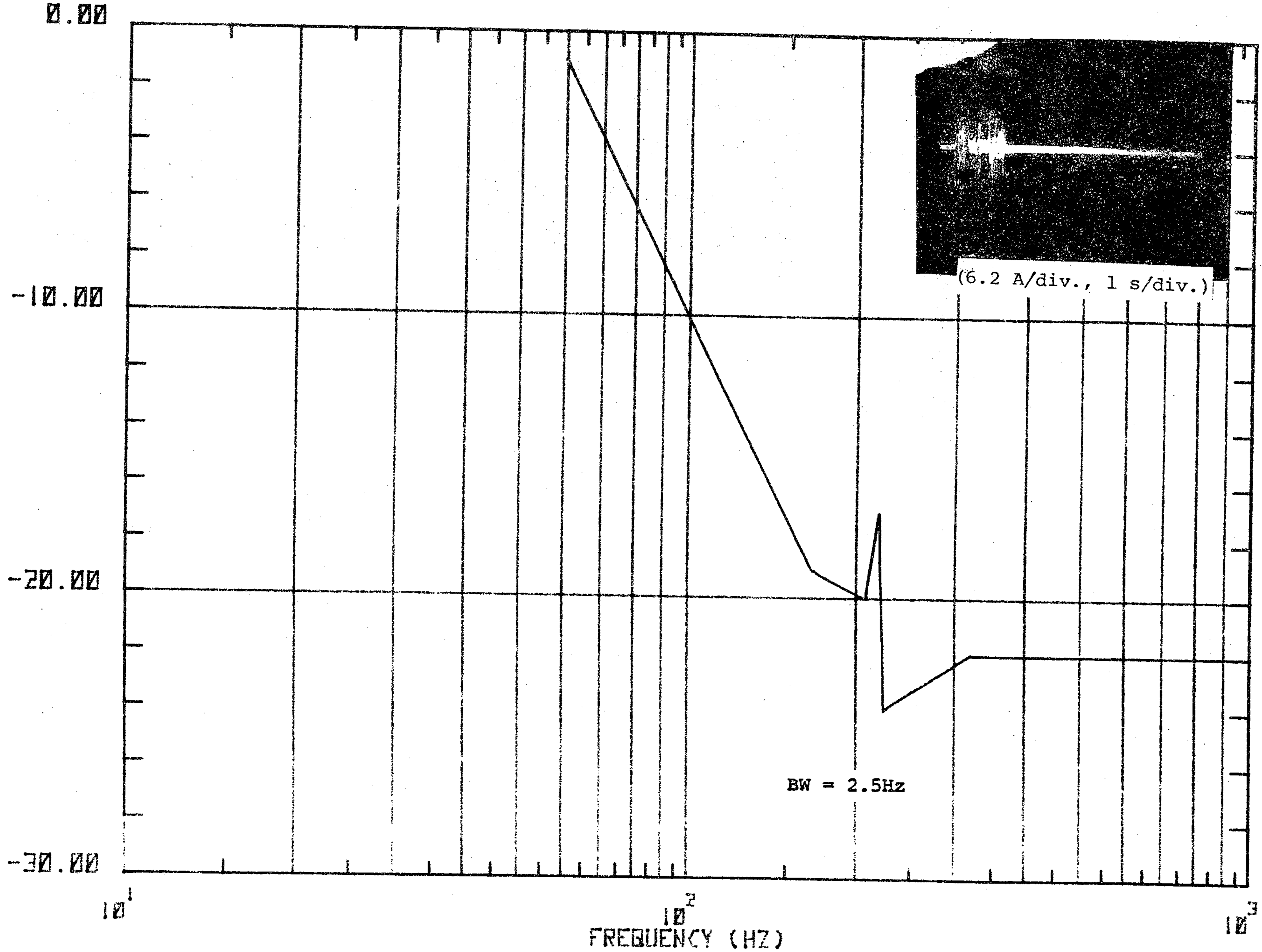

Figure 40. Waveform and spectrum of magnetic field strength, probe at position 1 and perpendicular to rails .

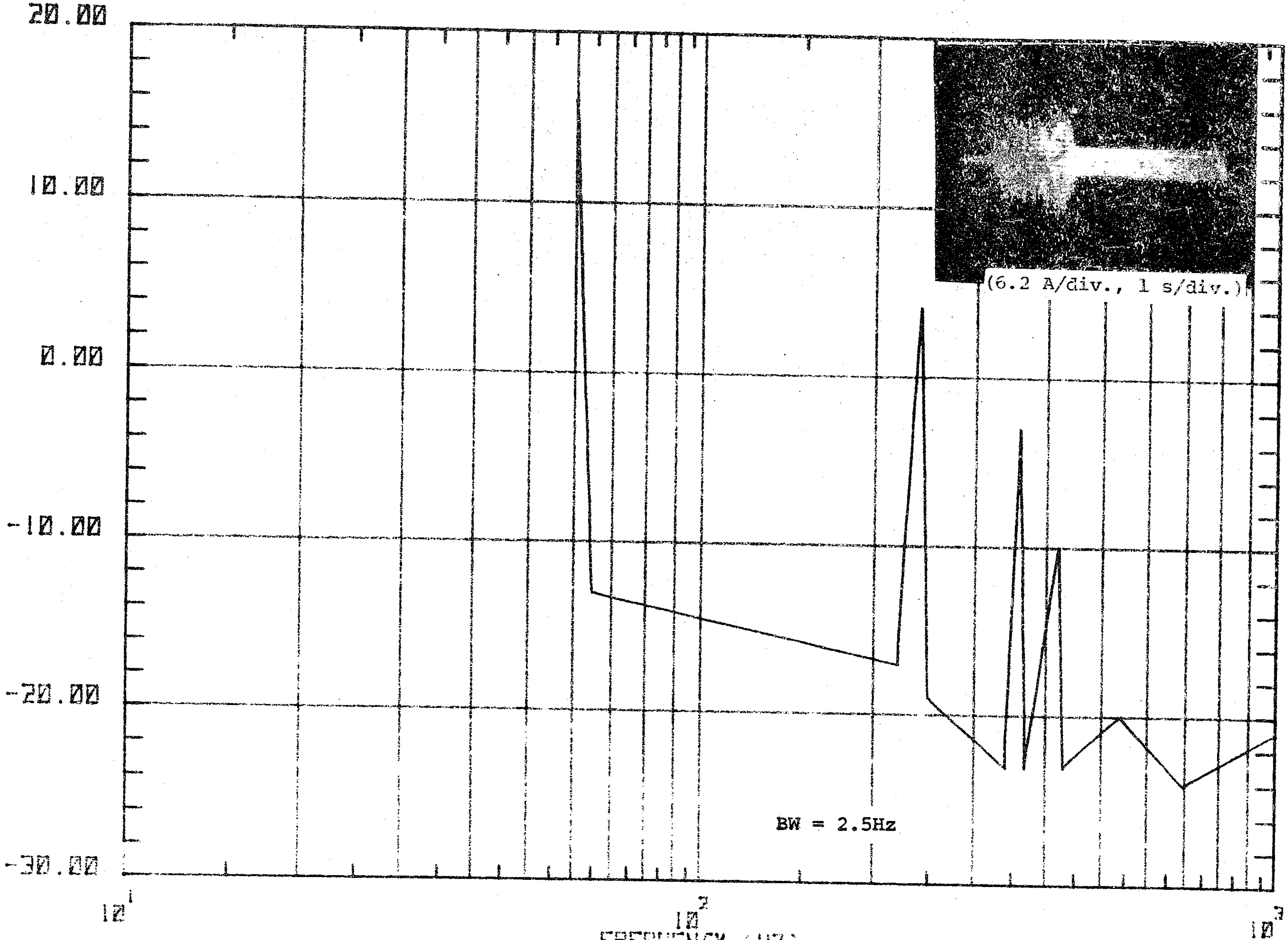

Figure 41. Waveform and spectrum of magnetic field strength, probe at position 2 and parallel to rails.

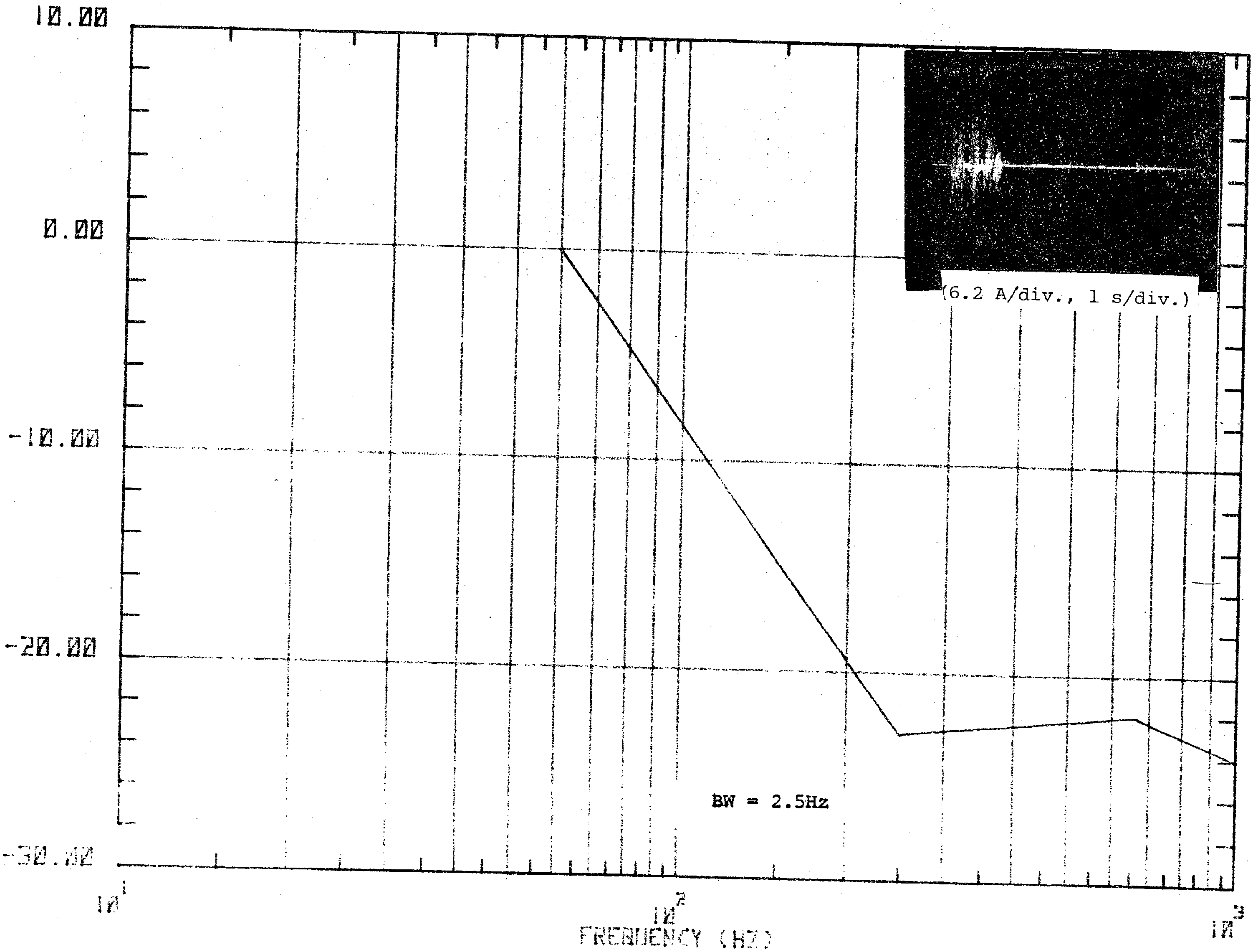

Figure 42. Waveform and spectrum of magnetic field strength, probe at position 2 and perpendicular to rails.

The waveform and spectrum of the magnetic field strength with the probe at location 3 and oriented parallel to the rails, are shown in Figure 43. At this time, the locomotive was drawing 2160 A dc/motor. The peak-to-peak amplitude of the waveform recorded was 47.74 A/m (16.9 A/m rms). The 60-Hz component of the spectrum sampled here was 15 dBA (5.6 A/m rms).

The waveform and spectrum of the magnetic field for location 3 with the probe placed perpendicular to the rails are shown in Figure 44. The amplitude of the waveform, displayed in this figure, is 37.2 A/m peak-to-peak (13.2 A/m rms), a decrease of 10.54 A/m from measurements taken with the probe oriented parallel to the rails. The 60-Hz component sampled at this time was 2 dBA/m (1.26 A/m rms), a decrease of 13 dBA/m from the sample shown in Figure 43.

The following day, another set of samplings was taken. This time, the loop was placed 6 inches from the inside rail at the location depicted as point "a" in Figure 30. The locomotive passed by traveling at 19 miles per hour, drawing 2200 amperes of dc current per motor. The frequency spectrum sampled at this time is given in Figure 45. From Figure 45, the 60-Hz component of the spectrum sampled was 6 dBA/m (2 A/m rms). In addition, a 90-Hz component of 3 dBA/m (1.4 a/m rms) was recorded.

RECORDED DATA

During these measurements, emission data was taken at 8 test points and recorded on 10 channels (see Figure 5), while the locomotive ran a track profile. From this, four 3600-foot tapes of data, recorded at 15 inches per second, were obtained. As this data was reviewed, various sections of tape were chosen to be replayed for more detailed observation of emissions recorded thereon. The waveforms and spectra, as displayed on a CRT, were then photographed. In the following paragraphs, results of this data review process are presented.

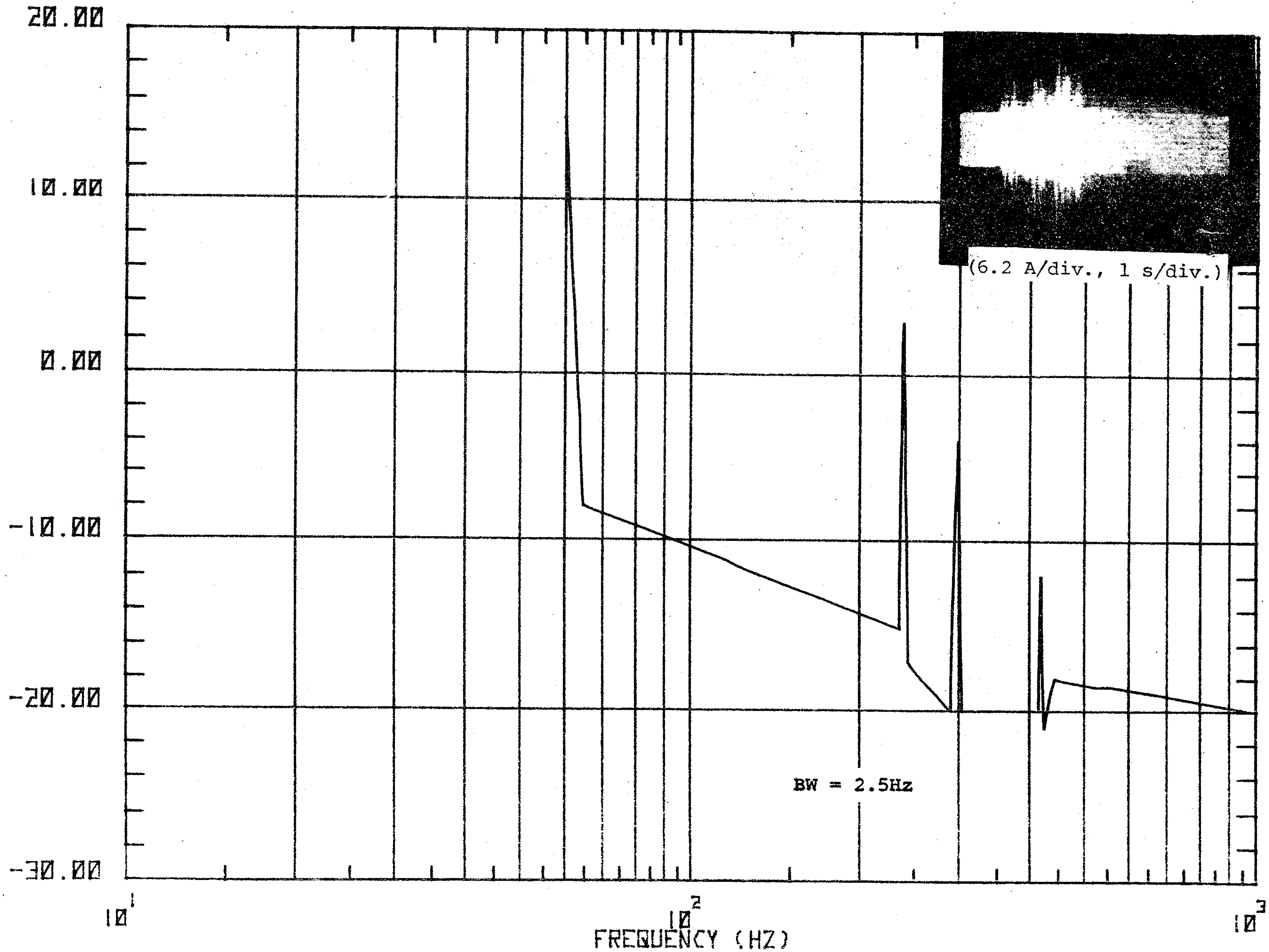

Figure 43. Waveform and spectrum of magnetic field strength recorded at the third location, probe parallel to rails.

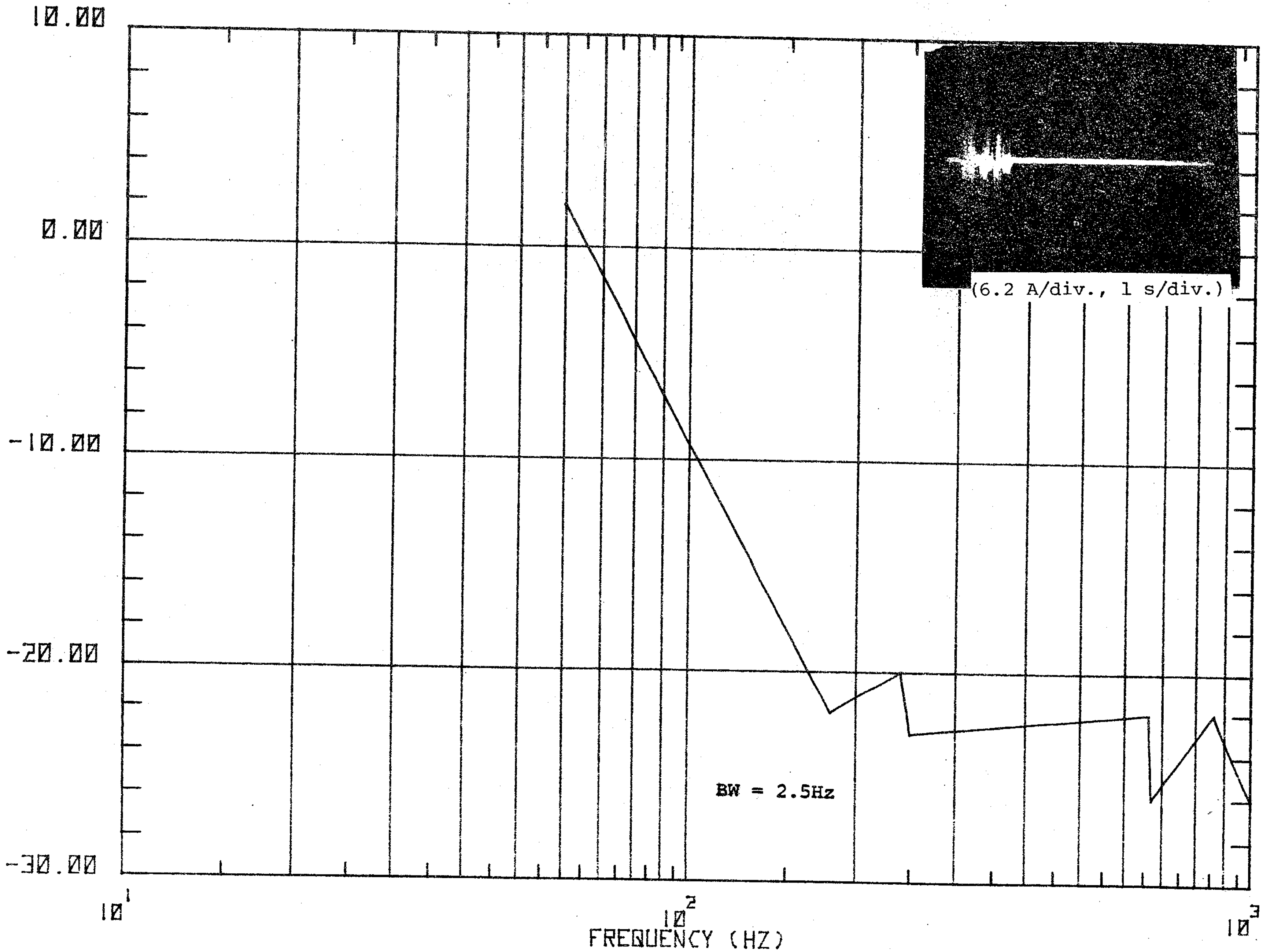

Figure 44. Waveform and spectrum of magnetic field strength recorded at third location, probe perpendicular to rails.

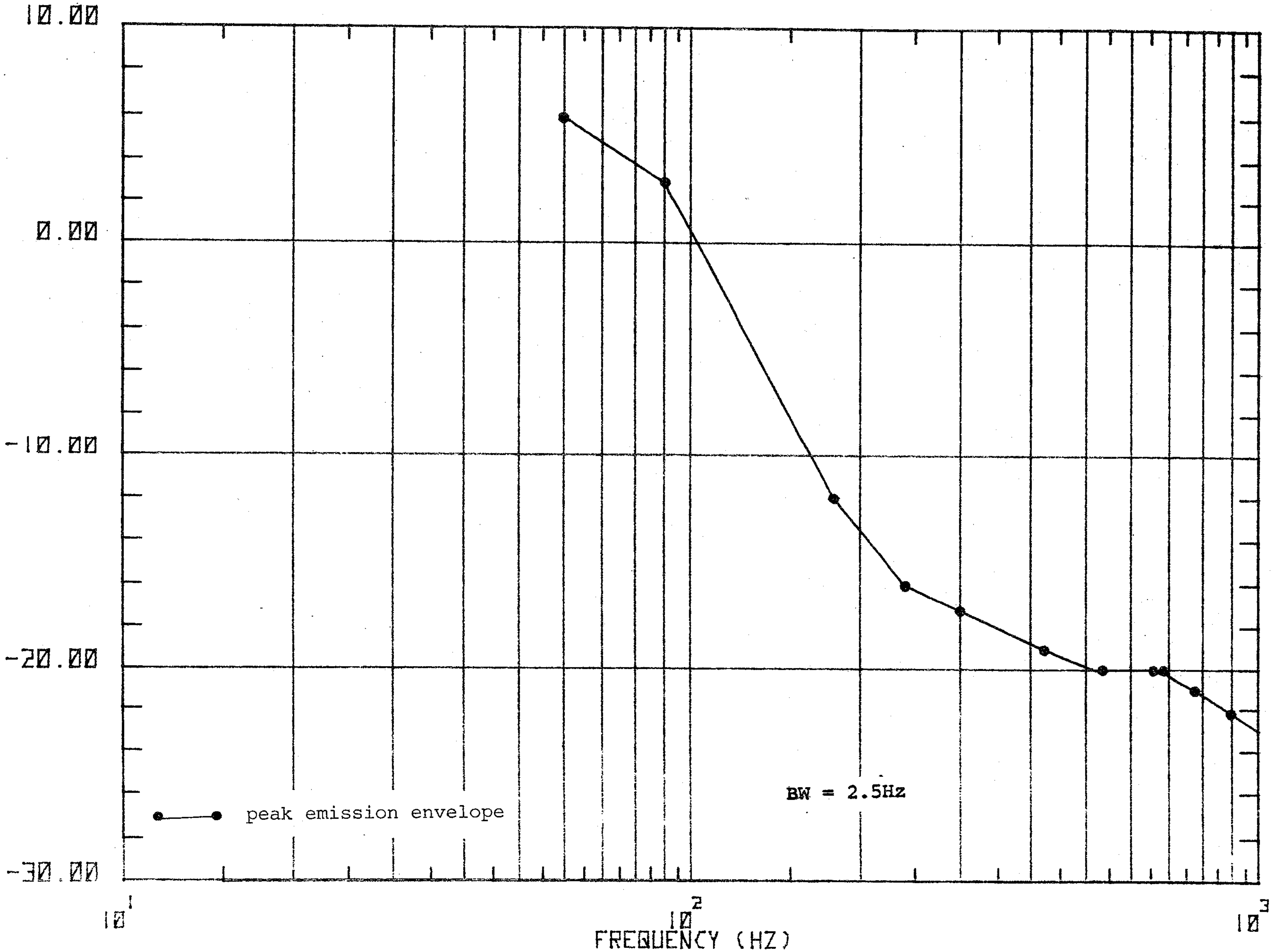

Figure 45. Spectrum of magnetic field strength, locomotive moving at 19 miles per hour.

Main Transformer Primary (Ground Side)

The current in the primary winding of the main transformer was sampled on the ground side using the AMPROBE current probe. The levels of current measured ranged from approximately 5 amperes peak-to-peak while the locomotive was coasting to a maximum of approximately 800 amperes peak-to-peak while the locomotive was accelerating.

An example of the primary current waveform and spectrum recorded while the locomotive was running a simulated revenue service run is presented in Figure 46. As this was recorded, the locomotive was traveling at approximately 10 mph and accelerating past the RTT substation and phase break. The amplitude of the time waveform shown in Figure 46 was measured to be approximately 628 amperes peak-to-peak (222 amperes rms or 47 dBA).[a] The 60-Hz component of the recorded current was 48 dBA (251 amperes rms). The discrepency between the rms values of the waveform and spectrum is attributed to several assumptions, one being the normal data recording error which is estimated at 1-2 dB.

The waveform and spectrum displayed in Figure 47 were recorded as the locomotive was traveling at a speed between 70 and 75 mph (accelerating towards 115 mph), and approaching the RTT substation. The waveform displayed here appears sinusoidal with a peak-to-peak amplitude of approximately 449 amperes (159 amperes rms). Referring to the spectrum, the 60-Hz component sampled was 43 dBA (141 amperes rms).

The waveform and spectrum of the primary current sampled just after the locomotive passed the substation are displayed in Figure 48. In this instance, the current waveform resembles a square wave rather than the sinusoidal waveform of Figure 47. The amplitude of this current was 337.2

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[a]On all waveform peak-to-peak to rms value conversions, a sinusoidal rest factor is assumed.

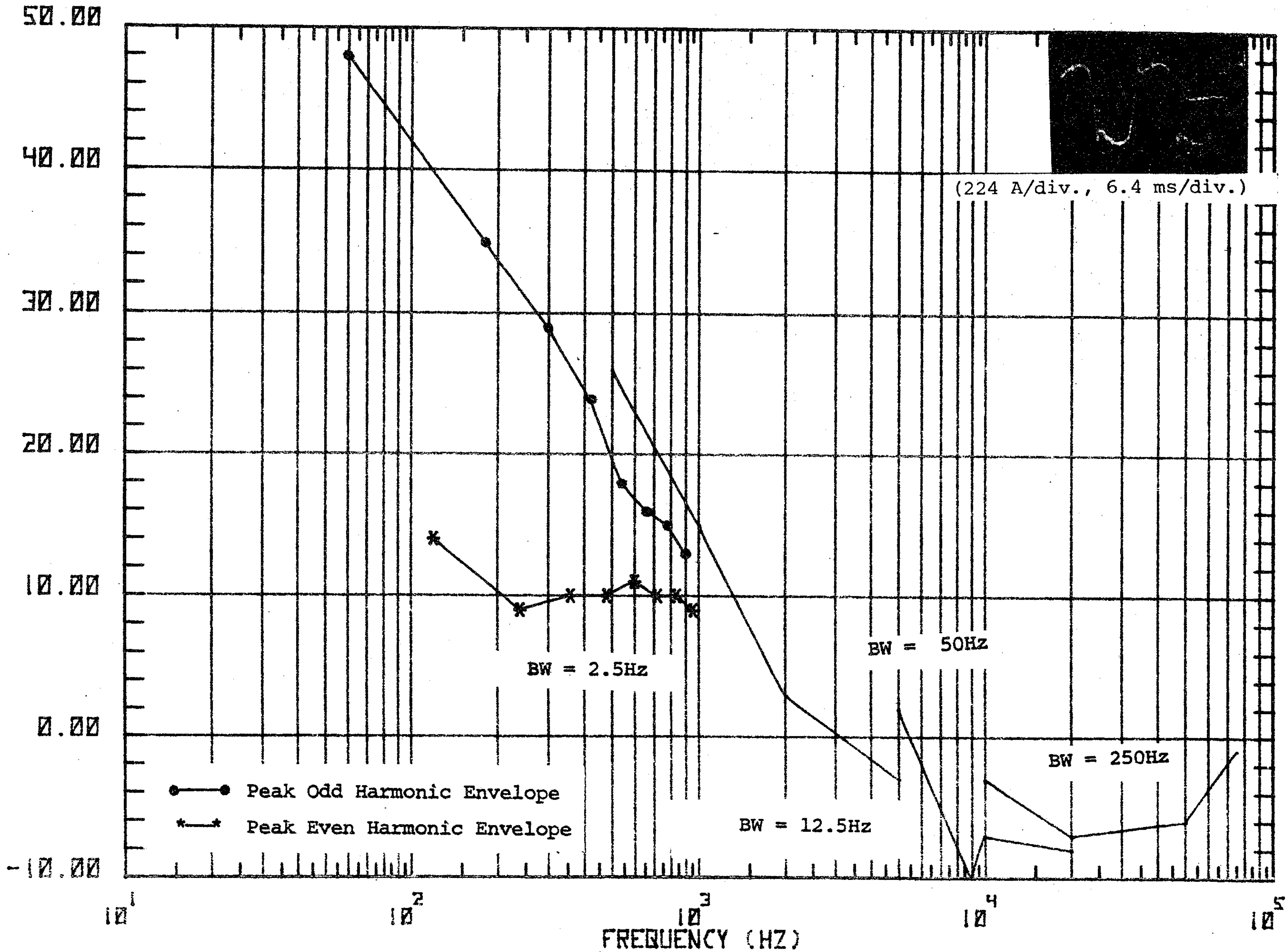


Figure 46. Waveform and spectrum of current in main transformer primary (ground side).

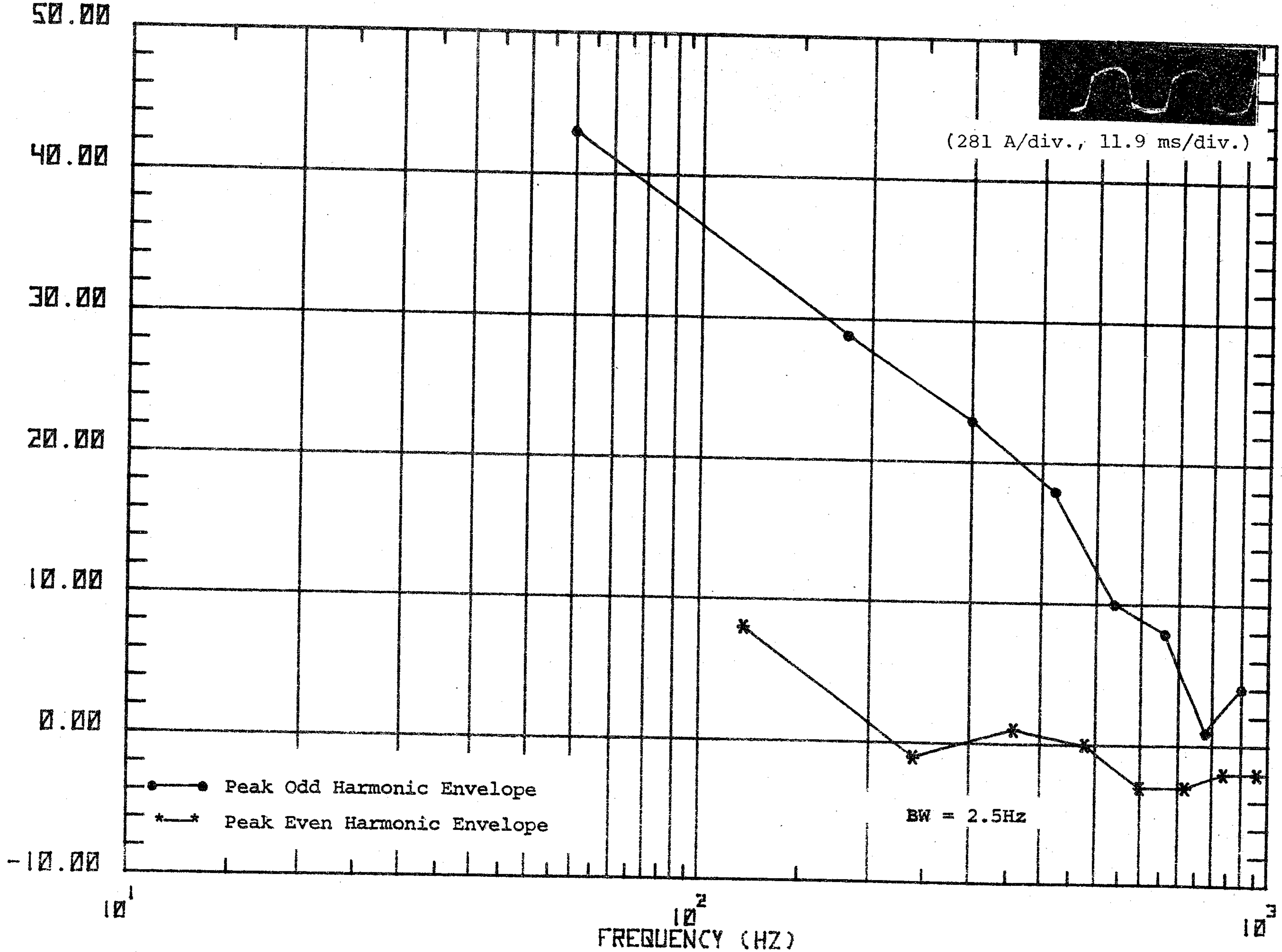


Figure 47. Waveform and spectrum of current in ground side of main transformer primary as locomotive approaches the substation.

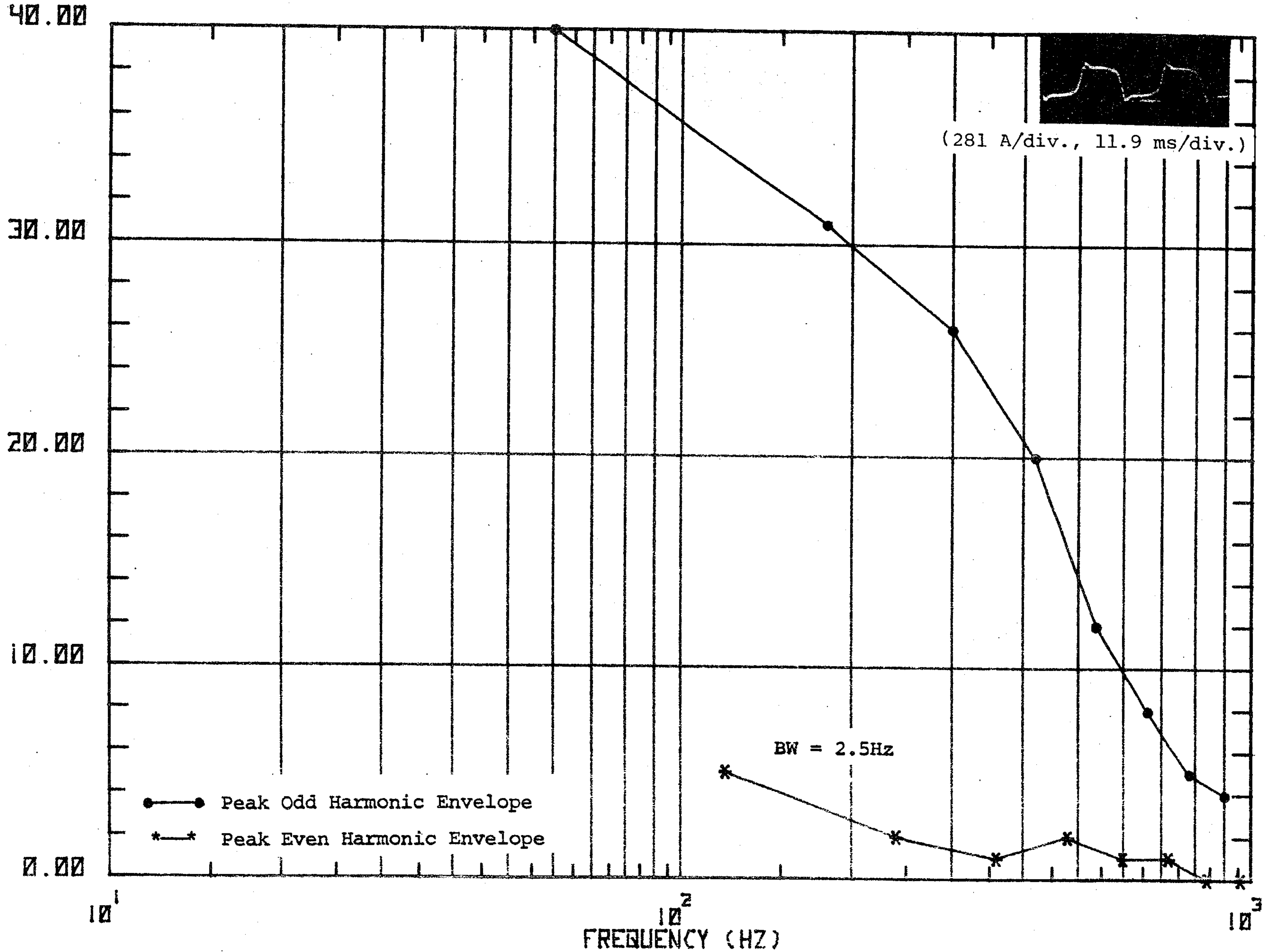


Figure 48. Waveform and spectrum of primary current (ground side) as locomotive passes substation.

amperes peak-to-peak (119.2 amperes rms), a decrease of approximately 112 amperes peak-to-peak from Figure 47. The 60-Hz component recorded at this time was 40 dBA (100 amperes rms), a decrease of 3 dBA from the spectrum presented in Figure 47.

While recording the next set of data, the locomotive ran a track profile in which it accelerated from 10 to 20 mph, maintained that speed for 1 minute, then accelerated from 20 to 30 mph, maintained that speed for 1 minute, etc. up to 110 mph. At that time, the locomotive maintained speed for 1 minute, then accelerated to 115 mph and maintained speed for approximately 2 laps (~ 14 minutes). Time waveforms and frequency spectra results of the maximum primary current drawn as the locomotive accelerated from one prescribed speed to the next are presented in Figures 49a-k.

The same 10-mph increment track profile described in the preceding paragraph was run again the following day with three exceptions: 1) the prescribed speeds were maintained for 2 minutes rather than 1 minute, 2) the profile started at 0 mph rather than 10 mph, and 3) the top speed was 110 mph rather than 115 mph. Time waveforms and frequency results of these measurements are given in Figures 50a-k.

A comparison of the levels of the first 10 harmonics recorded for both track profile samples is given in TABLE 5. In both samples, the locomotive was pulling the same five-car consist. In the second sample, the number 4 traction motor was off.

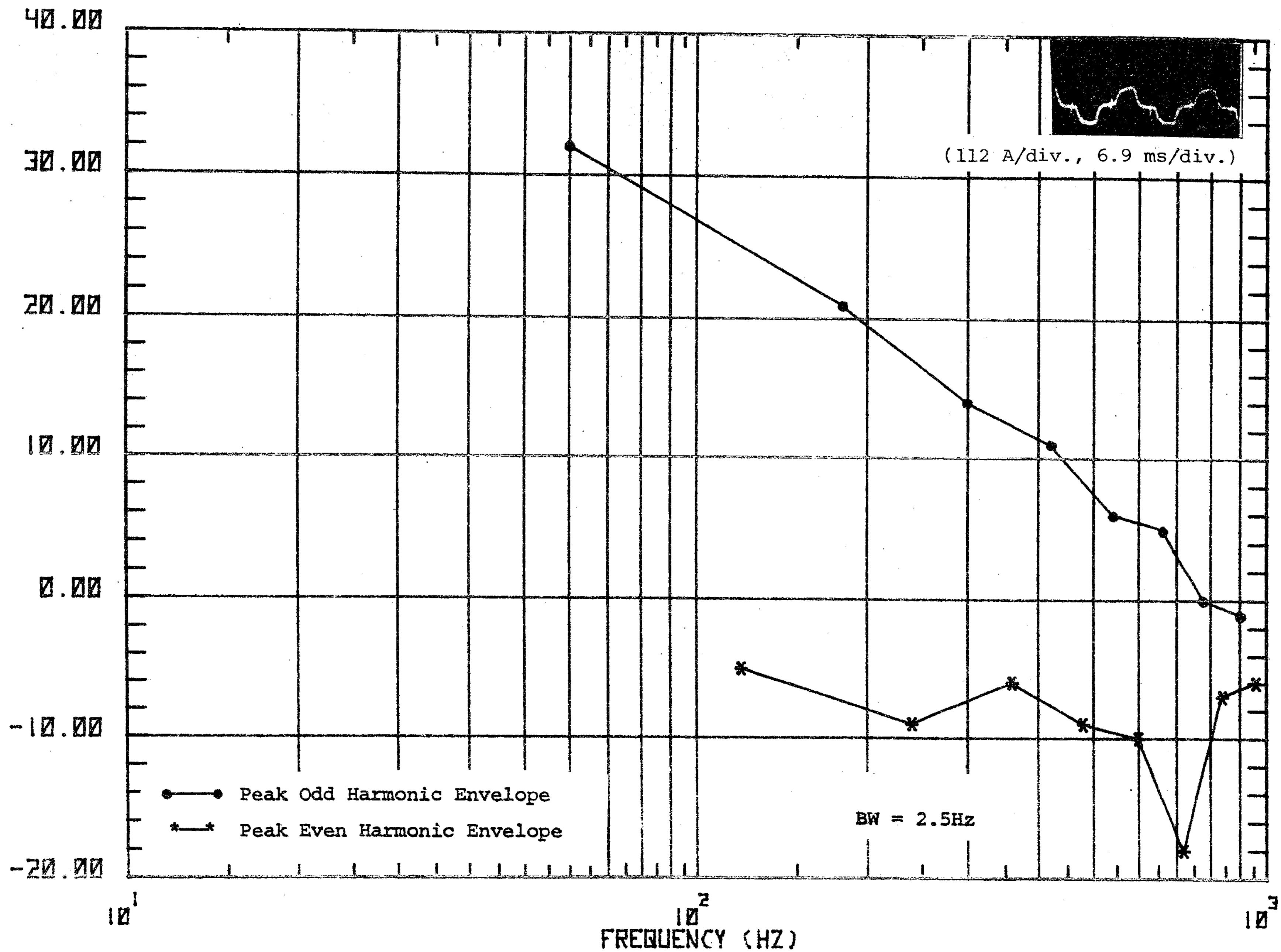


Figure 49a. Waveform and spectrum of primary current, locomotive accelerating from 10-20 mph.

