FRA/ORD-80/66.I

RAILROAD ELECTROMAGNETIC COMPATIBILITY

LOCOMOTIVE VOLUME 1

SUMMARY OF E-60 CP ELECTROMAGNETIC EMISSION YARD MEASUREMENTS

IIT Research Institute
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Annapolis, Maryland 21402

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15. Supplementary Notes This is the first of a series of interim reports documenting measurements of locomotive emission levels. A final report documenting analysis of the data and presenting a characterization of the locomotive emissions will be published in Fiscal Year 1981.

16. Abstract

Results of electromagnetic emission measurements performed on E-60 locomotives at AMTRAK's Wilmington, Delaware, Maintenance facility are presented. A description of the measurements and methodology employed is included.

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ENGLISH/METRIC CONVERSION FACTORS

LENGTH

From \ To	cm	m	km	in	ft	mi	nmi
cm	1	0.01	1x10^{-5}	0.3937	0.0328	6.21x10^{-6}	5.39x10^{-6}
m	100	1	0.001	39.37	3.281	0.0006	0.0005
km	100,000	1000	1	39370	3281	0.6214	0.5395
in	2.540	0.0254	2.54x10^{-5}	1	0.0833	1.58x10^{-5}	1.37x10^{-5}
ft	30.48	0.3048	3.05x10^{-4}	12	1	1.89x10^{-4}	1.64x10^{-4}
mi	160,900	1609	1.609	63360	5280	1	0.8688
nmi	185,200	1852	1.852	72930	6076	1.151	1

AREA

From \ To	cm^2	m^2	km^2	in^2	ft^2	mi^2	nmi^2
cm^2	1	0.0001	1x10^{-10}	0.1550	0.0011	3.86x10^{-11}	5.11x10^{-11}
m^2	10,000	1	1x10^{-6}	1550	10.76	3.86x10^{-7}	5.11x10^{-7}
km^2	1x10^{10}	1x10^{6}	1	1.55x10^{9}	1.08x10^{7}	0.3861	0.2914
in^2	6.452	0.0006	6.45x10^{-10}	1	0.0069	2.49x10^{-10}	1.88x10^{-10}
ft^2	929.0	0.0929	9.29x10^{-8}	144	1	3.59x10^{-8}	2.71x10^{-8}
mi^2	2.59x10^{10}	2.59x10^{6}	2.590	4.01x10^{9}	2.79x10^{7}	1	0.7548
nmi^2	3.43x10^{10}	3.43x10^{6}	3.432	5.31x10^{9}	3.70x10^{7}	1.325	1

VOLUME

From \ To	cm^3	liter	m^3	in^3	ft^3	yd^3	fl. oz.	fl. pt.	fl. qt.	gal.
cm^3	1	0.001	1x10^{-6}	0.0610	3.53x10^{-5}	1.31x10^{-6}	0.0338	0.0021	0.0010	0.0002
liter	1000	1	0.001	61.02	0.0353	0.0013	33.81	2.113	1.057	0.2642
m^3	1x10^{6}	1000	1	61,000	35.31	1.308	33,800	2113	1057	264.2
in^3	16.39	0.0163	1.64x10^{-5}	1	0.0006	2.14x10^{-5}	0.5541	0.0346	2113	0.0043
ft^3	28,300	28.32	0.0283	1728	1	0.0370	957.5	59.84	0.0173	7.481
yd^3	765,000	764.5	0.7646	46700	27	1	25900	1616	807.9	202.0
fl. oz.	29.57	0.2957	2.96x10^{-5}	1.805	0.0010	3.87x10^{-5}	1	0.0625	0.0312	0.0078
fl. pt.	473.2	0.4732	0.0005	28.88	0.0167	0.0006	16	1	0.5000	0.1250
fl. qt.	948.4	0.9463	0.0009	57.75	0.0334	0.0012	32	2	1	0.2500
gal.	3785	3.785	0.0038	231.0	0.1337	0.0050	128	8	4	1

MASS

From \ To	g	kg	oz	lb	ton
g	1	0.001	0.0353	0.0022	1.10x10^{-6}
kg	1000	1	35.27	2.205	0.0011
oz	28.35	0.0283	1	0.0625	3.12x10^{-5}
lb	453.6	0.4536	16	1	0.0005
ton	907,000	907.2	32,000	2000	1

TEMPERATURE

$°F = 5/9\ (°C - 32)$

$°C = 9.5\ (°F) + 32$

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SECTION 1

INTRODUCTION

BACKGROUND

The Electromagnetic Compatibility Analysis Center (ECAC) is conducting an ongoing measurement and analysis program of the electromagnetic compatibility of various aspects of the U.S. railroad system. This program is sponsored by the Federal Railroad Administration's Office of Research and Development, Freight Division (FRA/OR&D). As part of the program, ECAC has been tasked to develop measurement techniques and to measure the levels of electromagnetic emissions, both conducted and radiated, from the GP-40-2 diesel-electric and the E-60 CP and AEM-7 electric locomotives. From the data obtained, ECAC will identify sources of emissions and develop an overall characterization of each of the locomotives in terms of the levels of the frequency components of electromagnetic energy emitted by radiation and/or conduction. Results of this effort will be documented in a final report on locomotive EMC.

Characterization of the E-60 locomotive emissions entails three phases: measurements of locomotive emission levels in a yard environment (yard measurements), measurements of locomotive emission levels during a revenue run (road test measurements), and analysis of the data. The yard measurements were performed at AMTRAK's Wilmington, Delaware, and Philadelphia, Pennsylvania, facilities. This report summarizes the measurements in the yard. A consulting report summarizing the measurements taken during the revenue run will be published later in Fiscal year 1980.

OBJECTIVE OF THE YARD MEASUREMENTS

The objective of the yard measurements was to obtain data to be used as an input to the E-60 locomotive analysis and as an input in the process of selecting circuits whose emissions are to be sampled during the revenue run

APPROACH

In order to carry out the yard measurement task, the locomotive wiring diagrams of the E-60 CP locomotive were first obtained and reviewed. During this review process, locomotive subsystems that appeared to be potential sources or propagators of electromagnetic interference (EMI) were identified. Next, preliminary trips were taken to Wilmington, Delaware, to coordinate scheduling with General Electric field representatives and AMTRAK personnel. The nature of these discussions centered around technical aspects of the operation of the locomotive and identification of potential measurement locations.

Upon completion of the documentation review and technical discussion phases, the problem formulation phase was finalized. At this point, decisions were made as to which locomotive electrical circuits were to be measured. In addition, the parameters that determine the levels of emissions from these circuits were identified. Next, the measurement techniques developed during ECAC's phase one efforts were modified for the locomotive measurements. In addition, new techniques were developed in order to measure magnetic field strengths produced by circuits or components within the locomotive.

Measurements were performed at AMTRAK's Wilmington, Delaware, and Philadelphia, Pennsylvania, facilities. Since the measurements were performed on a non-interference basis and were dependent upon locomotive availability, the various measurements were not performed on one particular E-60 CP locomotive, but rather, on a number of E-60's. The data obtained from these measurements was then reviewed for data reduction purposes, and graphs of emission amplitude versus frequency were developed.

SECTION 2

SYSTEMS DESCRIPTION AND MEASUREMENT METHODOLOGY

SYSTEMS DESCRIPTION

A block diagram showing the major electrical systems of the E-60 CP locomotive is given in Figure 1. Power for the locomotive is supplied through an overhead catenary system, transmitted at 25 Hz with a nominal catenary voltage level of 11 KV. As shown in Figure 1 the secondary of the main transformer has eight windings. Six of these windings are used to power the traction motors. The seventh winding is used to power the blower motor (used to cool the main transformer and rectifiers), the oil pump motor, the cab heater and miscellaneous units in the locomotive. The seventh winding is also used to power the motor/alternator set which in turn supplies 60 Hz power to the train cars.[a]

Motive power for the E-60 locomotive is supplied by six dc traction motors (using rectified 25 Hz power). Each motor is mounted on a wheel/axle set. Three wheel/axle sets together with three traction motor and a carriage assembly constitute a truck. The E-60 is equipped with two trucks (one front, one rear). A simplified motoring diagram of a front truck is given in Figure 2. Refering to this figure, as the locomotive accelerates from standstill, tap switch number 1 is turned on, and the thyristors in bridge number 1 begin to conduct.[b] At this time, power is being supplied through secondary winding number 1 only and the locomotive is said to be operating in stage 1. When the thyristors in bridge number 1 conduct fully, assuming the locomotive still accelerates, tap switch

---

[a] This is true for the E-60's road numbered 956 to 970. The locomotives road numbered 950 to 955 do not have a motor/alternator set. Rather, they have a steam plant generator that supplies steam heat to the train cars and a diesel generator (in a trailing car) that supplies power to the train cars.

[b] A duality exists between the front and rear trucks, whereby, the thyristors in bridges 1 and 4 conduct at the same time, tap switches 2 and 5 are turned simultaneously, etc.

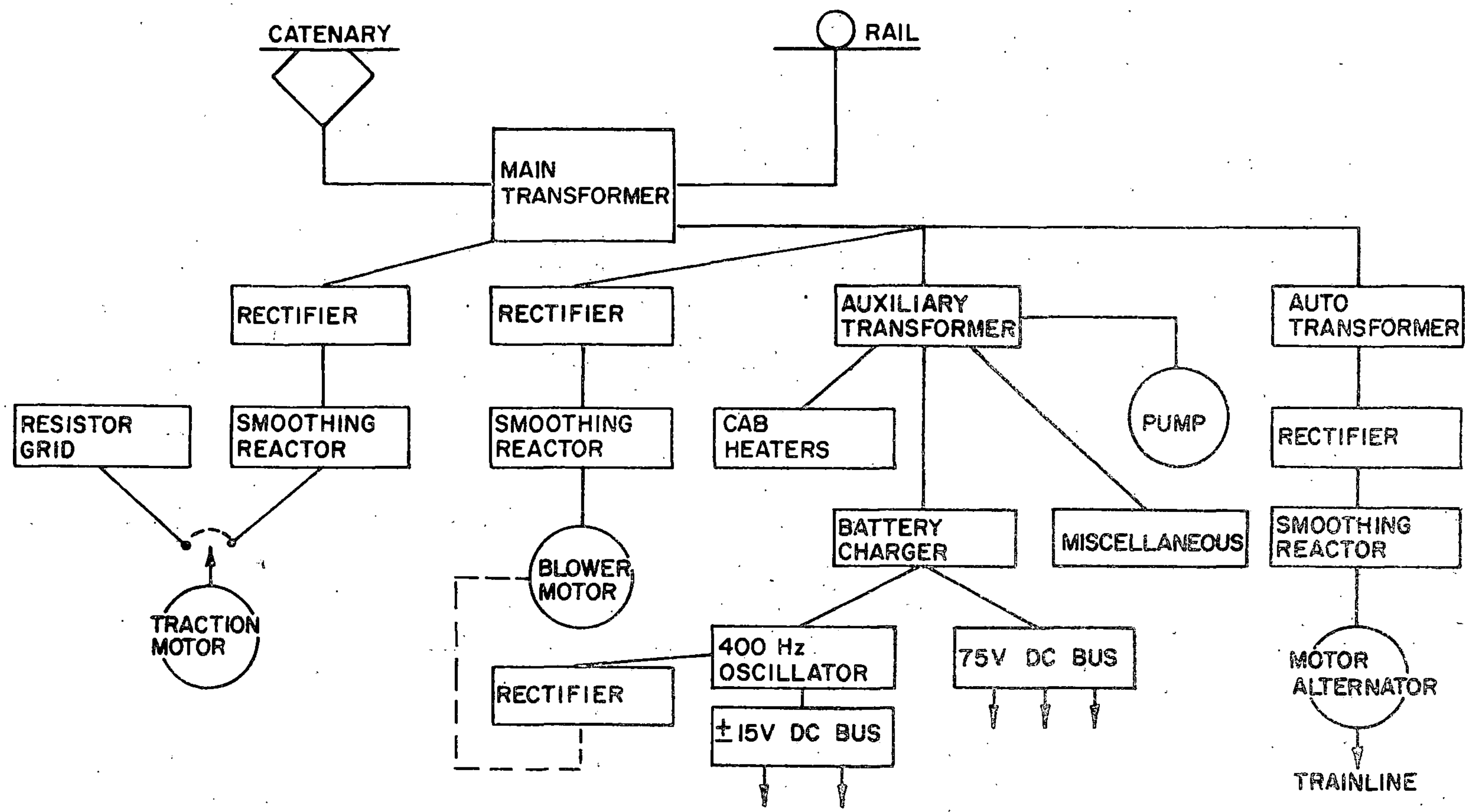


Figure 1. Block diagram of the major electrical systems of an E-60 CP locomotive.

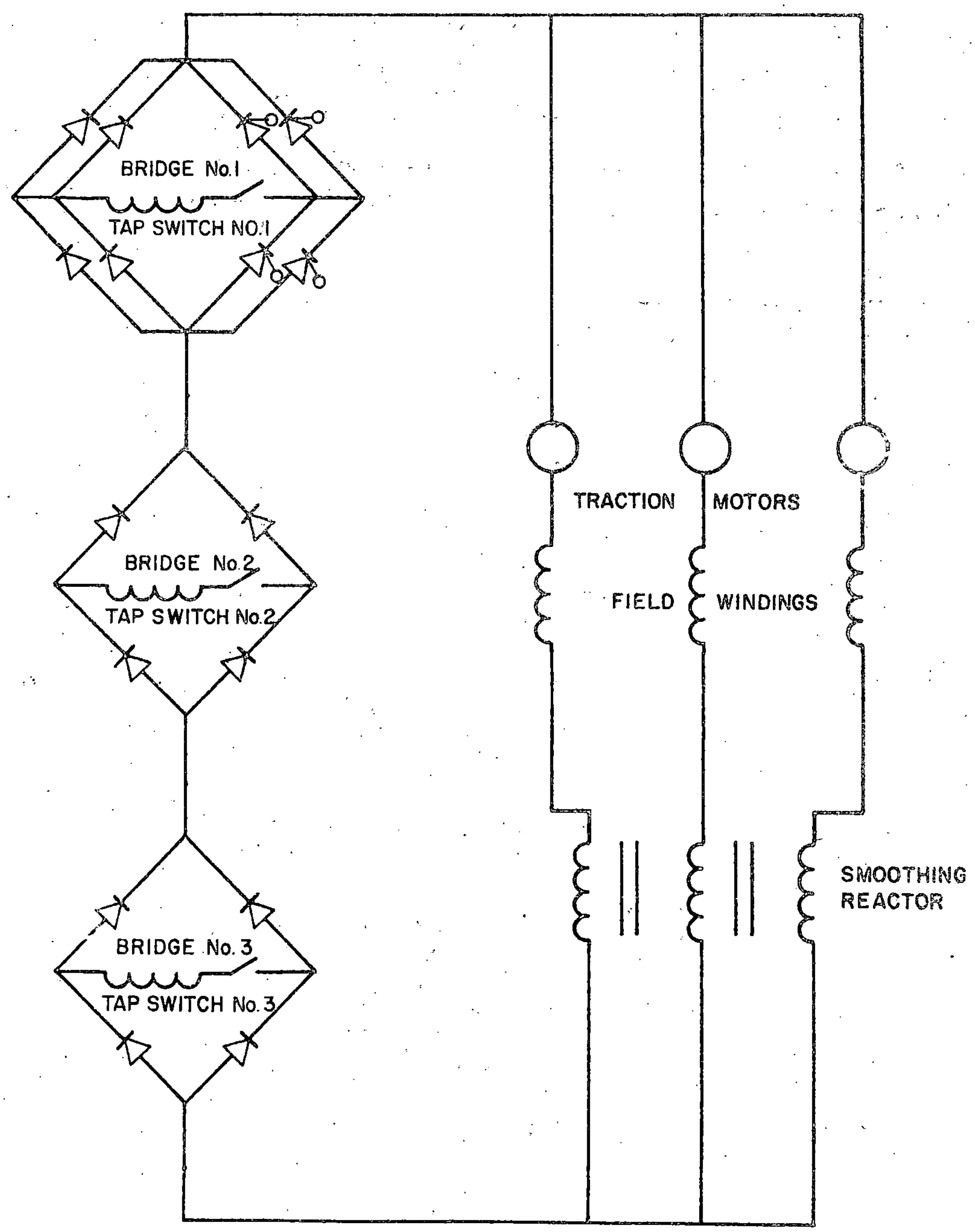


Figure 2. E-60 CP motoring diagram (1 truck).

number 2 is turned on and the number 2 secondary winding begins supplying power. At the same time that tap switch number 2 is turned on, the thyristors in bridge number 1 are retarded back to near zero conduction. The locomotive is now in stage 2. As the locomotive continues to accelerate, the thyristors in bridge number 1 again begin conducting. When the thyristors conduct fully, the third tap switch is turned on, and, simultaneously, the thyristors are retarded back to near zero conduction. The locomotive is now in stage 3. Again assuming the locomotive still accelerates, the thyristors will begin conducting and continue conducting up to maximum desired speed.

The locomotive is equipped with two types of brakes: service (air) and dynamic. Service brakes (shoe type) are used when the locomotive is traveling at very slow speeds (a few miles per hour) or, along with the dynamic brakes, under emergency stop conditions. In dynamic braking, the reaction motor leads are interchanged, and the motors become generators that supply power to a resistor grid. This power is then dissipated as I^2R heat losses.

MEASUREMENT METHODOLOGY

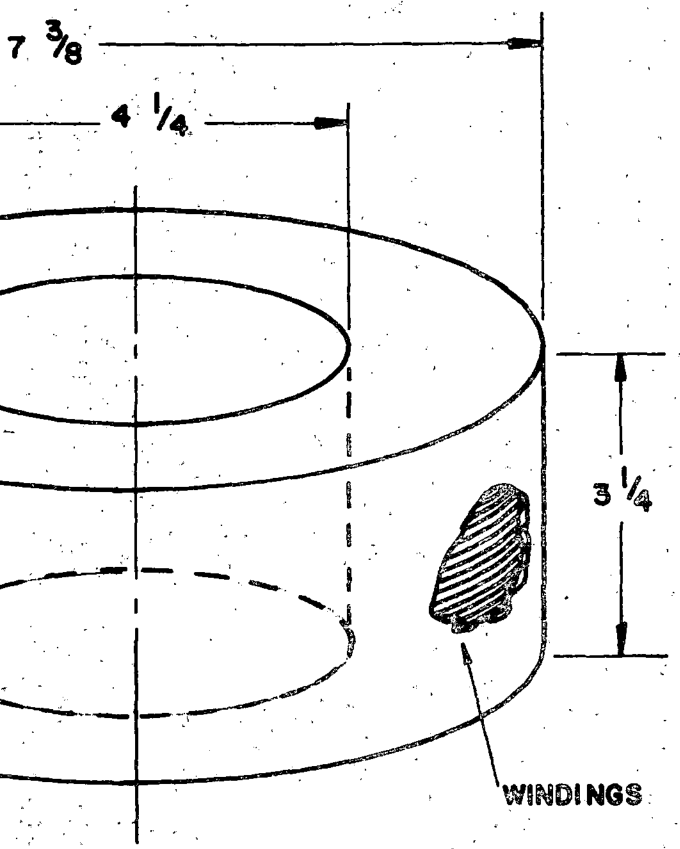
Measurement Equipment

The generic test equipments used in performance of the locomotive measurements and their respective functions are listed in TABLE 1. The swept type spectrum analyzers used, the Tektronics 7L5 and 7L13, displayed signal amplitudes as a function of frequency within the desired frequency range (25 Hz to 500 MHz). The oscilloscope selected, the Tektronics 7834/7A24/7B53, along with a C5A scope camera, provided time domain waveform photographs of the electromagnetic emissions. The Tektronics oscilloscope has a bandwidth of 300 MHz. This bandwidth was essential in order to resolve the rise times of the various transients produced within the locomotive.

The loop probe was used to measure both time varying magnetic fields and conducted ac currents throughout the frequency range of 25 Hz and 1 MHz.[a] The loop probe was designed, fabricated, and calibrated at ECAC because it was not available commercially. The probe samples the magnetic flux produced by the current in a conductor and produces an open circuit voltage at its terminals that is directly proportional to the rate of change of flux (see Figure 3b). The probe is terminated in a three ohm resistor. The terminal voltage is inversely proportional to the rate of change of flux, given a constant open circuit voltage. By the combination of the above two effects, the resulting terminated voltage is independent of the rate of change of flux throughout the frequency range of 25 Hz to 1 MHz.

[a] The loop probe is a coil consisting of approximately 17 lbs. of number 14 AWG wire wound into 1000 turns around a non-magnetic material as noted in in Figure 3.

Figure 3a.



Dimensions of ECAC current/magnetic field strength loop probe.

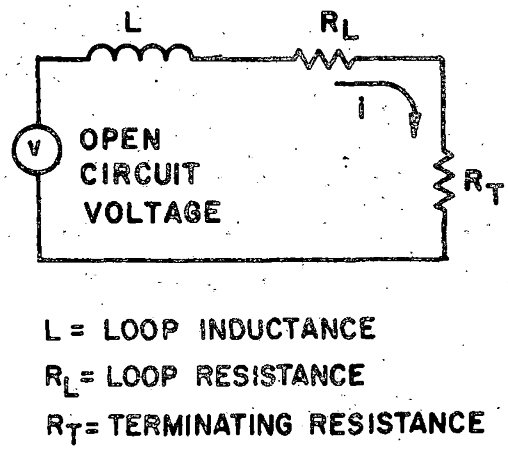


Figure 3b. Equivalent electrical circuit diagram.

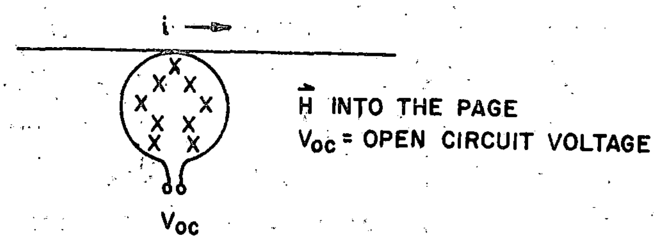


Figure 3c. Direction of magnetic field set up by current in a wire.

In order to obtain the appropriate loop probe factor, the loop was calibrated by injecting a known current into a wire of sufficient length so that edge effects are neglible (approximately 8 feet). The loop was placed against the wire, and the voltage was measured at the loop terminals. The procedure was then repeated with the wire and loop placed 2 feet above ground (in order to determine if the floor had any effect on the calibration procedure) and also with the loop placed against a four foot section of rail being used as the current carrying conductor.

The last two items listed in TABLE 1 are the voltage and electric field strength probes. The voltage probes used, the Tektronics 6201 probes, included X1, X10, and X100 dividers. The antennas used for electric field strength measurements were the Empire VA-105 antenna (14 kHz to 30 MHz), a 41 inch whip antenna (25 Hz to 19 kHz), and the same whip antenna connected to the Tektronics P6201 probes (30 MHz to 500 MHz).

Locomotive Measurement Techniques - General

The measurements performed may be separated into four categories: electric field strength, magnetic field strength, conducted current and terminal voltage measurements. The electric field strength measurements were performed with the antennas polarized both horizontally and vertically at various radial distances and azimuthal angles from the locomotive so as to obtain a representation of the electric field strength radiation characteristics. The magnetic field strength measurements were also performed at various radial distances and azimuthal angles in order to obtain a representation of the induction fields produced by the locomotive. Measurements of currents and voltage were performed on circuits within the locomotive in order to characterize their respective amplitudes and spectra. In addition, current measurements were made on the rails in order to ascertain the levels of the frequency components of the current in the rails.

Electric Field Strength Measurements

The configuration for electric field strength measurements is shown in Figure 4. The antenna was first placed close to the locomotive (approximately 1 meter) and polarized vertically. The antenna output was then

TABLE 1

SOURCE MEASUREMENT EQUIPMENTS

EQUIPMENT	FUNCTION
Spectrum Analyzer(s)	Display amplitudes of emissions vs. frequency from 25 Hz to 500 MHz
Oscilloscope	Display amplitude of waveforms vs. time
Oscilloscope Camera	Photograph spectrum analyzer and oscilloscope displays
Loop Probe	Measure current and magnetic field strength from 25 Hz to 1 MHz
Amprobe	Measure currents within the frequency range of 25 Hz and 300 kHz
Voltage Probes	Measure voltages over a frequency range of dc to 500 MHz
Electric Field Strength Probes	Measure electric field strengths over a frequency range from 25 Hz to 500 MHz

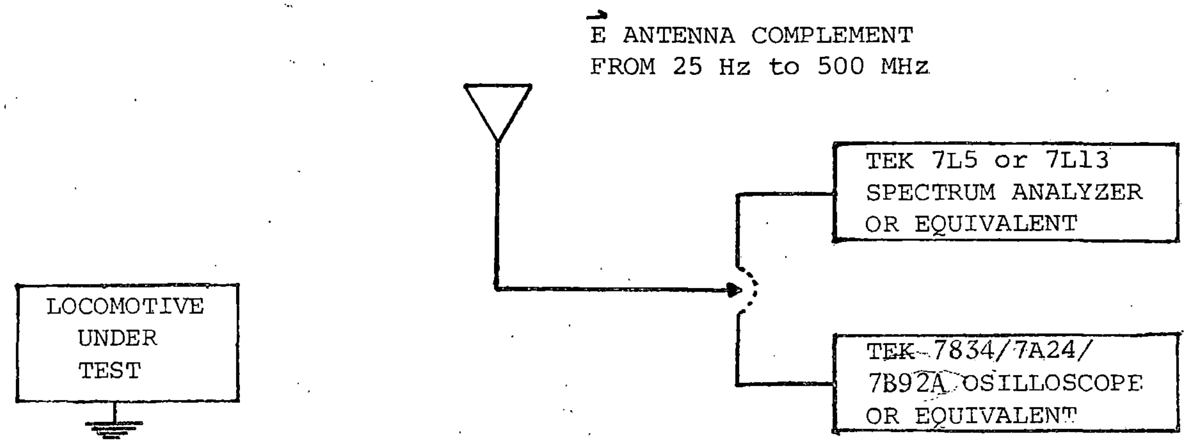


Figure 4. Radiated electric field strength source measurement test configuration.

connected to the oscilloscope, and from the displayed output, it was determined whether the radiated emissions could be detected. If signals of sufficient strength were noted, then frequency domain measurements were performed between 25 Hz and 500 MHz. This frequency range was selected because the lower bound (25 Hz) is the fundamental frequency of the power grid for the railroad while the upper bound (500 MHz) is slightly higher, in frequency, than the highest UHF frequency allocated for railroad radio communications use (non-microwave links). The spectrum analyzer was set on a maximum hold position so as to accummulate the maximum spectral level at each frequency. Photographs and germane comments were taken for all measurements. The above procedure was then repeated with the antennas polarized horizontally.

Upon completion of measurements at the initial location, time domain measurements were performed at various locations around the locomotive with the antennas both horizontally and vertically polarized. During this procedure, points where emission levels appeared to be highest were recorded. The antenna was then placed at each of these locations, and time and frequency domain measurements were performed radially outward at octave distances from the locomotive to the point where practical aspects of the surroundings and/or equipment sensitivities limited further measurements.

Magnetic Field Strength Measurements

The procedure used for magnetic field strength measurements was the same as that noted above for electric field strength measurements with two exceptions. First, the magnetic field strength loop probe was used instead of the antenna assortment (see Figure 5). Second, since the loop probe responds to magnetic field strengths between 25 Hz and 1 MHz, measurements were limited within this frequency range.

Conducted Current Measurements

The test configuration used to measure conducted currents is shown in Figure 6. The procedure used for conducted current measurements was as

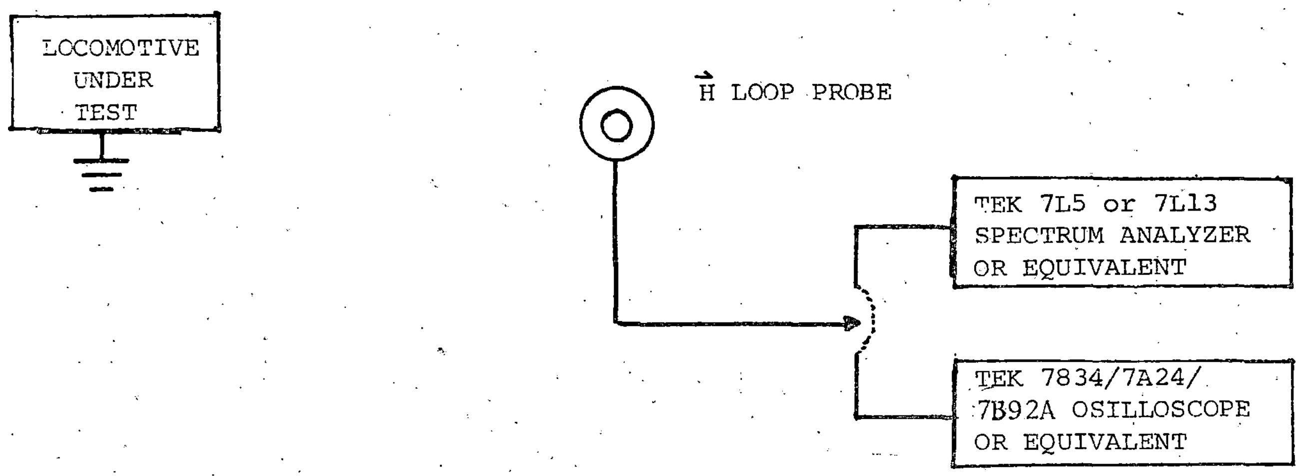


Figure 5. Magnetic field strength measurement test configuration.

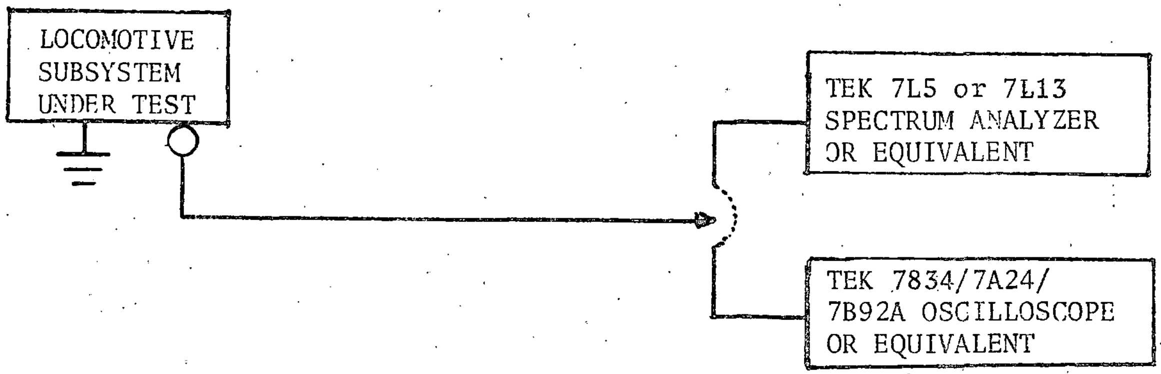


Figure 6. Conducted current test configuration.

follows: First, time waveform measurements were taken using the current loop probe in order to obtain a display of current amplitude versus time. Three types of waveforms were recorded: a display showing a long time periodicity (many cycles), a display showing one cycle, and a display of a portion of one cycle detailing leading edge information. Second, measurements of the maximum levels of energy versus frequency were taken between 25 Hz and 1 MHz, with photographs and germane comments for each measurement.

In the case of rail current measurements, measurements were then taken at octave distances from the locomotive along the rail, to the point where practical engineering judgement warranted discontinuance, in order to ascertain the degree of attenuation occurring in the rail.

Terminal Voltage Measurements

The test configuration for measurements of terminal voltages (i.e., battery, dc buses, etc.) is shown in Figure 7. As in the case of the current measurements, three photographs of the waveform were taken (long time periodicity, one cycle, portion of one cycle detailing leading edge information). Measurements of voltage levels versus frequency were then performed from dc to frequencies where the signals approach the noise level of the analyzer (maximum 100 MHz). Both the time waveform and frequency spectra measurements were performed while the locomotive subsystem under test was operating in its normal steady state and also during any transition states.

UNITS OF MEASURED DATA

The data obtained from the spectrum analyzer display were given in terms of dBV (decibels above one volt). These units were then converted to appropriate units for the various tests performed. The units used were dBA (decibels above one ampere) for conducted currents, dBV for terminal voltage measurements, dBV/m (decibels above one volt per meter) for electric field strength measurements, and dBA/m (decibels above one ampere per meter) for magnetic field strength measurements. The equations for conversion are as follows:

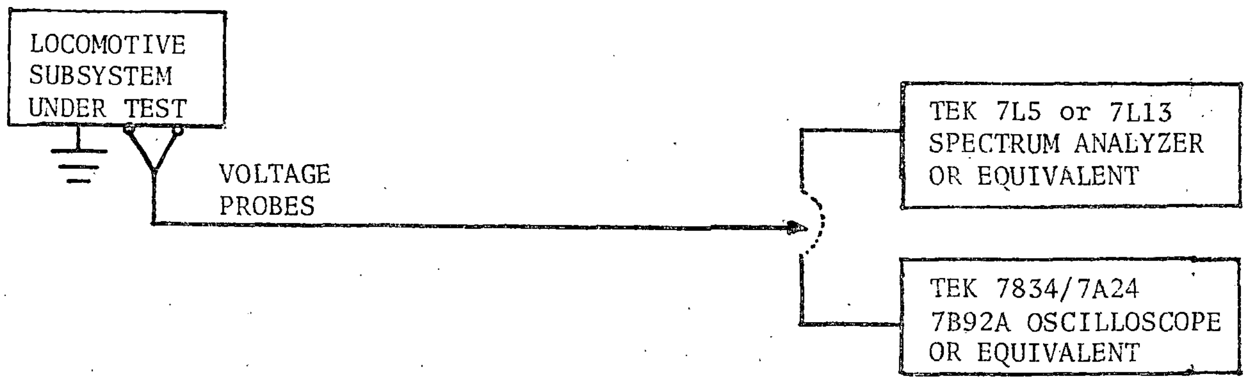


Figure 7. Terminal voltage test configuration.

$$dBA = dBV + PF_I + BWF \quad (1)$$

$$dBV = dBV + PF_V + BWF \quad (2)$$

$$dBA/m = dBV + AF_H + BWF \quad (3)$$

$$dBV/m = dBV + AF_E + BWF \quad (4)$$

where

BWF = bandwidth factor, in dB

PF_I = loop probe conversion factor, equals 59 dBA/V for a 3 ohm load and 35 dBA/V for a 50 ohm load[a] for the frequency range of 20 Hz to 1 MHz

PF_V = voltage probe factor, equals 0, 20, 40 and 59 dB for the X1, 10, 100, 1000 voltage probes respectively for the frequency range of dc to 100 MHz

AF_H = magnetic field strength antenna factor, equals 64 dBA/m/V for frequency range of 20 Hz to 1 MHz

AF_E = electric field strength antenna factor, in dBV/m/V.

Bandwidth Factor

When the energy of the received signal is distributed throughout the frequency band, instead of being concentrated at one or more specific frequency(s), the energy should be expressed on a per unit bandwidth basis. When the waveform of this received signal is impulsive, the analyzer amplitude response will be in direct proportion to the analyzer bandwidth. When the waveform of the signal is continuous but noise-like (White Gaussian noise), the analyzer will respond in proportion to the square root of the bandwidth. These statements are based on the analyzer responding to the peak value of the processed waveform.[1] For normalizing the data to a specific bandwidth, for example 10 kHz, the following equations should be used:

---

[a] These values only valid for the probe calibration shown in Figure 8.

[1] Martin, H., A Model of the Parameters of Man-Made Electrical Noise as a Function of Bandwidth, ECAC-TN-78-006, ECAC, Annapolis, MD, April 1978.

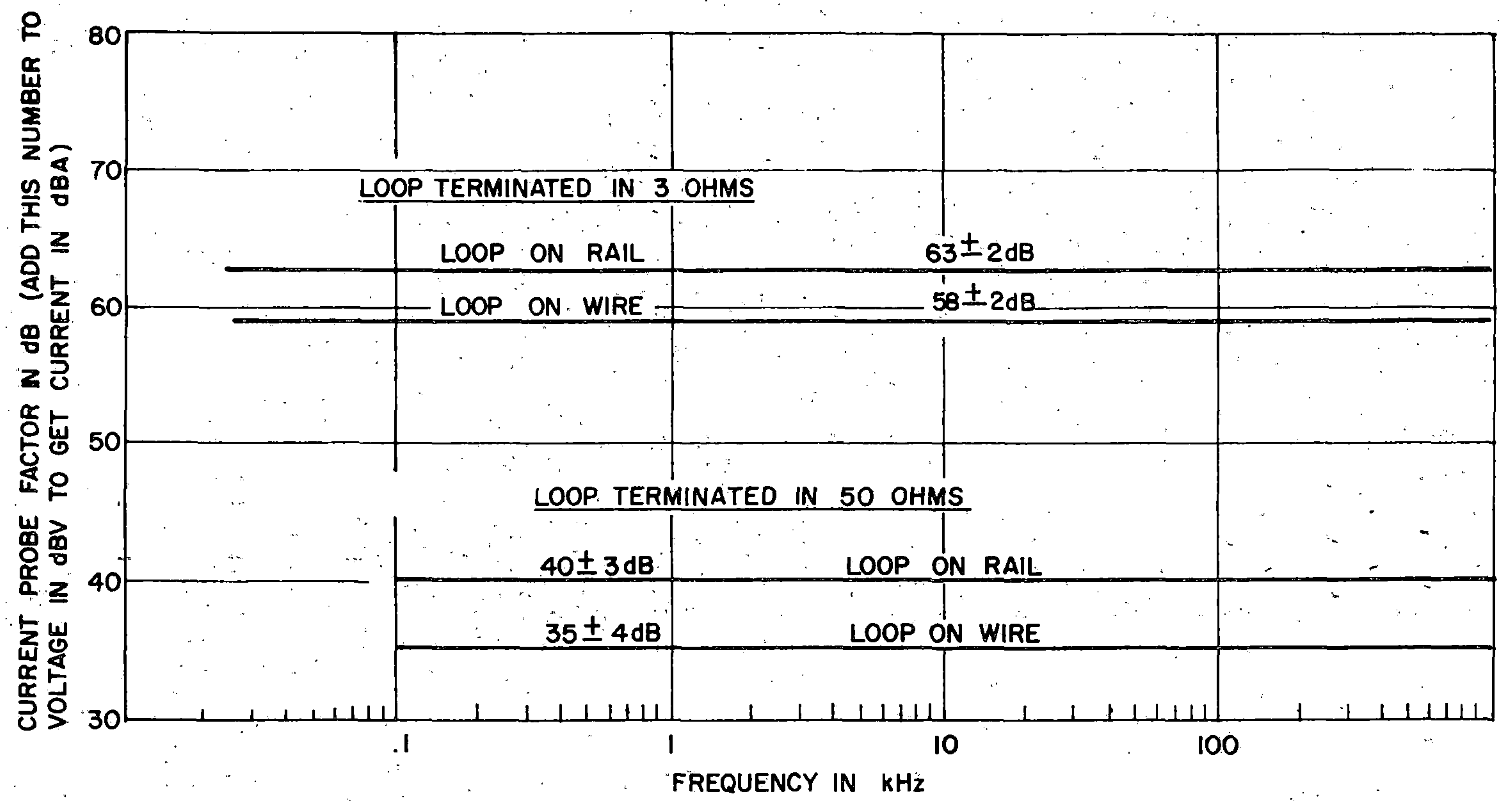


Figure 8. Current/magnetic field strength probe conversion chart.

$$BWF = -20 \log \frac{BWM}{10} \qquad (5)$$

for impulsive noise.

For continuous noise,

$$BWF = -10 \log \frac{BWM}{10} \qquad (6)$$

For specific frequencies (e.g., harmonics, spectral lines)

$$BWF = 0$$

where

BWM = analyzer bandwidth, in kHz.

Probe Factor

The probe factor is a frequency independent conversion factor used when converting measurements (between 25 Hz and 1 MHz) obtained using the loop probe from voltage to current units. The factor, expressed as a function of frequency, is given in Figure 8. The whip antenna and termination antenna factor relates the electric field strength to the voltage the antenna delivers to a 50 ohm resistor.

SECTION 3

MEASUREMENT RESULTS

INTRODUCTION

The locomotive yard measurement effort involved sampling time waveforms and/or frequency spectra of currents and/or voltages of various electrical currents within the locomotive that were identified either to be potential sources of emission or to be potentially susceptible to these emissicns. In addition, time waveform and/or frequency spectra samplings of current in the rail and of magnetic and electric field strength were obtained. Systems identified as being potential sources included the blower motor, smoothing reactor, catenary, and the traction motors. Systems that were identified initially either as being potential propagators or as being potentially susceptible to electromagnetic interference included the main transformer, cab signal pick-up system, and the 5, 15, and 74 volt dc buses. In the following sections, results of these measurements are given.

1.0 MAIN TRANSFORMER

The following measurements were performed on the ground side of the primary winding of the main transformer under the following conditions:

1.1 current measurements with the main transformer breaker open
1.2 current measurements with the breaker closed and all major electrical systems off
1.3 current measurements with the oil pump motor on and the blower motor on idle
1.4 current measurements with the oil pump on, blower motor on full speed, and the motor/alternator (M/A) set on idle (unloaded)
1.5 current measurements with the oil pump on, blower motor on full speed, and the M/A set on run (unloaded)
1.6 current measurements with the oil pump motor on, blower motor on full, and the traction motors on

1.7 current measurements with the oil pump motor on, blower motor on full, dynamic brakes on, and the M/A set on run (unloaded)

1.8 current measurements with the oil pump motor on, blower motor on idle, and pantograph making and breaking contact.

The first set of data was taken at AMTRAK's Wilmington, Delaware, maintenance facility with the loop probe coupled to the ground side primary of the main transformer of an E-60 CP locomotive with the main breaker switch open (Figure 9). During this and all other measurements on the main transformer primary, unless otherwise noted, a ground strap (from the main transformer to ground) providing a current path parallel to the test point was disconnected. The current spectrum recorded for this ambient condition is shown in Figure 10. A 25 Hz fundamental frequency with an amplitude of -24 dBA (63 milliamperes), induced from the 11.5 KV catenary was observed. The same test was repeated later that night on a different E-60 CP at AMTRAK's Race Street facility in Philadelphia. These results are shown in Figure 11. In this test, the induced fundamental was 110 milliamperes (-19 dBA). For frequencies above 100 kHz, the current spectrum levels were less than -110 dBA (3.16 micro-amperes), as recorded in a 3 kHz spectrum analyzer bandwidth.

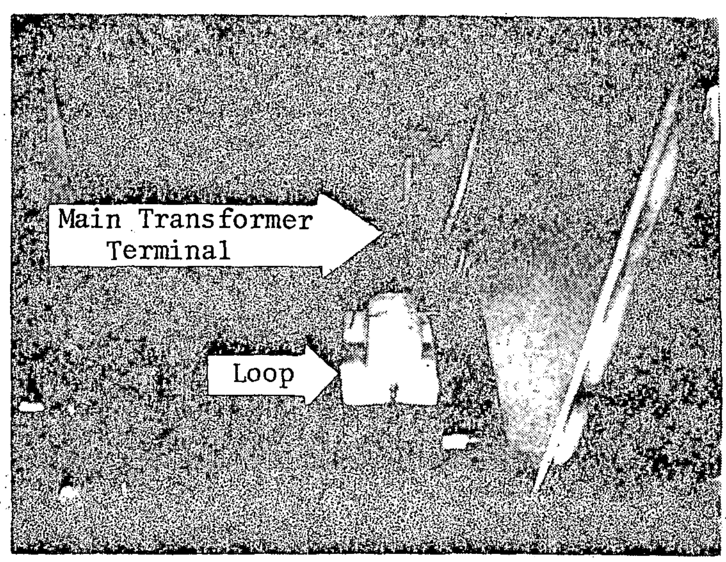


Figure 9. Current loop up against the ground side terminal of the primary winding of main transformer.

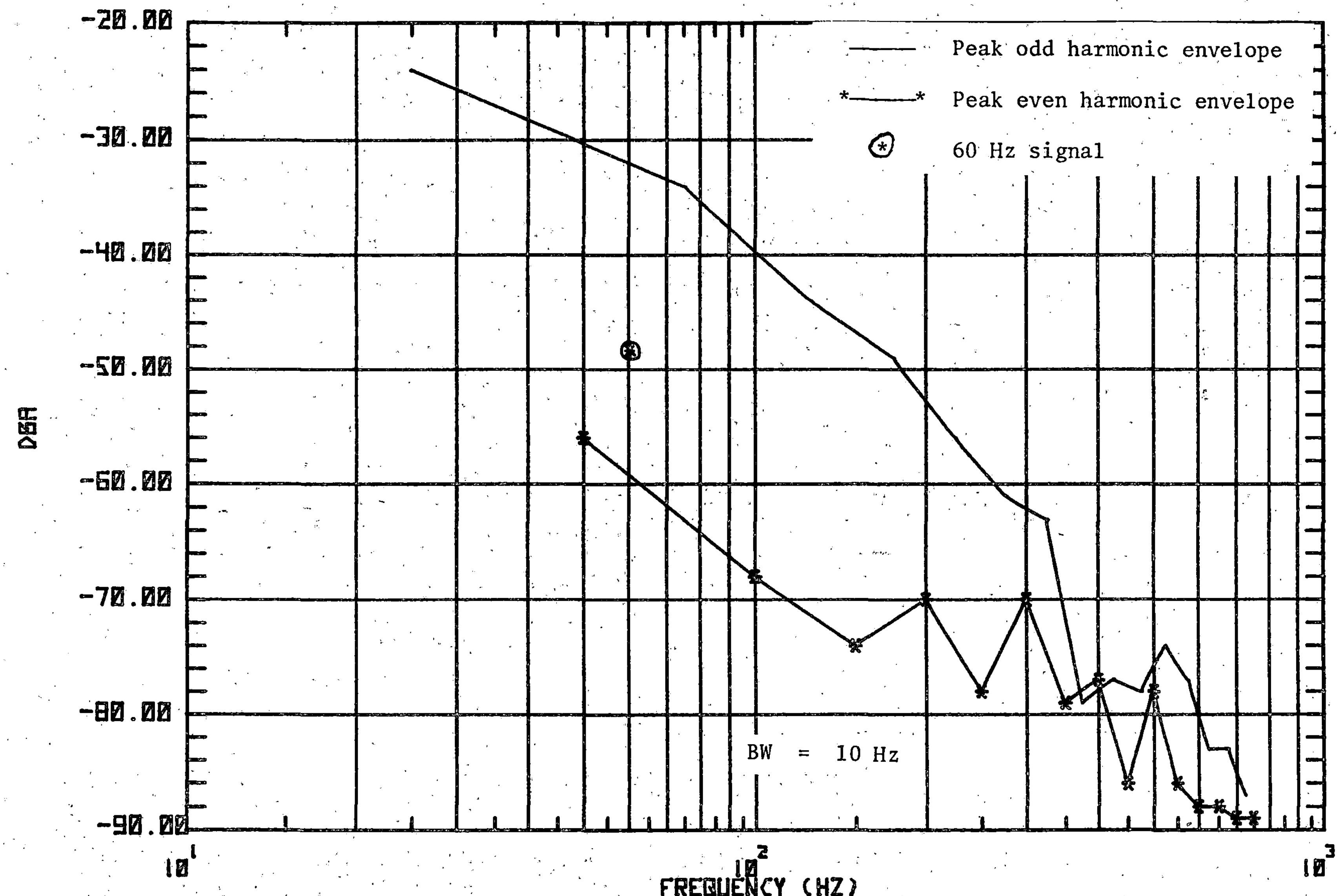


Figure 10. Primary current of main transformer with pantograph breaker switch open-Wilmington.

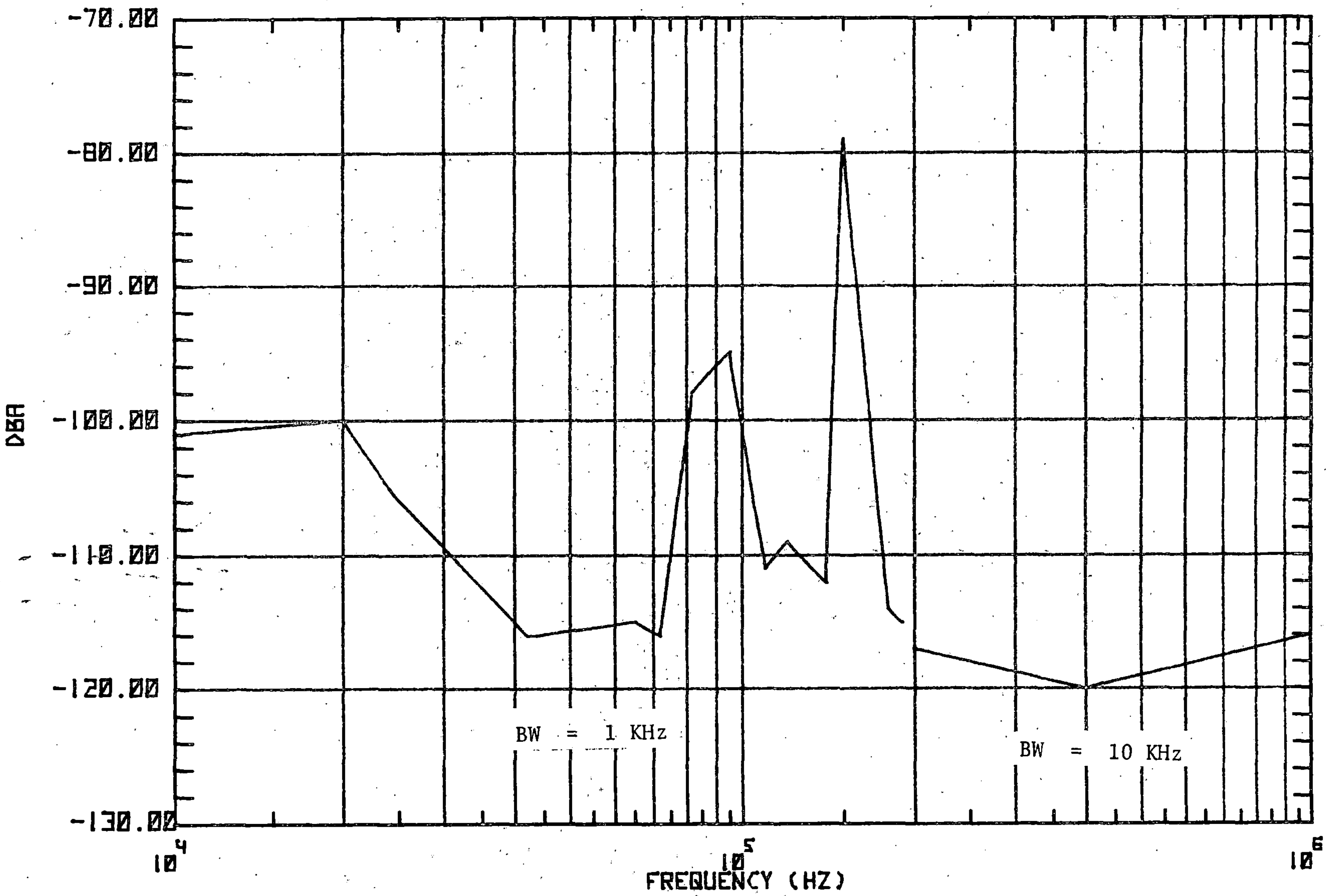


Figure 10. (continued).

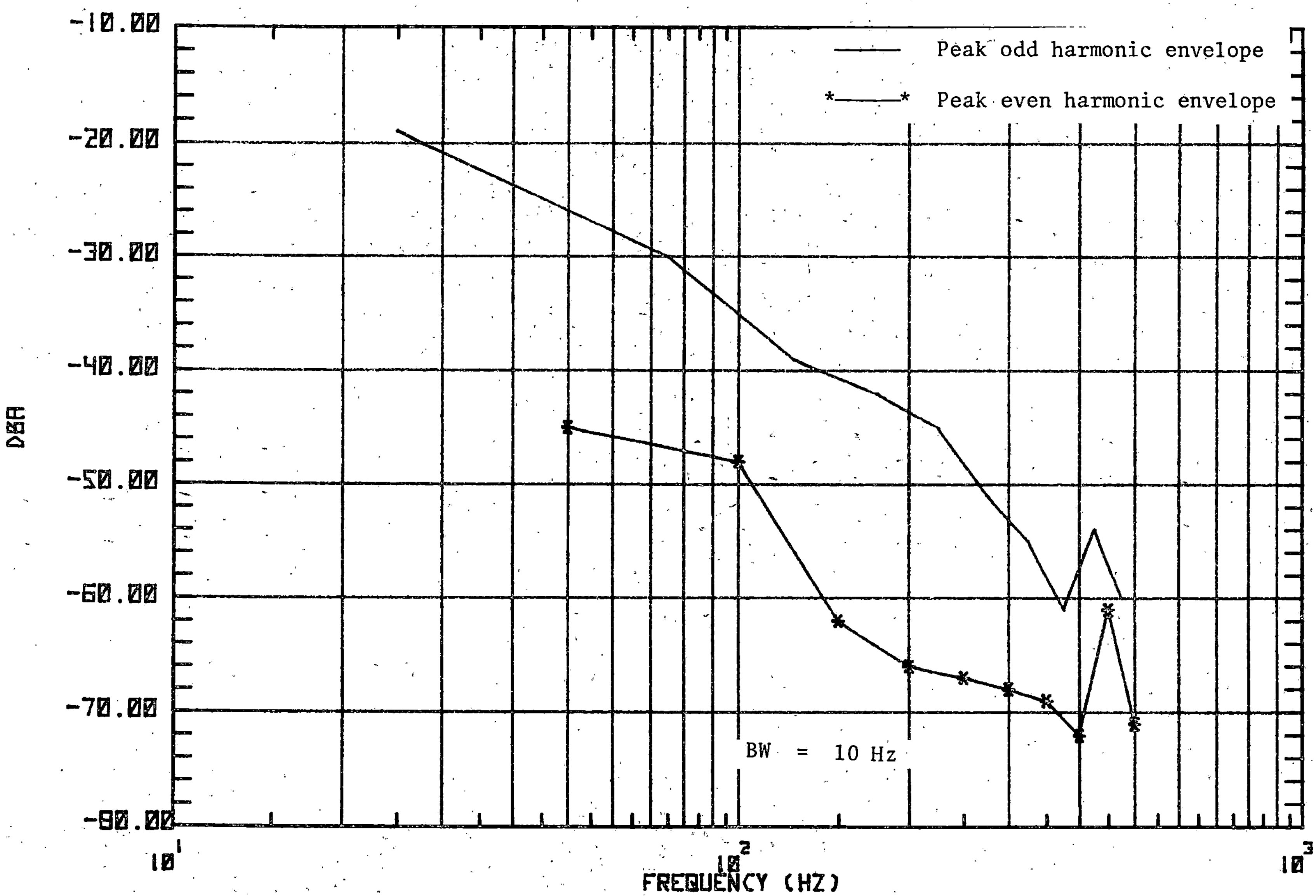


Figure 11. Main transformer primary current with main breaker open-Philadelphia.

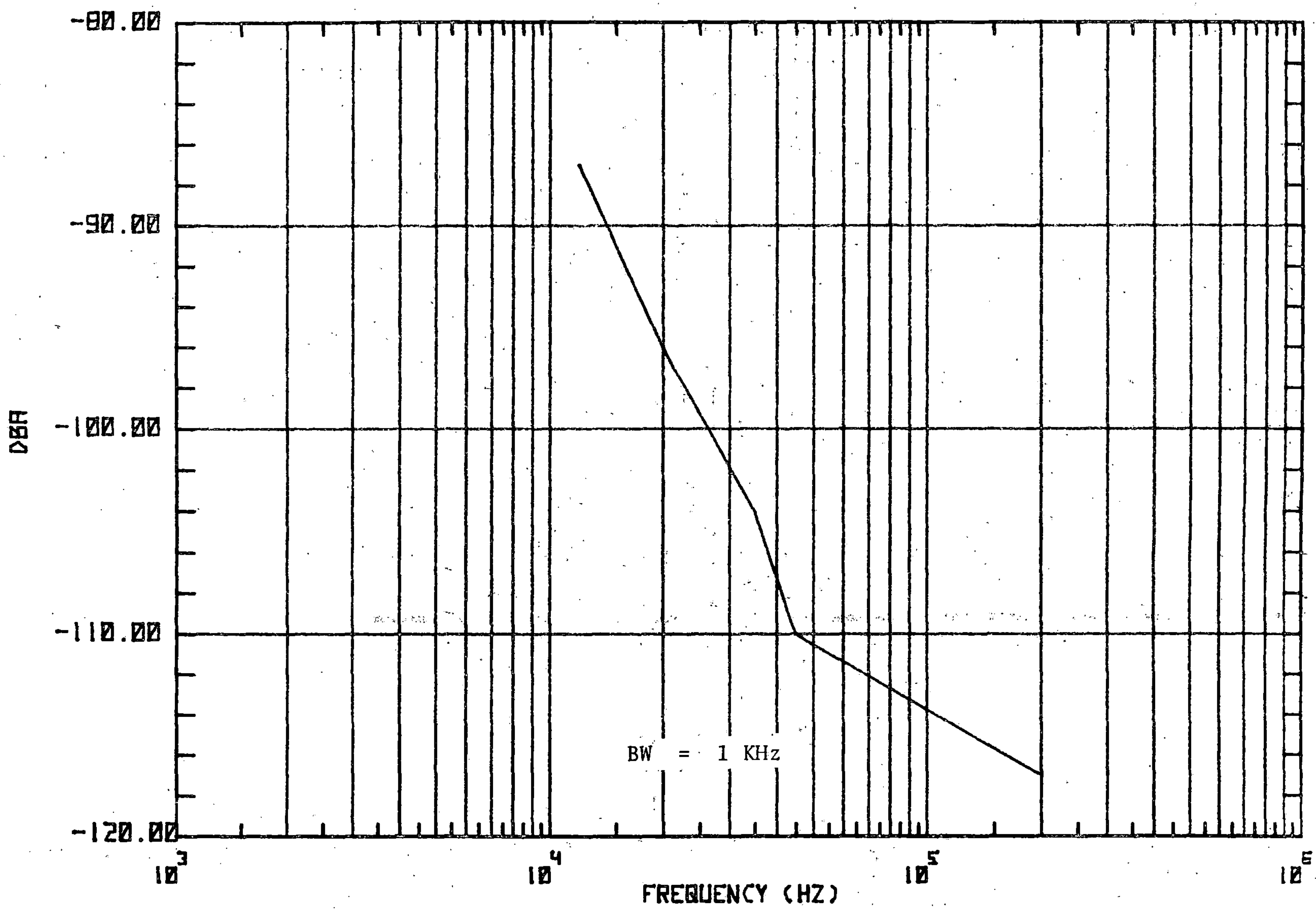


Figure 11. (continued).

Measurements were then performed with the main transformer breaker closed and all major electrical items housed within the engine turned off.[a] Pictures of the current waveform under these conditions are given in Figures 12A and B.

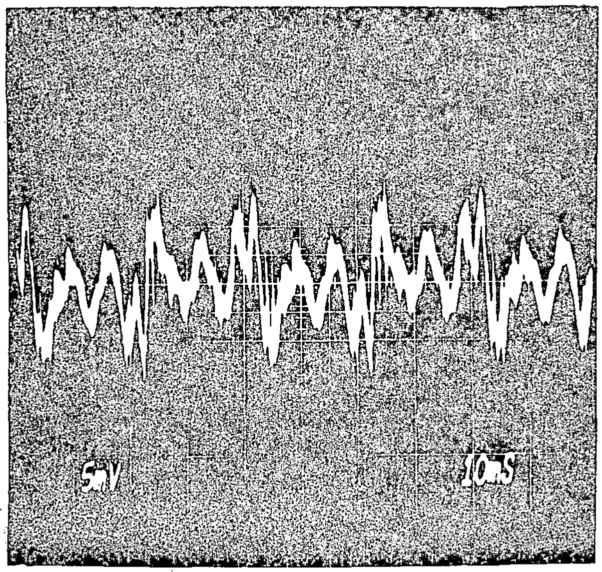


Figure 12A. Waveform of current in ground side primary of main transformer with breaker closed and all major electrical items turned off. (Amplitude = 15.8 amps/div and time = 10 ms/div).

