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Railroad Electromagnetic Compatibility Locomotive Volume 2

Summary of E-60 CP Road Test Electromagnetic Emission Measurements

IIT Research Institute under contract to
DEPARTMENT OF DEFENSE
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Analysis Center
Annapolis, Maryland 21402

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This is the second in a series of interim reports documenting measurements of locomotive emission levels. A final report documenting analysis of the data and presenting characterizations of locomotive emission levels is planned for FY 82.

16. Abstract

Results of electromagnetic emission measurements performed on an E-60 locomotive during a revenue service run from Washington, D.C., to New Haven, Connecticut, and back are presented. A description of the measurements and methodology employed is included.

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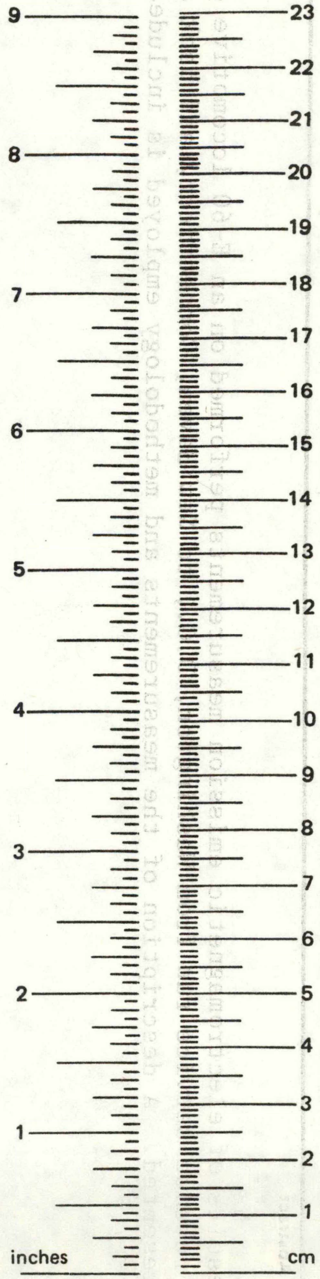
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

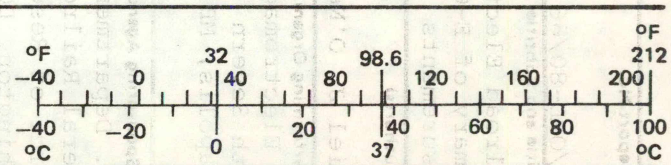
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2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

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



Approximate Conversions from Metric Measures

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



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SECTION 1

INTRODUCTION

BACKGROUND

In an effort to assess the electromagnetic compatibility of various aspects of the United States railroad system, the Federal Railroad Administration, Office of Research and Development (FRA/OR&D), Freight Systems, has tasked the Electromagnetic Compatibility Analysis Center (ECAC) to conduct an ongoing measurement and analysis program. As part of this program, ECAC has sampled the electromagnetic emission levels of an E-60 CP locomotive during a revenue run from Washington, DC, to New Haven, Connecticut, and return. Results of these measurements are presented in this report.[a]

The data obtained from the road test measurements will be analyzed along with data obtained from the E-60 yard measurements,[1] and an overall characterization of the electromagnetic emission levels of the E-60 CP locomotive will be developed. This characterization, together with characterizations to be developed for the AEM-7 electric and GP 40-2 diesel-electric locomotives, will be documented in a final report on locomotive electromagnetic emissions tentatively scheduled for publication in Fiscal Year 1982.

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[a]In all, five 14 inch reels of tape containing recorded data along with numerous photographs taken during the revenue service run were obtained. Included in this report are some pertinent examples of the type of data collected.

[1]O'Neill, D., Summary of E-60 CP Electromagnetic Emission Measurements, Volume 1: Yard Measurements, ECAC-CR-80-027, Electromagnetic Compatibility Analysis Center, Annapolis, MD, October 1980, FRA/ORD-80/66.1, PB81 117988.

OBJECTIVE

The objective of the road test measurements was to obtain data to be used as an input to the E-60 locomotive analysis.

APPROACH

The data required to develop the E-60 characterization was obtained in two different environments: in a railroad yard and on the mainline. In the yard, emissions from circuits were isolated and sampled under various combinations of control parameters (see Reference 1). Upon completion of the yard measurements, the data obtained and the parameter considerations noted initially were reviewed. From this, circuits whose emissions were to be sampled during the road test measurements were identified along with the respective emission sampling locations. Since the road test measurements required the recording of the emission levels of the various circuits identified, an 8-channel, 14-inch reel-to-reel tape recorder was obtained and calibrated.