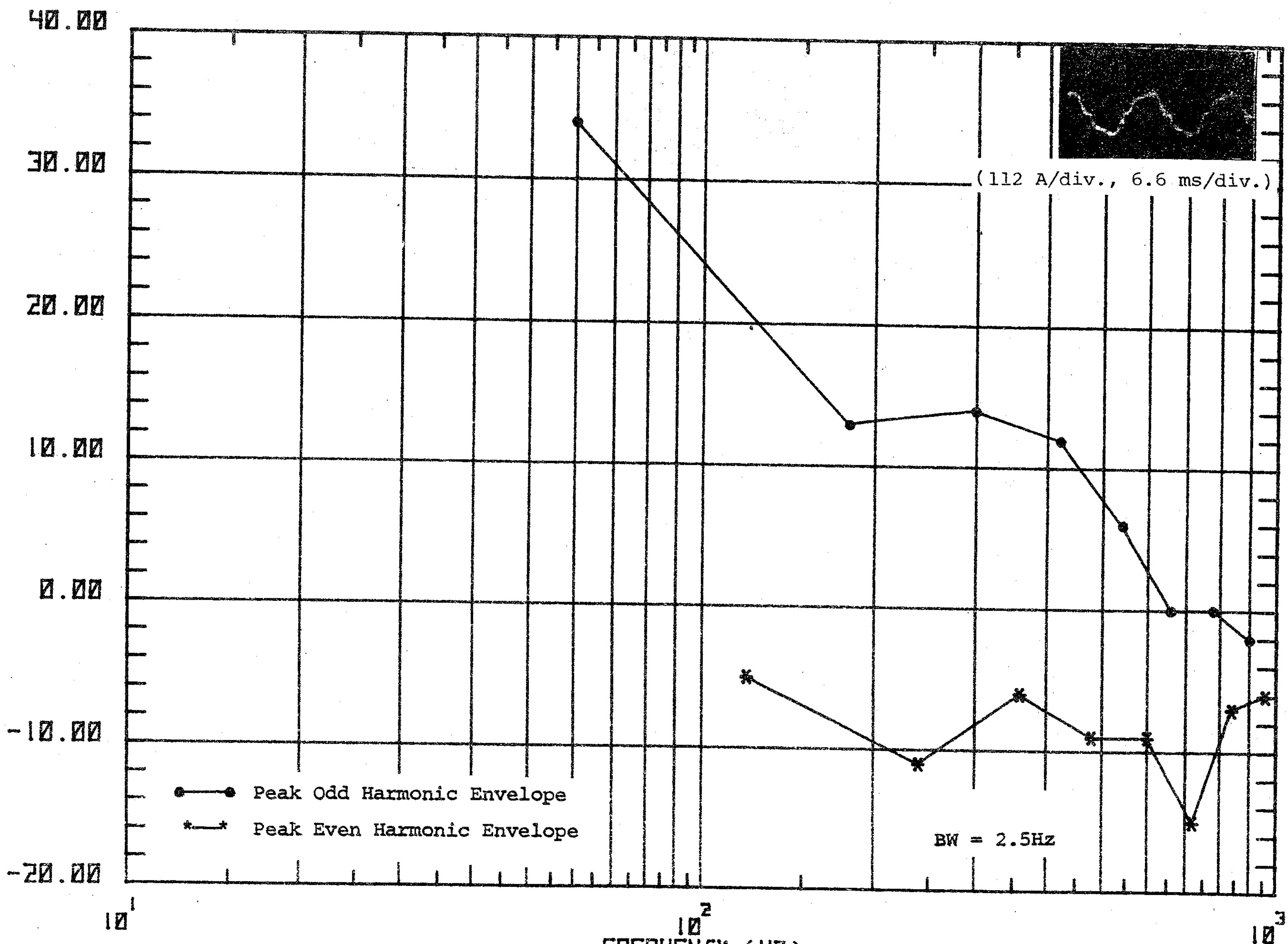


Figure 49b. Waveform and spectrum of primary current, locomotive accelerating from 20-30 mph.

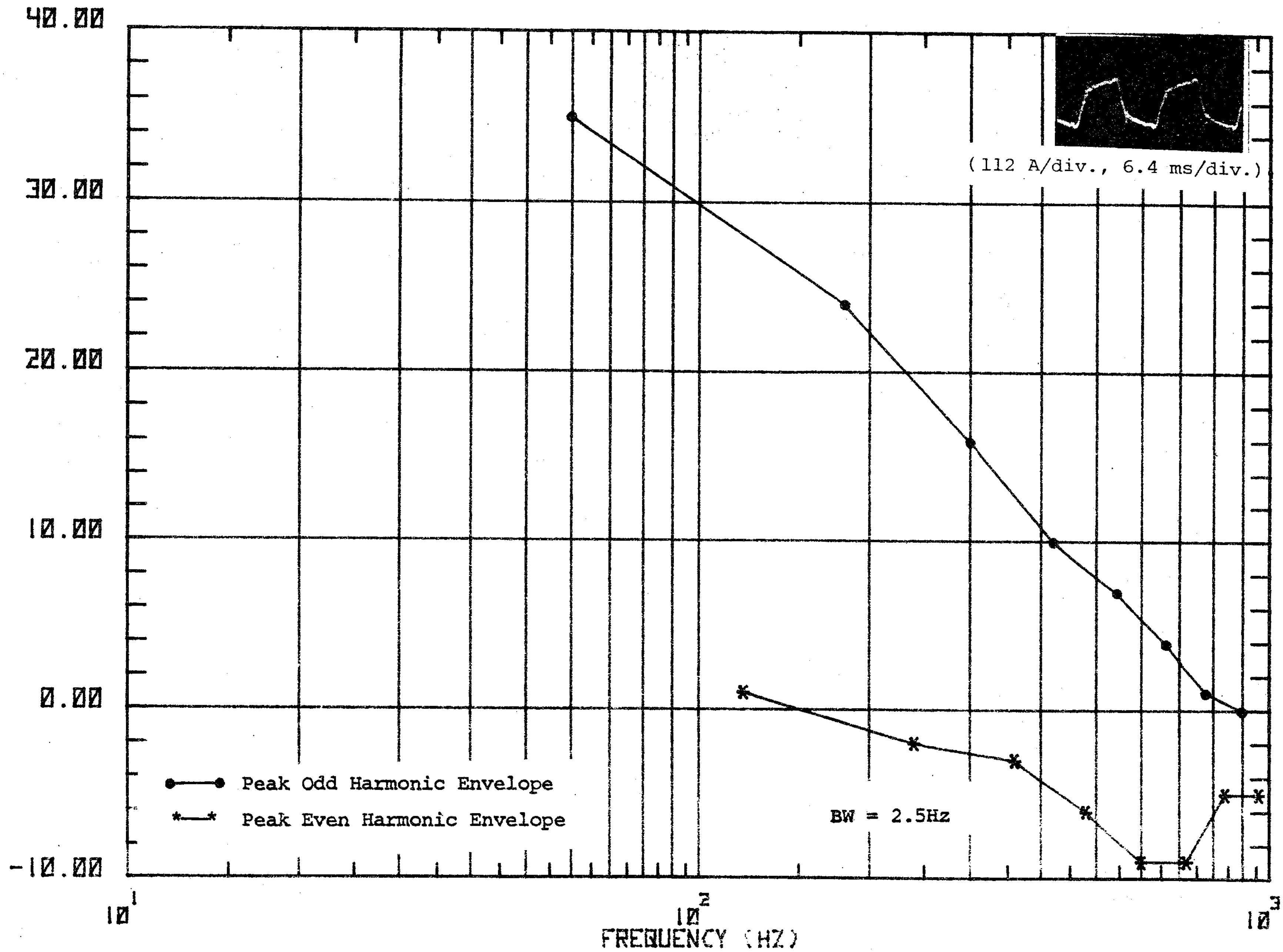


Figure 49c. Waveform and spectrum of primary current, locomotive accelerating from 30-40 mph.

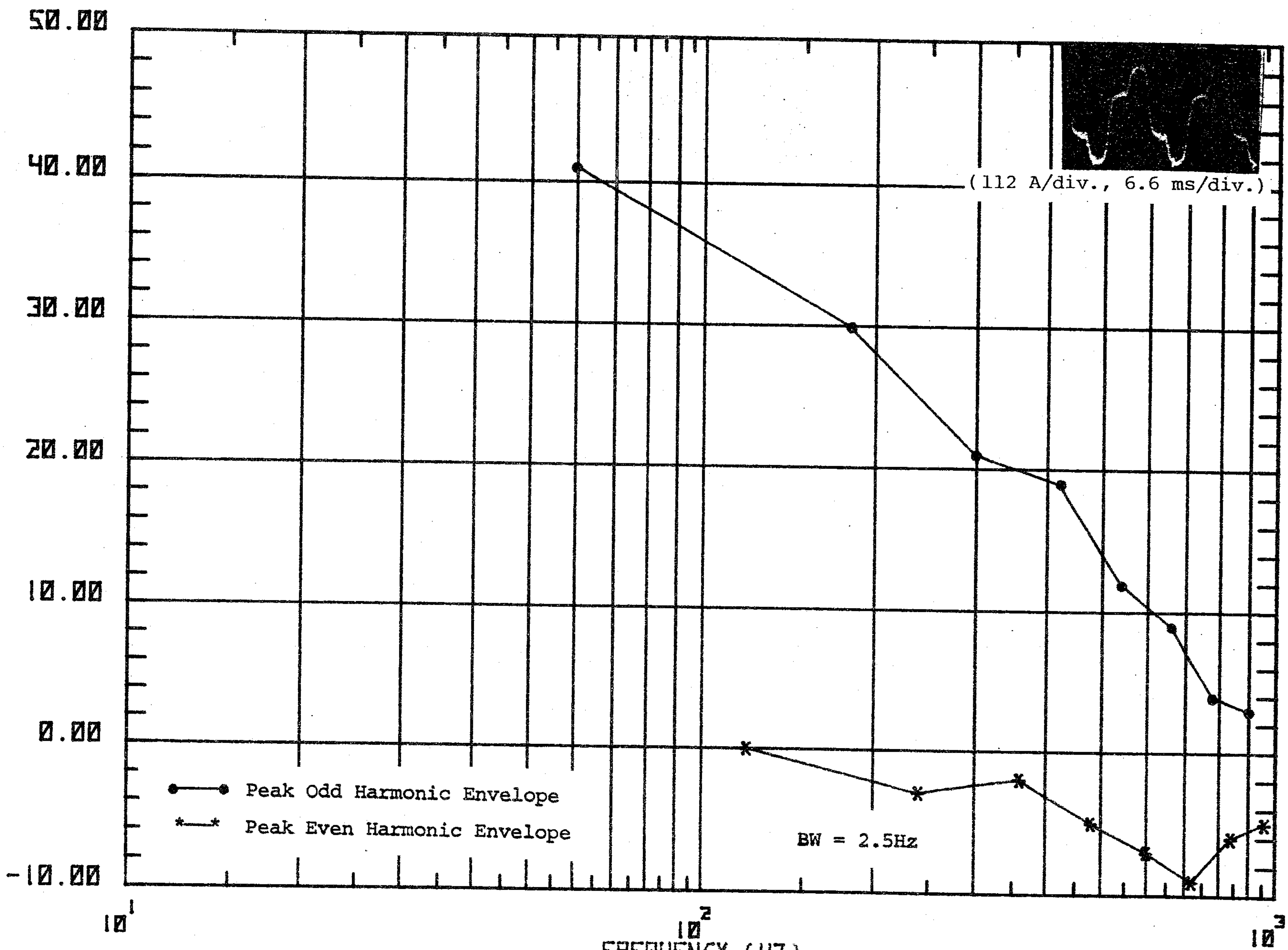


Figure 49d. Waveform and spectrum of primary current, locomotive accelerating from 40 to 50 mph.

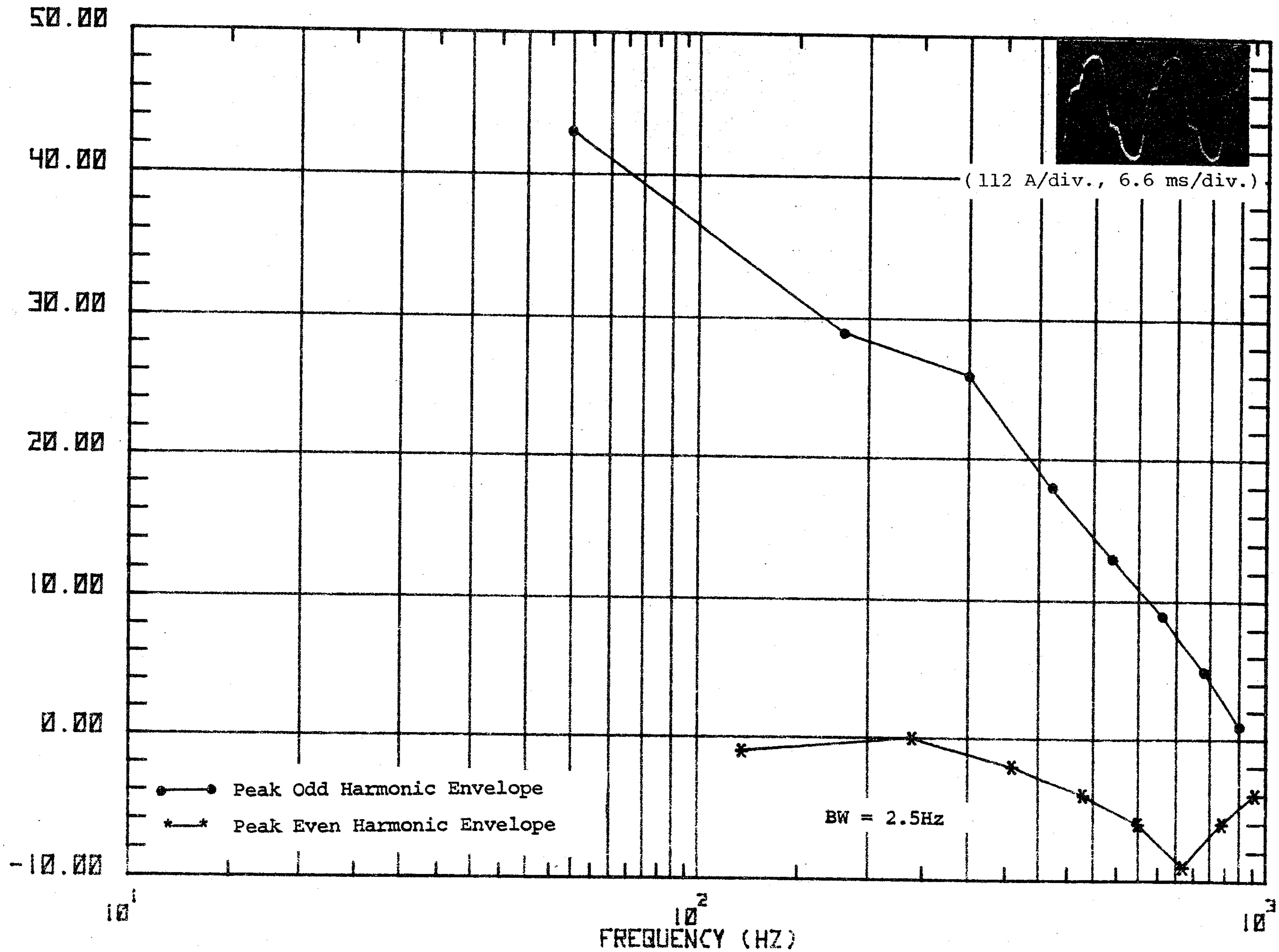


Figure 49e. Waveform and spectrum of primary current, locomotive accelerating from 50-60 mph.

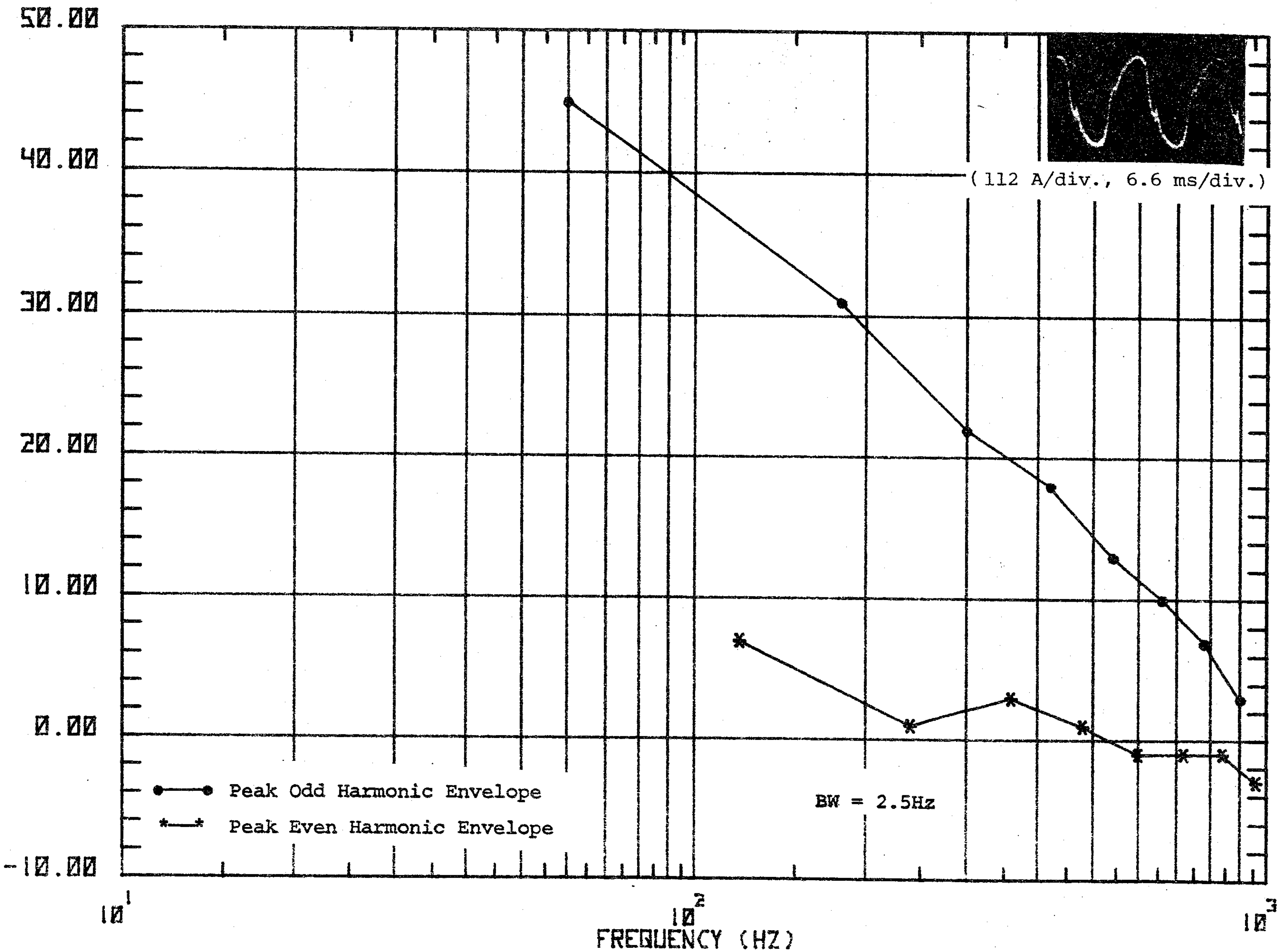


Figure 49f. Waveform and spectrum of primary current, locomotive accelerating from 60-70 mph.

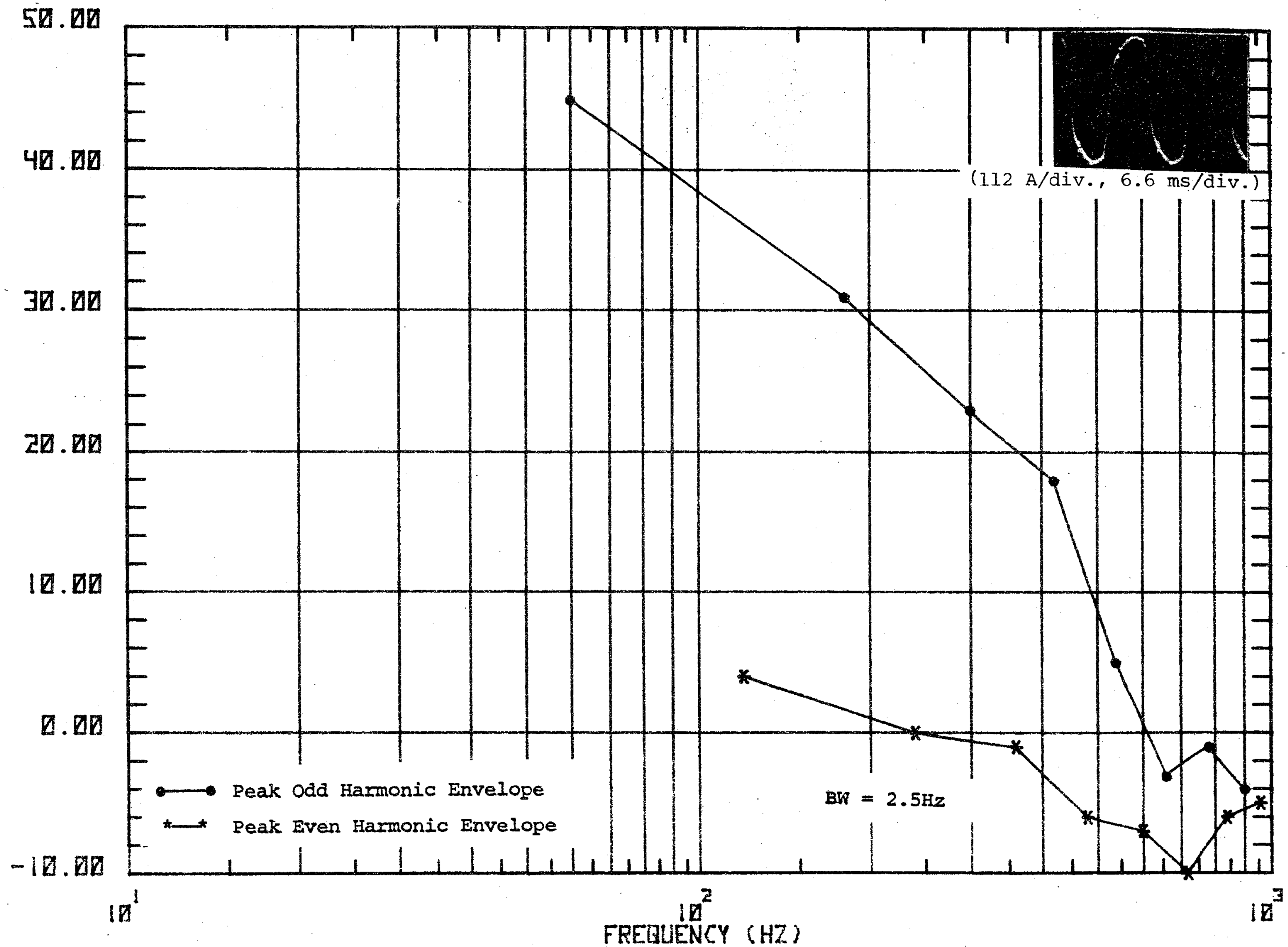


Figure 49g. Waveform and spectrum of primary current, locomotive accelerating from 70-80 mph.

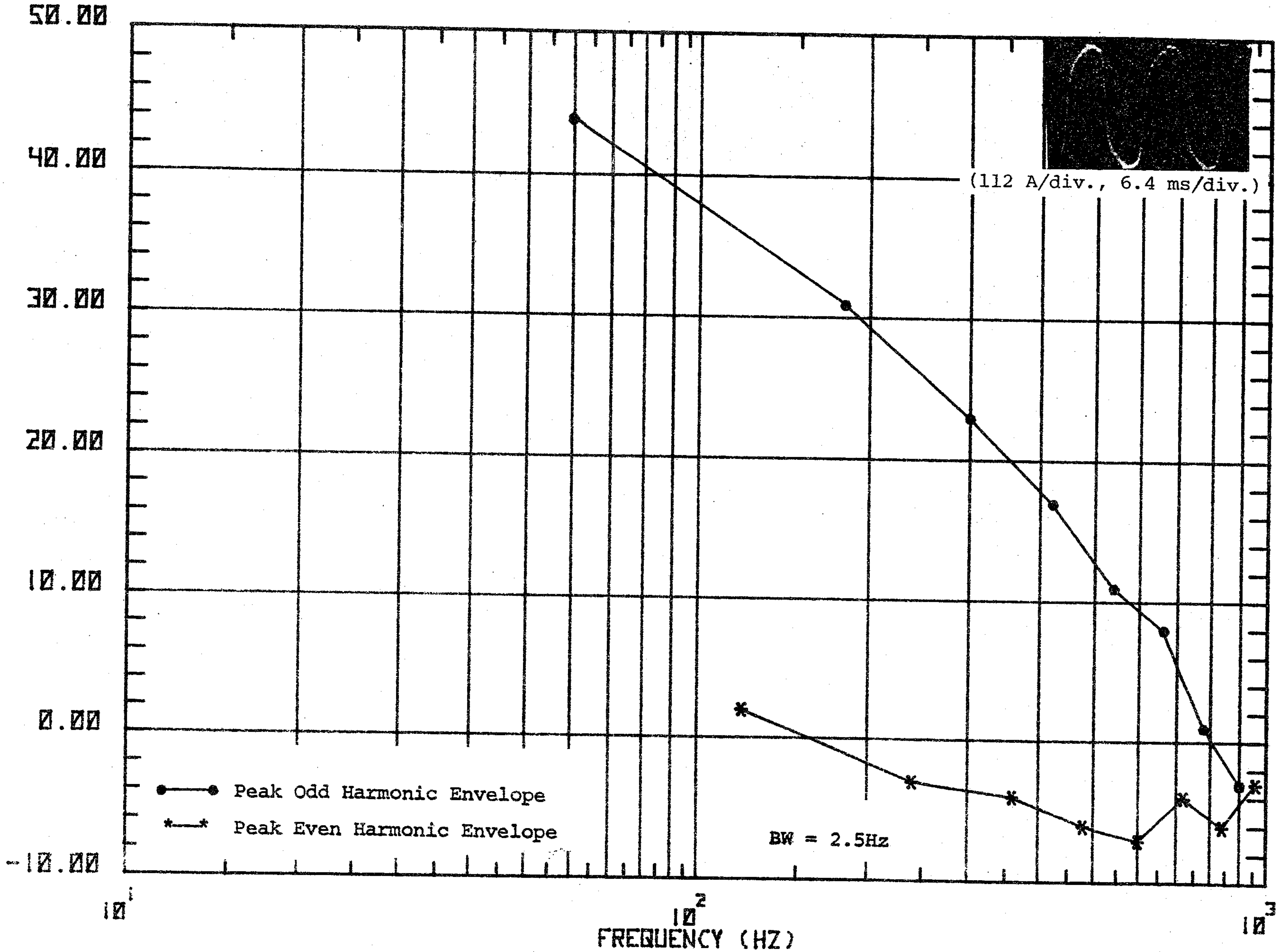


Figure 49h. Waveform and spectrum of primary current, locomotive accelerating from 80-90 mph.

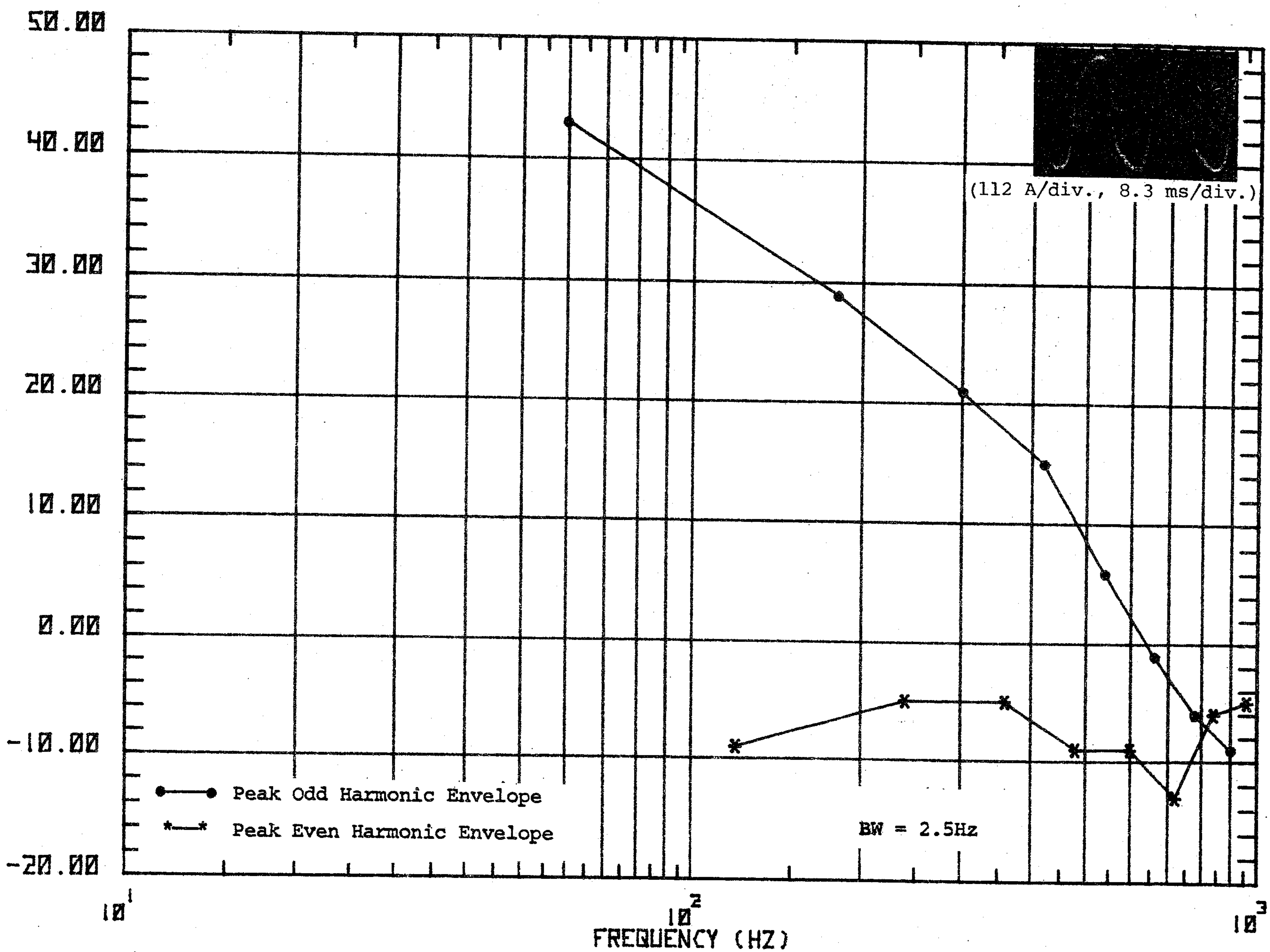


Figure 49i. Waveform and spectrum of primary current, locomotive accelerating from 90-100 mph.

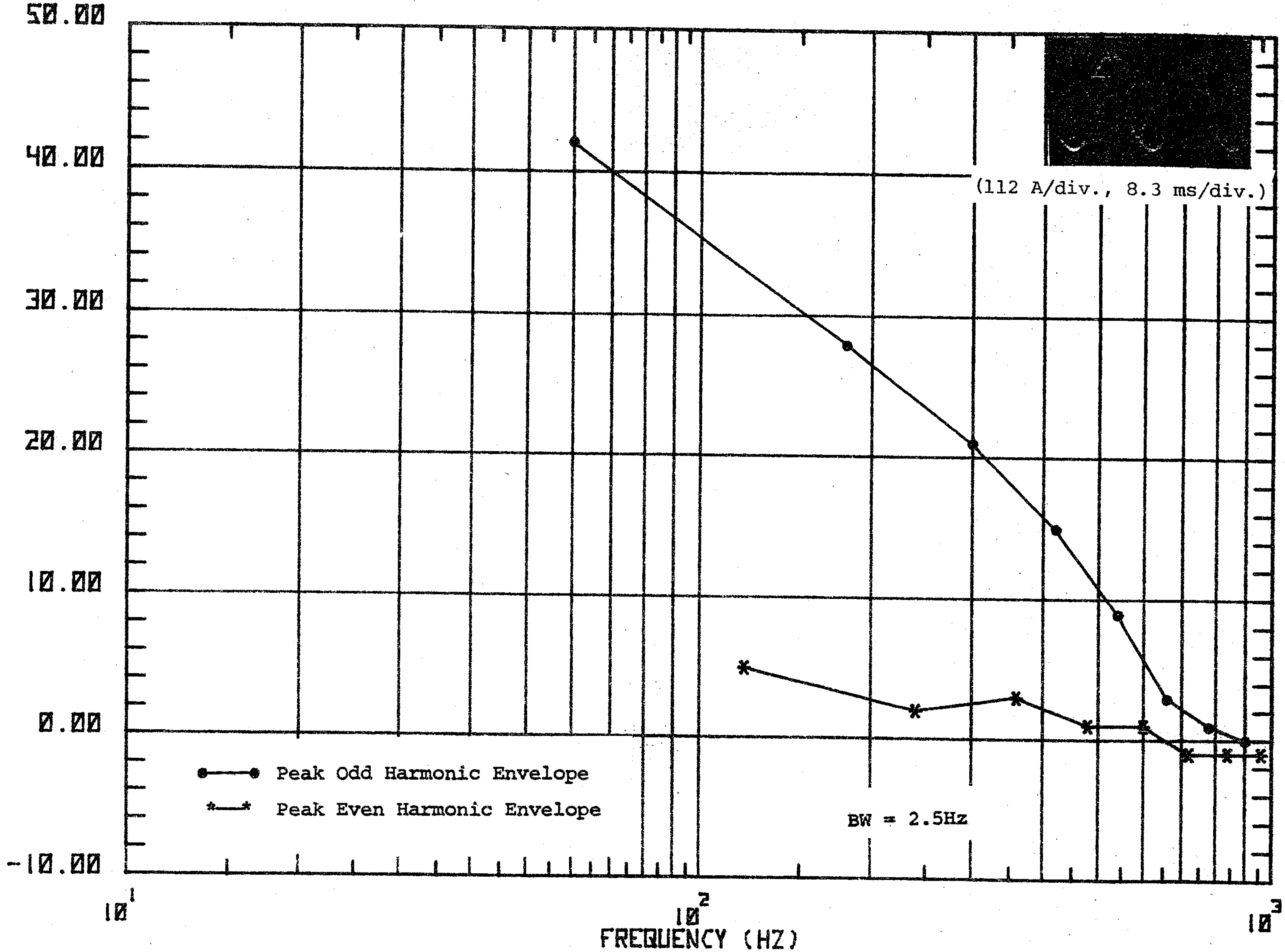


Figure 49j. Waveform and spectrum of primary current, locomotive accelerating from 100-110 mph.

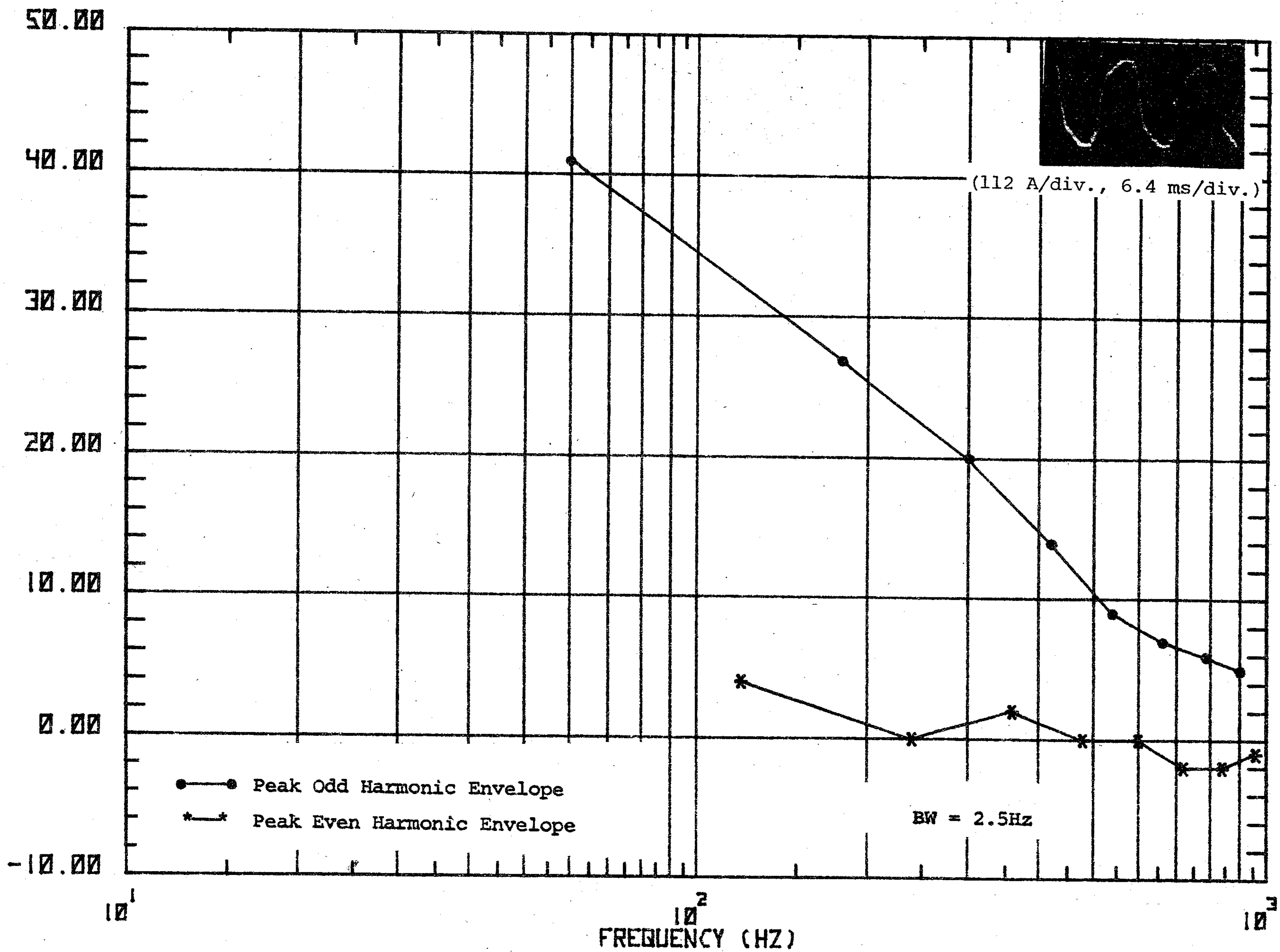


Figure 49k. Waveform and spectrum of primary current, locomotive accelerating from 110 to 115 mph.

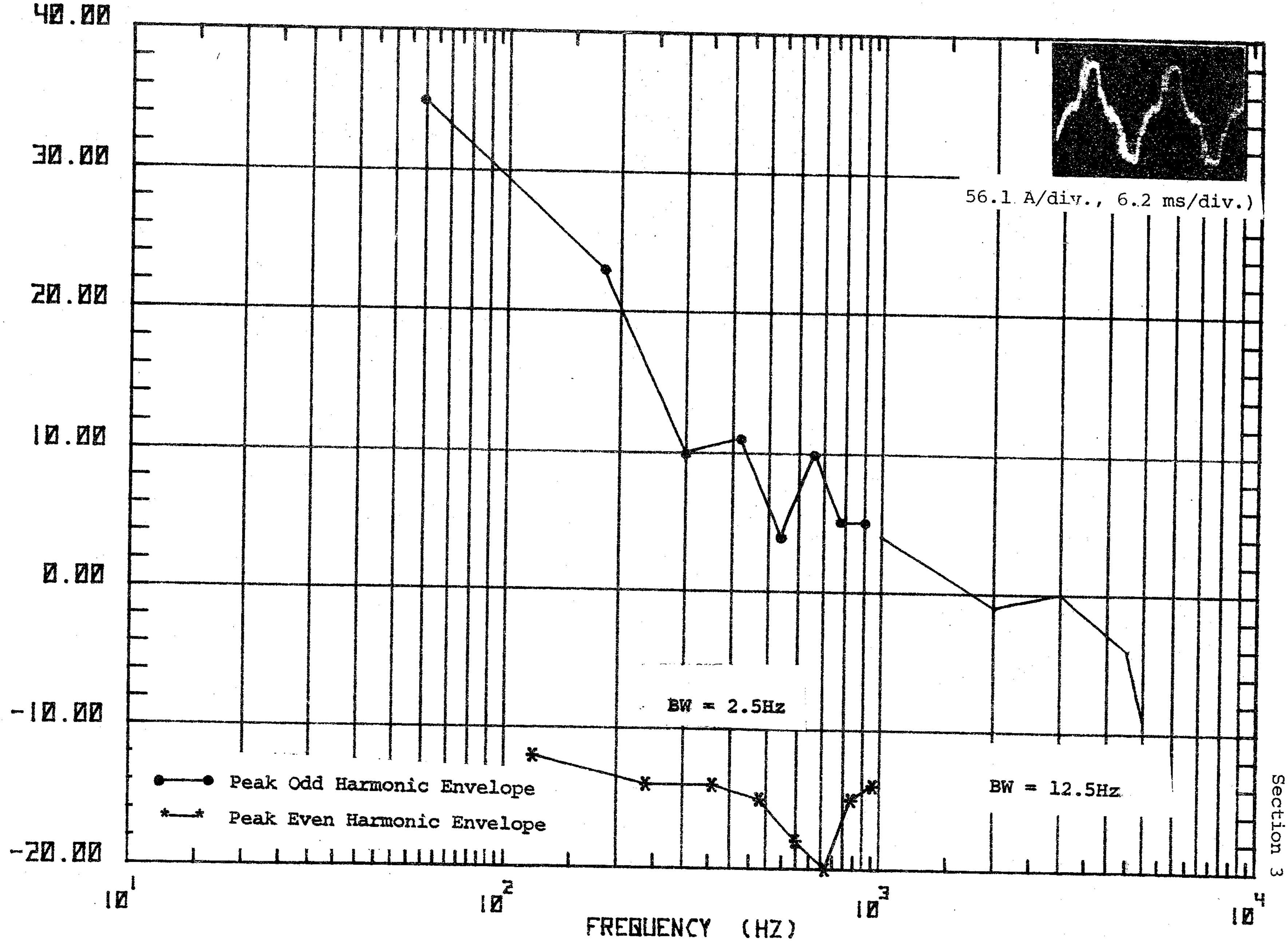


Figure 50a. Waveform and spectrum of primary current, locomotive accelerating from 0-10 mph (sample 2).