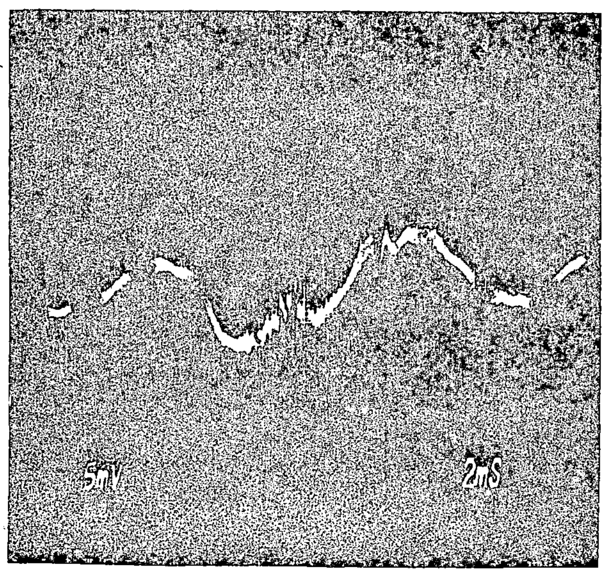


Figure 12B. Waveform of current in ground side primary of the main transformer (time = 2 ms/div, Amplitude = 7.9 amperes/div).

[a] This test and all the following tests were performed at AMTRAK's Wilmington, DE, Maintenance Facility unless otherwise noted.

In Figures 12A and B, a periodic structure (40 milliseconds period) corresponding to the 25 Hz power source is displayed. The current spectrum, between 25 Hz and 1 MHz, is given in Figure 13. The larger crest factor of the spectrum, between 300 kHz and 1 MHz, indicates an impulsive type of noise. A local AM broadcast station is noticeable at 940 kHz. Measurements were also performed with the oil pump motor turned on. The current spectrum for this condition did not change significantly from the previous measurement.

In the next set of measurements, the blower motor was turned on idle, and the oil pump motor was on. The results of these measurements are shown in Figure 14. Under these conditions, the 25 Hz fundamental was 15 dBA.

The next set of data was taken with the blower motor on idle, the M/A set on idle (unloaded), and the oil pump and various small electrical items (such as lights and radio) on. The results of these measurements are given in Figure 15. The 25 Hz fundamental is 37 dBA (70 amperes). The approximate rms value, measured from the waveform, is 62 amperes. The distributed spectrum between 10 and 25 kHz is intentionally missing from the graph because the analyzer was suspected of responding inaccurately in this region. Upon completion of these measurements, the blower motor was turned off, and the measurements were repeated. At lower frequencies, the energy levels decreased by approximately 2 dBA, whereas at higher frequencies (above 250 Hz) the energy levels remained essentially unchanged. Time waveform results are displayed in Figures 16A and B.

Next, current measurements were performed with the blower motor turned on full speed, the M/A set turned on idle (unloaded), and the oil pump and various small electrical units housed in the locomotive turned on. The current waveform obtained under these conditions, over a 50 millisecond time interval, is given in Figure 17. Results of spectrum measurements, between 25 Hz and 1 MHz, are given in Figure 18. Again, the spectrum between 10 and 20 kHz has been purposely omitted.

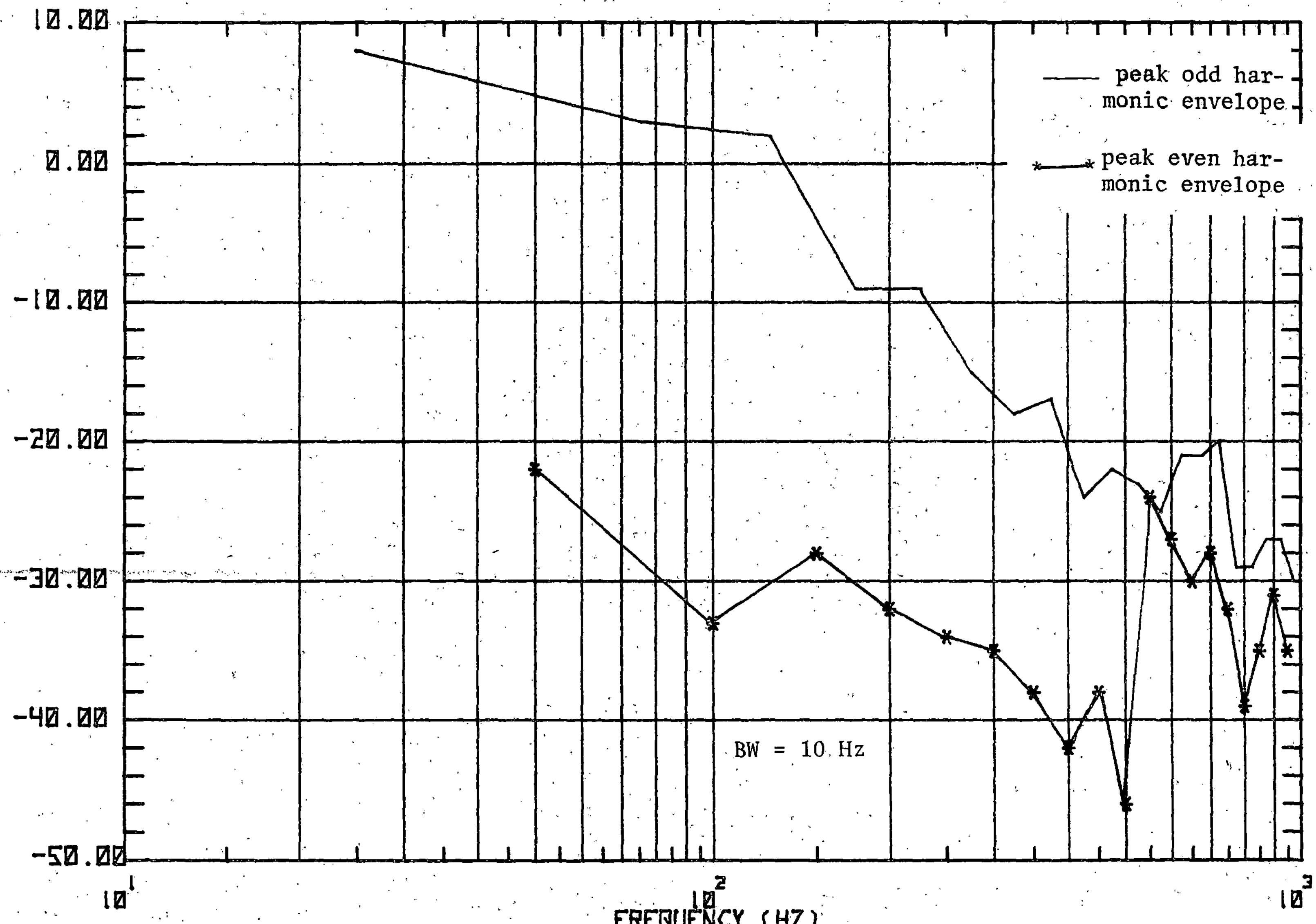


Figure 13. Current spectrum, main transformer primary, main breaker closed.

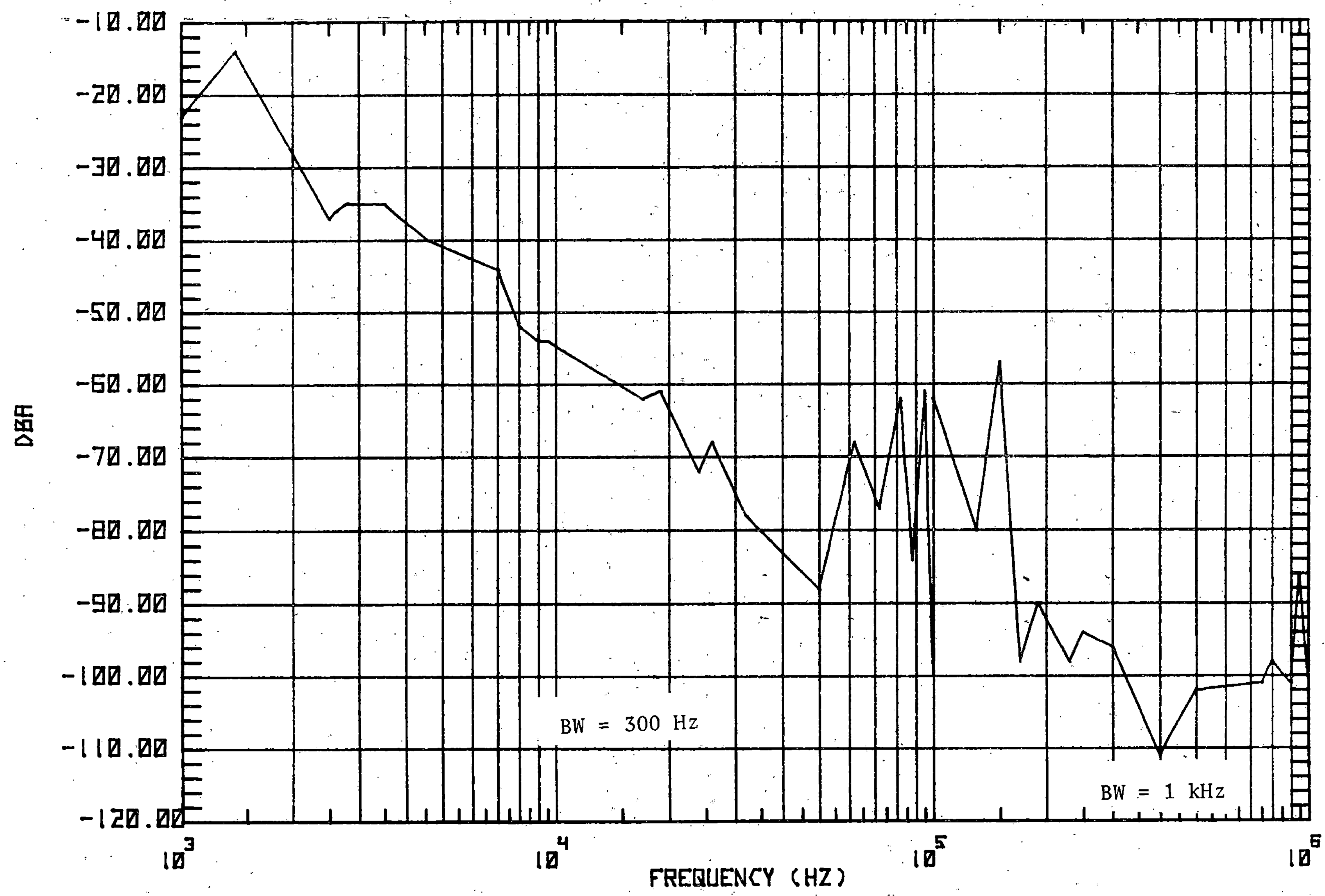


Figure 13. (continued).

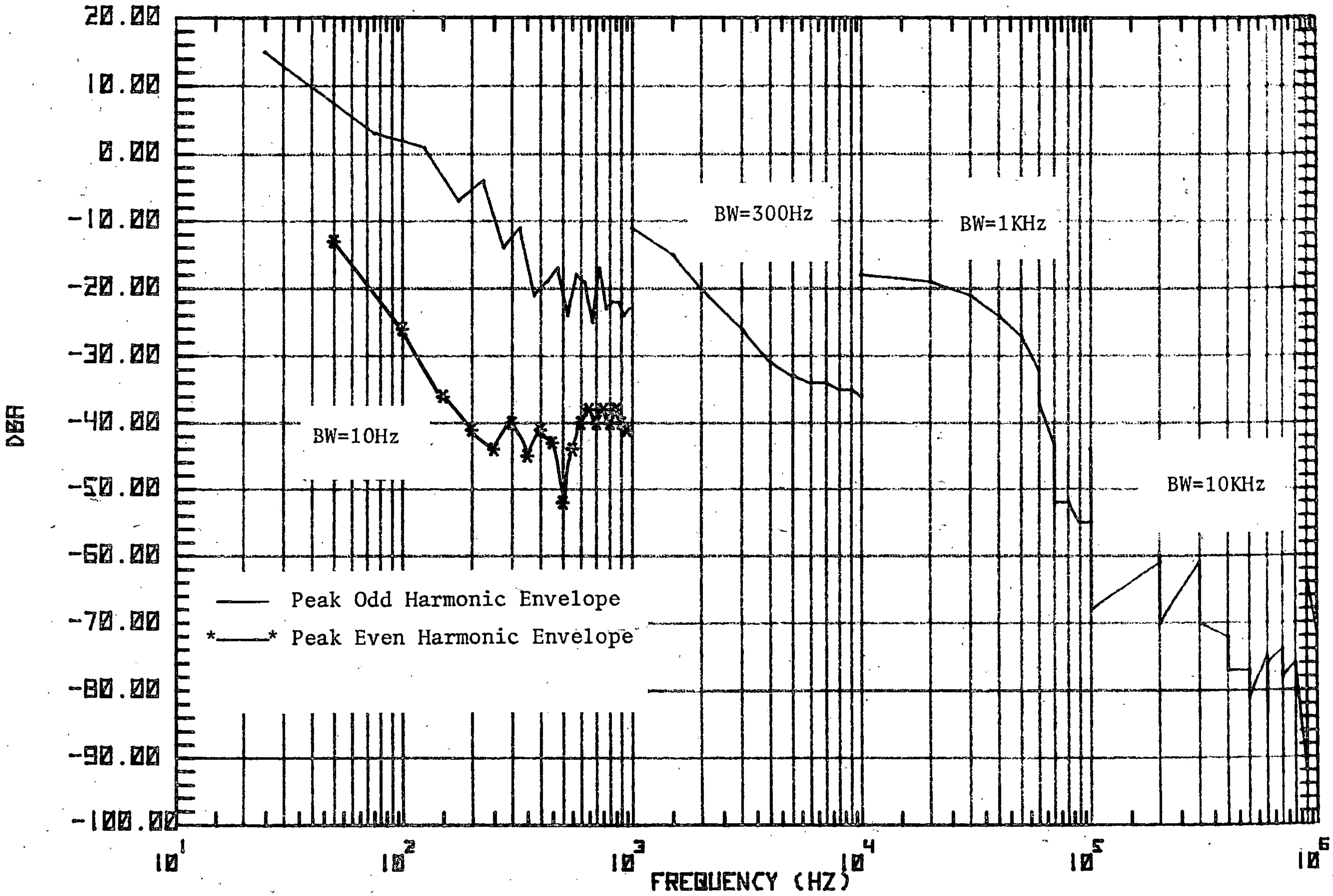


Figure 14. Main transformer primary current with blower motor on.

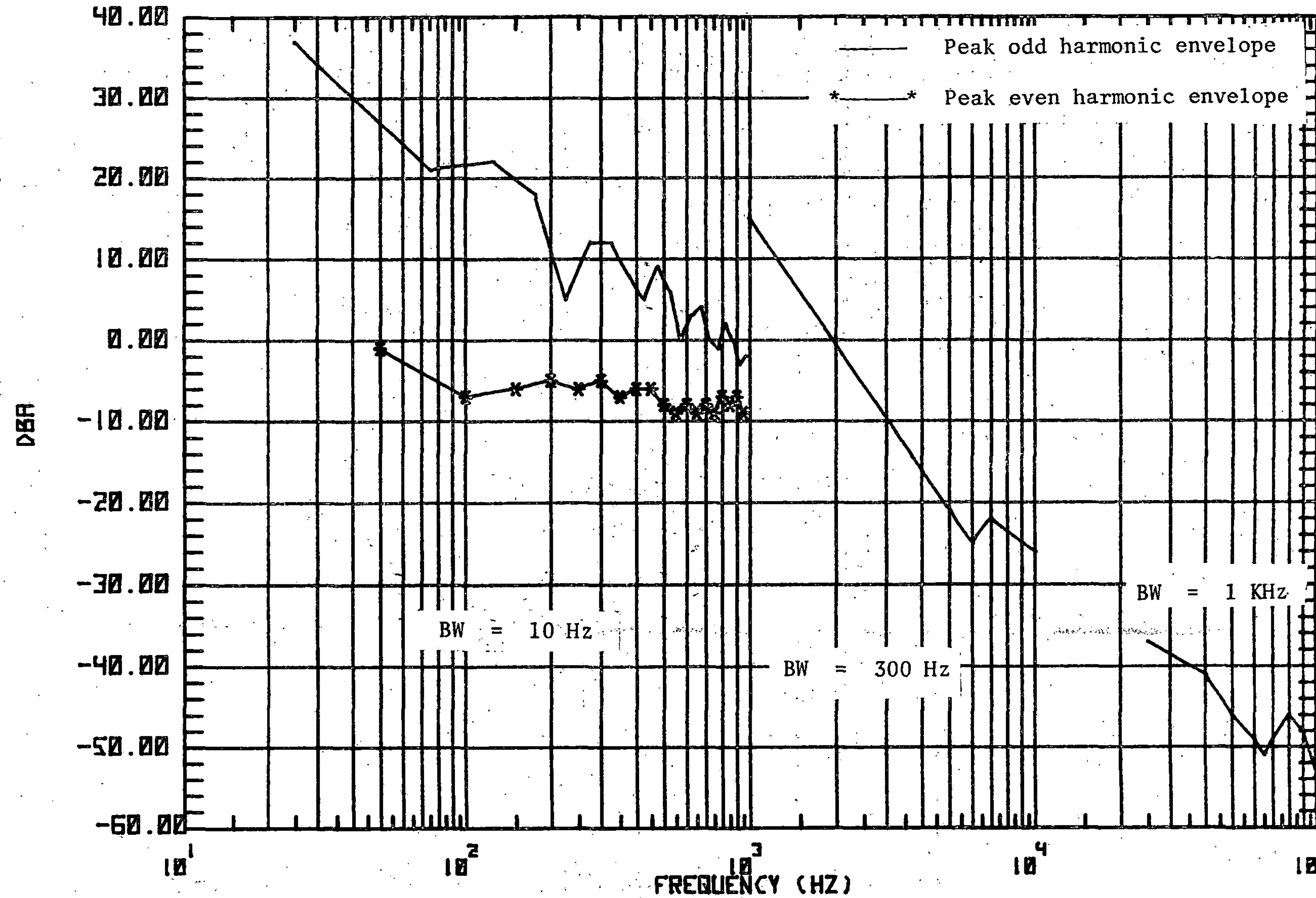
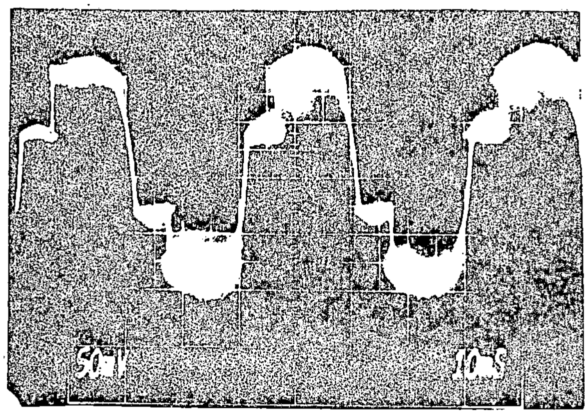
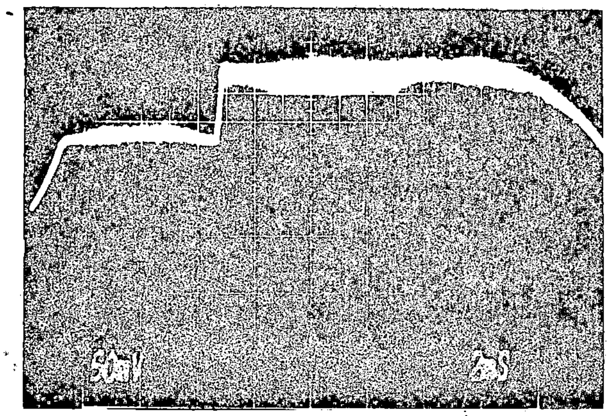


Figure 15. Main transformer primary current with blower motor and M/A on.



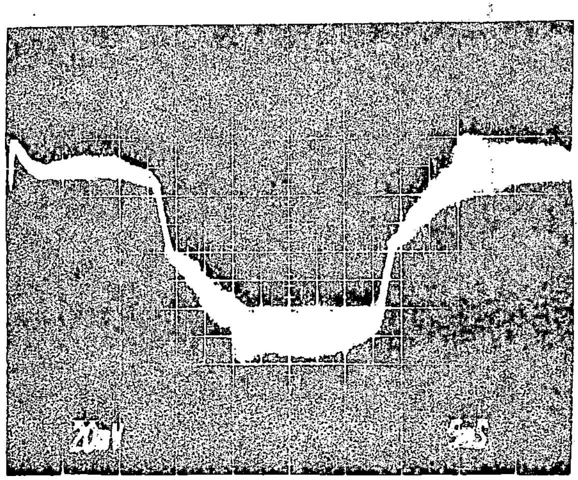
(45 Amperes/div, 10 msec/div)

Figure 16A. Waveform of current in primary of main transformer with blower motor and M/A set on idle.



(45 Amperes/div, 2 msec/div)

Figure 16B. Waveform of current in primary of main transformer with blower motor and M/A set on idle.



(17.8 Amperes/div, 5 msec/div)

Figure 17. Main transformer primary current waveform with blower motor on full and M/A on idle and unloaded.

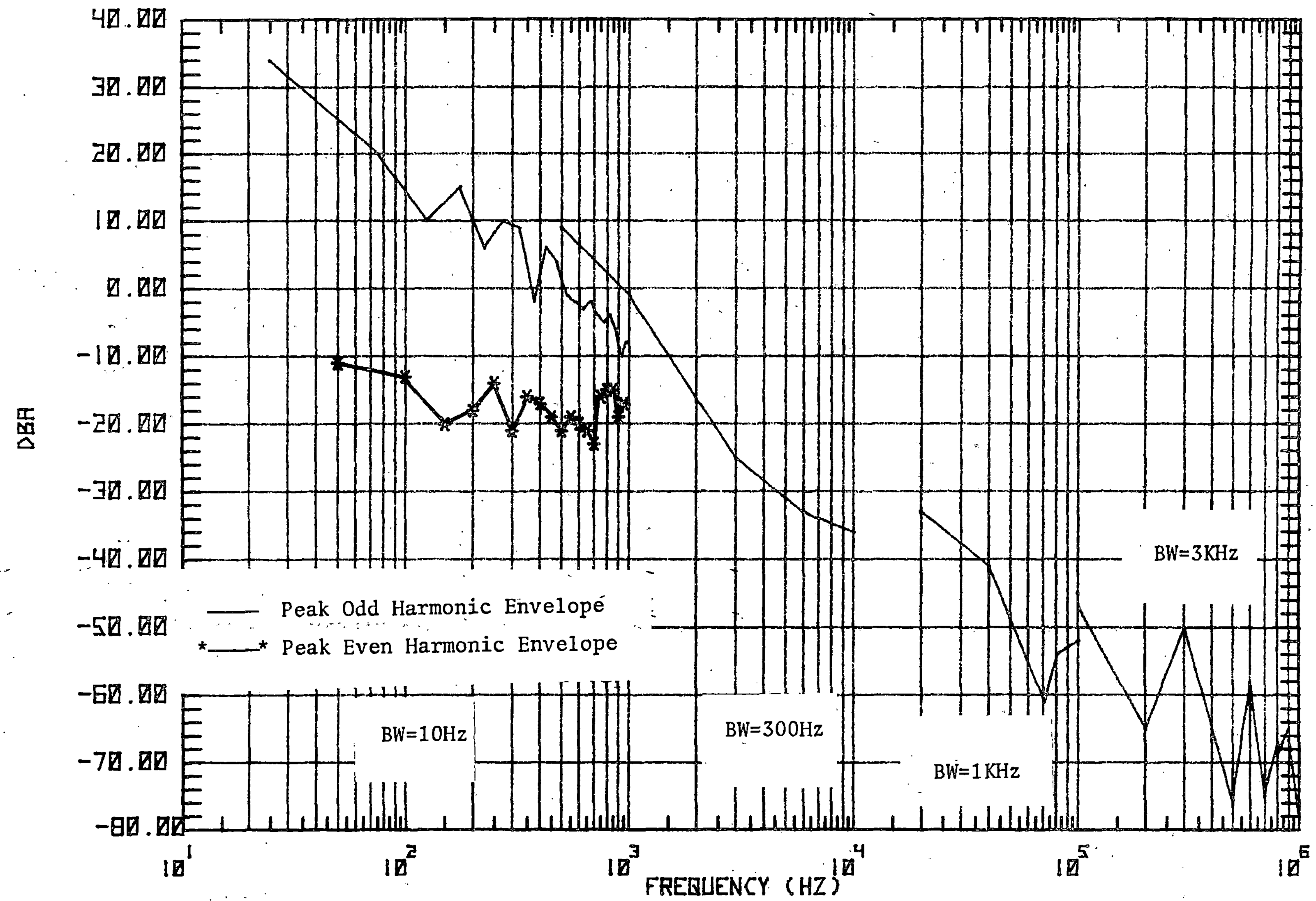


Figure 18. Main transformer primary current with blower motor on full (condition 1.5).

Next, data were obtained with the blower motor on idle, the traction motors on (drawing 450 amperes dc per truck), and the oil pump motor and various small electrical units housed in the locomotive turned on. Current waveform photographs obtained under these conditions are given in Figures 19A and B. The frequency spectrum of the current, between 25 Hz and 1 MHz, was sampled, and results are given in Figure 20.

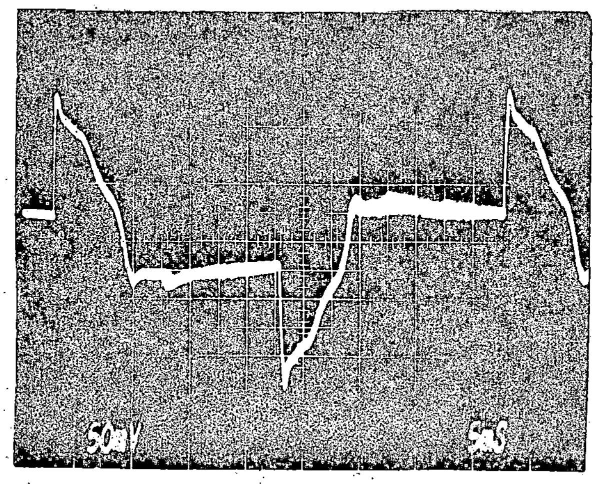


Figure 19A. Waveform of current in main transformer primary while locomotive is moving, (traction motors drawing 450 amperes dc/truck amplitude = 44.6A/div, time = 5 ms/div).

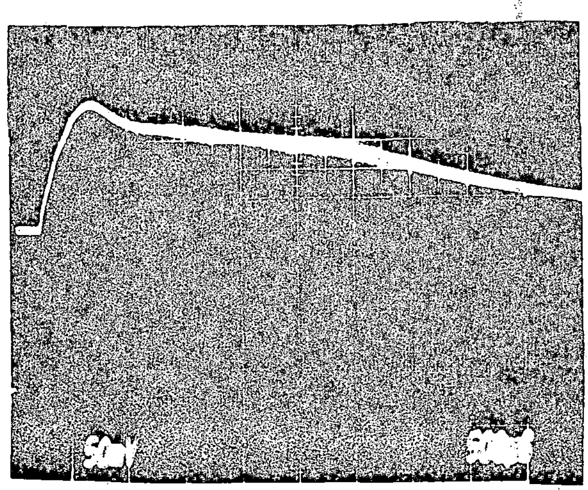


Figure 19B. Main transformer primary current waveform with traction motors drawing 450 amperes dc/ truck (amplitude = 44.6A/div, time = 500 μs/div).

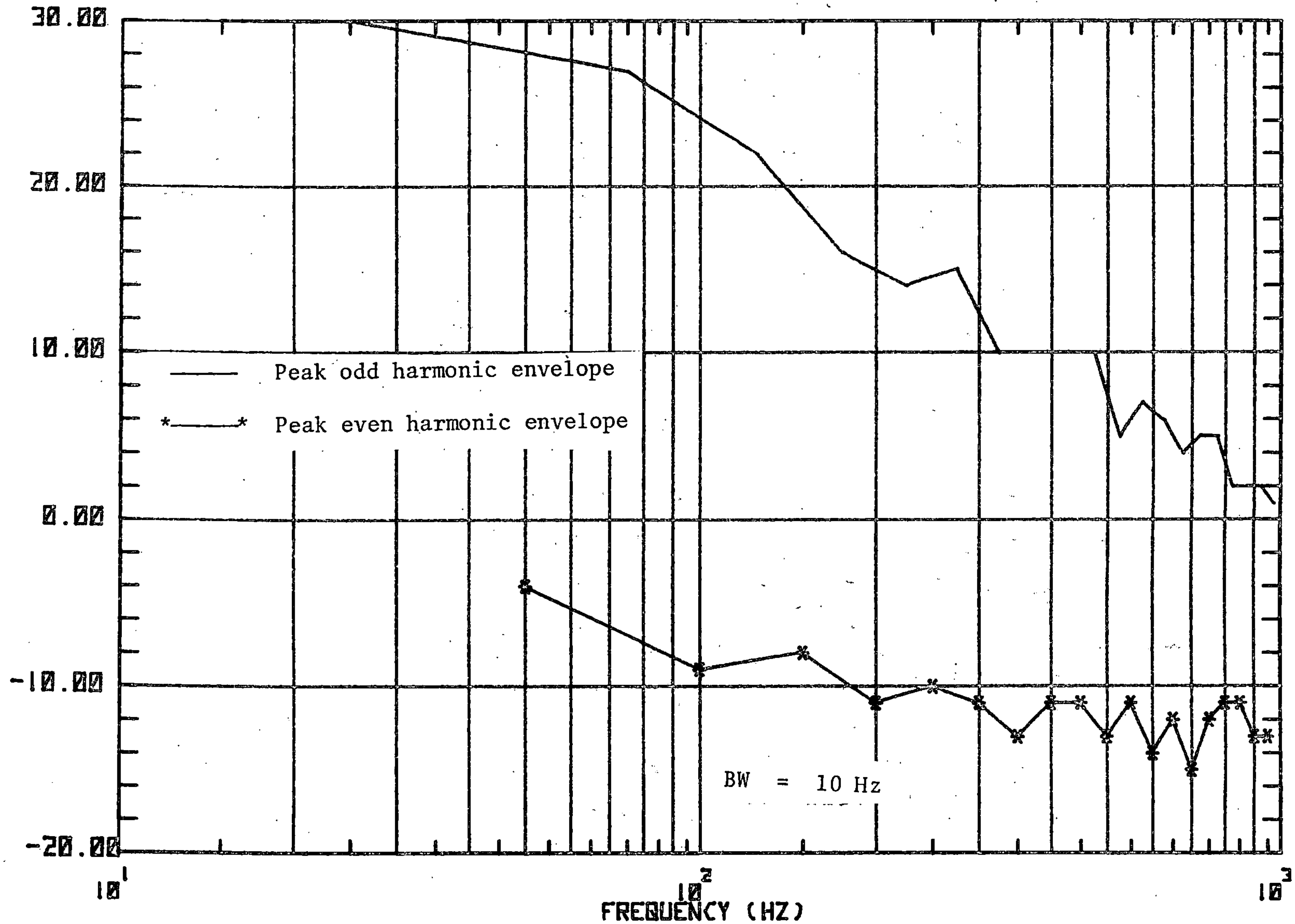


Figure 20. Spectrum of current in primary winding of main transformer with traction motor drawing 450 ampere dc/truck.

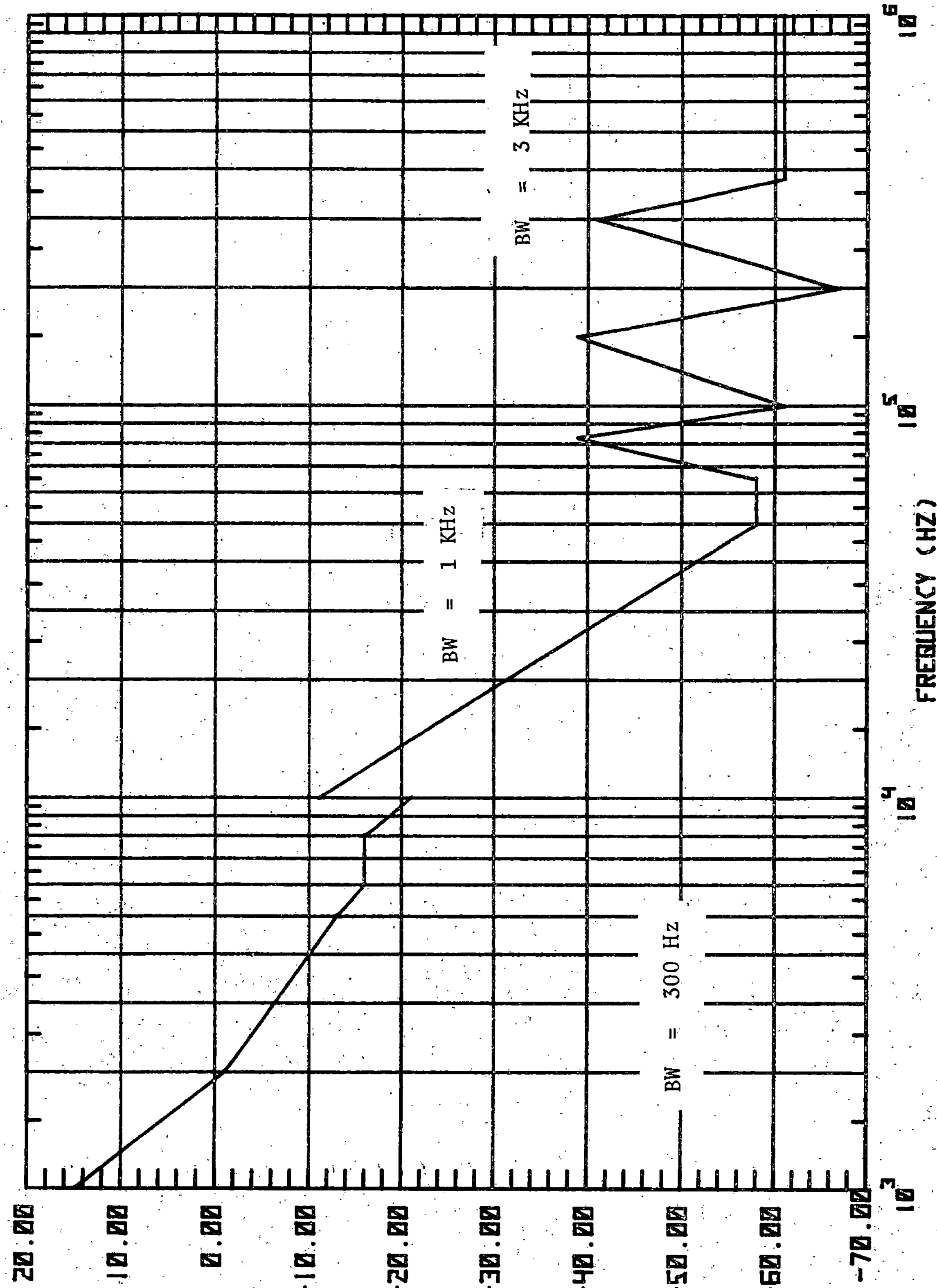
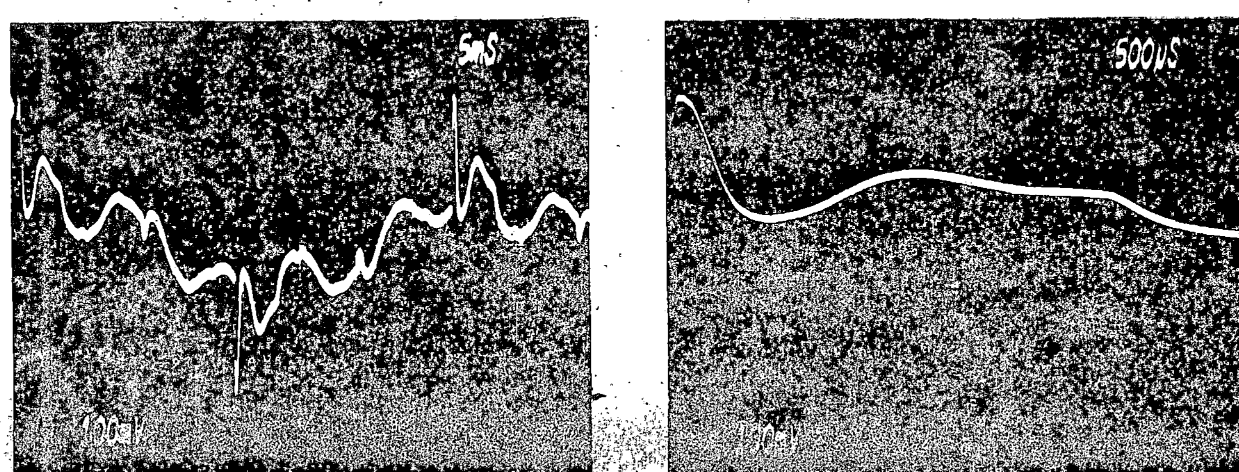


Figure 20. (continued).

In the next data measurement sequence, the blower motor was turned on full speed, the dynamic brake was set in position 8, and the oil pump and various small electrical units were turned on. During this test, the ground strap connecting the main transformer primary to the engine ground, which was previously disconnected, was connected (see Figure 9). Since this presented a current path parallel to the test point, the measured current amplitudes were actually a fraction of the total main transformer primary current. The amprobe current probe was used to sample the average current in the strap and at the test point location. The current in the strap was 47 amperes while the current at the test point was 30 amperes. Results of time waveform and frequency spectrum measurements under these conditions are given in Figures 21 and 22, respectively.



(5 millisecond/div) (500 μsecond/div)

Figure 21. Main transformer primary current, condition 1.7 (amplitude = 89 amperes/div)

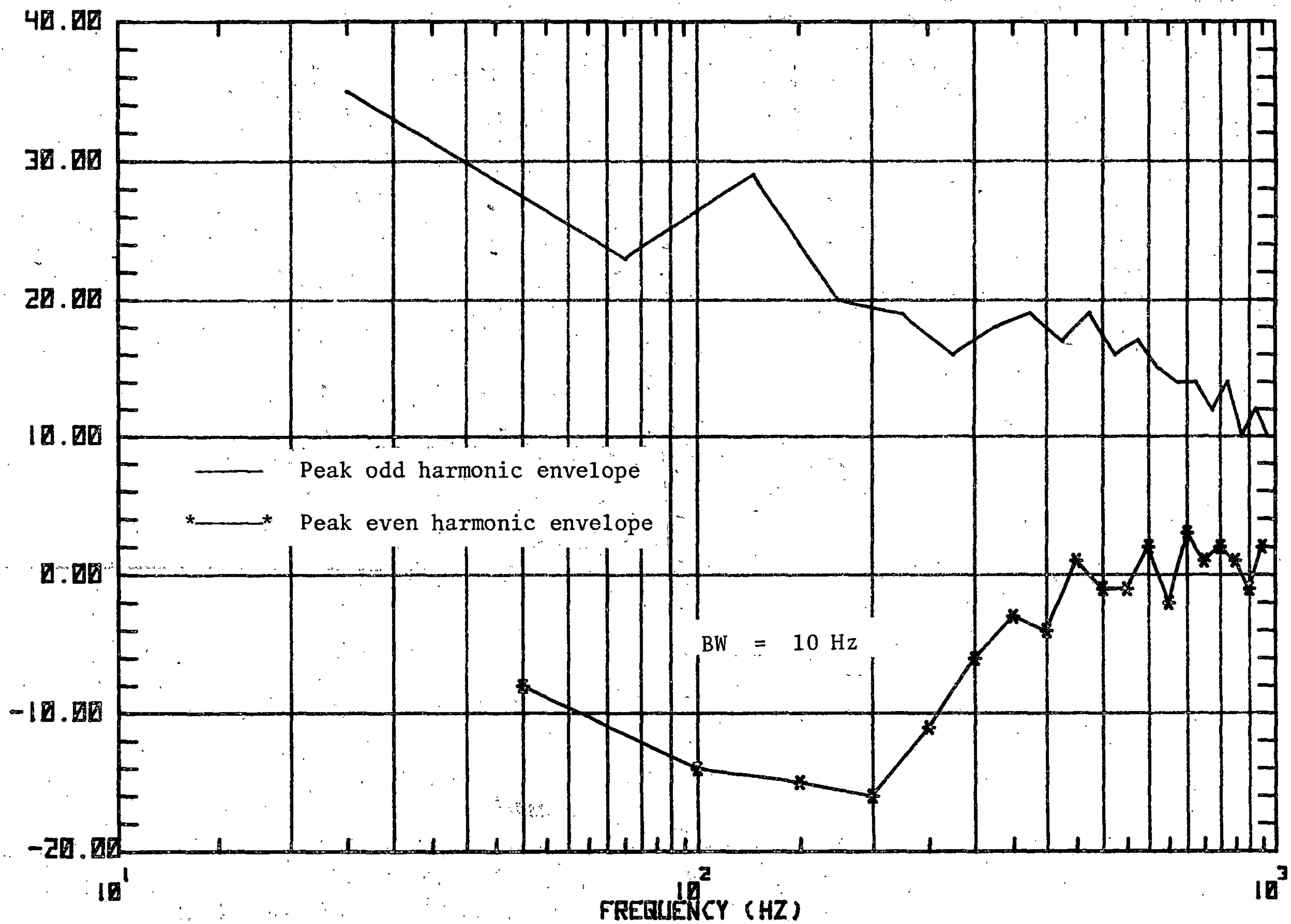


Figure 22. Main transformer primary current with blower on full and the dynamic brake in position 8.

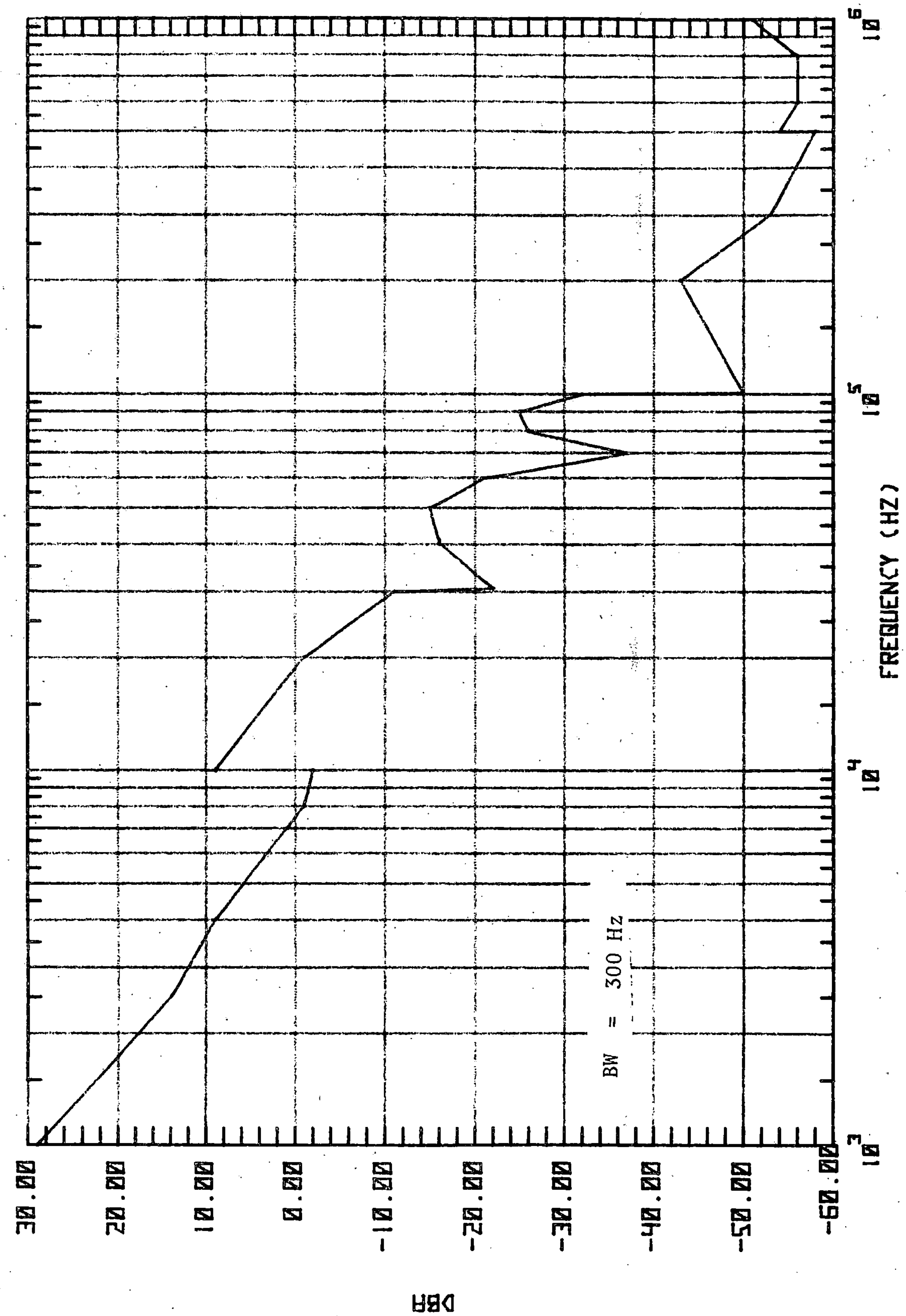


Figure 22. (continued).

Next, the current waveform of transients produced by the main breaker closing were sampled at the main transformer primary test location. During these measurements, all major electrical systems within the locomotive were turned off. Results of these samplings are given in Figure 23.

Referring to Figure 23, approximately 25 seconds elapses before the primary current reaches its steady state condition (36 amperes peak-to-peak). Initial transient oscillations of 623 amperes peak-to-peak, at approximately 4 MHz, were present at irregular bursts (approximately every 10 micro-seconds) for 200 micro-seconds. In addition, a large surge of current, approximately 712 amperes peak, occurred between 10 and 20 milliseconds into the transient. This is the 25 Hz component value that decays to steady state.

2.0 SMOOTHING REACTOR

Frequency spectra and time waveform measurements of current at the output of the smoothing reactor were performed with the M/A set on idle (unloaded) and the oil pump motor and various small electrical units housed within the locomotive turned on. The time waveform and frequency spectrum results are presented in Figures 24 and 25, respectively. Referring to Figure 24, the rms value was found to be 220 amperes. Referring to Figure 25, the 25 Hz component shown is approximately 45 dBA (158 amperes) in a 10 Hz analyzer bandwidth.

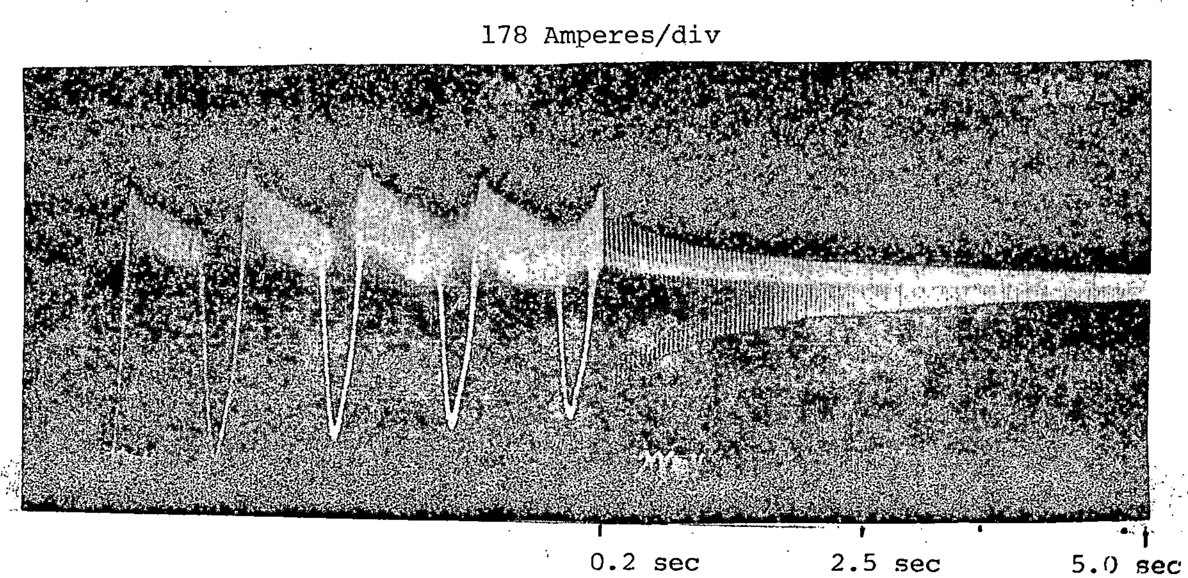
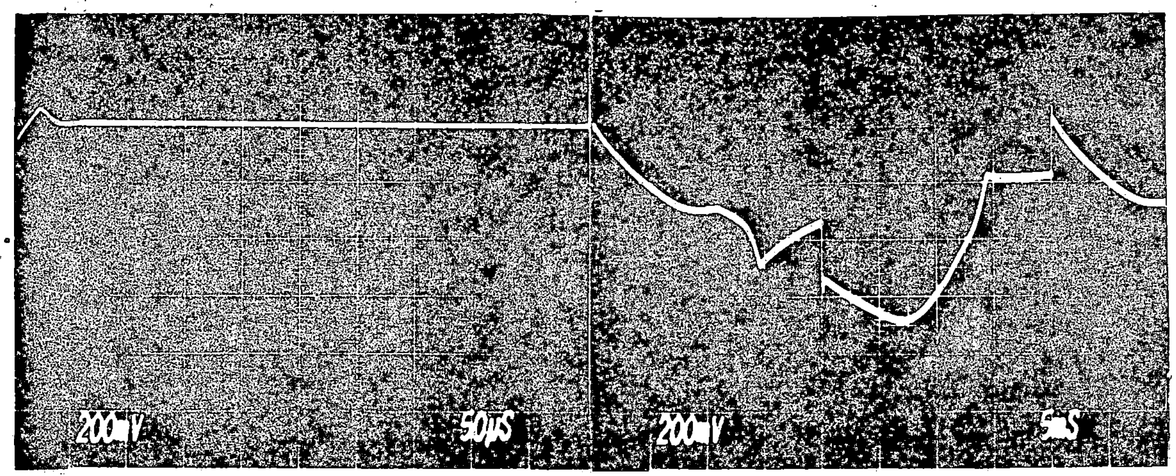


Figure 23. Transients caused by mainbreaker closing sampled on the ground side of the primary winding of the main transformer.

0 amperes ...



(5 msec/div) (50 µsec/div)

Figure 24. Waveform of ac current in cable from smoothing reactor. (amplitude = 178 amp/div)

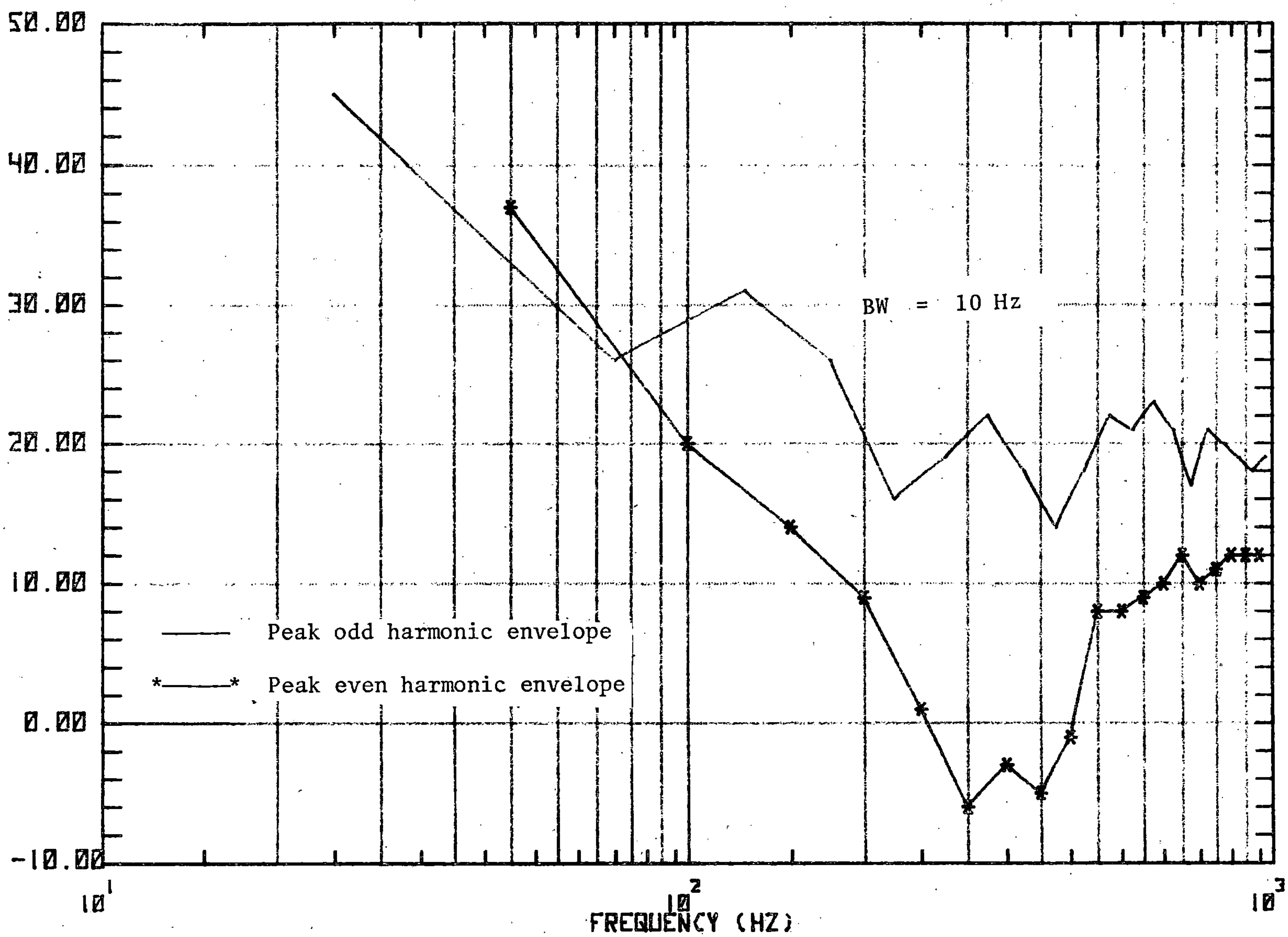


Figure 25. Spectrum of current at smoothing reactor output.

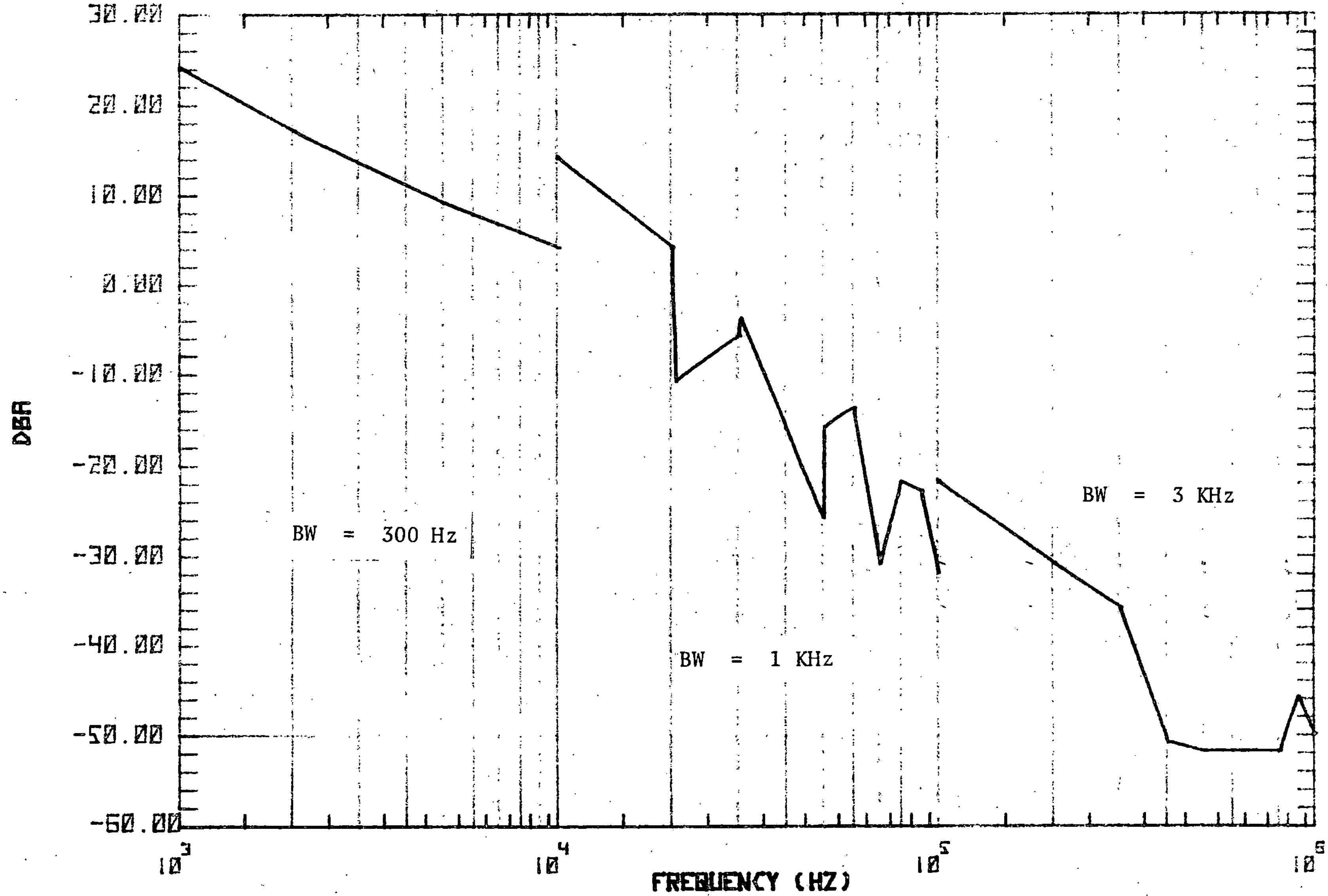


Figure 25. (continued).

3.0 AUTOTRANSFORMER

The autotransformer is used to power the motor/alternator set. A diagram of a typical autotransformer is given in Figure 26. The following measurements were performed on the autotransformer under the prescribed conditions:

3.1 current measurements with the M/A set on idle (unloaded), the blower motor on idle, and the oil pump motor and various small electrical units housed in the locomotive on.

3.2 voltage measurements between the series terminal and ground with the above devices turned on.

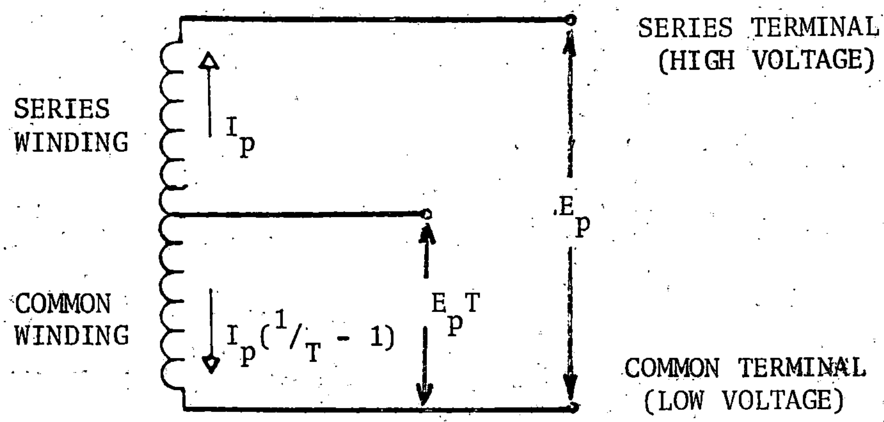


Figure 26. Diagram of autotransformer (I_p=current in series winding, E_p= voltage between series and common terminals. T-turns ratio).

Conducted current measurements were obtained by placing the current loop probe next to the common terminal of the autotransformer, as shown in Figure 27. Both current time waveform and frequency spectrum samplings were obtained, and results are presented in Figures 28 and 29, respectively. The rms value, from the waveform (Figure 28), was found to be 520 amperes. Referring to Figure 29, the 25 Hz component of the current was 55 dBA (562 amperes).