The measurements were performed on an AMTRAK passenger train (consisting of a locomotive and nine cars) traveling from Washington, DC, to New Haven, Connecticut, and back. In addition to recording emission levels on tape, several "real time" photographs of the various currents and voltage were taken.[a] Upon completion of the measurements, the tapes were evaluated, and photographs were taken of time waveforms and frequency spectra of the various currents and voltages as they were displayed on the analyzer/oscilloscope. This data along with the "real time" data and data obtained in the yard will be used to develop a characterization of the electromagnetic emissions of the E-60 CP locomotive.

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[a]The term real time refers to photographs taken of the swept-type spectrum analyzer displays during the road test.

SECTION 2

SYSTEM DESCRIPTION AND MEASUREMENT METHODOLOGY

SYSTEM DESCRIPTION

The electric traction system is composed of two major components: the locomotive and the traction power feed system. In the following paragraphs, general descriptions of these two components are given.

Locomotive

Figure 1 is a block diagram showing the major electrical systems of the E-60 CP locomotive. Power for the locomotive is supplied through an overhead catenary system transmitted at 25 Hz with a nominal catenary voltage level of 11 kV. The secondary of the locomotive's main transformer has seven 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 motor/alternator set which in turn supplies 60-Hz power to the train cars,[a] the oil pump motor, the cab heaters, and miscellaneous units in the locomotive.

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 motors and a carriage assembly constitute a truck. The E-60 is equipped with two trucks (one front, one rear). Figure 2 is a simplified motoring diagram of a front truck. Referring to this figure, as the locomotive accelerates from standstill, tap switch number 1 is turned on, and the thyristors in bridge number 1 begin

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

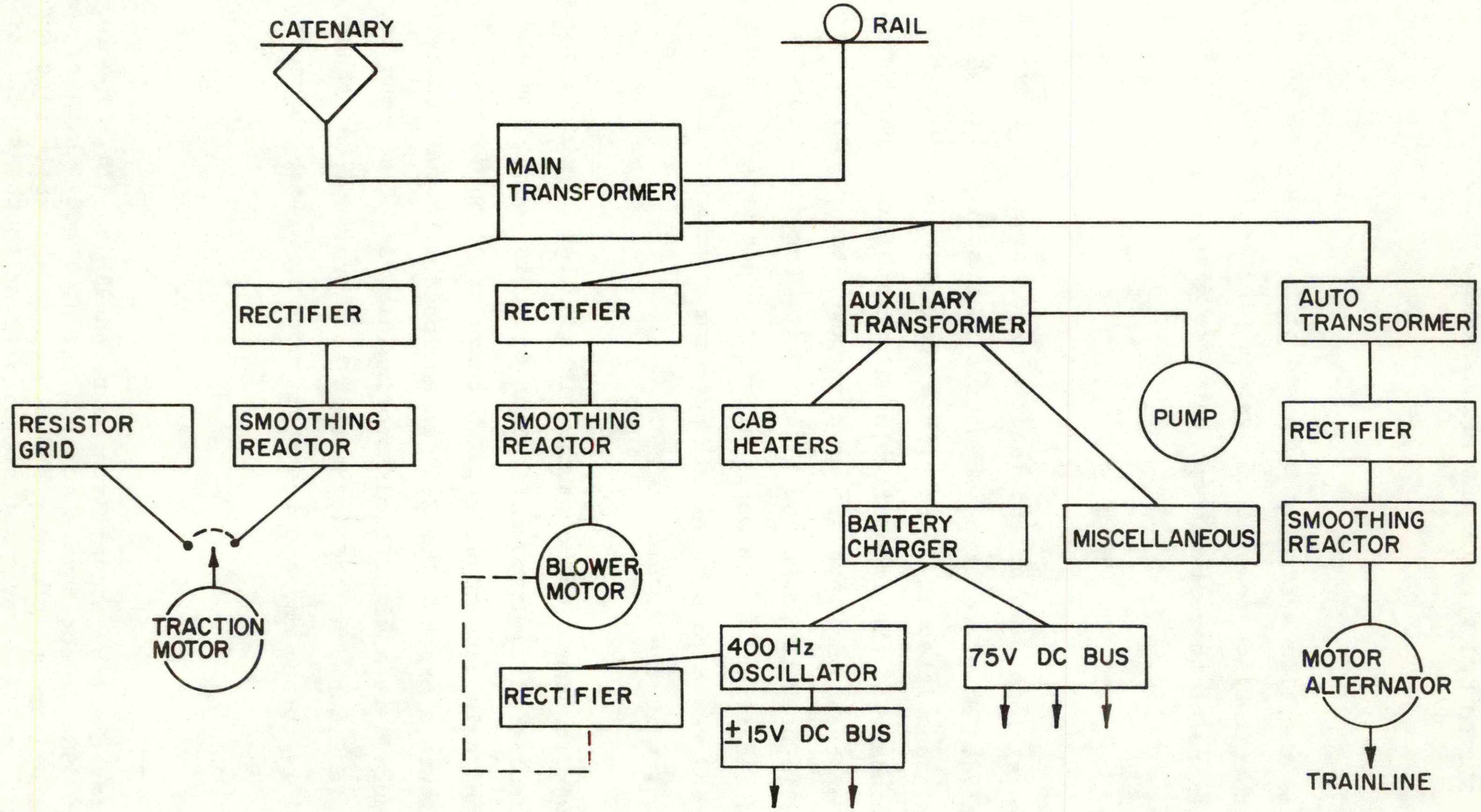

FIGURE 1. BLOCK DIAGRAM OF THE E-60's MAJOR ELECTRICAL SYSTEMS.