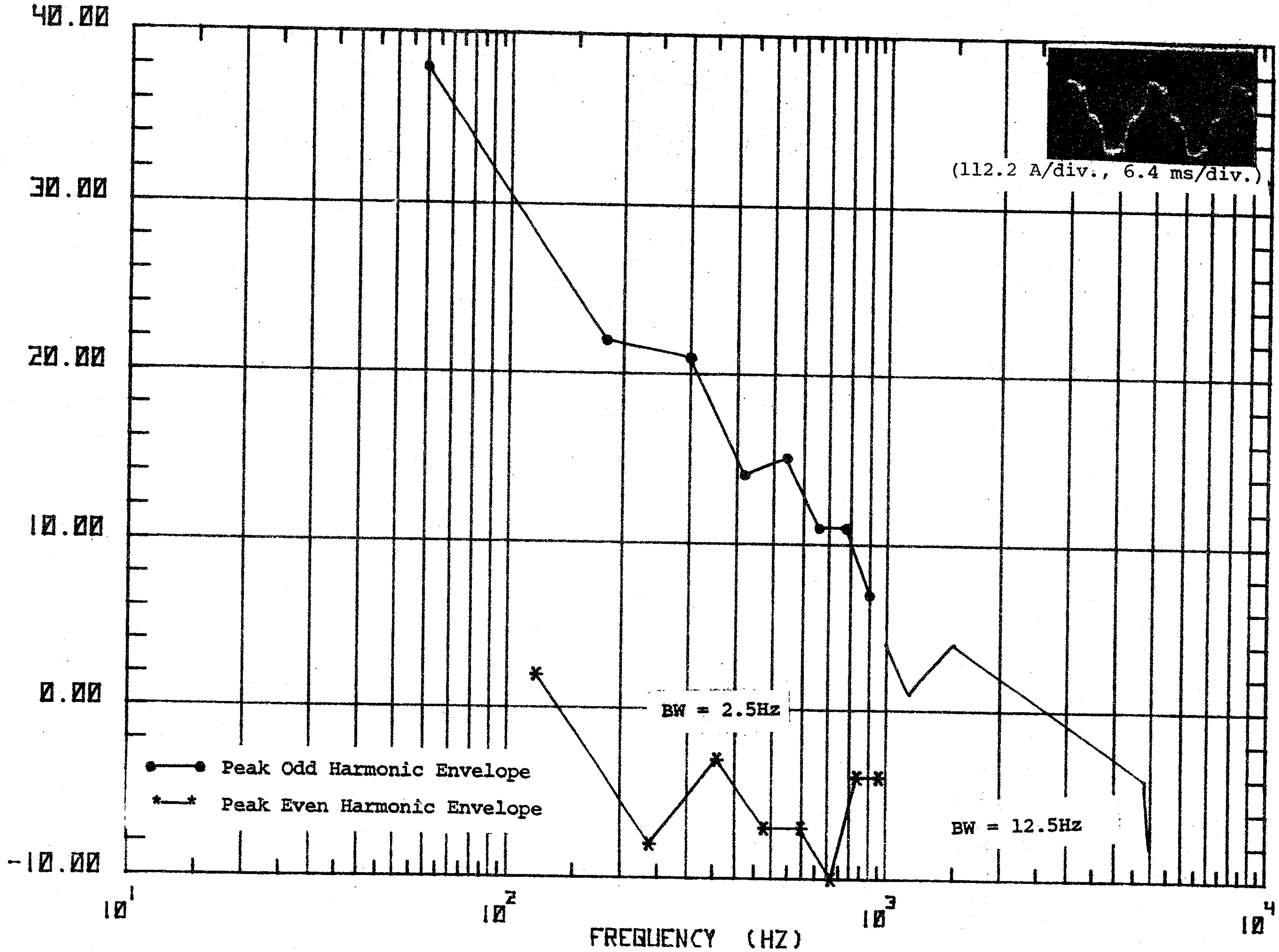


Figure 50b. Waveform and spectrum of primary current, locomotive accelerating from 10-20 mph (sample 2).

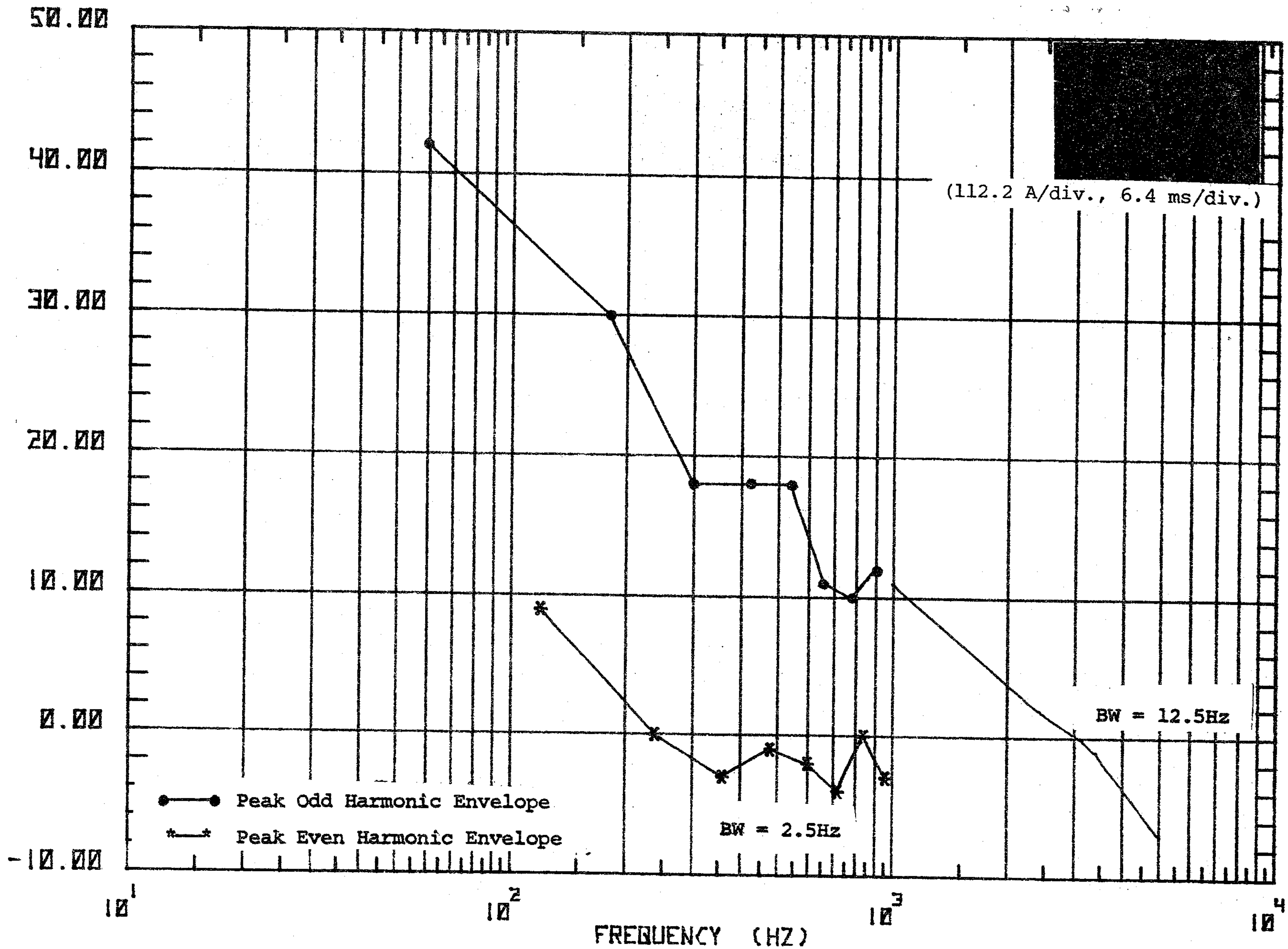


Figure 50c. Waveform and spectrum of primary current, locomotive accelerating from 20-30 mph (sample 2).

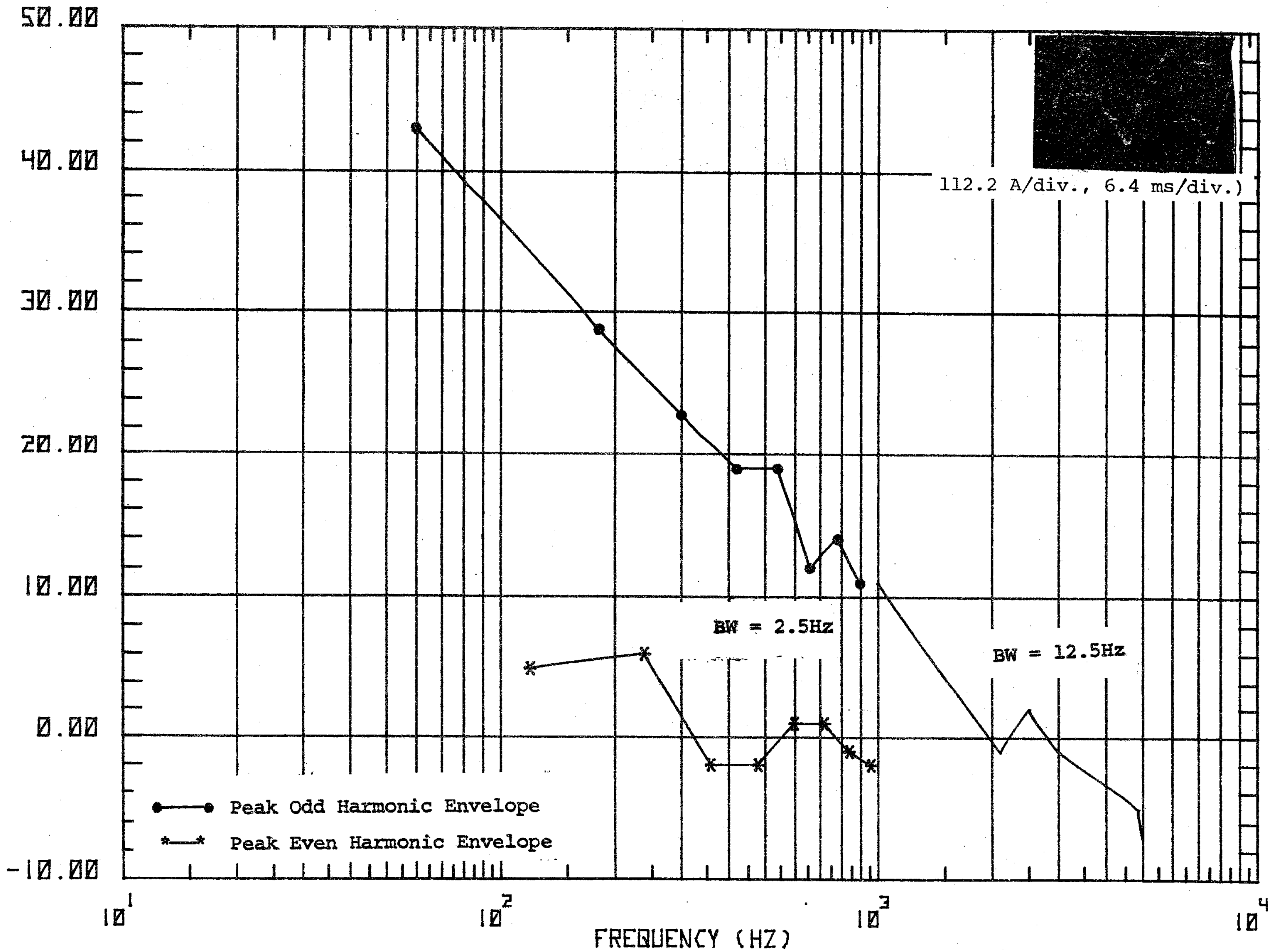


Figure 50d. Waveform and spectrum of primary current, locomotive accelerating from 30-40 mph (sample 2).

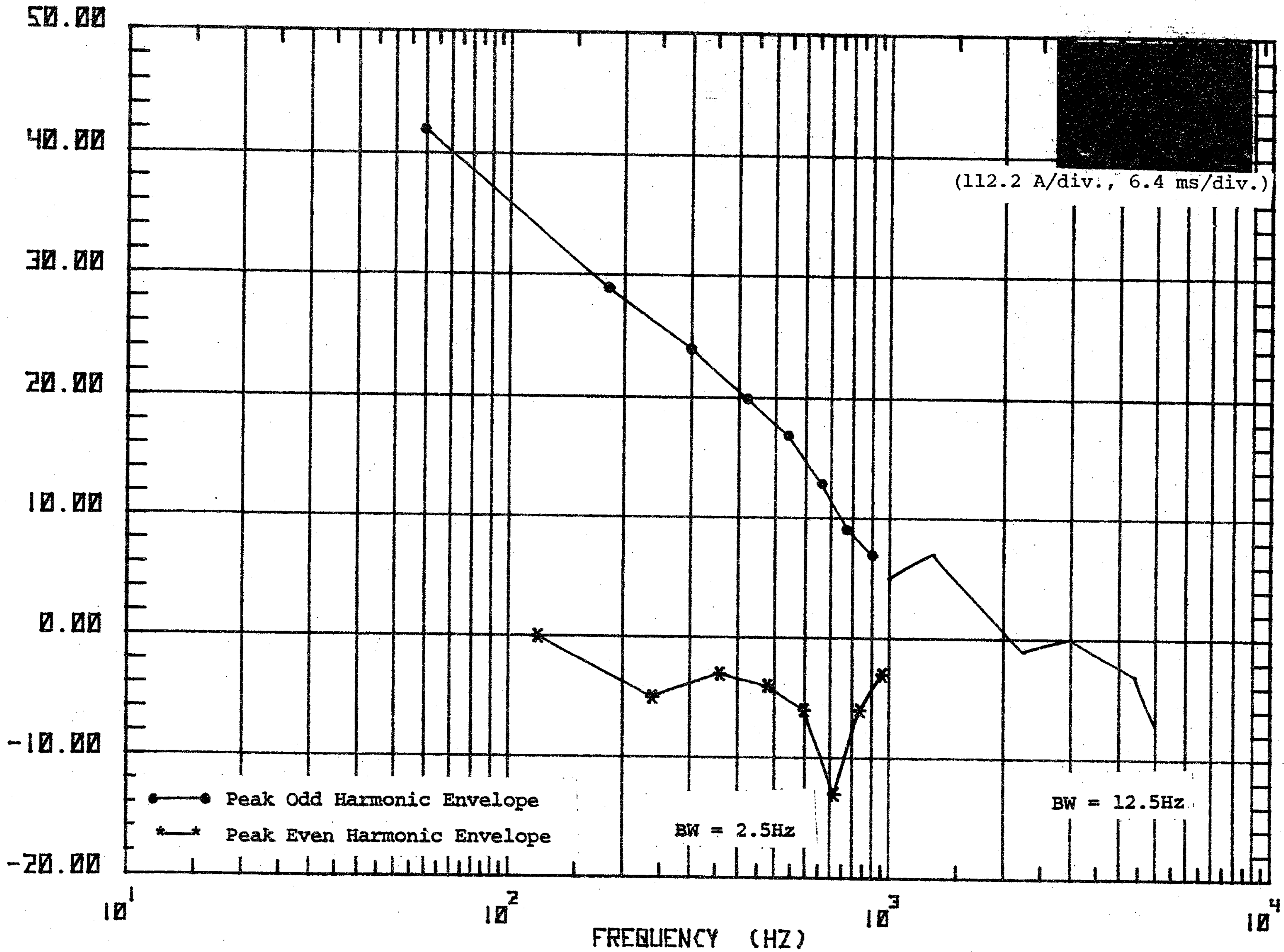


Figure 50e. Waveform and spectrum of primary current, locomotive accelerating from 40-50 mph (sample 2).

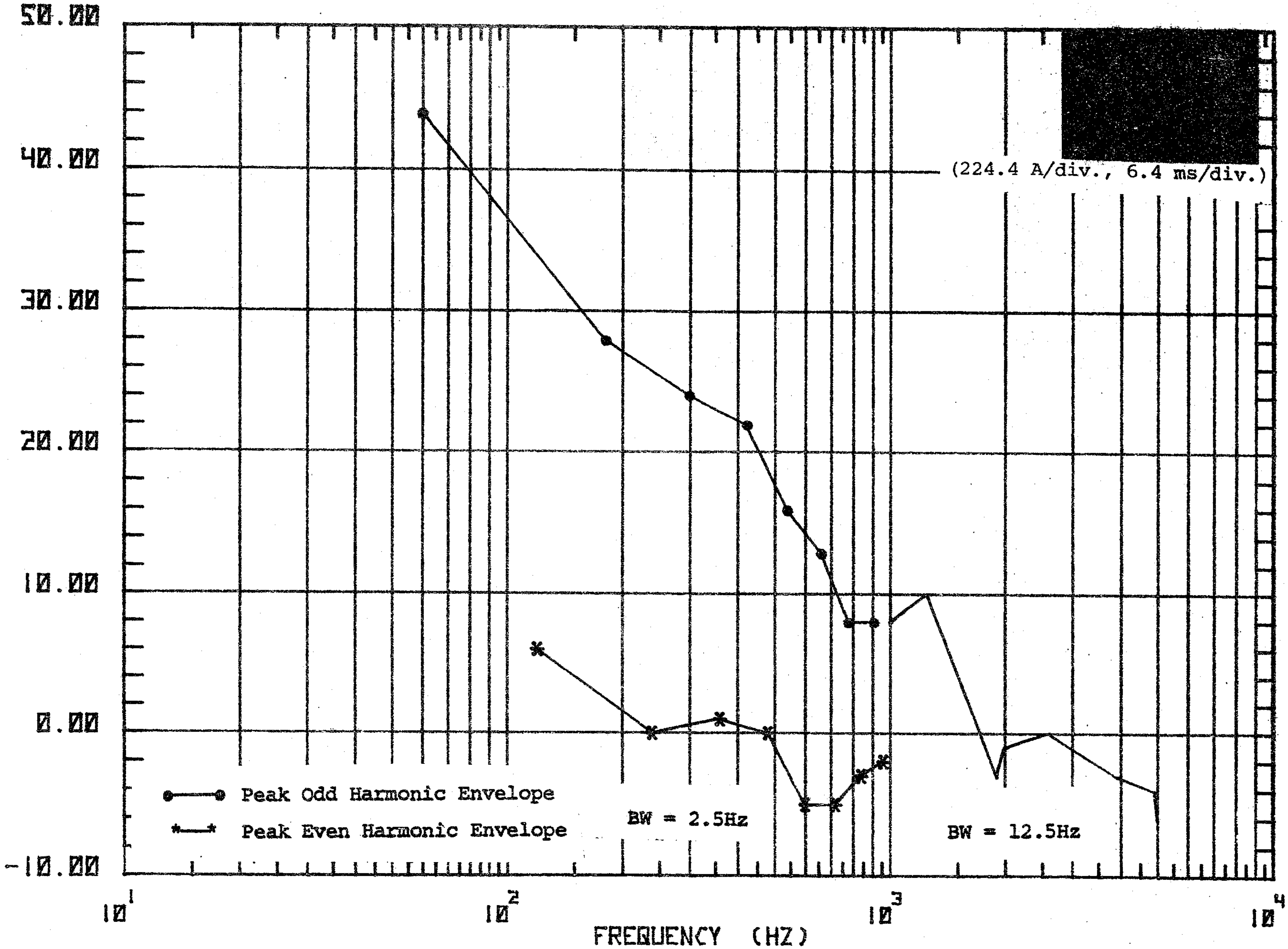


Figure 50f. Waveform and spectrum of primary current, locomotive accelerating from 50-60 mph (sample 2).

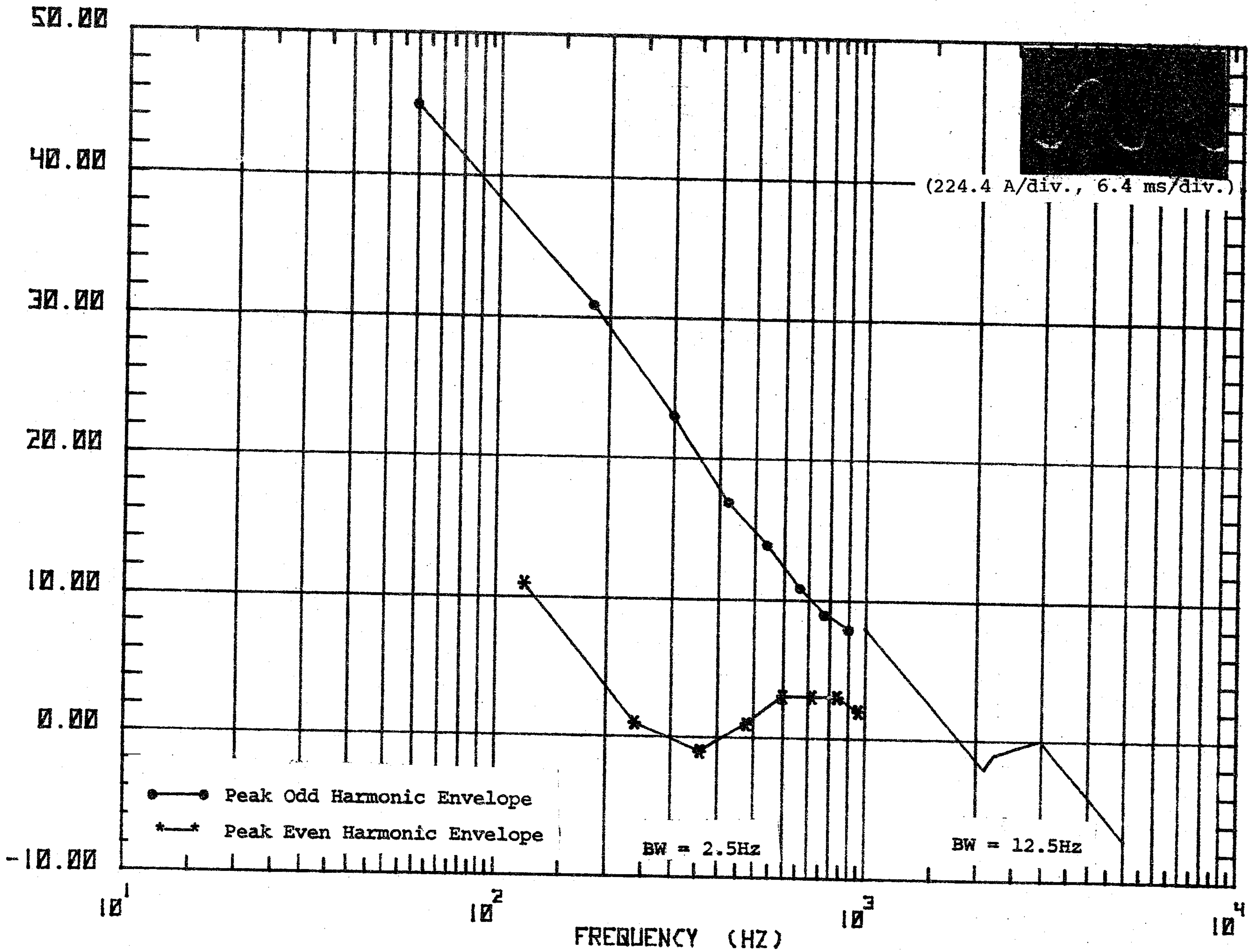


Figure 50g. Waveform and spectrum of primary current, locomotive accelerating from 60-70 mph (sample 2).

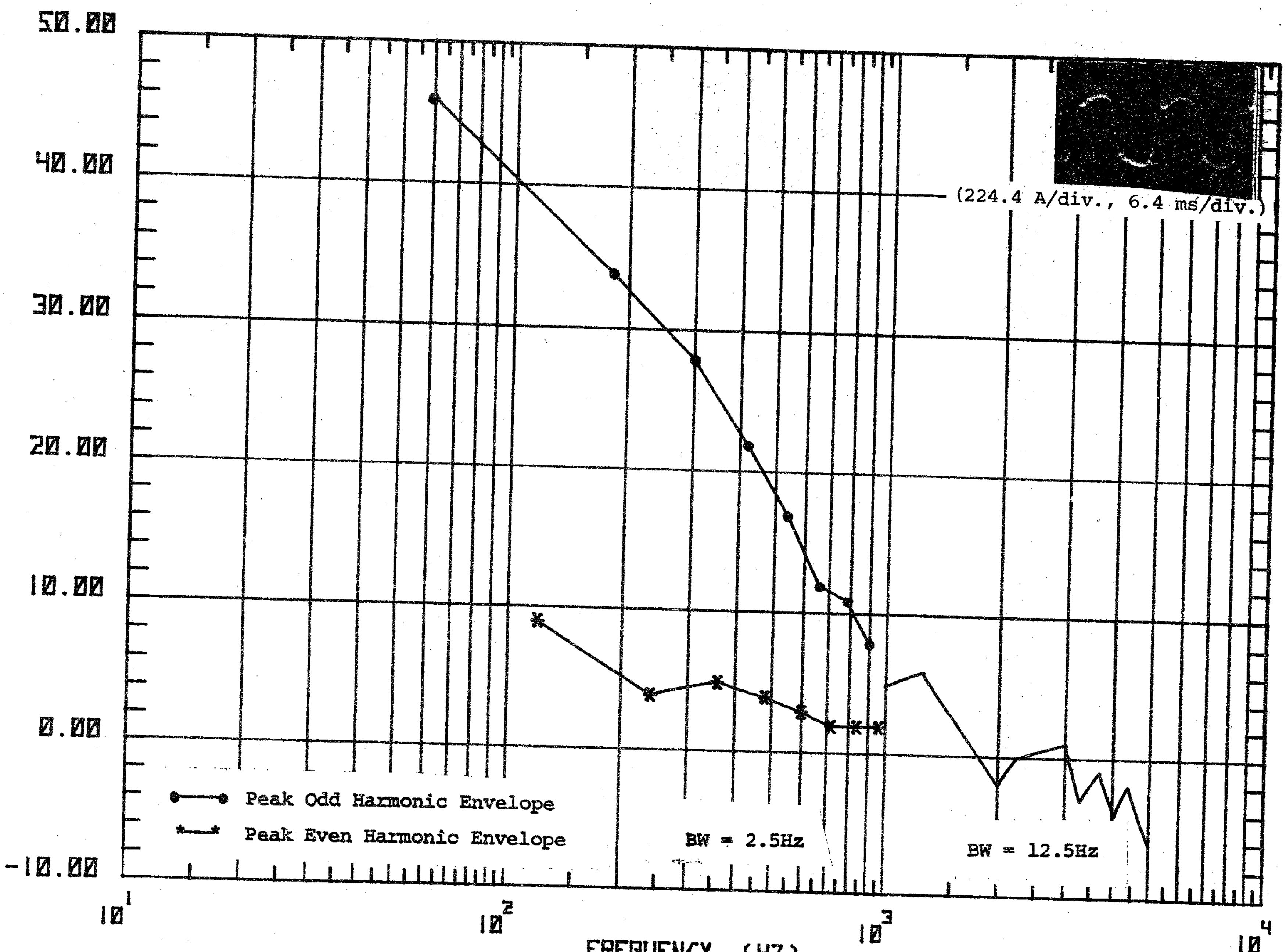


Figure 50h. Waveform and spectrum of primary current, locomotive accelerating from 70-80 mph (sample 2).

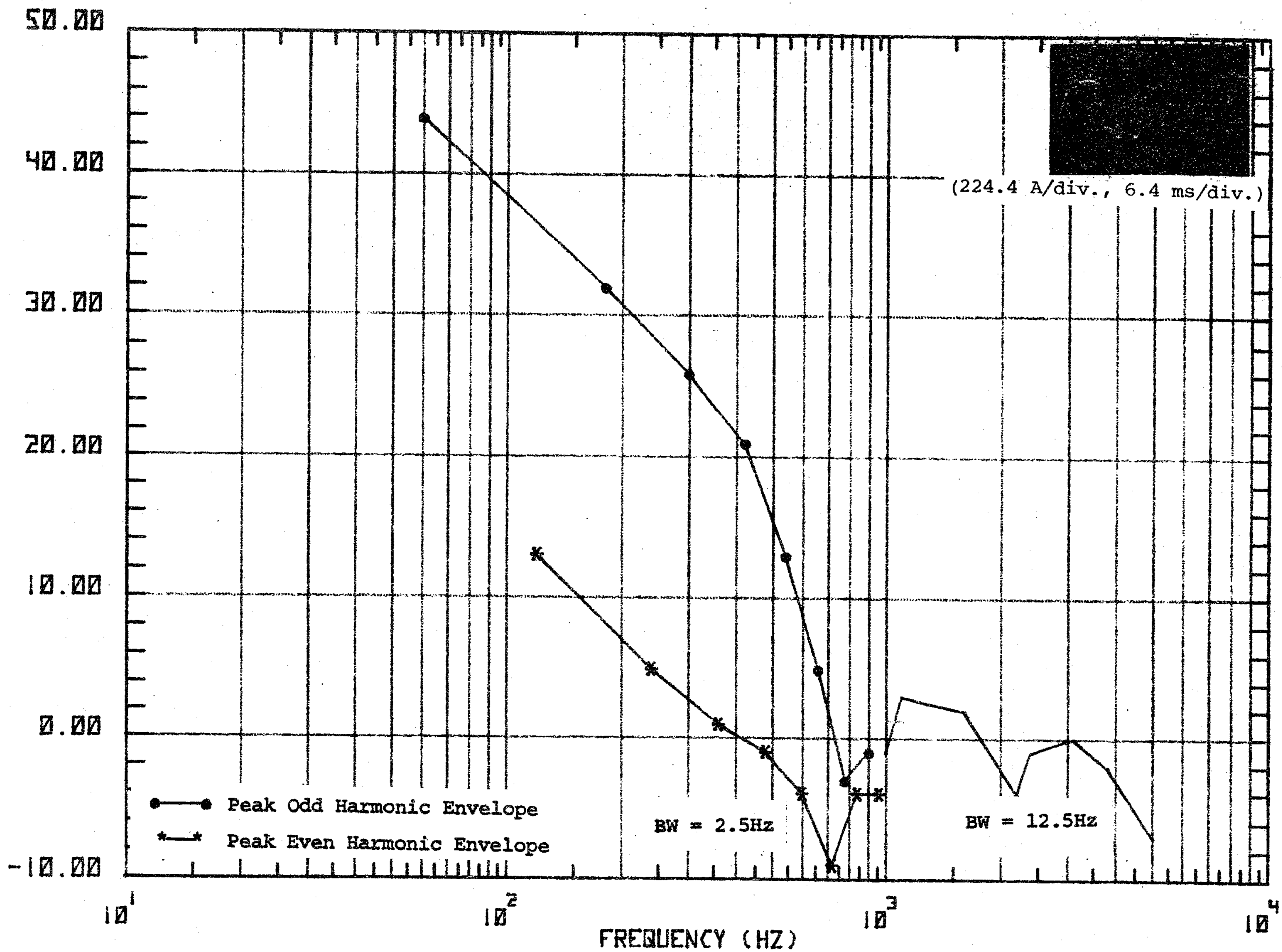


Figure 50i. Waveform and spectrum of primary current, locomotive accelerating from 80-90 mph (sample 2).

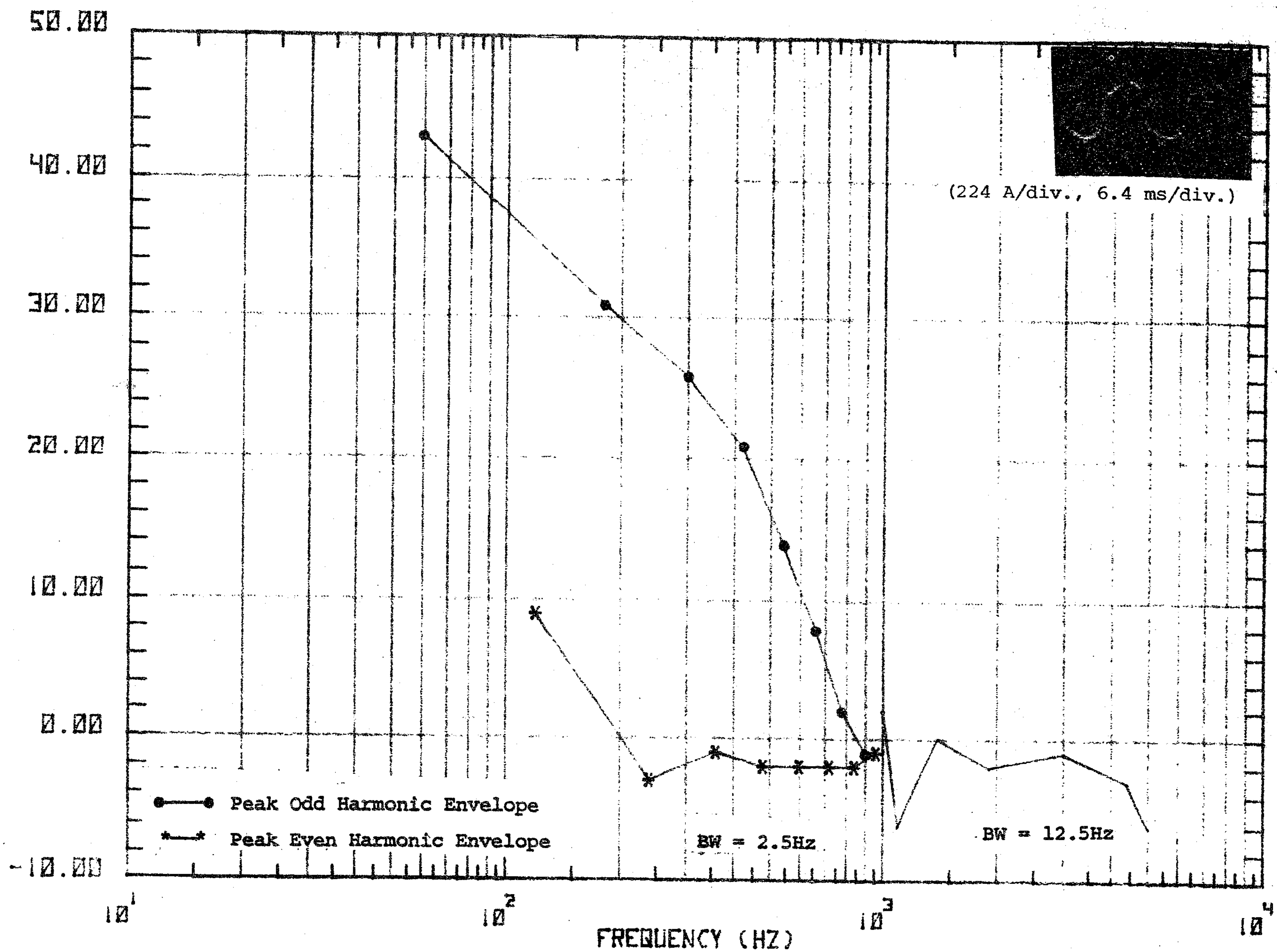


Figure 50j. Waveform and spectrum of primary current, locomotive accelerating from 90-100 mph (sample 2).

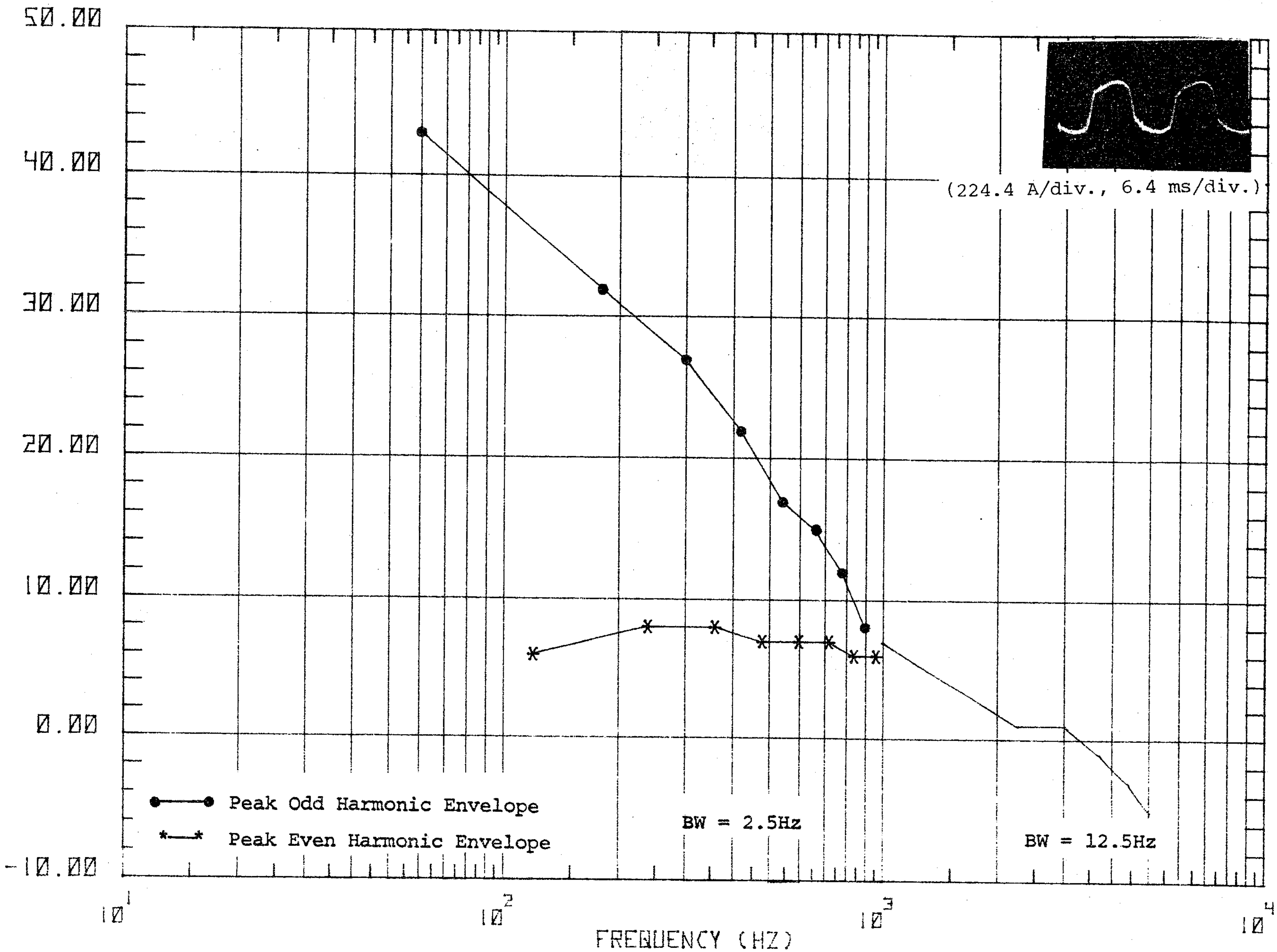


Figure 50k. Waveform and spectrum of primary current, locomotive accelerating from 100-110 mph (sample 2).

TABLE 5

COMPARISON OF PRIMARY CURRENT HARMONIC LEVELS FOR TWO SAMPLES OF LOCOMOTIVE, 10-MPH INCREMENT RUN[a]

Speed Increment (mph)	Sample 1 Frequency Component in Hz										Sample 2 Frequency Component in Hz									
	60	120	180	240	300	360	420	480	540	600	60	120	180	240	300	360	420	480	540	600
0-10											35 (56.2)	-12	23	-14	10	-14	11	-15	4	-18
10-20	32 (39.8)	-5	21	-9	14	-6	11	-9	6	-10	38 (79.4)	2	22	-8	21	-3	14	-7	15	-7
20-30	34 (50.5)	-5	13	-11	14	-6	12	-9	6	-9	42 (125.9)	9	30	0	18	-3	18	-1	18	-2
30-40	35 (56.2)	1	24	-2	16	-3	10	-6	7	-9	43 (141.2)	5	29	6	23	-2	19	-2	19	1
40-50	41 (112.2)	0	30	-3	21	-2	19	-5	12	-7	42 (125.9)	0	29	-5	24	-3	20	-4	17	-6
50-60	43 (141.2)	-1	29	0	26	-2	18	-4	13	-6	44 (158.5)	6	28	0	24	1	22	0	16	-5
60-70	45 (177.8)	7	31	1	22	3	18	1	13	-1	45 (177.8)	11	31	1	23	-1	17	1	14	3
70-80	45 (177.8)	4	31	0	23	-1	18	-6	5	-7	46 (199.5)	9	34	4	28	5	22	4	17	3
80-90	44 (158.5)	2	31	-3	23	-4	17	-6	11	-7	44 (158.5)	13	32	5	26	1	21	-1	13	-4
90-100	43 (141.2)	-9	29	-5	21	-5	15	-9	6	-9	43 (141.2)	9	31	-3	26	-1	21	-2	14	-2
100-110	42 (125.9)	5	28	2	21	3	15	1	9	1	43 (141.2)	6	32	8	27	8	22	7	17	7

[a]The current levels shown are in units of dBA (amperes rms).

In the first sample, it was not ascertained whether all four traction motors were on or the fourth traction motor was off. Comparing emission levels during the 10-20 mph increment, the 60-Hz component of the current drawn was 6 dBA higher in the second sampling than the first. This pattern of higher current levels recorded for sample 2 versus sample 1 appears to hold true for all frequencies displayed for speeds up to 40 mph. After that, the levels appear equivalent ($\pm$ 1 or 2 dBA).

The next set of data presented was recorded as the locomotive accelerated from 10 to 115 mph. During this time, the ground side primary current was observed to undergo six waveshape changes from the original waveform. These seven waveforms, along with their respective frequency spectra, are given in Figures 51a-g. In Figure 51a (waveshape #1), the waveform resembles a rough sinusoid with odd harmonics dominating the spectrum. In Figure 51b, the periodic signal level flattens out just before quickly rising to the peak value. While the odd harmonics continue to dominate the spectrum, the even harmonics have increased by roughly 10 dBA. The third waveform (waveshape #3), shown in Figure 51c, resembles waveshape #2 with the exception that a second plateau is observed. This waveshape is associated with a 2-5 dB increase in odd harmonic levels along with a 5-9 dB decrease in the even harmonic levels. The fourth waveform (Figure 51d) resembles waveshape #1; however, there are some differences. For instance, the levels of the odd harmonics relative to the fundamental are higher in waveshape #4 than waveshape #1. Also, the levels of the odd harmonics relative to the even harmonics (i.e., fundamental relative to second harmonic, third harmonic relative to fourth, etc.) are greater in waveshape #4 than in waveshape #1.

The fifth waveshape (Figure 51e) appears sinusoidal and smoother than waveshape #4. The third harmonic of this waveform along with the ninth, eleventh, thirteenth, and fifteenth harmonics has dropped significantly. For example, the third harmonic dropped from 41 dBa (112.2 amperes rms) to 33 dBa (44.67 amperes rms). The sixth waveform appears to have flatter peaks than the five waveforms already discussed. In this case, the even harmonics from the second through the fourteenth have decreased drastically from those of

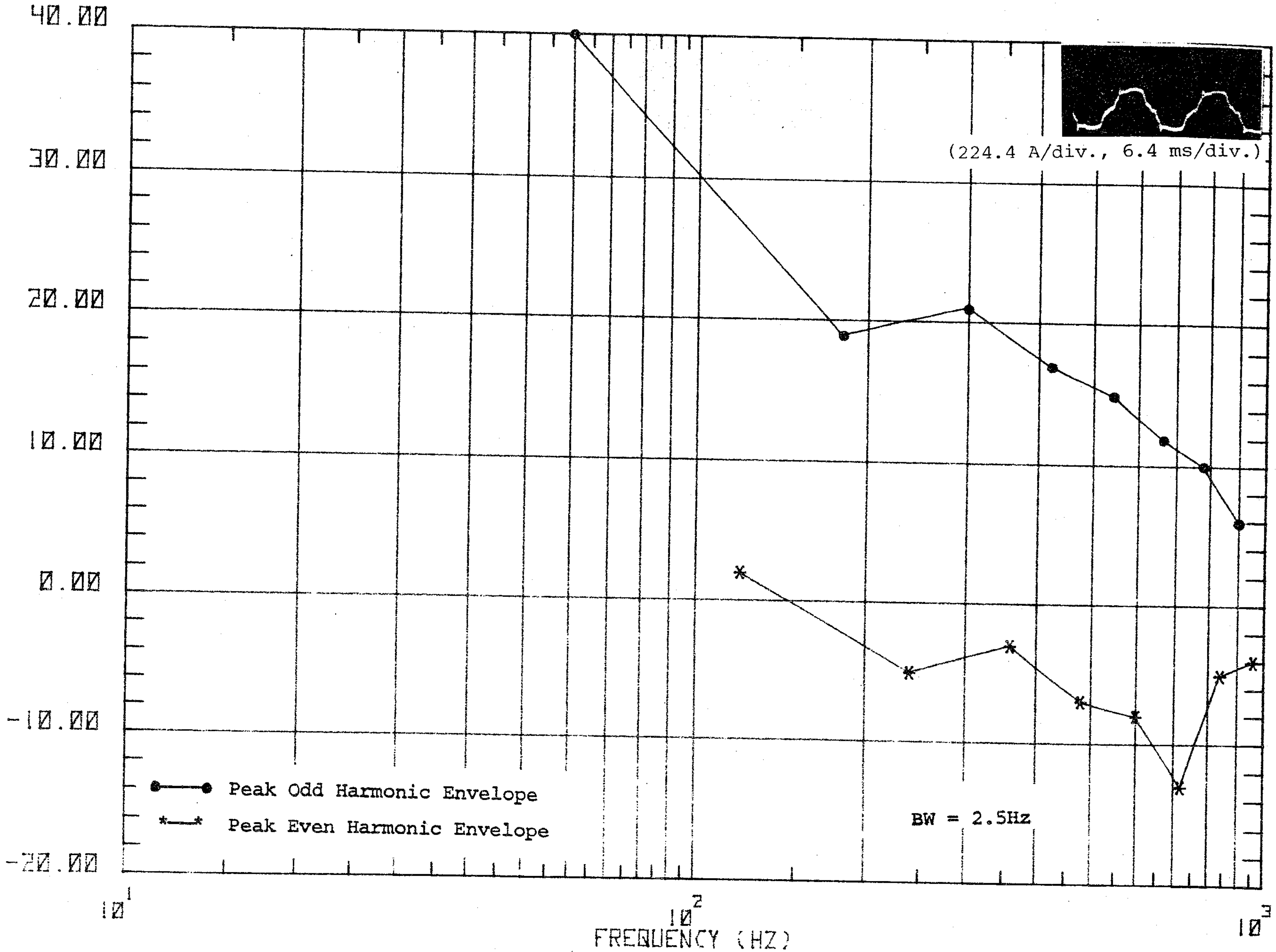


Figure 51a. Waveform and spectrum of ground side primary current waveshape #1.