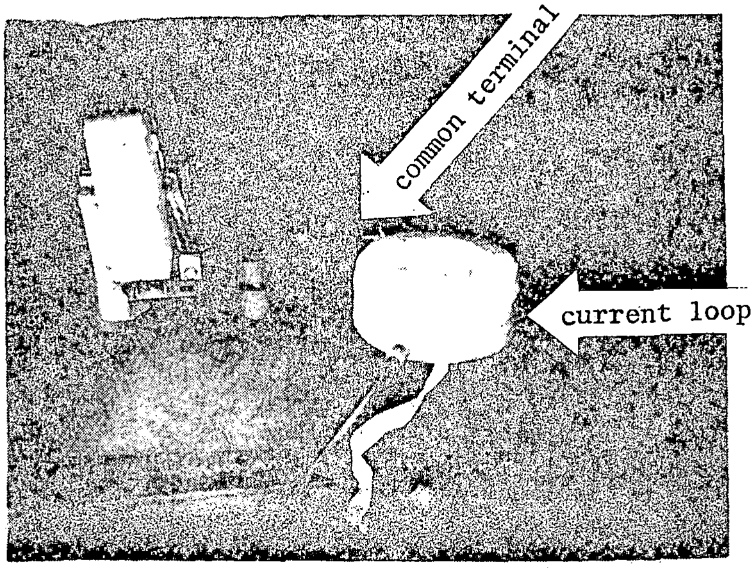


Figure 27. Inductively coupled loop sampling current in common terminal cable

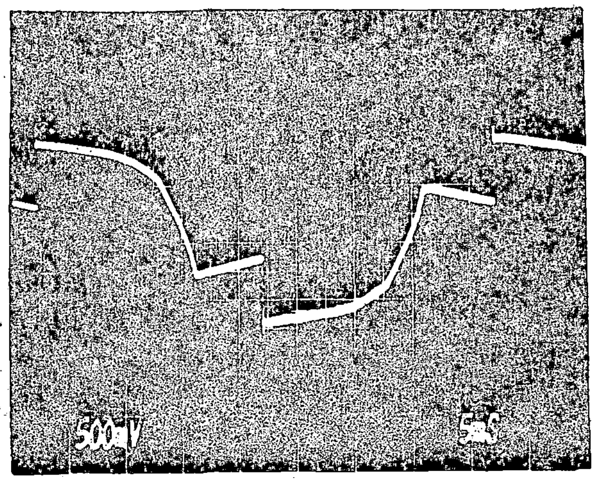


Figure 28. Autotransformer current waveform, M/A set on idle, blower motor on (446 amperes/div, 5 milliseconds/div).

Referring to Figure 27, two cables were connected to the terminal of the autotransformer. Because of space limitations, the loop was not touching both cables; therefore, the readings were low by approximately 4 dBA.

Voltage waveform and spectrum measurements were next performed between the series terminal (high voltage terminal) and ground. Results of these waveform and spectrum measurements are given in Figures 30 and 31, respectively. The rms voltage of the waveform, given in Figure 30, is 583 volts. From Figure 31, the 25 Hz fundamental component is approximately 501 volts (54 dBV).

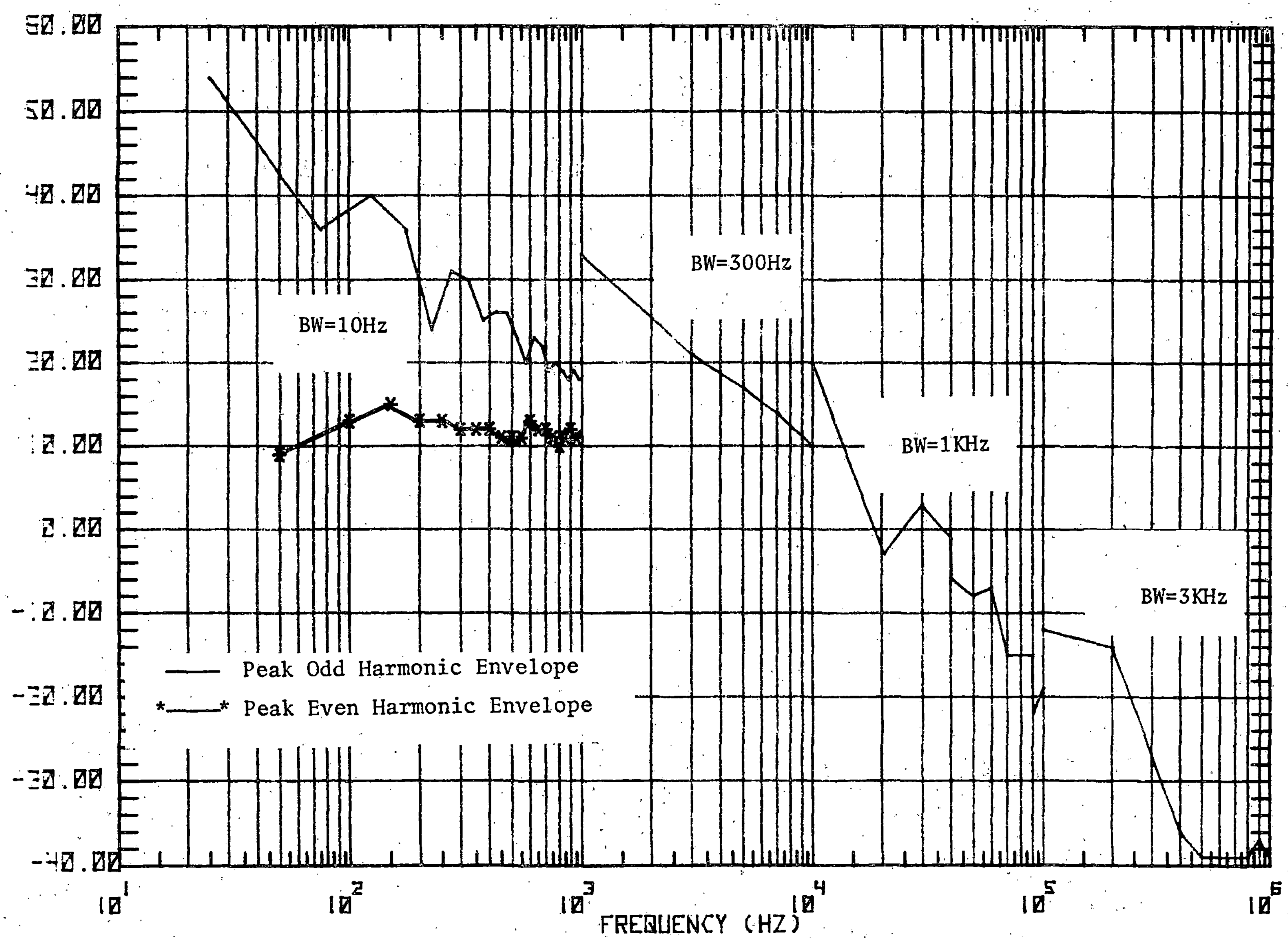


Figure 29. Spectrum of current in common terminal of autotransformer.

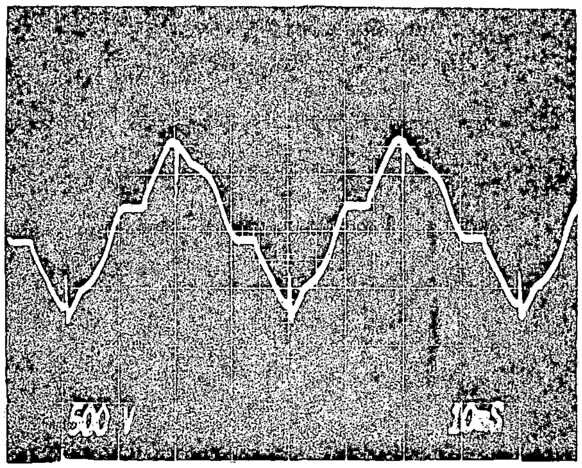


Figure 30. Voltage between the series terminal of autotransformer and ground. (500 volt/div, 10 millisecond/div)

4.0 MOTOR/ALTERNATOR SET

The motor/alternator set is used to generate and supply three phase, 60 Hz power to the passenger cars. The M/A set is composed of a dc motor and an alternator. The dc motor acquires power from the rectified output of the autotransformer and is used as the prime mover for the alternator.

The time waveform and frequency spectrum of the M/A current were sampled with the M/A supplying power to a resistive load. The current was sampled with the current loop placed at two different test points. Initially, the inductively coupled current loop was placed against all four cables (three phases plus neutral) in order to sample the effective current resulting from the combination of phased currents (see Figure 32). The waveform and spectrum obtained from the samplings are given in Figures 33 and 34, respectively. From Figure 33, the current waveform sampled was approximately 78 amperes peak-to-peak. Ideally, if the load was perfectly balanced, the effective current should be zero, which, from Figure 33, is obviously not the case. However, since the effective current waveform appears to be a sinusoid, it can be surmised that the three individual currents, although unbalanced, are monotonic.

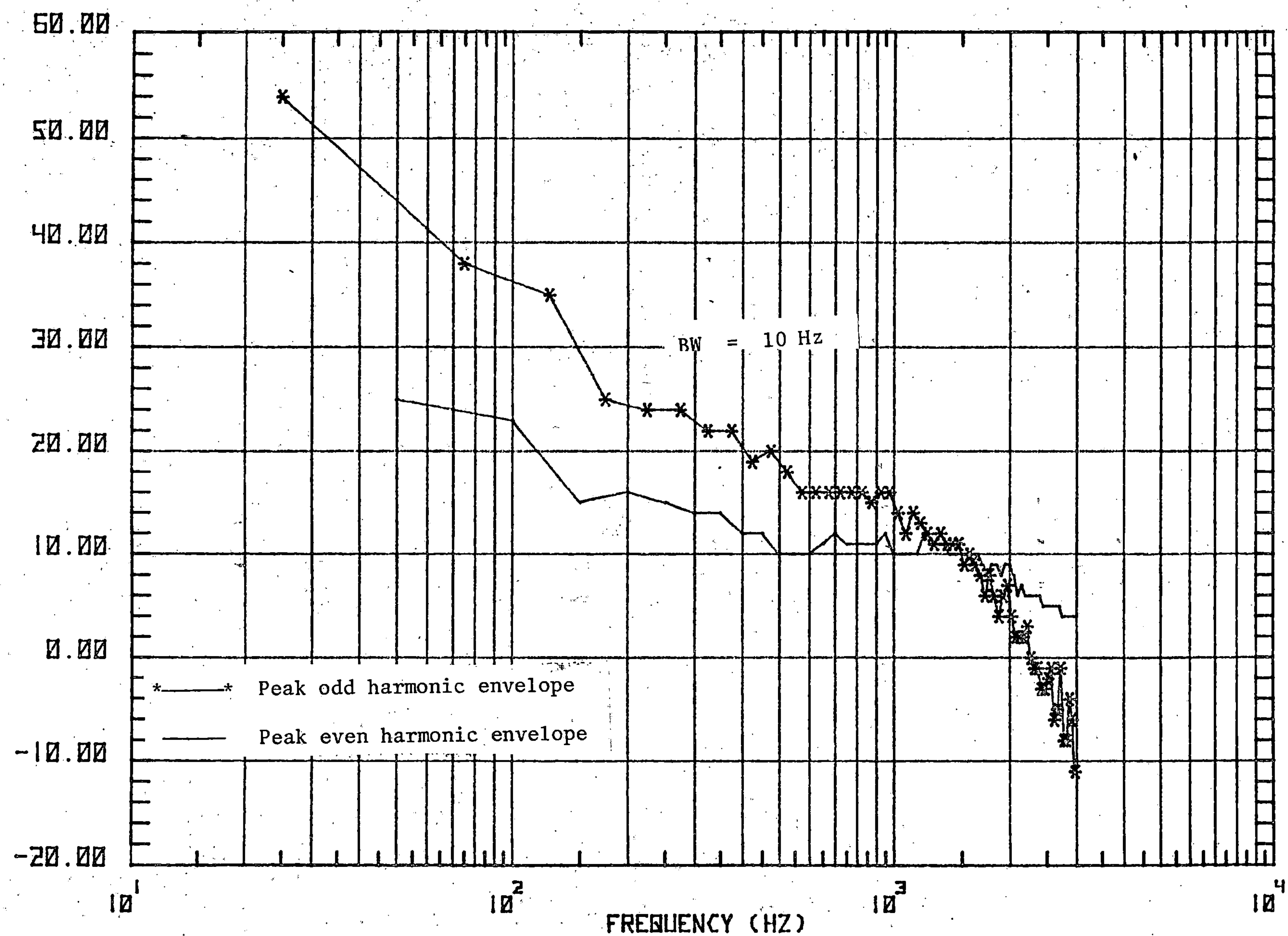


Figure 31. Autotransformer voltage spectrum.

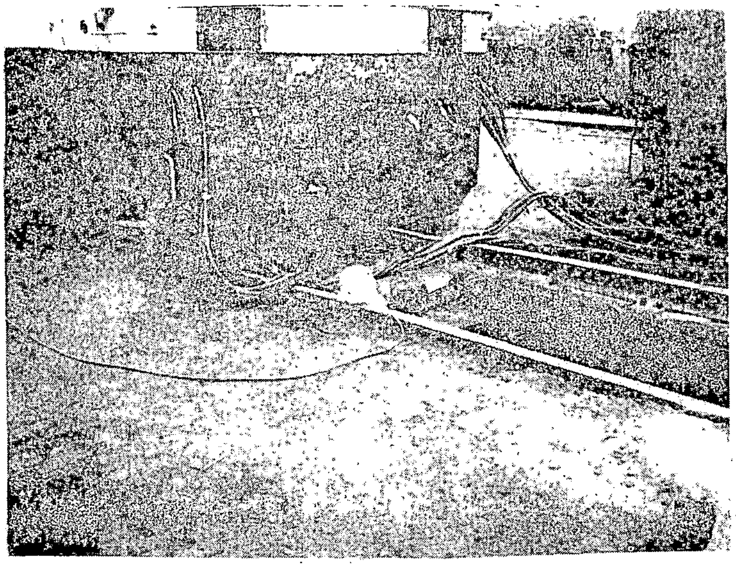


Figure 32. **Four sets of 3 phase cables from M/A set, note current loop in foreground.**

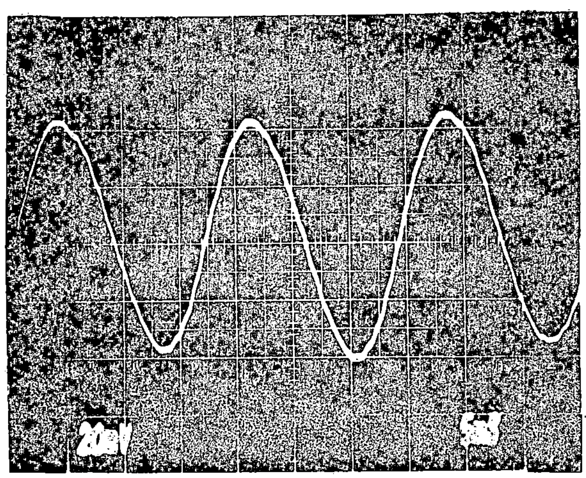


Figure 33. Effective current waveform of 3 phase current cables (17.8 amperes/div, 5 milliseconds/div).

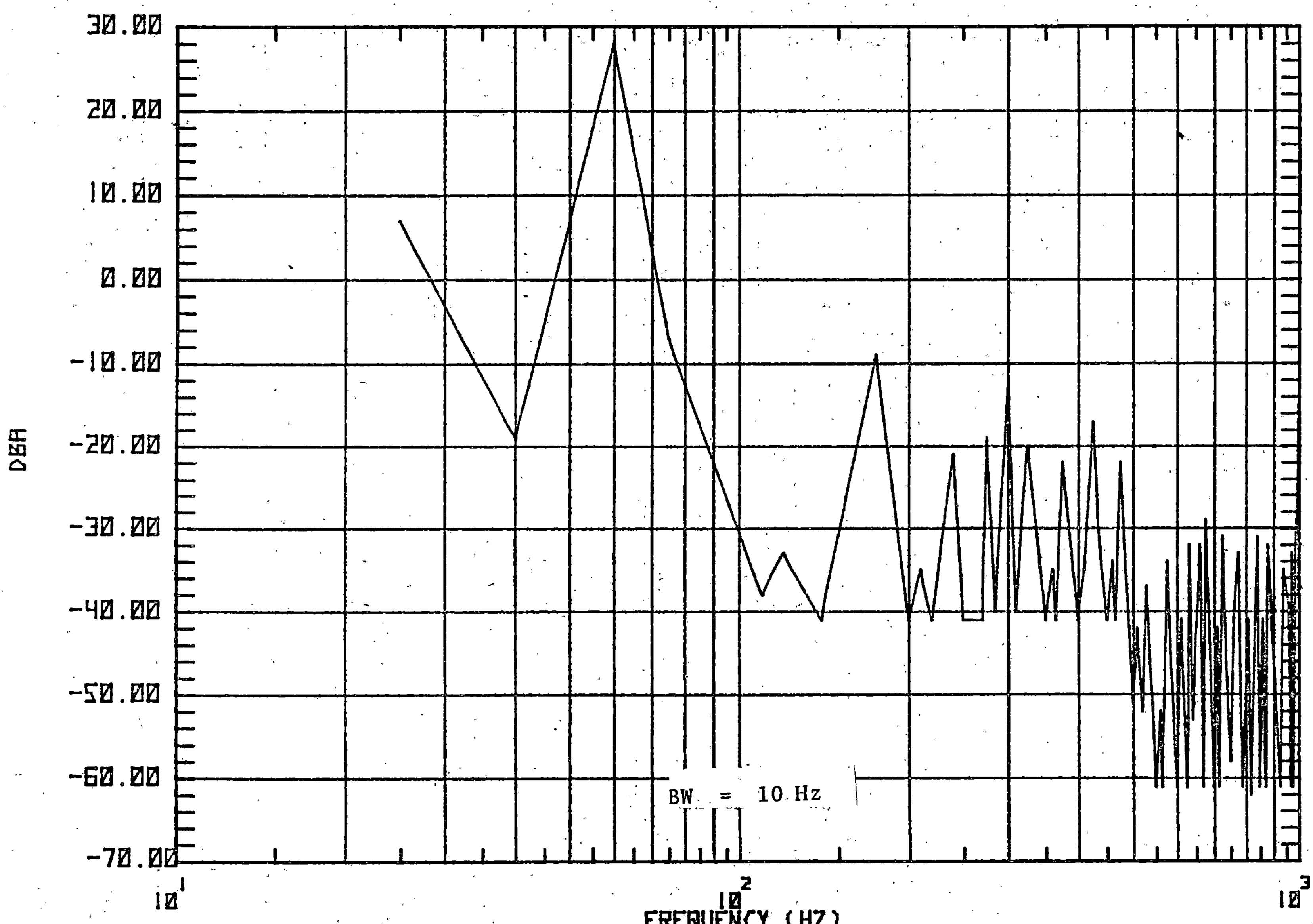


Figure 34. Effective current spectrum of 3 phase M/A output.

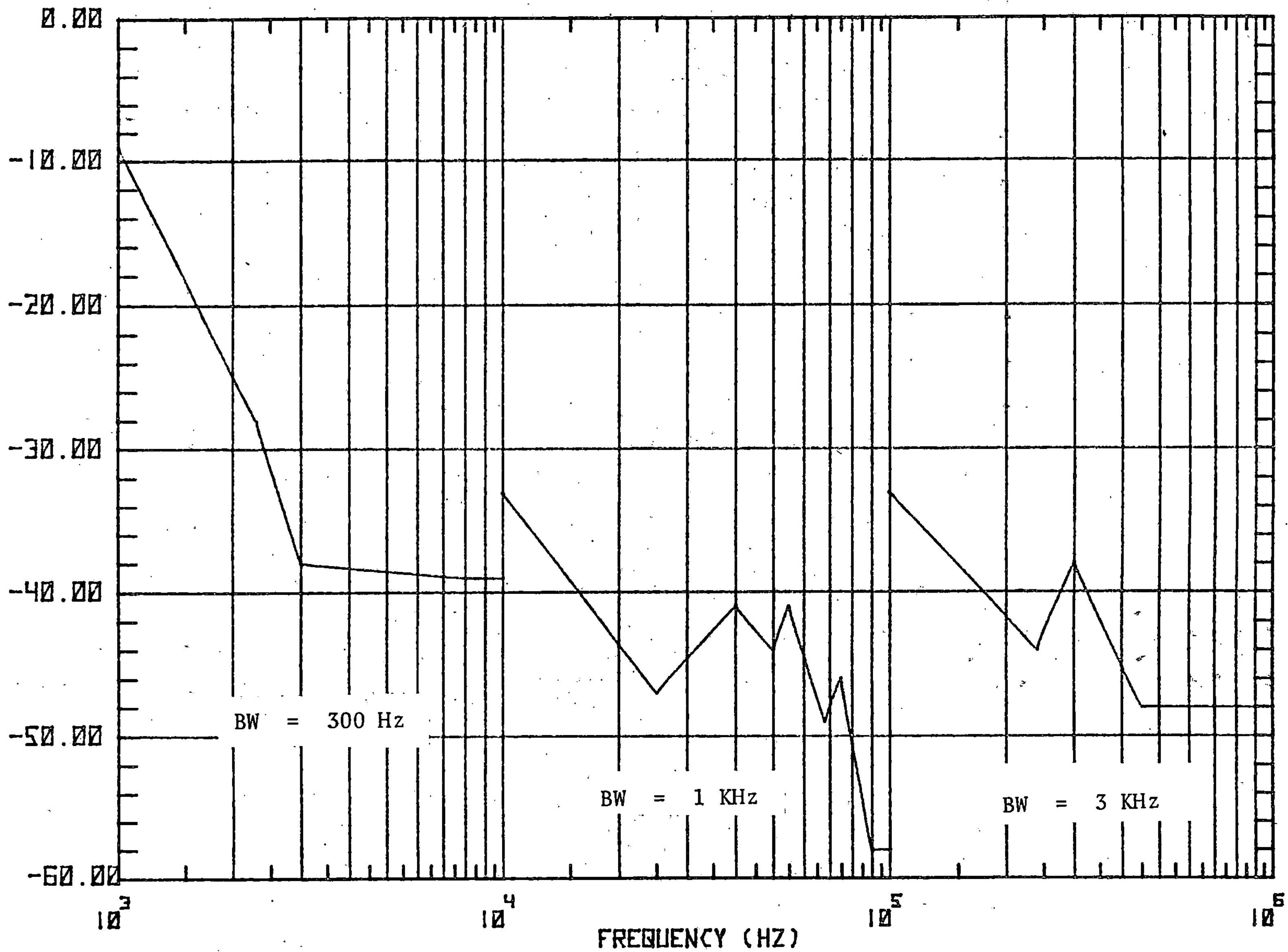
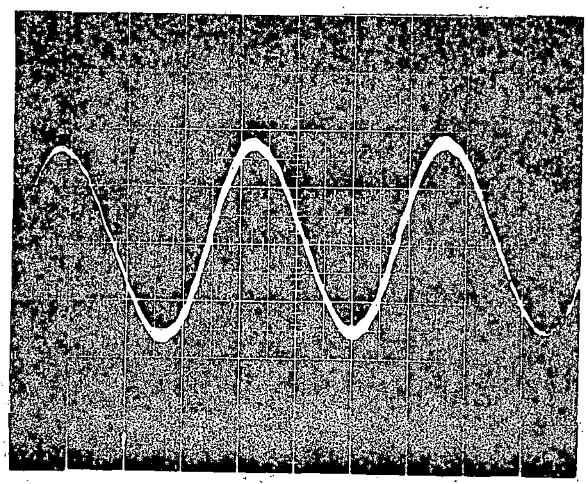


Figure 34. (continued).

Next, the current was sampled in one cable (one phase) of the 3 phase output. The waveform and spectrum obtained from these samplings are shown in Figures 35 and 36, respectively. From Figure 35, the current sampled was 156 amperes peak-to-peak.



(44.6 amps/div, 5 msec/div)

Figure 35. Current waveform of one of three phases of M/A set output.

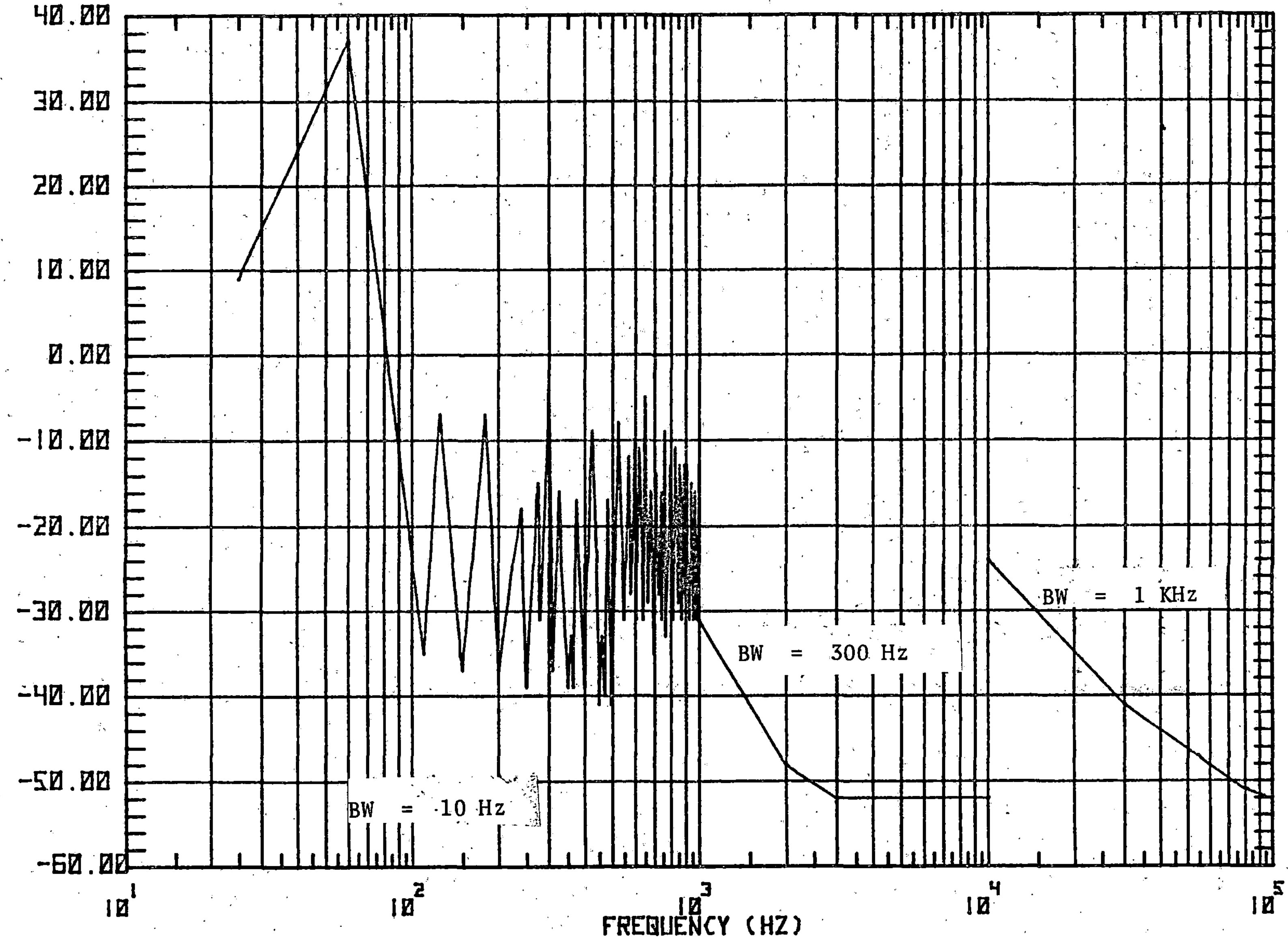


Figure 36. Current spectrum for one of three phases of M/A output.

5.0 TRACTION MOTOR

The current in the armature cable of a traction motor was sampled under the following conditions:

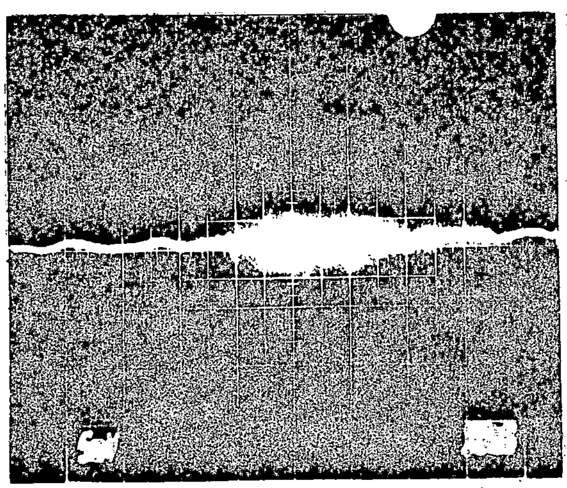
5.1 Traction motor off, oil pump and small electrical items housed in the locomotive on.

5.2 Traction motor off, blower motor on full, oil pump and small electrical items housed in the locomotive on.

5.3 Traction motor drawing 450 amperes dc per truck, blower motor on full, oil pump and small electrical devices in the locomotive on.

5.4 Traction motor drawing 1000 amperes dc per truck, blower motor on full, oil pump and small electrical items in the locomotive on.

The measurements of the current time waveform and frequency spectrum for condition 5.1 above (traction motor and blower motor off) are shown in Figures 37 and 38, respectively. These figures indicate a current is present in this circuit even though the traction motor is turned off.



(amplitude=4.5 amp/div, time=10 msec/div)

Figure 37. Waveform of current in traction motor armature cable with motor turned off.

Referring to Figure 38, the current in the armature was measured to be -21 dBA (90 milliamperes) at 75 Hz and -23 dBA (70 milliamperes) at 125 Hz. The current level beyond 225 Hz, as recorded in a 10 Hz bandwidth, decreased to below -40 dBA (10 milliamperes).

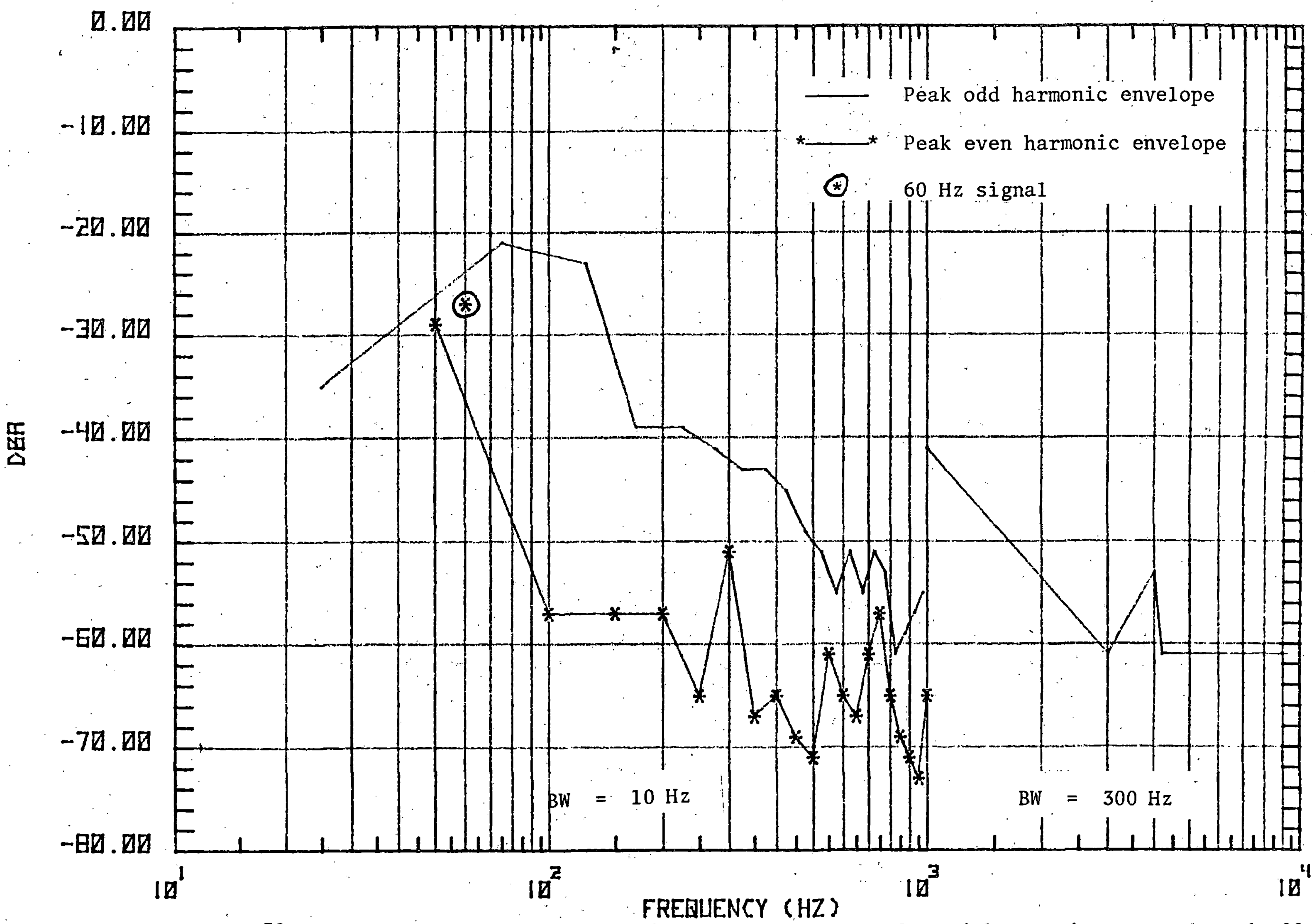


Figure 38. Spectrum of current in traction motor armature cable with traction motor turned off.

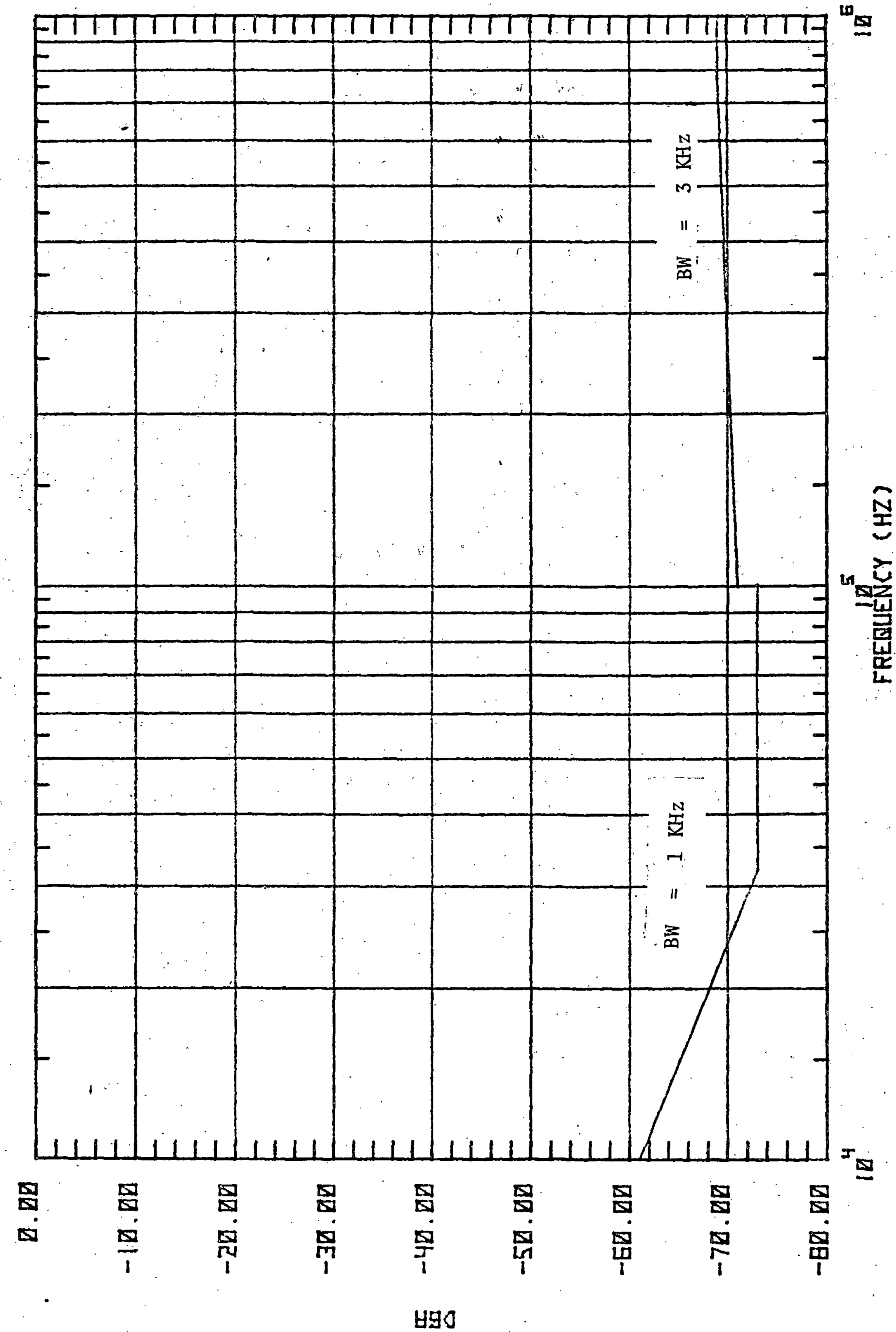
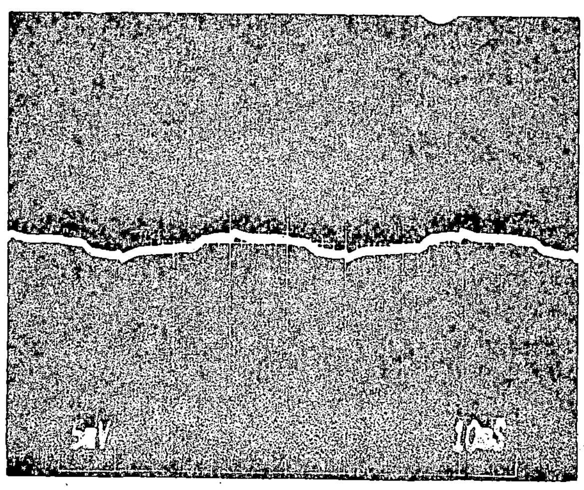


Figure 38. (continued).

Time waveform and frequency spectrum measurements of armature cable current with the traction motor off and blower motor on (condition 5.2) were obtained and are shown in Figures 39 and 40, respectively. Referring to Figure 39, the waveform of the current in the armature cable is very similar to the current waveform at the ground side terminal of the main transformer primary winding (see Figure 17). The basic difference between the results is the amplitude of the current and not the waveform.



(amplitude=4.5 amperes/div, time=10 ms/div)

Figure 39. Waveform of current in traction motor armature cable (condition 5.2).

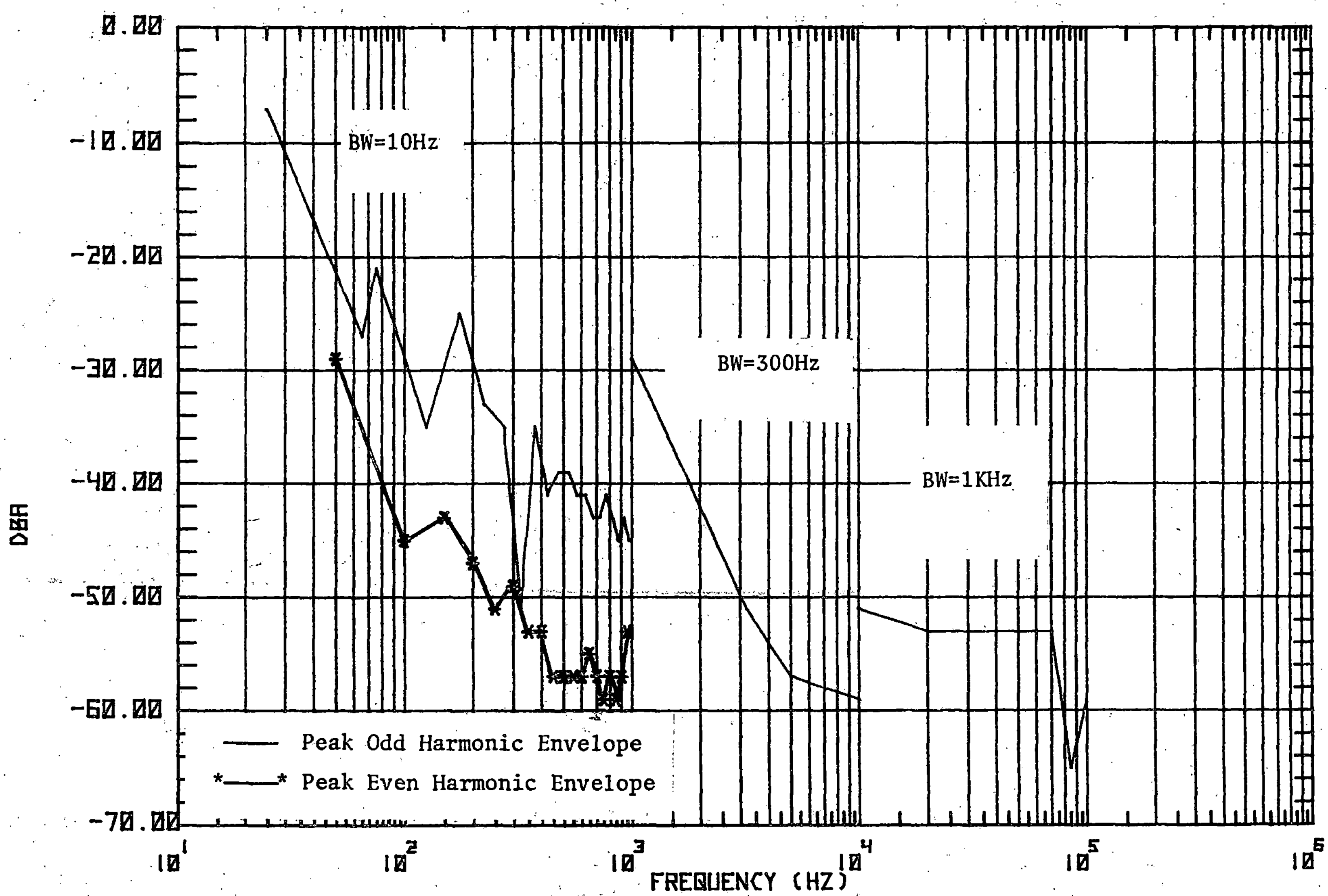


Figure 40. Spectrum of current in traction motor armature cable (condition 5.2).

Next, the frequency spectrum, between 25 Hz and 1 MHz, of the current in the armature cable with the traction motor drawing 450 amperes dc per truck (condition 5.3) was sampled, and results are shown in Figure 41. The 25 Hz component was measured to be 9 dBA (2.82 amperes), while the 75 Hz component measured was 7 dBA (2.24 amperes).

The throttle was then set to notch #4, and frequency spectrum measurements were performed between 25 Hz and 1 MHz with traction motors drawing 1000 amperes dc per truck (condition 5.4). Results of these measurements are given in Figure 42. The 25 Hz component measured was 16 dBA (6.31 amperes), while the next predominent component, 75 Hz, was 13 dBA (4.47 amperes).

6.0 BATTERY

Current measurements were performed at the following locations under the conditions described:

6.1 Current measurements on the cable from the negative terminal of the 74 volt battery with the blower motor on idle, the oil pump on, and various minor electrical systems in the locomotive on.

6.2 Current measurements on the cable from the positive terminal of the battery with the blower motor on idle, the oil pump on, and small electrical systems in the locomotive on.

Results of the time waveform and frequency spectrum measurements under condition 6-1 are shown in Figures 43 and 44, respectively. The amplitude of the time waveform from Figure 43, was 19.8 amperes peak-to-peak.

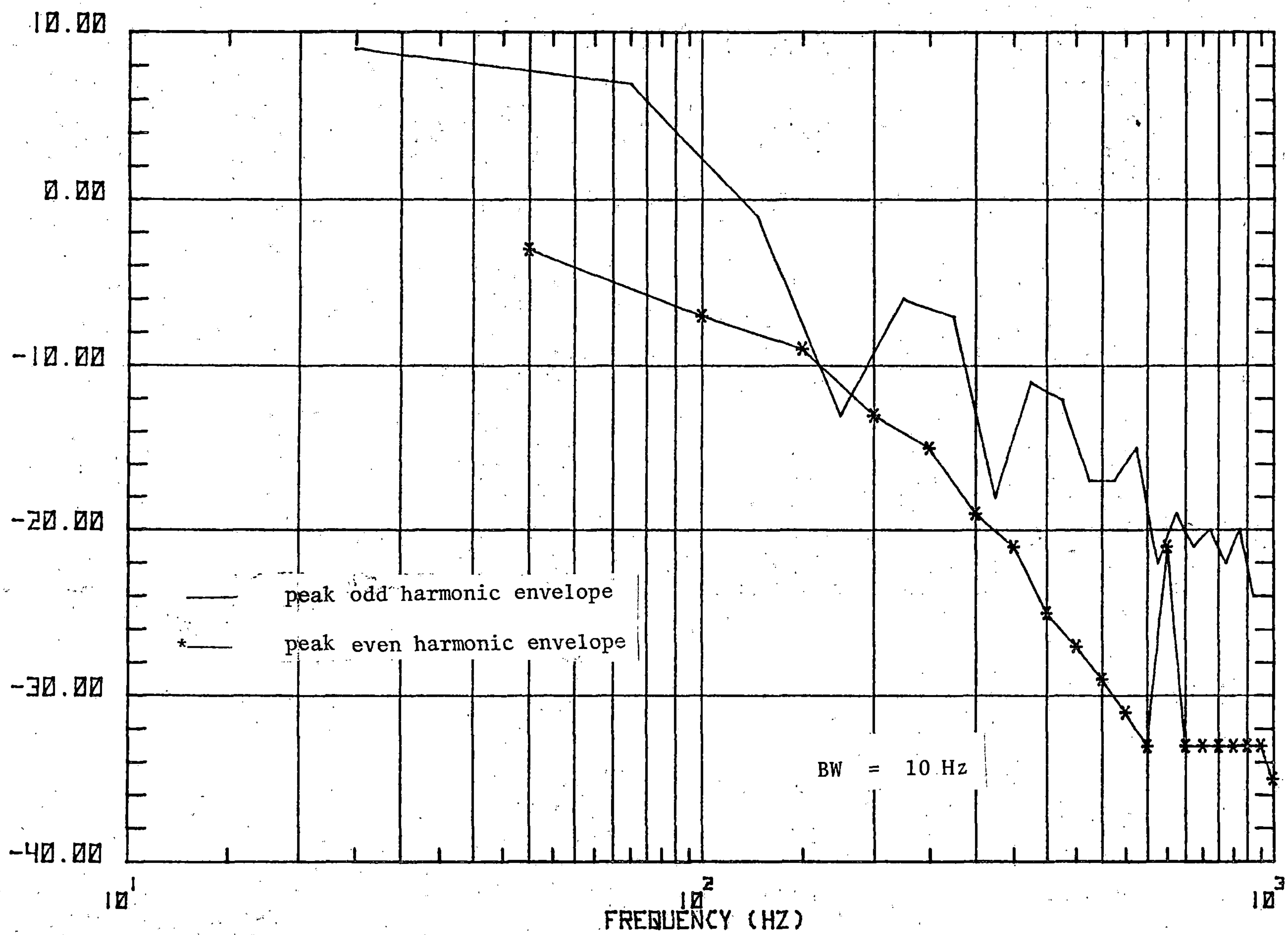


Figure 41. Frequency spectrum of current in traction motor armature cable (condition 5.3).

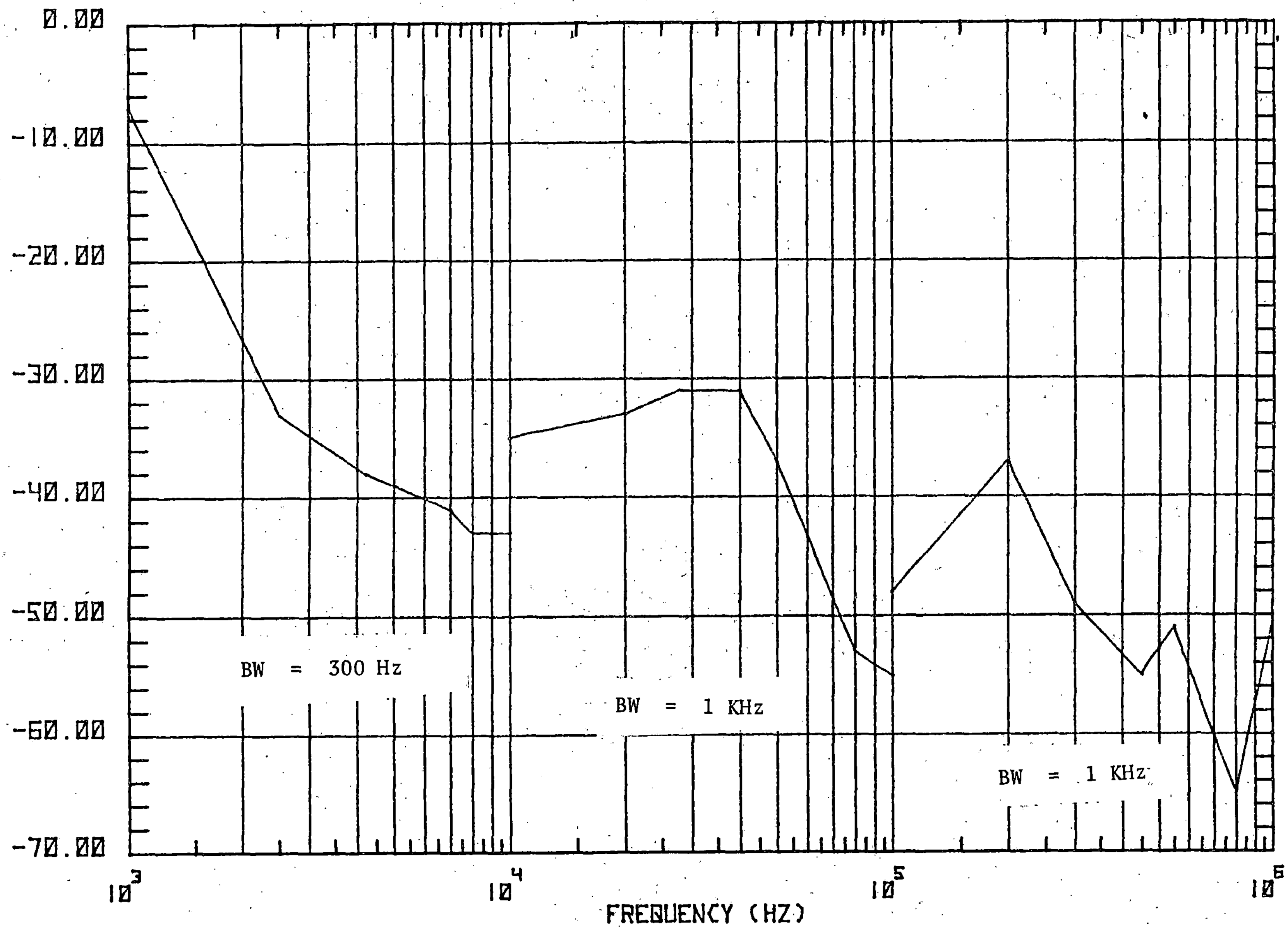


Figure 41. (continued).

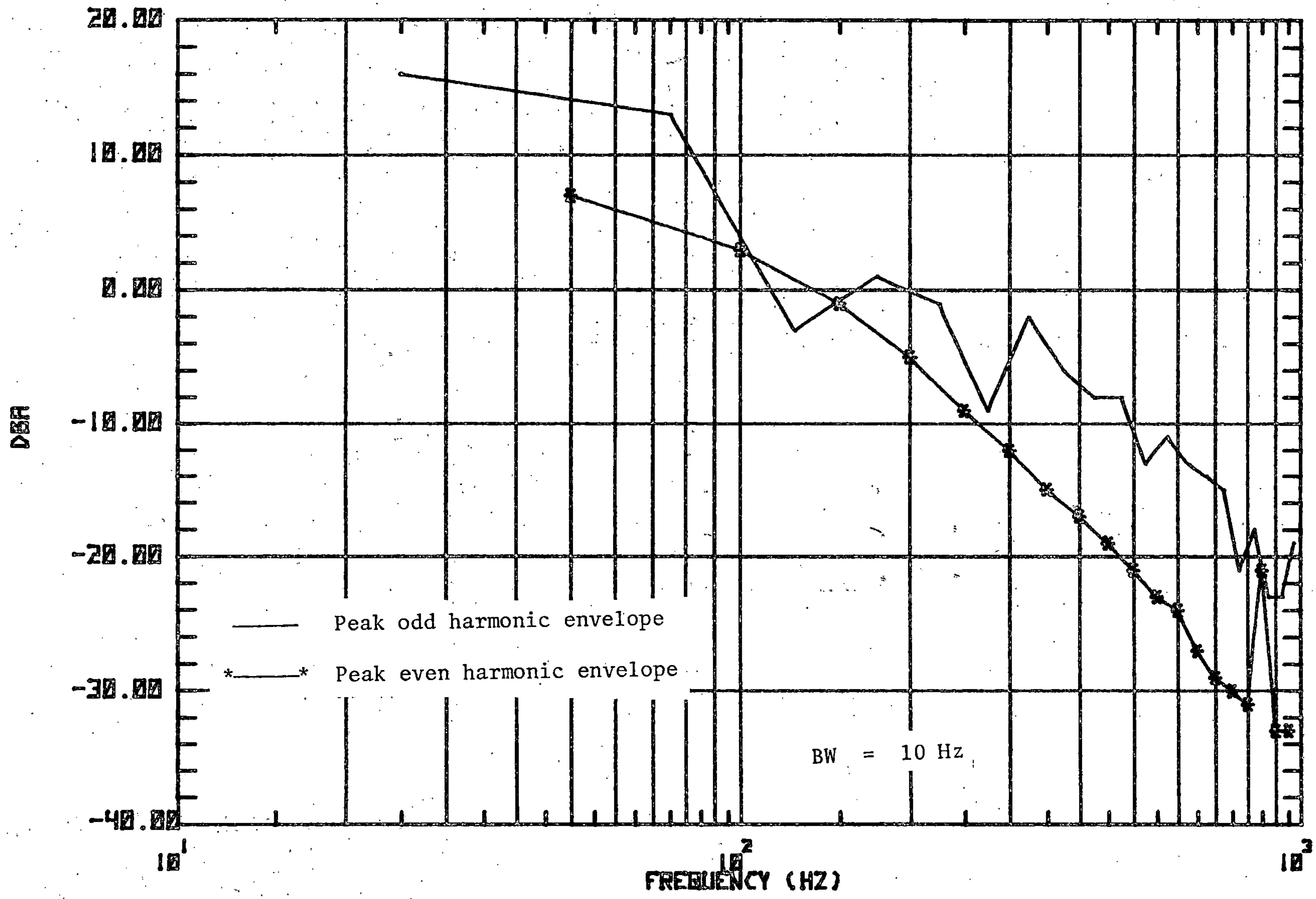


Figure 42. Frequency spectrum of current in traction motor (condition 5.4).

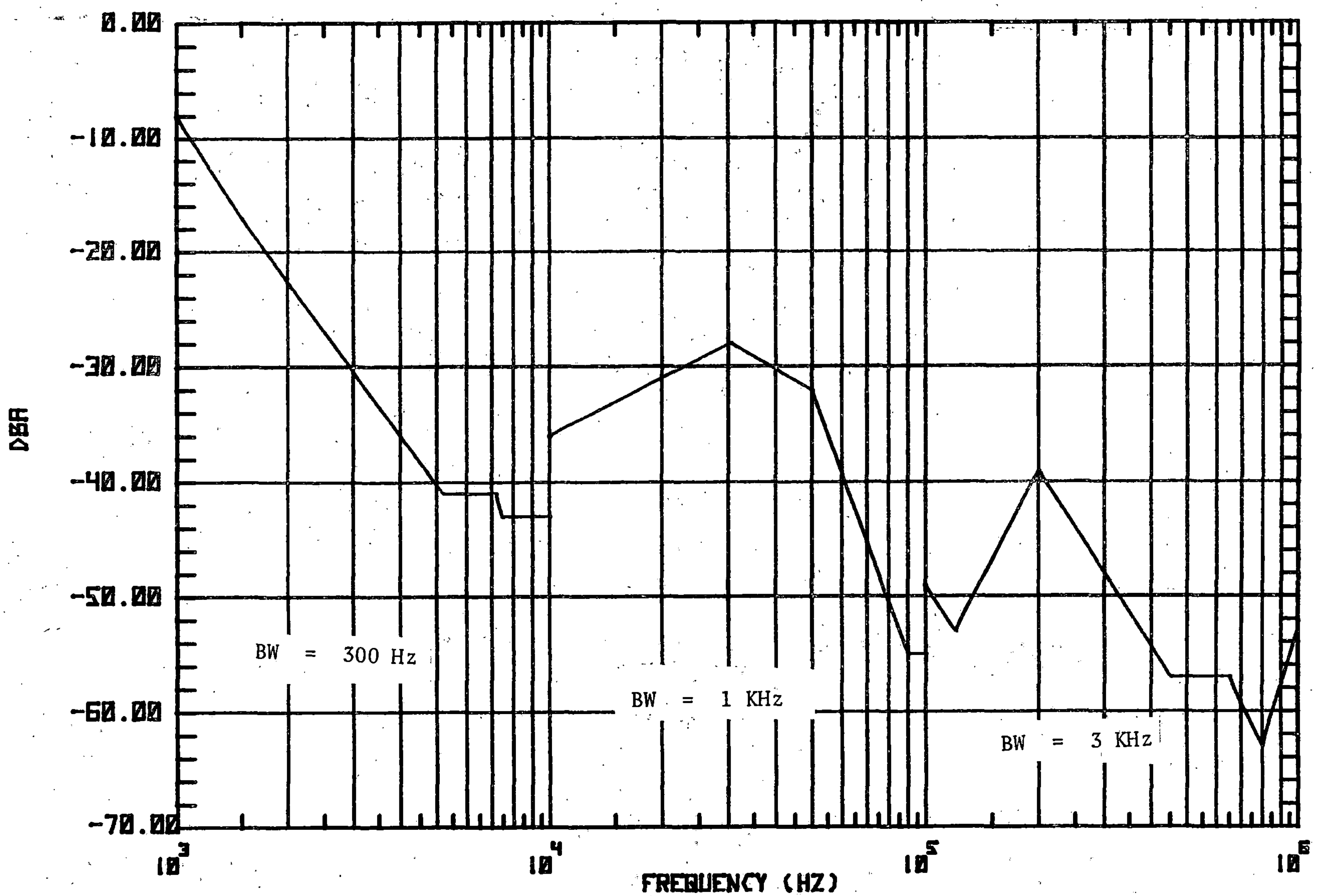
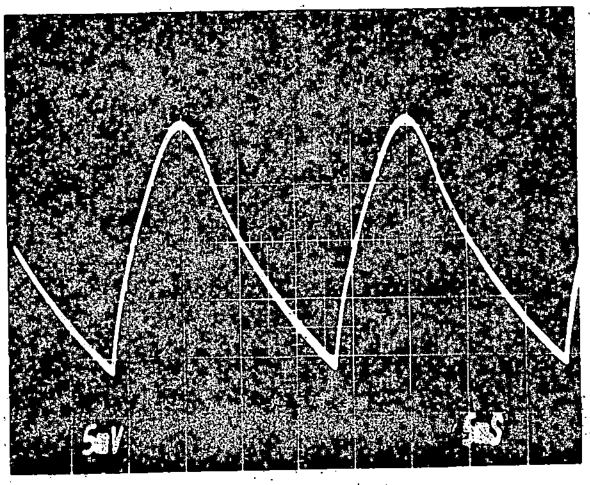


Figure 42. (continued).



(amplitude=4.5 amperes/div, time=5 ms/div)

Figure 43. Waveform of current in cable from negative terminal of battery.

The above measurements were then repeated on the cable from the positive terminal of the battery (condition 6.2). The time waveform results obtained under these conditions are shown in Figure 45, while the frequency spectrum results are given in Figure 46. In Figure 45, the amplitude of the time waveform of the current was approximately 36.5 amperes peak-to-peak.

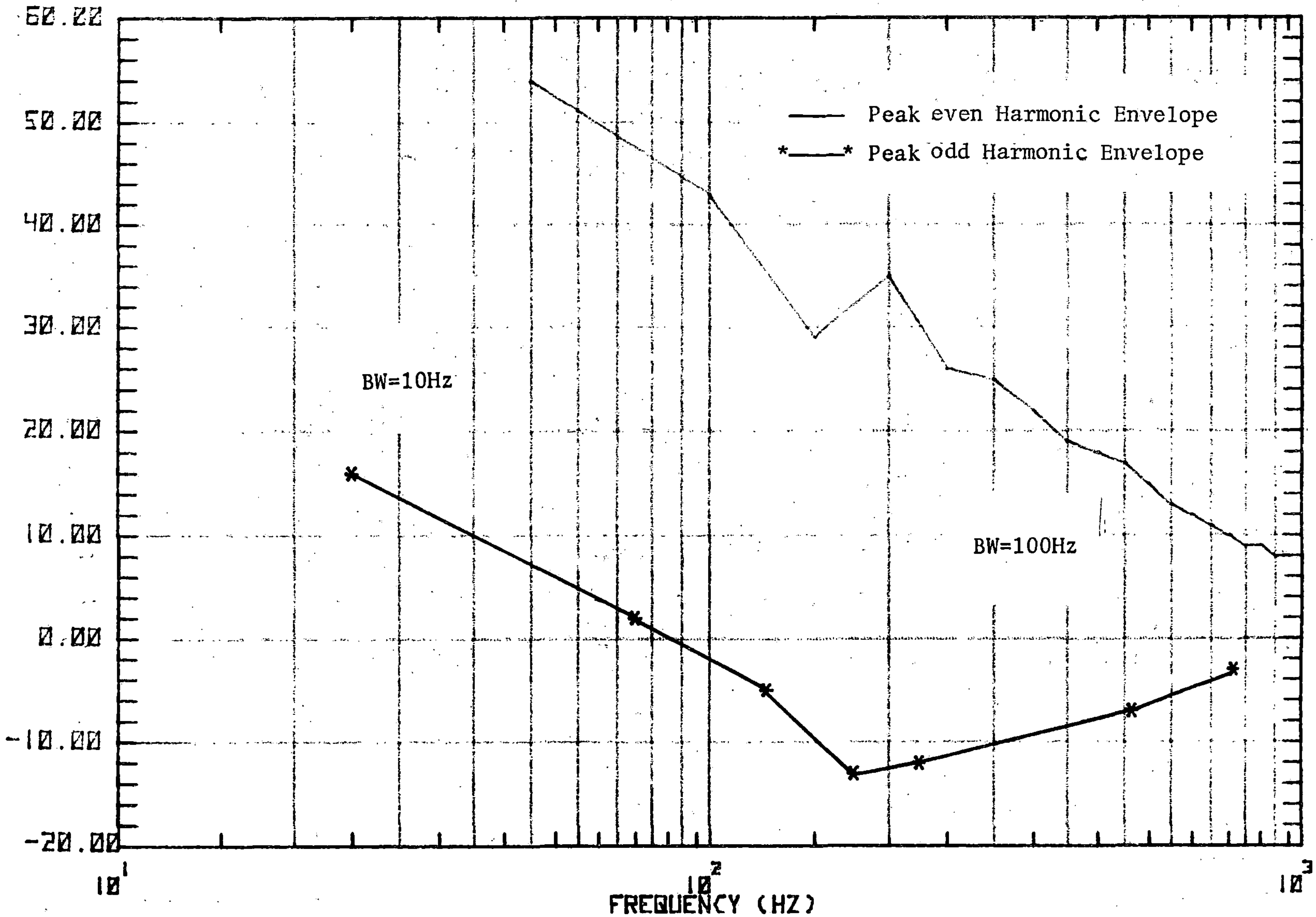


Figure 44. Spectrum of current in cable from negative terminal of battery.

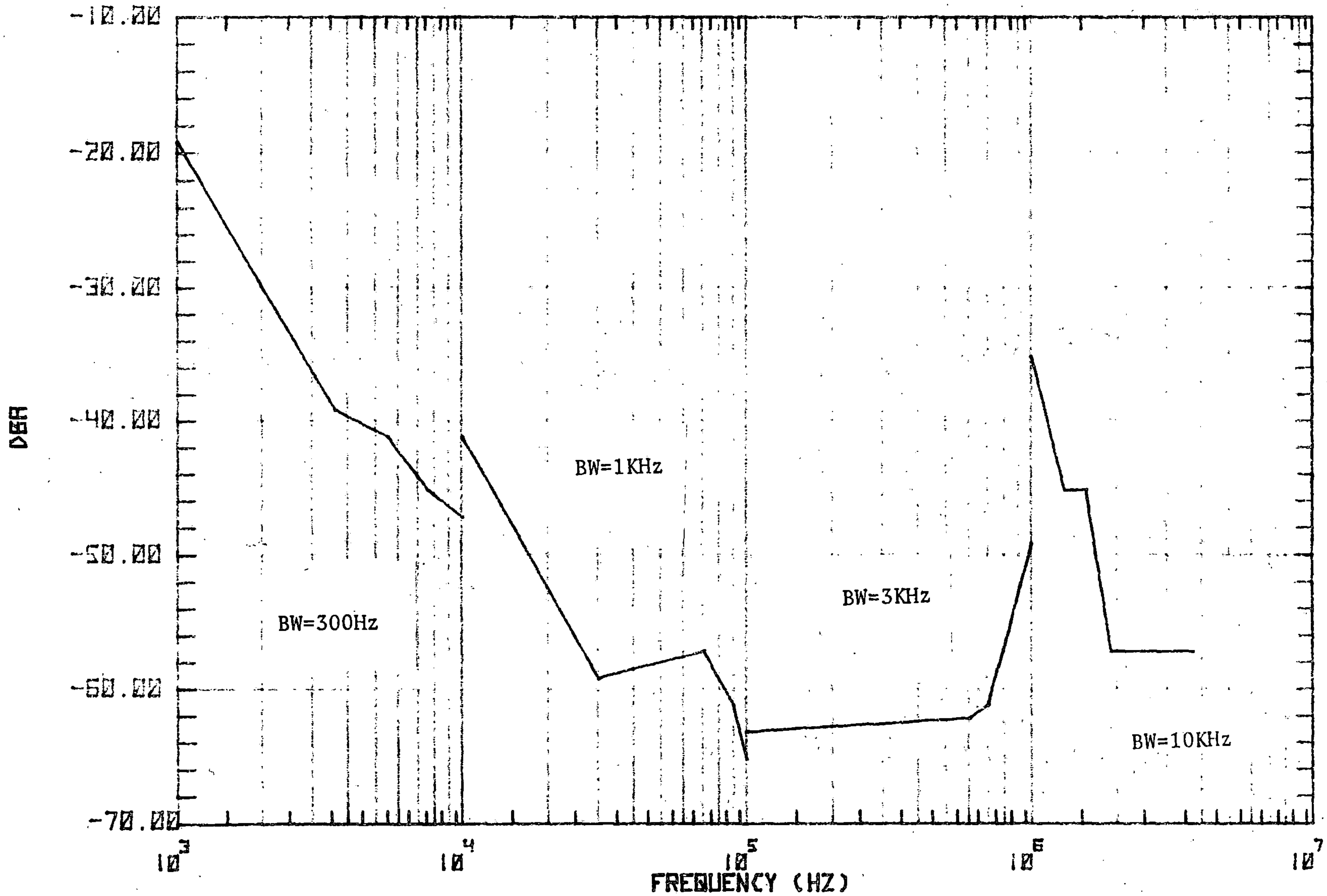
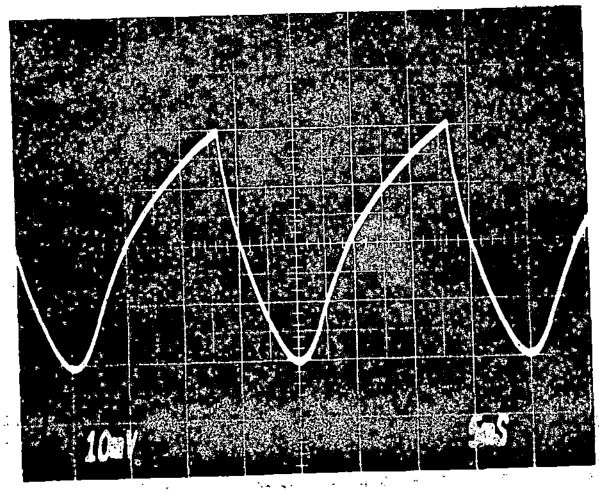


Figure 44. (continued).



(amplitude=8.9 amperes/div, time=5 ms/div)

Figure 45. Waveform of current in cable from positive terminal of battery.

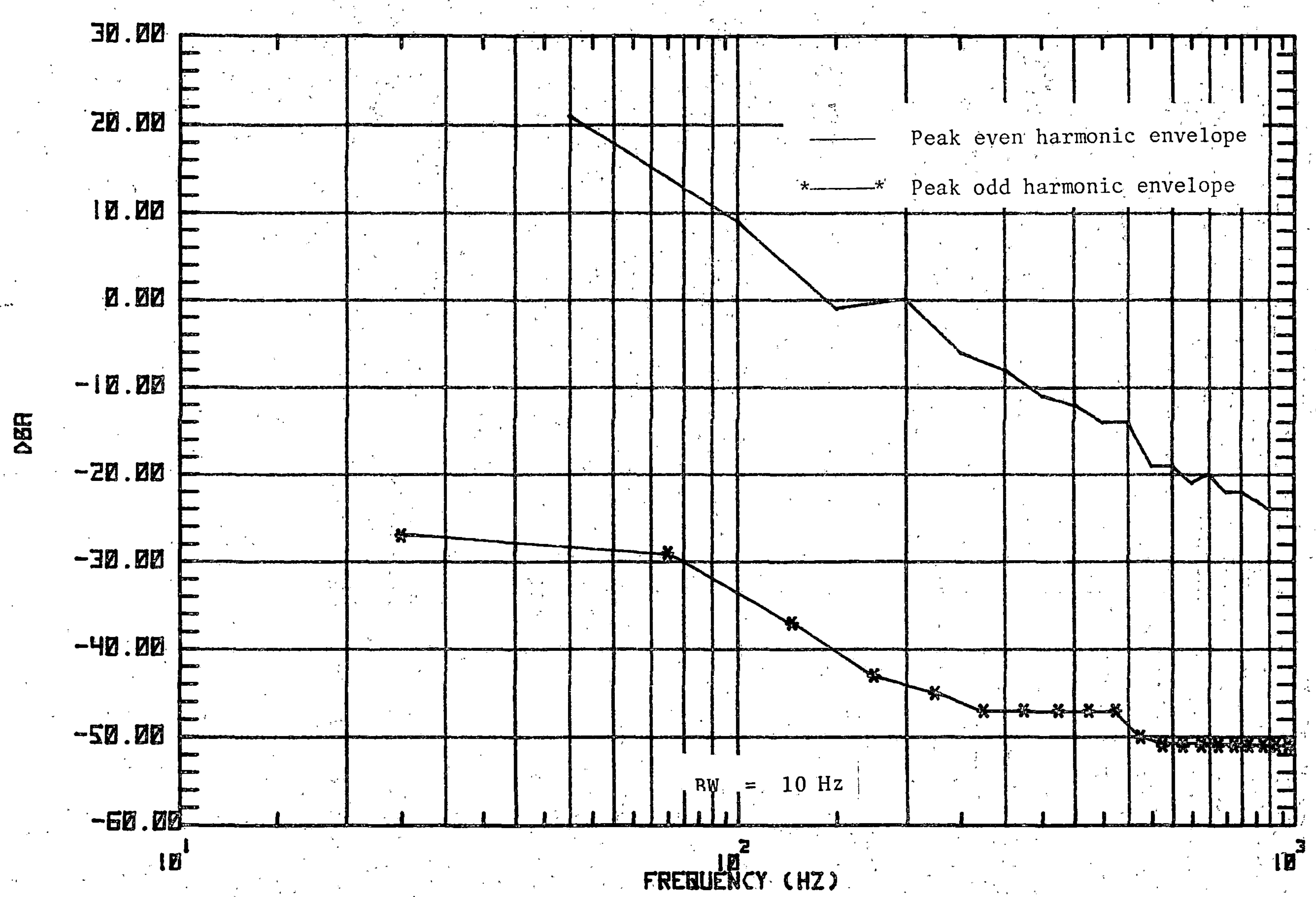


Figure 46. Spectrum of current from cable at positive terminal.

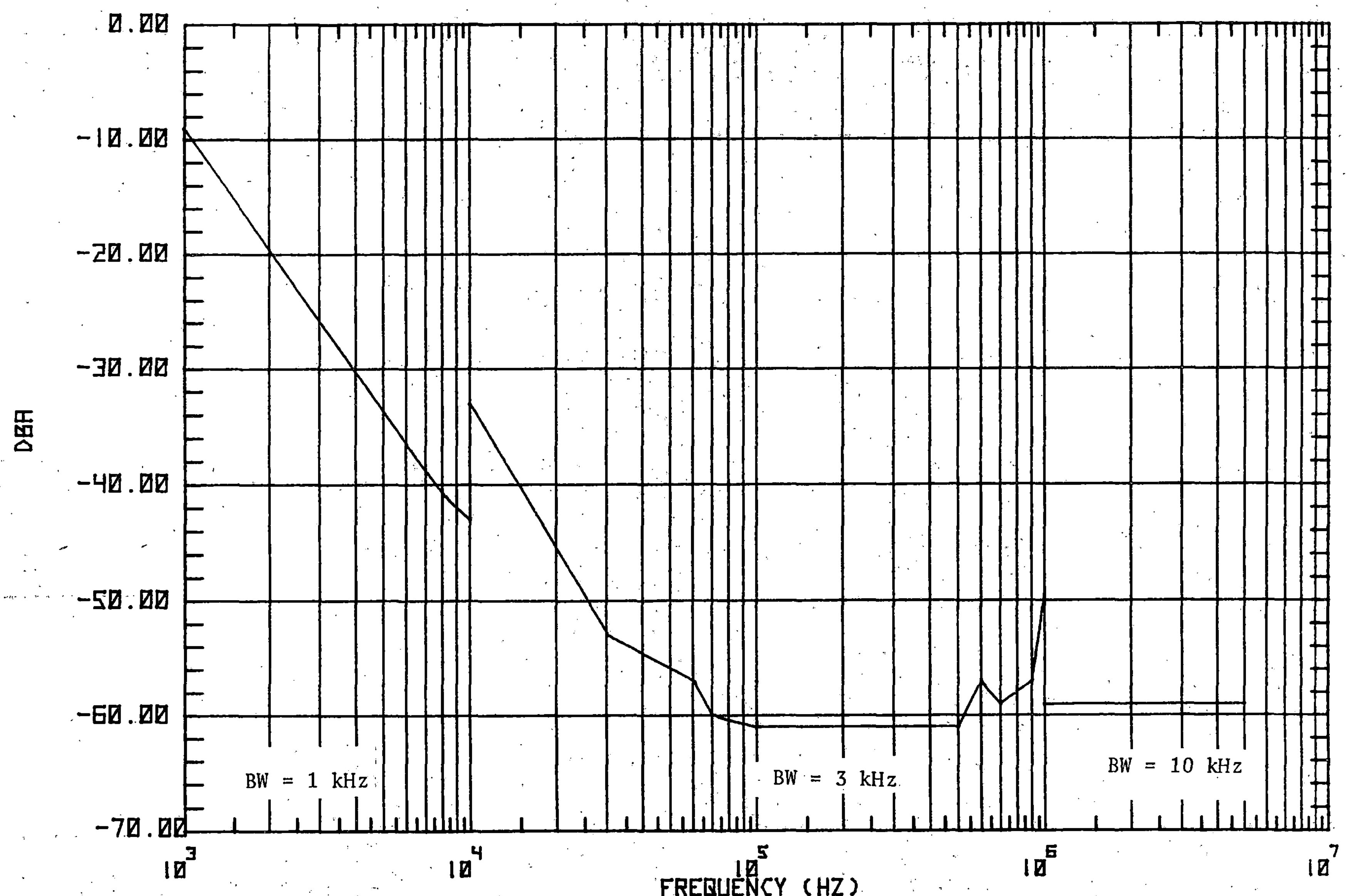


Figure 46. (Continued).

Referring to Figure 46, the 50 Hz component, in a 10 Hz resolution bandwidth, is 21 dBA (11.22 amperes). From the waveform, the current was calculated to be 12.6 amperes.

7.0 BATTERY CHARGER

Time waveform and frequency spectrum measurements of battery charger currents or voltages were obtained at the following locations, under the specified conditions:

7.1 Current measurements on the ac lead of the battery charger with one 5 HP steam plant motor on, blower motor on idle, oil pump motor and various small electrical systems housed in the locomotive on.

7.2 Current measurements in the cable connected to the ac terminal of the battery charger with two 5 HP steam plant motors on, blower motor on idle, oil pump and various small electrical devices within the locomotive on.

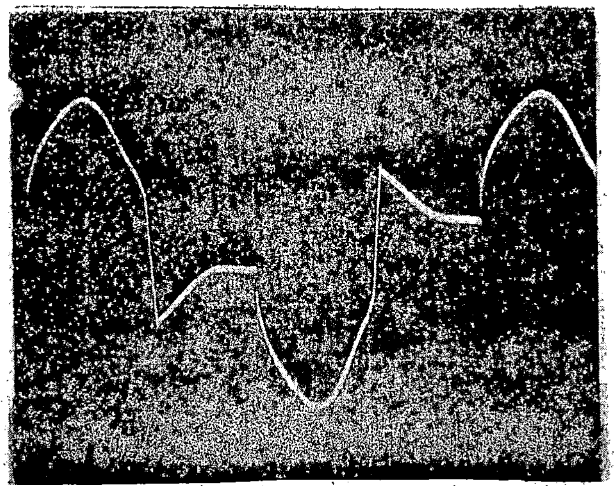
7.3 Measurement of current in the cable connected to the negative dc terminal of the battery charger with one 5 HP steam plant motor on, blower motor on, oil pump and various small electrical devices within the locomotive on.

7.4 Measurement of current in the cable connected to negative dc terminal of battery charger with traction motors drawing 450 amperes dc per truck, blower motor on, oil pump on, and various small electrical items housed in the locomotive on.

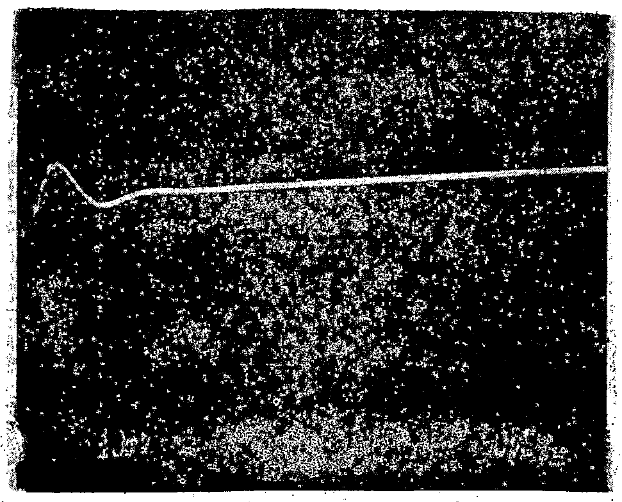
7.5 Measurement of current in the cable connected to negative dc terminal of battery charger with the traction motors drawing 1050 amperes dc per truck, blower motor on, oil pump motor and various small electrical items housed in the locomotive on.

7.6 Measurements of voltage transients at the negative dc terminal of the battery charger with main breaker closing.

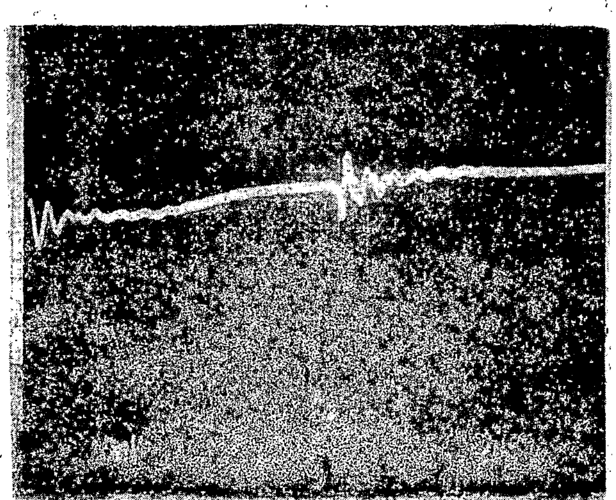
Results of the time waveform measurements of the current in ac input cable to the battery charger, under condition 7-1, are given in Figures 47, A B. The current waveform sampled under this condition was approximately 50 amperes peak-to-peak. Results of current spectra samplings are presented in Figure 48.



(A) 8.9 ampere/div, 5 msec/div



(B) 8.9 ampere/div, 50 μsec/div



(C) 8.9 ampere/div, 2 μsec/div

Figure 47. Current in ac lead at input to battery charger.

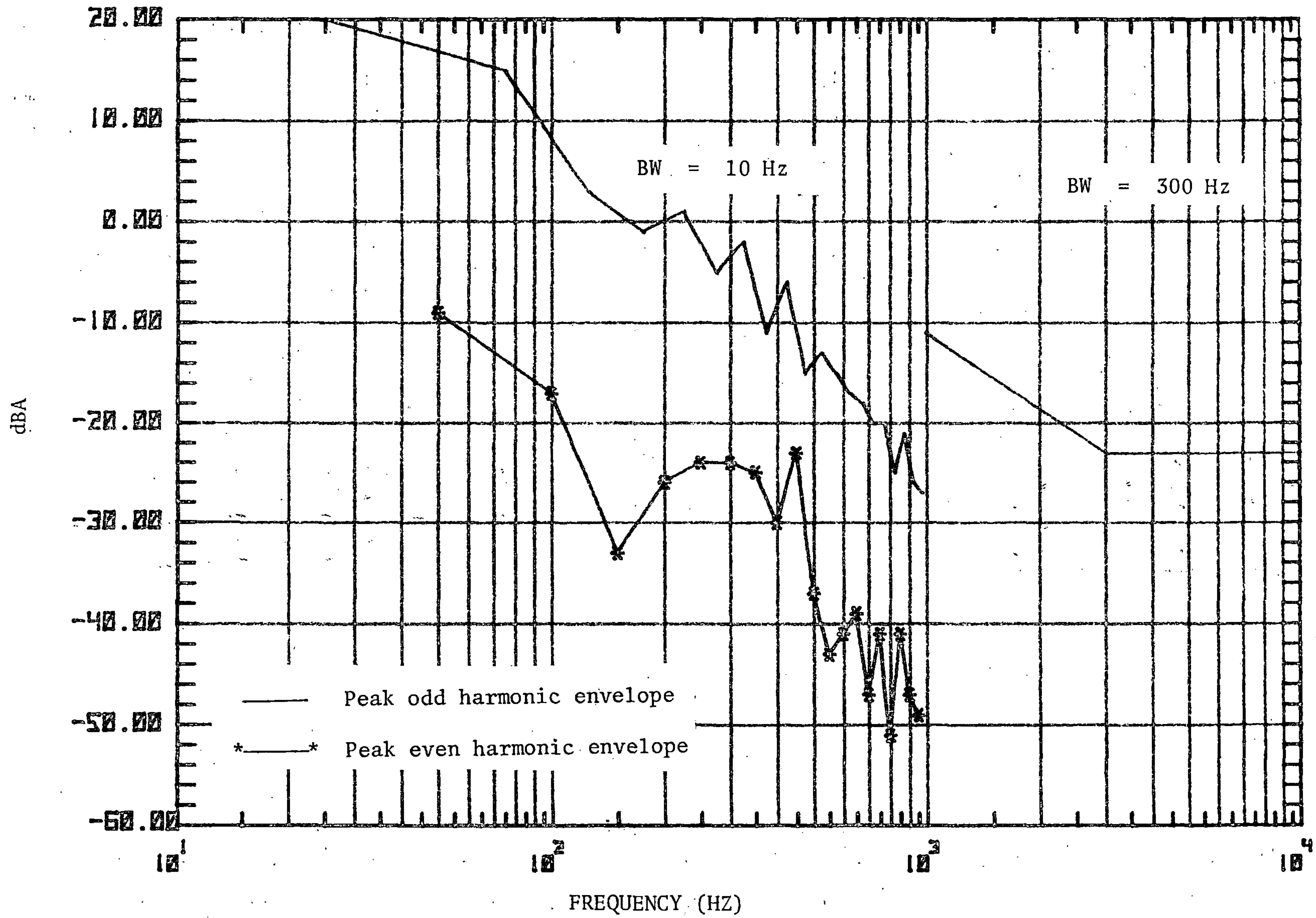
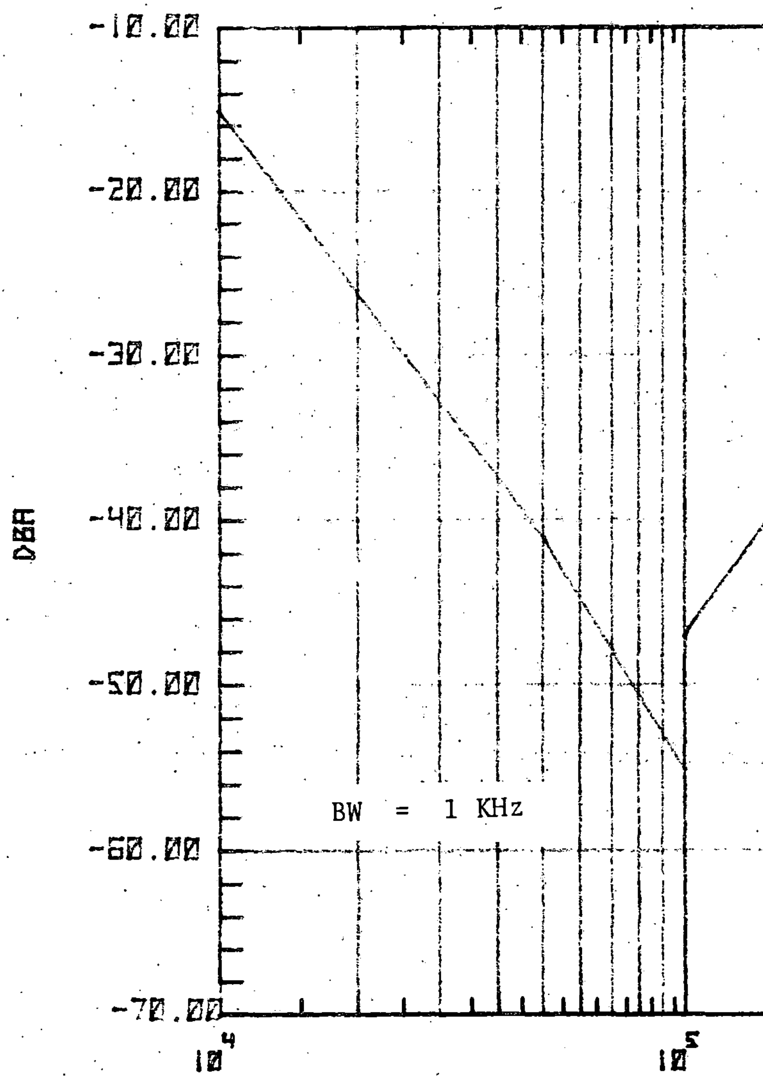
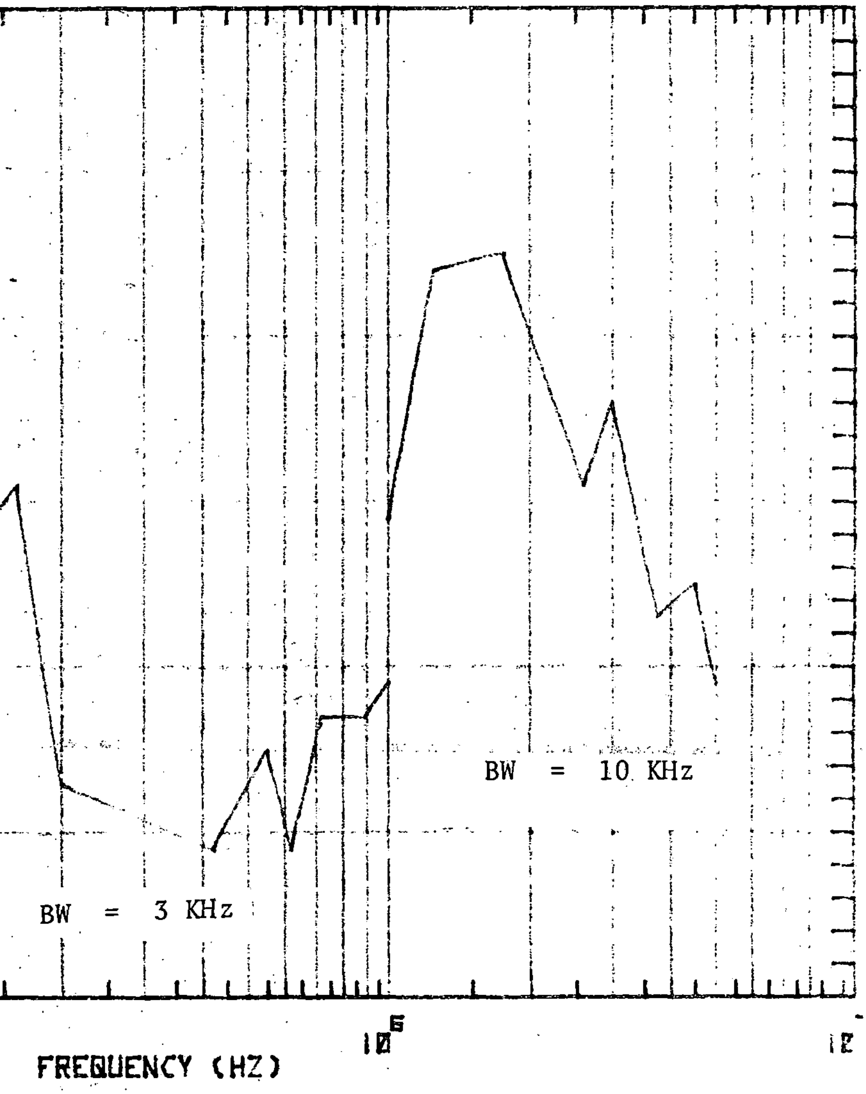


Figure 48. Spectrum of current in lead to ac terminal of battery charger (condition 7.1).

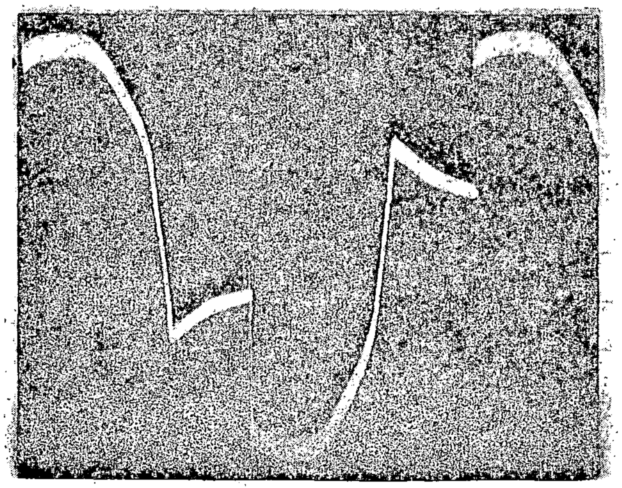


Figure

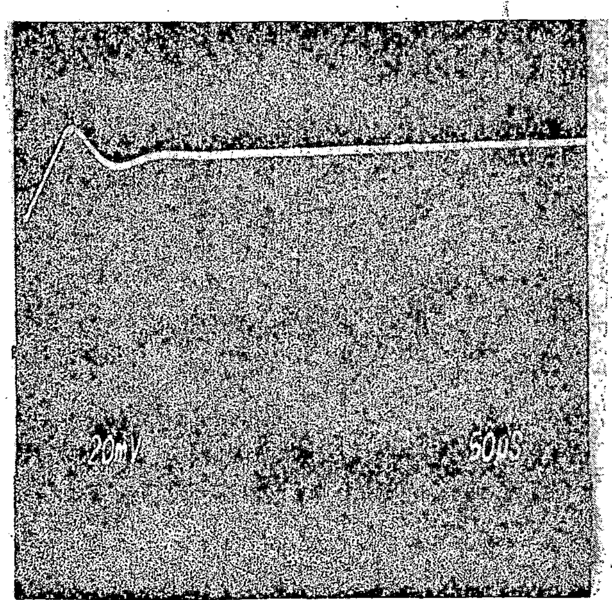


48. (continued).

Next, the time waveform of the current in the ac lead was sampled with both steam plant motors on (condition 7.2). Results of this measurement are given in Figures 49A, B. The amplitude recorded was approximately 142 amperes peak-to-peak. The thickness of the traces indicates that a slow beat note exists between the two motors.



(A) 50 millisecond time interval, 17.8 amperes per division.



(B) 500 μsecond time interval, 17.8 amperes per division.

Figure 49. Waveform of current in ac lead at input to battery charger.

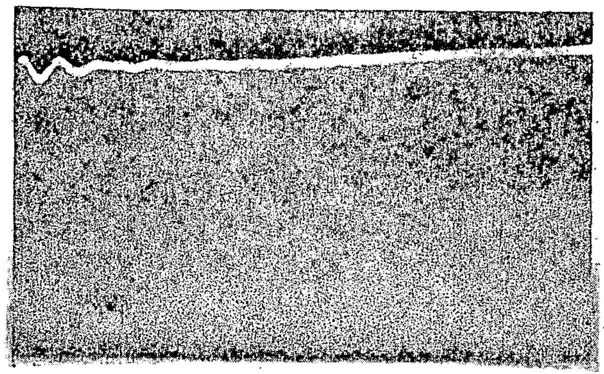


Figure 49c. Waveform of current in ac lead at input to battery charger.

The current loop probe was then placed next to the negative dc terminal of the battery charger, with one steam plant motor operating (condition 7.3), and the time waveform and frequency spectrum of the current in the cable were sampled. The current loop probe placement for this measurement is shown in Figure 50. The current waveform obtained during these measurement proceedings is presented in Figure 51. The amplitude of the waveform of the current sampled was 71.2 amperes peak-to-peak.

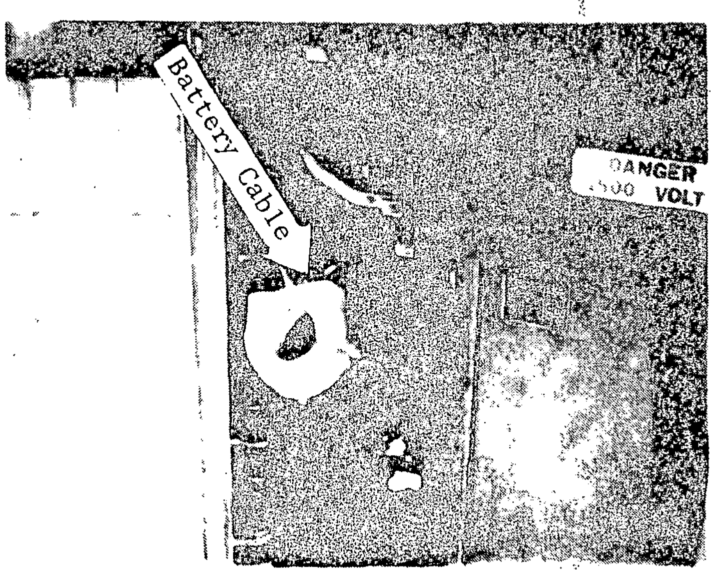


Figure 50. Current loop sampling current in lead from negative dc terminal of battery charger.

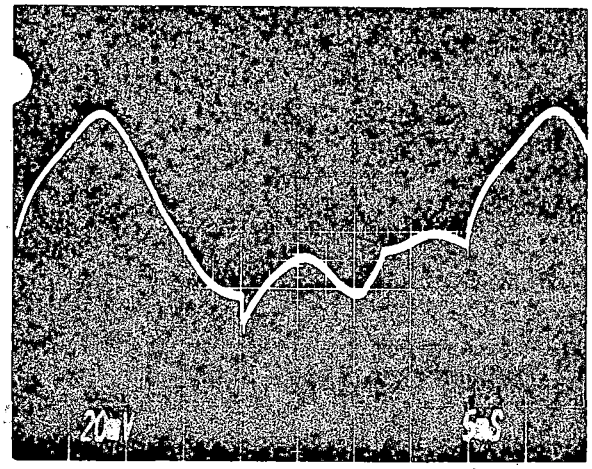


Figure 51. Waveform of current in lead from negative dc terminal of battery charger over a 50 millisecond time interval, (17.8 amperes per division).

Frequency spectrum measurements were performed between 25 Hz and 5 MHz, and results are presented in Figure 52. The 25 Hz component, as measured in a 10 Hz resolution bandwidth, was 21 dBA (approximately 11.22 amperes). At 1 MHz, a mound of energy approximately 15 dBA, in a 10 kHz resolution bandwidth, above the neighboring emission levels is observed. This mound of energy was also observed when current measurements were performed on the cable leading to the armature of the traction motor (see Figure 38), the cause of which was not uncovered during the measurement proceedings.

Next, the steam plant motor was turned off, and the traction motors were turned on and were drawing 450 amperes dc per truck (condition 7.4). A time waveform photograph showing the variation of the current levels over a 50 millisecond time interval was obtained and is shown in Figure 53.

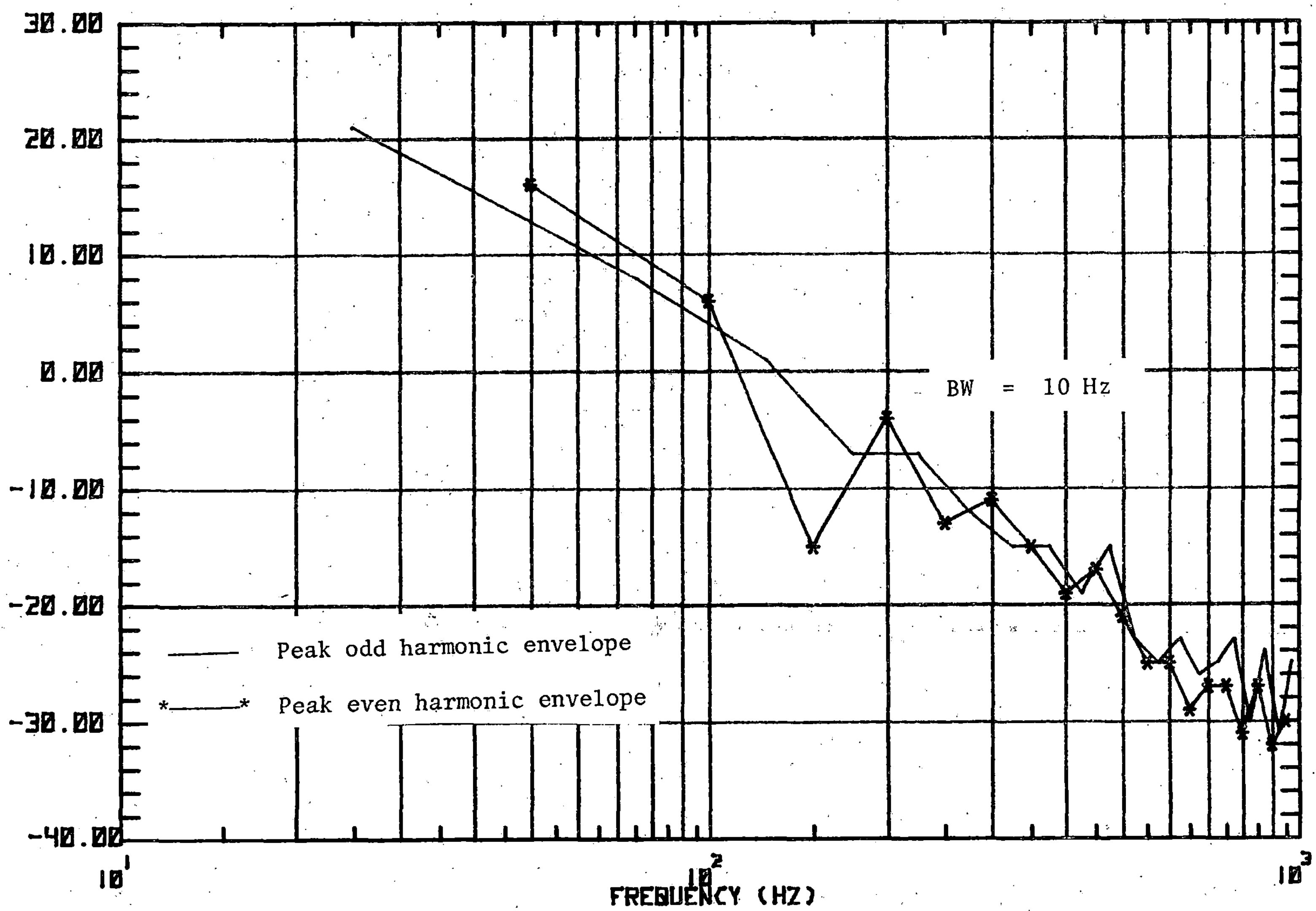


Figure 52. Spectrum of current in cable from negative dc terminal of the battery charger with one steam plant motor on.

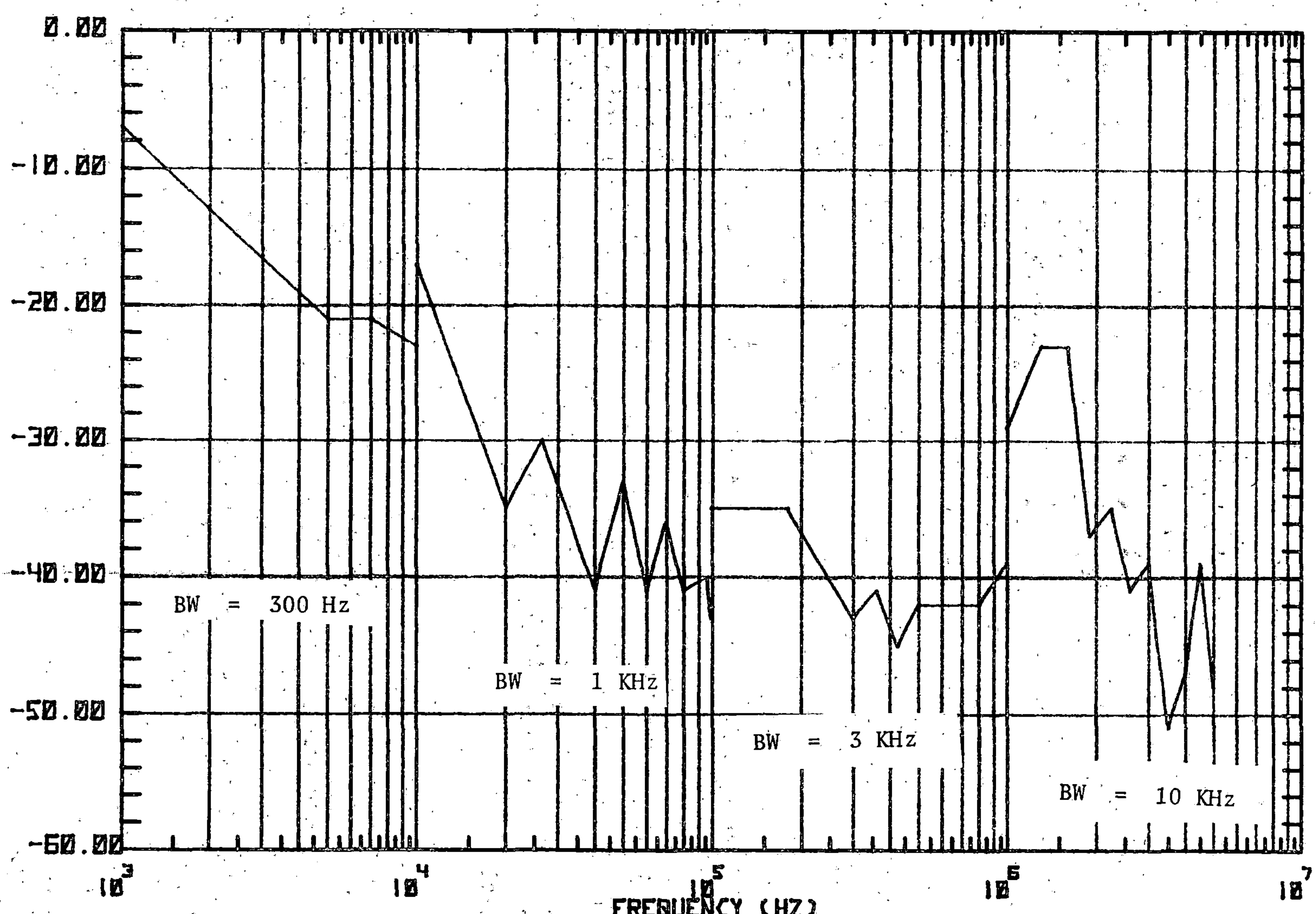
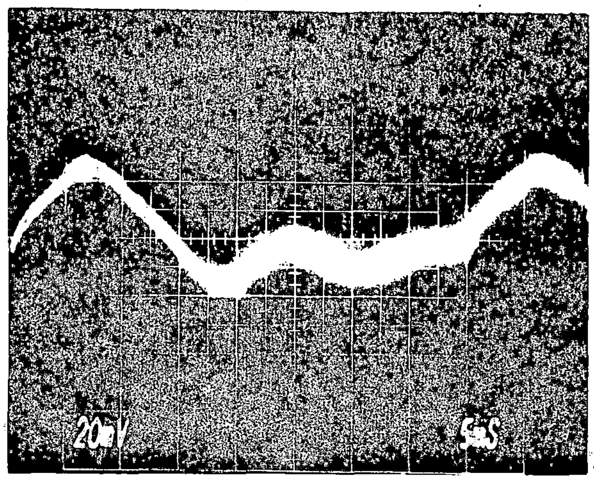


Figure 52. (continued).



(5 milliseconds/div, 17.8 amperes/div)

Figure 53. Waveform of current in cable from negative dc terminal of battery charger (condition 7.4).

The variation of energy levels versus frequency, between 25 Hz and 5 MHz, was measured and is displayed in Figure 54. From Figure 54 both odd and even harmonics of 25 Hz are noticeable between 25 Hz and 1 kHz. The 25 Hz and 50 Hz components, recorded in a 10 Hz resolution bandwidth, were 17 dBA (approximately 7.1 amperes) and 15 dBA (approximately 5.6 amperes), respectively. The mound of energy, noted previously around 1 MHz, is again noticeable.

The traction motors were then set to draw 1050 amperes dc per truck, and the frequency spectrum of the current in the cable from the negative terminal of the battery charger was sampled (condition 7.5). Results of this sampling are given in Figure 55. Comparing Figures 55 and 54, the energy levels of the spectral components appear equivalent.

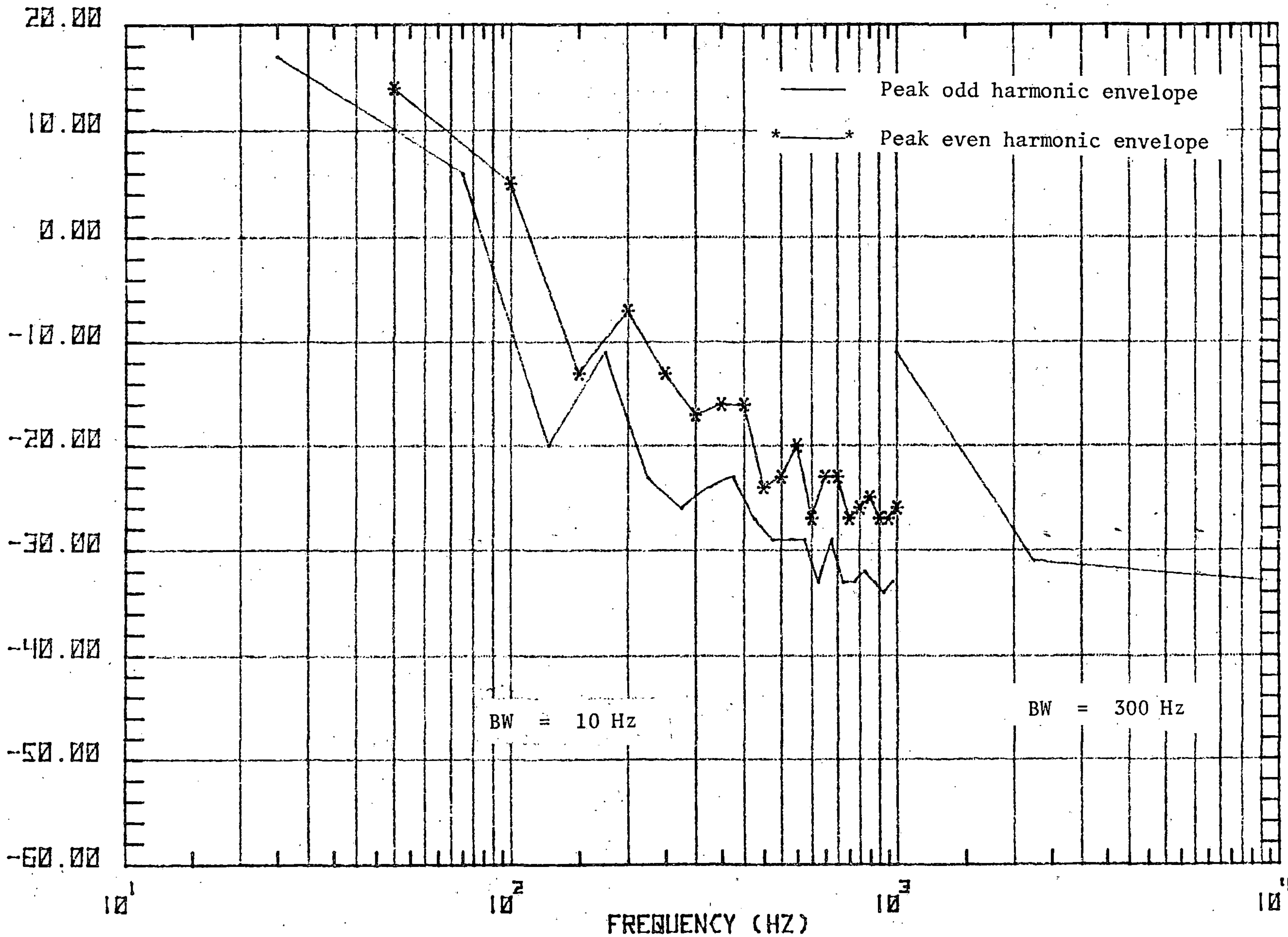


Figure 54. Spectrum of current in negative dc terminal of battery charger (condition 7.4).

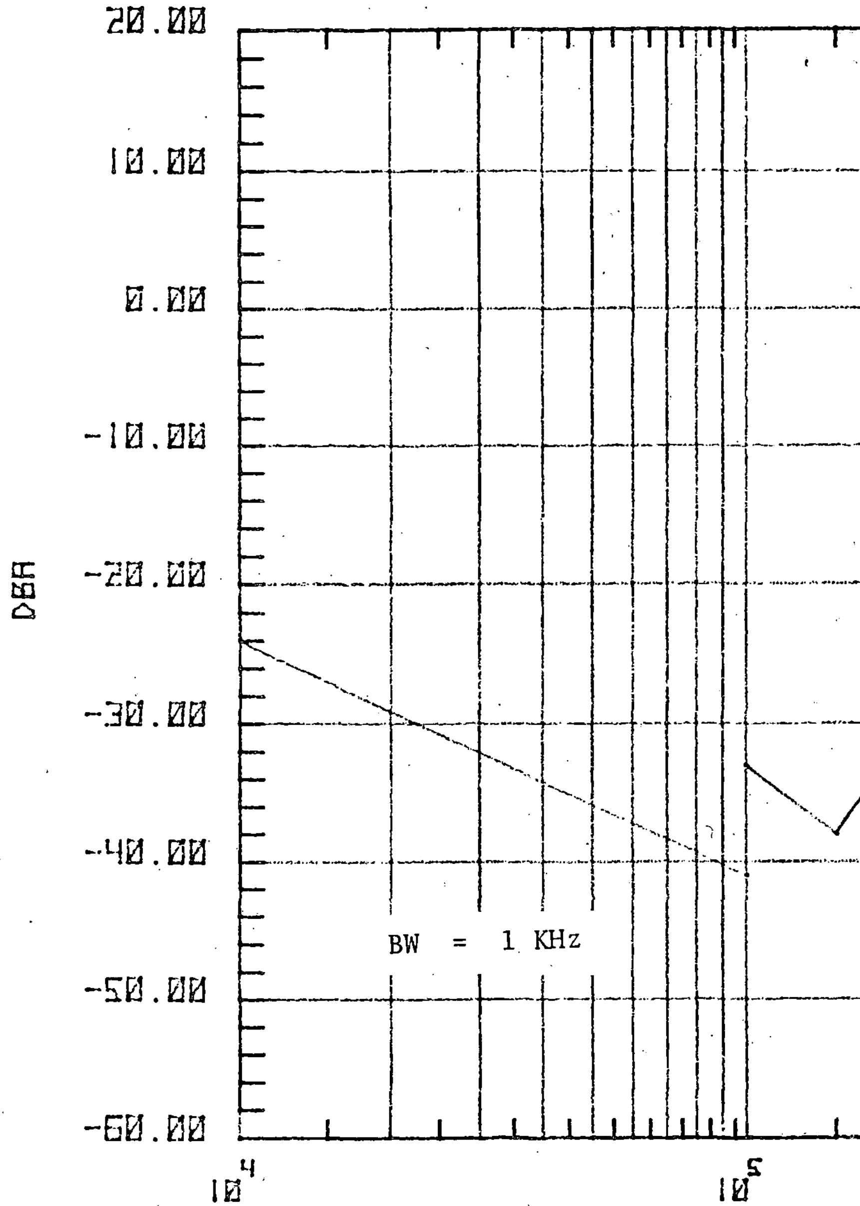
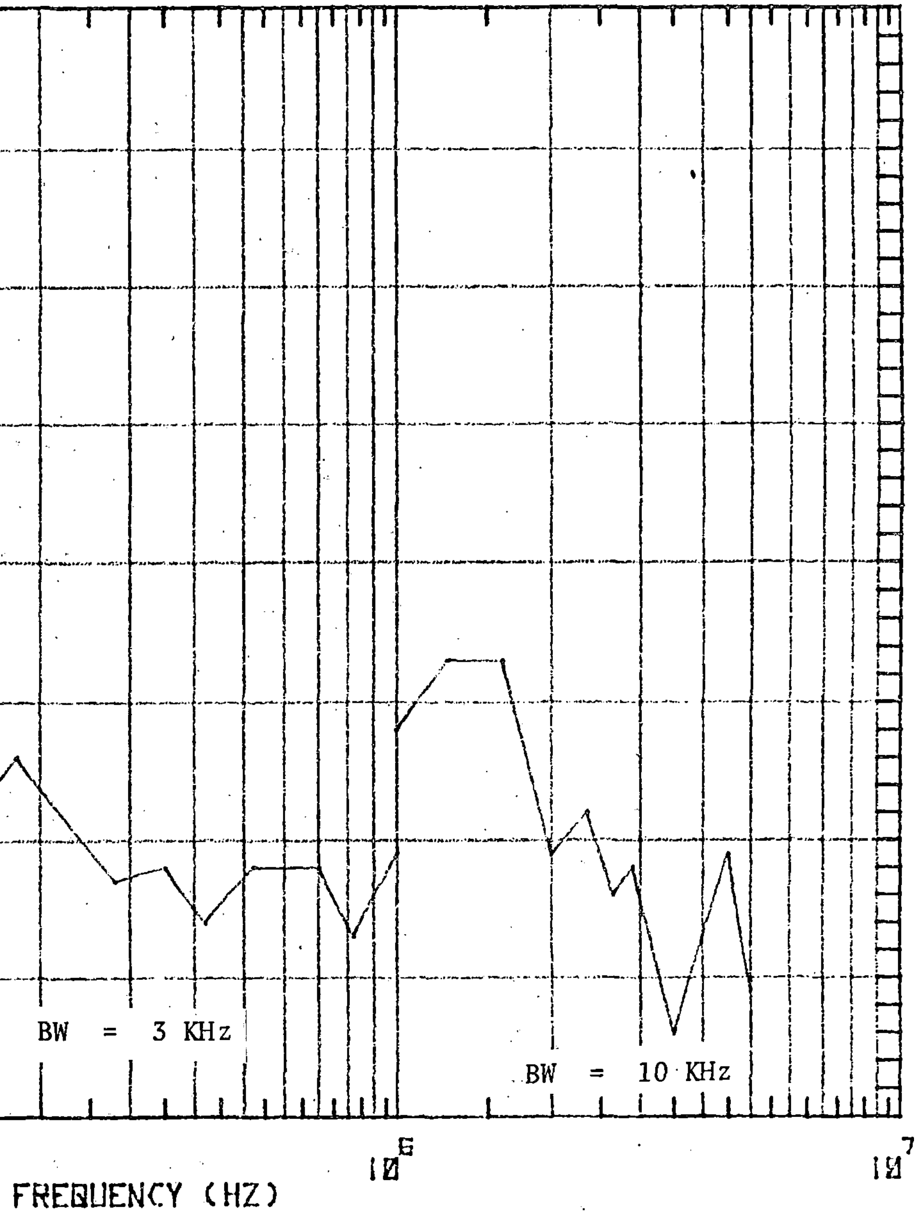

DBA
20.00
10.00
0.00
-10.00
-20.00
-30.00
-40.00
-50.00
-60.00
BW = 1 KHz
10^4
10^5

Figure 54.



(continued).

Next, the voltage probes were connected between the negative dc terminal of the battery charger and ground as shown in Figrue 56. The main breaker was then closed and a time waveform of the voltage transient was recorded. The transient recorded is presented in Figure 57. The transient oscillations are approximately 80 volts greater than the rest voltage of -32 volts dc.

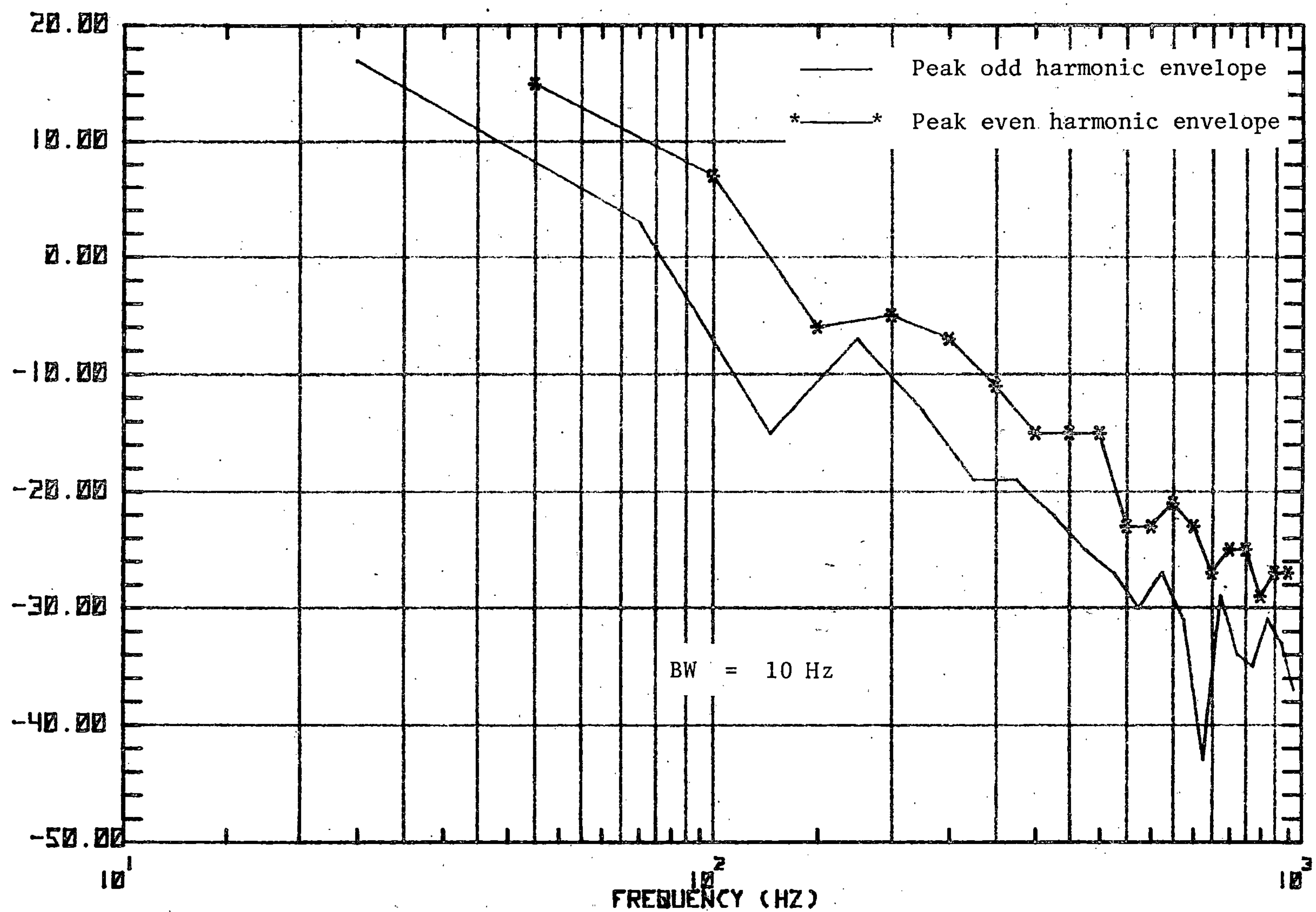


Figure 55. Spectrum of current in negative dc battery charger cable with traction motor drawing 1050 ampered dc per truck (condition 7.5).