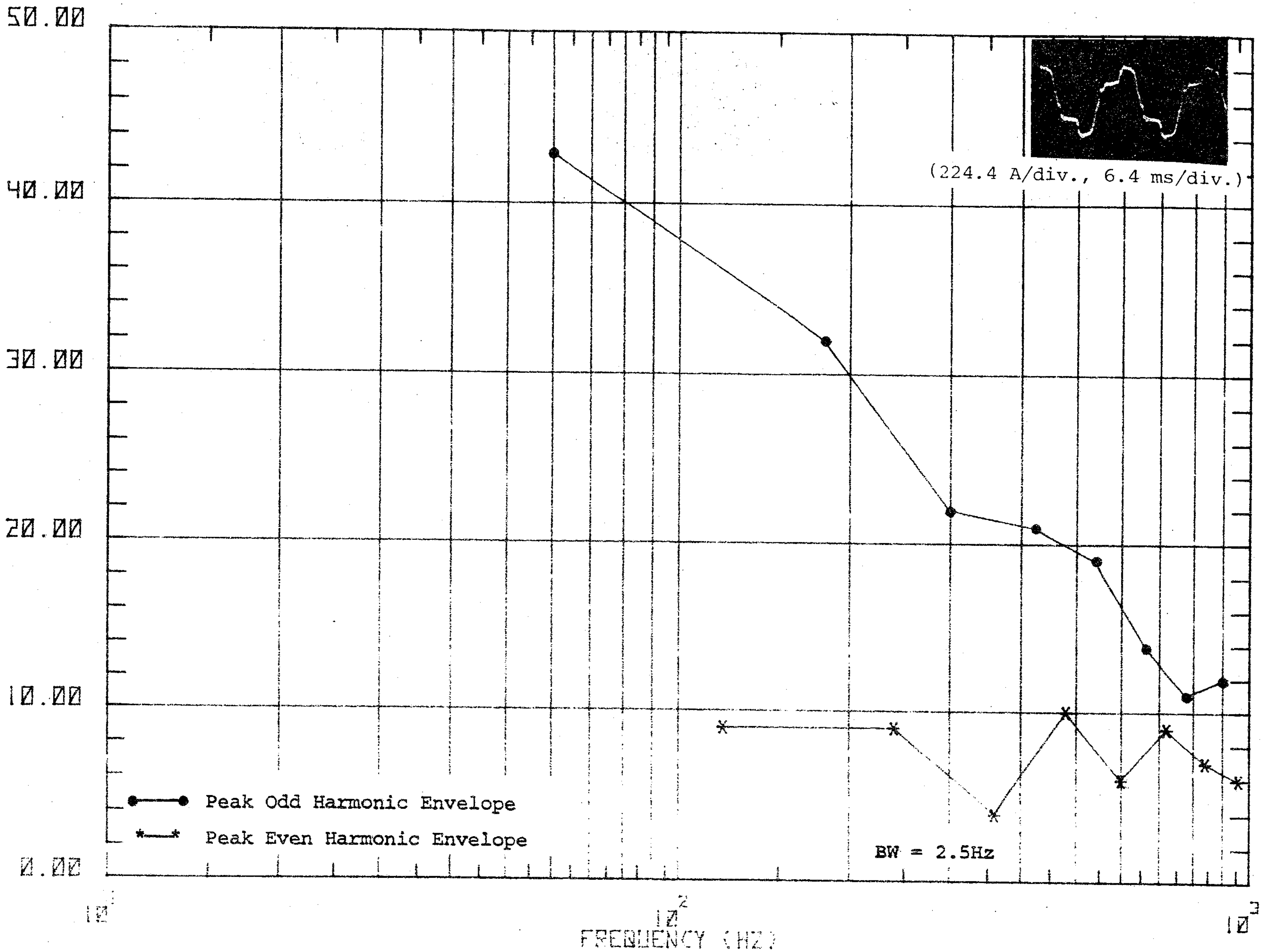


Figure 51b. Waveform and spectrum of ground side primary waveshape #2.

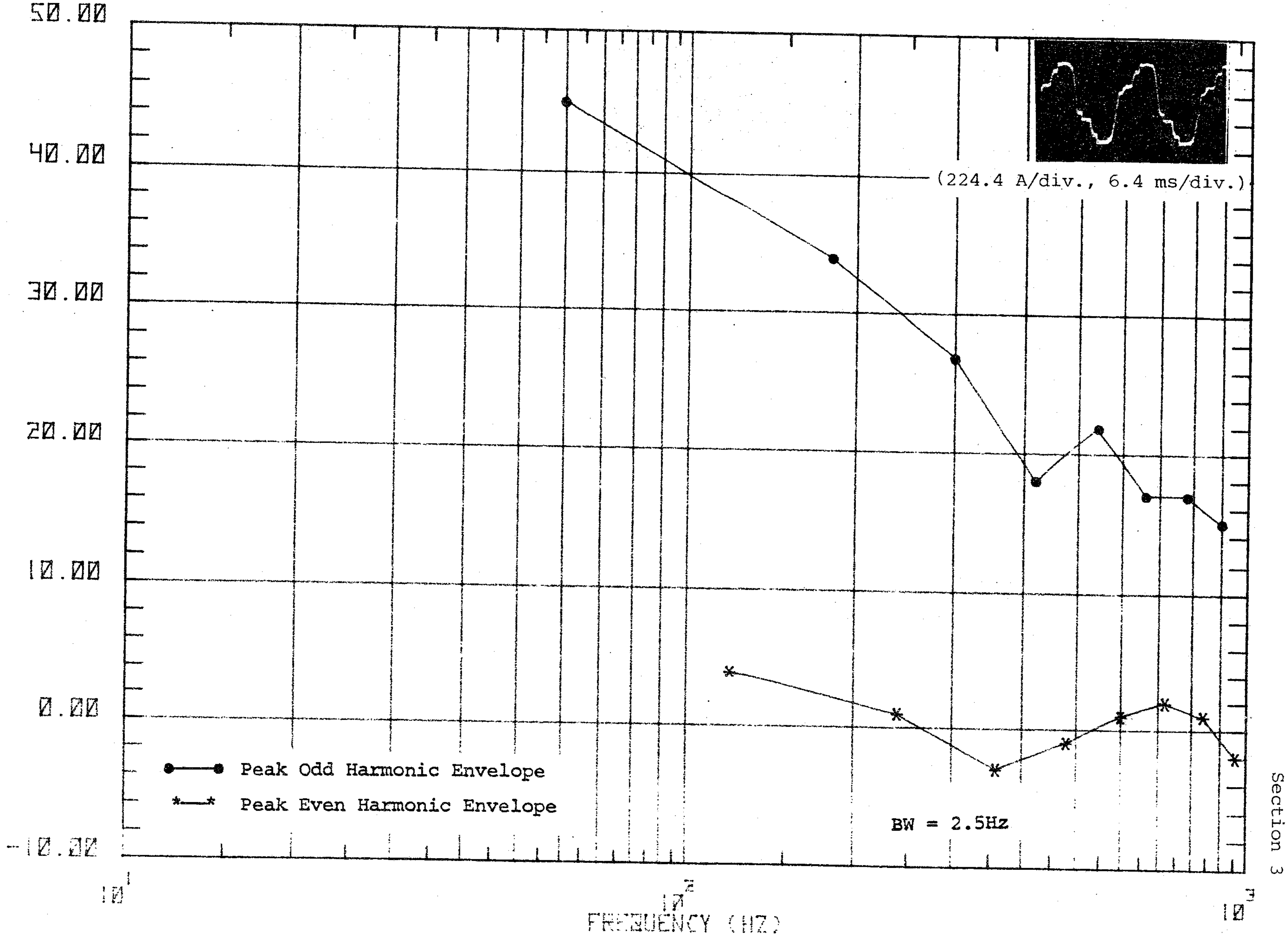


Figure 51c. Waveform and spectrum of primary current waveshape #3.

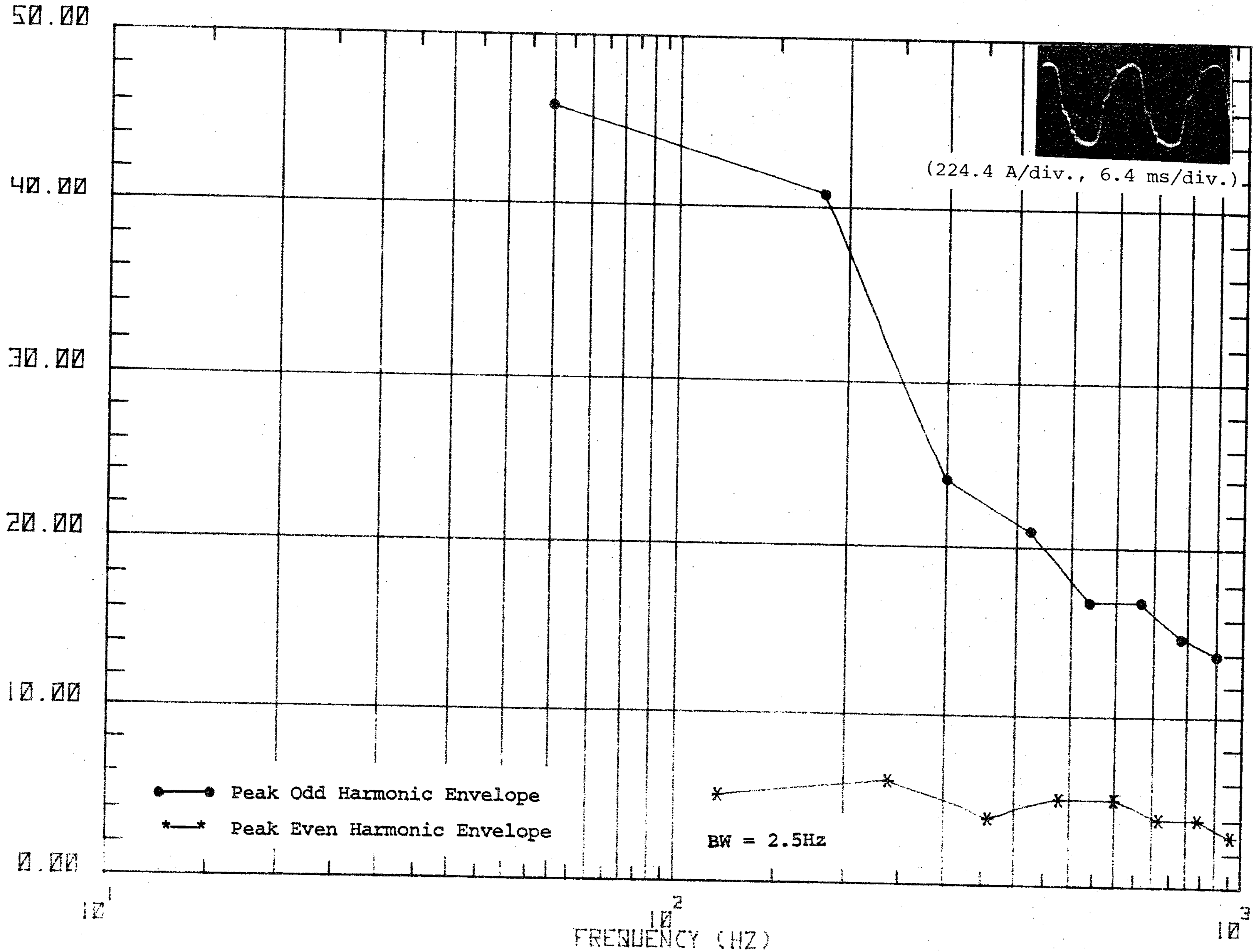


Figure 51d. Waveform and spectrum of ground side primary current waveshape #4.

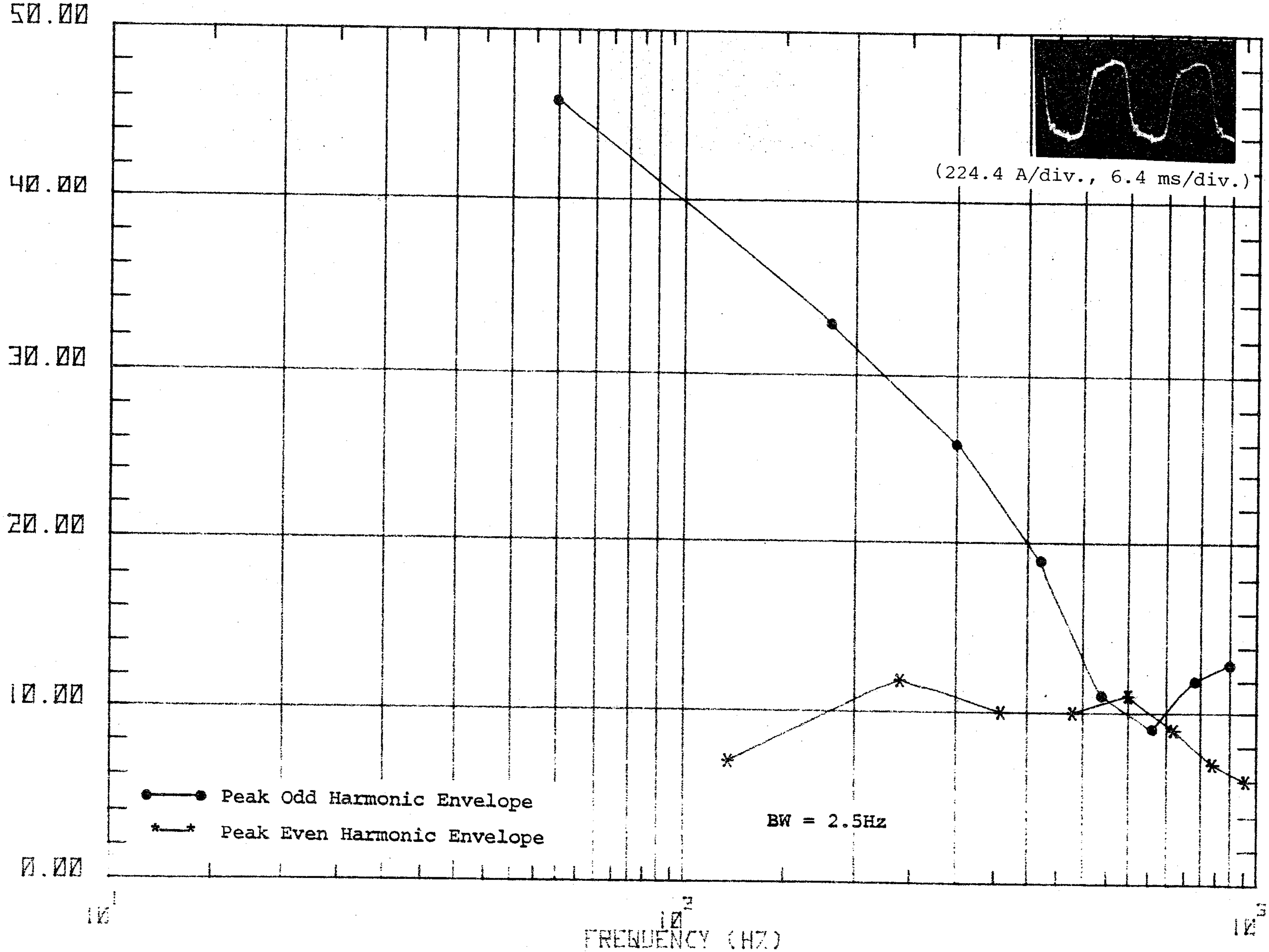


Figure 51e. Waveform and spectrum of primary current waveshape #5.

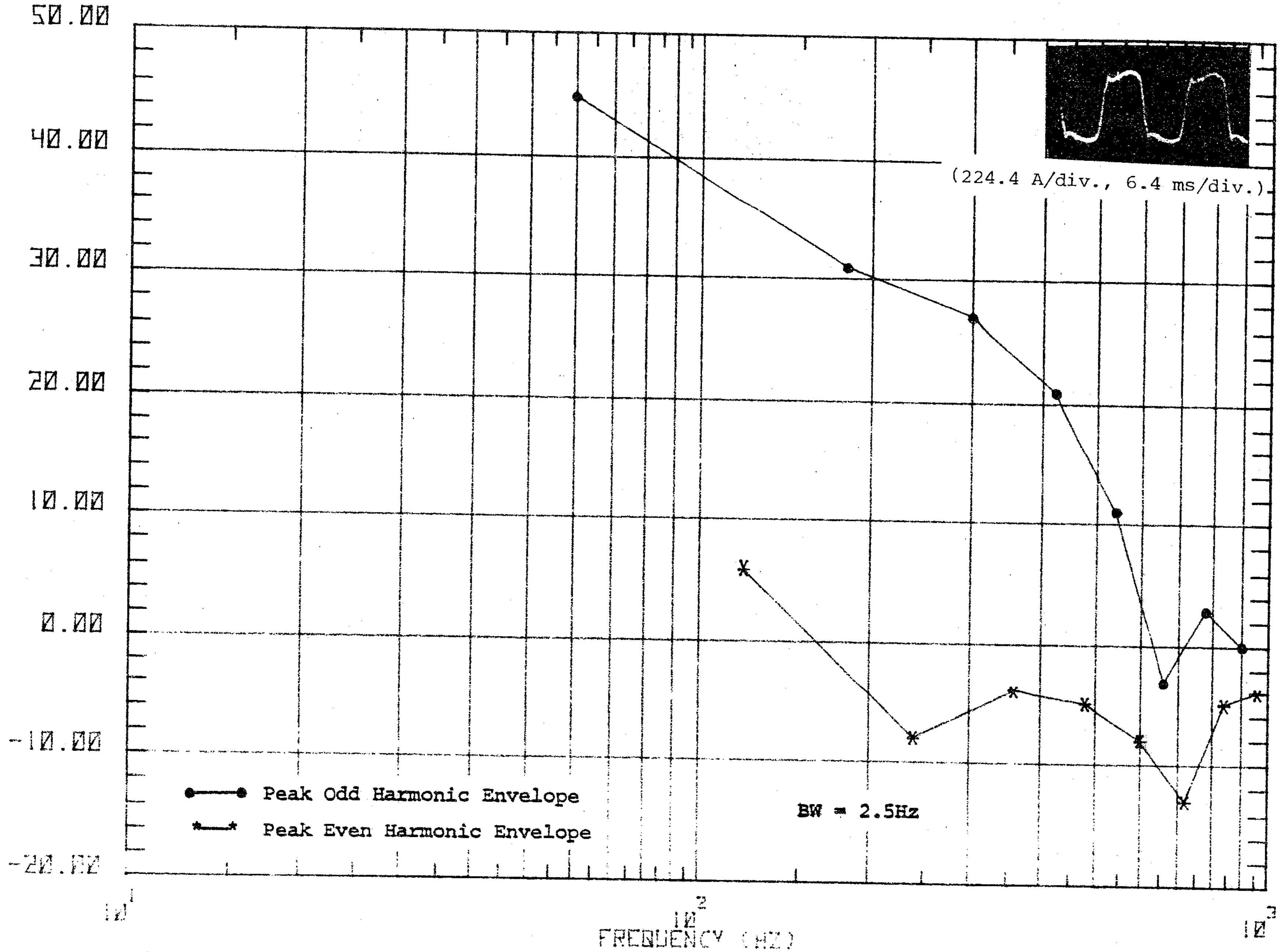


Figure 51f. Waveform and spectrum of ground side primary waveshape #6.

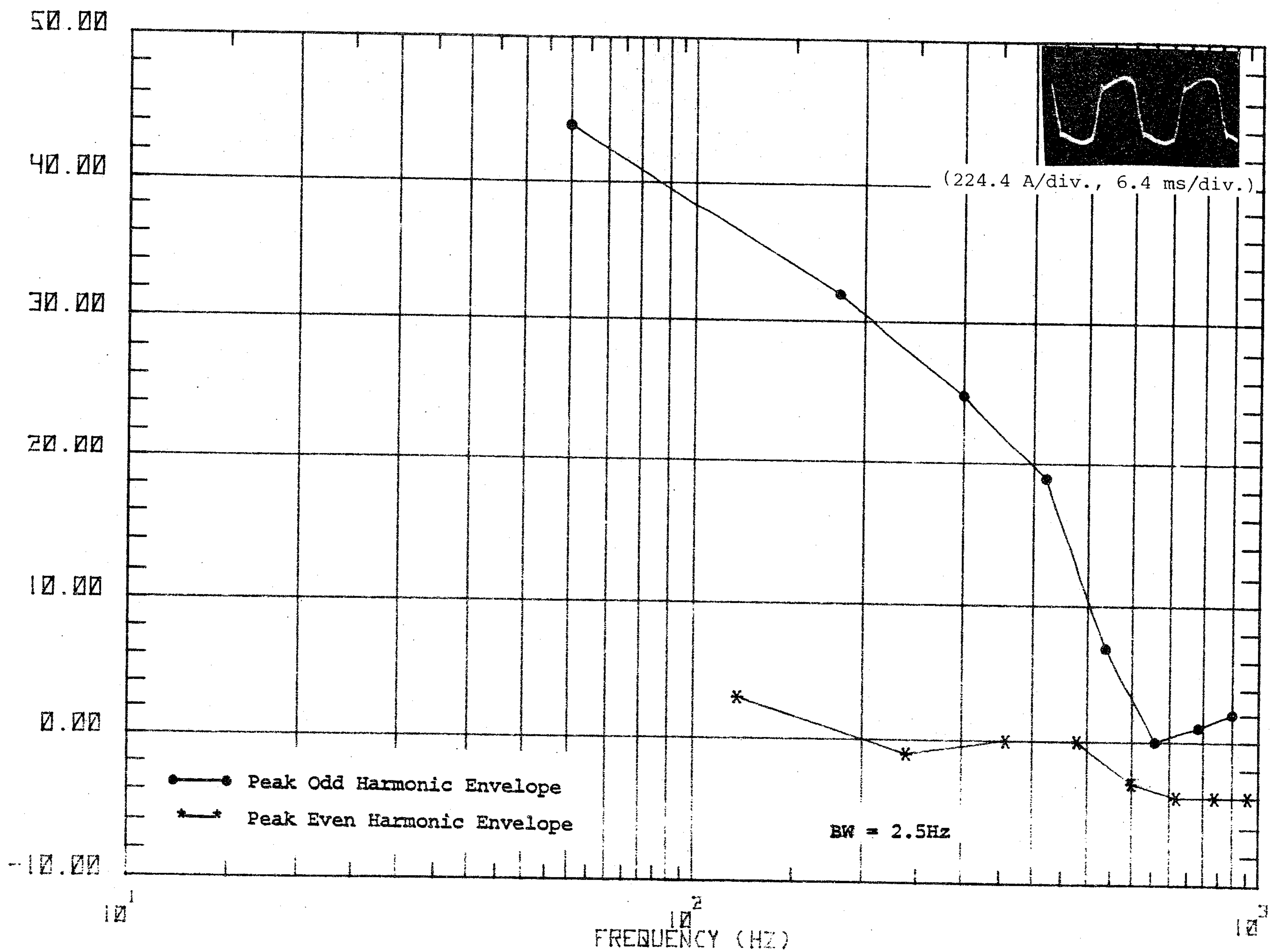


Figure 51g. Waveform and spectrum of ground side primary current waveshape #7.

waveshape #6 (from 14 to 23 dB per even harmonic) as have the odd harmonics from the eleventh to the fifteenth (12 to 15 dB per odd harmonic). The seventh waveshape is shown in Figure 51g. In this case, both the even and odd harmonic levels within the ranges noted for waveshape #6 have increased (1 to 6 dB for the even harmonics and 2 to 4 dB for the odd harmonics), while the other frequency component levels remain unchanged ($\pm$ 1 dB).

Main Transformer Primary (High Side)

The current in the primary winding of the main transformer was sampled on the high voltage side using a Tektronix P6202 probe connected to the current probe used by the TTC engineers performing endurance measurements on the AEM-7. Since information regarding the TTC's probe calibration was not known, an assumption was made to relate the emission levels recorded in dBV to units of current in dBA. The assumption was that the 60-Hz fundamental current level should be equivalent when sampled simultaneously on both the high voltage and ground sides of the primary.

To equate these currents, data obtained on both the high and ground sides of the primary were compared as the locomotive ran a 10-mph increment run. The ground side current mesurements are shown in Figures 50a-k. The difference in levels of the 60-Hz component (in dBV) between these two current samplings was noted for each 10-mph increment. These numbers were then used to find an average difference between the 60-Hz levels sampled on the high and ground sides. This average difference (in dB) was then added to the conversion factor used to relate levels sampled on the ground side from dBV to dBA.

Time waveform and frequency spectrum results of the current sampled on the high side of the primary during the 10-mph increment run noted above are given in Figures 52a-k. In addition, the first 10 harmonic levels of the current sampled on both the high and ground sides of the primary winding for each 10-mph increment are presented in TABLE 6. From a comparison of the recorded levels, two observations are made. First, the current levels sampled

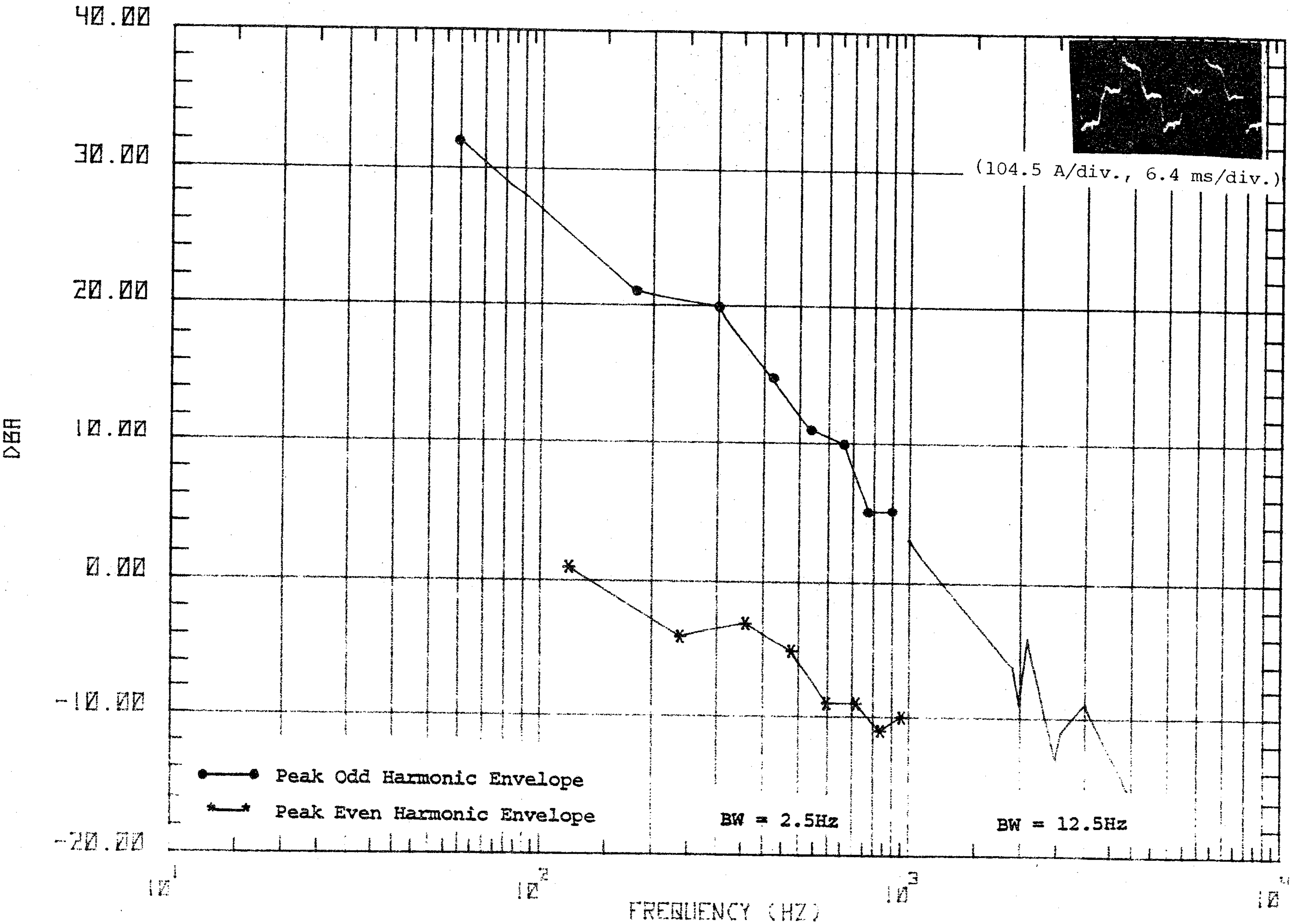


Figure 52a. Waveform and spectrum of primary current (sampled on the high side), locomotive accelerating from 0 to 10 mph.

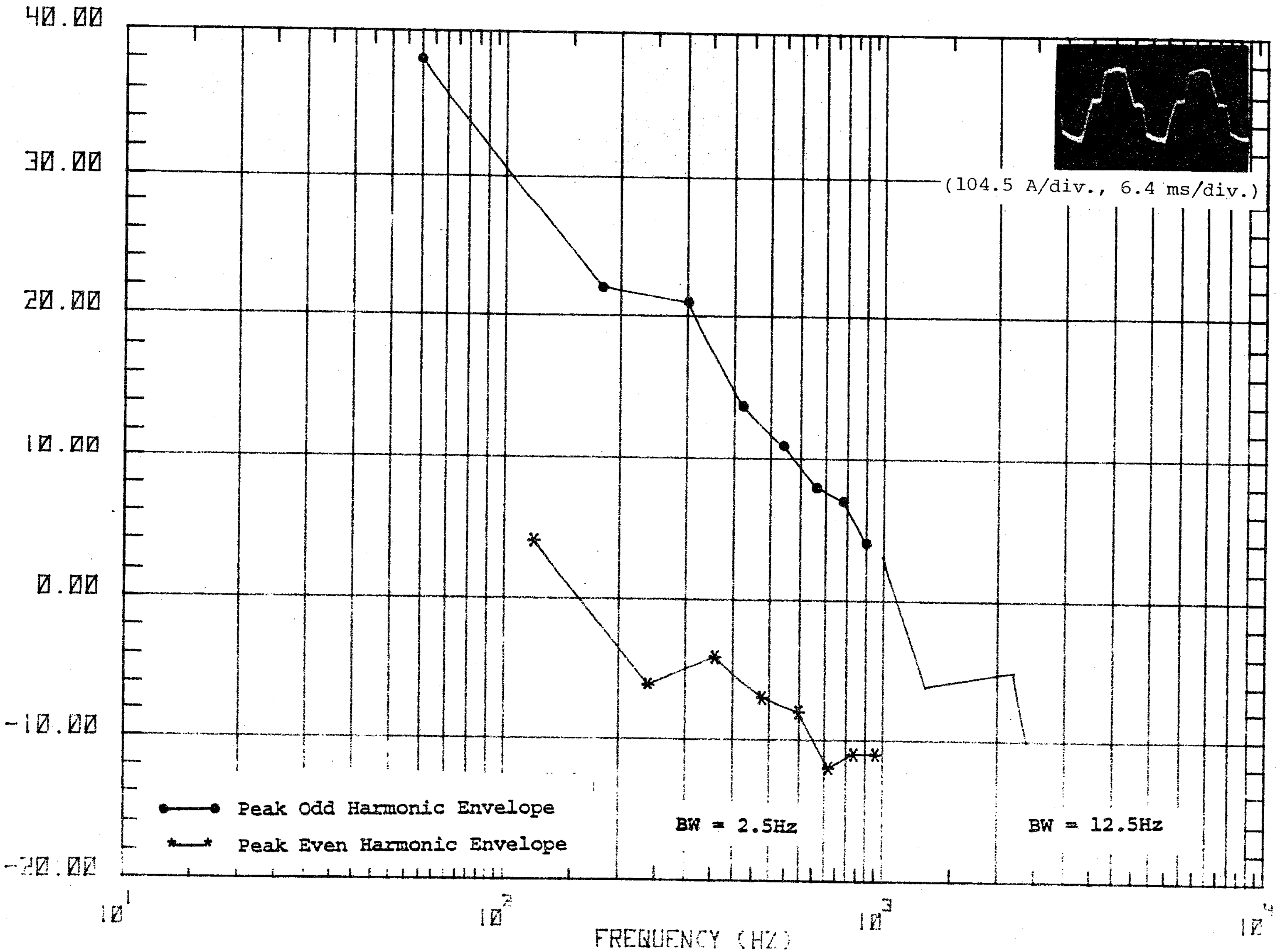


Figure 52b. Waveform and spectrum of primary current (sampled on the high side), locomotive accelerating from 10 to 20 mph.

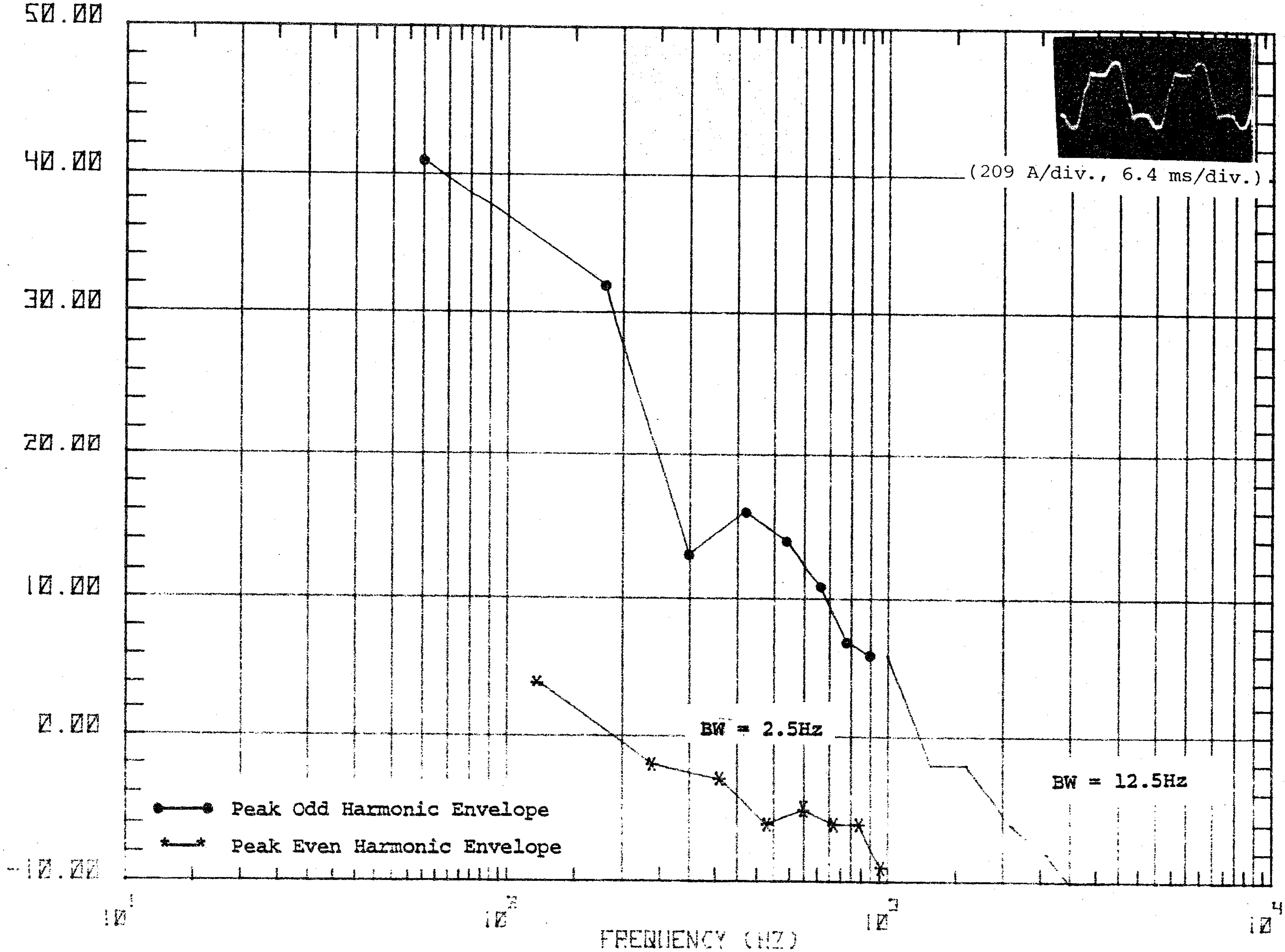


Figure 52c. Waveform and spectrum of primary current (sampled on the high side), locomotive accelerating from 20 to 30 mph.

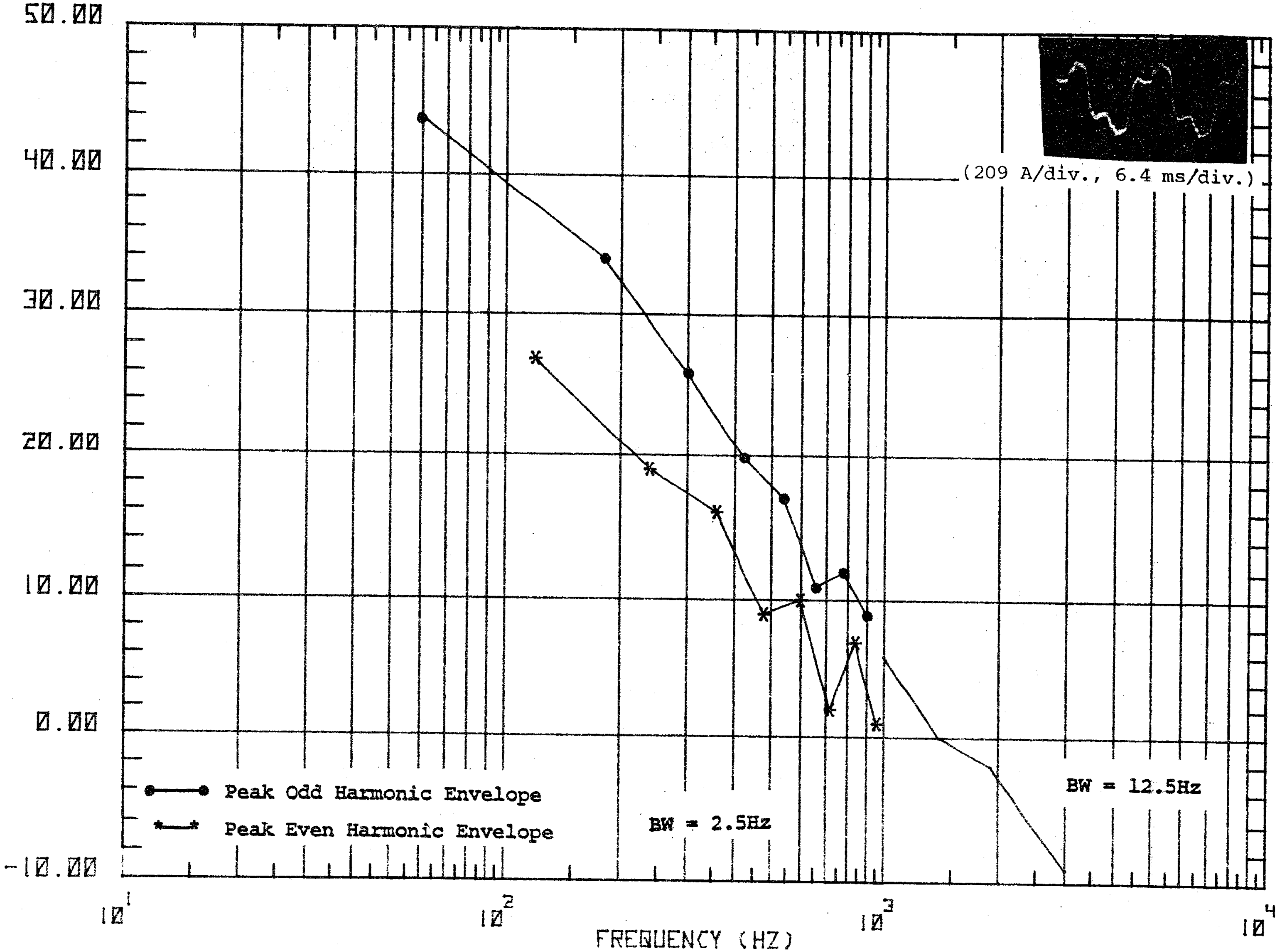


Figure 52d. Waveform and spectrum of primary current (sampled on the high side), locomotive accelerating from 30 to 40 mph.

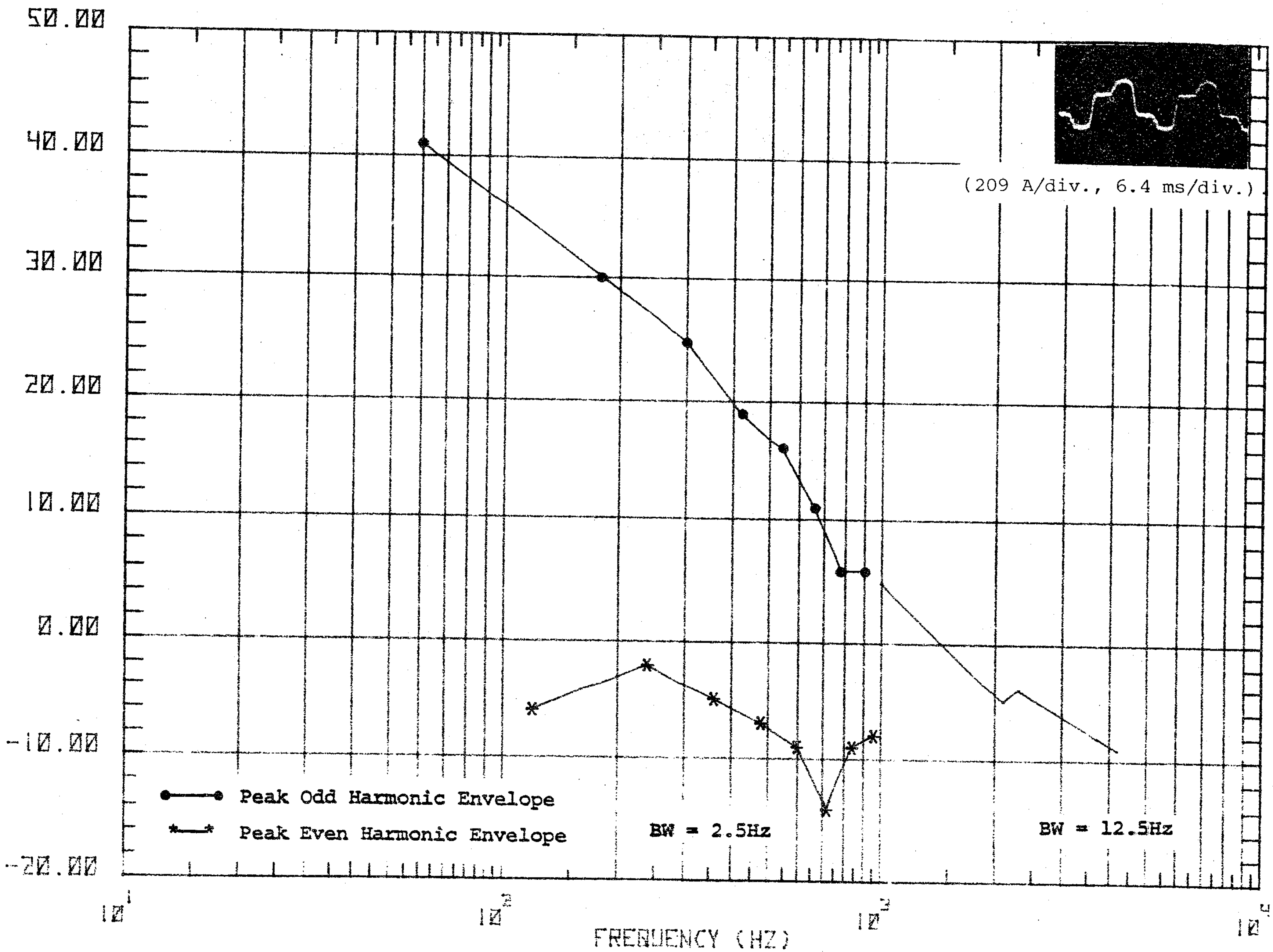


Figure 52e. Waveform and spectrum of primary current (sampled on the high side), locomotive accelerating from 40 to 50 mph.