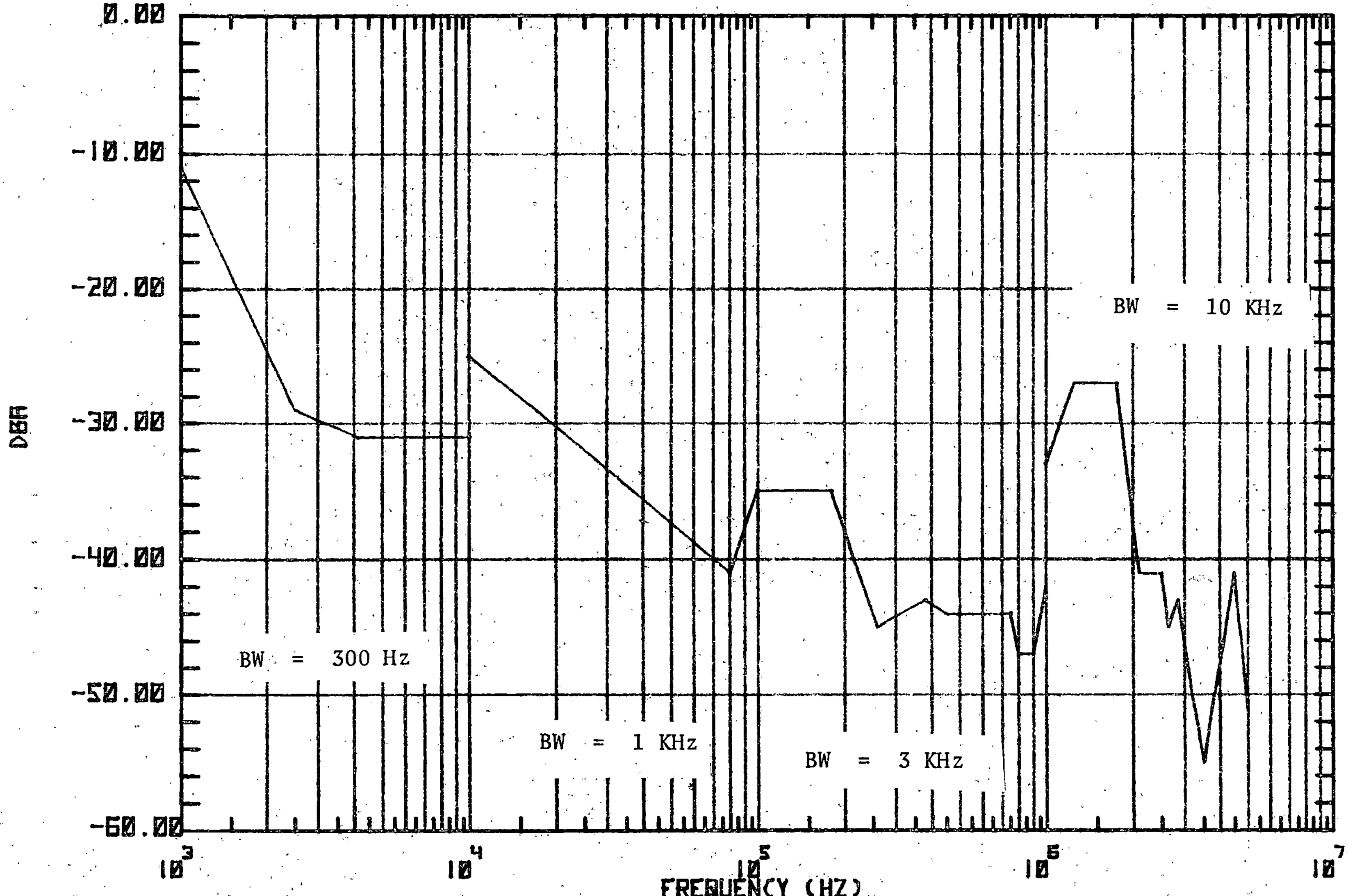


Figure 55. (continued).

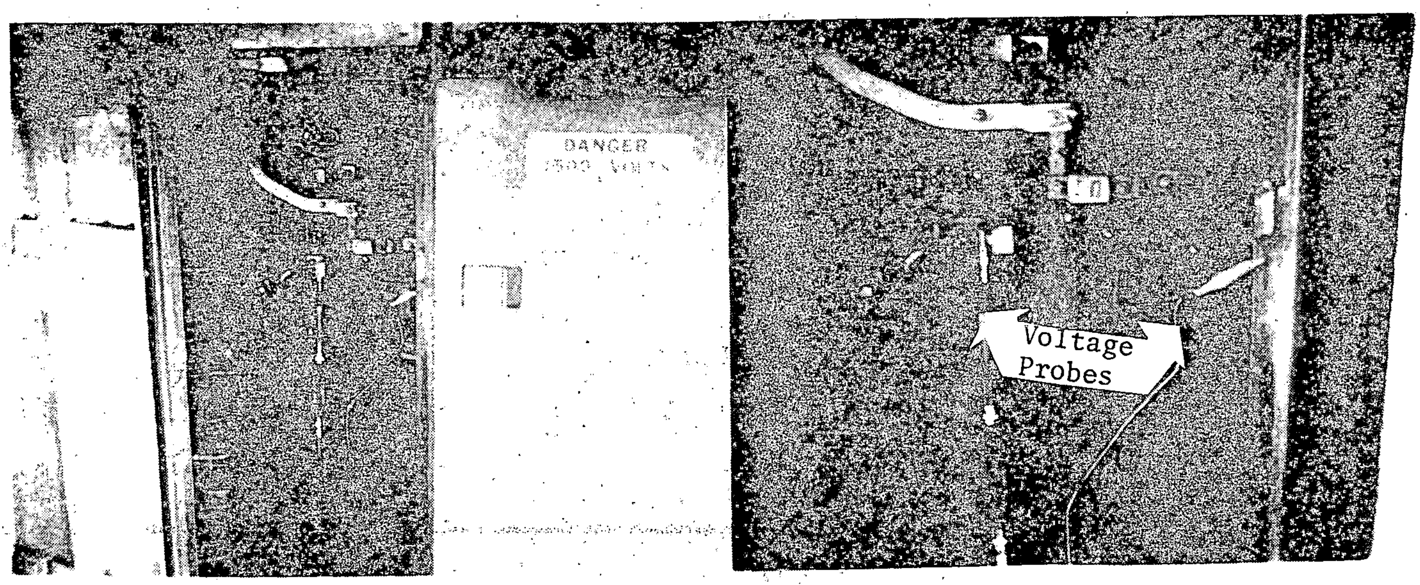


Figure 56. Probe placement for voltage transient measurements.

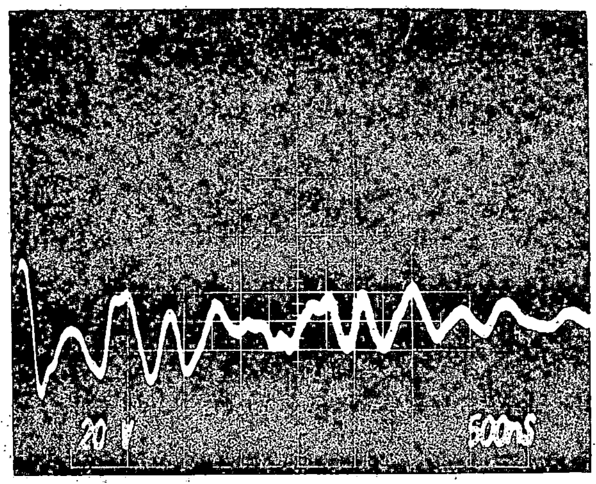


Figure 57. Waveform of voltage transient between the negative dc terminal and ground. (20 volts/div, 500 ns/div, center line = 0 volt dc)

8.0 74 VOLT dc BUS

Measurements of voltage and current were made on the 74 Volt dc bus at the following locations, under the specified conditions:

8.1 Current measurements on the cable connected to the negative terminal of the 74 volt dc bus with the blower motor on idle, oil pump on, and various small electrical devices in the locomotive on.

8.2 Voltage measurements across the 74 volt dc bus with the blower motor on idle, oil pump on, and various small electrical devices in the locomotive on.

8.3 Voltage across the bus with the blower on idle, M/A set on idle (unloaded), oil pump and various small electrical devices housed in the locomotive on.

8.4 Voltage across the bus with the blower on idle, the M/A set delivering 700 amperes to a resistive load, oil pump and various small electrical devices housed in the locomotive on.

8.5 Voltage across the bus with the blower motor on idle, M/A set on idle (unloaded), the oil pump and various small electrical devices in the cab on, and the dynamic brake in position 2.

8.6 Voltage across the bus with the blower motor on idle, the M/A set on idle (unloaded), dynamic brake in position 8, oil pump motor and small electrical devices in the locomotive on.

8.7 Voltage across 74 volt bus with blower motor on idle, oil pump and small electrical devices in the locomotive on.

8.9 Voltage across 74 volt bus during staging test.

Voltage at 74 volt receptacle with the main breaker closing.

The current in the cable connected to the negative terminal of the 74 volt dc bus was sampled, and the results, over a 50 millisecond time interval, are shown in Figure 58. The current waveform appears to vary from approximately a positive 11.25 amperes to a negative 11.7 amperes.

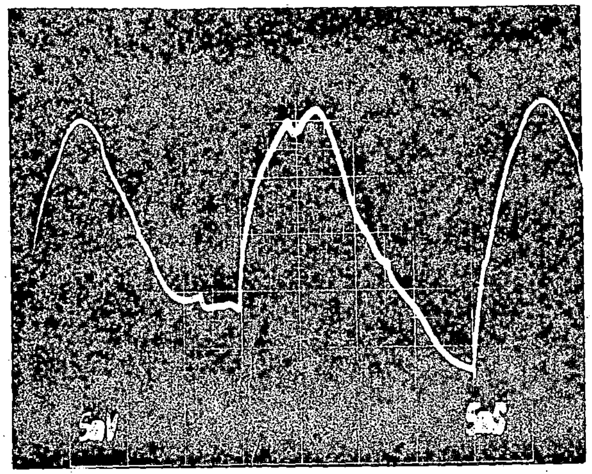


Figure 58. Waveform of current in cable connected to negative terminal of 74 volt dc bus. (Amplitude=4.5 ampere/div, time=5 ms/div)

Next, the levels of current, with respect to frequency, between 25 Hz and 1 kHz were sampled in the cable connected to the negative terminal of the 74 volt bus. Results of these measurements are shown in Figure 59. Referring to Figure 59, the even harmonics of 25 Hz appear to predominate. The 50 Hz component, for example, was 17 dBA (approximately 7.1 amperes) in a 10 Hz analyzer bandwidth. The 25 Hz component, on the other hand, was 3 dBA (approximately 1.4 amperes) in a 10 Hz resolution bandwidth.

Next, the voltage across the 74 volt bus was sampled (condition 8.3). The results obtained during these measurements are displayed in Figure 60. From Figure 60, voltage pulses occuring every 20 milliseconds with an amplitude of 300 volts are observed.

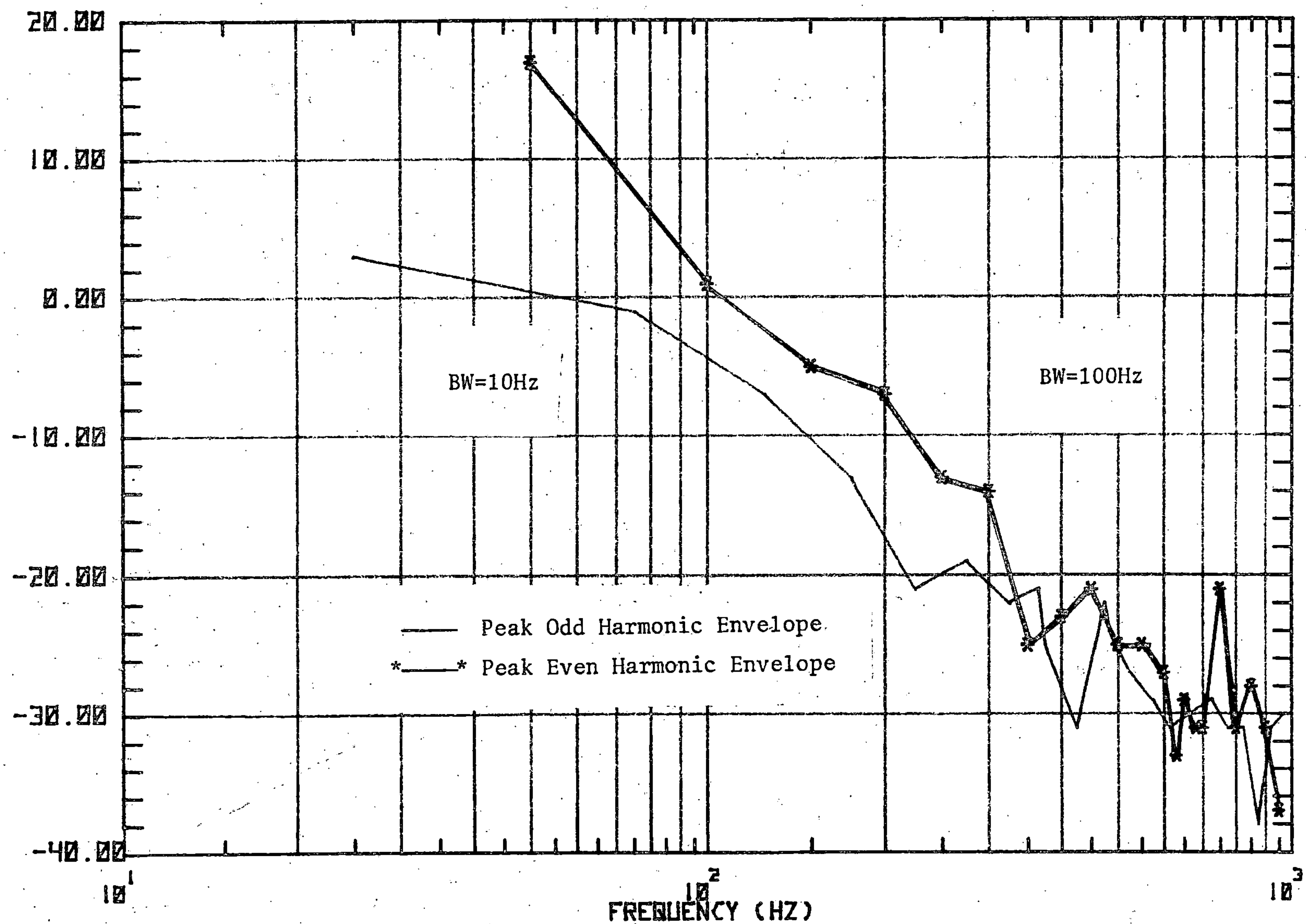
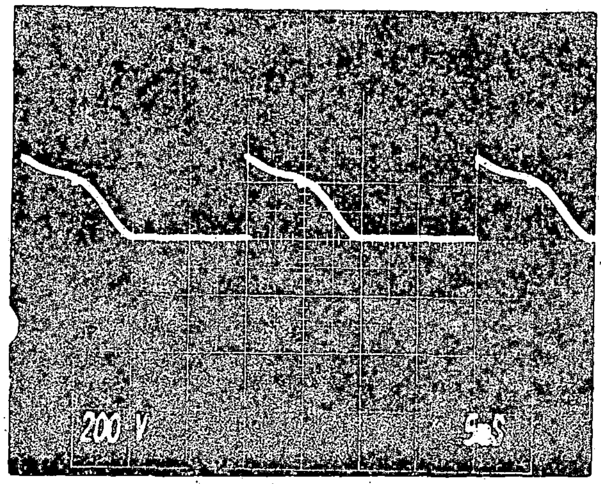


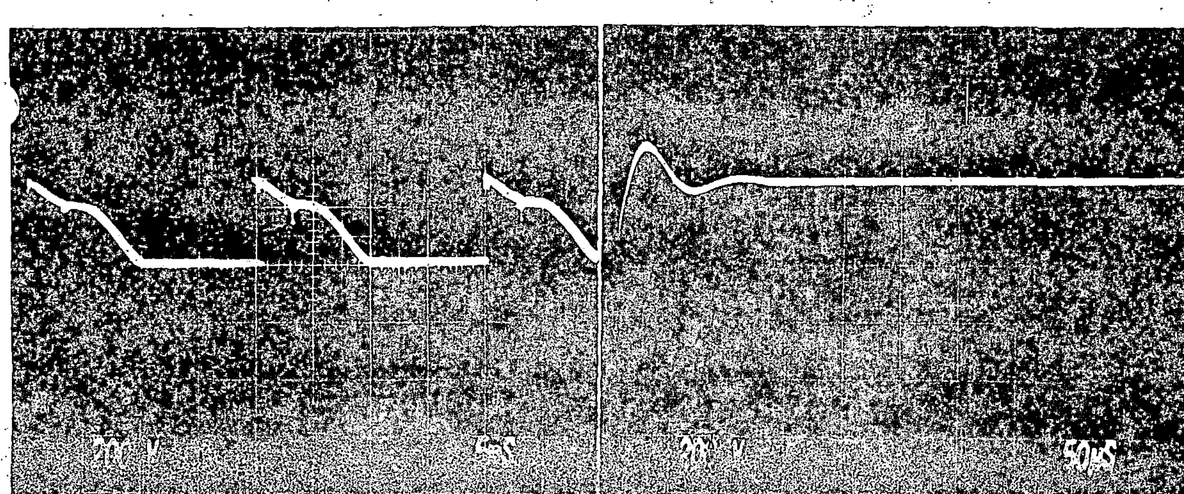
Figure 59. Spectrum of current in cable connected to negative 74 volt **dc** bus.



(200 volts/div, 5 ms/div)

Figure 60. Voltage across 74 volt dc bus (condition 8.3).

The M/A set was then connected, delivered 700 amperes of current to a resistive load. Time waveform measurements of the voltage across the 74 volt bus were then performed, and results are given in 61. In Figure 61, the same voltage pulses seen in Figure 60 are present. Results of frequency spectrum measurements, between 25 Hz and 5 MHz, are given in Figure 62. Referring to Figure 62, the even harmonics appear to predominate. The 50 Hz component, for example, was recorded at 40 dBV (100 volts) in a 10 Hz resolution bandwidth, while the 25 Hz component was 10 dBV (3.16 volts).



(5 msec/div) (50 μsec/div)

Figure 61. Waveform of the voltage across the terminals of the 74 volt dc bus (condition 8.4) (200 volts/div)

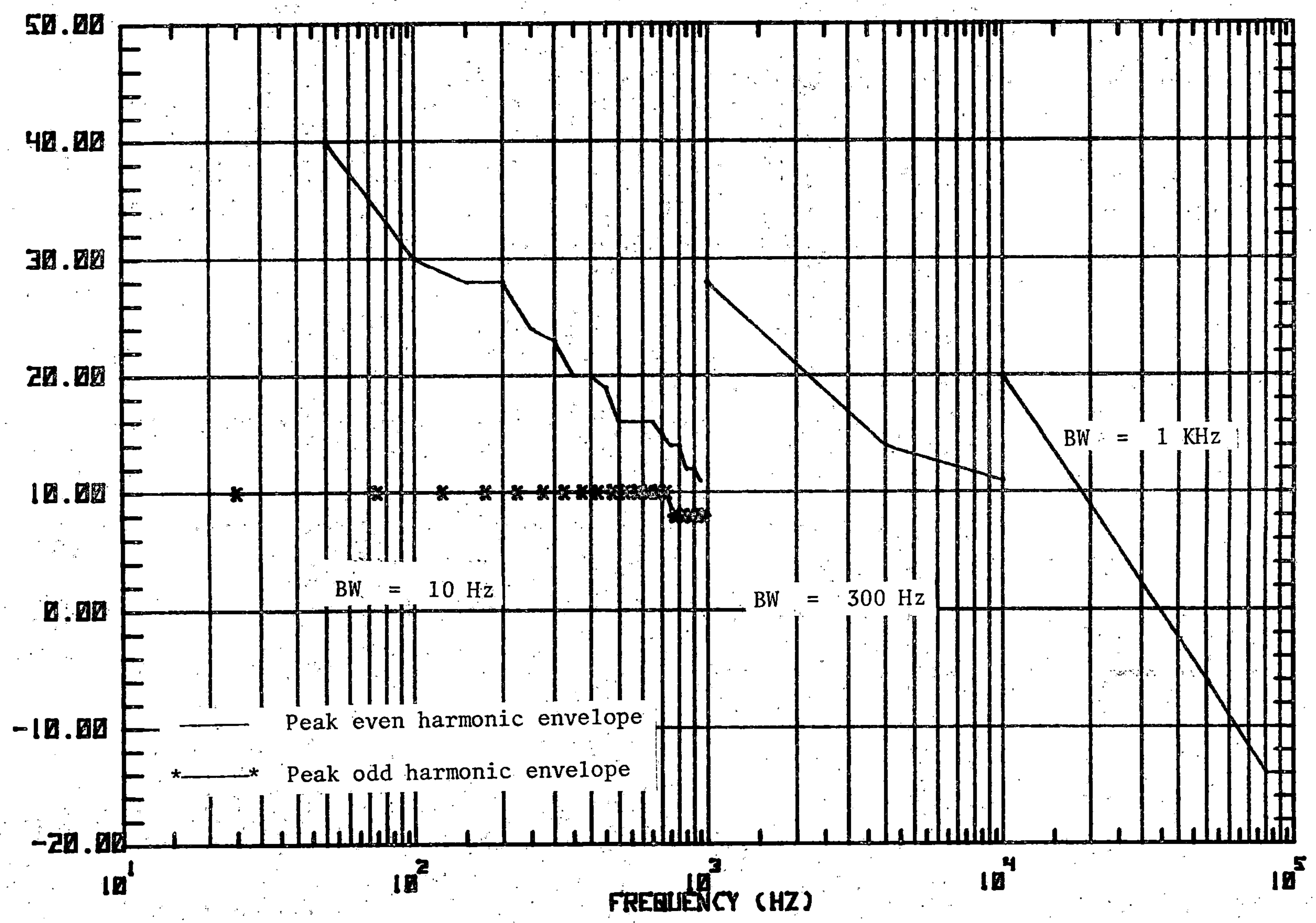


Figure 62. Voltage spectrum across 74 volt dc bus with M/A set on.

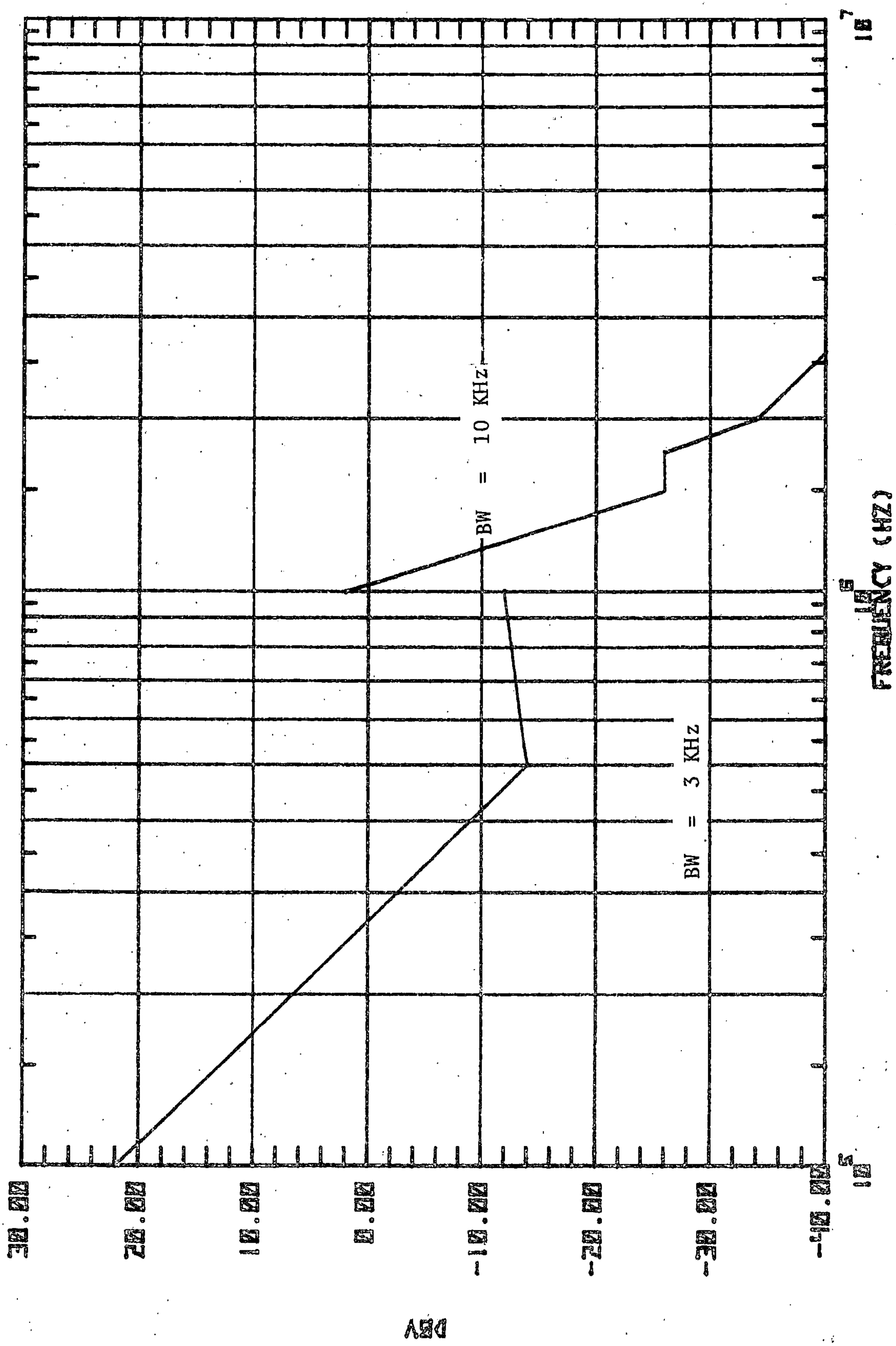
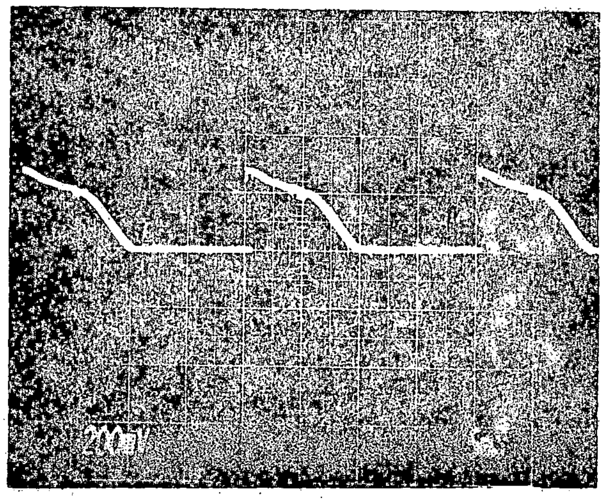


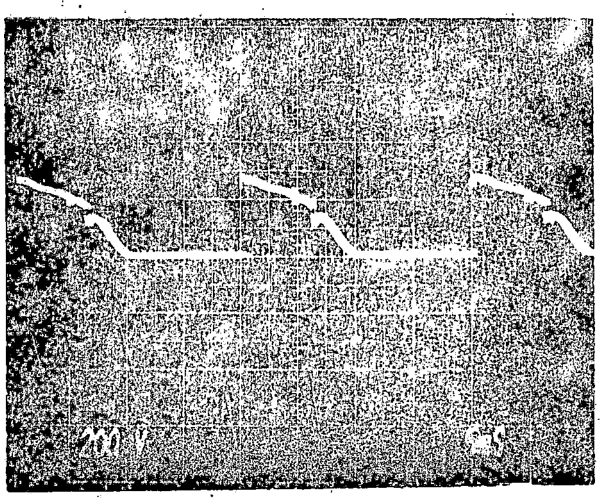
Figure 62. (continued).

Time waveforms of the voltage across the bus were then obtained, under conditions 8.5 and 8.6, and are shown in Figures 63 and 64, respectively.



(200 V/div, 5 ms/div)

Figure 63. Voltage spectrum across 74 volt dc bus (condition 8.5).

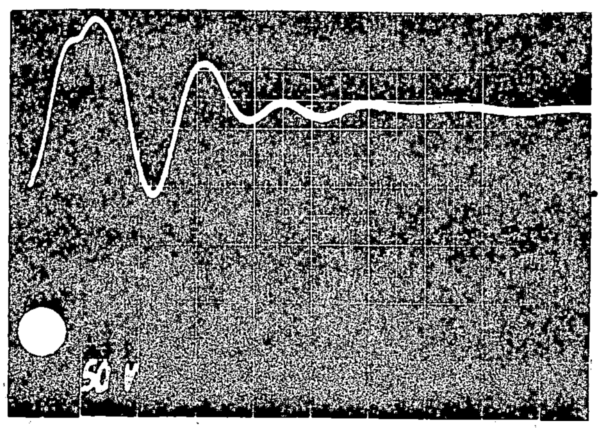


(200 v/div, 5 ms/div)

Figure 64. Voltage spectrum across 74 volt dc bus (condition 8.6).

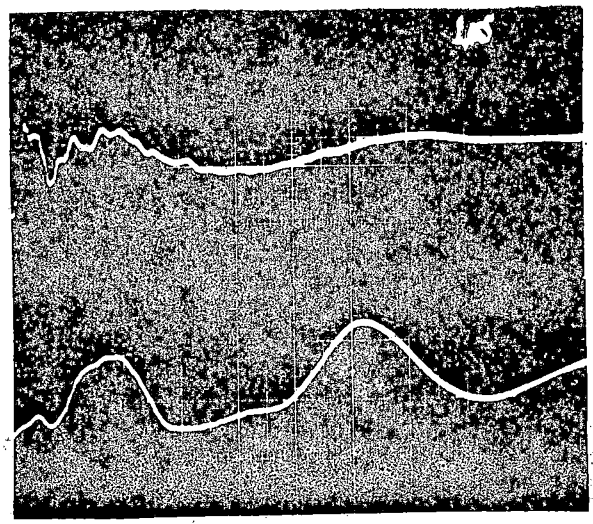
Next, the voltage time waveform across the 74 volt dc bus was sampled while the blower motor was on idle (steady state). Results of these steady state measurements are given in Figure 65. From Figure 65, the leading edge transient of a repetitive signal is observed. The period of this signal is 40 milliseconds. The transient voltage levels recorded reached approximately 150 volts peak-to-peak before settling down to the steady state level (74 volts).

Upon completion of the steady state measurements, the voltage time waveform across the bus was sampled while staging tests were performed. During the staging test, a battery powered tap switch testing box is used to initiate a pre-set sequence of traction motor tap switching operations that simulates actual road tap switch sequencing. The purpose of the staging test is to determine if any traction motor control problems exist. Results of these measurements are presented in Figure 66.



(50 v/div, 10 μsecond/div)

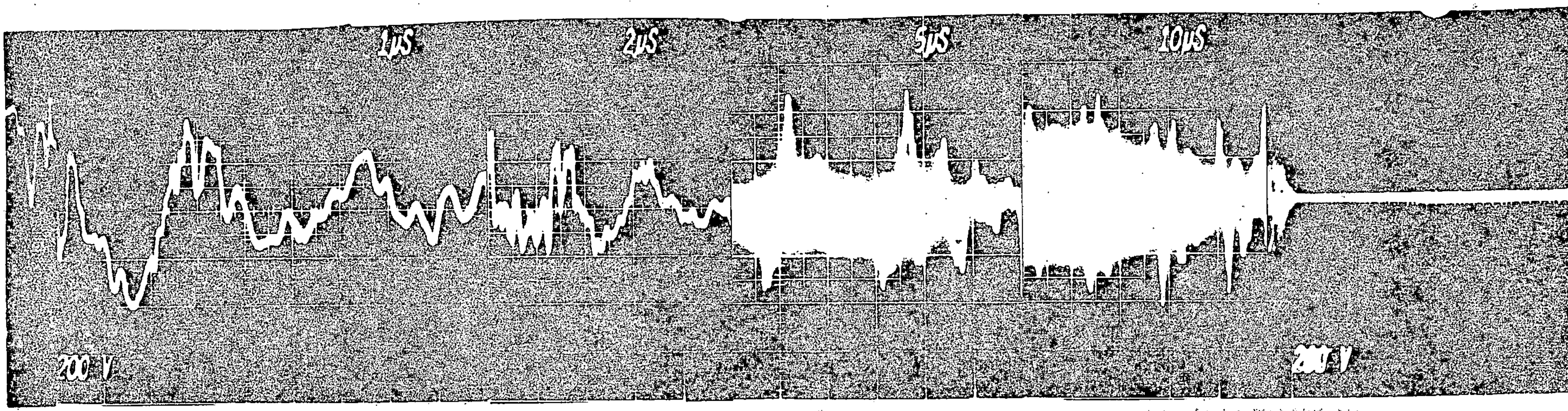
Figure 65. Voltage across 74 volt bus with blower motor on idle (condition 8.7).



(50 v/div, 1 μs/div)

Figure 66. Voltage across 74 volt bus during staging test.

Voltage transients caused by the main breaker closing as observed at the 74 volt dc receptacle, are shown in Figure 67. The duration of the transient was approximately 200 microseconds with amplitude of 800 volts peak-to-peak.



(1 µsec/div) (2 µsec/div) (5 µsec/div) (10 µsec/div)

Figure 67. Voltage transients at the 74 volt dc receptacle caused by the main breaker closing. (200 volts/div)

9.0 15 VOLT dc BUS

The following voltage measurements were performed on the 15 volt dc bus:

9.1 Voltage across the 15 volt bus with the blower motor on idle, oil pump and various small electrical devices located in the locomotive on.

9.2 Voltage transients caused by the staging test sampled across the 15 volt bus.

9.3 Voltage transients caused by the main breaker opening and closing sampled across the 15 volt bus.

The waveform of the voltage across the 15 volt bus (condition 9.1) over a 50 microsecond time interval is given in Figure 68. The transient amplitudes recorded were 0.5 volts peak-to-peak. Results of the transient voltage measurements during staging are given in Figure 69. Staging produced transients of 7 volts peak-to-peak with ringing frequencies of 30 MHz. The duration of the transients exceeded 200 microseconds.

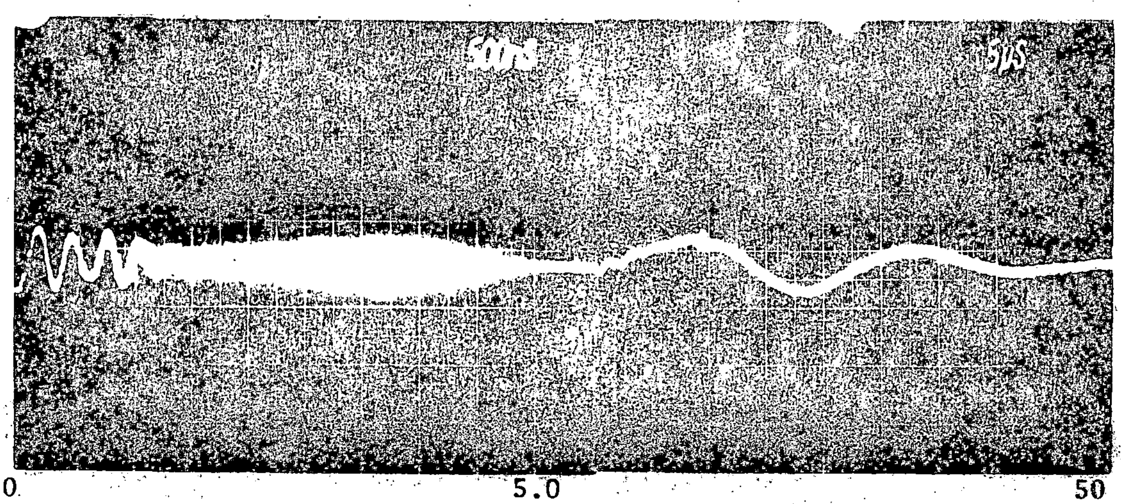


Figure 68. Waveform of voltage across the 15 volt bus, condition 9.1. (0.5 volts/div)

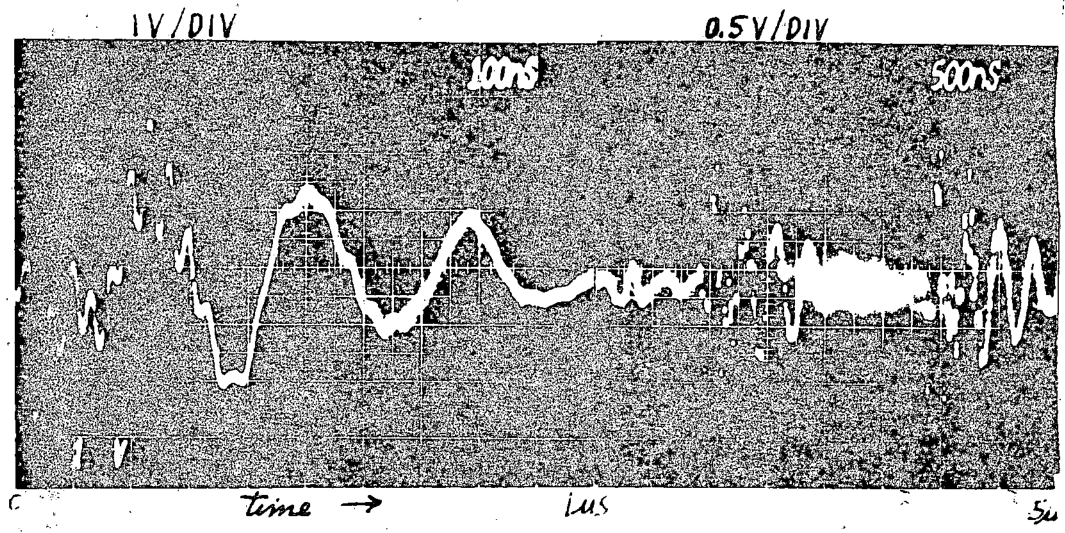
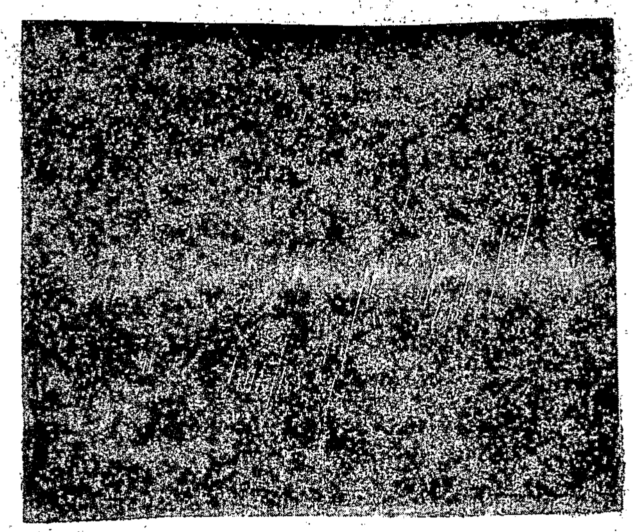
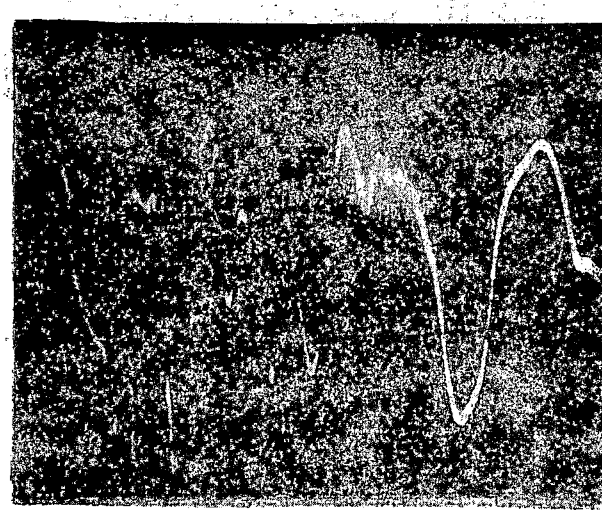


Figure 69. Voltage transients across the 15 volt bus caused by staging.

Next, voltage transients across the 15 volt bus caused by the main breaker closing were recorded, and the results are given in Figures 70A, B. From Figure 70, the transient levels reached 60 volts peak-to-peak.



(10 volt/div, 1 μsecond/div)



(10 volt/div, 100 μsecond/div)

Figure 70 A and B. Voltage transients across the 15 volt bus caused by main breaker closing.

10.0 5 VOLT dc BUS

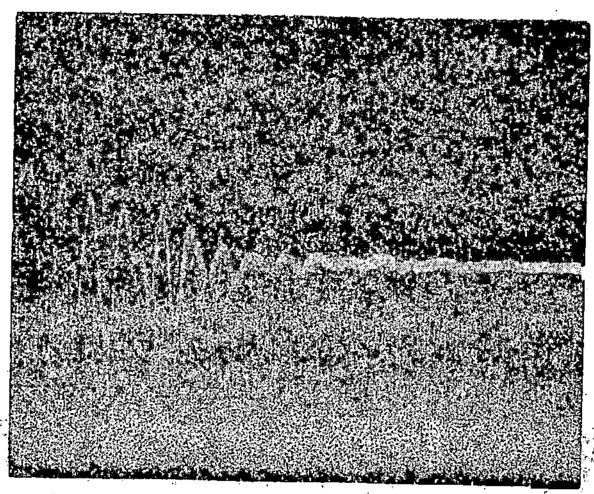
The voltage across the 5 volt dc bus was sampled under the following conditions:

10.1 Blower motor on idle, oil pump and various small electrical devices on

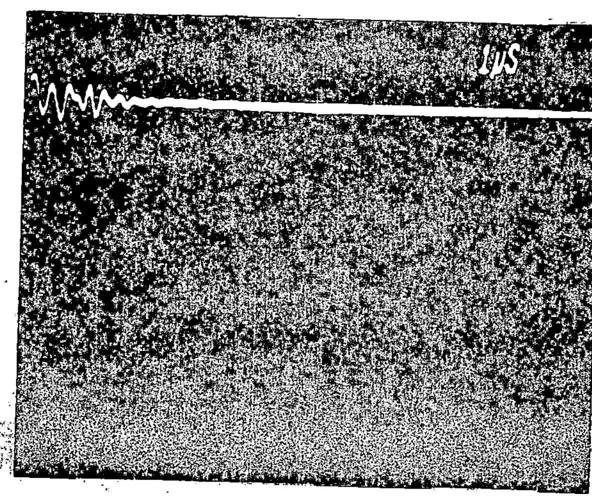
10.2 Main breaker closing

10.3 Staging test

The waveform of the voltage across the 5 volt bus with the blower motor on idle (condition 10.1) is given in Figure 71A and B. The voltage transient levels measured were 1.7 volts peak-to-peak.



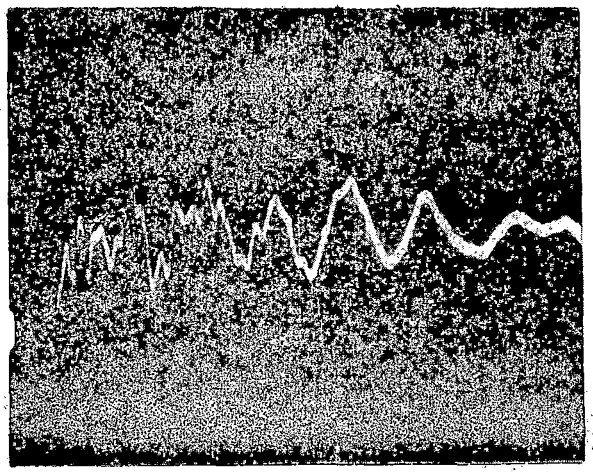
(500 n second/div)



(100 μsecond/div)

Figure 71A and B. Voltage across 5 volt bus under condition 10.1 (2 volt/div).

The waveform of the voltage transients across the 5 volt bus while the main breaker was closing is given in Figure 72. The transients, in this case, reached 70 volts peak-to-peak.



(20 volt/div, 200 n seconds/div)

Figure 72. Voltage transients caused by the main breaker closing as seen across the 5 volt bus .

The transients produced by staging as seen across the 5 volt dc bus are given in Figure 73. Thirty volt peak-to-peak transients were produced during staging.

11.0 Cab Signalling

The voltage across the cab signal pick-up was sampled under the following conditions:

11.1 All major electrical systems off, only various small electrical systems within the locomotive on.

11.2 Blower motor on idle, oil pump and various small electrical devices in the locomotive on.

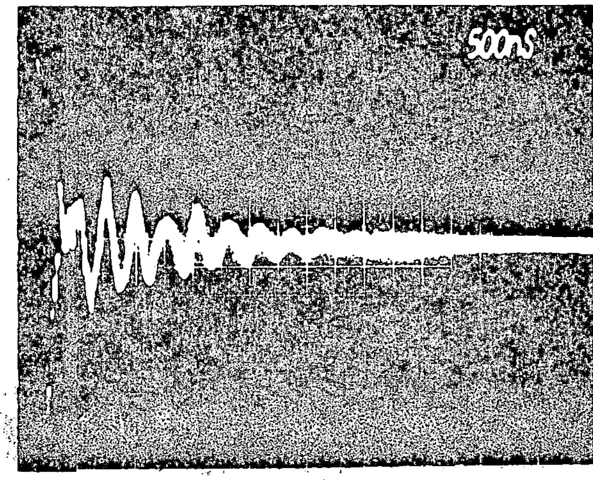
11.3 Blower on full, oil pump and various small electrical items on.

11.4 Blower on idle, M/A set on run (unloaded), oil pump and small electrical devices on.

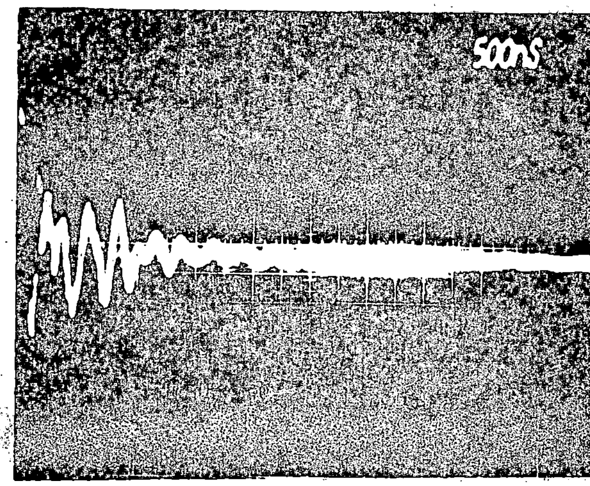
11.5 Blower on full, M/A set on run (unloaded), dynamic brake in position 1, oil pump and small electrical systems on.

11.6 Blower motor on full, traction motors running, oil pump and small electrical systems in the locomotive on.

11.7 Blower motor on full, M/A set delivering 700 amperes, oil pump and small electrical items in the locomotive on.

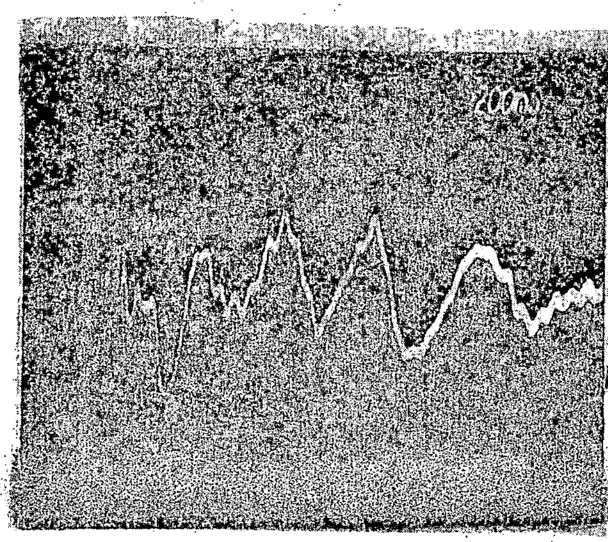


..5 volt..

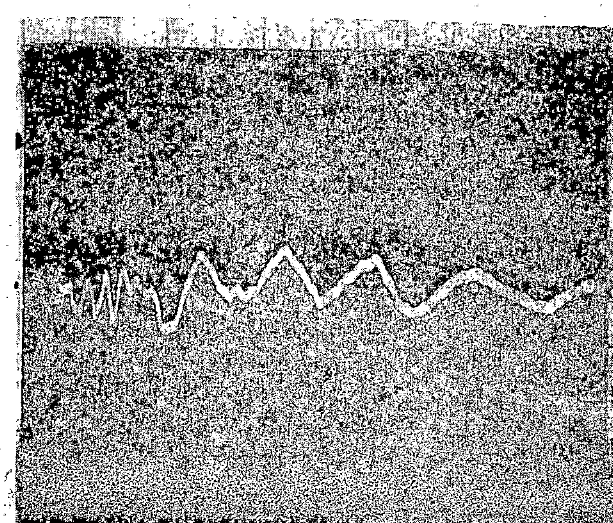


A
(0.5 volt/div, 500 n sec/div)

B
(1 volt/div, 500 n sec/div)



..+5 volt..



C
(10 volt/div, 200 n sec/div)

D
(20 volt/div, 200 n sec/div)

Figure 73. Voltage transients across the 5 volt dc bus caused by staging tests.

For the cab signalling voltage measurements, the voltage probes were connected to the cab signal input, located in the cab of the locomotive, as shown in Figure 74.

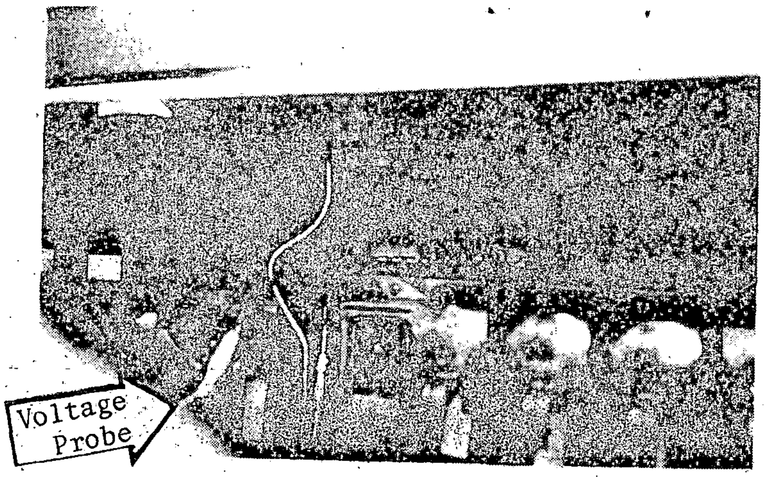
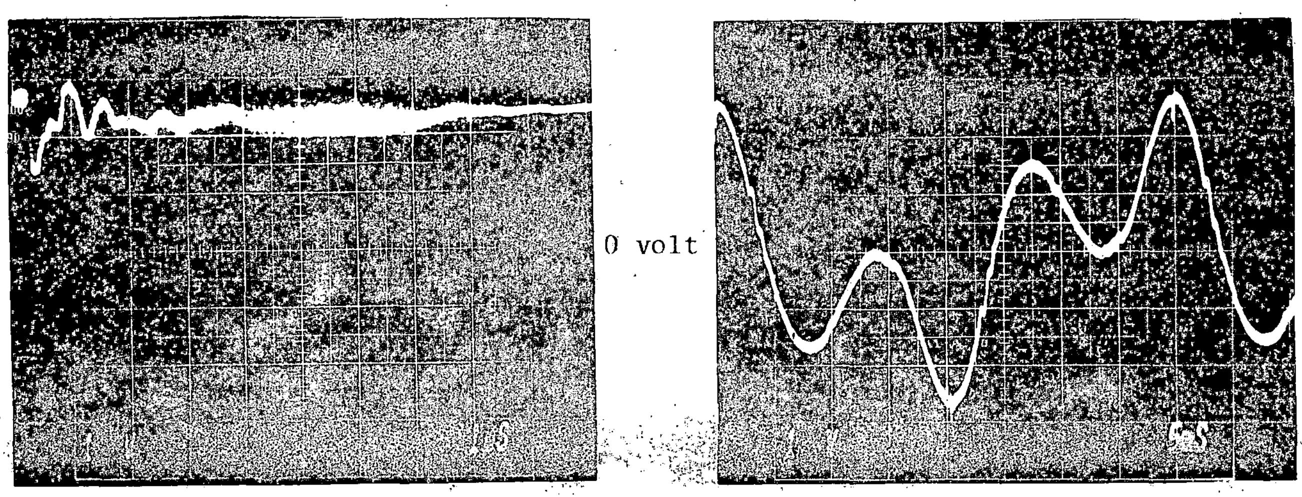


Figure 74. Voltage probe placement for measurements of voltage across cab signal pick-up.

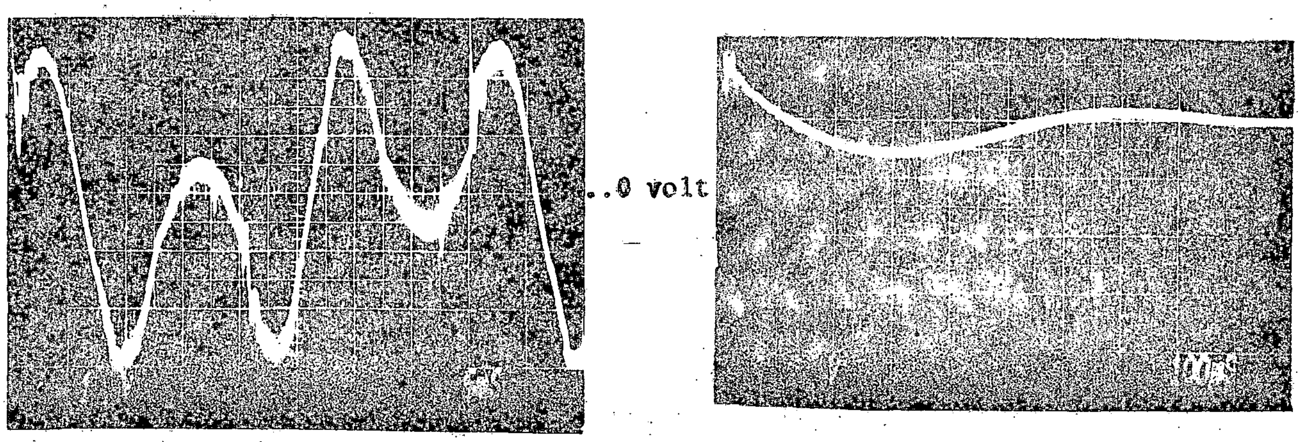
Results of the voltage samplings, taken across the cab signal pick-up terminals with all major electrical systems turned off (condition 11.1), are given in Figures 75 A and B. The voltage level recorded was 5.6 volts peak-to-peak.



(1 volt/div, 1 μ second/div) (1 volt/div, 5 n seconds/div)

Figure 75 A and B. Cab signal voltage with blower motor off (condition 11.1).

Next, the blower motor and oil pump were turned on, and the measurements were repeated. These results are given in Figure 76A and B. In this case, the voltage recorded was 5.5 volts peak-to-peak.

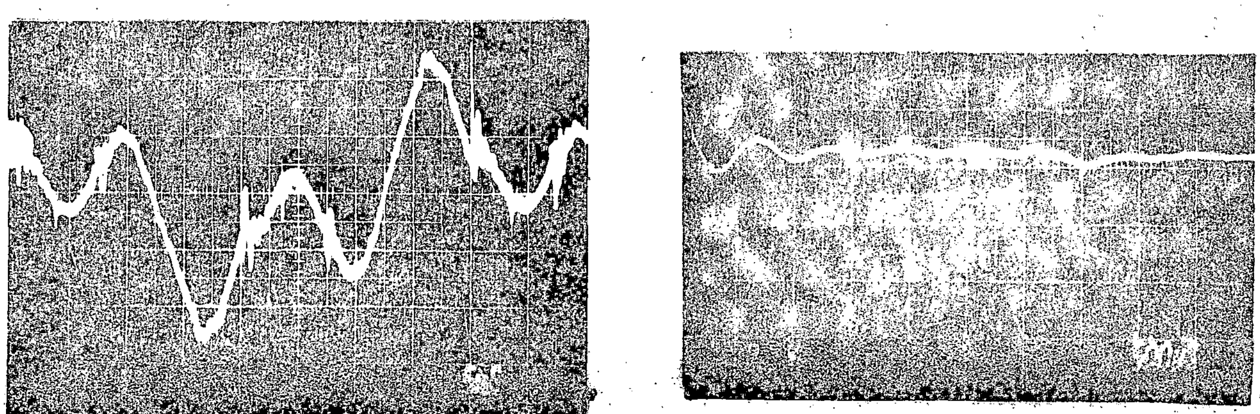


(1 volt/div, 5 ms/div)
A

(2 volt/div, 100 μsecond/div)
B

Figure 76A and B. Voltage at cab signal pick-up with blower motor idling (condition 11.2).

The blower motor was then turned on full speed, and the measurements repeated. Time waveform photographs, under these conditions, are given in Figure 77A and B.



(1 volt/div, 5 ms/div)
A

(200 volt/div, 500 μsecond/div)
B

Figure 77A and B. Voltage at cab signal pick-up with blower motor on full.

The frequency spectrum, between 25 Hz and 5 MHz, for condition 11.3 is given in Figure 78. The 25 Hz and 75 Hz components are prevalent in Figure 78, with amplitudes reaching approximately 0.8 volts. Signal components around 1 MHz appear here at levels exceeding 0.03 volts. These signals are believed to originate from the blower motor.

Next, the voltage waveform at the cab signal input was sampled with the blower motor on full speed and the M/A set on run (condition 11.4). Results of these measurements are shown in Figure 79.

The blower motor was then turned on full speed, the dynamic brake was set into position 1 (condition 11.5), and the waveform and spectrum of the voltage across the cab signal pick-up were recorded. Results of the waveform and spectrum measurements are given in Figures 80 and 81, respectively. The 60 Hz component, in Figure 81, was 0 dBV (1 volt). The 100 Hz component, which is of interest because it is the operating frequency of the cab signalling device, was recorded at -26 dBV (50 millivolts).

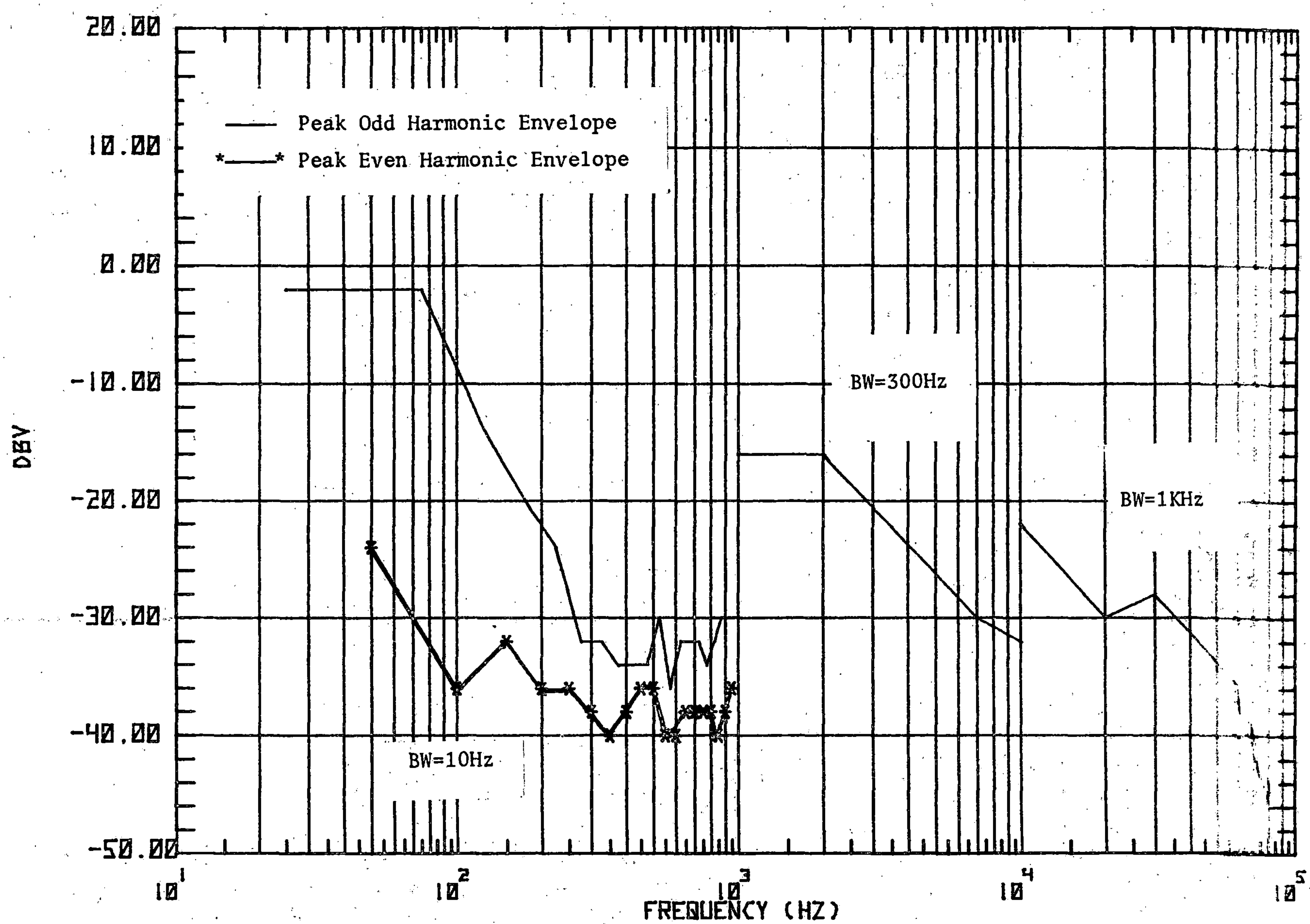


Figure 78. Voltage spectrum at cab signal input (condition 11.3).

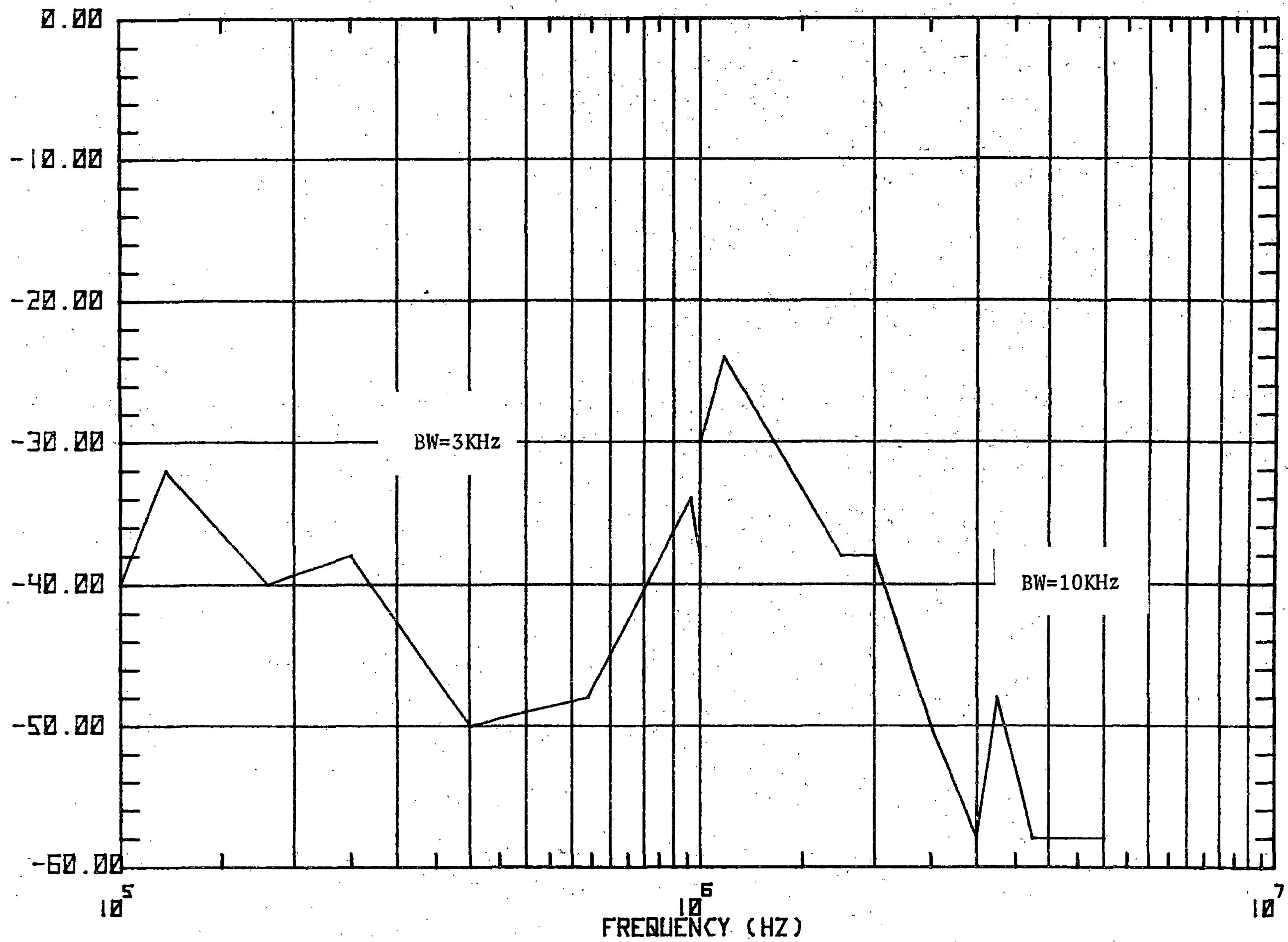
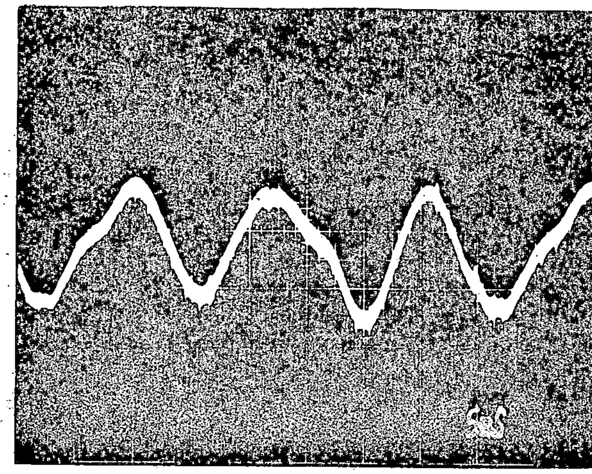
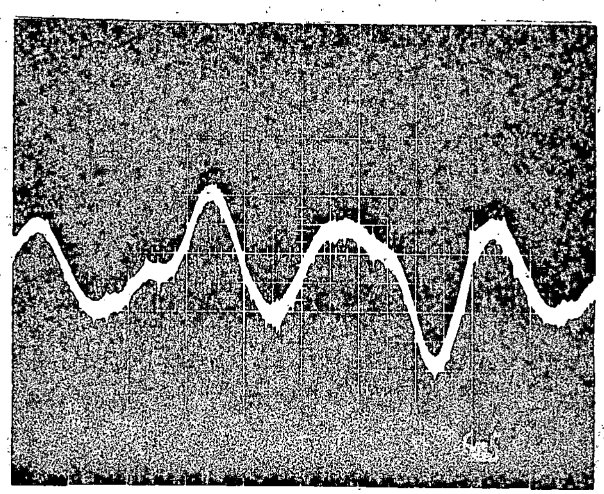


Figure 78. (continued).



(amplitude=0.5 volt/div, time=5 ms/div)

Figure 79. Waveform of voltage across cab signal input terminals (condition 11.4).



(amplitude=0.5 volt/div, time=5 ms/div)

Figure 80. Waveform of voltage across cab signal (condition 11.5).

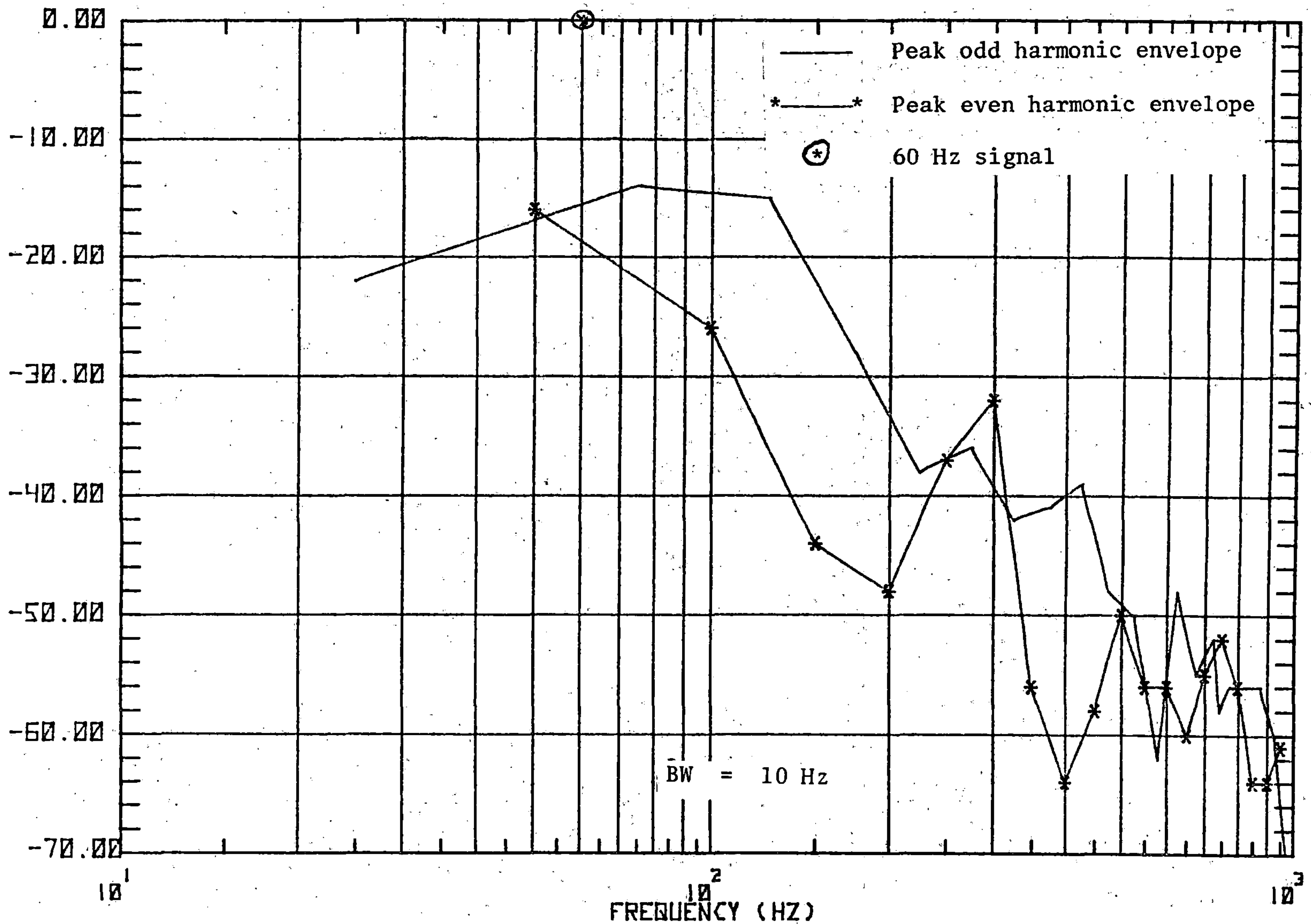


Figure 81. Cab signal pickup voltage spectrum (condition 11.5).

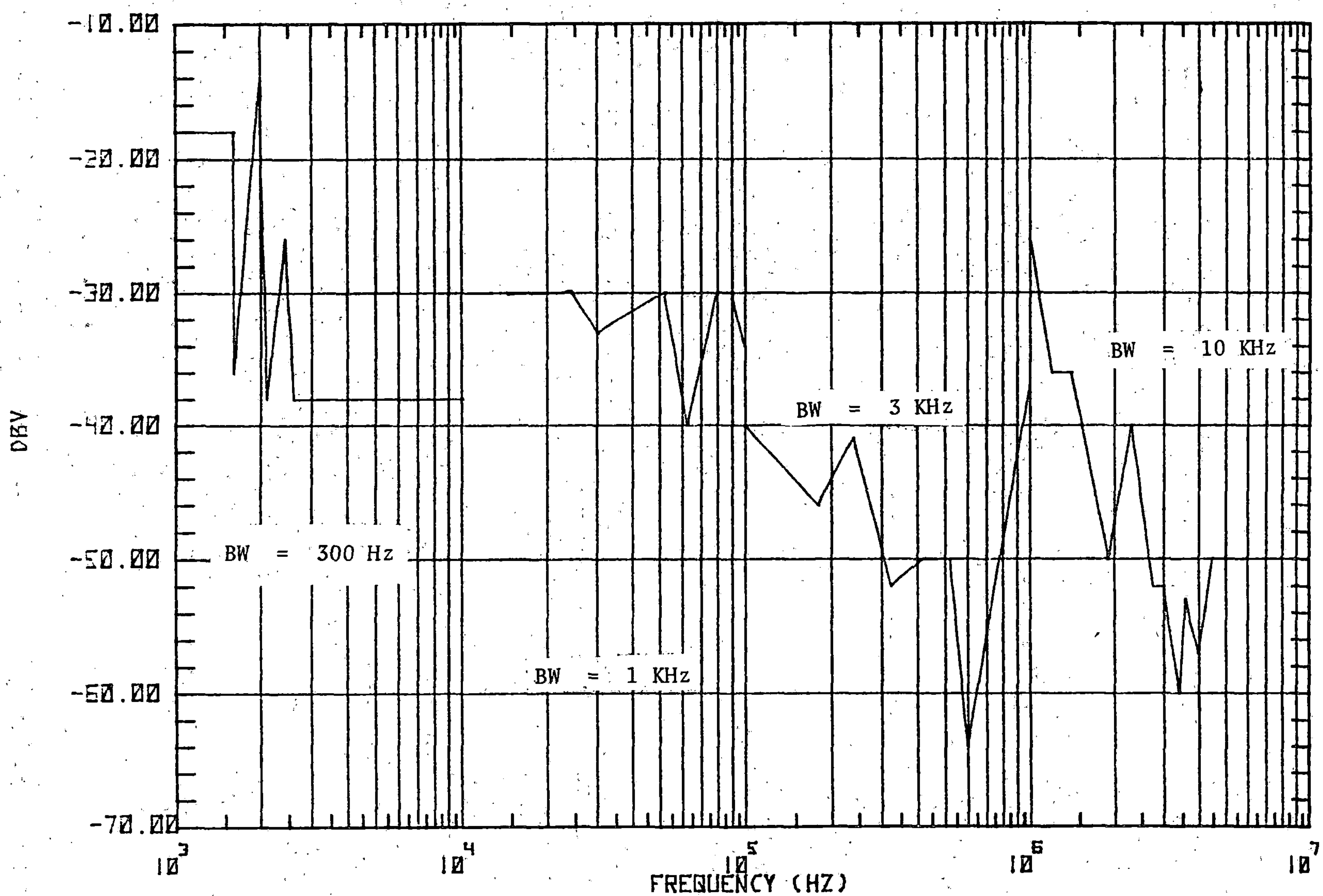


Figure 81. (continued).

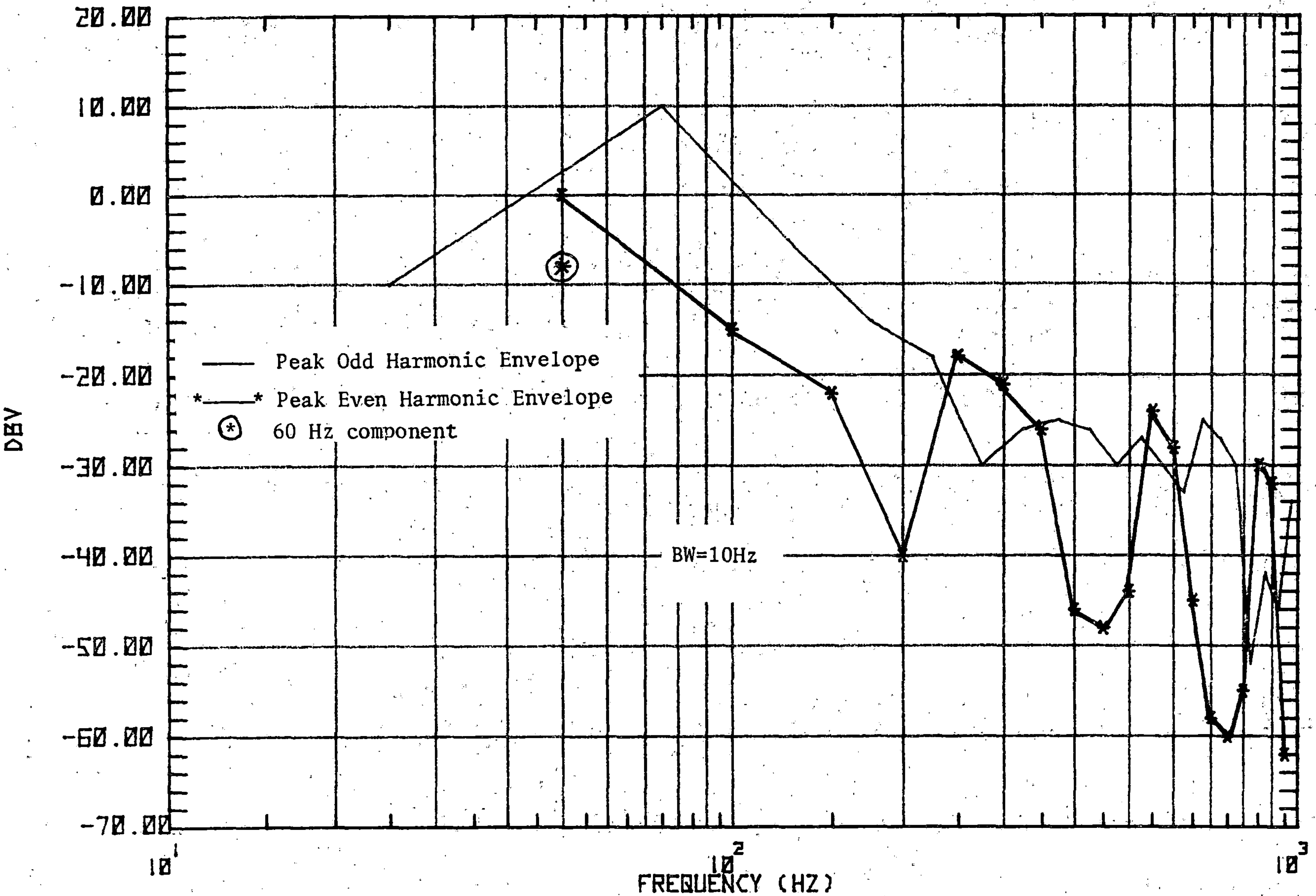


Figure 82. Frequency spectrum of voltage across the cab signal pickup (condition 11.6).

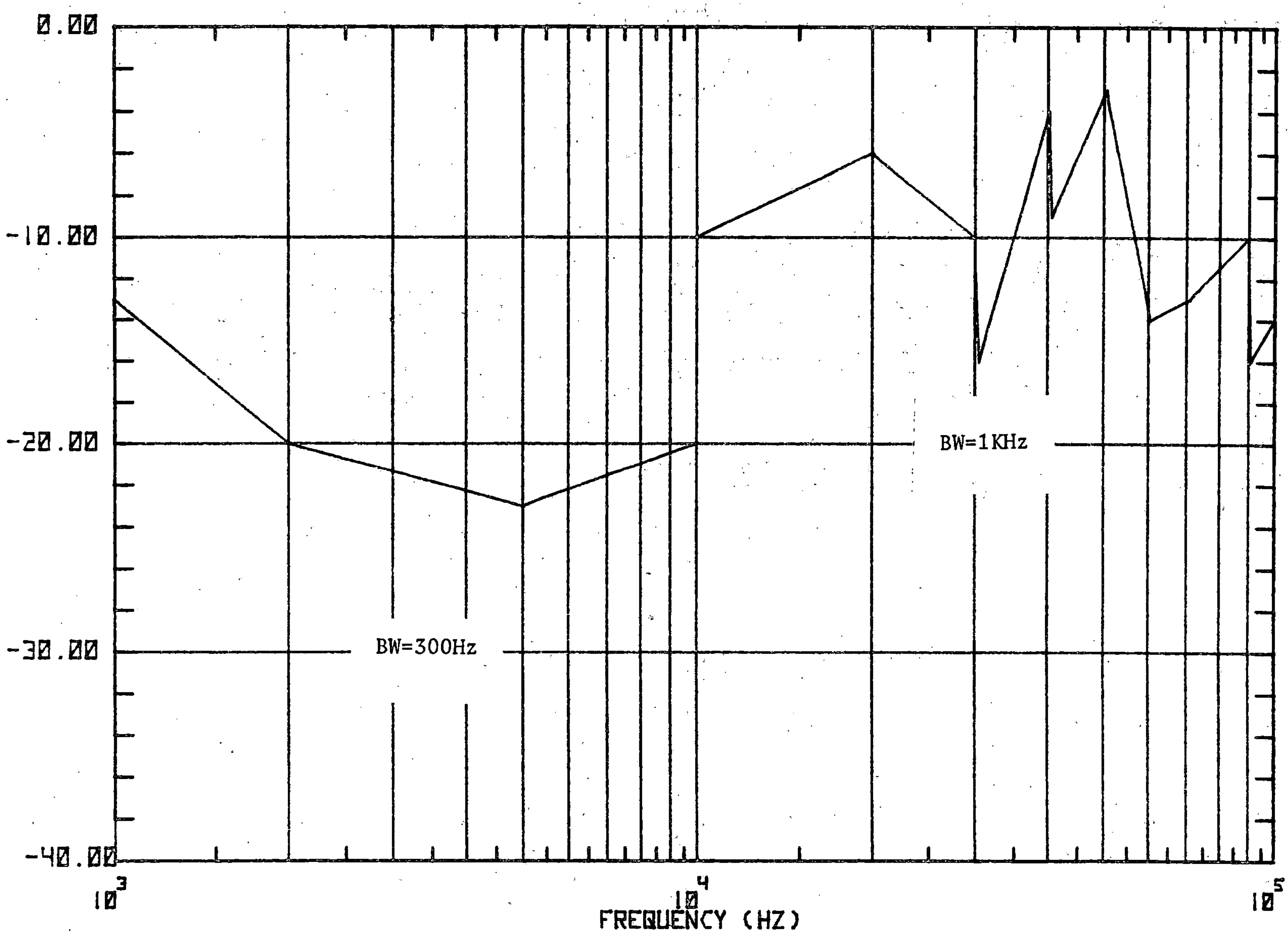


Figure 82. (continued).

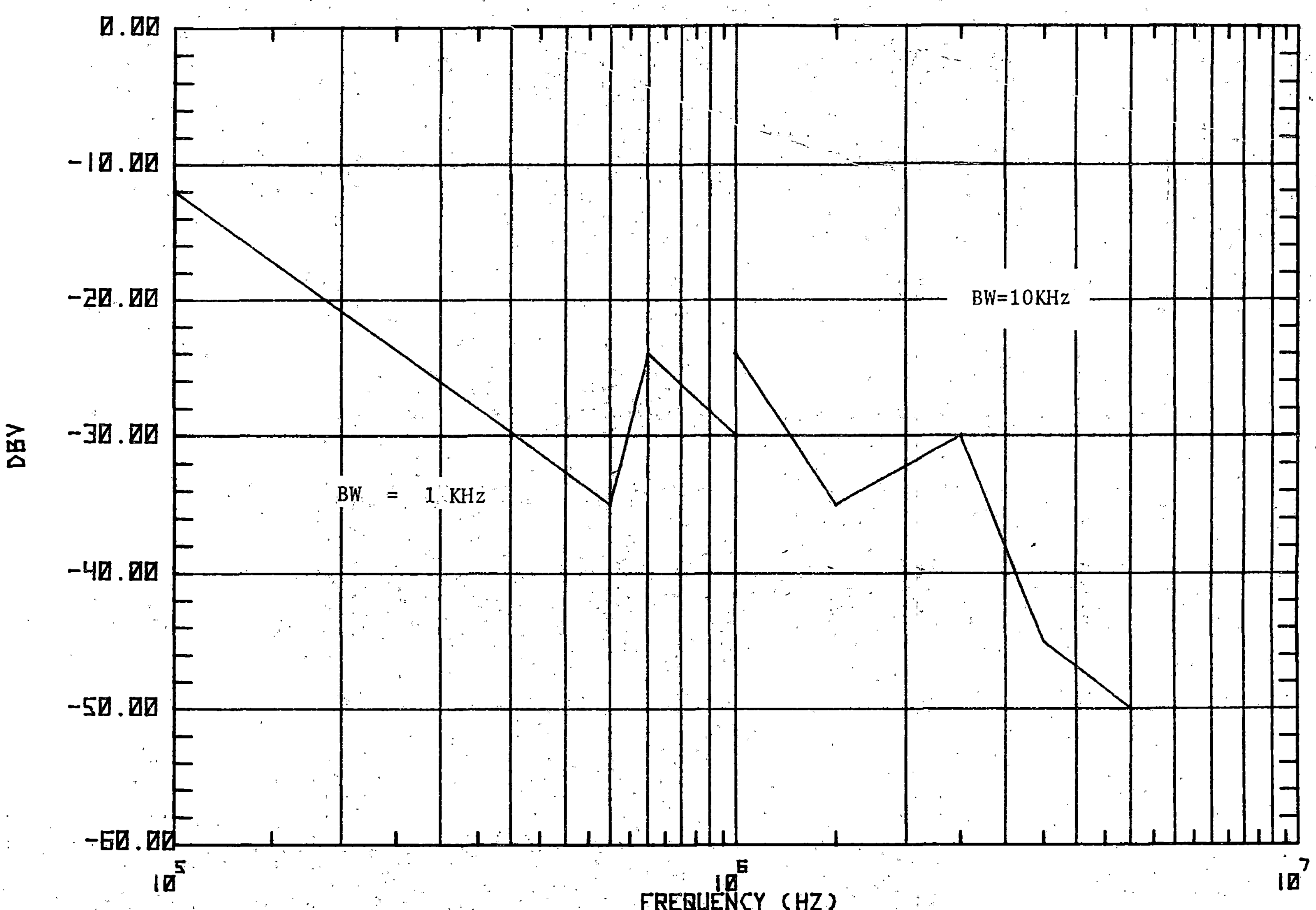
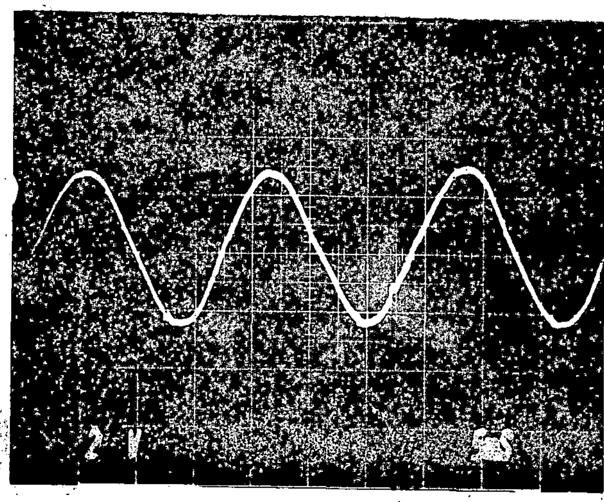


Figure 82. (continued).

Next, the traction motors were turned on (drawing 1000 amperes dc per truck), and the engine was moved back and forth slowly. The spectrum of the cab signal pick-up voltage under these conditions is given in Figure 82. The curve illustrated in Figure 82 shows strong odd harmonics of 25 Hz (3.1 volts at 75 Hz, for example). The 60 Hz component is 0.9 volts.

The traction motors were then turned off, and the M/A set was connected to a resistive load that was drawing 700 amperes of current. The waveform and spectrum of the voltage across the cab signal pick-up under these conditions are given in Figures 83 and 84, respectively. The 60 Hz component, in Figure 84, is 2.51 volts (8 dBV) with odd harmonics of 60 Hz dominating the spectrum. A component appears at approximately 85 Hz at a level of 0.16 volts. It is suspected that this is an intermodulation product of the 25 and 60 Hz signals.



(2 volts/div, 5 ms/div)

Figure 83. Voltage waveform across cab signal pick-up with M/A set delivering 700 amperes to a load (condition 11.7).

12.0 RAIL CURRENT

Measurements of the time waveform and frequency spectrum of current in the rail were made at the following locations, under the specified conditions:

12.1 At the right rear of the locomotive with the blower motor off, oil pump and minor electrical units on.

12.2 Right rear of the locomotive with blower motor on idle, oil pump and minor electrical items on.

12.3 Left rear of locomotive with blower motor on idle, oil pump and minor electrical devices on.

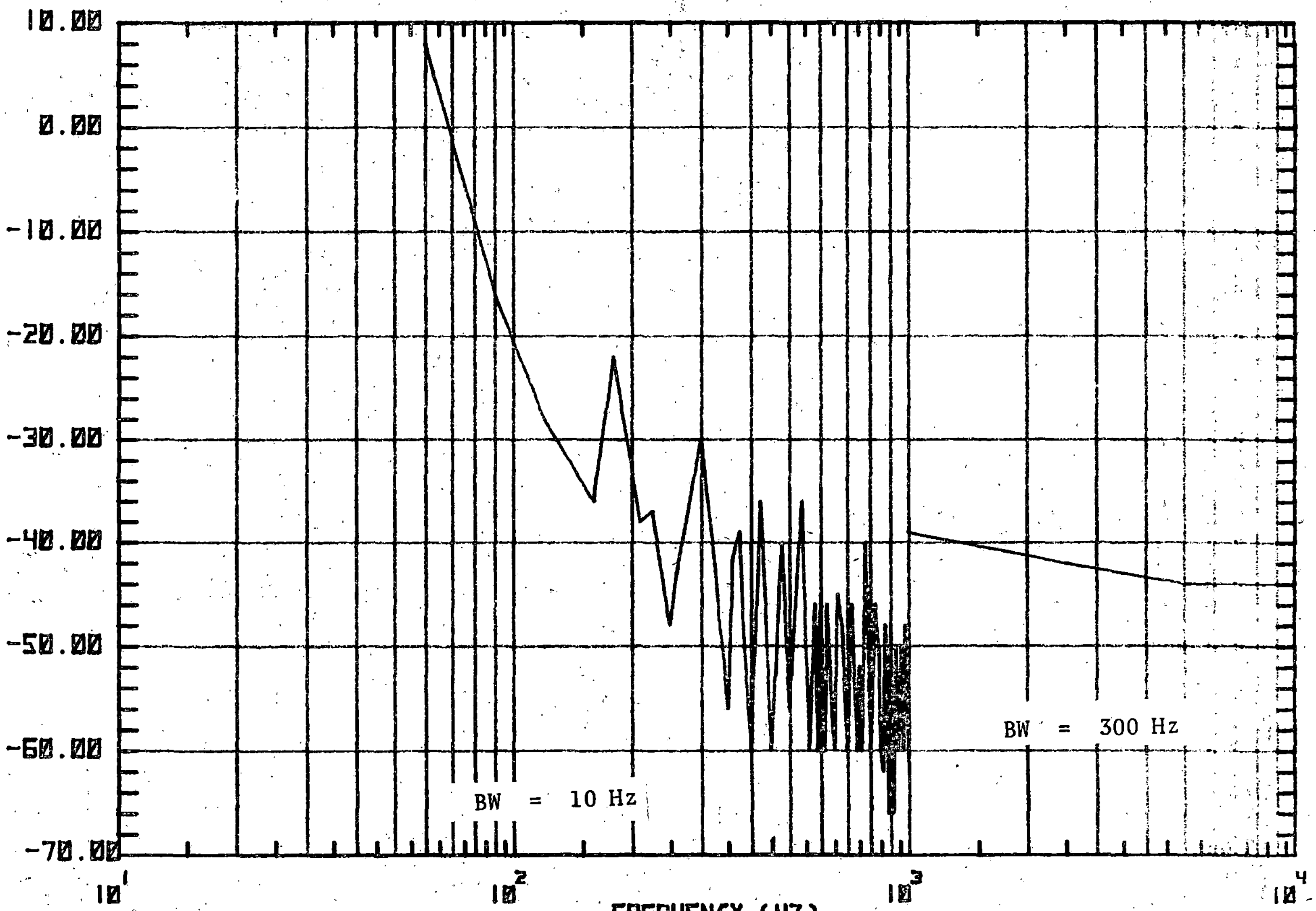


Figure 84. Voltage spectrum across cab signal pickup (condition 11.7).

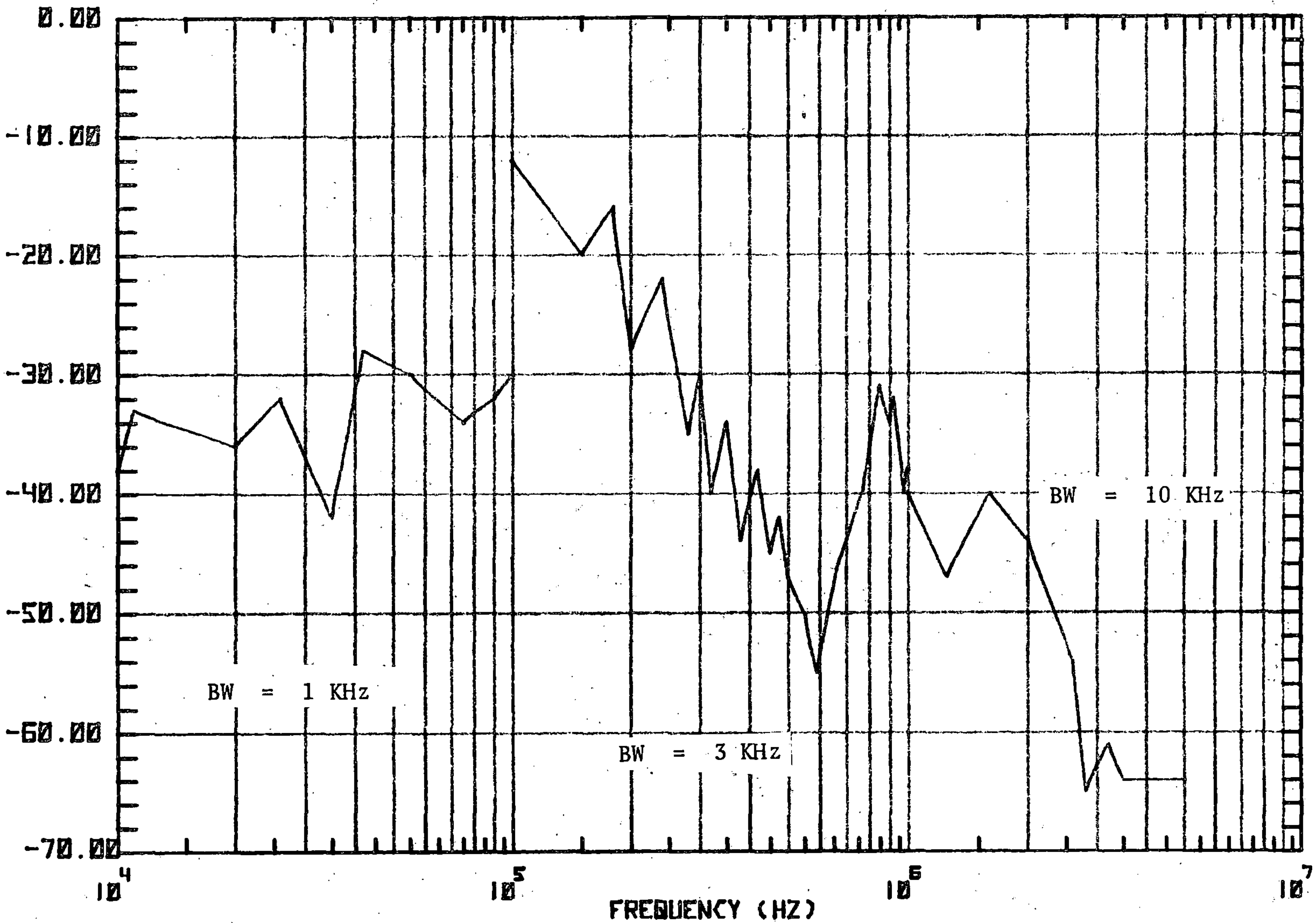


Figure 84. (continued).

12.4 Left front of locomotive with blower motor on idle, oil pump and minor electrical devices on.

12.5 Right front of locomotive with blower motor on idle, oil pump and minor electrical devices on.

12.6 Right rear of locomotive with blower motor on full, M/A on idle, oil pump and minor electrical devices on.

12.7 Right rear of locomotive (41.5 feet away) with blower motor on full, M/A on idle, oil pump and minor electrical devices on.

12.8 Right rear of locomotive (83 feet away) with blower motor on full, M/A on idle, oil pump and minor electrical devices on.

12.9 Both rails, 51 feet away from locomotive and one foot on either side of the ground node with blower motor on full, oil pump and minor electrical devices on.

12.10 Cab signals on.

The current spectrum in the right rear rail was initially sampled with the blower motor turned off (condition 12.1). Results of these measurements are given in Figure 85 Next, the blower motor was turned on (idle) and the current spectrum was sampled. These results are given in Figure 86. The current spectra in the left rear, left front, and right front rails (conditions 12.2 12.3, and 12.4) are given in Figures 87, 88, and 89, respectively.

The 25 Hz component in Figure 86 is 13 dBA (approximately 4.5 amperes). The 25 Hz components of Figures 87, 88, and 89 are 1.0, 0.25, and 1.8 amperes, respectively. Theoretically and ideally, the sum of these four currents should equal the current in the main transformer primary. The current measured in the main transformer primary at this time was 5.6 amperes.

The current spectrum measured in the right rear rail, with the blower motor on full, the M/A set on idle (unloaded), and the oil pump and various minor electrical devices on, at distances of 0, 41.5, and 83 feet (conditions 12.6, 12.7 and 12.8 are given in Figures 90, 91, and 92, respectively. The locomotive was oriented in such a way that the front truck was resting inside an isolated section of track. The rear truck was resting on rails that were grounded at one end

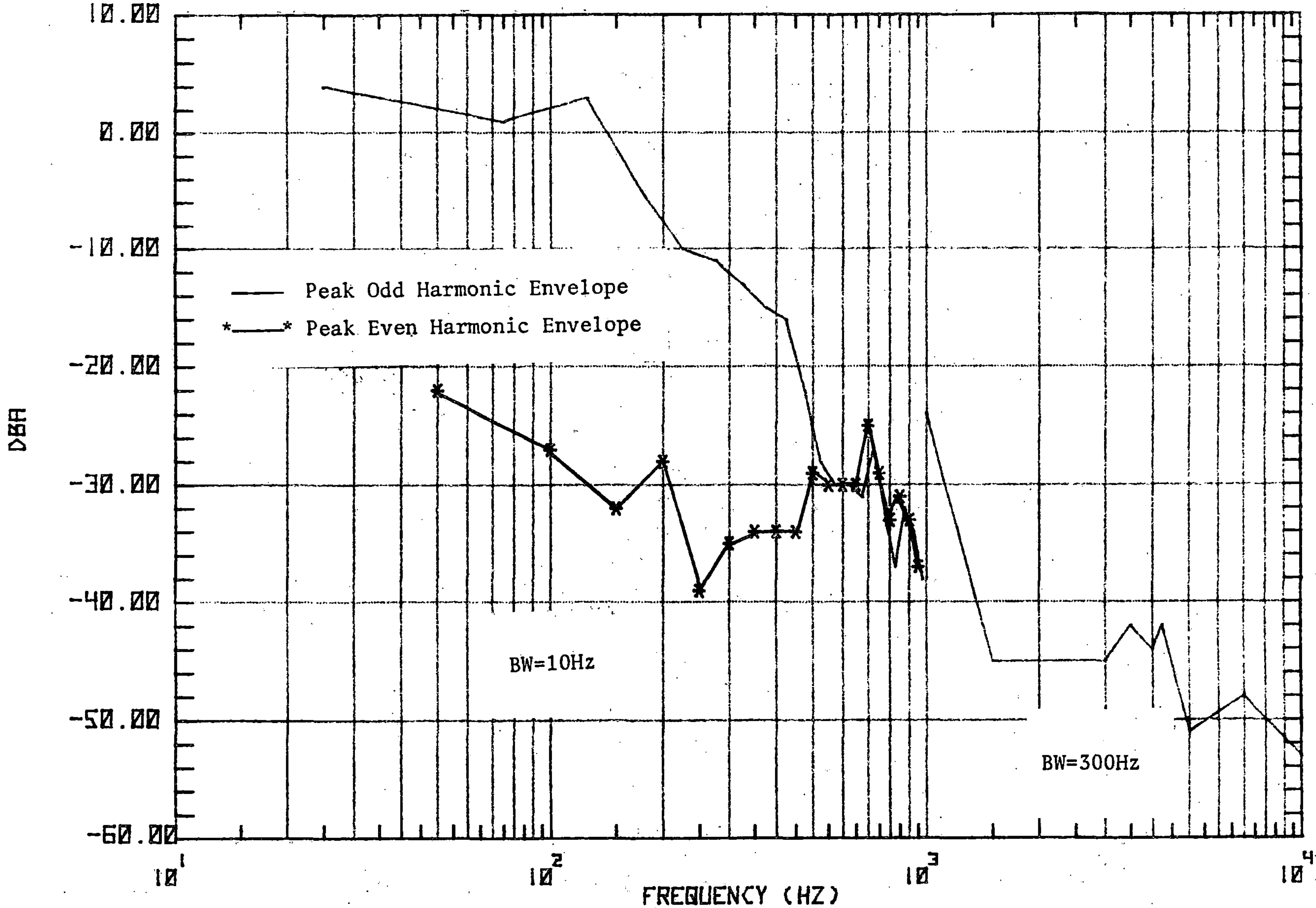


Figure 85. Current spectrum in right rear rail (condition 12.1).

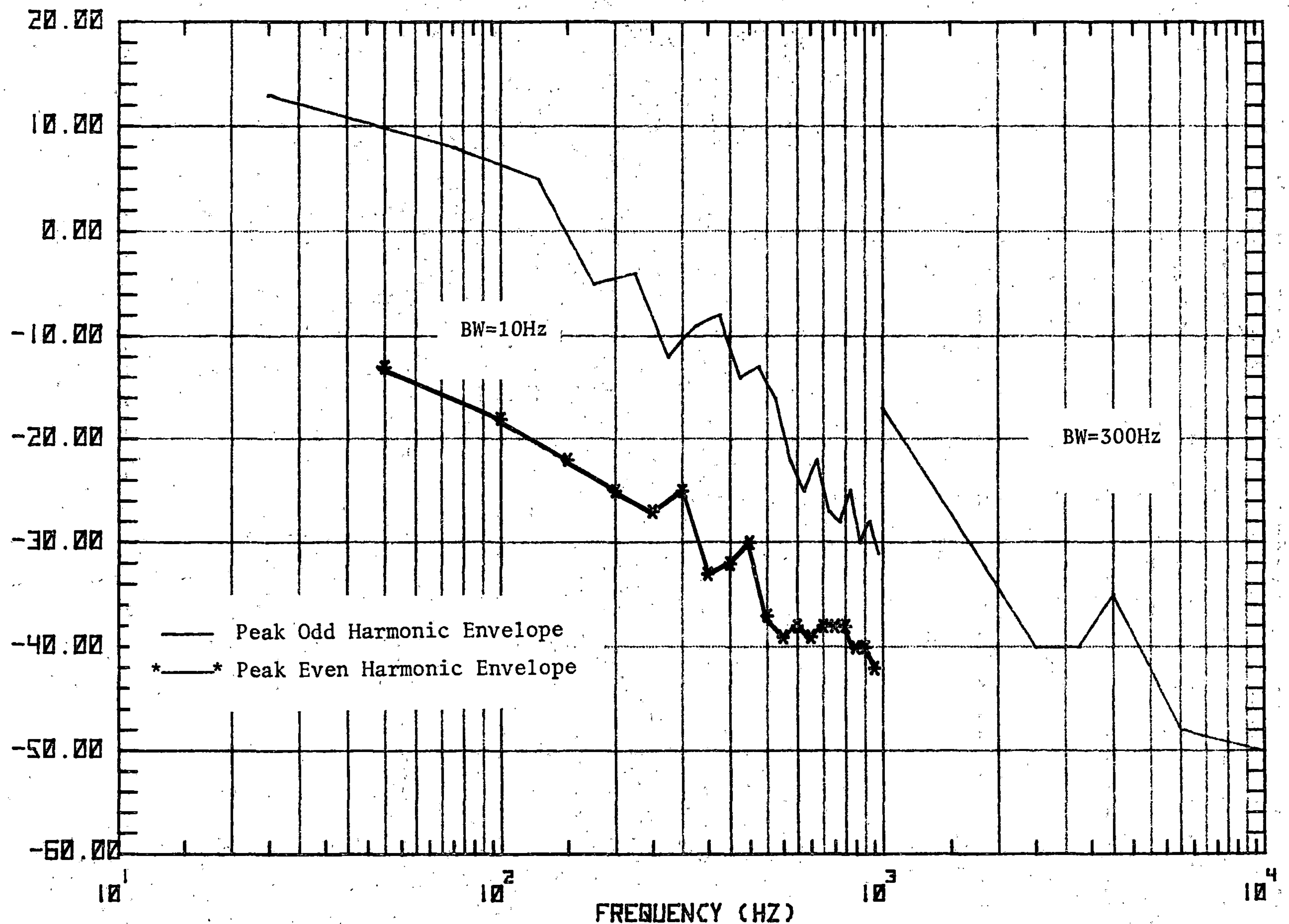


Figure 86. Current spectrum in right rear rail (condition 12.2).

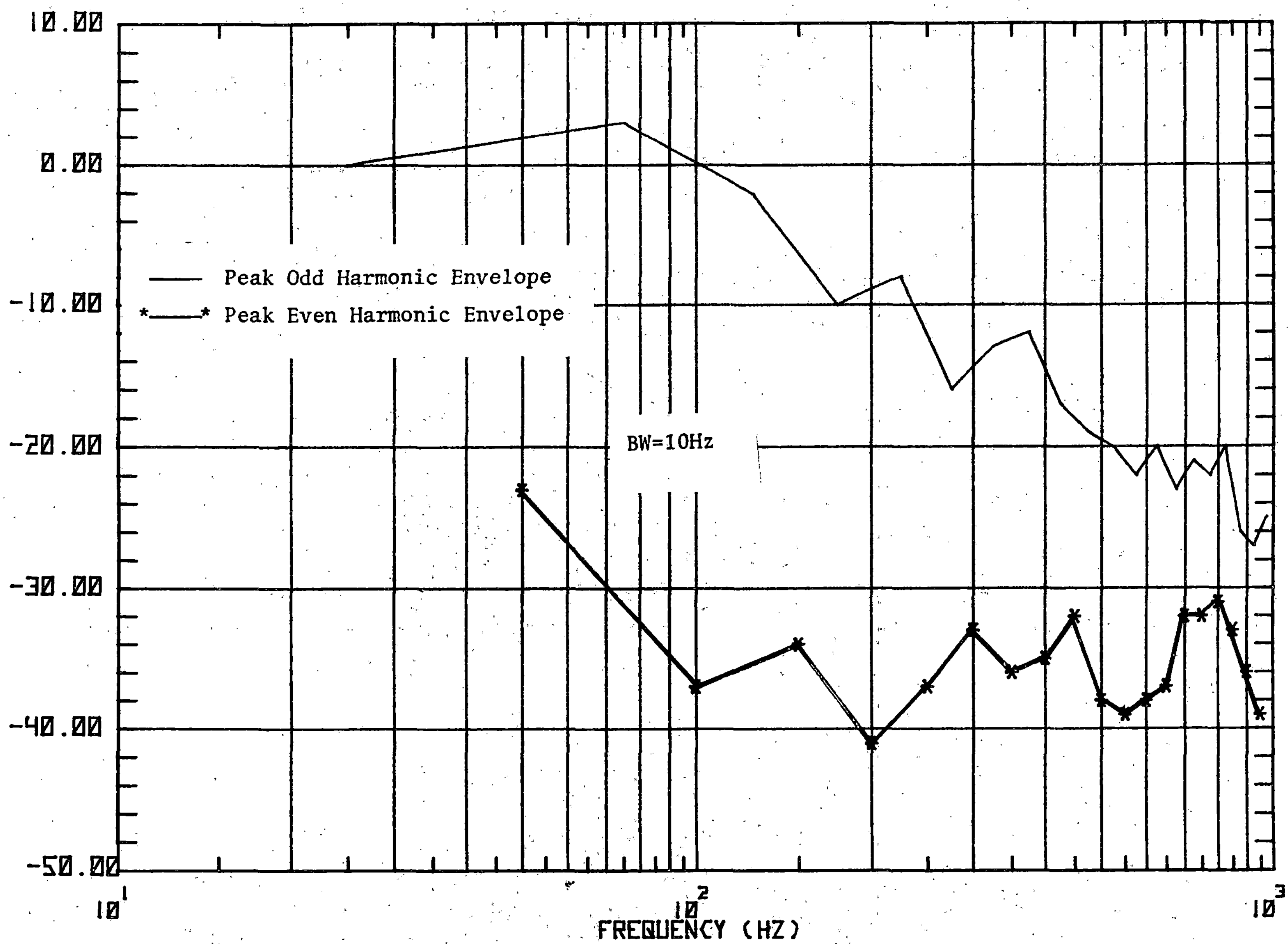


Figure 87. Current spectrum in left rear rail (condition 12.3).

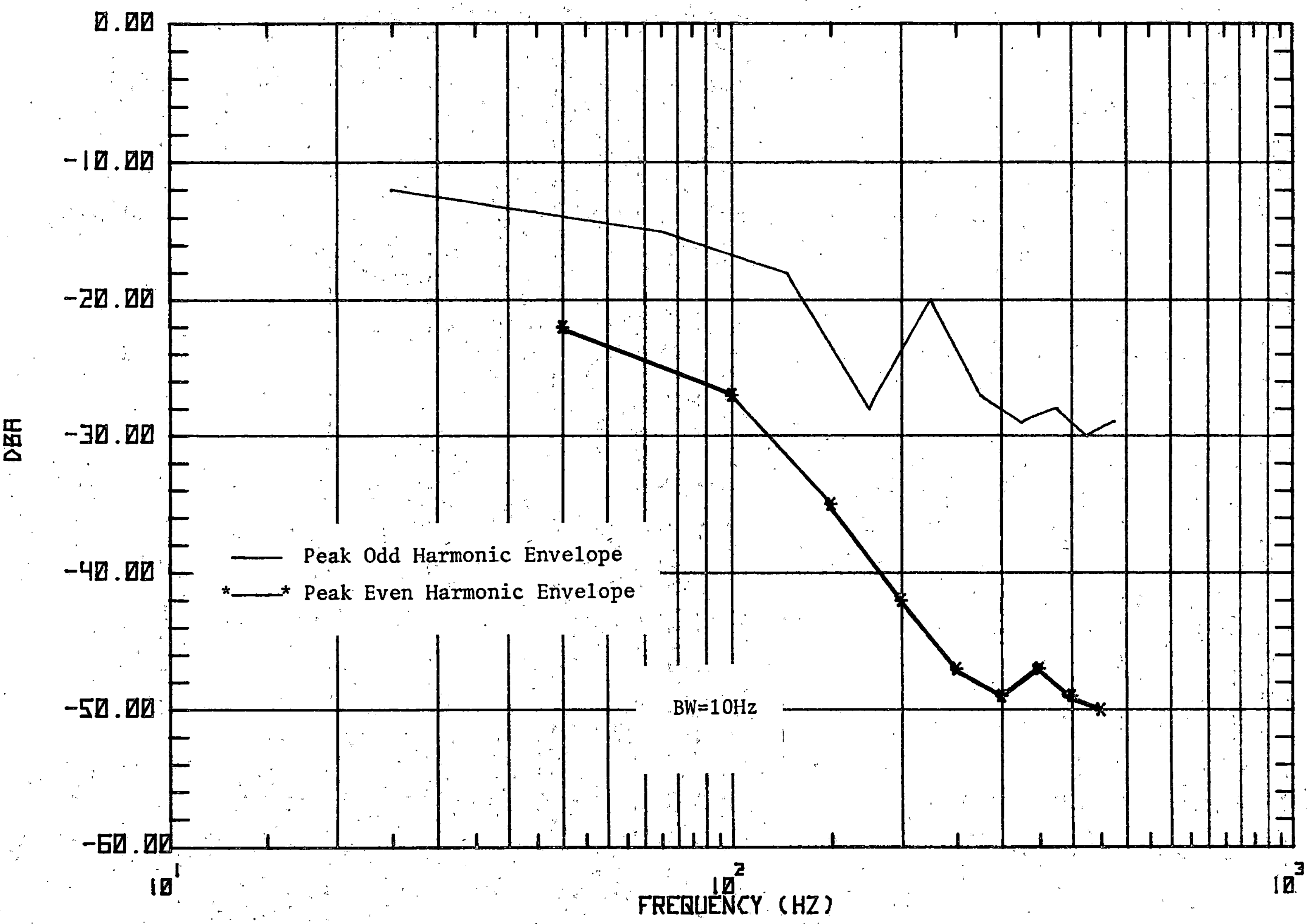


Figure 88. Current spectrum in left front rail (condition 12.4).

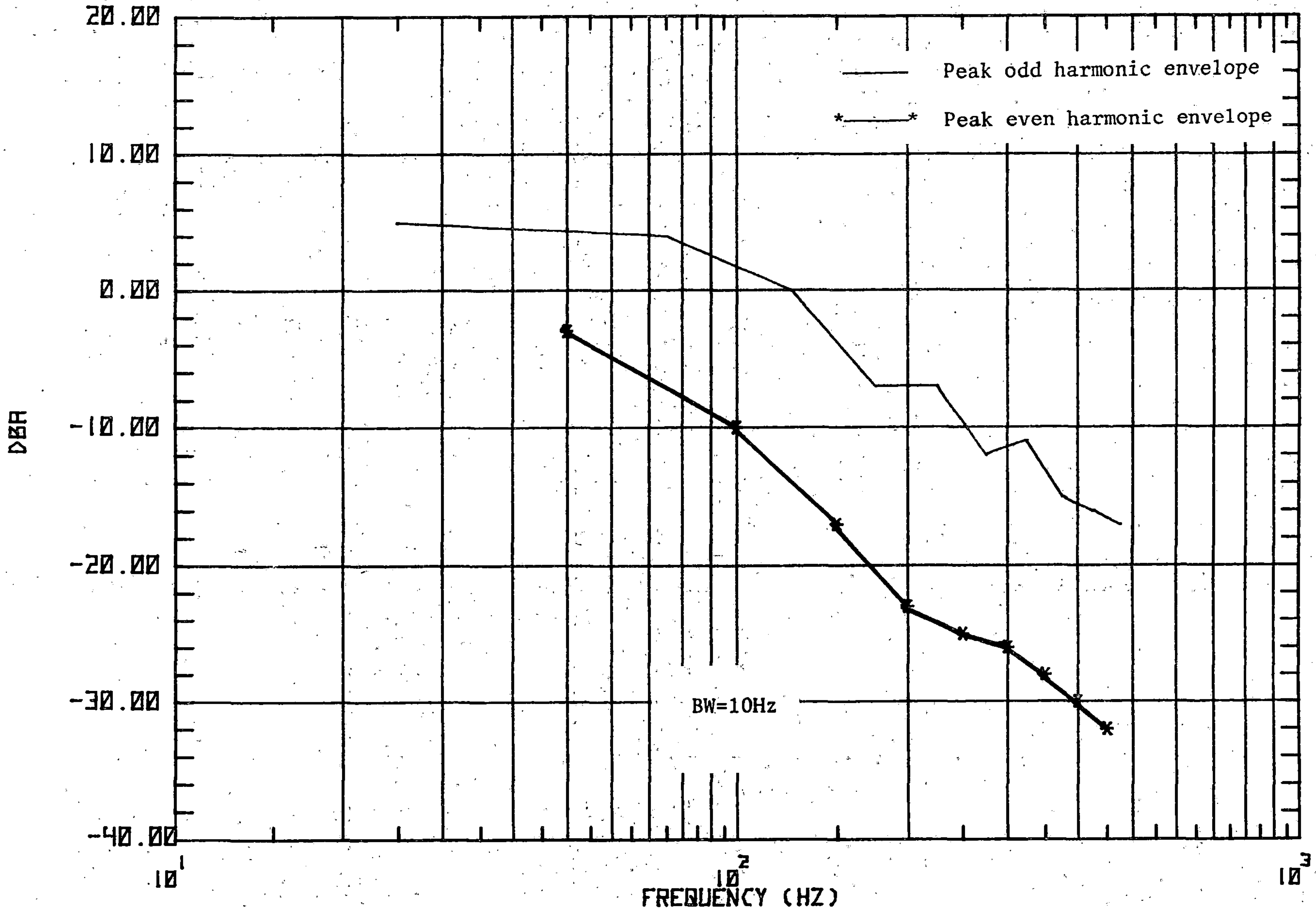


Figure 89. Current spectrum in right front rail (condition 12.5).

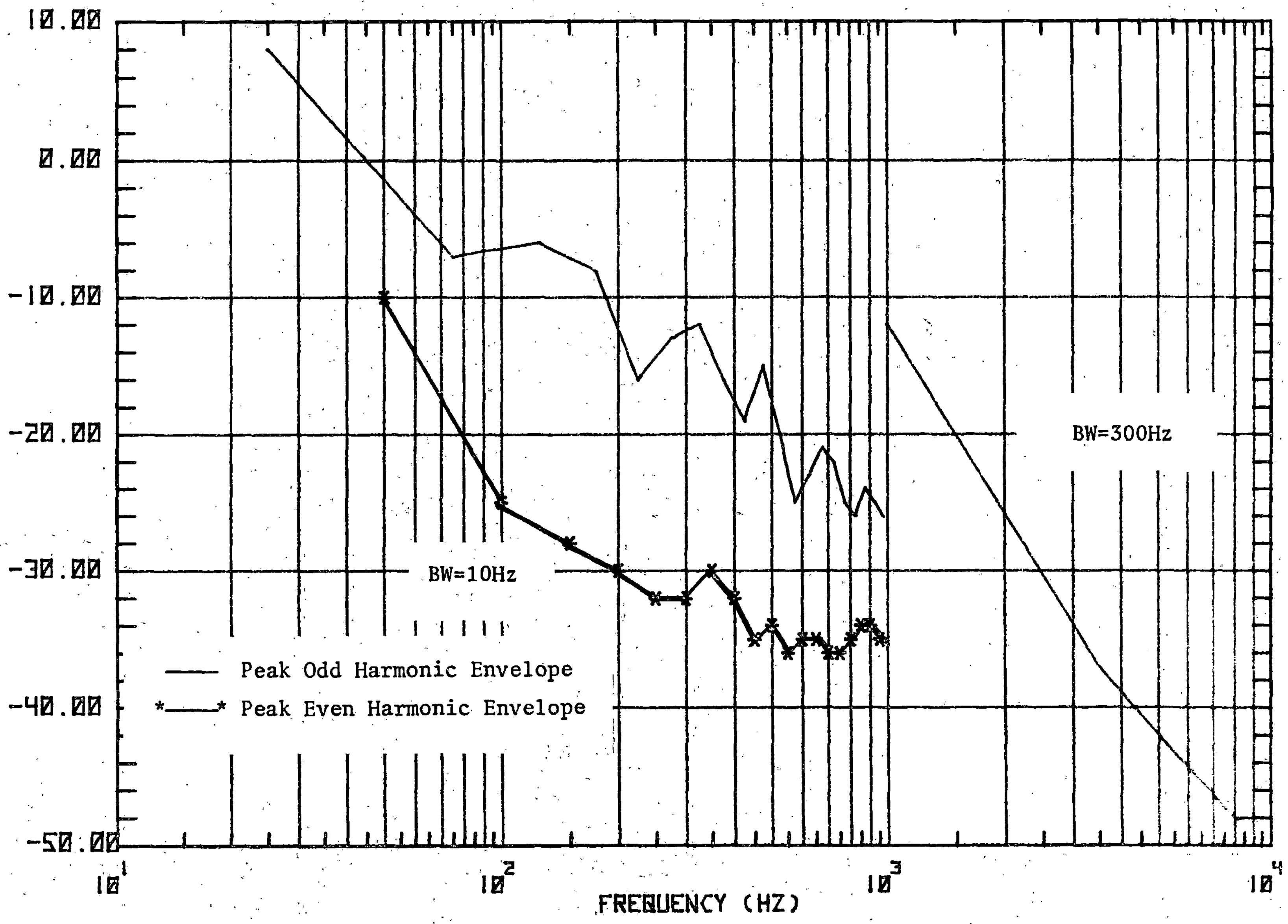


Figure 90. Current spectrum in right rear rail, 0 feet from locomotive (condition 12.6).