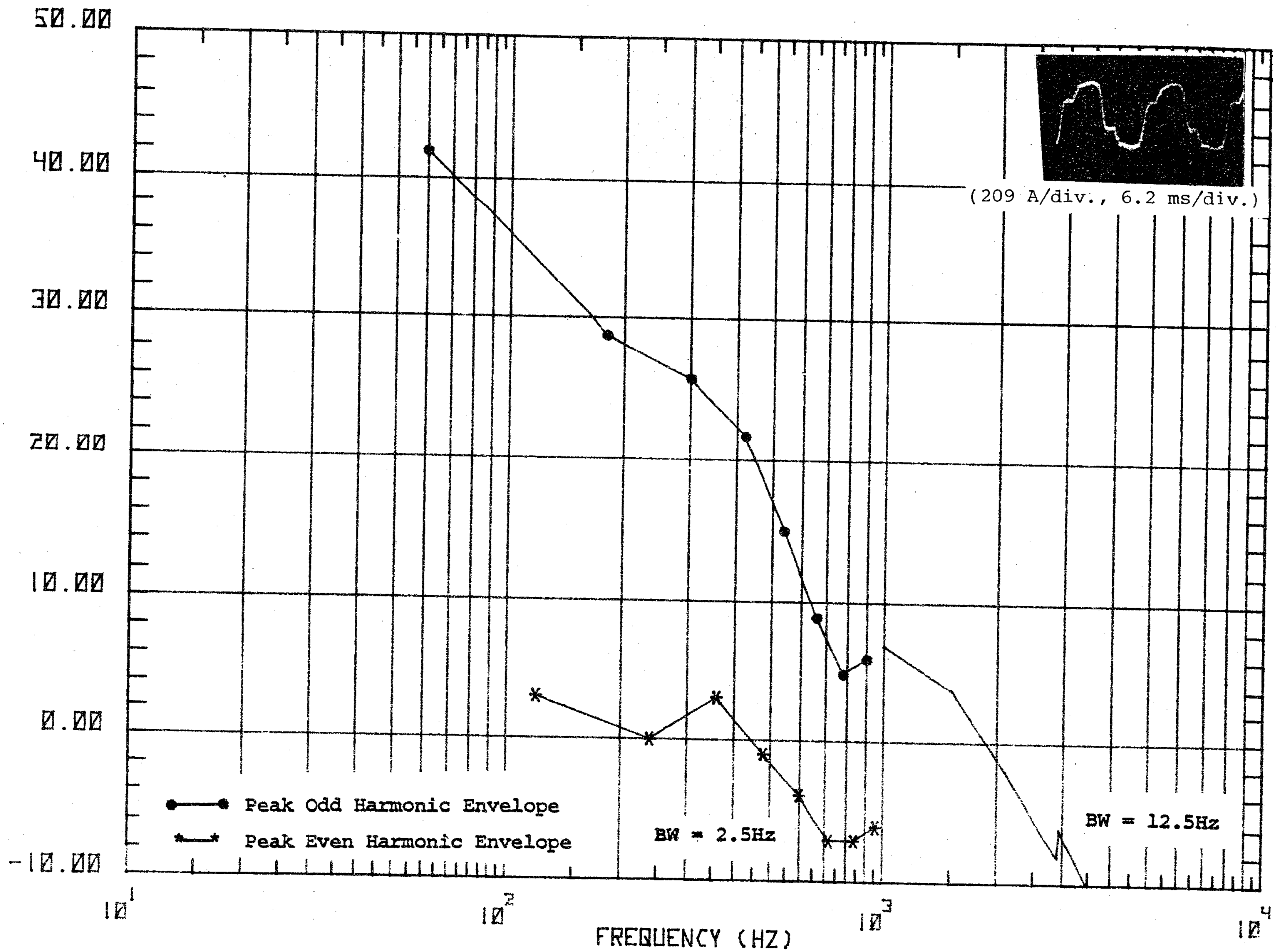


Figure 52f. Waveform and spectrum of primary current (sampled on the high side), locomotive accelerating from 50 to 60 mph.

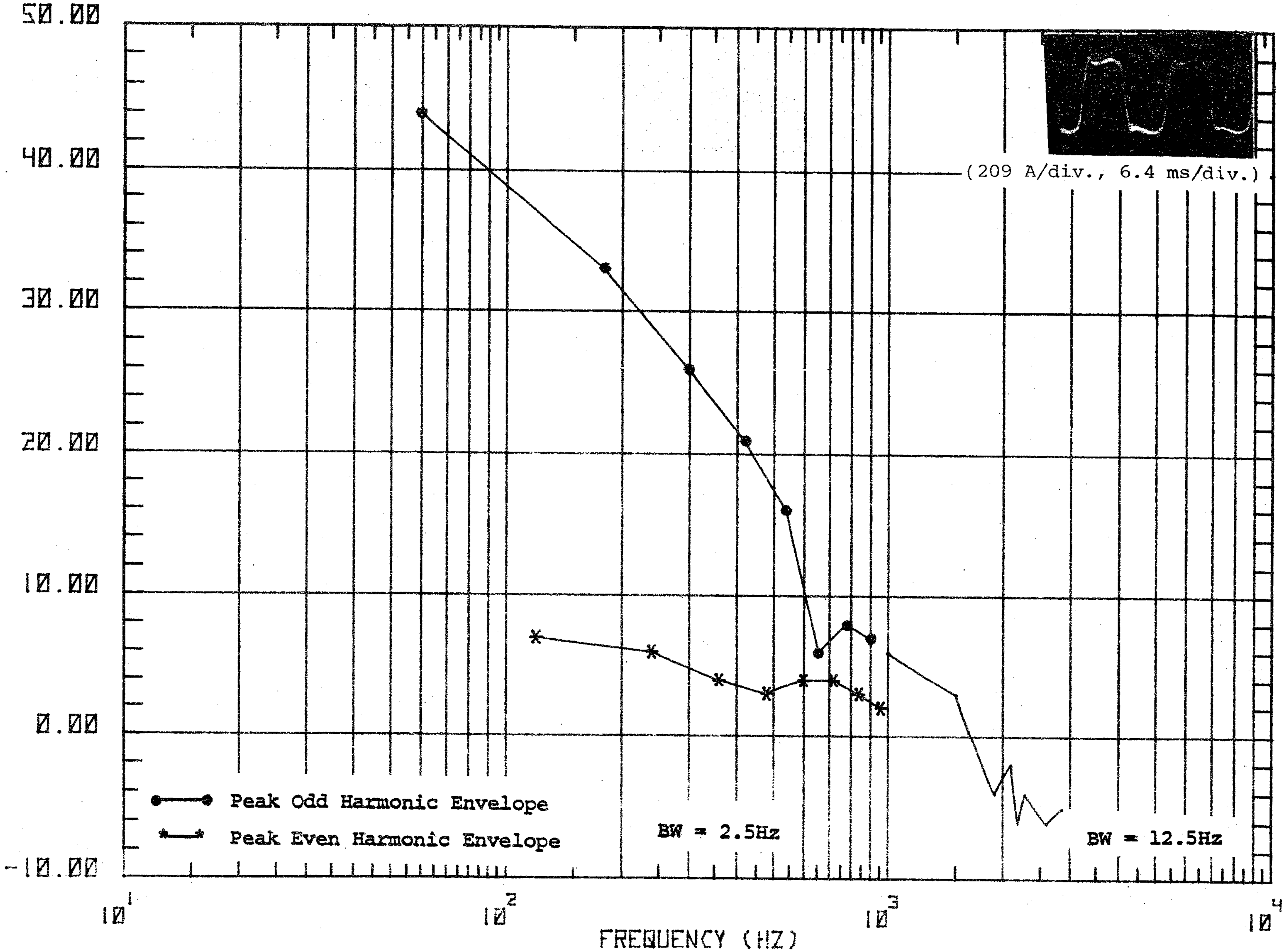


Figure 52g. Waveform and spectrum of primary current (sampled on the high side), locomotive accelerating from 60 to 70 mph.

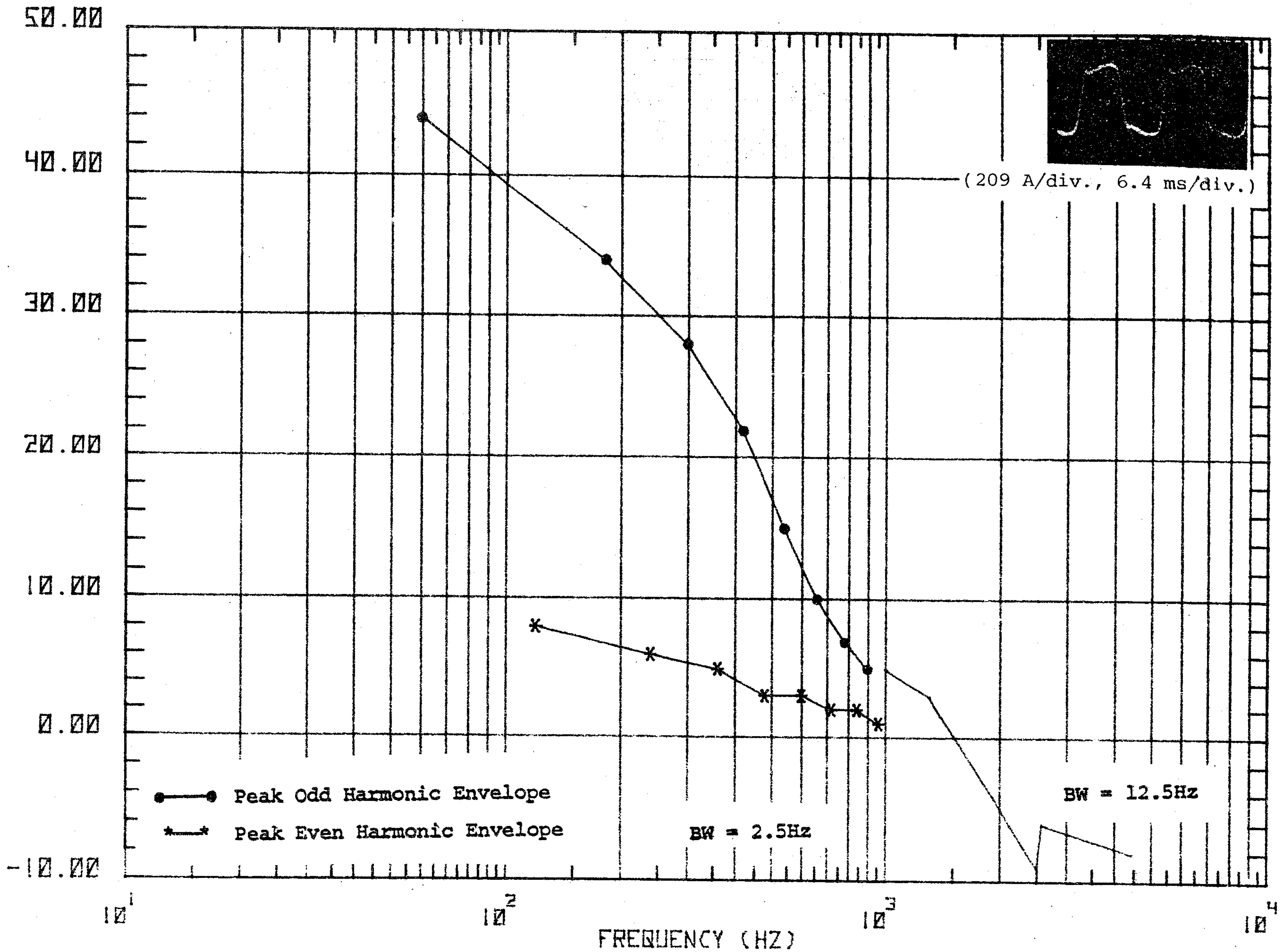


Figure 52h. Waveform and spectrum of primary current (sampled on the high side), locomotive accelerating from 70 to 80 mph.

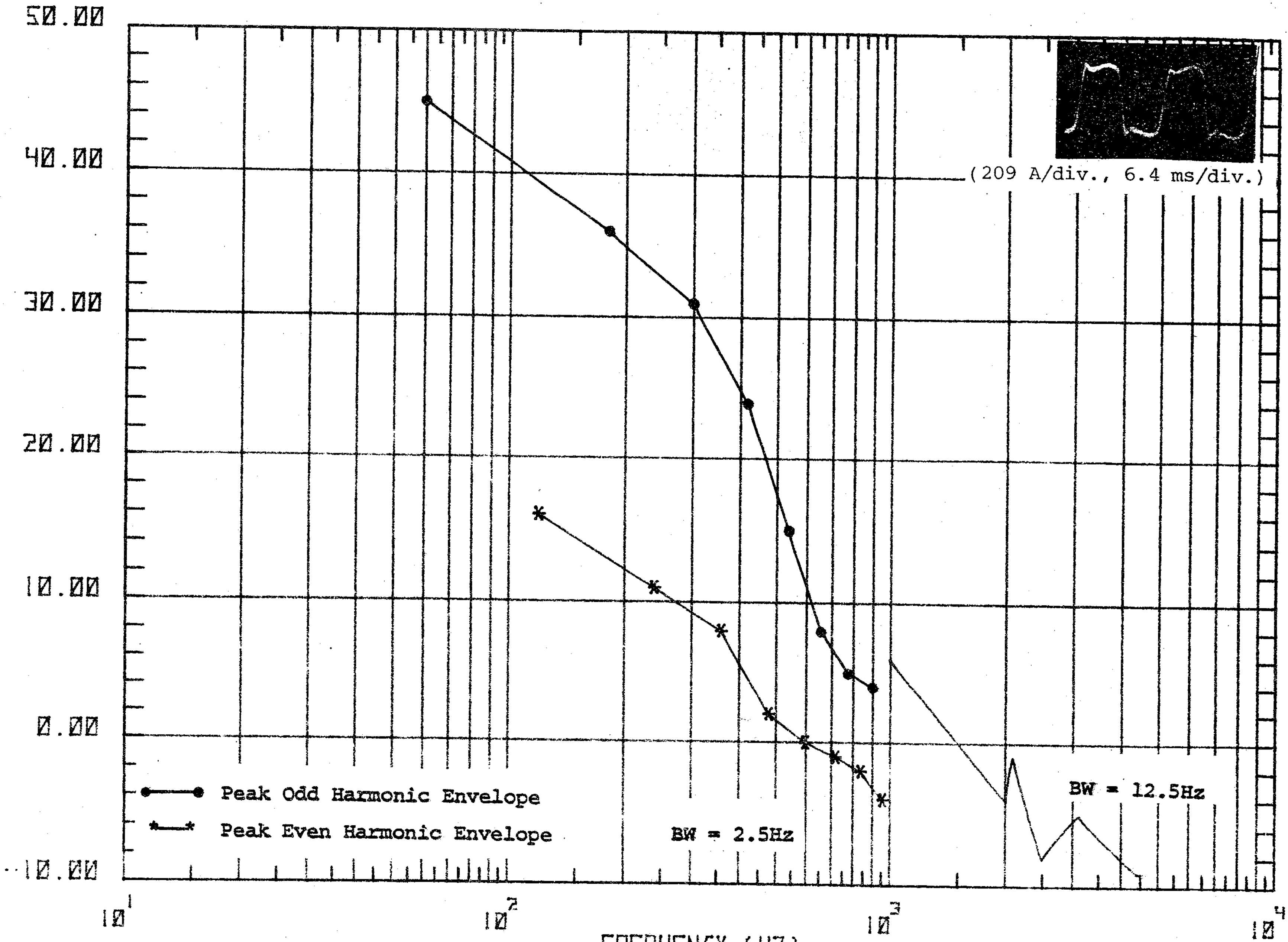


Figure 52i. Waveform and spectrum of primary current (sampled on the high side), locomotive accelerating from 80 to 90 mph.

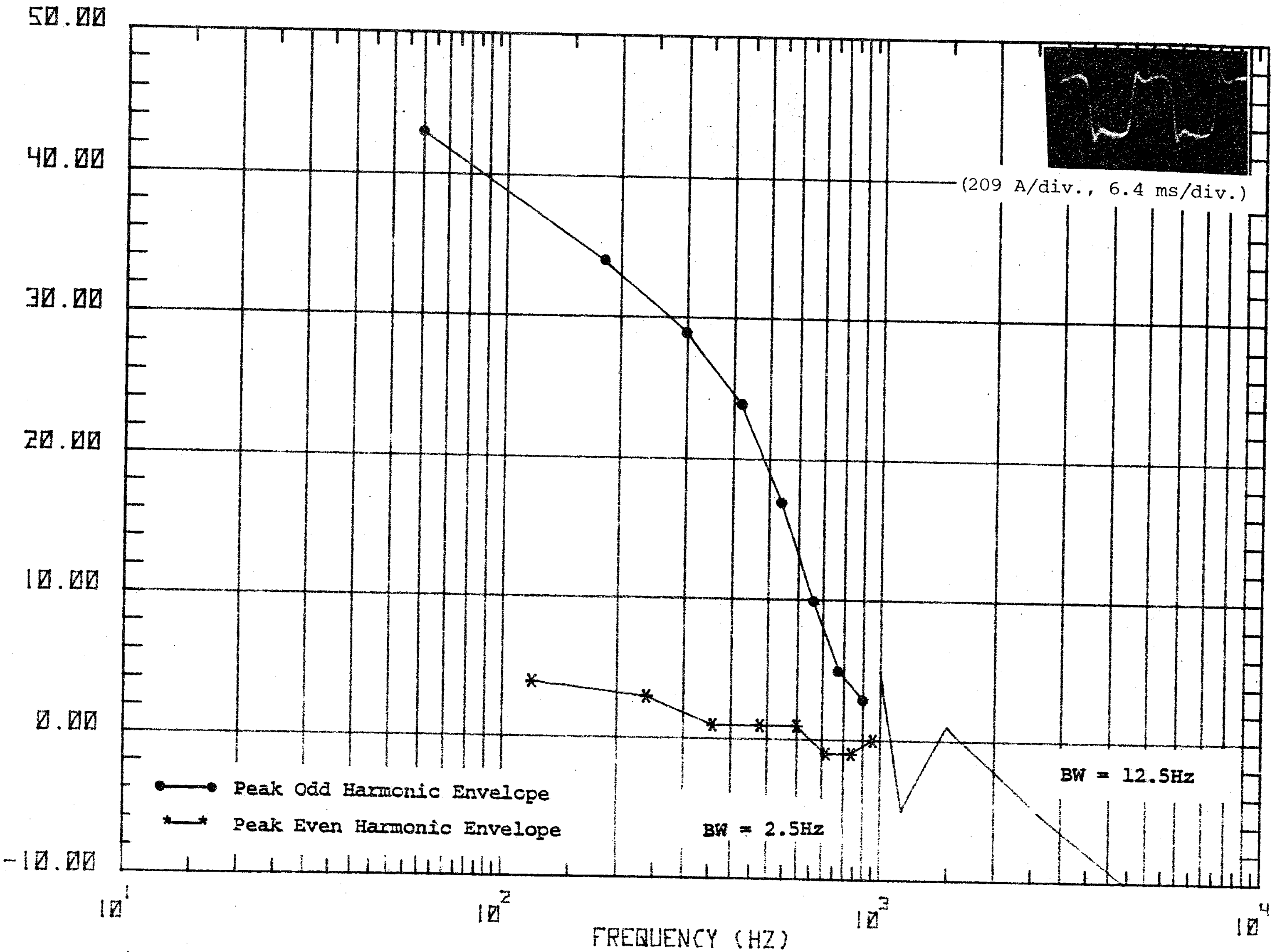


Figure 52j. Waveform and spectrum of primary current (sampled on the high side), locomotive accelerating from 90 to 100 mph.

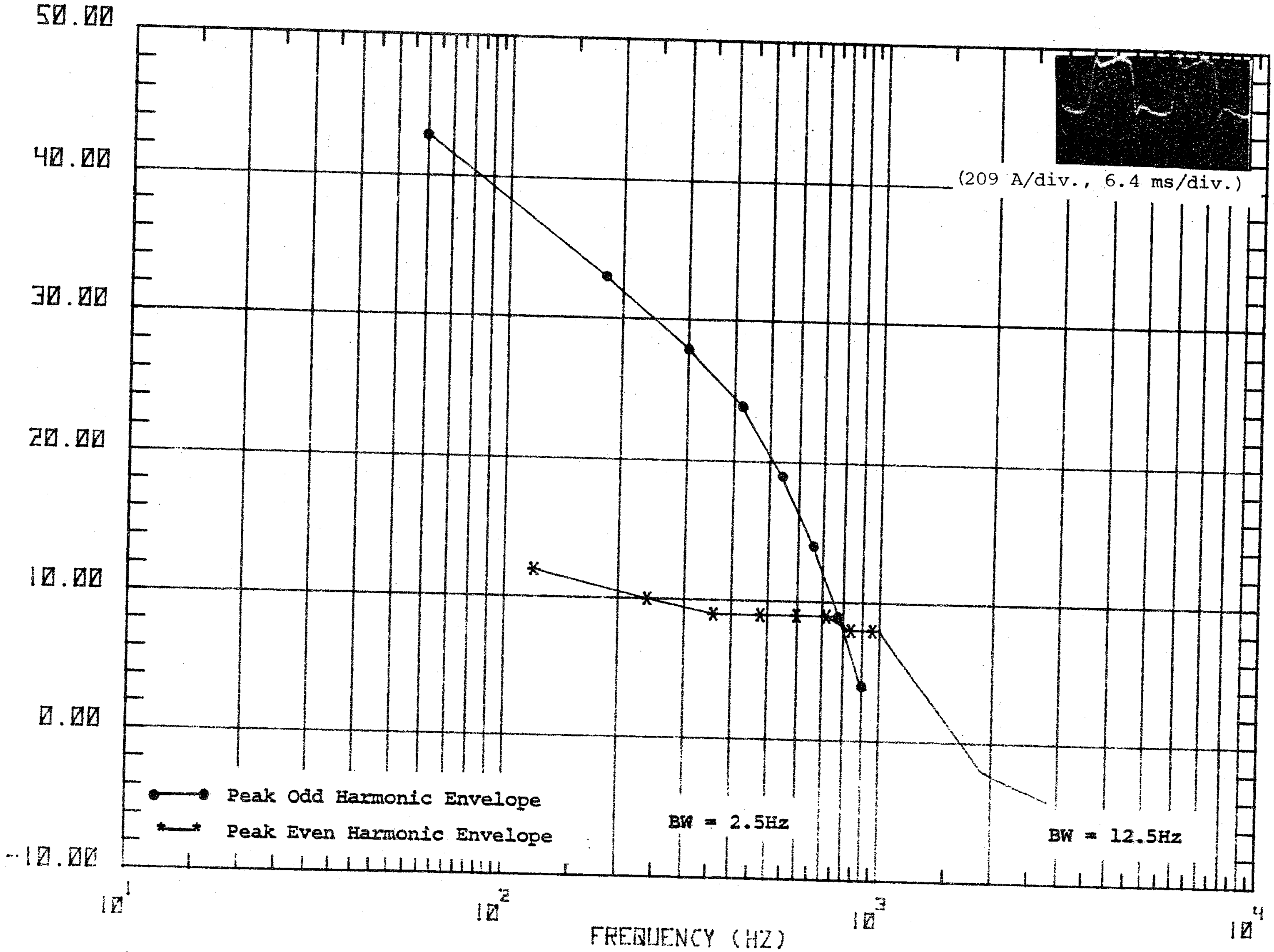


Figure 52k. Waveform and spectrum of primary current (sampled on the high side), locomotive accelerating from 100 to 110 mph.

TABLE 6

COMPARISON OF CURRENT HARMONIC LEVELS IN dBA SAMPLED ON HIGH VOLTAGE AND GROUND SIDES OF MAIN TRANSFORMER PRIMARY FOR LOCOMOTIVE 10-MPH INCREMENT RUN[a]

Speed Increment (mph)	Ground Side Sample Frequency Component in Hz									
	60	120	180	240	300	360	420	480	540	600
0-10	35 (56.2)	-12	23	-14	10	-14	11	-15	4	-10
10-20	38 (79.4)	2	22	-8	21	-3	14	-7	15	-7
20-30	42 (125.9)	9	30	0	18	-3	18	-1	18	-2
30-40	43 (141.2)	5	29	6	23	-2	19	-2	19	1
40-50	42 (125.9)	0	29	5	24	-3	20	-4	17	-6
50-60	44 (158.5)	6	28	0	24	1	22	0	16	-5
60-70	45 (177.8)	11	31	1	23	-1	17	1	14	3
70-80	46 (199.5)	9	34	4	28	5	22	4	17	3
80-90	44 (158.5)	13	32	5	26	1	21	-1	13	-4
90-100	43 (141.2)	9	31	-3	26	-1	21	-2	14	-2
100-110	43 (141.2)	6	32	8	27	8	22	7	17	7

Speed Increment (mph)	High Voltage Side Sample Frequency Component in Hz									
	60	120	180	240	300	360	420	480	540	600
0-10										
10-20	38 (79.4)	4	22	-6	21	-4	14	-7	11	-8
20-30	41 ((112.2)	4	32	-2	13	-3	16	-6	14	-5
30-40	44 (158.5)	27	34	19	26	16	20	9	17	10
40-50	41 (112.2)	-6	30	-2	25	-5	19	-7	16	-9
50-60	42 (125.9)	3	29	0	26	3	22	-1	15	-4
60-70	44 (158.5)	7	33	6	26	4	21	3	16	4
70-80	44 (158.5)	8	34	6	28	5	22	3	15	3
80-90	45 (177.8)	16	36	11	31	8	24	2	15	0
90-100	43 (141.2)	4	34	3	29	1	24	1	17	1
100-110	43 (141.2)	12	33	10	28	9	24	9	19	9

[a]The current levels shown are in units of dBA (amperes rms).

on the high side appear larger than the corresponding levels on the low side for all frequencies sampled above 60 Hz. Second, in two instances (30-40 mph and 100-110 mph) the levels of the even harmonics sampled on the high side increased dramatically (up to 23 dBA) relative to the levels of the same harmonics sampled at other increments of speed. It is important to note that this increase in even harmonic levels was not observed on the low side of the primary during these two speed intervals. It is reasoned that stray capacitance on the high side of the transformer acts as a filter to attenuate the high frequency components of the current.

Next, the time waveform and spectrum of the high-side primary current, sampled at the same time as the ground side primary current displayed in Figure 46, are presented in Figure 53. Comparing Figures 46 and 53, the harmonic levels of the current up to 1 kHz appear higher (by up to 4 dBA) for the high-side samplings than the ground-side samplings. However, from 1-2 kHz, the levels on the ground side appear higher. Since the AEM-7 endurance test personnel primarily have an interest in the lower frequencies of the current for their AEM-7 tests, their probe and cable responses may be limited to several kHz.

Catenary Voltage

The voltage level of the catenary with respect to ground was sampled using the Tektronix P6202 probe connected to TTC's catenary voltage probe. In Figures 54a-k, the time waveforms and frequency spectra of the catenary voltage sampled while the locomotive was performing a 10-mph increment run are presented. This data was recorded at the same time as the main transformer ground-side primary current data shown in Figures 49a-k. Referring to Figure 54, during the first interval (10-20 mph) the peak-to-peak value of the voltage waveform was 87,126 volts (30,803 volts rms). The 60-Hz component of the spectrum sampled at this time was 88 dBV (25119 volts rms). The third harmonic sampled was 25 dB down from the fundamental (63 dBV or 1412 volts rms). The second harmonic recorded was 49 dBV (282 volts rms); however, the levels sampled for the other even harmonics up to 1 kHz, ranged from 37 to 39 dBV (70.8 to 89.1 volts rms).

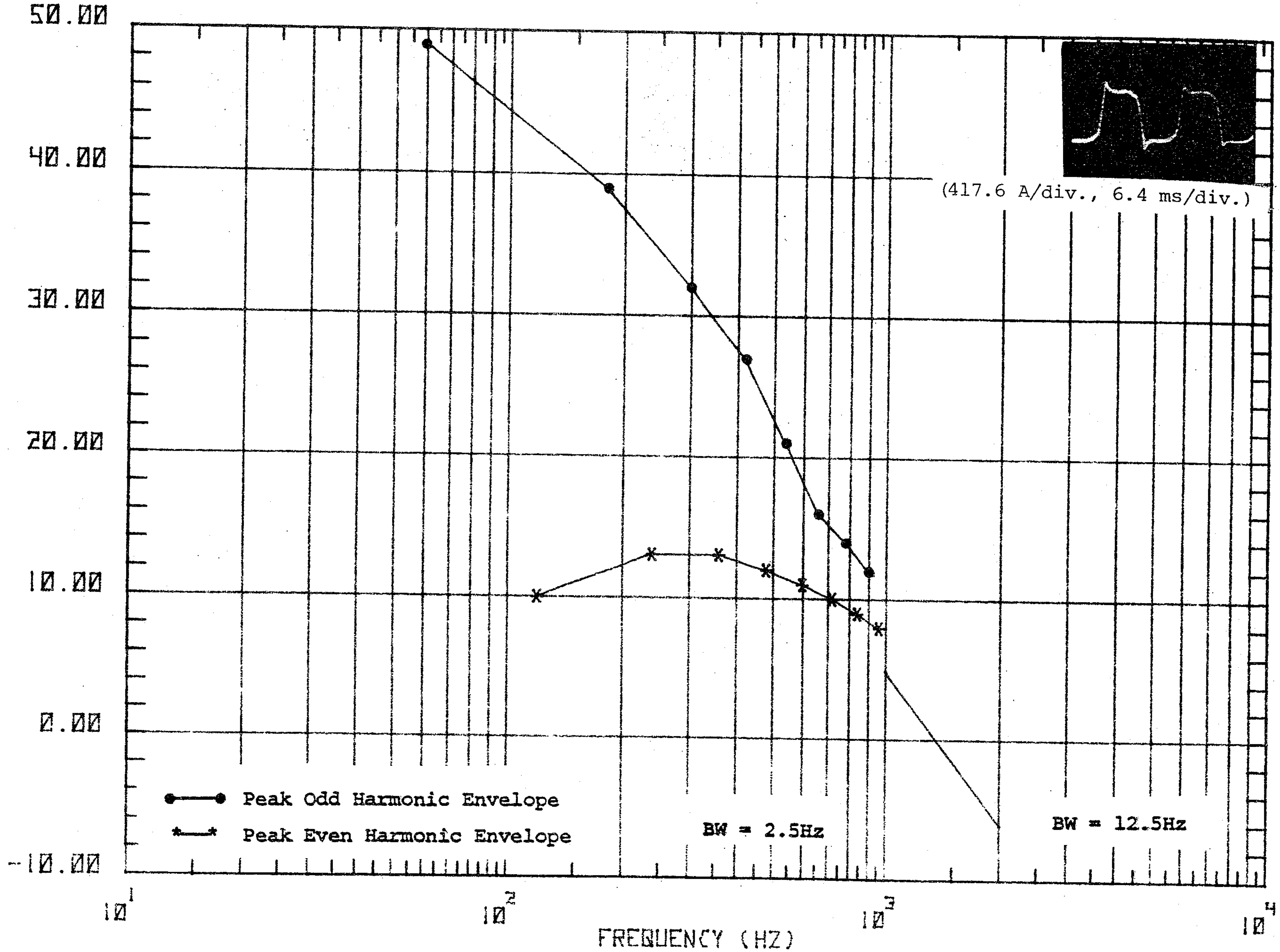


Figure 53. Waveform and spectrum of main transformer primary current (high side) sampled during a simulated revenue service run.

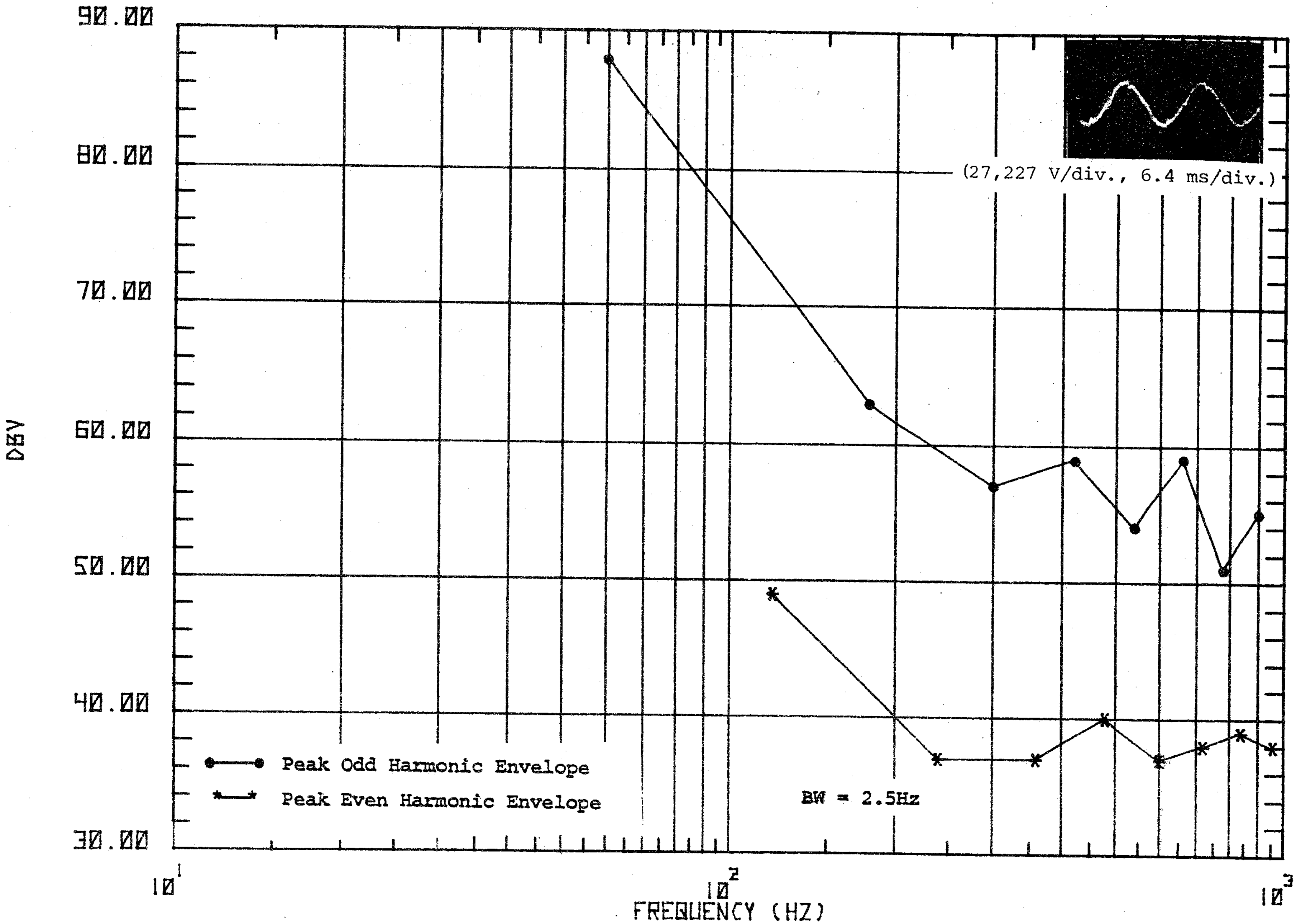


Figure 54a. Waveform and spectrum of catenary voltage sampled during 10-mph increment run, 10 to 20 mph.

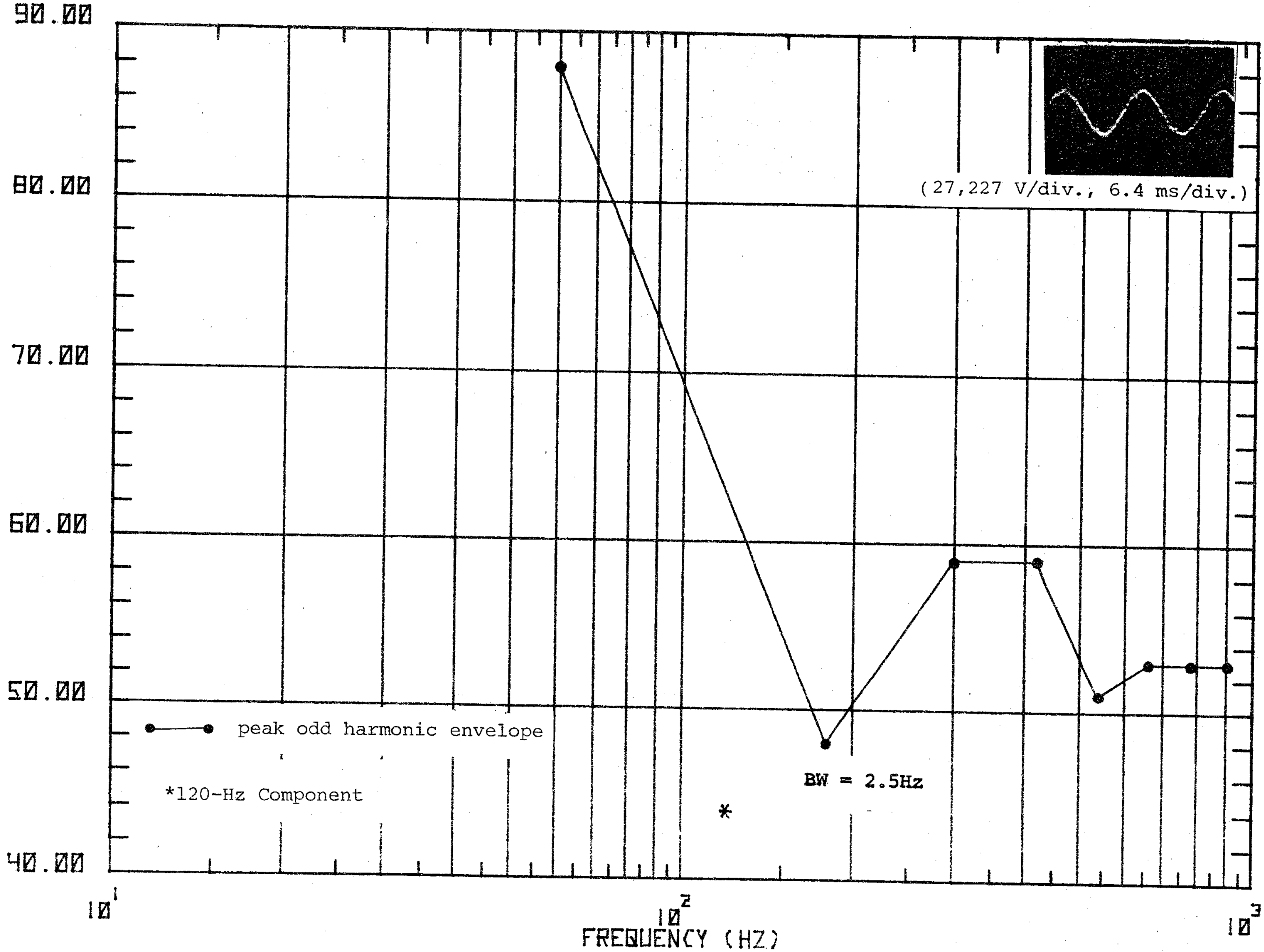


Figure 54b. Waveform and spectrum of catenary voltage sampled during 10-mph increment run, 20 to 30 mph.

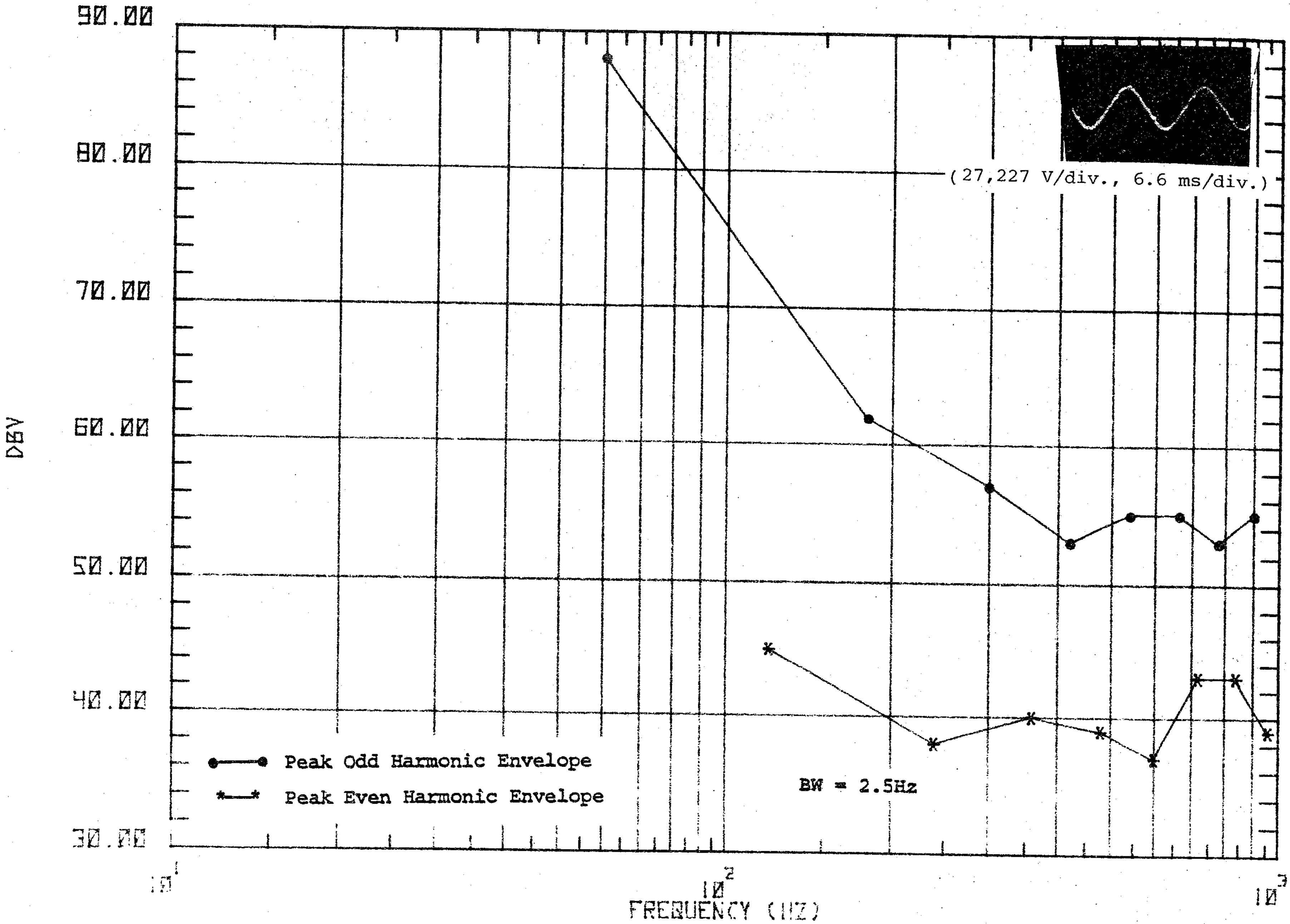


Figure 54c. Waveform and spectrum of catenary voltage sampled during 10-mph increment run, 30 to 40 mph.