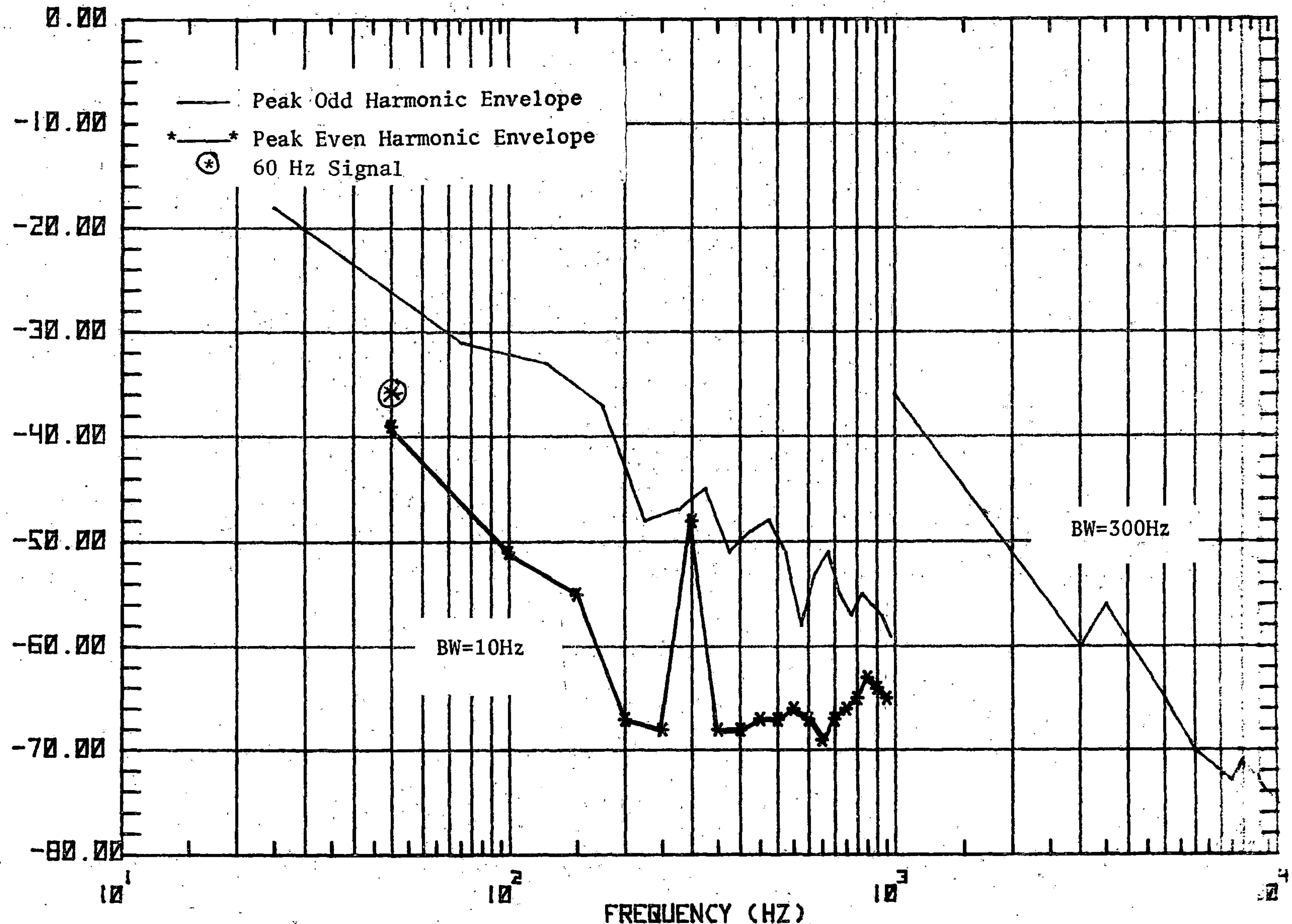


Figure 91. Current spectrum in right rear rail, 41.5 feet from locomotive (condition 12.7).

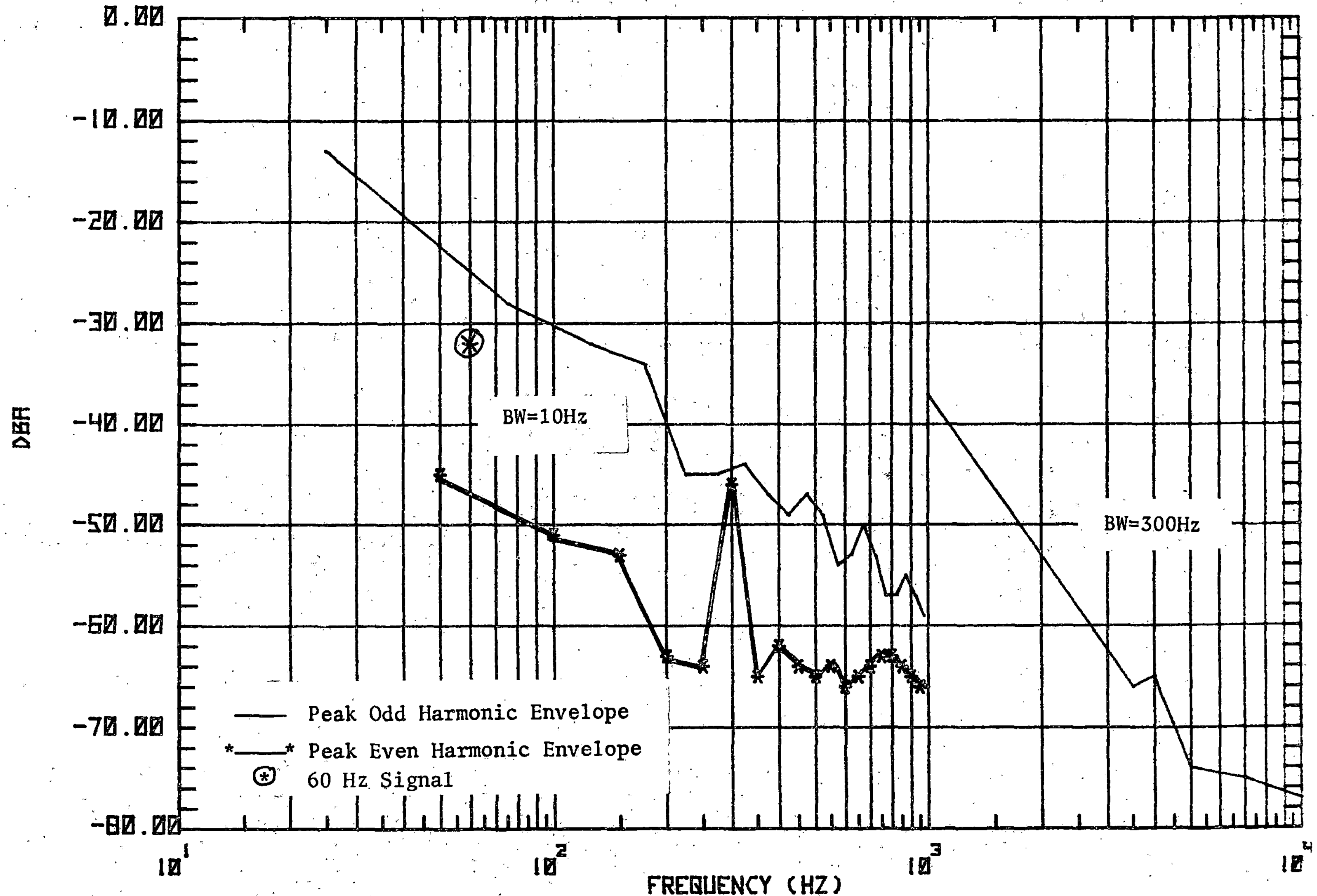


Figure 92. Current spectrum in right rear rail, 83 feet from locomotive (condition 12.8).

(in the maintenance shop) and jumpered at the other end, past the insulated section of track, to the tracks beyond (see Figure 93).

The 25 Hz component of the current spectrum shown in Figure 90 was 2.5 amperes. The current in the main transformer primary was 70 amperes. Apparently, the majority of the current distribution was in one of the other three rail locations. Scheduling of the locomotive and the testing time interval did not permit resolution of the current distribution phenomena.

Next, rail current measurements were performed with the engine located 51 feet away from the current loop probe (condition 12.9). The engine was situated with the rear truck on regular track and the front truck on the insulated section of track. The rail current in the insulated section of track was then measured. This was done to insure that the measured current was coming from the locomotive under test and not from another engine electrically connected to the grounding system.

Waveforms of rail current were sampled on the right track in front of the locomotive, on the right track 51 feet from the front of the locomotive, on the left track in front of the locomotive, and on the left track 51 feet from the front of the locomotive (shown in Figures 94, 95, 96, and 97, respectively). The peak-to-peak rail currents were 21.7, 18.2, 25.9 and 30.1 amperes for the above four measurement locations.

Fifty-two feet in front of the locomotive was a ground node. A test was performed to measure the current in the left rail at distances of 51, 52, and 53 feet, respectively, from the front of the engine. The peak-to-peak currents were 39.9 24.5 and 9.8 amperes, respectively, for the 51, 52, and 53 foot locations (see Figures 98, 99, and 100). The level of current sampled here was significantly different from the level obtained in the previous test. Time constraints and locomotive scheduling restricted resolution of this phenomena.

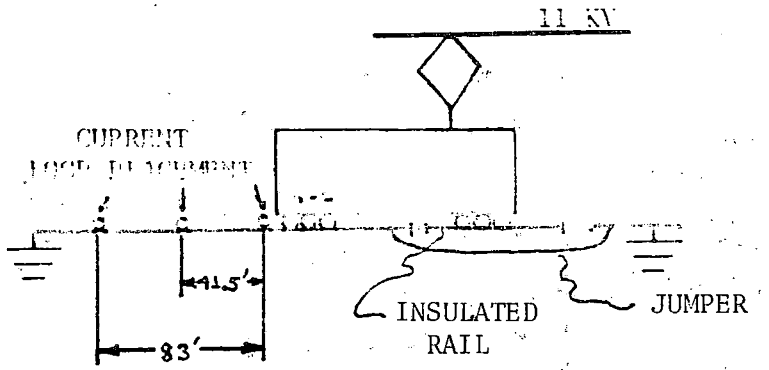
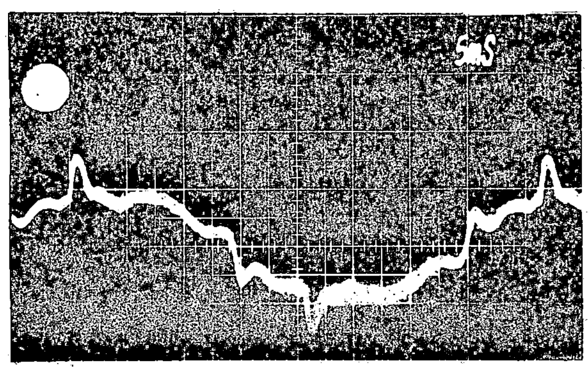
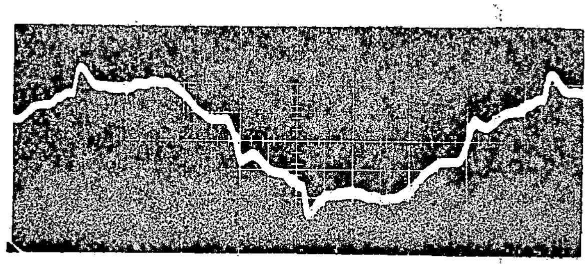


Figure 93. Locomotive location for rail current measurements (conditions 12.6, 12.7, and 12.8).



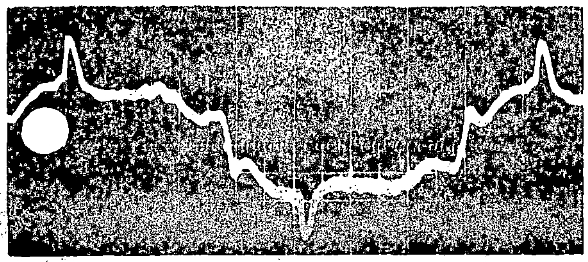
(amplitude=7 ampere/div, time=5 ms/div)

Figure 94. Waveform of rail current in right front rail (condition 12.9).



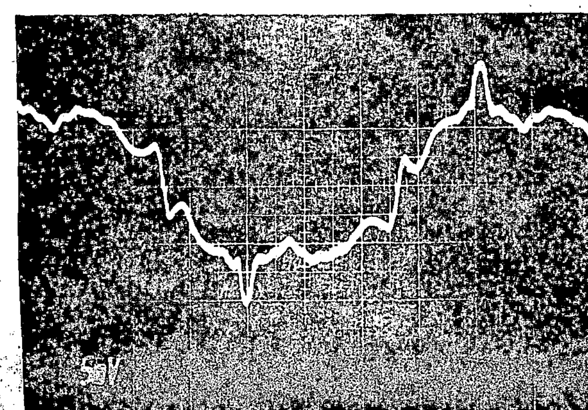
(amplitude=7 ampere/div, time=5 ms/div)

Figure 95. Waveform of rail current 51 feet from locomotive on right front rail (condition 12.9).



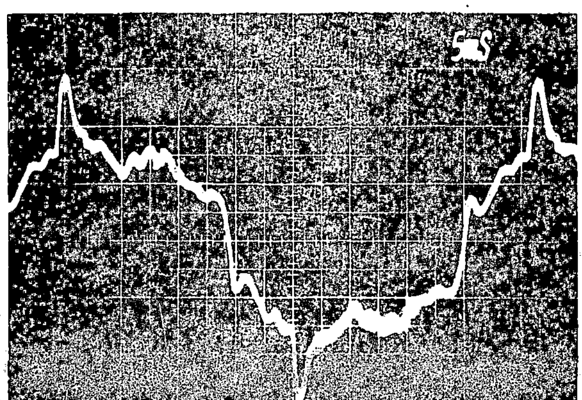
(7 ampere/div, 5 msec/div)

Figure 96A. Waveform of rail current in left front rail, 0 feet from locomotive (condition 12.9).



(7 ampere/div, 5 msec/div)

Figure 97. Waveform of rail current 51 feet from locomotive in left front rail (condition 12.9).



(7 ampere/div, 5 msec/div)

Figure 98A. Waveform of rail current one foot in front of ground node. (51 feet from locomotive)

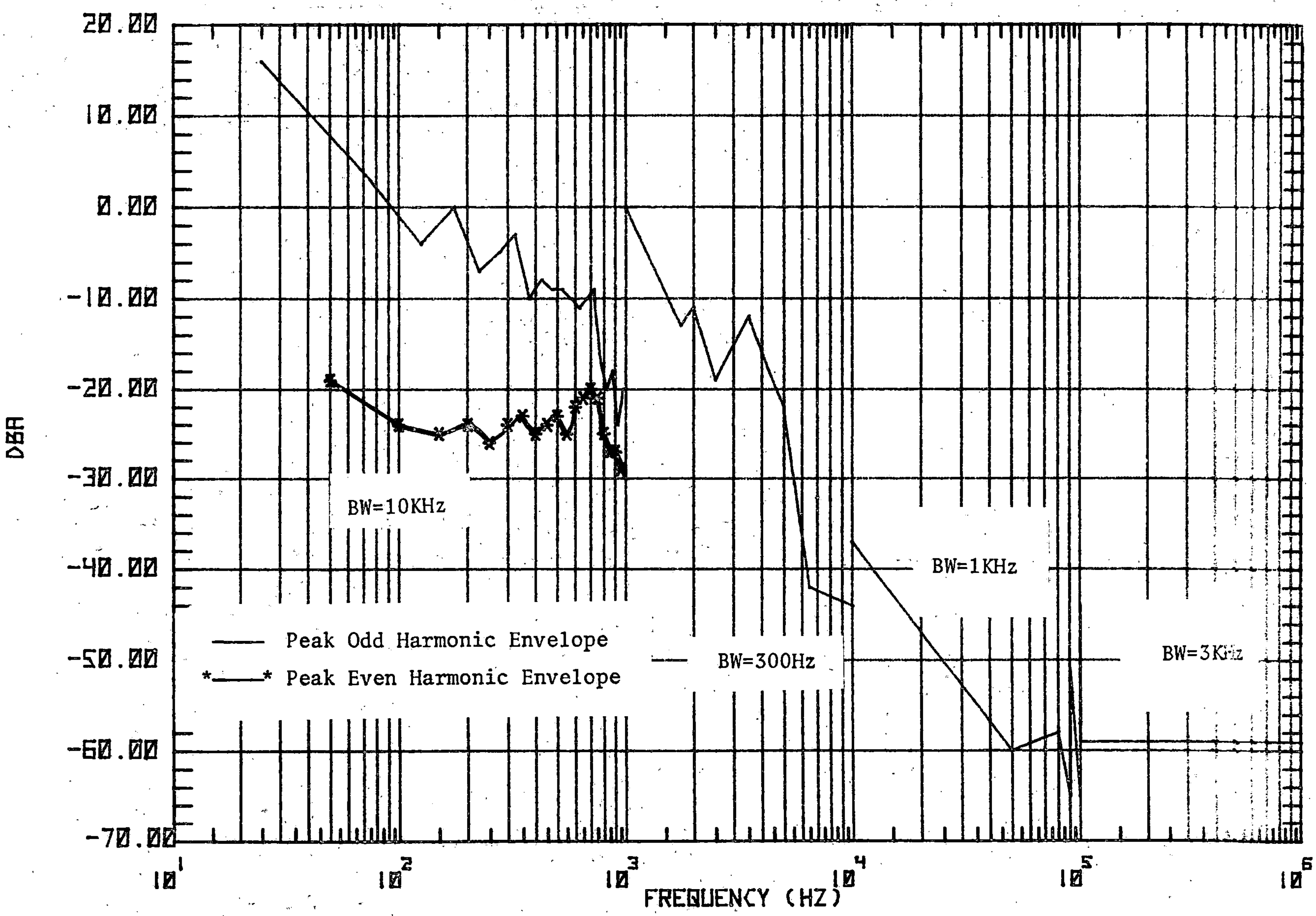


Figure 96B. Spectrum of rail current in left front rail, 0 feet from locomotive (condition 12.9).

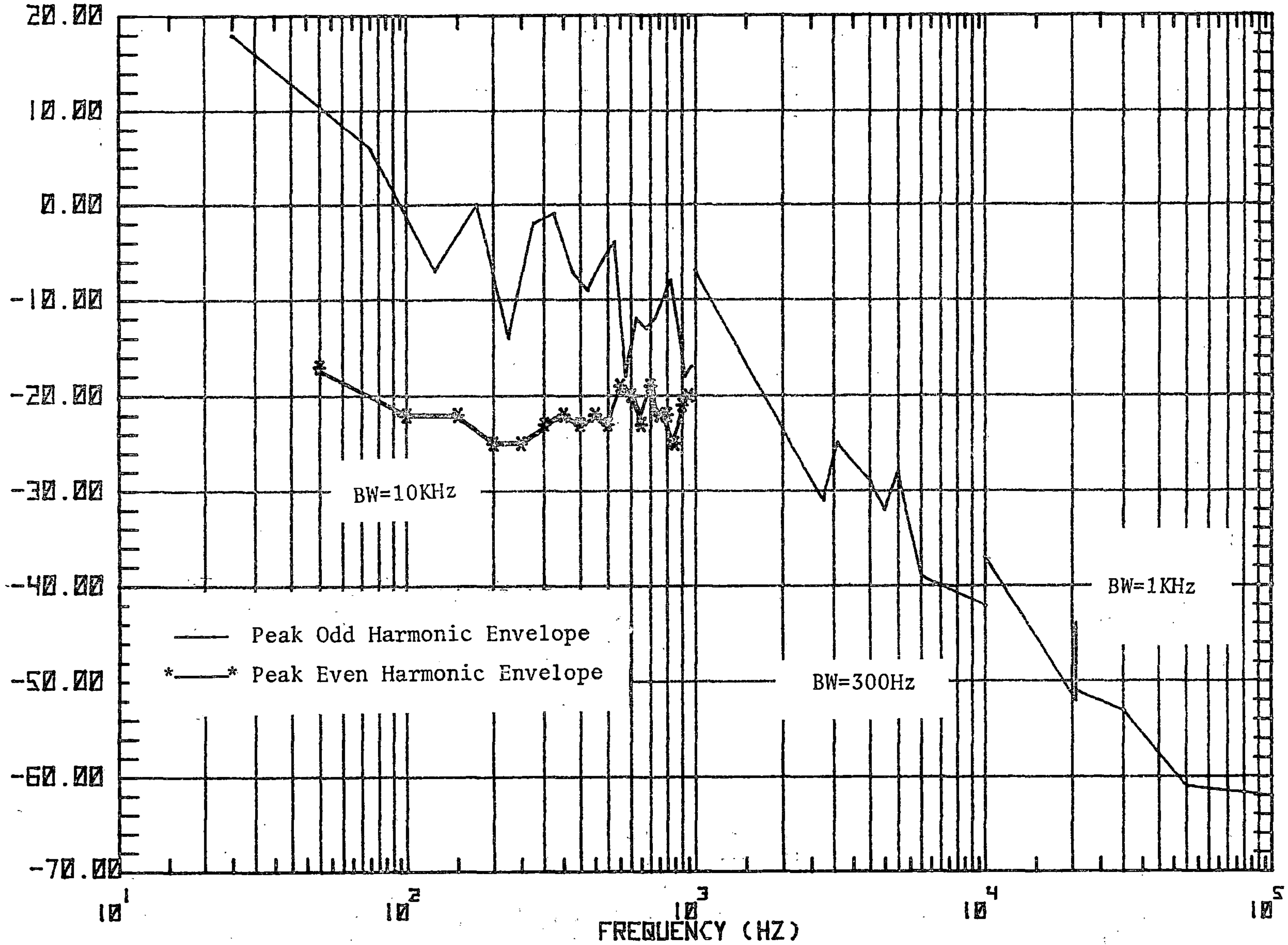
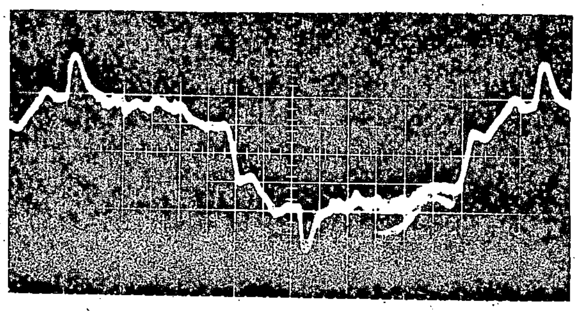
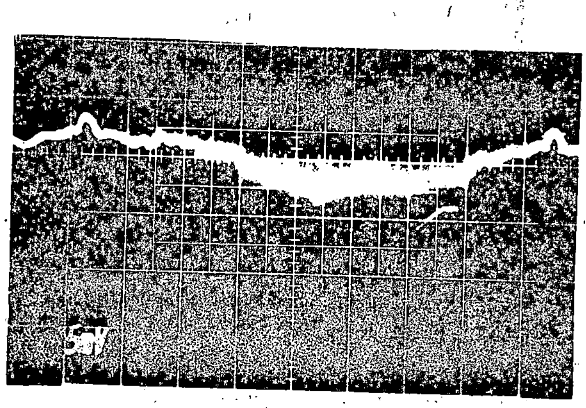


Figure 98B. Spectrum of rail current 1 foot in front of ground node (51 feet from locomotive).



(7 ampere/div, 5 msec/div)

Figure 99. Waveform of current in left rail, 52 feet from locomotive.



(7 ampere/div, 5 msec/div)

Figure 100A. Waveform of left rail current, 53 feet from locomotive.

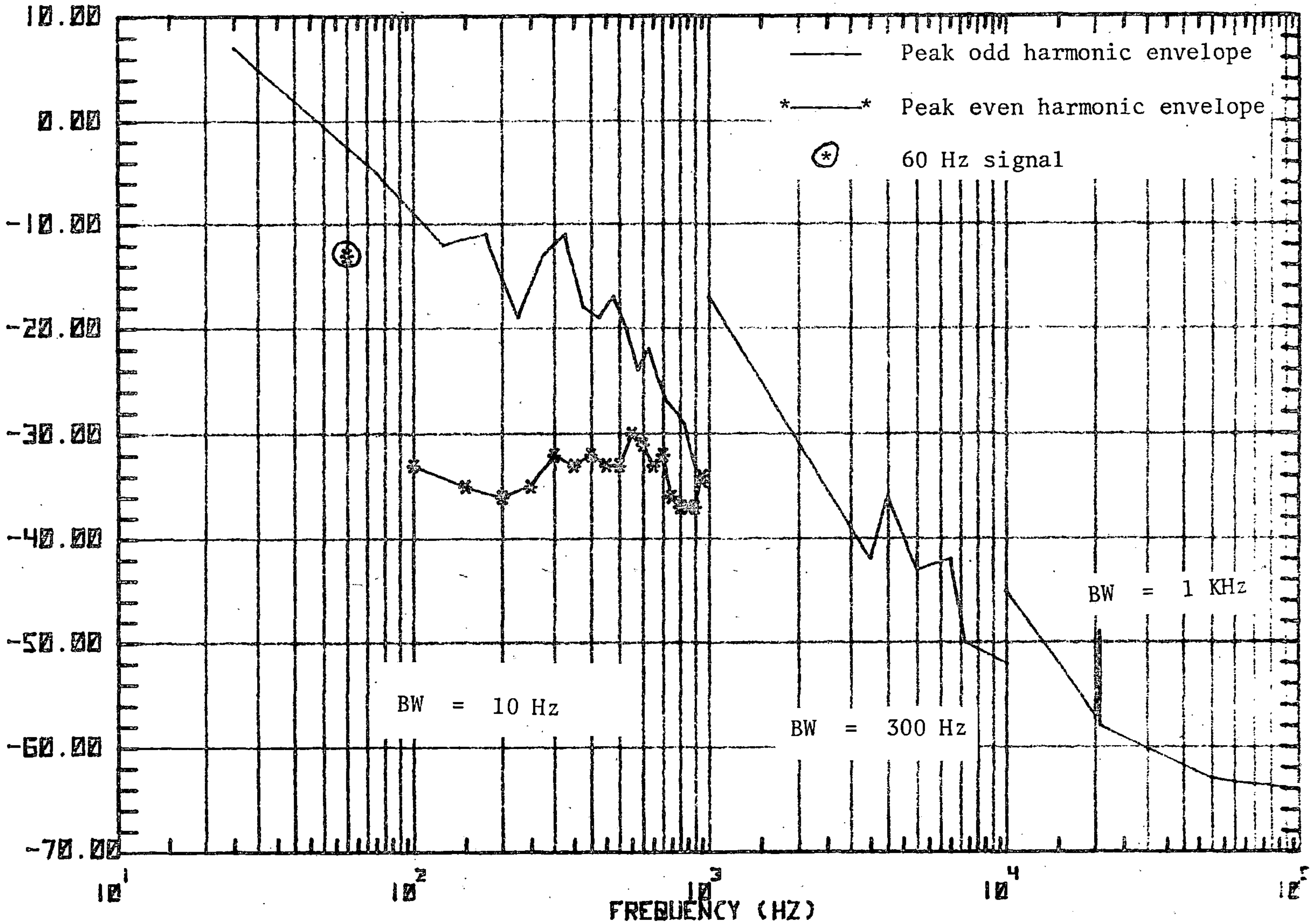


Figure 100B. Spectrum of left rail current, 53 feet from locomotive.

Rail current spectrum measurements were then performed on track numbers 6 and 7 at the Wilmington yard with the cab signalling on (see Figures 101 and 102). On track 6, the 100 Hz component was -10 dBA (0.3 amperes). Two amperes of current were delivered to track 6 by the cab signal generator. Possibly, some of the cab signal generator current was lost in the ground system.

13.0 Ambient Environment

The electric field strength in the 160-162 MHz frequency range was sampled at the VHF antenna with the engine off. The connection to the VHF antenna was made at the end of the antenna cable at the VHF radio input. Background yard noise and two carriers received by the antenna are displayed in Figure 103. The carriers were recorded at 161.54 and 161.73 MHz with amplitudes of -68 dBV/m and -59 dBV/m respectively. The amplitudes displayed were normalized to a 10 kHz analyzer bandwidth.

In addition, the impulsive electrical noise generated by the main breaker opening and closing was sampled. The electric field strength intensity at 161 MHz, for this condition, was -28 dBV/m, recorded using a 30 kHz receiver bandwidth.

14.0 Electric Field Strengths

The electric field strength radiated by the locomotive was sampled, using vertically polarized antennas, under the following conditions:

14.1 Ten feet in front of the locomotive with the blower motor on idle, the M/A set on (unloaded), the oil pump and various small electrical units within the locomotive on.

14.2 Ten feet in front of the locomotive with the blower motor on full, the M/A set on (unloaded), the oil pump and various small electrical units within the locomotive on.

14.3 Around a perimeter 10 feet from the locomotive with the blower motor on full, the M/A set on (unloaded), oil pump and various small electrical

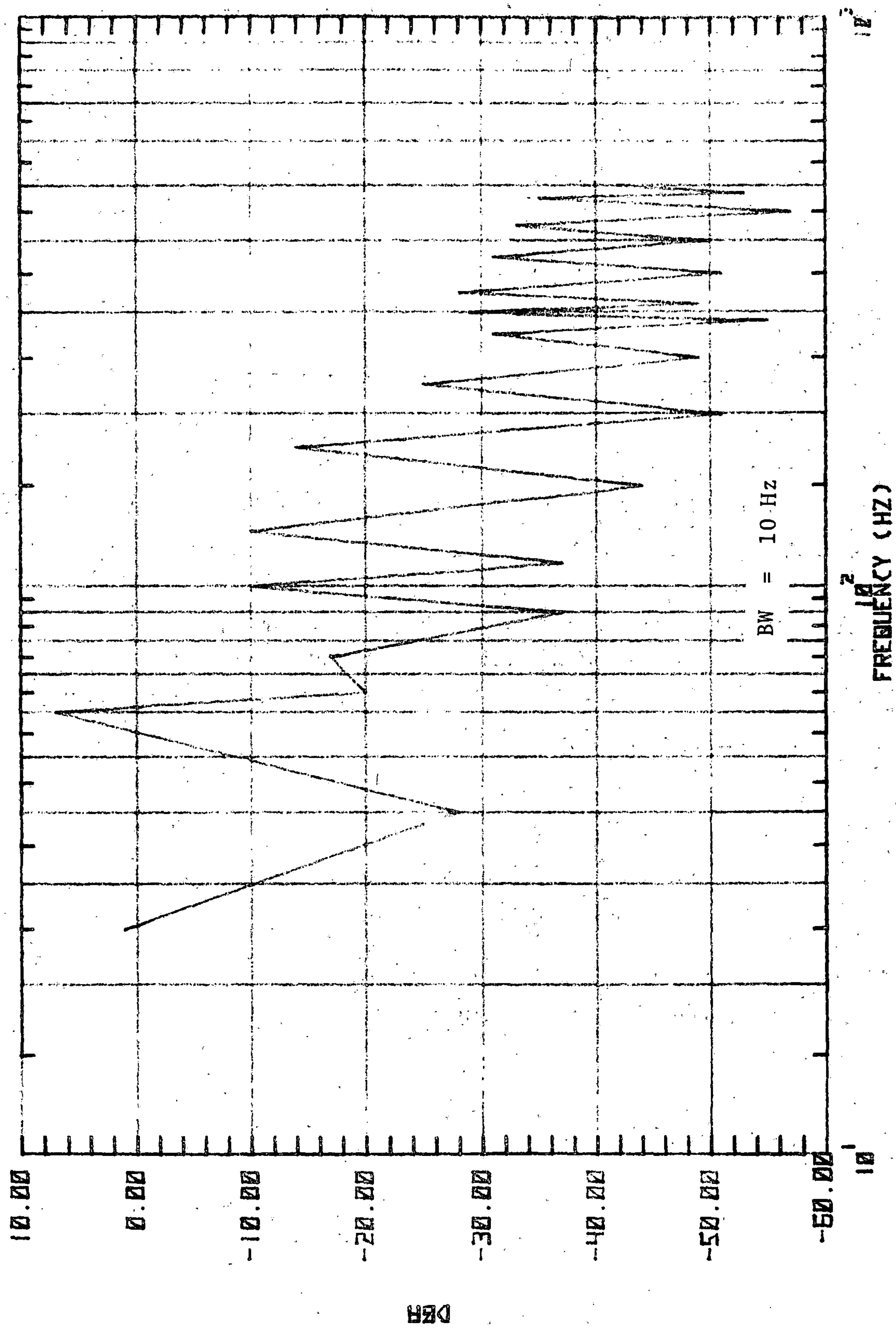


Figure 101. Rail current in track #6 with cab signal on.

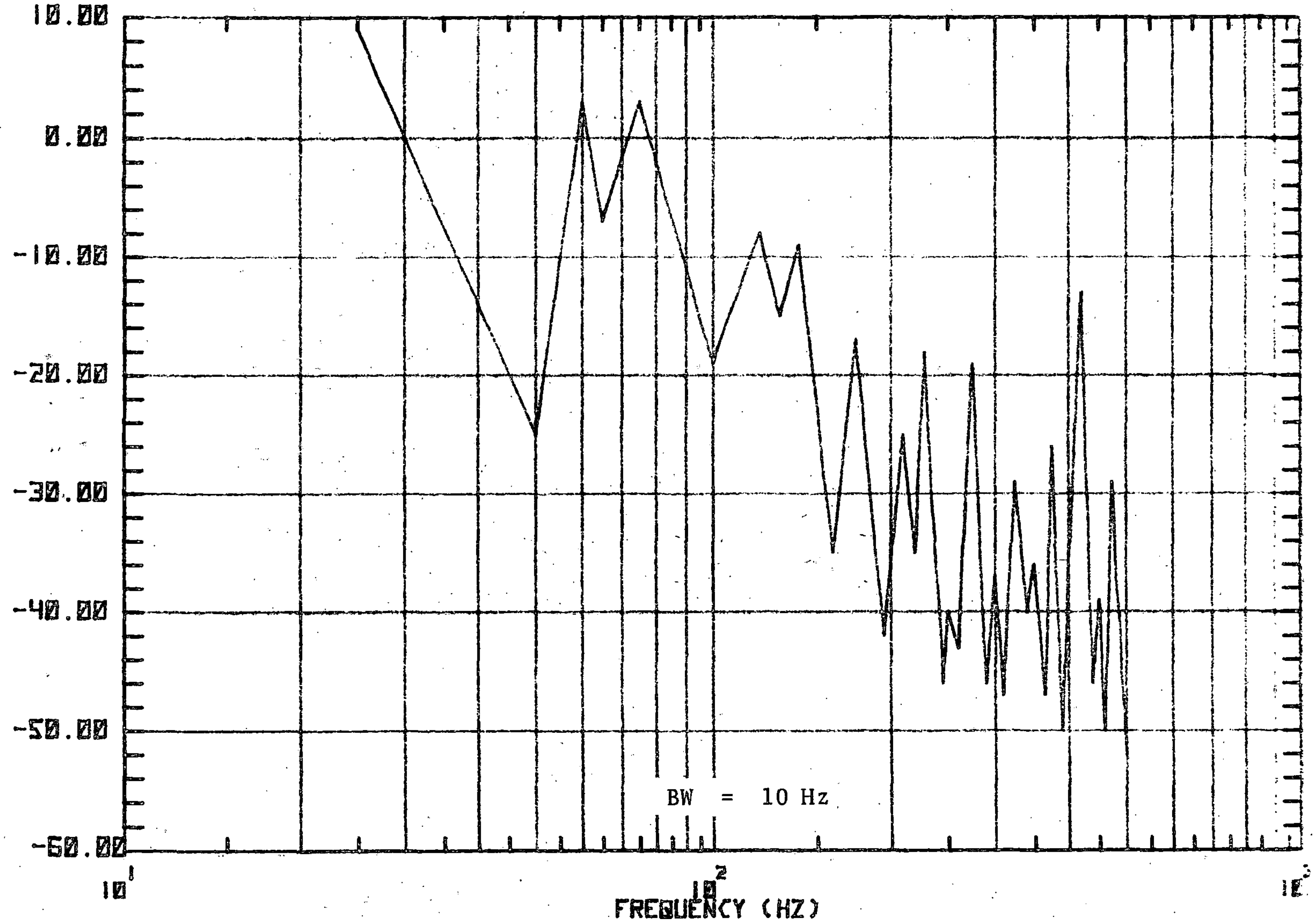
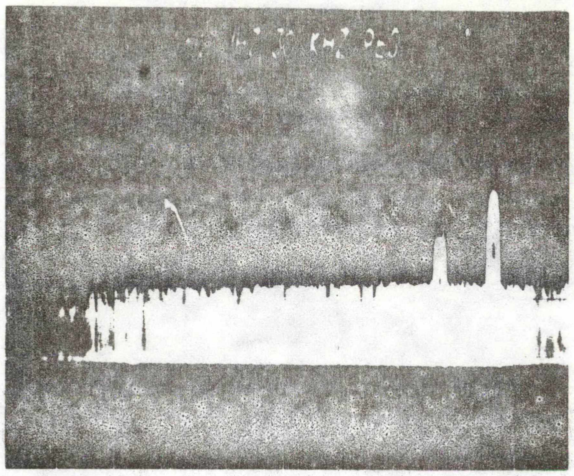


Figure 102. Rail current in track #7 with cab signal on.



... 52 dBμV/m

161 MHz

Figure 103. Electric field strength at VHF receiving antenna. (Amplitude=10 dBμV/m/div, frequency = 0.2 MHz/div.

devices within the locomotive on.

14.4 Thirty feet in front of two locomotives with the blower motor on full, the M/A set on (unloaded), the oil pump and various small electrical devices on.

14.5 Inside the cab with the blower motor on full, the M/A set on, the oil pump and various minor electrical systems on.

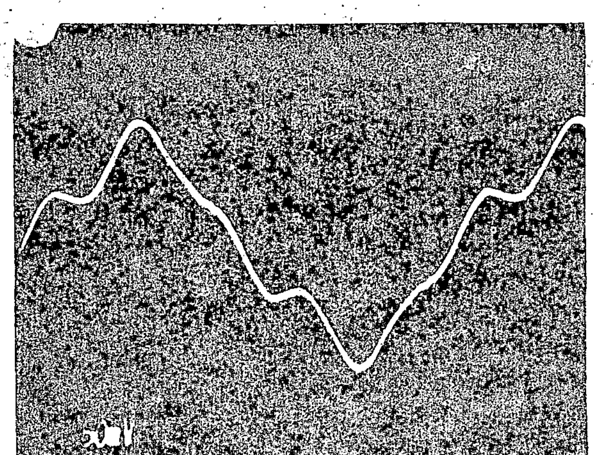
14.6 Next to the locomotive with the blower motor on full, dynamic brake in positions 0 and 5, respectively, M/A set on run (unloaded) and oil pump and minor electrical systems on.

14.7 Next to the locomotive with the blower motor on full, dynamic brake in positions 2 and 8, respectively, oil pump and minor electrical units on.

14.8 Around the perimeter of the locomotive at various distances with the blower motor on full, the dynamic brake in position 8, the oil pump and various minor electrical systems on.

14.9 Electric field strength of transients radiated from the main breaker closing and from the dynamic brake system.

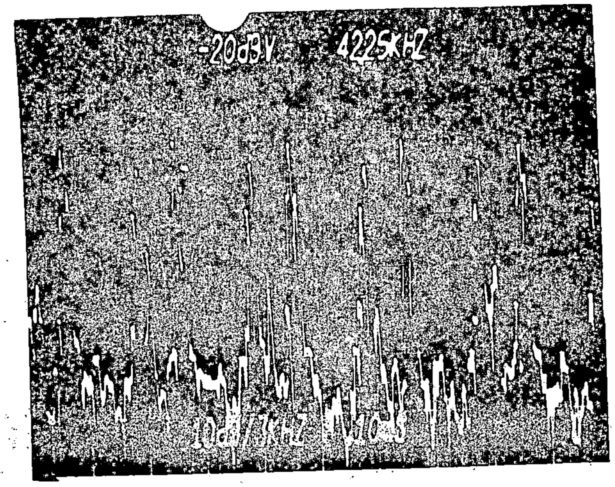
The time waveform of the electric field strength under condition 14.1 is given in Figure 104. The waveform measurements were made possible using an electric field strength probe with a uniform frequency response (± 1 dB) throughout the range from 25 Hz to 100 kHz. In addition, two waveforms, at 42.25 and 1550 kHz, were detected and are shown in Figures 105 and 106, respectively. The detected signal at 42.25 kHz had a period of 20 milliseconds (twice the period of a 25 Hz signal), while the 1550 kHz signal had an 8 millisecond period (approximately twice the period of a 60 Hz signal). The frequency spectrum, between 25 Hz and 5 MHz, is given in Figure 107.



(706 V/m/div, 5 msec/div)

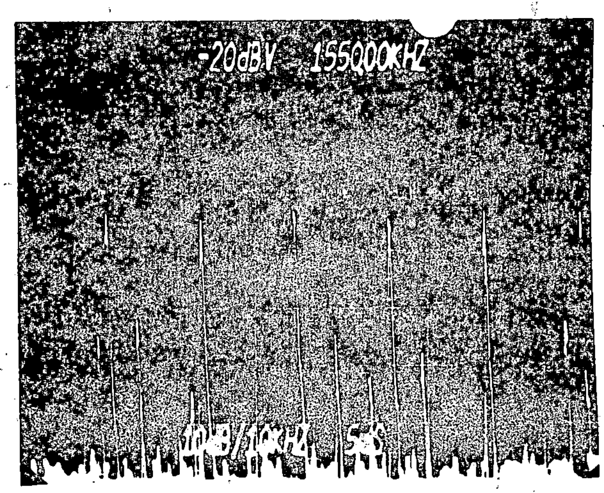
Figure 104. Time waveform of electric field strength (condition 14.1).

15 dBV/m....



(10 dBV/m/div, 10 millisecond/div)

Figure 105. Electric field strength waveform detected at 42.25 kHz (condition 14.1).



(10 dBV/m/div, 5 millisecond/div)

Figure 106. Electric field strength waveform detected at 1550 kHz (condition 14.1).

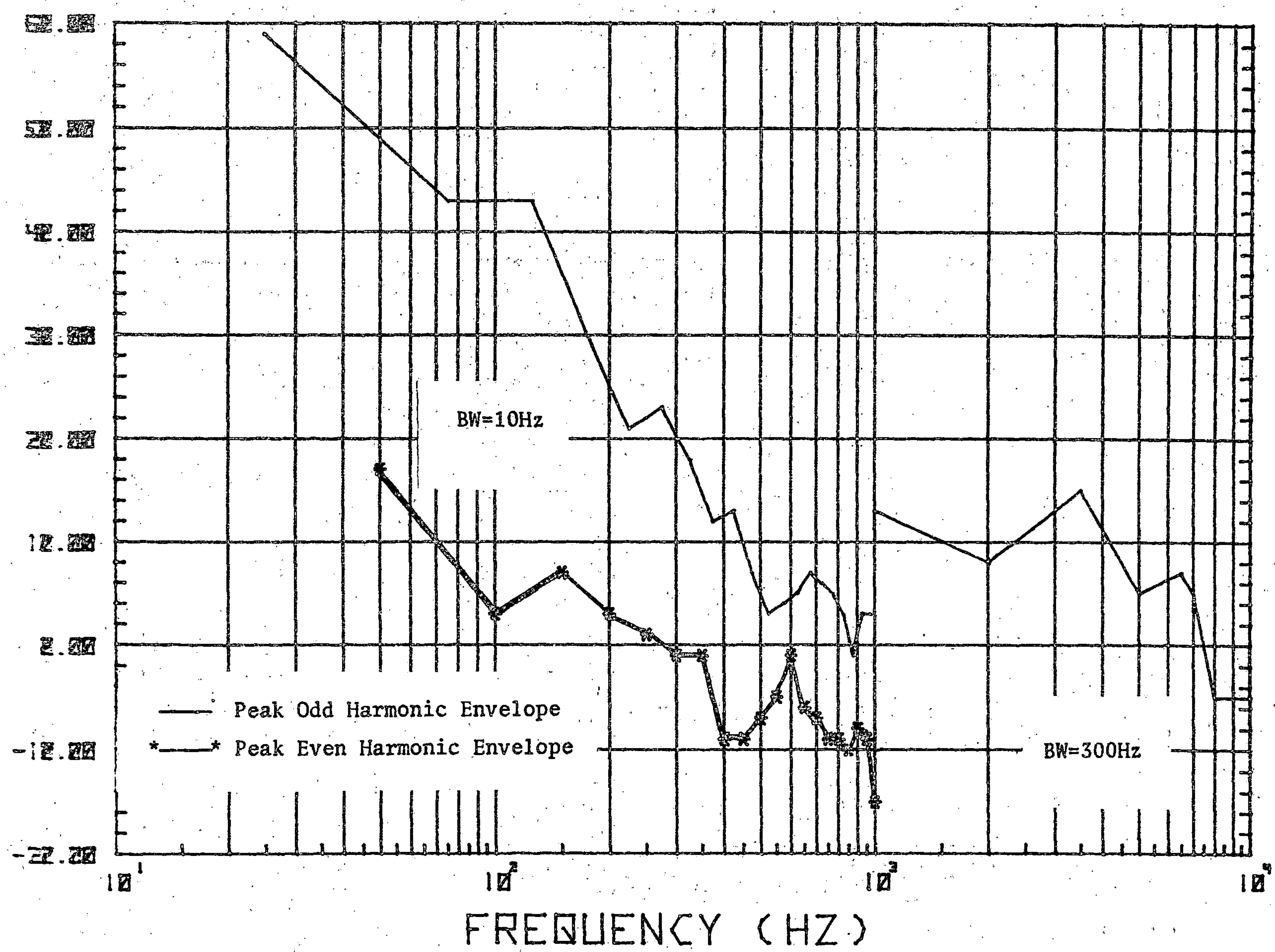


Figure 107. Electric field strength in front of locomotive (condition 14.1).

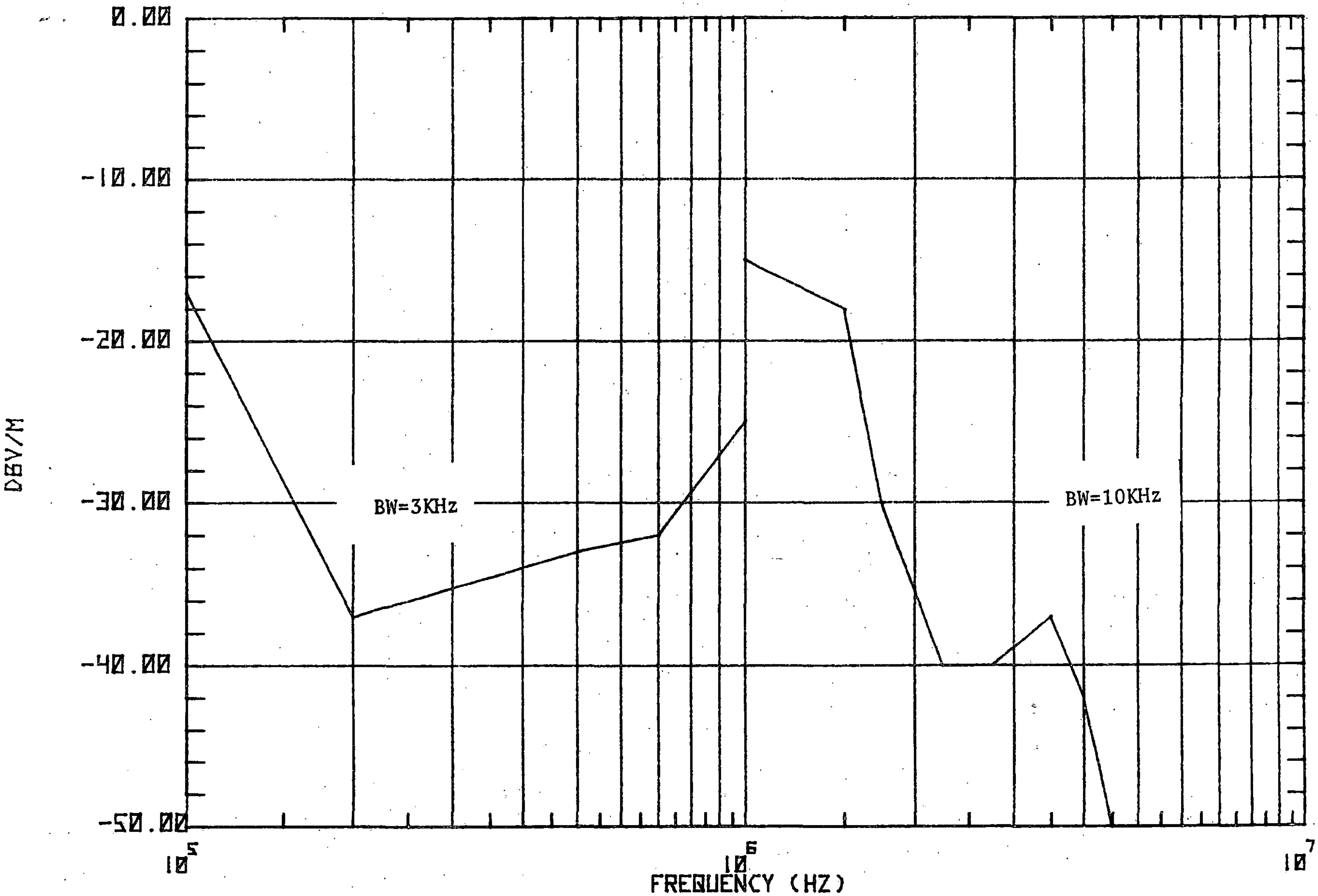


Figure 107. (continued).

The frequency spectrum of the electric field strength obtained with the blower motor on full (condition 14.2) is given in Figure 108.

The electric field strengths at 25 Hz at various locations on a perimeter located 10 feet from the locomotive (condition 14.3) are given in Figure 109. In Figure 109, the electric field strengths varied from 380 to 849 volts per meter. Next, electric field strengths were measured in a 1 kHz receiver bandwidth with a center frequency of 3 kHz at several distances away from the rear and left side of the locomotive[a]. The magnitude of these electric field strengths are given in Figure 110.

The electric field strength spectrum approximately 30 feet in front of two engines (condition 14.4) is shown in Figure 111. As a general point of observation, the emission levels displayed in Figure 111 appear greater than those observed in Figure 107. For example, the electric field strength at 25 Hz in Figure 107 was 891 volts per meter, whereas, in Figure 111, the electric field strength was 1000 volts per meter. At this point, it is not possible to determine whether the radiations were emitted from the engines or the catenary (although most evidence favored the catenary being the radiator). The waveform of the electric field strength is given in Figure 112.

[a] 3 kHz as well as 7 kHz and 90 kHz were chosen as center frequencies of measurement samplings because initial samplings, obtained across the frequency band of 25 Hz to 500 MHz, indicated significant levels of energy at these frequencies.

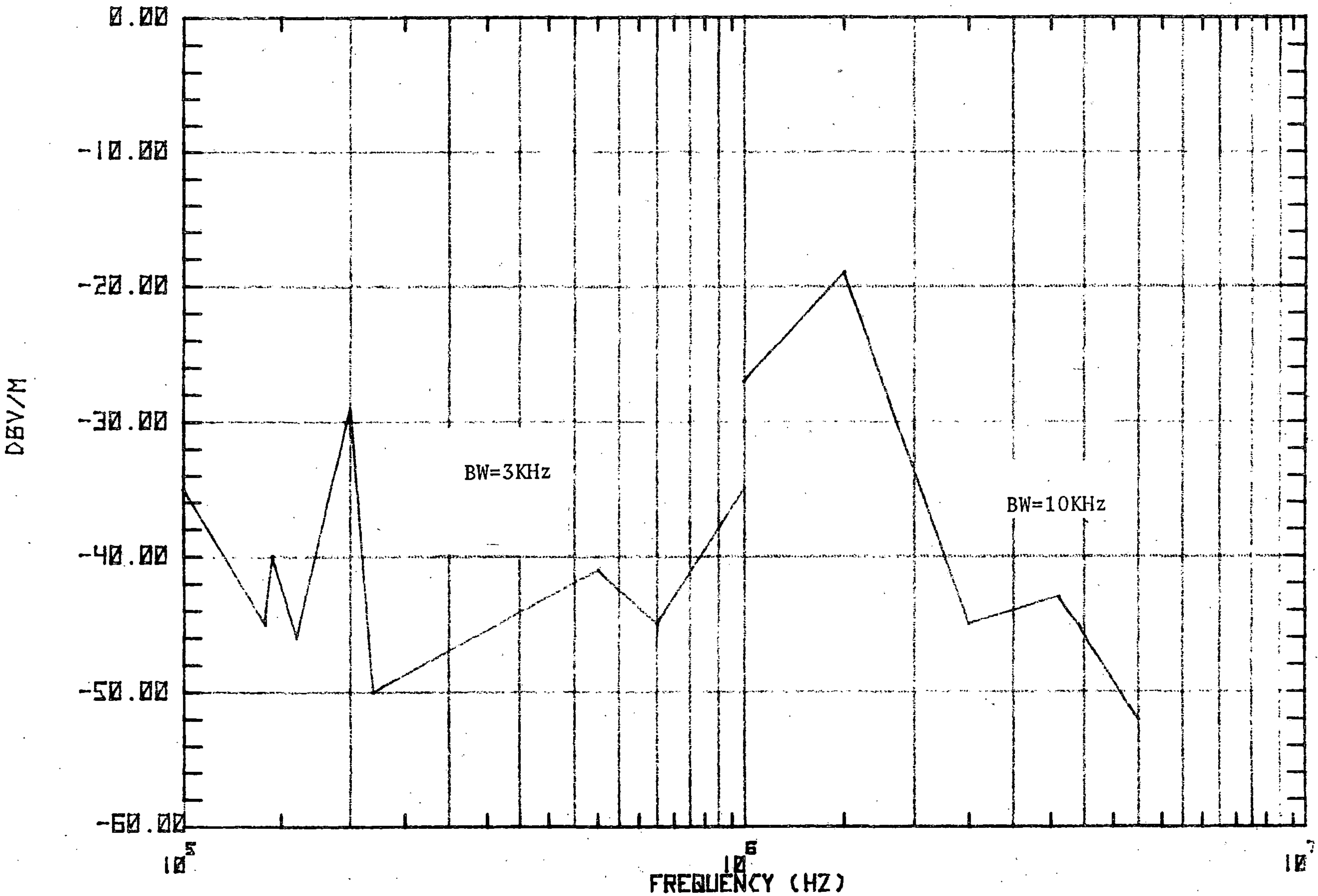


Figure 108. Electric field strength in front of locomotive with blower on full (condition 14.2).

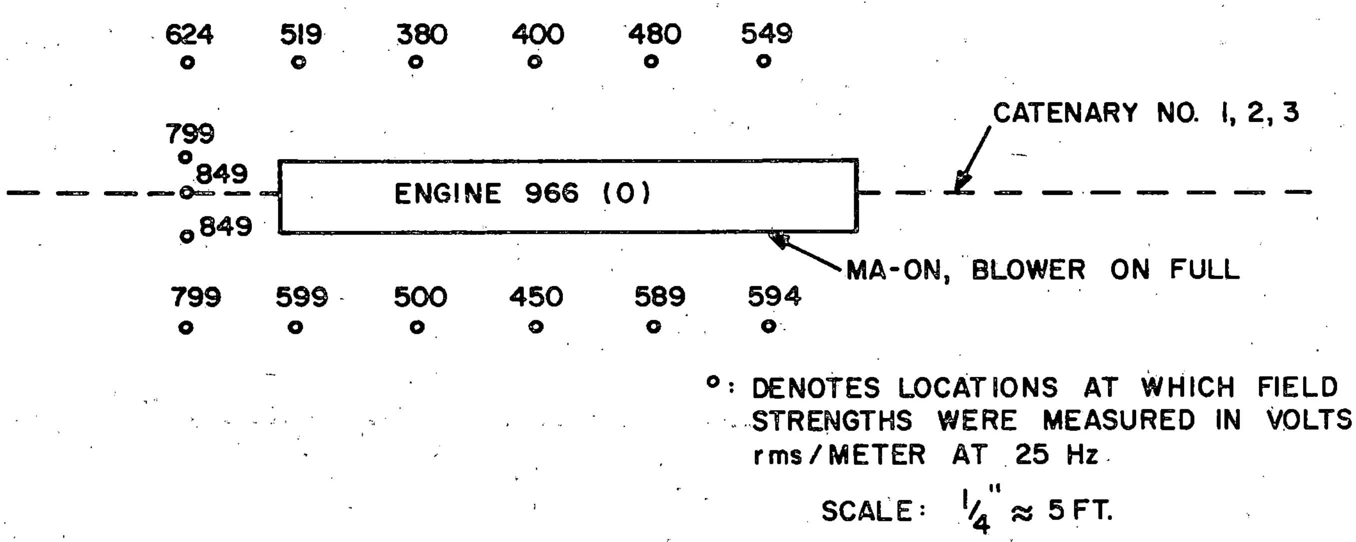


Figure 109. Electric field strength at various distances around the locomotive (f=25 Hz).

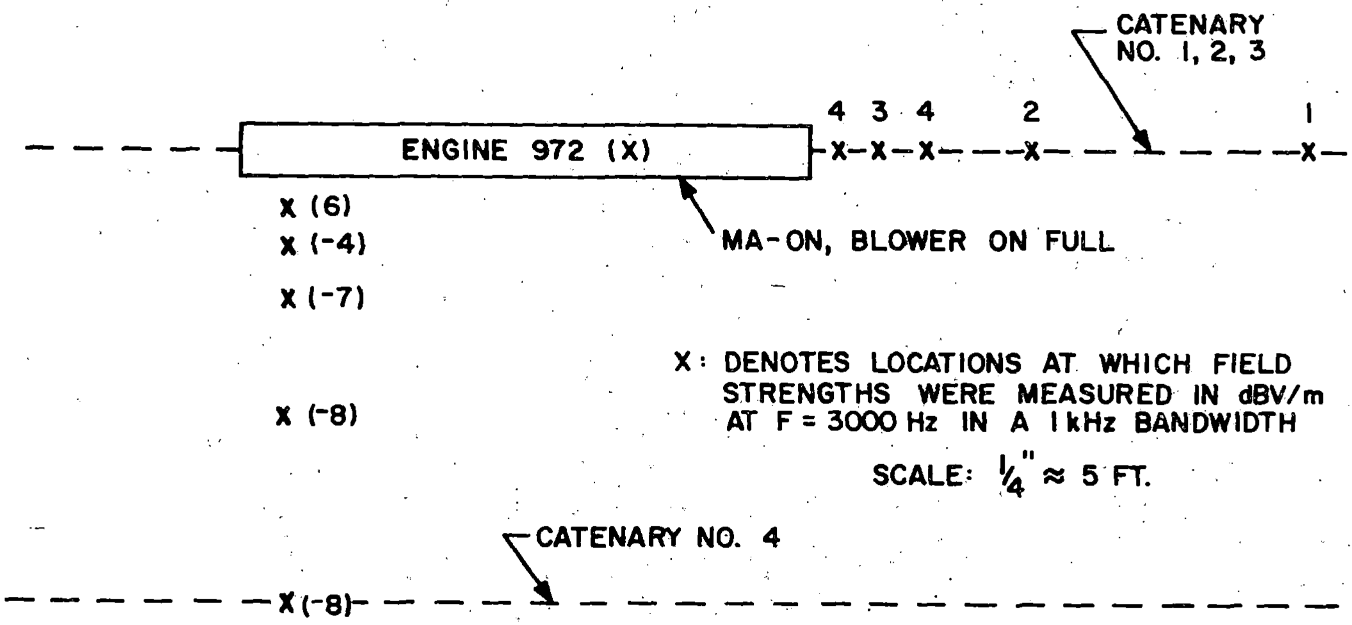


Figure 110. Electric field strength at various distances around the locomotive (f=3 kHz).

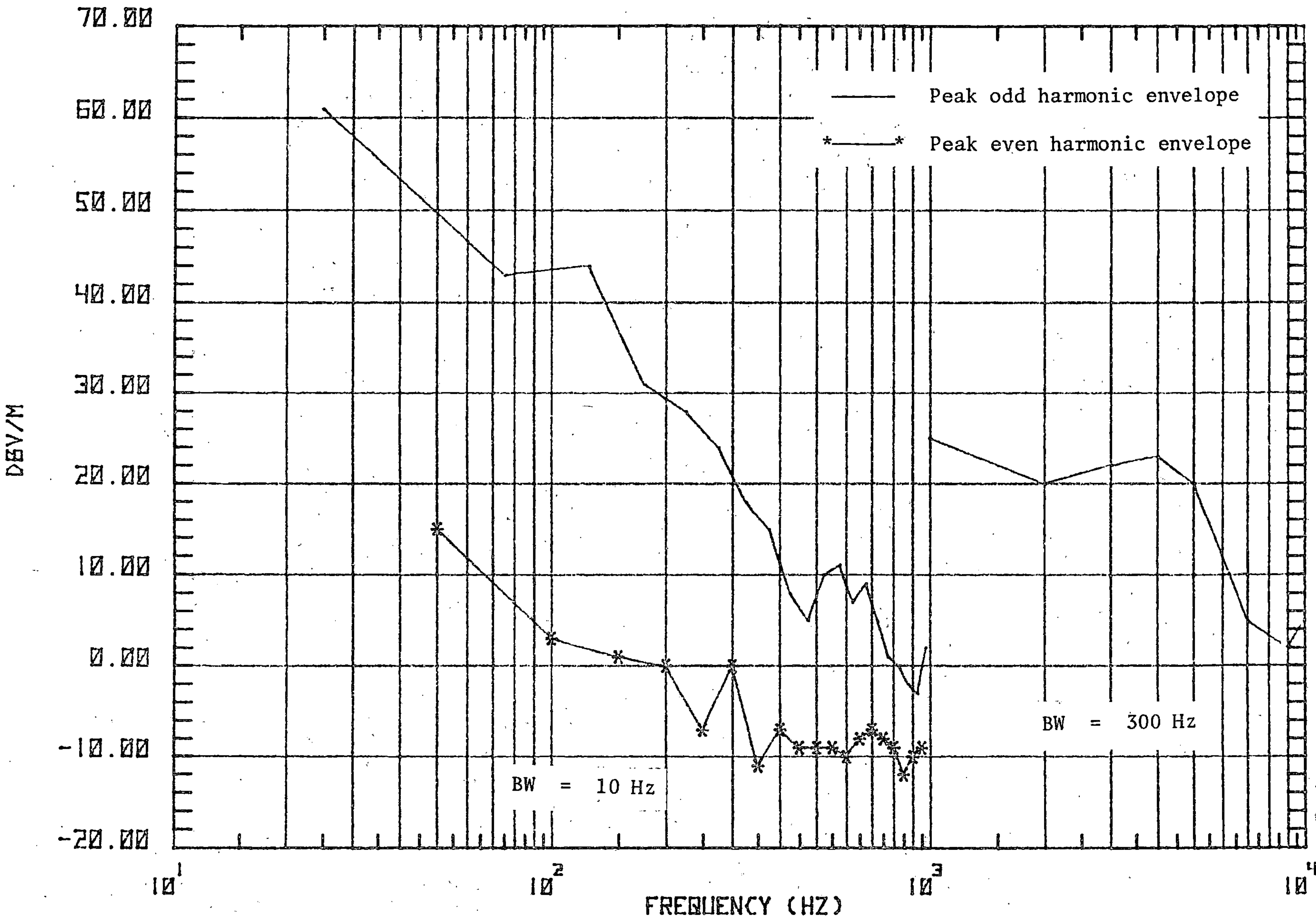


Figure 111. Electric field strength spectrum, 30 feet in front of engine 972 and 954 (condition 14.4).

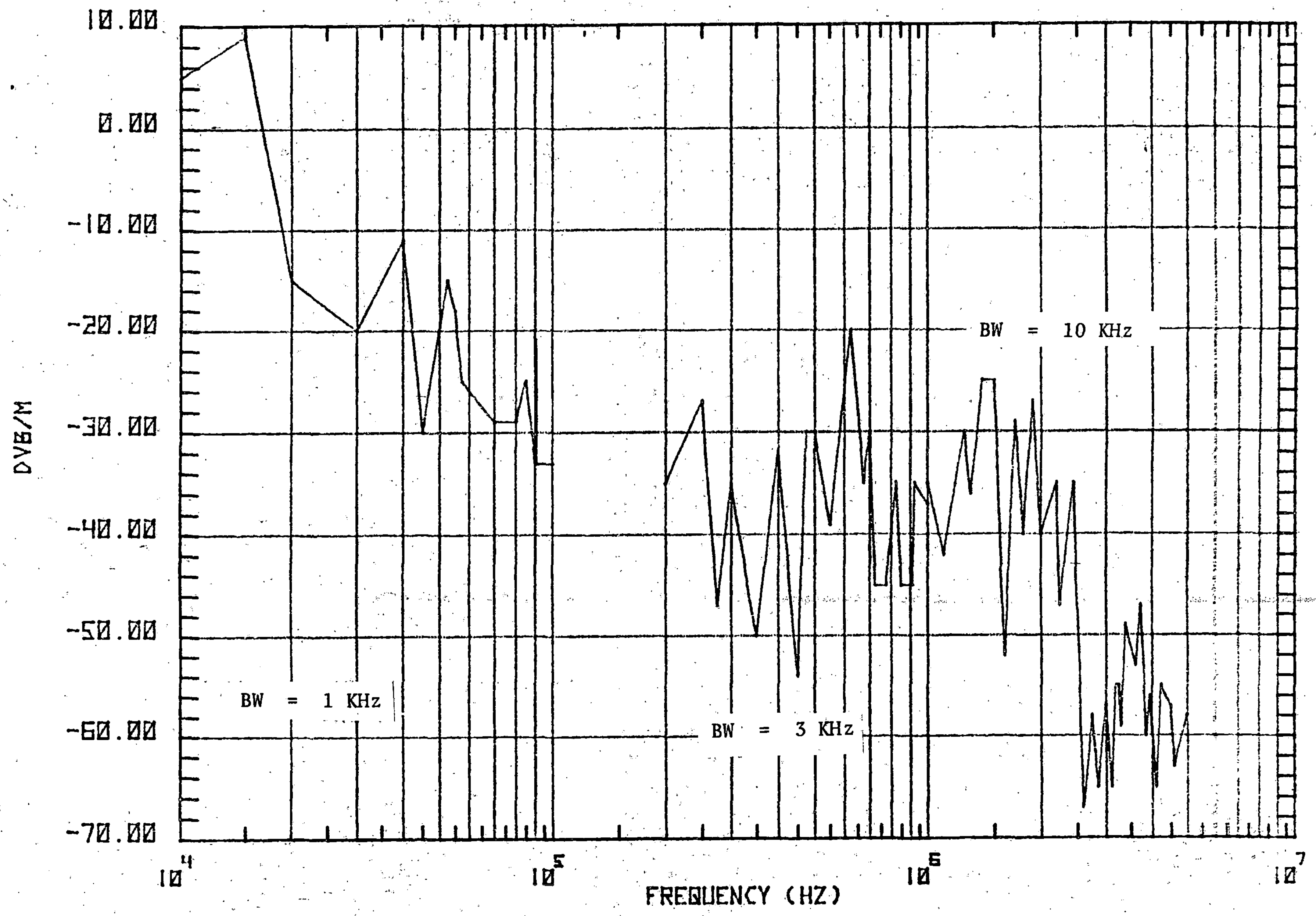
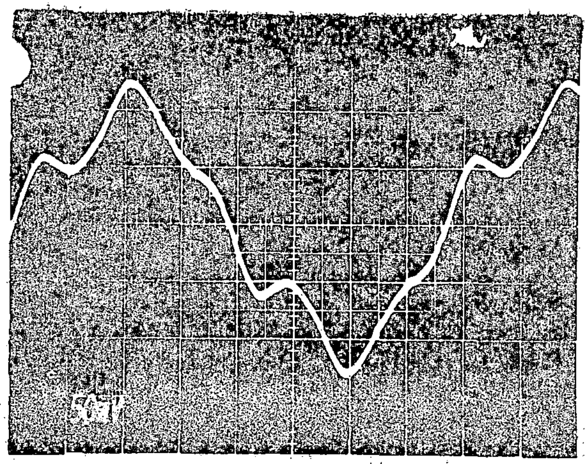


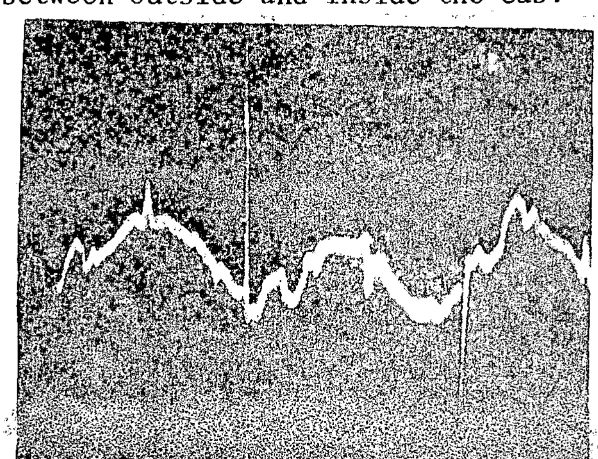
Figure 111. (continued).



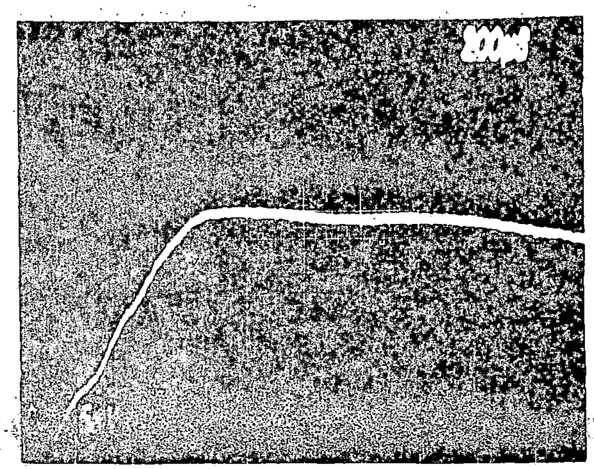
(706 V/m/div, 5 millisecond/div)

Figure 112. Electric field strength waveform, 30 feet in front of locomotives #972 and 954 (condition 14.4).

The next set of data was taken inside the cab of the locomotive with the blower motor on full and the M/A set on (condition 14.5). The electric field strength waveforms recorded under these conditions are given in Figure 113. Note that a spike of approximately 280 volts per meter is seen in Figure 113. This spike was related to the dynamic brake control of the engine. A list of levels found inside the cab is given in TABLE 2. In comparison with the previous measurements, a 20-30 dB attenuation in electric field strength level exists at 25 Hz between outside and inside the cab.



(5 millisecond/div)



(200 μsecond/div)

Figure 113. Electric field strength inside cab, condition 14.5 (71V/m/div)

TABLE 2

RMS FIELD STRENGTHS AT 25 Hz INSIDE THE CAB

Engineers seat	50.2 V/m
Middle seat	35 V/m
Third seat	43 V/m

Next, the electric field strength spectrum between 25 Hz and 10 kHz was sampled alongside of the locomotive with the dynamic brake control on various settings (Figure 114). The spectrum, shown in Figure 114 was recorded with the blower motor on full, the M/A set on run (unloaded), and the dynamic brake set in positions zero (off) and five. In Figure 115, the data presented was recorded with the blower motor on full and the dynamic brake and M/A set both off. In Figure 116, the data displayed was recorded with the blower motor on full, the M/A set off, and the dynamic brake in positions two and eight. The data displayed in Figures 114, 115, and 116 gave evidence that the dynamic brake system radiated energy in excess of the background levels by 10-15 dBV/m.

Electric field strength levels were then sampled at various locations around the perimeter of and away from the locomotive. The tests were performed at 7 and 90 kHz. At 7 kHz (Figure 117), the levels ranged from 0 to 17 dBV/m in a 1 kHz receiver bandwidth. At 90 kHz, the levels ranged from -4 to 9 dBV/m around the engine perimeter, from 4 to 12 dBV/m away from the front and rear of the engine, -11 to 1 dBV/m away from the clear side of the engine, and -2 to 8 dBV/m away from the side of the engine facing other 11 KV catenaries (see Figure 118. These sets of data were taken in a 10 kHz receiver bandwidth with the locomotive's dynamic brake in position 8.

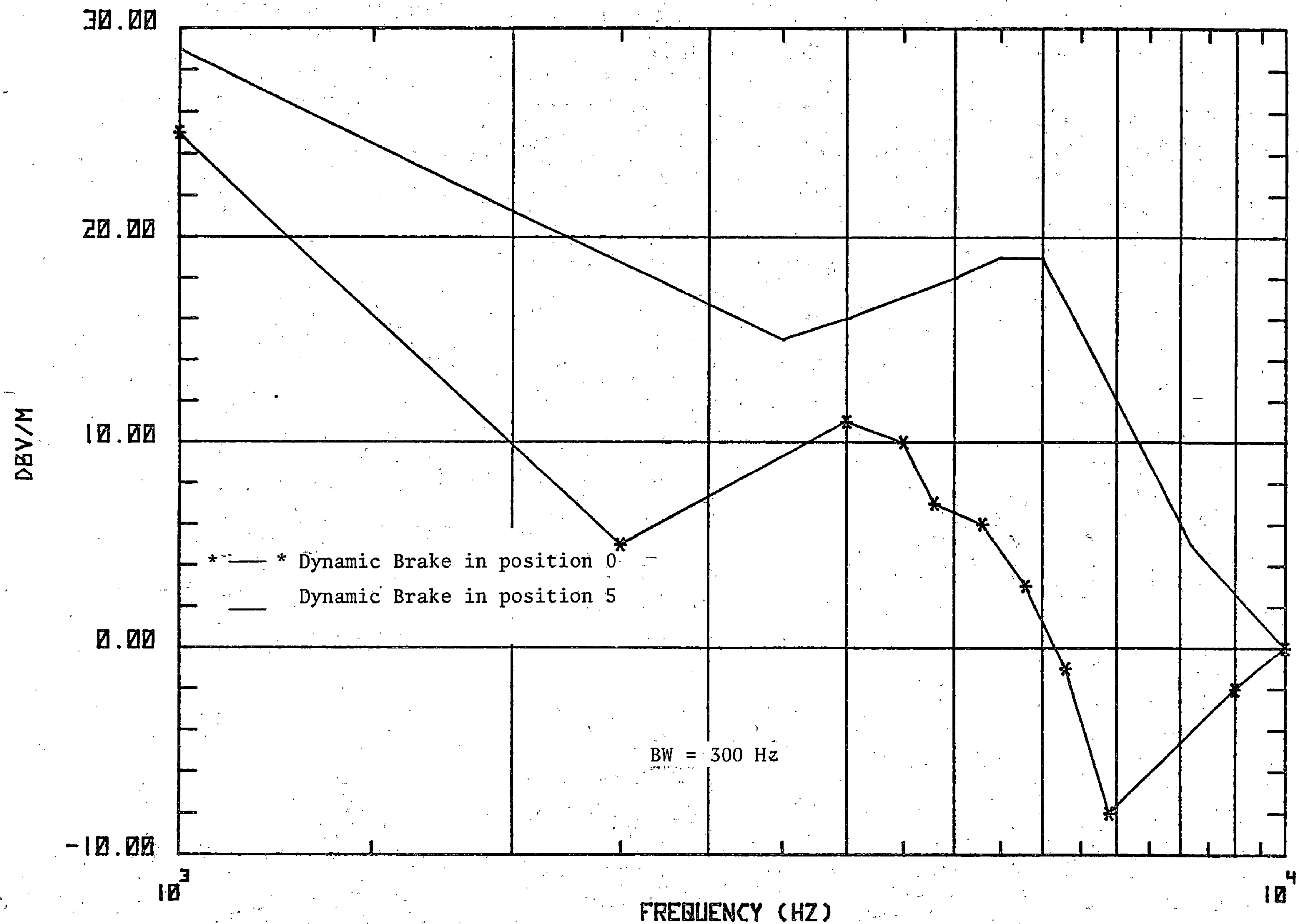


Figure 114. Electric field strength sampled 3 feet from left door with dynamic brake in positions 0 and 5.

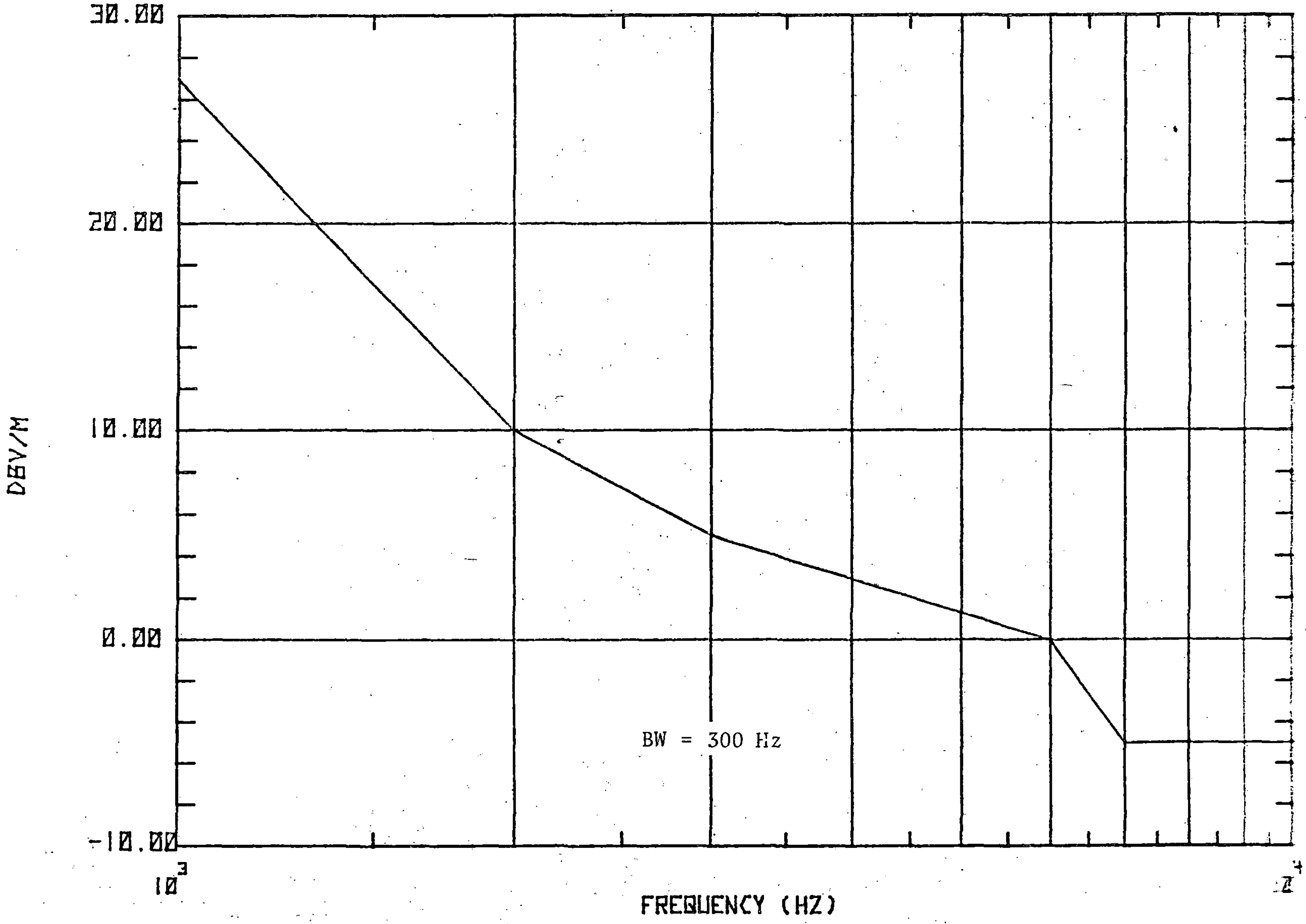


Figure 115. Electric field strength spectrum 3 feet from the left door of the engine with the M/A and dynamic brake off.

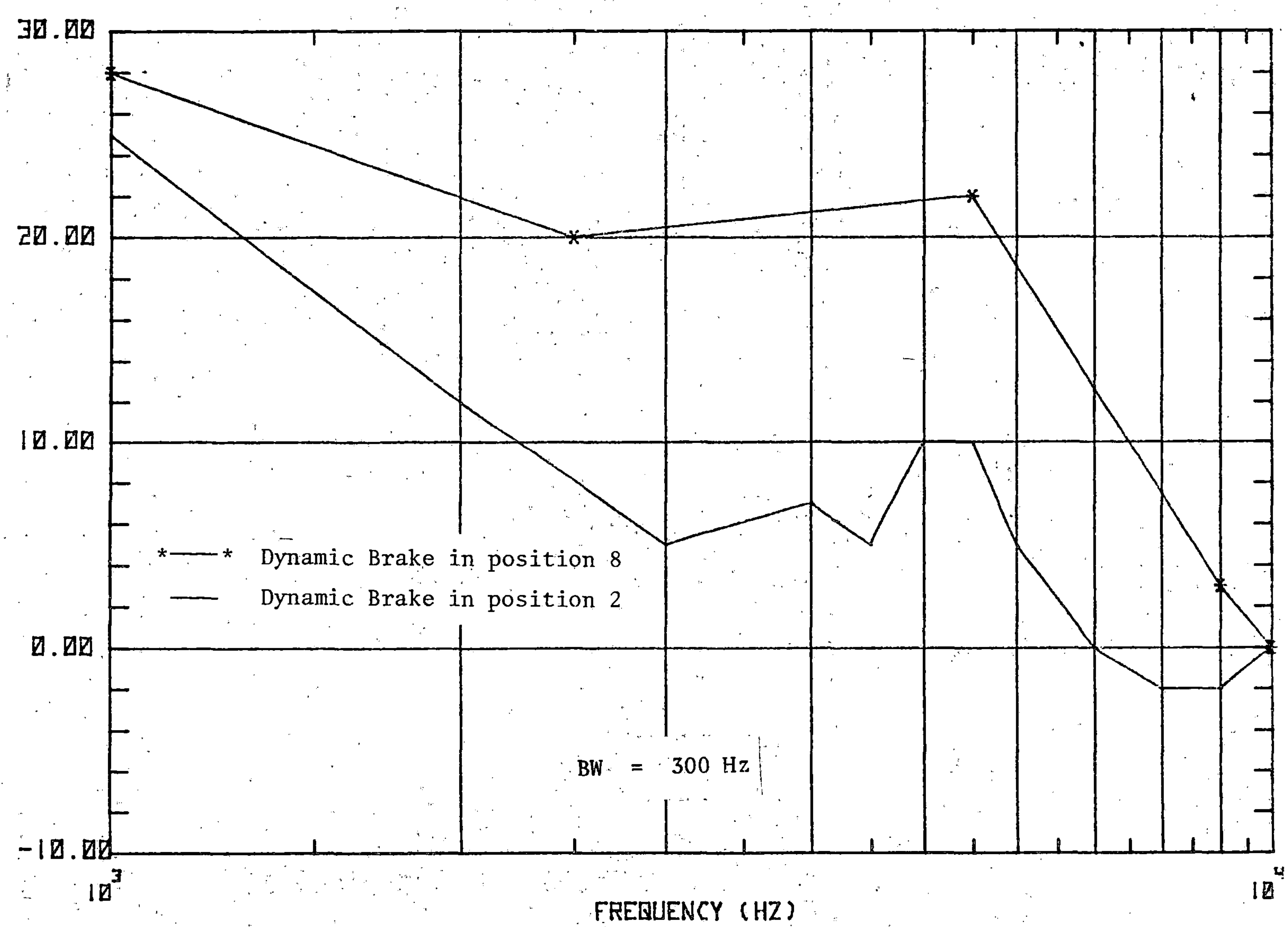


Figure 116. Electric field strength spectrum 3 feet from left door of locomotive with dynamic brake in positions 2 and 8.

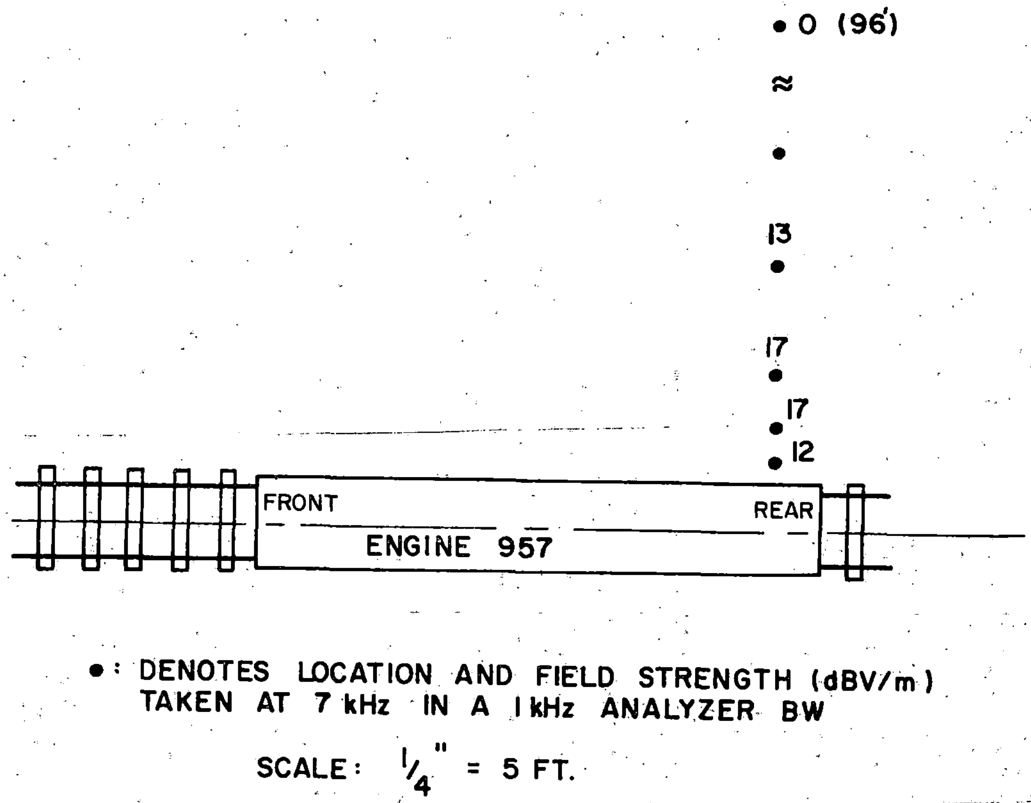


Figure 117. Electric field strength at various locations around engine (f=7 kHz).

The electric field strengths of transients were measured at a point 5 feet-7 inches from the side of the engine and 24 feet-9 inches from the rear. The transients were caused by the pantograph main breaker opening and closing. A second set of measurements was performed with the dynamic brake system switched on and off. These results are displayed in TABLE 3. The responses measured were treated as impulsive noise and are expressed in a 10 kHz receiver bandwidth.

15.0 Magnetic Field Strength Measurements

The magnetic field strength ($\overline{H}$) was measured under the E-60 locomotive with the magnetic field strength probe resting on the crossties. At first, the H field was measured next to the rails close to, but not under, the engine with the loop placed at $\alpha = 0^{o}$ with respect to the longitudinal axis of the locomotive (see Figure 119). These measurements were made, at 25 Hz, to establish a baseline for the following $\overline{H}$ field measurements. The initial readings were 1.2, 1.6, and 4.4 amperes per meter for the right rail, center of rails, and left rail, respectively. The loop

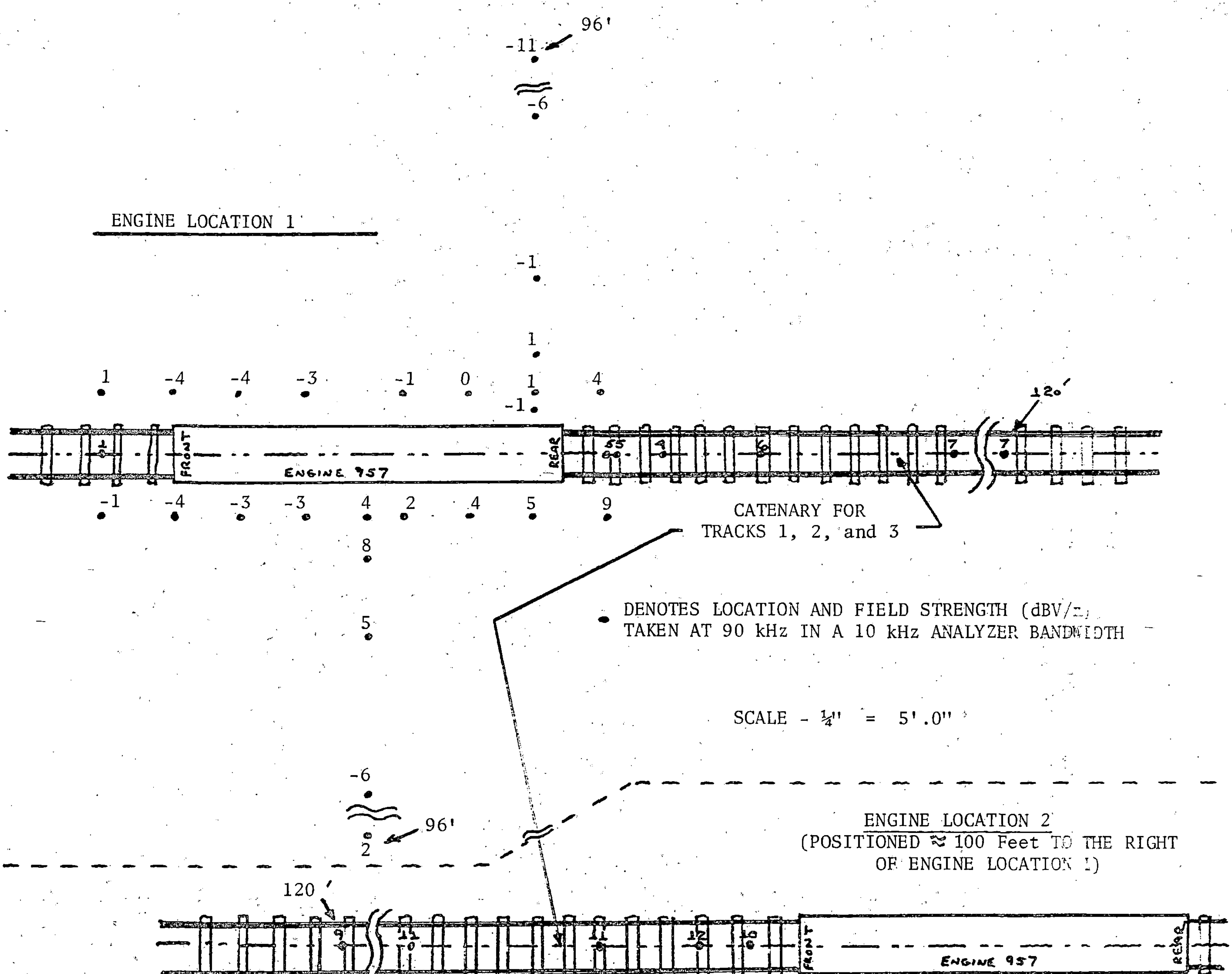


Figure 118. Electric field strength at various locations around engine (f=90 kHz).

TABLE 3

TRANSIENT ELECTRIC FIELD STRENGTH 5 FEET - 7 INCHES FROM THE SIDE OF THE LOCOMOTIVE AND 24 FEET - 9 INCHES FROM THE REAR

		Cause of Transients	
Analyzer Center Frequency (MHz)	Electric Field Strength (dBV/m/10 kHz	Dynamic Brake on/off	Pantograph Breaker on/off
5.0	-14.5		X
4.0	-9.5		X
3.0	-4.5		X
2.0	2.5		X
1.0	1.5		X
0.5	7.5		X
0.25	9.5		X
0.125	18.5		X
0.064	20.5		X
0.032	20.5		X
0.064	30.5		X
0.032	22.5		X
0.016	28.0		X
0.032	-0.5	X	
0.064	-2.5	X	
0.125		X	
0.25	-13.0	X	
0.5	-30.5	X	
1.0	-30.5	X	
2.0	-25.5	X	
3.0	-49.5	X	
5.0	-47.5	X	
	-39.5		

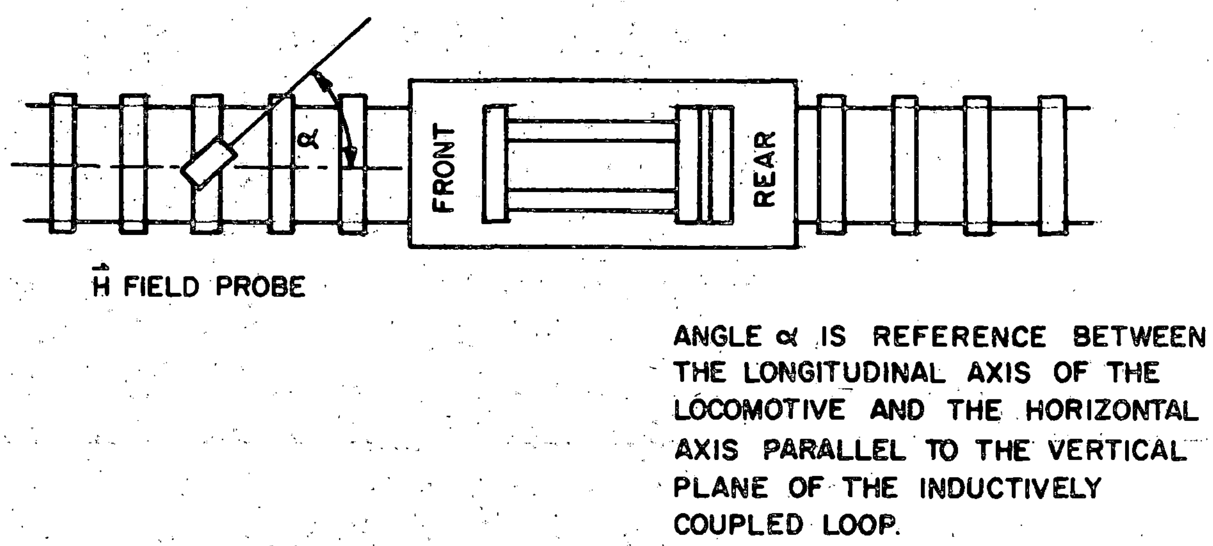
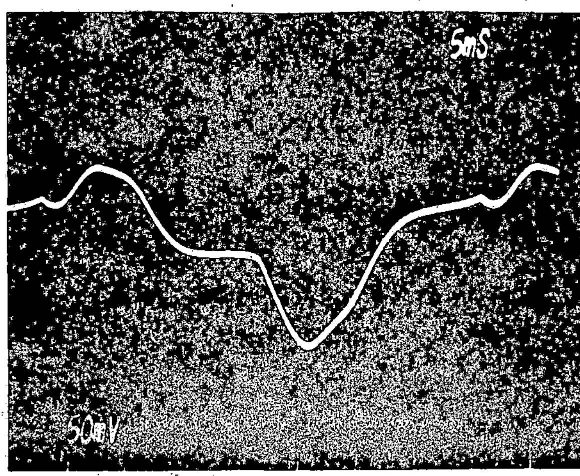


Figure 119. Illustration showing angle α.

was then centered between the two rails on the crossties, and the engine was moved back and forth over the loop while the levels of the loop output signal were observed. Maximum observed levels were then correlated with distances between the loop and the rear of the engine. During these measurements , the M/A set was on with no load connected to it, the blower motor was turned on full speed, and the dynamic brake was placed in position 8. The current drawn by the main transformer was 82 amperes.

The waveform and spectrum of the H-field, 29 feet-4 inches from the rear of the engine, are given in Figures 120 and 121, respectively. In Figure 121 both odd and even harmonics occupy the spectrum. The M/A set was then turned off, and the amplitude of the waveform reduced to a very small value, indicating that the source of the magnetic field, displayed in Figures 120 and 121 was the M/A set.



(80 amperes/m/div, 5 millisecond/div)

Figure 120. Waveform of magnetic field strength 29 feet-4 inches from rear of locomotive.

The H-field waveform and spectrum at a distance of 26 feet-6 inches from the rear of the engine are given in Figure 122. In this case, the spectrum is dominated by even harmonics of 25 Hz.

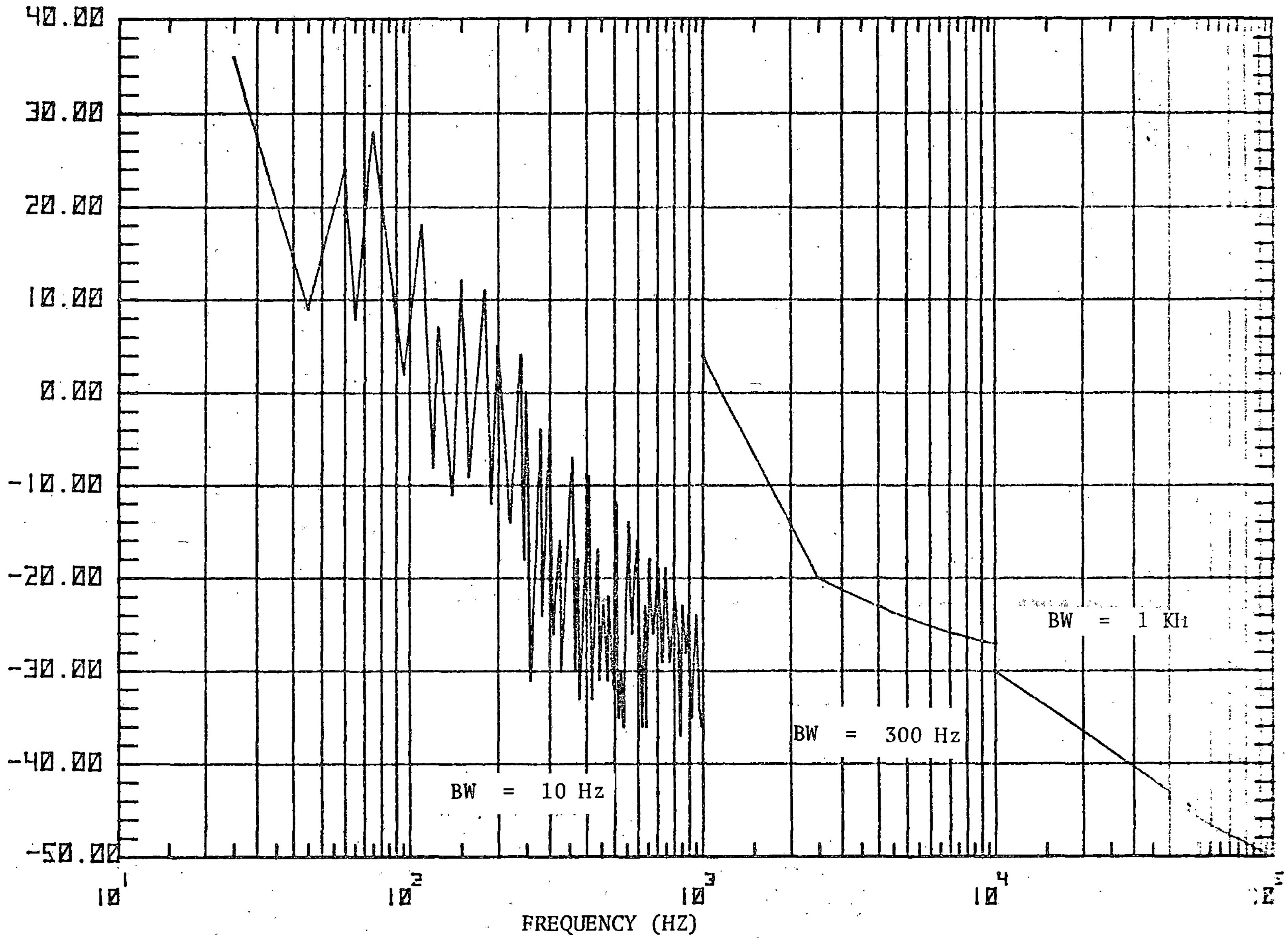
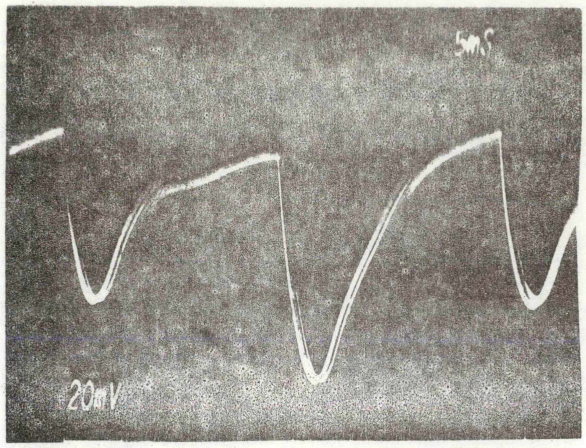


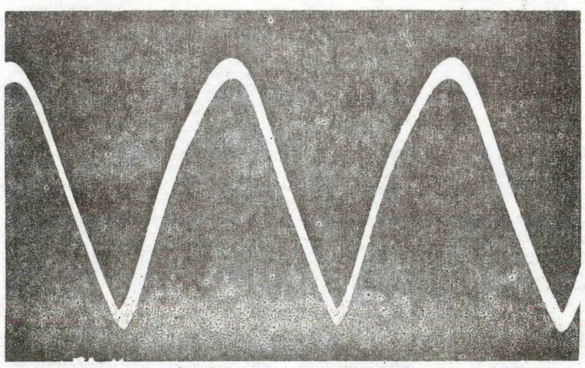
Figure 121. Spectrum of magnetic field 29 feet-4 inches from rear of locomotive.



(32 ampere/m/div, 5 millisecond/div)

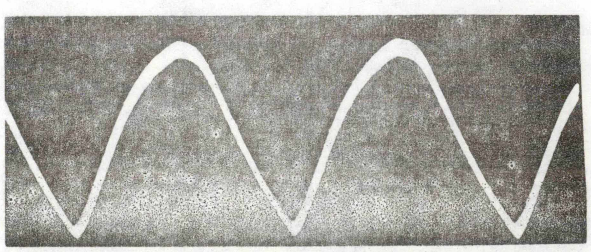
Figure 122A. Magnetic field strength waveform, 26 feet 6 inches from rear of engine.

The magnetic field strength waveform and frequency spectrum at a distance of 40 feet from the locomotive with the loop placed at $\alpha = 0^{o}$ and $\alpha = 90^{o}$, with respect to the longitudinal axis of the locomotive, are given in Figures 123 and 124 respectively.



(80 ampere/m/div, 5 millisecond/div)

Figure 123A. Waveform of H-field 40 feet from locomotive with loop placed 0^{o} with respect to longitudinal axis of the locomotive.



(32 ampere/m/div, 5 millisecond/div)

Figure 124A. Waveform of H-field 40 feet from locomotive ($\alpha = 90^{o}$).

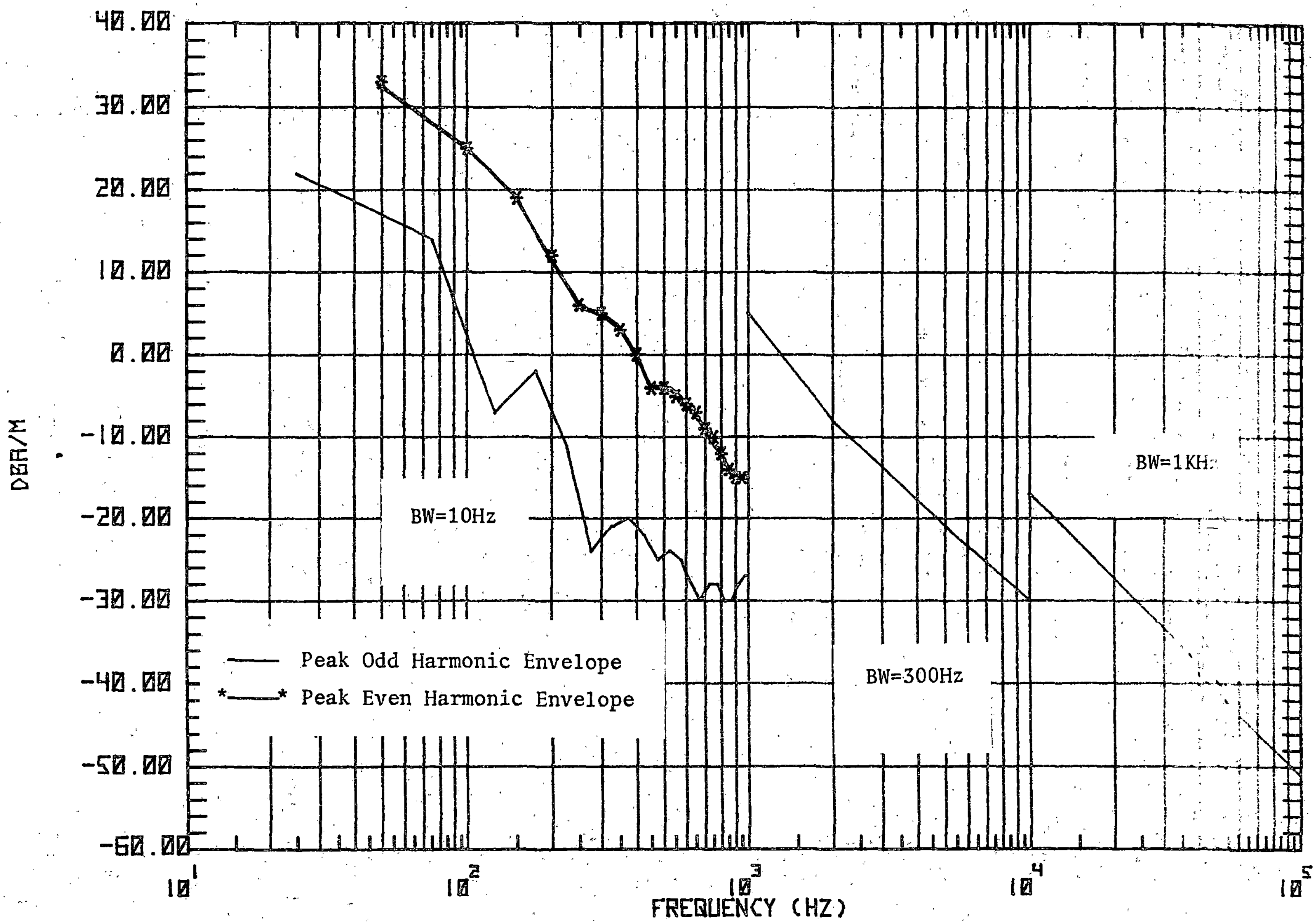


Figure 122B. Magnetic field strength spectrum, 26 feet-6inches from rear of engine.

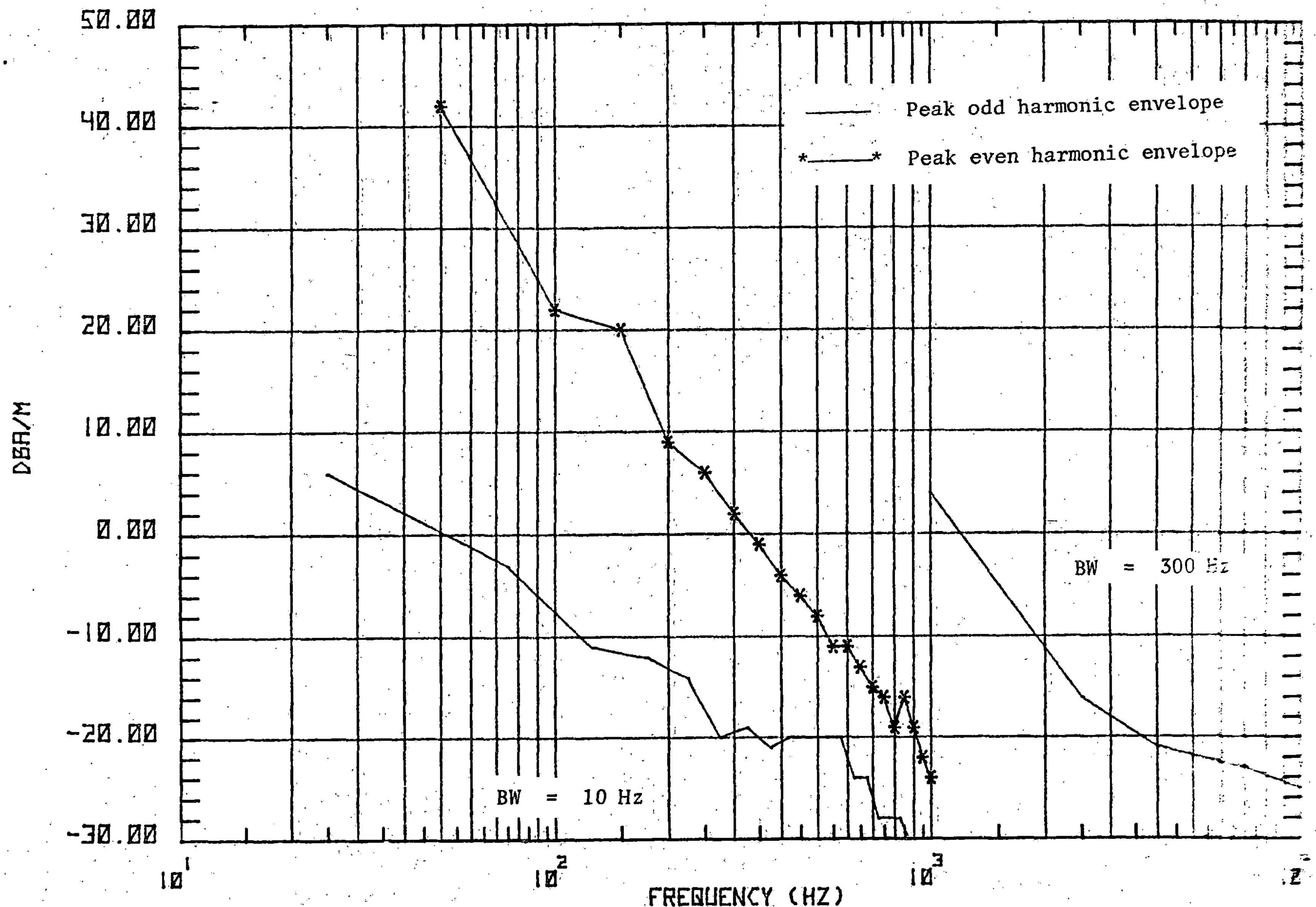


Figure 123B. Spectrum of H-field 40 feet from locomotive with loop placed 0^o with respect to longitudinal axis of the locomotive.

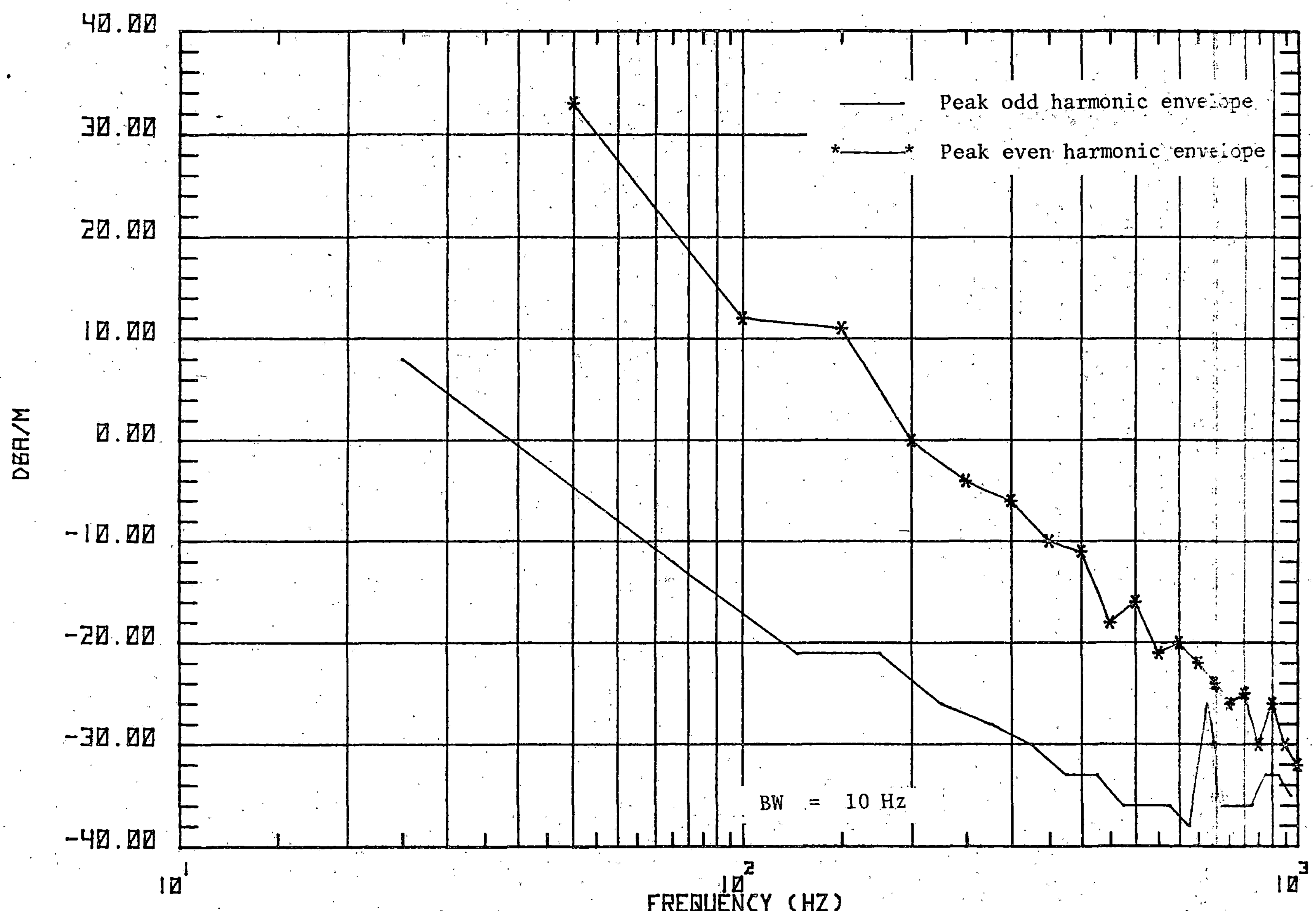


Figure 124B. Spectrum of H-field 40 feet from locomotive (α = 90).

Next, measurements were performed in order to find locations of maximum magnetic field strength intensity under the locomotive. The tests were performed by initially locating several distances from the rear of the engine where maximum levels were observed. Next, at each of these distances, the magnetic field strength was sampled at a point 6 inches on each side of both rails (4 points). At each point, the probe was rotated to find the angle at which the magnetic field strength was maximum. The test points, distances, maximum levels, and angles are given in Figure 125.

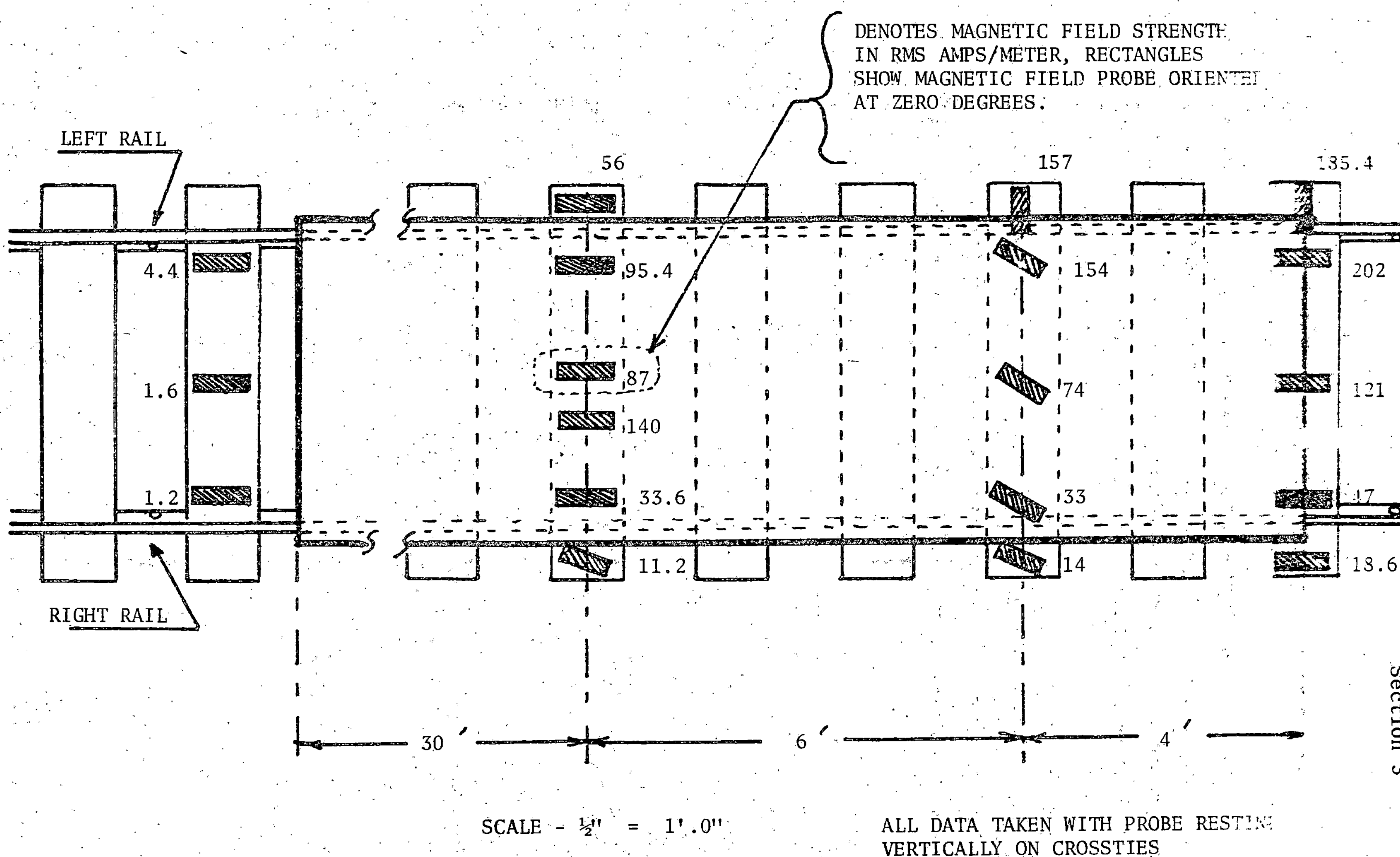


Figure 125. Various locations of maximum magnetic field strength underneath engine.

SECTION 4

SUMMARY

In the preceding pages, the pertinent emission data obtained, along with the controlling parameters and the measurement methodology employed, at the Wilmington Yard are presented. This data, together with data obtained during a revenue service run, will be analyzed, and a characterization of the locomotive's emission levels will be developed. Similar efforts will be undertaken to characterize the emissions of an AEM-7 electric and a diesel-electric locomotive. The culmination of these efforts being a report on locomotive emission levels tentatively scheduled for publication in Fiscal Year 1981.