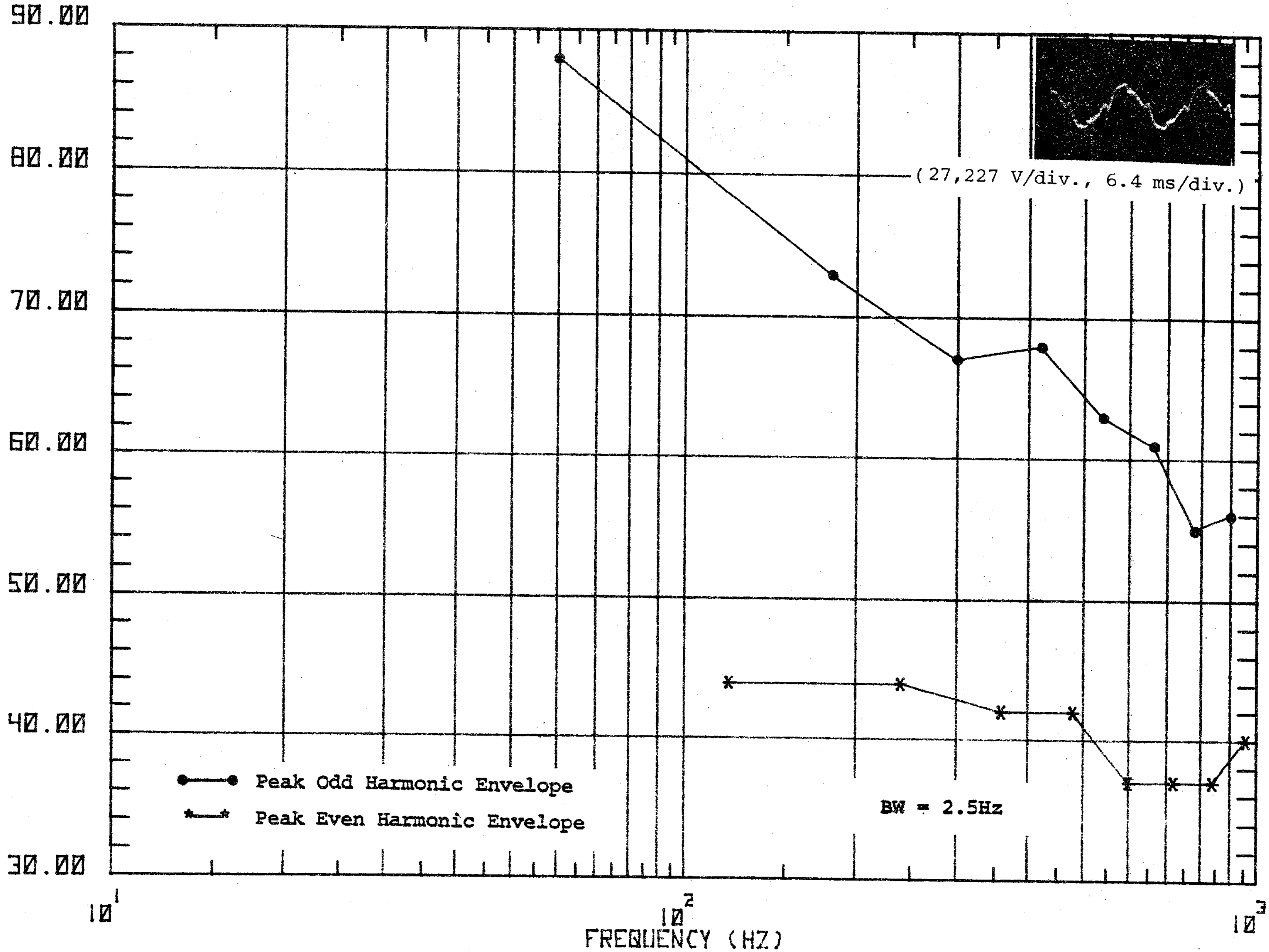


Figure 54d. Waveform and spectrum of catenary voltage sampled during 10-mph increment run, 40 to 50 mph.

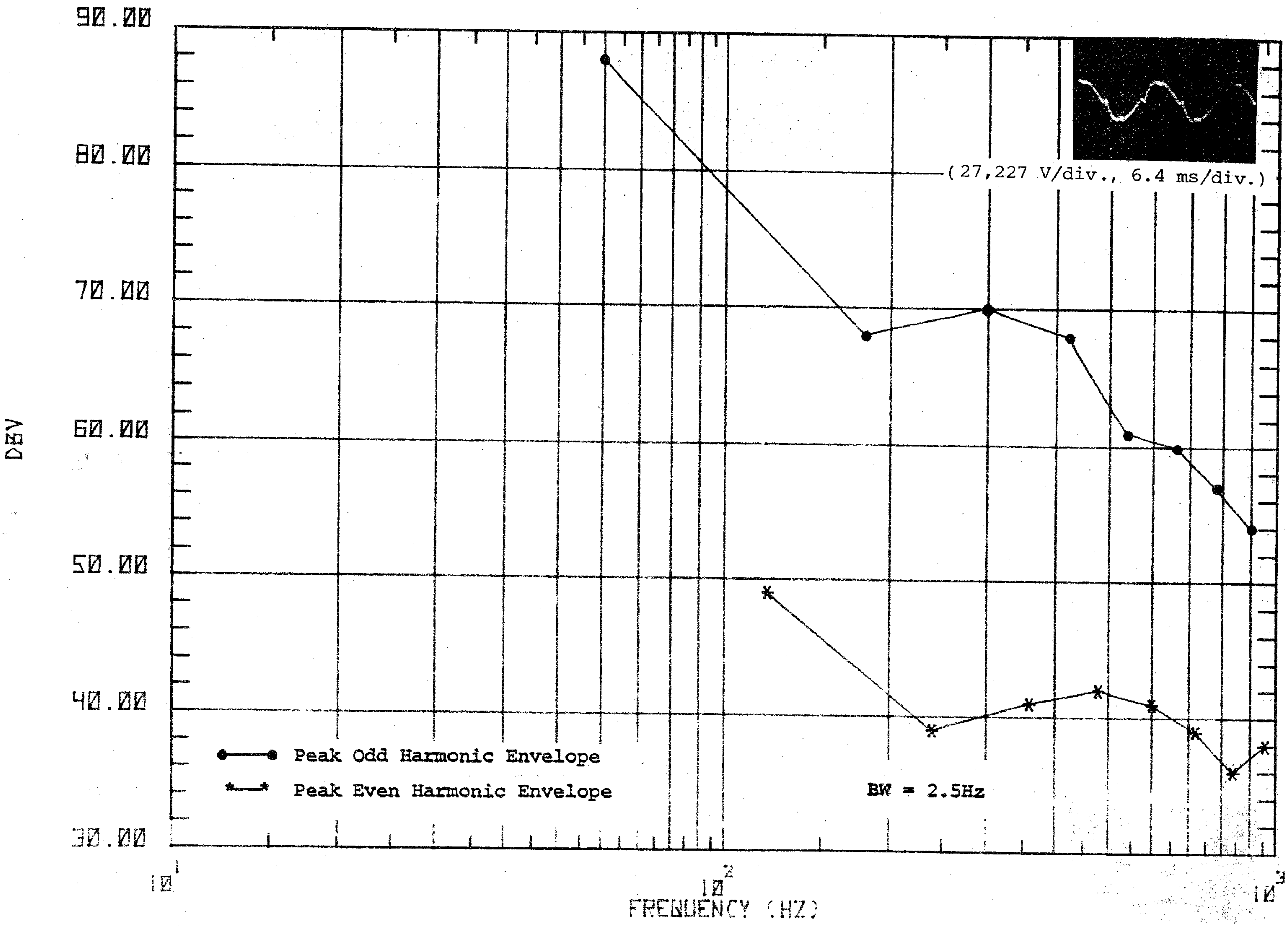


Figure 54e. Waveform and spectrum of catenary voltage sampled during 10-mph increment run, 50 to 60 mph.

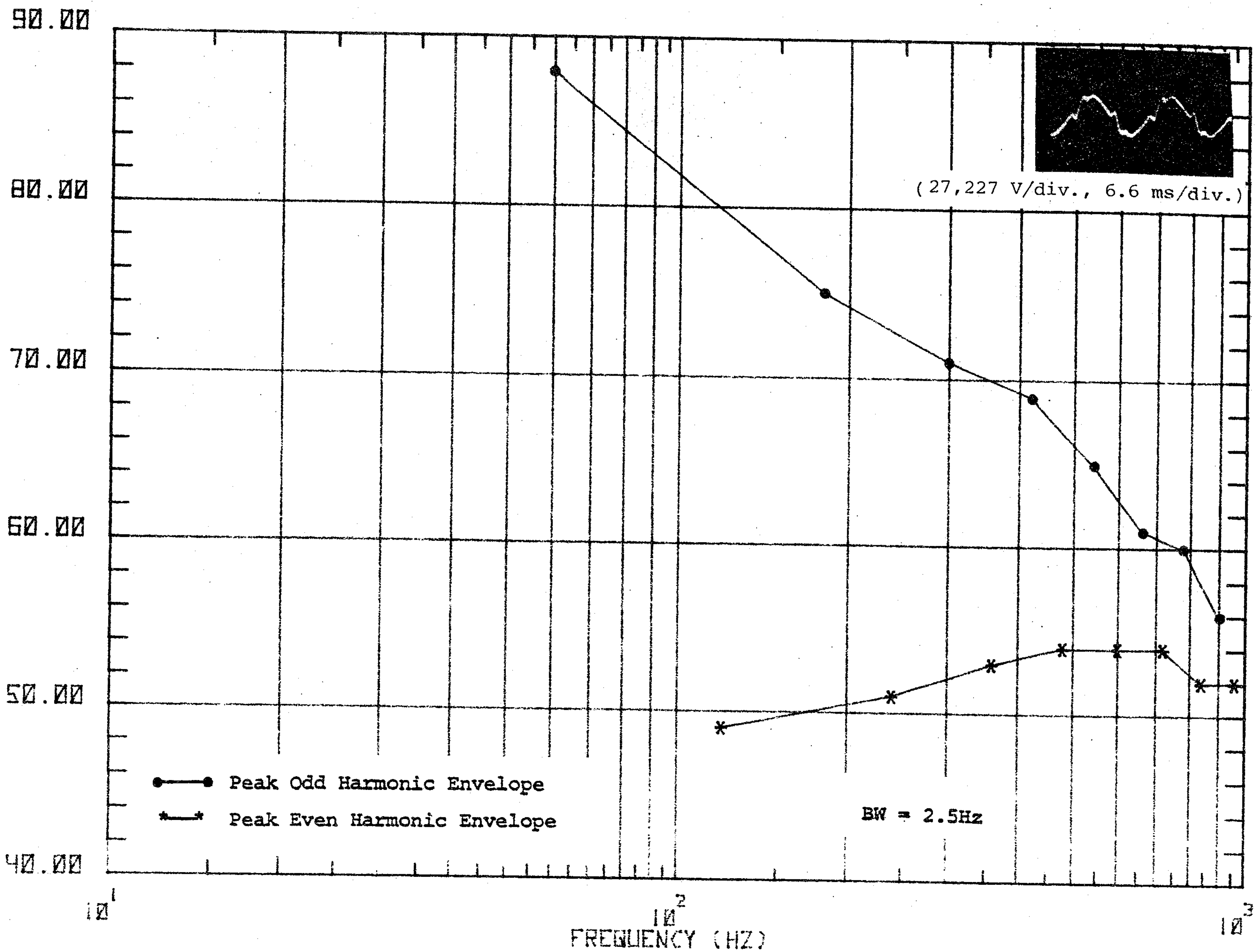


Figure 54f. Waveform and spectrum of catenary voltage sampled during 10-mph increment run, 60 to 70 mph.

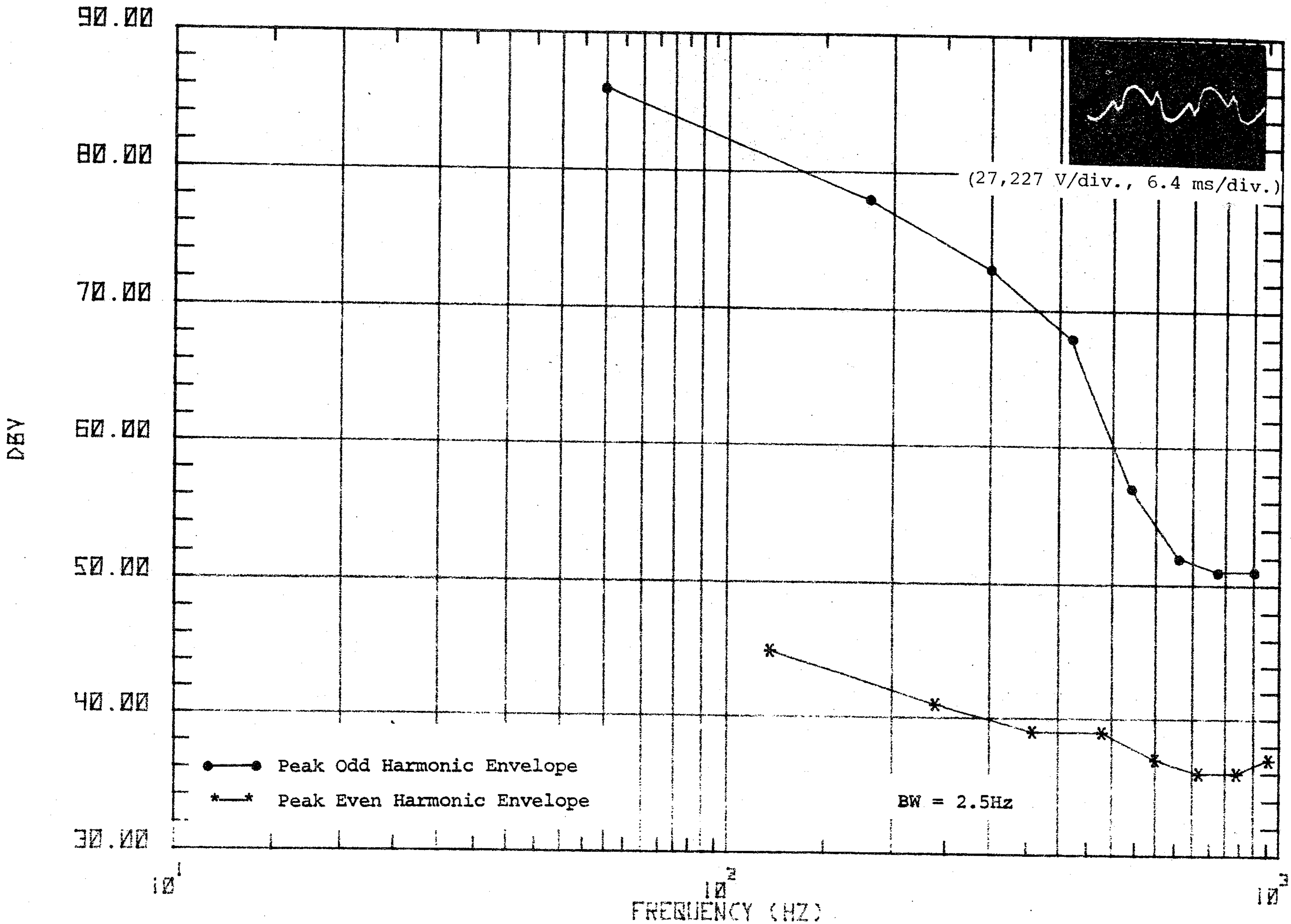


Figure 54g. Waveform and spectrum of catenary voltage sampled during 10-mph increment run, 70 to 80 mph.

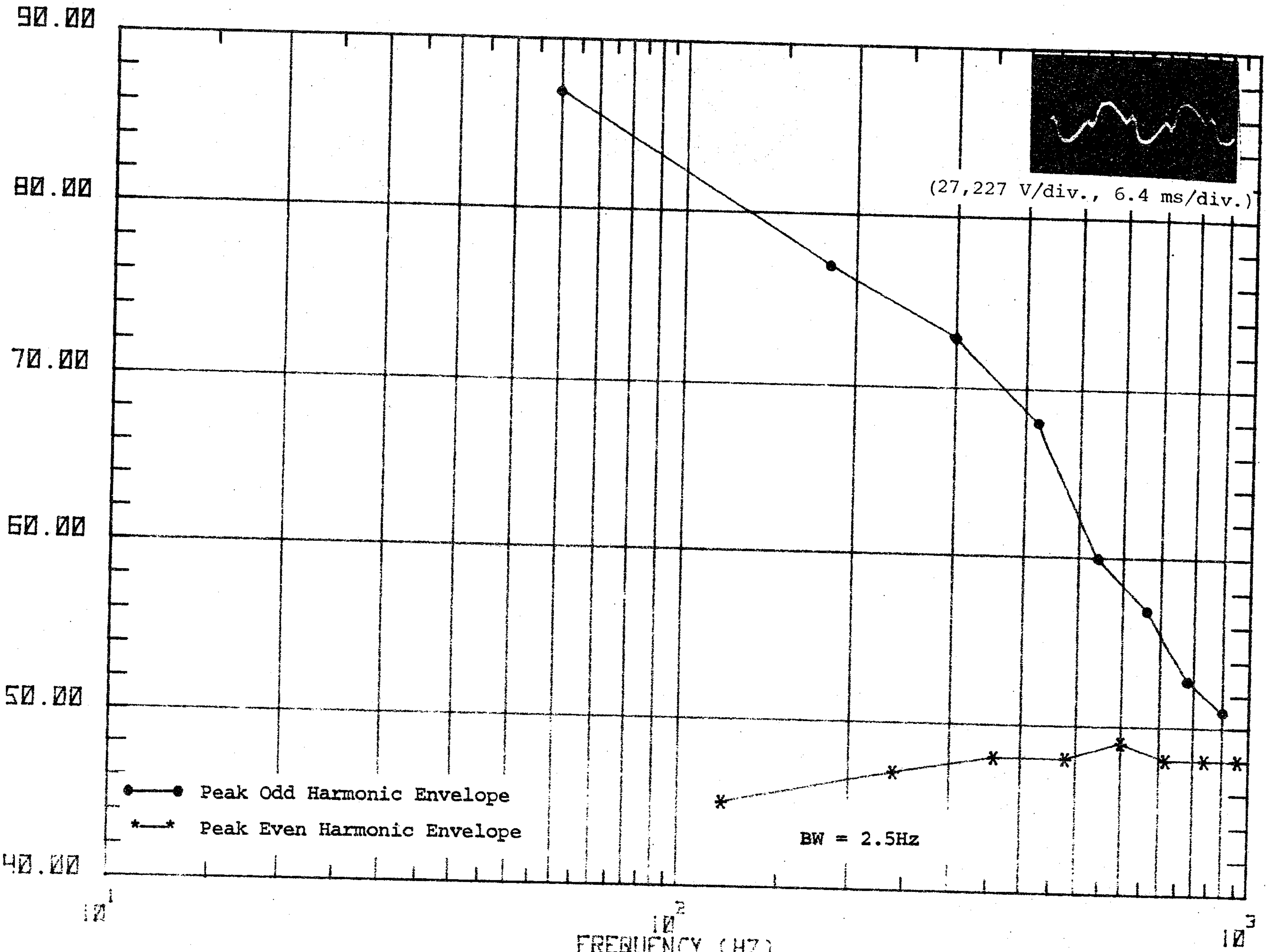


Figure 54h. Waveform and spectrum of catenary voltage sampled during 10-mph increment run, 80 to 90 mph.

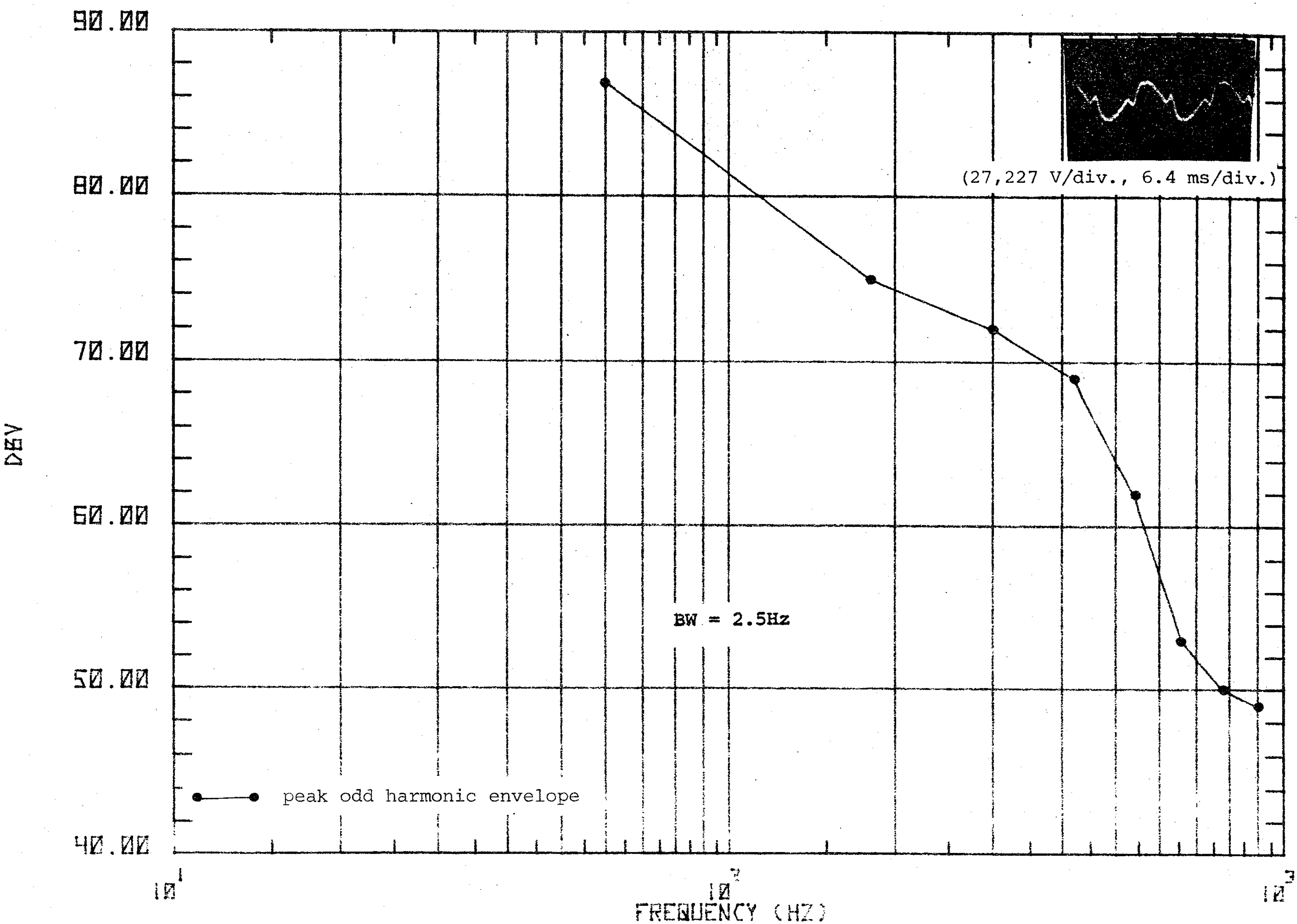


Figure 54i. Waveform and spectrum of catenary voltage sampled during 10-mph increment run, 90 to 100 mph.

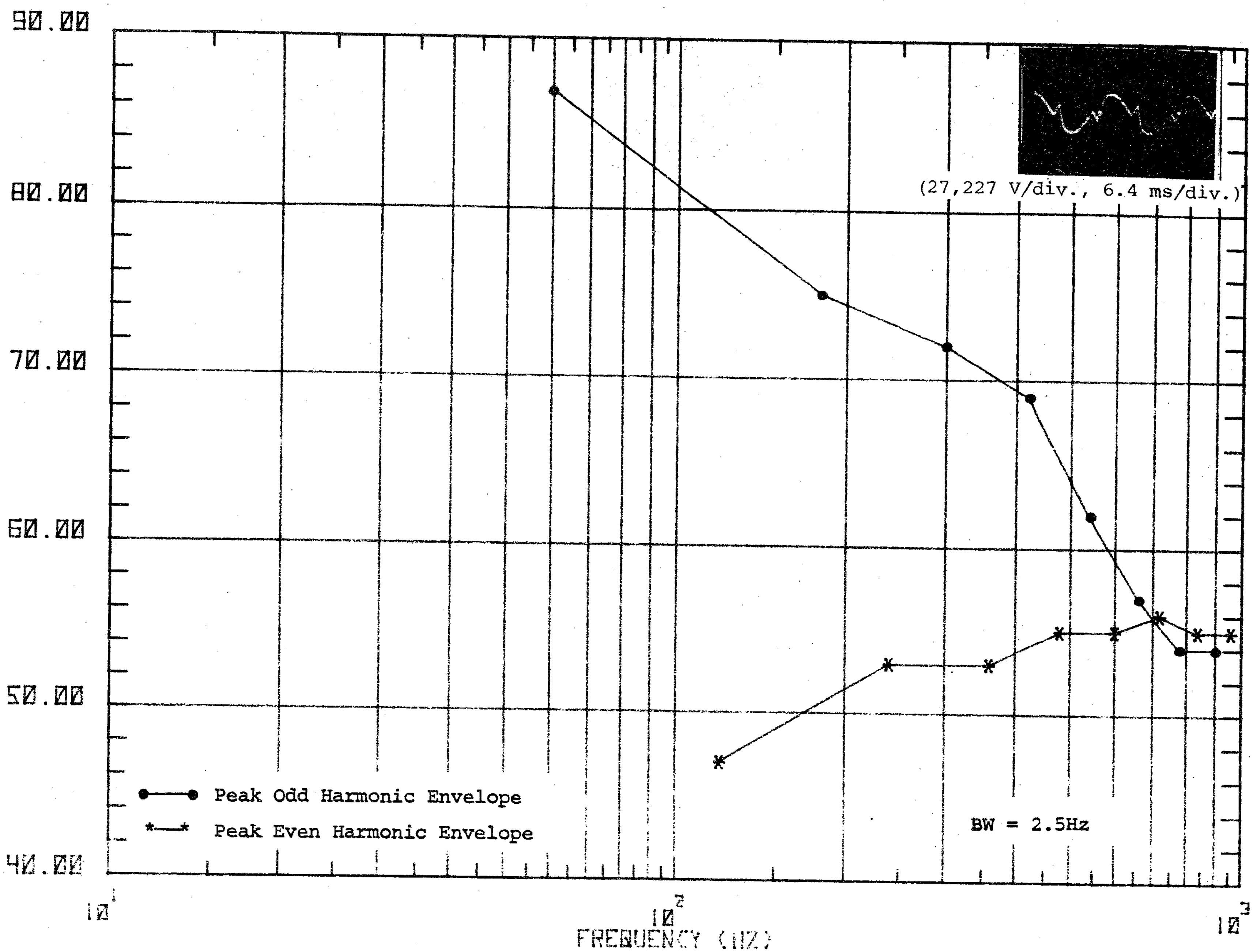


Figure 54j. Waveform and spectrum of catenary voltage sampled during 10-mph increment run, 100 to 110 mph.

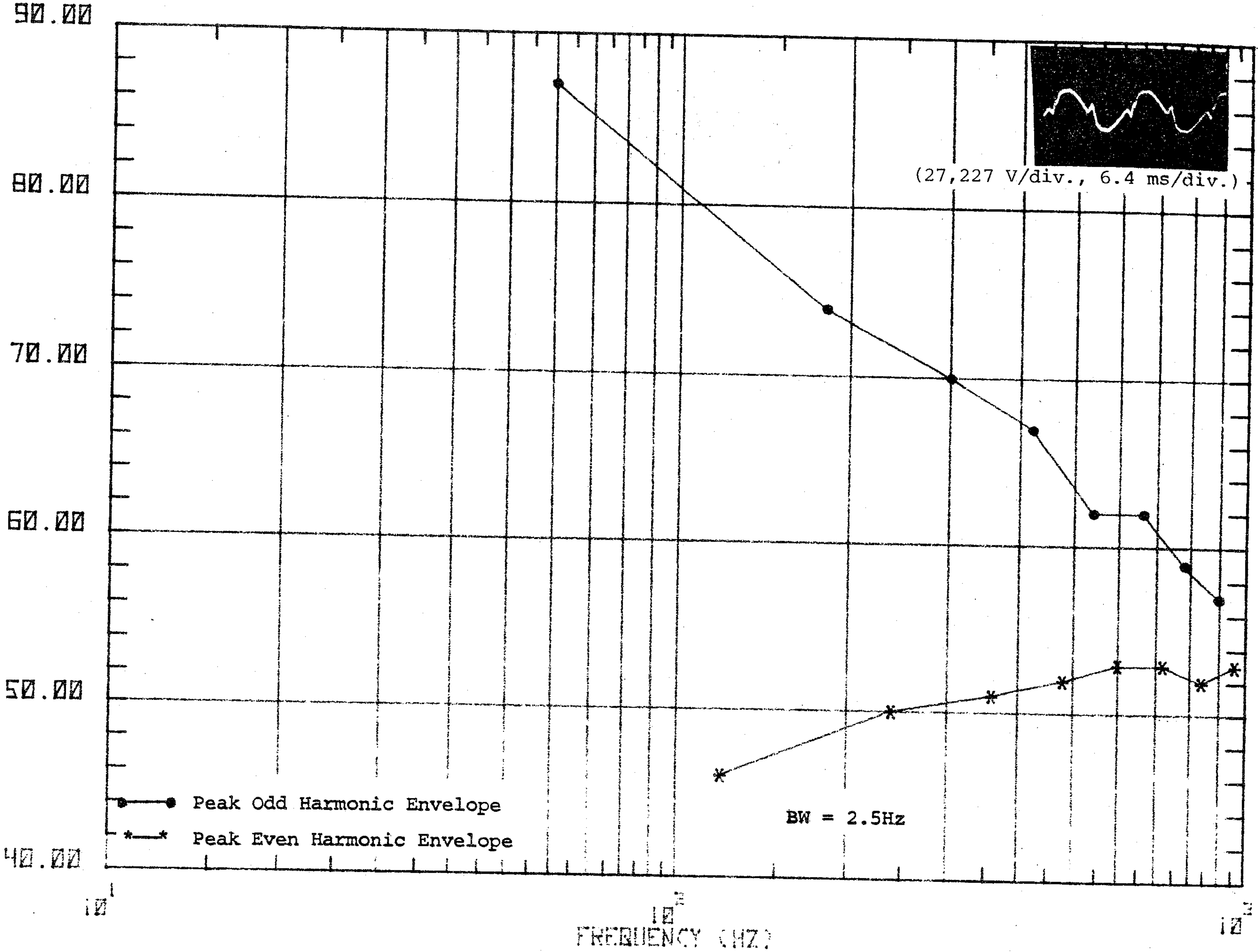


Figure 54k. Waveform and spectrum of catenary voltage sampled during 10-mph increment run, 110 to 115 mph.

Reviewing Figures 54a-k, it is observed that, although the voltage waveshape changes, the peak-to-peak level of the catenary voltage remains constant (87,126 volts peak-to-peak) up to 50 mph. After this, the catenary voltage level drops to 76,236 volts peak-to-peak (26,953 volts rms), and remains constant for the remainder of the run. From the voltage spectra sampled before and after the voltage dropped (Figures 54d and 54e), the 60-Hz components remained the same. However, the 180-Hz third harmonic dropped 5 dB from 73 dB (4467 volts rms) to 68 dBV (2512 volts rms). The first ten harmonics levels of the catenary voltage as well as the corresponding ground-side primary current harmonic levels are given in TABLE 7.

<u>Traction Motor Armature</u>

The ac current in one of three cables leading to the armature winding of traction motor number 2 was sampled using the ECAC current probe. Since the current in only one cable was able to be sampled, the current waveforms and spectra shown in this section do not represent the total ac armature current drawn, but rather, a fraction of that total current (possibly 1/3 of the total current).

An example of the armature current waveform and spectrum (sampled from 60 Hz to 1 kHz) recorded as the AEM-7 was moving is given in Figure 55. At this time, the train had just passed the RTT substation and phase break, and was accelerating towards 115 mph (presently traveling at approximately 10 mph). The corresponding waveform and spectrum of the main transformer primary current (ground side) sampled at this time is shown in Figure 46. Referring to Figure 55, as was expected, the even harmonics of 60 Hz dominate the spectrum. The 120-Hz component, for instance, was 39 dBA (89.13 amperes rms) compared with 29 dBA (28.2 amperes rms) for the 60-Hz component. The amplitude of the waveform was 333 amperes peak-to-peak (117.67 amperes rms).

Another example of the current waveform and spectrum sampled during the profile run is presented in Figure 56. This time, the locomotive was just

TABLE 7

COMPARISON OF PRIMARY CURRENT AND CATENARY VOLTAGE HARMONIC LEVELS

Speed Increment (mph)	Main Transformer Primary Current (Ground-Side) Frequency Component (Hz)										Catenary Voltage Frequency Components (Hz)									
	60	120	180	240	300	360	430	480	540	600	60	120	180	240	300	360	420	480	540	600
0-10	35[a] (56.2)	-12	23	-14	10	-14	11	-15	4	-18	88[b] (25118)	49	63	37	57	37	59	40	54	37
10-20	38 (79.4)	2	22	-8	21	-3	14	-7	15	-7	88 (25118)	44	48	--[c]	59	--	59	--	51	8
20-30	42 (125.9)	9	30	0	18	-3	18	-1	18	-2	88 (25118)	45	62	38	57	40	53	39	55	37
30-40	43 (141.2)	5	29	6	23	-2	19	-2	19	1	88 (25118)	44	73	44	67	42	68	42	63	37
40-50	42 (125.9)	0	29	-5	24	-3	20	-4	17	-6	88 (25118)	49	68	39	70	41	68	42	61	41
50-60	44 (158.5)	6	28	0	24	1	22	0	16	-5	88 (25118)	49	75	51	71	53	69	54	65	54
60-70	45 (177.8)	11	31	1	23	-1	17	1	14	3	86 (19952)	45	78	41	73	39	68	39	57	37
70-80	46 (199.5)	9	34	4	28	5	22	4	17	3	87 (22387)	45	77	47	73	48	68	48	60	49
80-90	44 (158.5)	13	32	5	26	1	21	-1	13	-4	87 (22387)	--	75	--	72	--	69	--	62	--
90-100	43 (141.2)	9	31	-3	26	-1	21	-2	14	-2	87 (22387)	47	75	53	72	53	69	55	62	55
100-110	43 (141.2)	6	32	8	27	8	22	7	17	7	87 (22387)	46	74	50	70	51	67	52	62	53

[a] Current levels shown are in units of dBA (amperes rms).

[b] Voltage levels shown are in units of dBV (volts rms).

[c] Levels were to low with respect to presented levels to be displayed on the CRT.

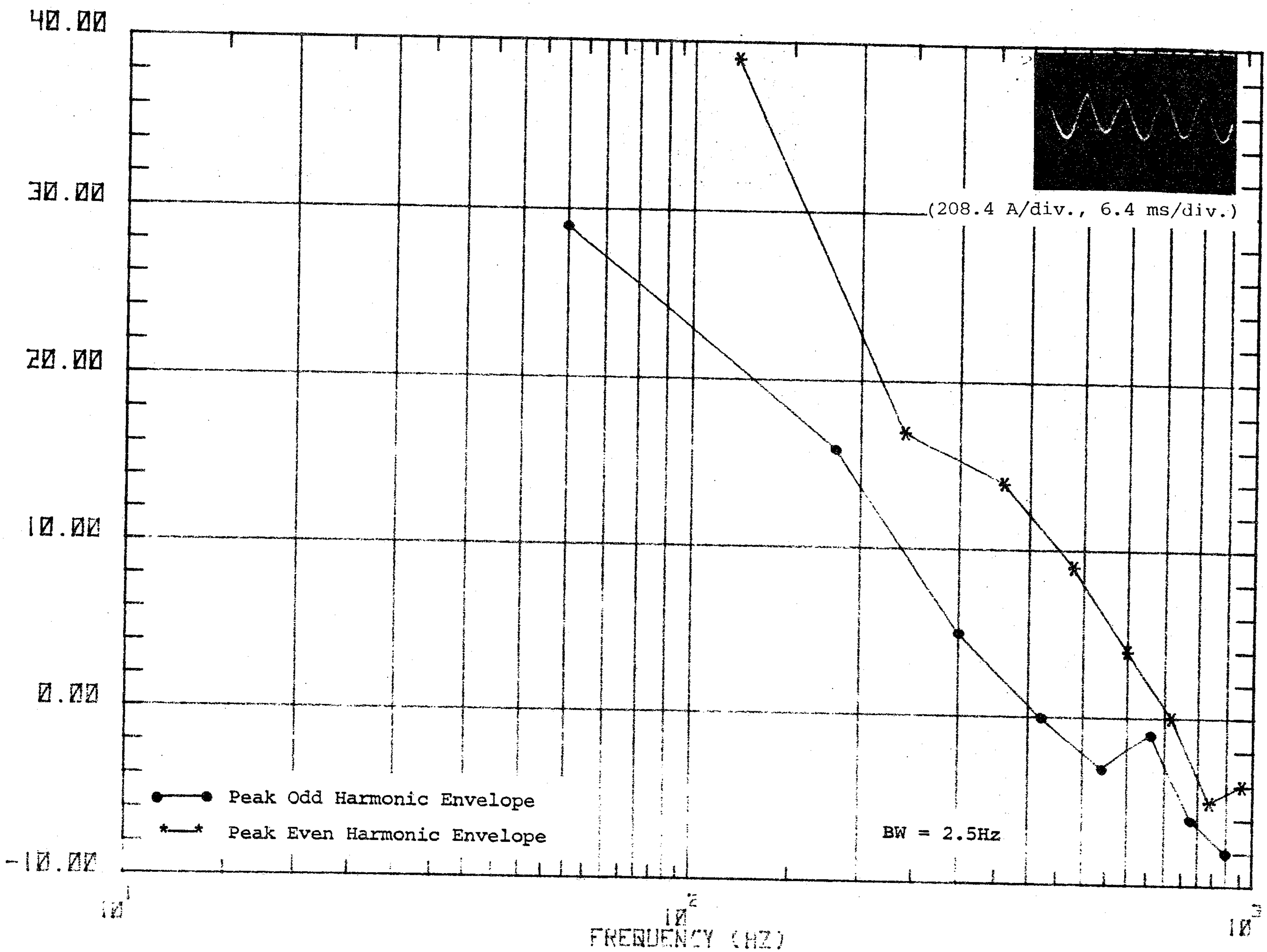


Figure 55. Waveform and spectrum of armature current (ac) sampled during a simulated revenue service run.

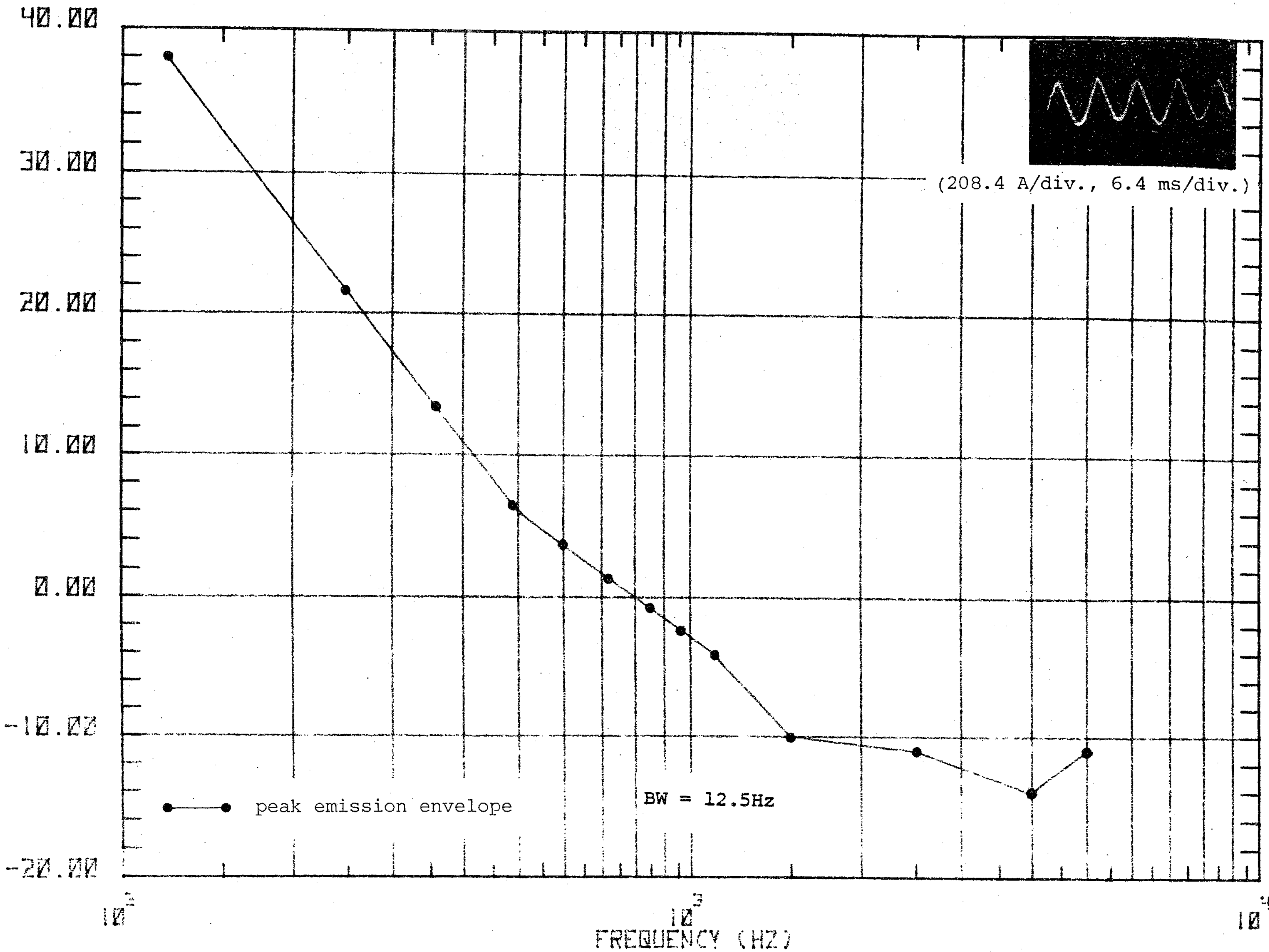


Figure 56. Waveform and spectrum of armature current (ac) sampled during simulated revenue service run (sample 2).

starting up from standstill and accelerating to 115 mph. The 120-Hz component sampled here was 38 dBA (79.4 amperes rms). In this instance, beyond 120 Hz the emission levels decreased rapidly (46 dBA/decade up to 1.2 kHz).

The waveforms and spectra of the armature current corresponding to the seven main transformer primary current waveforms, noted in Figure 51, were sampled and are presented in Figures 57a-g. In Figures 57b, 57c, 57d, and 57f, the peak odd harmonic envelope is not illustrated to 1 kHz. This is due to the fact that the levels of the odd harmonics, beyond the points displayed in these figures, dropped off rapidly with respect to increasing frequency to the point where the difference in displayed spectral levels exceeded the display range of the FFT analyzer.

As in Figure 55, the spectra shown in Figure 57 are dominated by the even harmonics of 60 Hz. The levels of the 120-Hz components sampled for these seven waveforms ranged from 34 to 42 dBA (50.1 to 125.9 amperes rms), an increase of 16 to 21 dBA over the corresponding 60-Hz components. Comparing the ground side primary and armature current waveforms, there appears to be no relationship between the changes in the primary current waveform and corresponding armature waveform. The armature current waveform appeared to change only with respect to amplitude and not shape.

Trigger Pulse Generator

The trigger pulse generator is used to produce a signal that is then sent to the gate of the thyristor and subsequently fires (turns on) the thyristor. The output of one of the trigger pulse generators (card YXX 141) was sampled using a Tektronix P6201 probe connected between the output (pin #18) and ground (pin #10). Waveforms of the output voltage obtained from these samplings are given in Figures 58a-g. In addition, the waveforms of the ground side primary current and armature current (number 2 traction motor), simultaneously sampled, are also presented in Figure 58. The ground side primary current waveforms here are the same seven waveshapes shown in Figure 51.

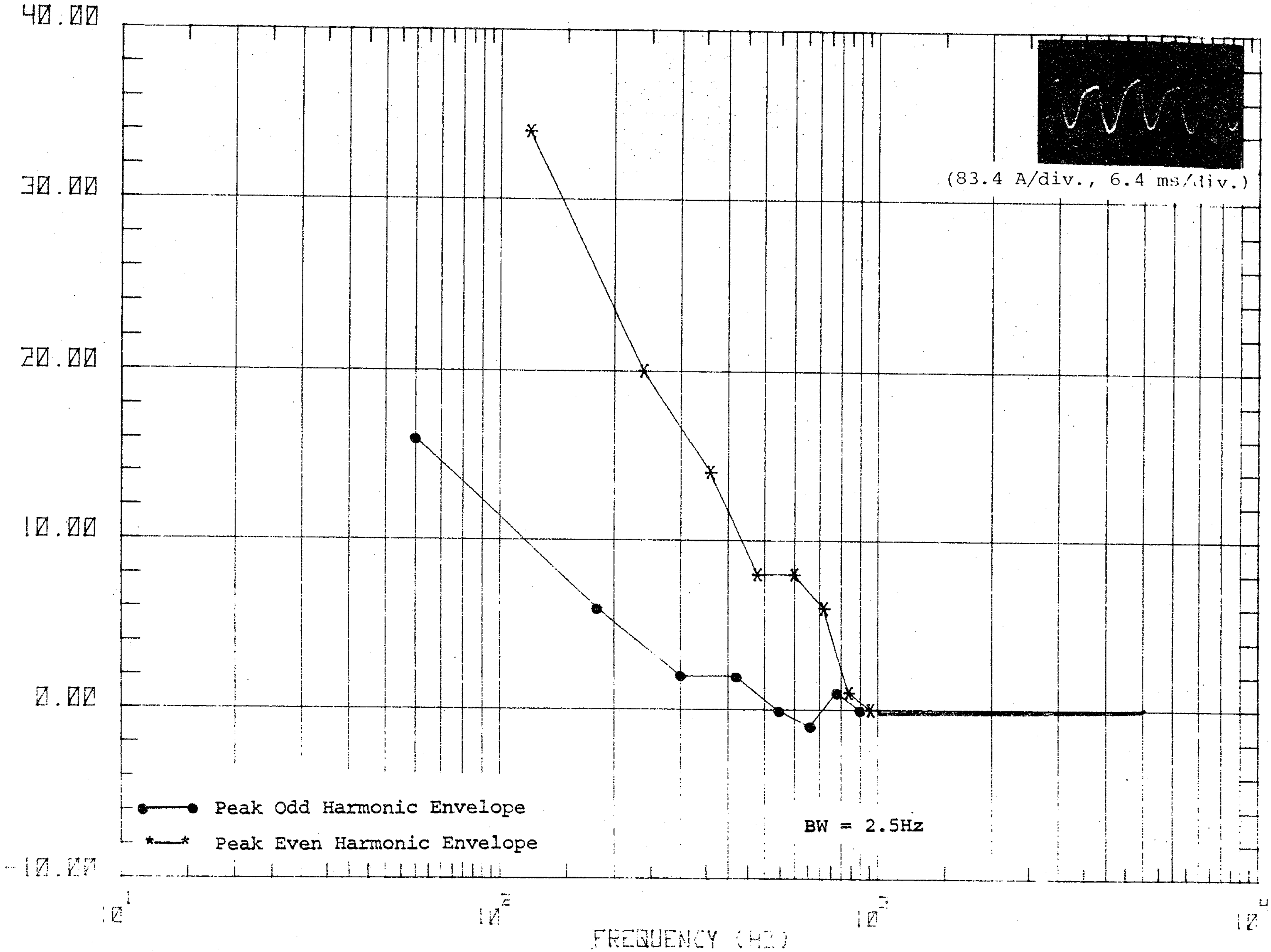


Figure 57a. Waveform and spectrum of armature current (ac) corresponding to primary current waveshape #1.

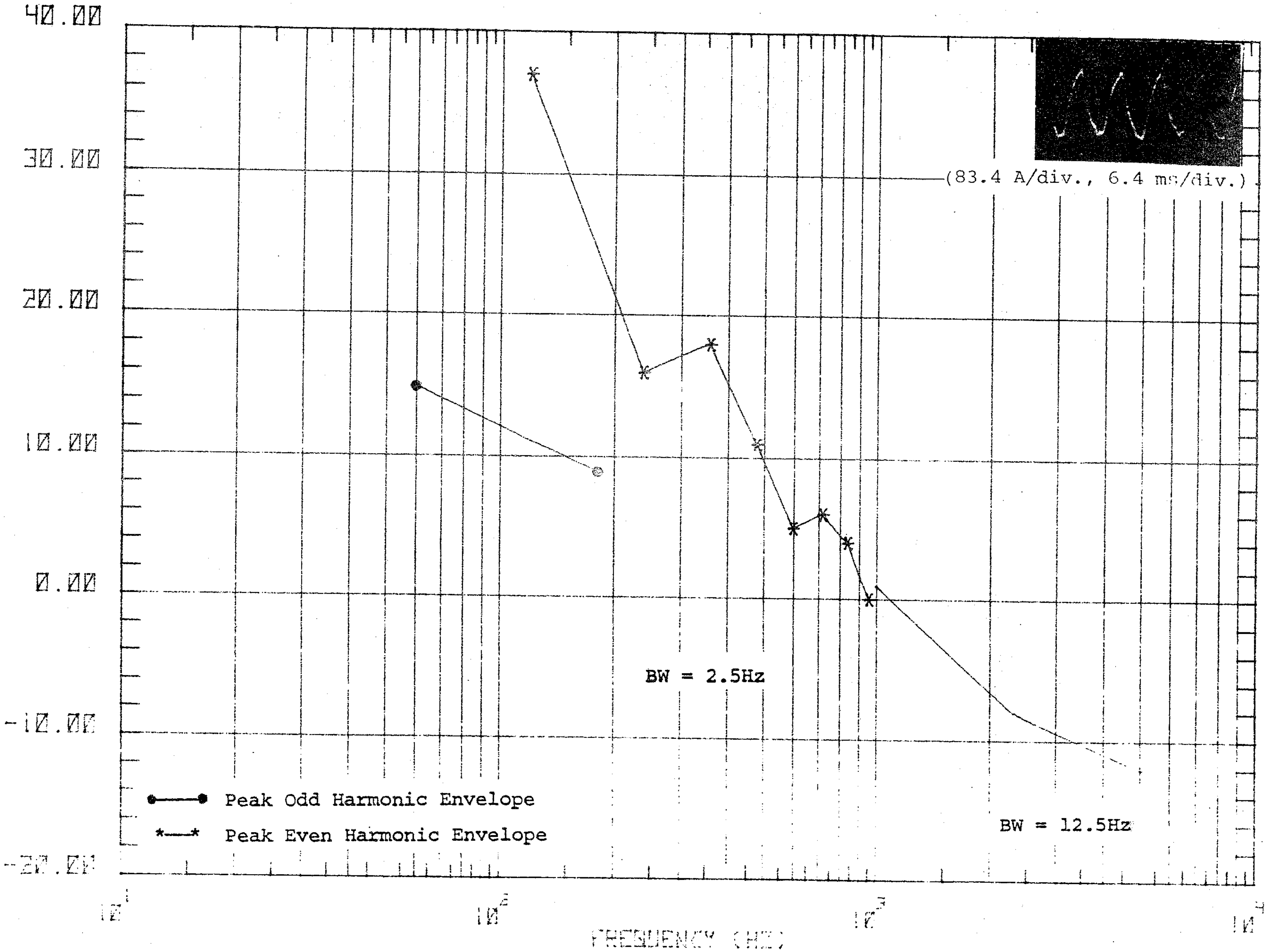


Figure 57b. Waveform and spectrum of armature current (ac) corresponding to primary current waveshape #2.

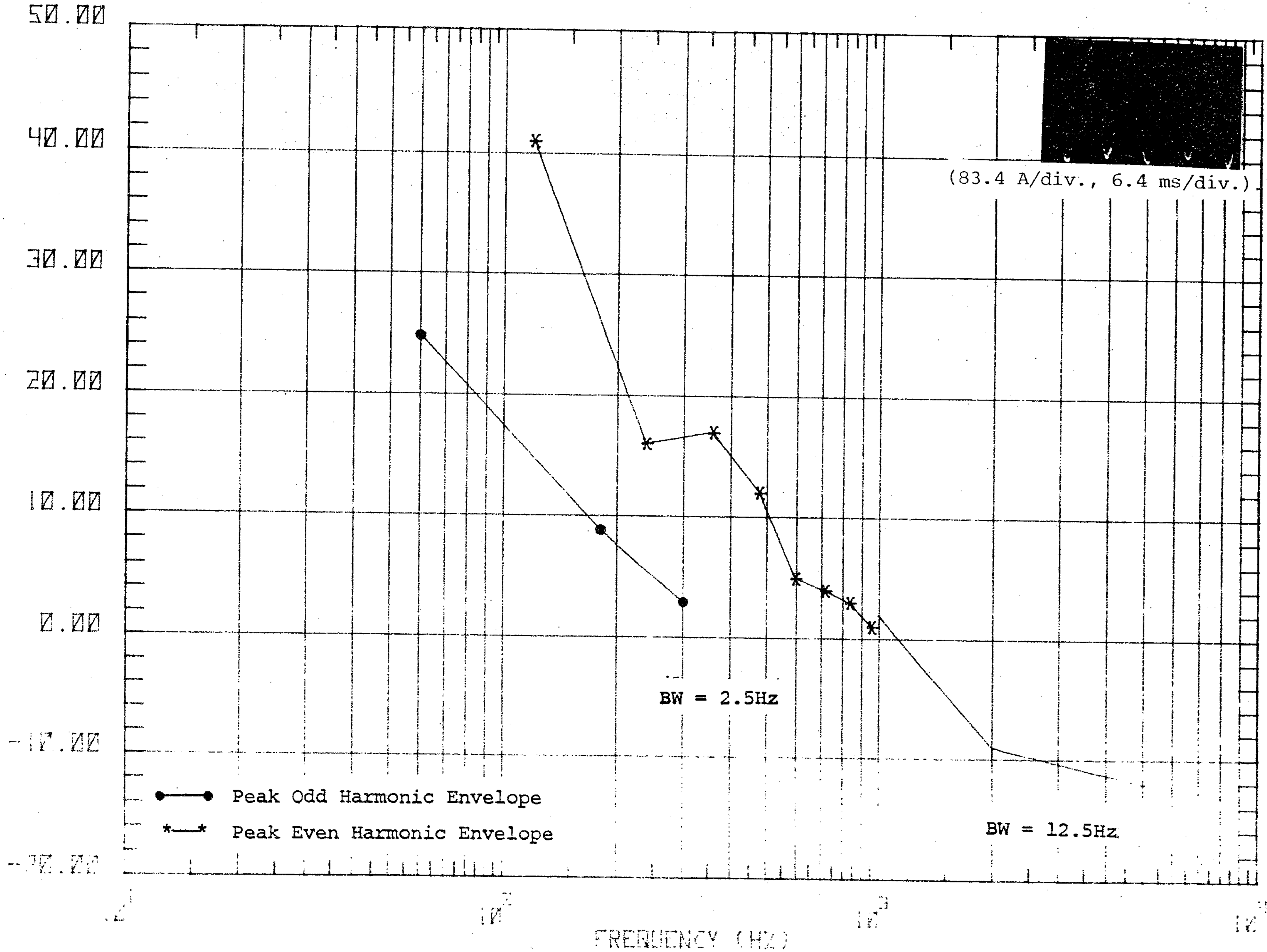


Figure 57c. Waveform and spectrum of armature current (ac) corresponding to primary current waveshape #3.

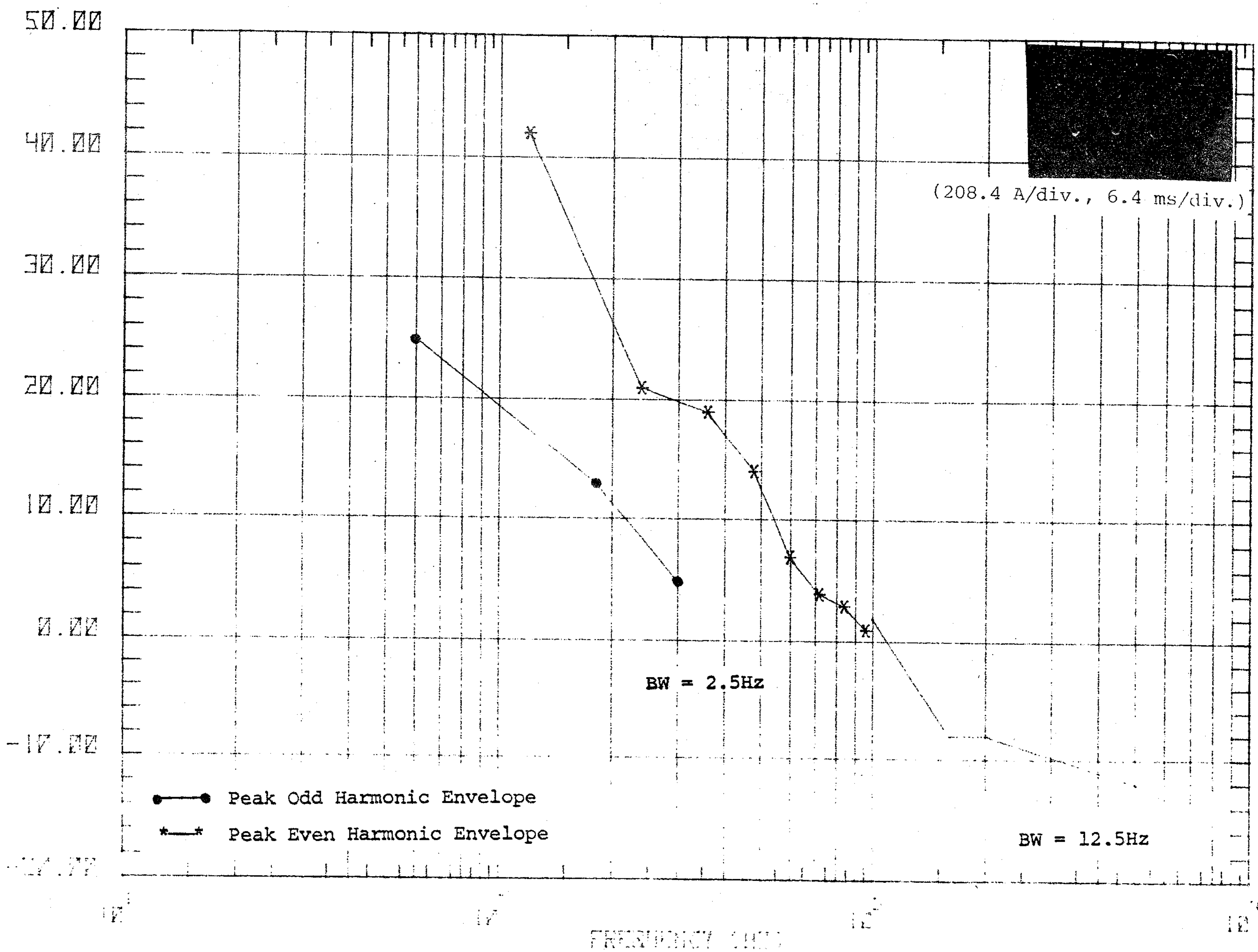


Figure 57d. Waveform and spectrum of armature current (ac) corresponding to primary current waveshape #4.

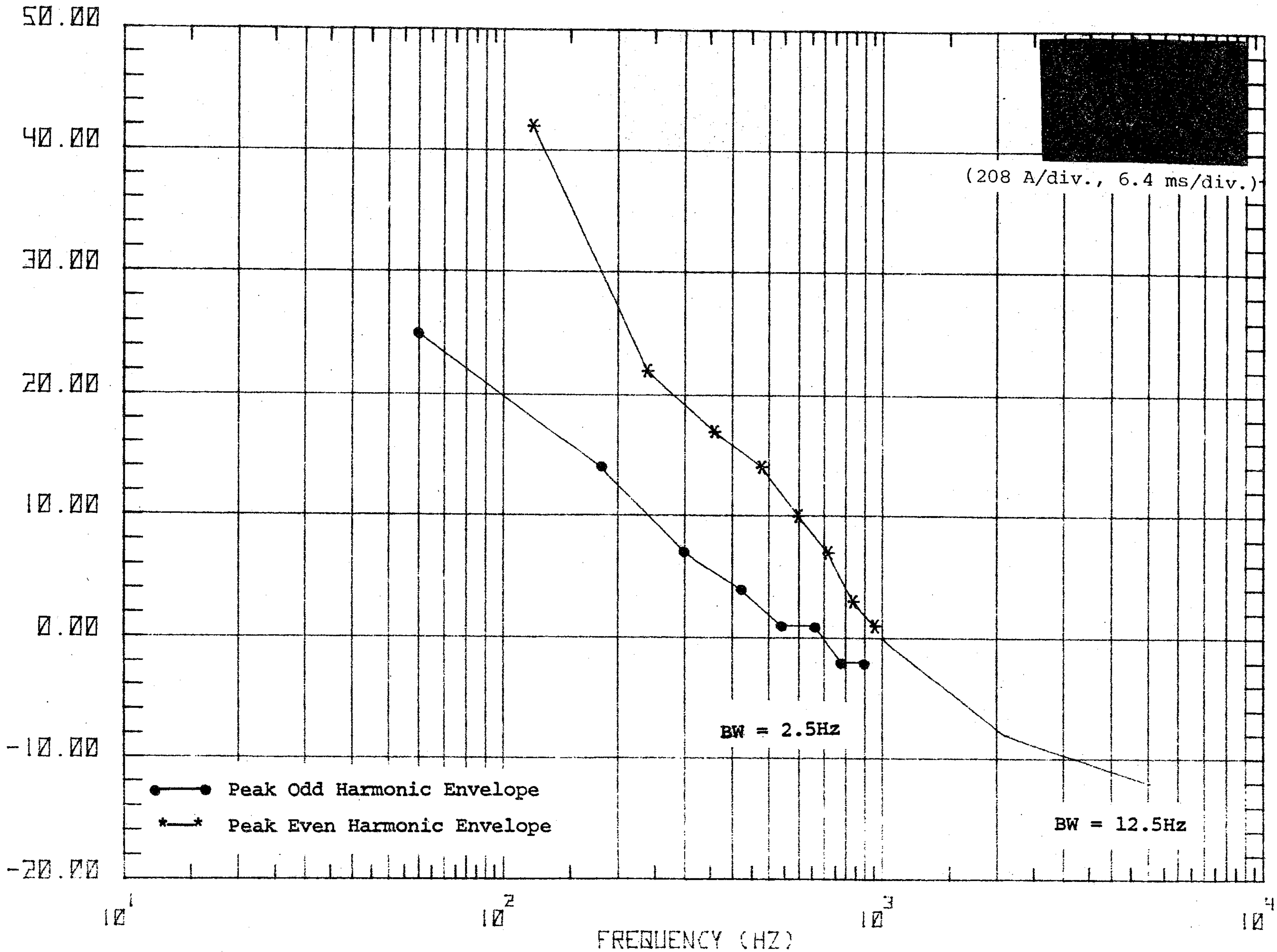


Figure 57e. Waveform and spectrum of armature current (ac) corresponding to primary current waveshape #5.

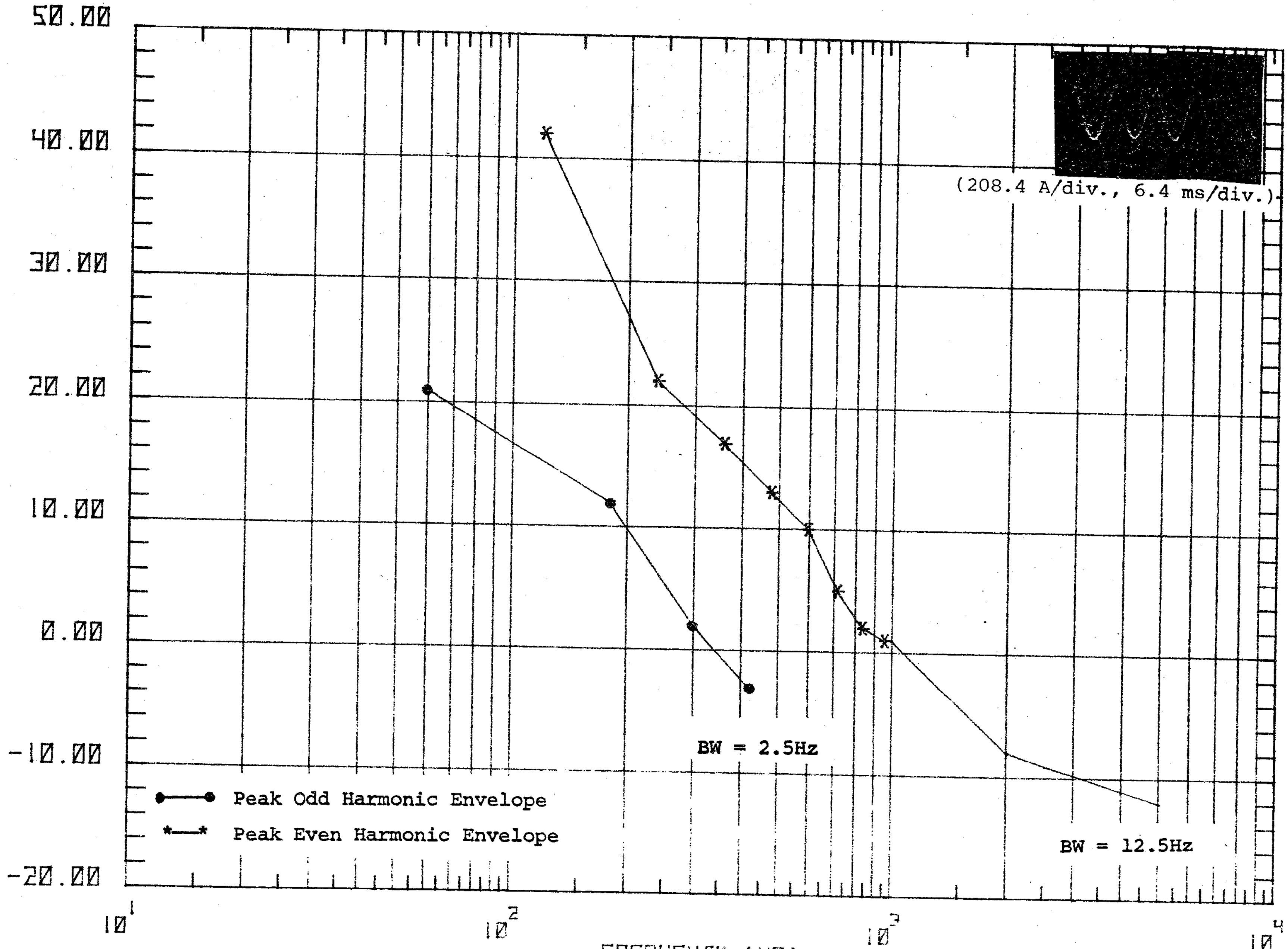


Figure 57f. Waveform and spectrum of armature current (ac) corresponding to primary current waveshape #6.

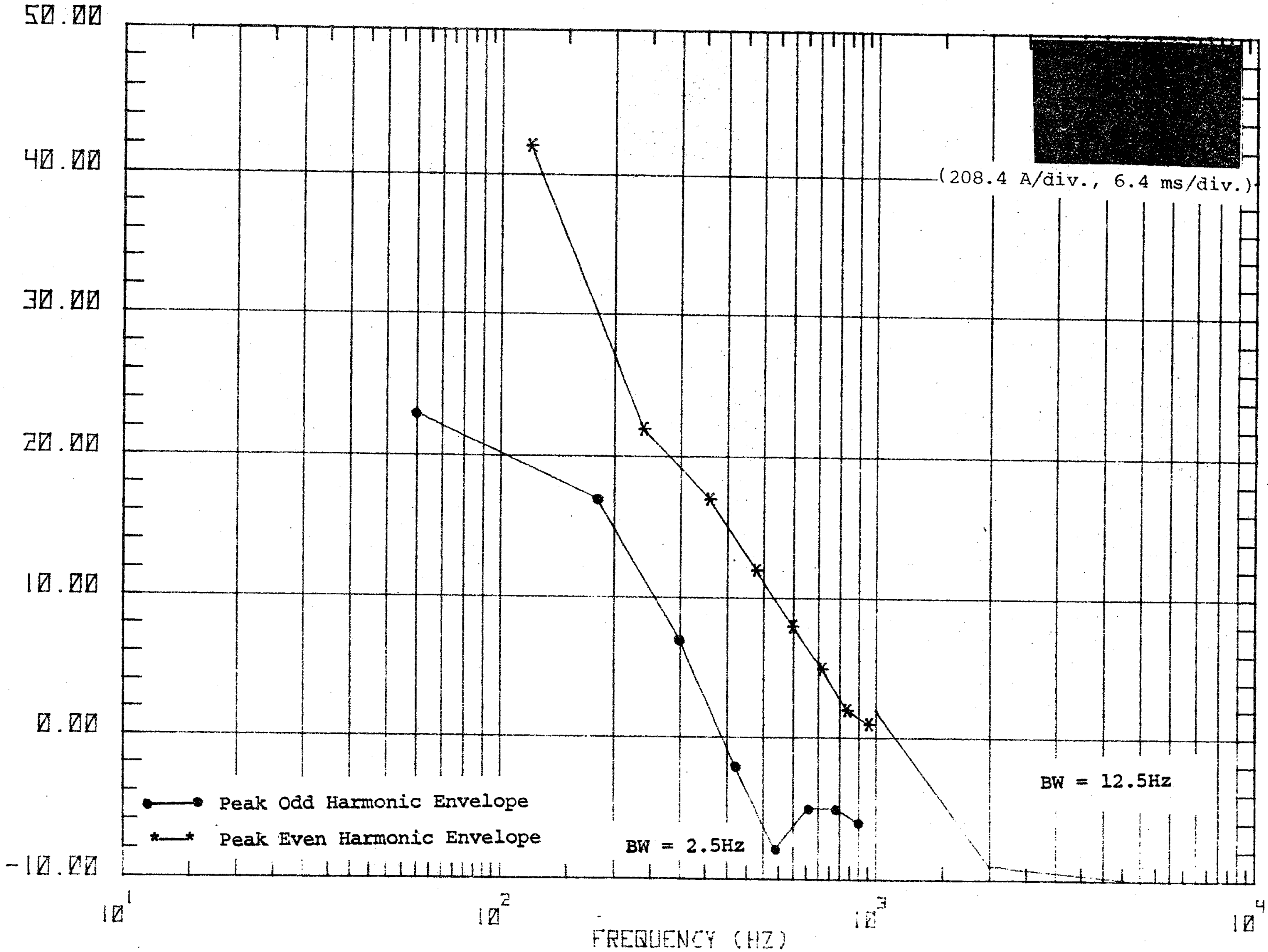
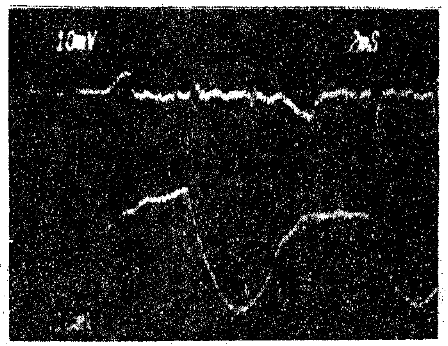


Figure 57g. Waveform and spectrum of armature current (ac) corresponding to primary current waveshape #7.

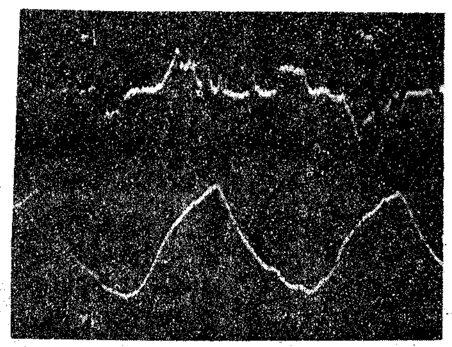
Trigger Pulse



Armature

a. Primary = 127 amperes rms.
Trigger pulse = 0.63 V/div., 2 ms/div.
Armature = 41.7 A/div., 2 ms/div.

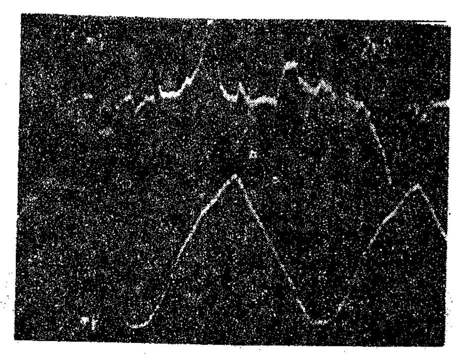
Trigger Pulse



Armature

b. Primary = 190 amperes rms.
Trigger pulse = 0.63 V/div., 2 ms/div.
Armature = 83.4 A/div., 2 ms/div.

Trigger Pulse

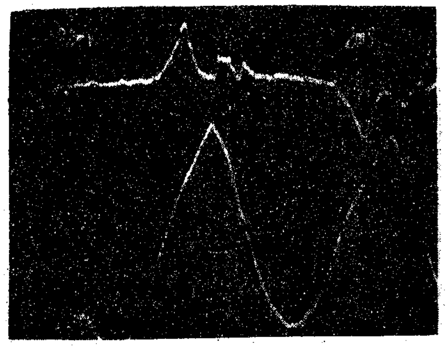


Armature

c. Primary = 206.2 amperes rms.
Trigger pulse = 0.63 V/div., 2 ms/div.
Armature = 83.4 A/div., 2 ms/div.

Figure 58. Waveform of trigger pulse generator output.

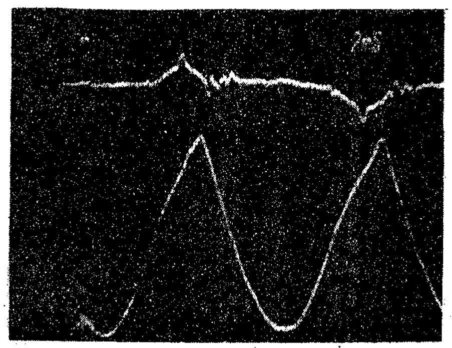
Trigger Pulse



Armature

d. Primary = 222 amperes rms.
Trigger = 1.26 V/div., 2 ms/div.
Armature = 83.4 A/div., 2 ms/div.

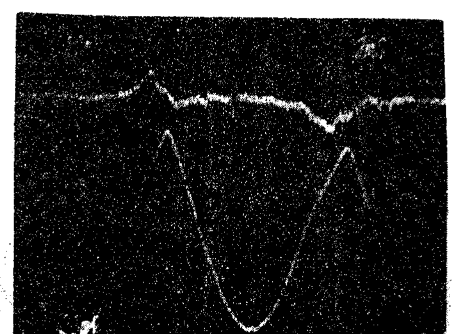
Trigger Pulse



Armature

e. Primary = 198.3 amperes rms.
Trigger pulse = 1.26 V/div., 2 ms/div.
Armature = 83.4 A/div., 2 ms/div.

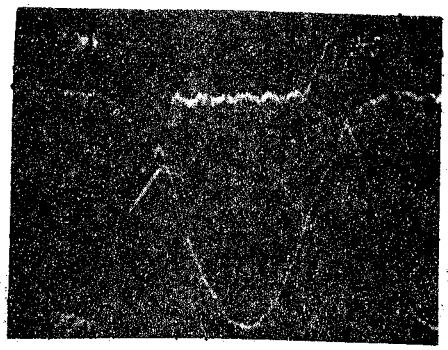
Trigger Pulse



Armature

f. Primary = 198.3 amperes rms.
Trigger pulse = 0.63 V/div., 2 ms/div.
Armature = 83.4 A/div., 2 ms/div.

Figure 58. Waveform of trigger pulse generator output (Continued)



g. Primary = 167 amperes rms.
Trigger pulse = 0.63 V/div., 2 ms/div.
Armature = 83.4 A/div., 2 ms/div.

Figure 58. Waveform of trigger pulse generator output (Continued).

As can be seen in Figure 58, the output of the trigger pulse generator varied from 0.88 volts peak-to-peak to 3.41 volts peak-to-peak. However, no apparent correlation can be made concerning the output of the trigger pulse generator and the seven ground side primary waveshapes without further analysis.

74-Volt dc Bus

The voltage across the 74-volt dc bus was sampled using the Tektronix P6201 probe. An example of the waveform and spectral data collected is given in Figure 59. At this time, the train had just passed the RTT substation. The locomotive traction power was supplied by traction motors 3 and 4 only. From Figure 59, the amplitude of the ac waveform recorded was 270.5 volts peak-to-peak (95.7 volts rms). Regarding the spectrum, the odd harmonics appear to predominate. The 60-Hz component, for example, was measured to be 40 dBV (100 volts rms) versus a 120-Hz component of 16 dBV (6.31 volts rms).

The time waveform and frequency spectrum of the voltage across the 74-volt bus recorded on a direct channel while the locomotive was accelerating

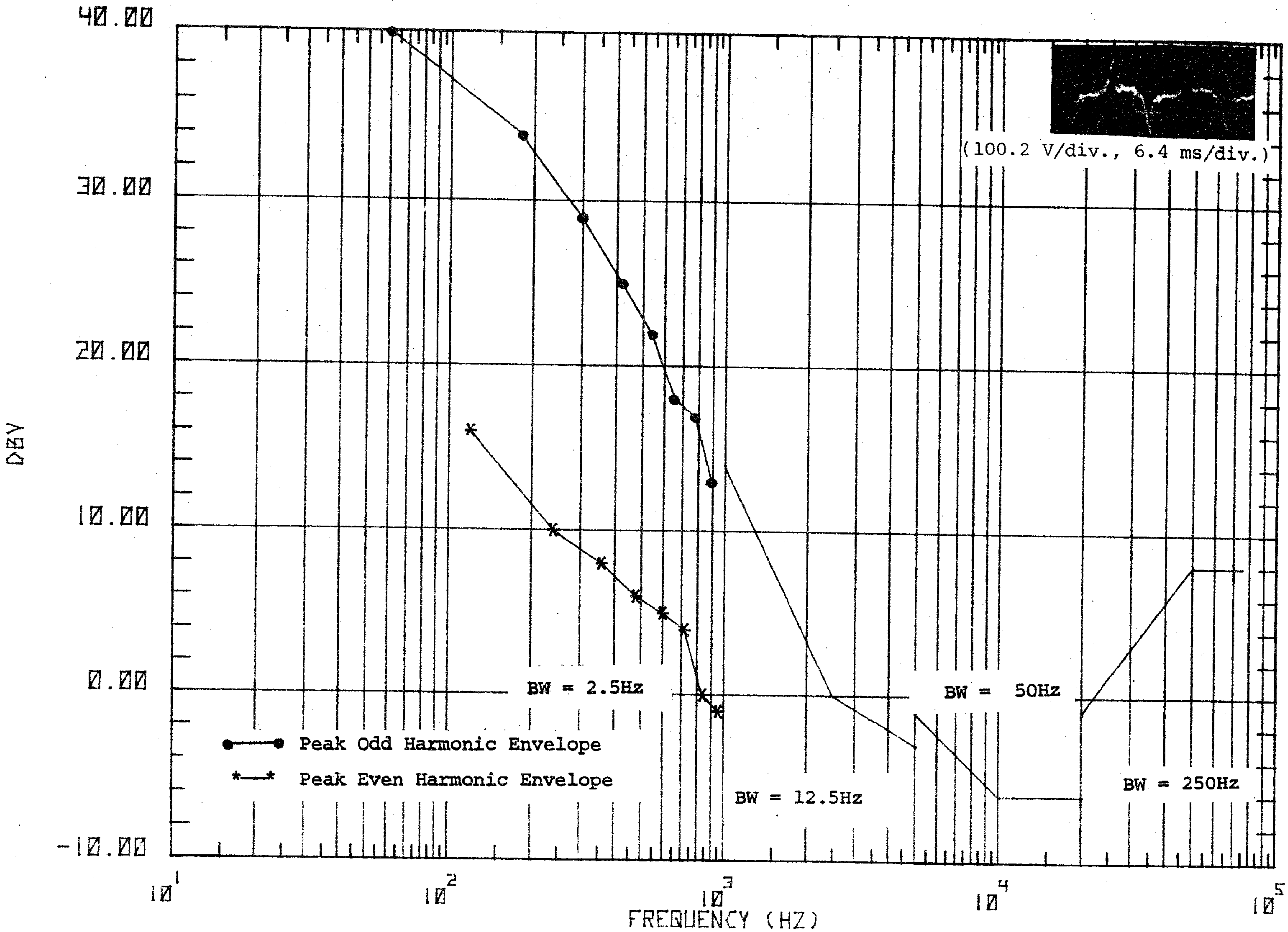


Figure 59. Waveform and spectrum of voltage across 74-volt bus as train runs simulated revenue service run.

from standstill to 115 mph are given in Figure 60. At this time, the locomotive had just started up (traveling at roughly 3 mph) with all four traction motors running. It is important to note that since this emission data was recorded on a direct channel, the frequency components of the voltage below 400 Hz are not included. Nevertheless, the spectrum shown in Figure 60 does give a good indication of the amplitudes of the higher frequency components (400 Hz to 20 kHz) of the voltage.

Cab Signal Pickup - Voltage Measurements

The voltage induced in one of the cab signal pickups was sampled using the Tektronix P6202 probe. During these measurements (as well as cab signal current measurements), the cab signal pickup coil, situated at the rear of the locomotive, was not terminated.

The waveform and spectra of the induced voltage sampled just before and after the locomotive passed the RTT substation and phase break are given in Figures 61 and 62, respectively. At this time, the locomotive was accelerating (initially from standstill) to 115 mph. As the locomotive approached the phase break, it was traveling at approximately 65 mph. Comparing Figures 61 and 62, it is apparent that the voltage levels recorded and shown in Figure 62 are significantly higher than those shown in Figure 61. The reason for this is that as the locomotive approaches the phase break, the vehicle operator reduces the throttle setting to zero, thus allowing the locomotive to coast through the phase break. This is done to avoid any arcing across the phase break which may occur if the locomotive were drawing large amounts of current as it entered the phase break.

Next, cab signal voltage waveforms and spectra, recorded at the same time as the seven ground side primary current waveshapes presented in Figure 51, are given in Figures 63a-g. As in the case of the trigger pulse generator output voltage and the armature current, there seems to be no direct correlation between the cab signal voltage and the ground side primary current waveshapes. However, further analysis may provide some correlation between these signals.

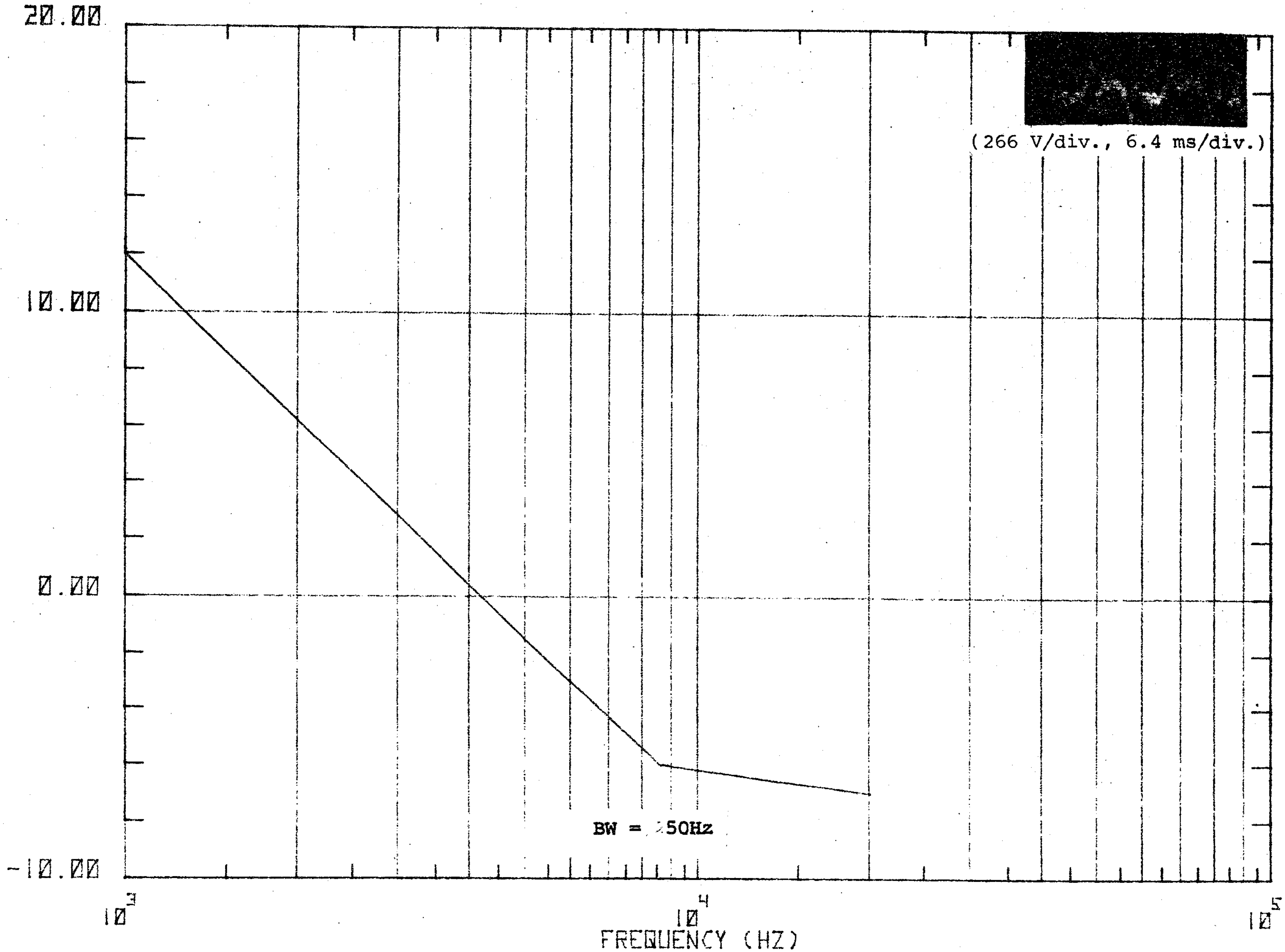


Figure 60. Waveform and spectrum of voltage across 74-volt bus recorded as locomotive accelerated from 0 mph (recorded on direct channel).

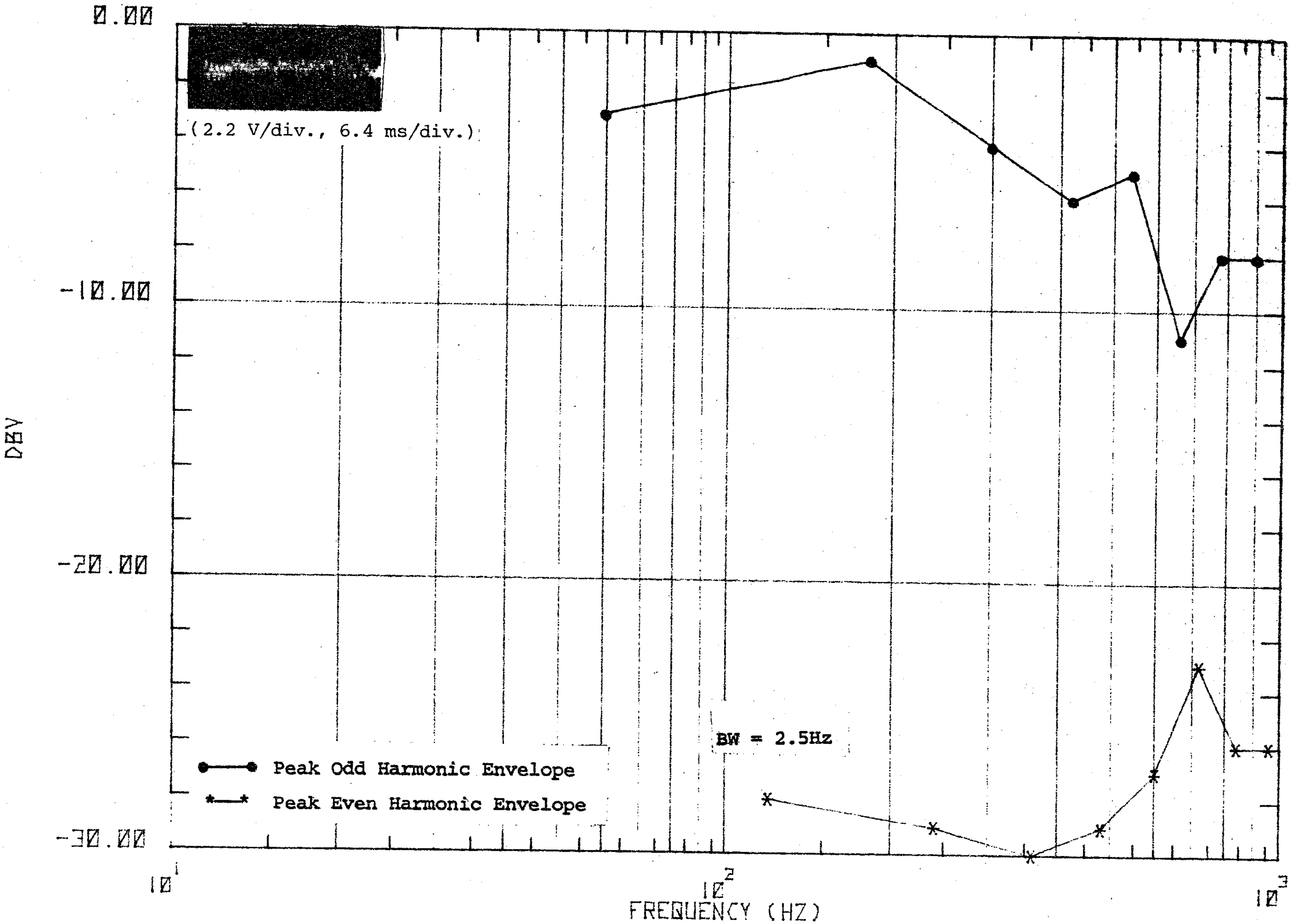


Figure 61. Waveform and spectrum of cab signal voltage sampled as locomotive approached phase break.

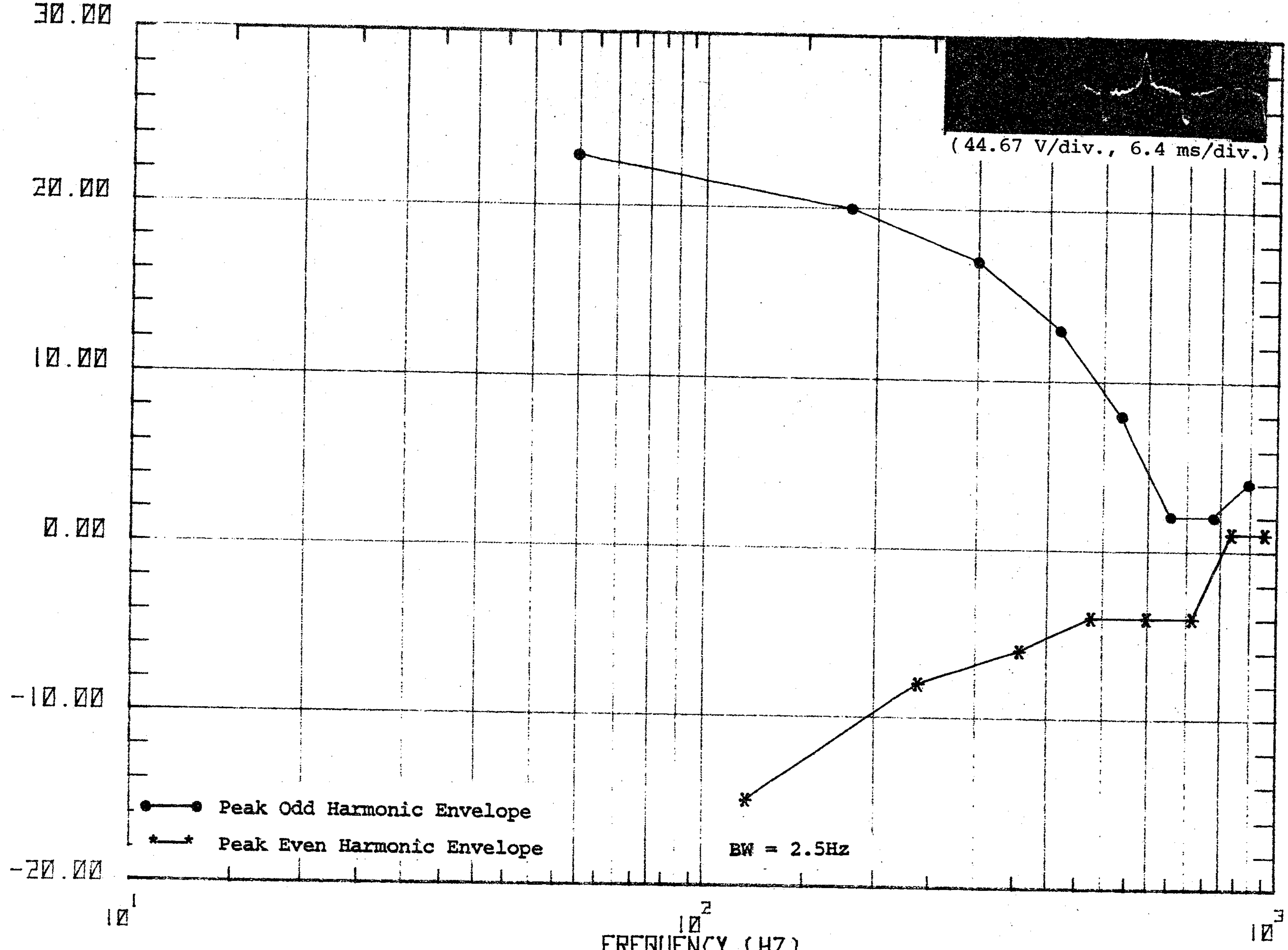


Figure 62. Waveform and spectrum of cab signal voltage sampled just after locomotive passed through phase break.

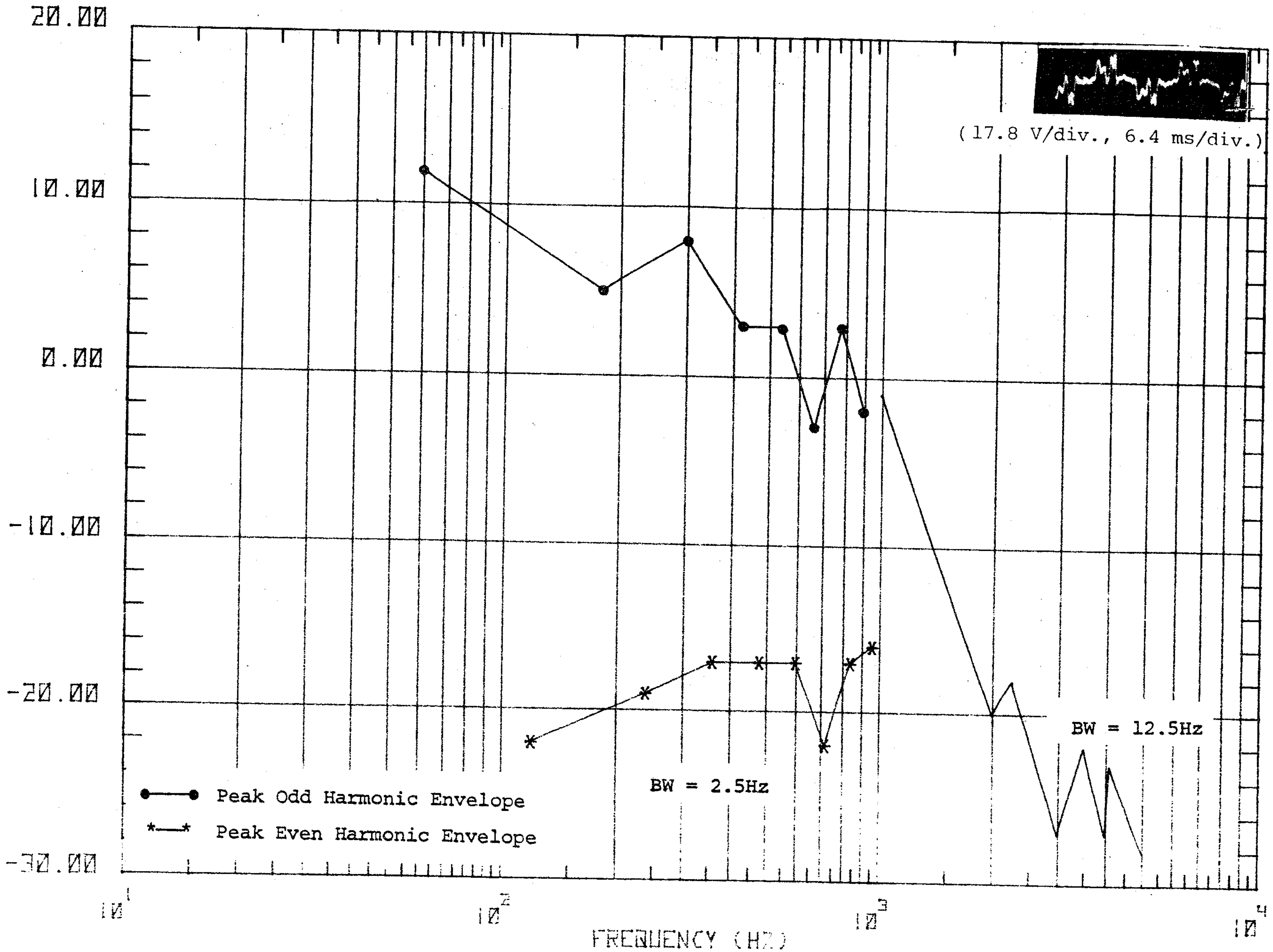


Figure 63a. Waveform and spectrum of cab signal voltage corresponding to ground side primary current waveshape #1.

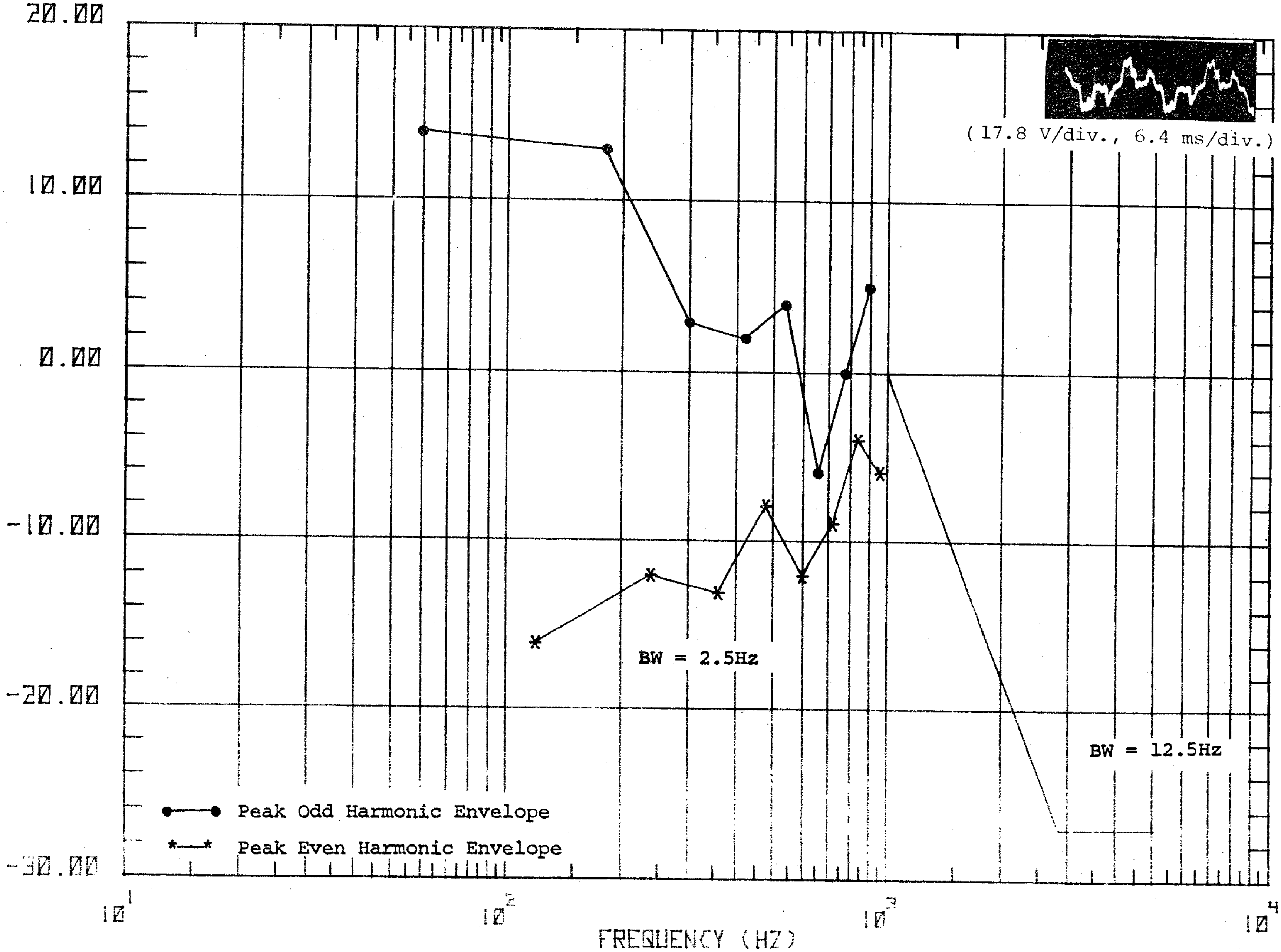


Figure 63b. Waveform and spectrum of cab signal voltage corresponding to ground side primary current waveshape #2.

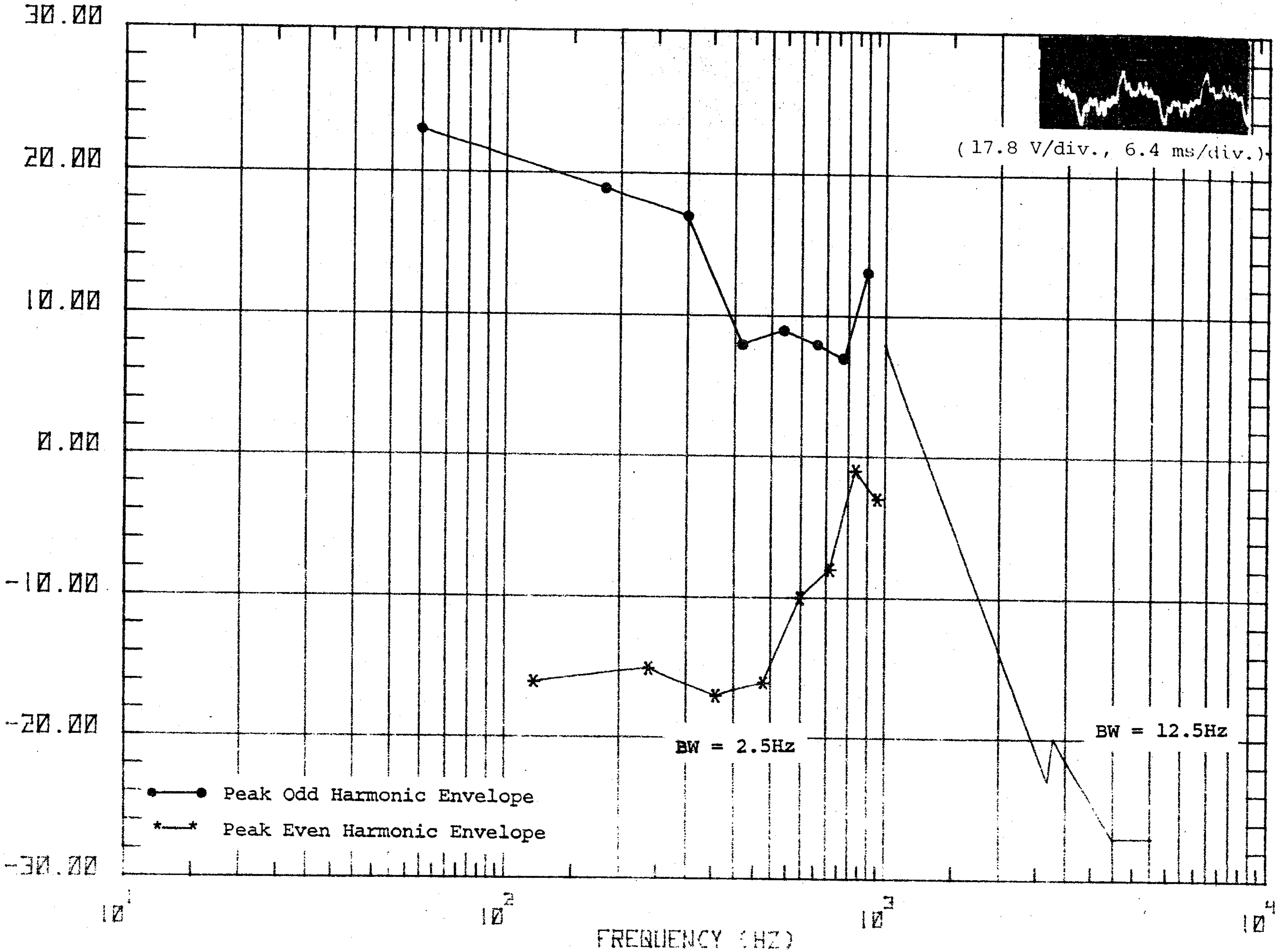


Figure 63c. Waveform and spectrum of cab signal voltage corresponding to ground side primary current waveshape #3.

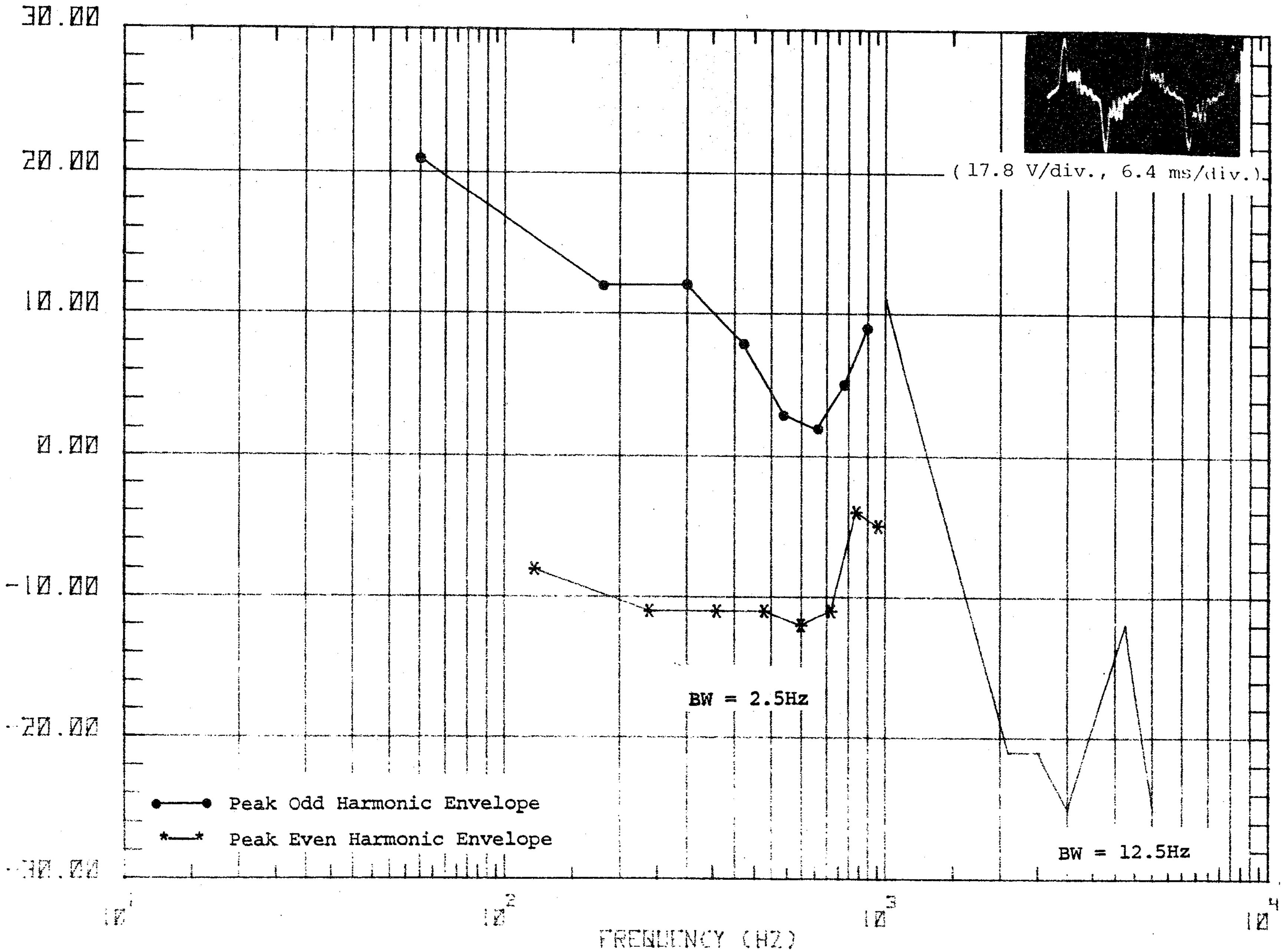


Figure 63d. Waveform and spectrum of cab signal voltage corresponding to ground side primary current waveshape #4.

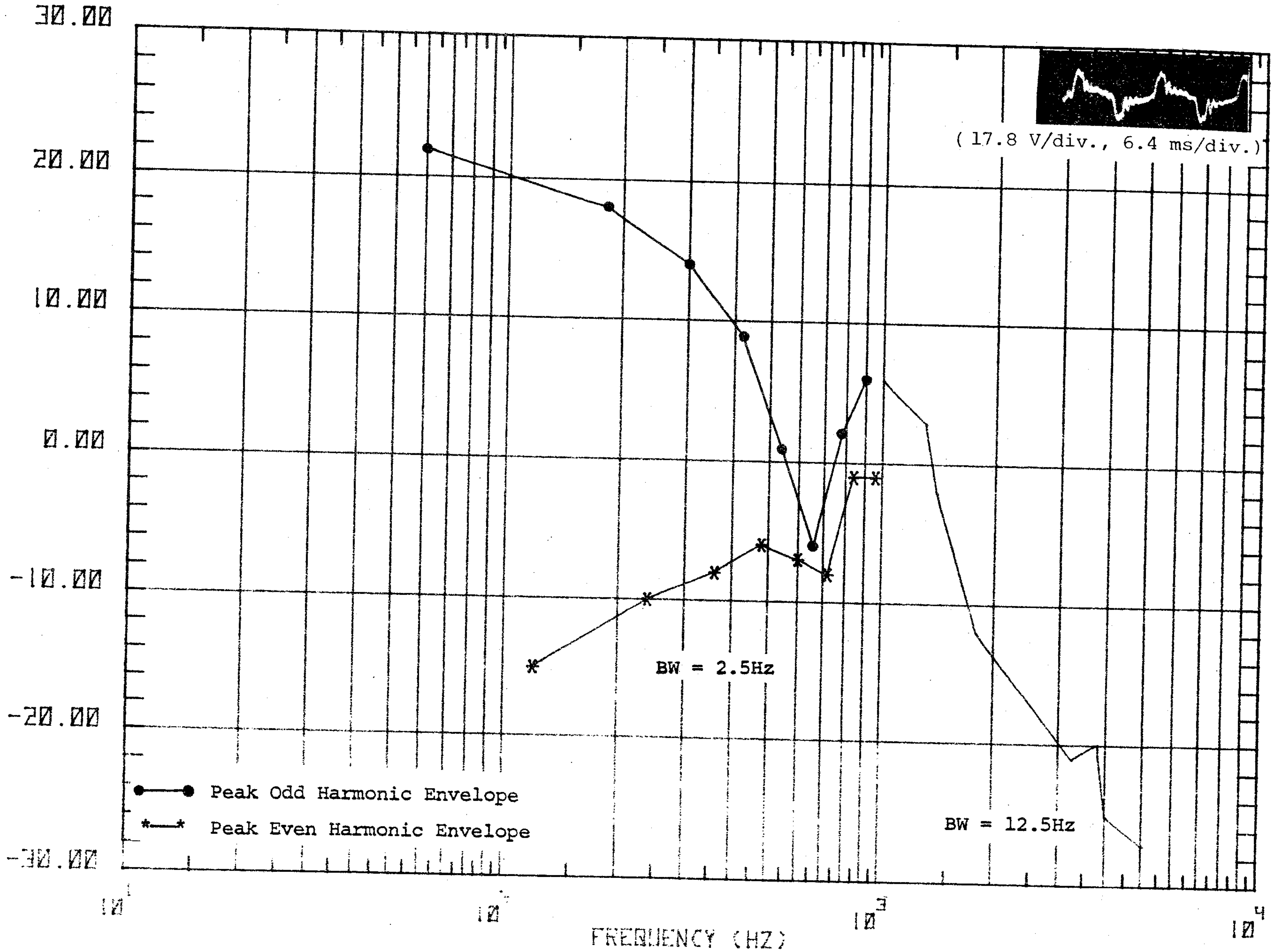


Figure 63e. Waveform and spectrum of cab signal voltage corresponding to ground side primary current waveshape #5.

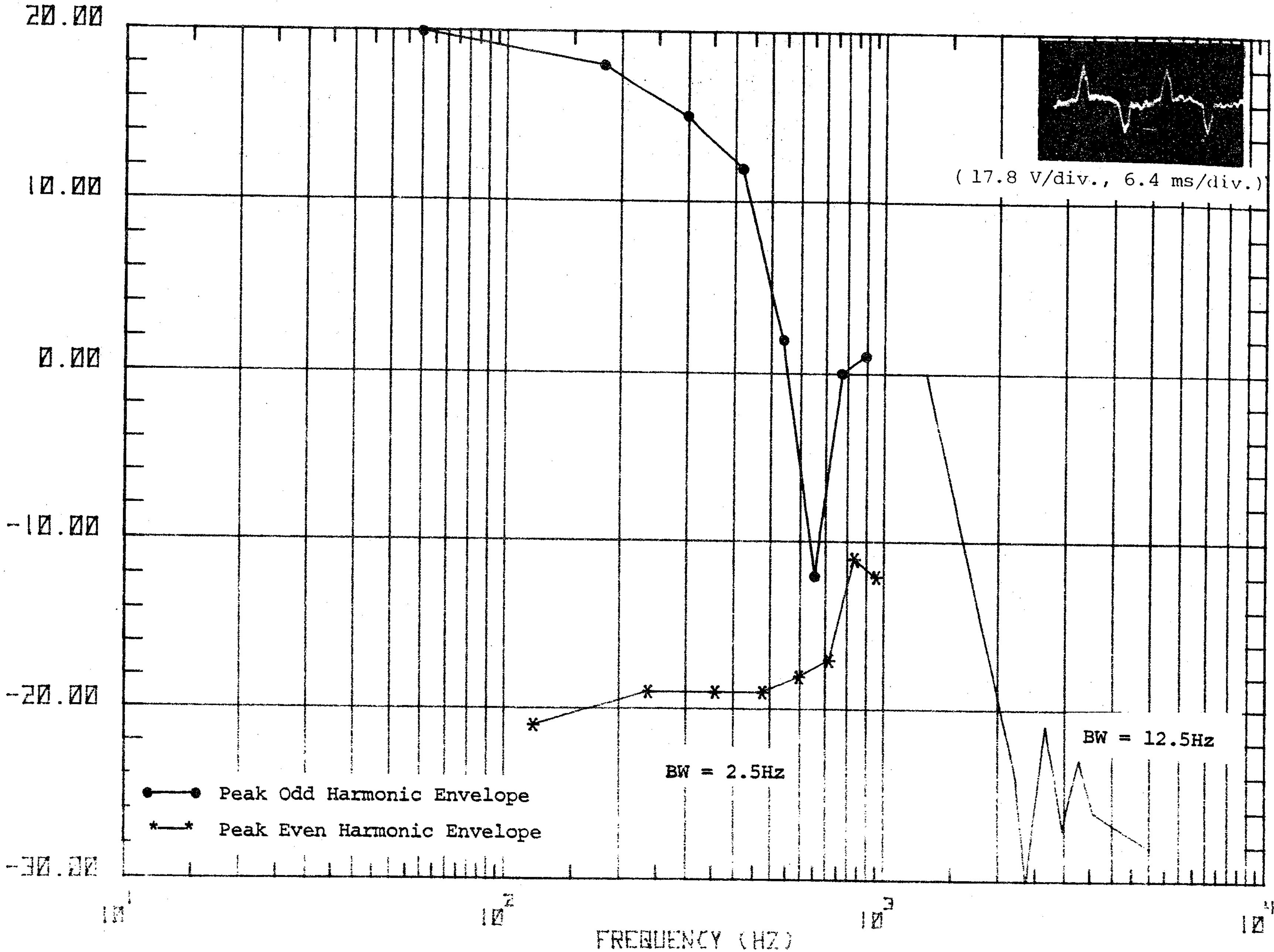


Figure 63f. Waveform and spectrum of cab signal voltage corresponding to ground side primary current waveshape #6.

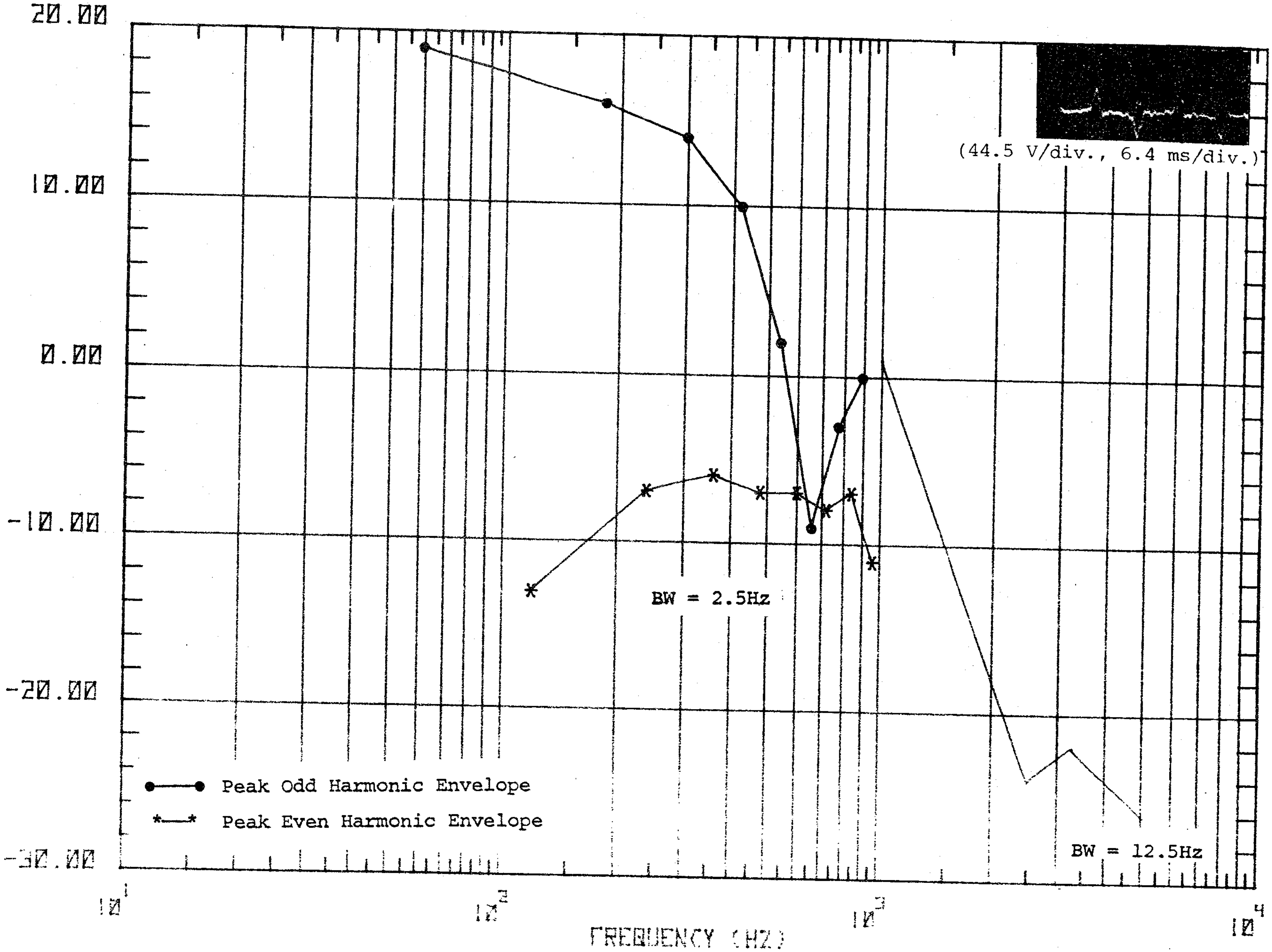


Figure 63g. Waveform and spectrum of cab signal voltage corresponding to ground side primary waveshape #7.

Cab Signal Pickup - Current Measurements

The current in the unterminated cab signal pickup situated at the rear of the locomotive was sampled using a Tektronix P6022 current probe. The currents sampled at the same time as the voltages shown in Figures 61 and 62 are given in Figures 64 and 65. From these figures, the currents sampled were extremely small, 0.30 dBA (0.032 ampere rms) and -24 dBA (0.064 ampere rms), respectively, for the 60-Hz components displayed in Figures 64 and 65.

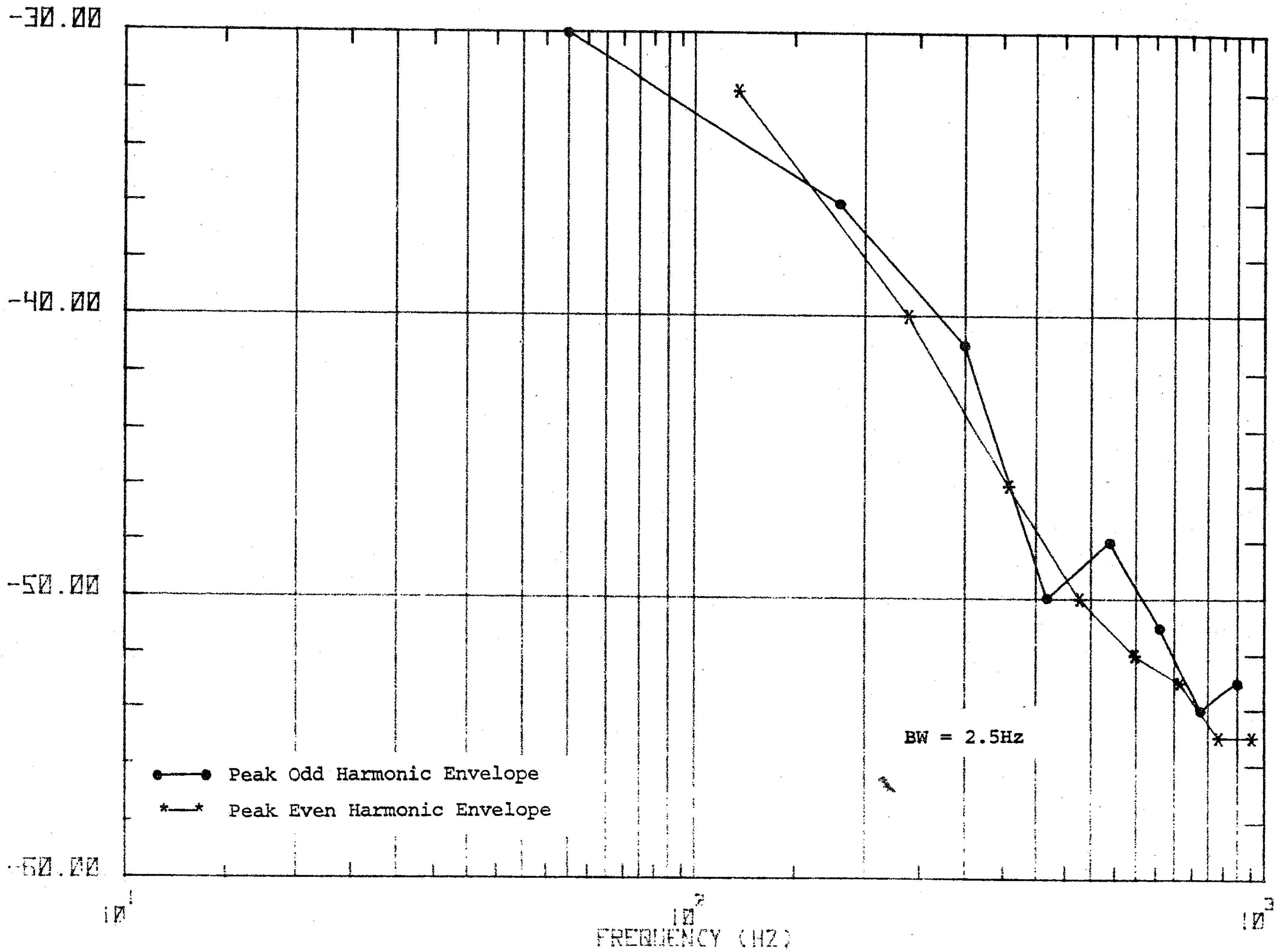


Figure 64. Spectrum of current in cab signal pickup as locomotive approaches phase break.

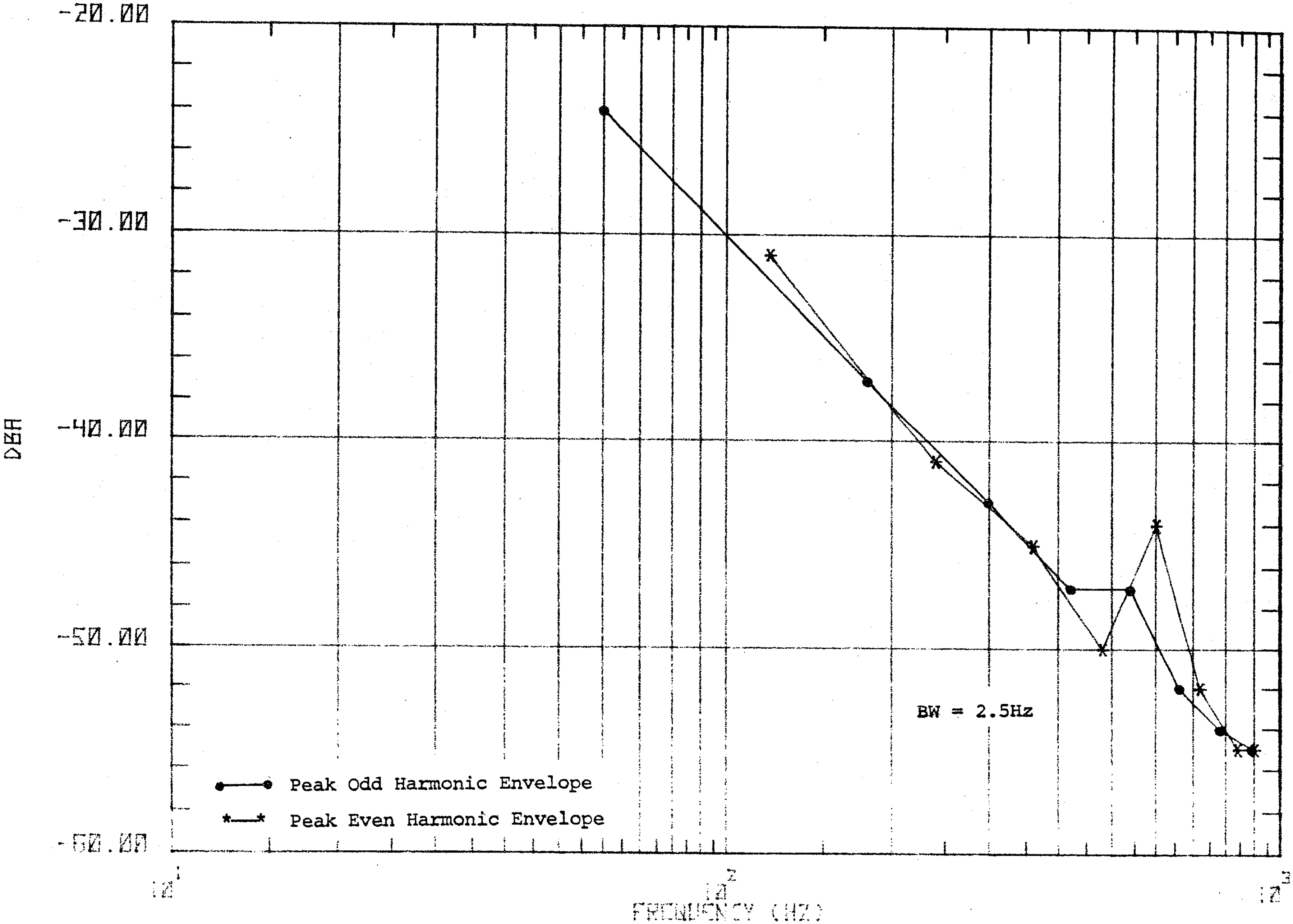


Figure 65. Spectrum of current in cab signal pickup as locomotive approaches phase break.

SECTION 4

SUMMARY

In the preceding sections, pertinent emission data and controlling parameters and the measurement methodology employed during AEM-7 emission testing in Pueblo, Colorado, during August 1980 are presented as well as same data characteristics. In the future, this data will be further analyzed, and a characterization of the locomotive emission levels will be developed. In addition, a parallel effort will be undertaken using the emission data already collected to develop a characterization of the emission levels of the E-60 locomotive. A similar data collection and analysis procedure will also be undertaken to characterize the emissions of a diesel-electric locomotive. The culmination of these efforts will be a report on locomotive emissions.