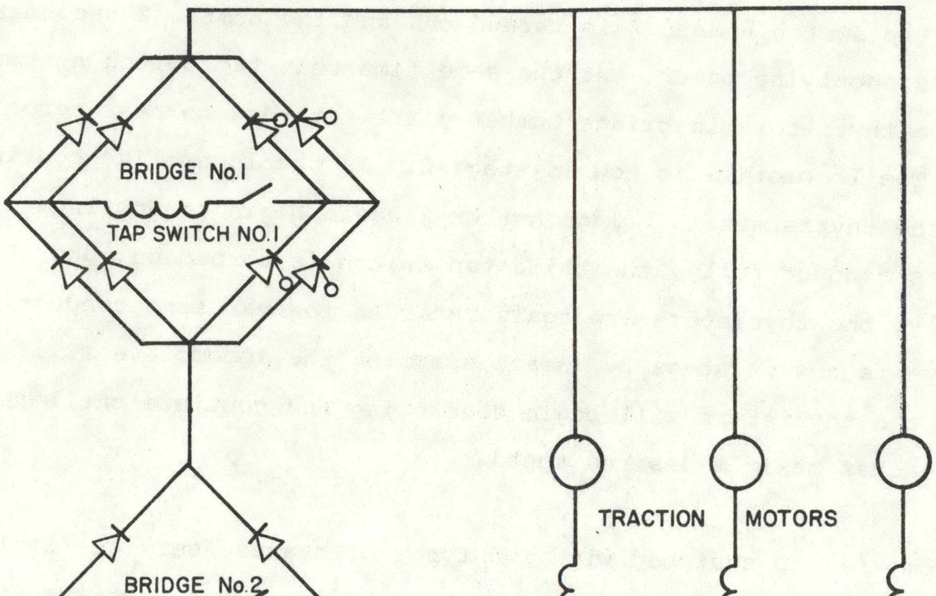

FIGURE 2. E-60 CP MOTORING DIAGRAM (1 TRUCK).

to conduct.[a] 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 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 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 again retarded to near zero conduction. The locomotive is now in stage 3. Again assuming the locomotive still accelerates, the thyristors will begin conducting and continue until the locomotive reaches maximum desired speed.

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

Power Feed System[2]

The electrified section of the Northeast Corridor presently extends from Washington, DC, to New Haven, Connecticut, a total of 300 route miles (see

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[a]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 on simultaneously, etc.

[2]Avery, Roger M., "Various AC Traction Power Feeding Systems Which Mitigate EMI and Their Relative Costs," presentation to AAR/IEEE/AREA Railroad Electromagnetic Compatibility Working Group, Symposium on Railroad Electromagnetic Compatibility, May 1980.

Figure 3). The traction power feed system presently in use is a multiple feed (double end feed) system operating at 11 kV, 25 Hz (see Figures 4a and 4b). Power is supplied by 25-Hz power generators. As shown in Figure 4a, power is transmitted at 138 kV, 25 Hz and then stepped down at the substation to 11 kV. As a locomotive travels between substations, it draws current from both substations as shown in Figure 4b. The percent of the current drawn from a particular substation is dependent upon the relative distance between the locomotive and that substation.

DISCUSSION OF MEASUREMENT METHODOLOGY

The measurement instrumentation used and their respective functions are given in TABLE 1. The reel-to-reel tape recorder used, the Honeywell 101, is able to record signals in two different modes, FM and direct. In the FM mode, the input signal is frequency modulated and then recorded on tape. The frequency response of the recorder in this mode extends from dc to 10 kHz (±3 dB). In the direct mode, the input signal is recorded on tape without any modulation. In this mode, the frequency response of the recorder extends from 200 Hz to 75 kHz (±3 dB).

The spectrum analyzer (Tektronix 7L5) and the oscilloscope (Tektronix 7A24) were used to display frequency spectra and time waveforms of the currents and voltages sampled. These displays were photographed using a Tektronix C-53 scope camera. The probes used to sample the emissions included an AMPROBE to measure levels of current in the primary of the main transformer, a Tektronix P6201 probe set (with terminations and Tektronix 1101 probe power supplies) to measure levels of voltage across the 74-volt dc bus, N-P test points, and cab signal pickup and an ECAC current probe to measure levels of current in the number 5 traction motor armature winding. (For a description of the characteristics of the ECAC current probe, see pages 7-9 in Reference 1.)

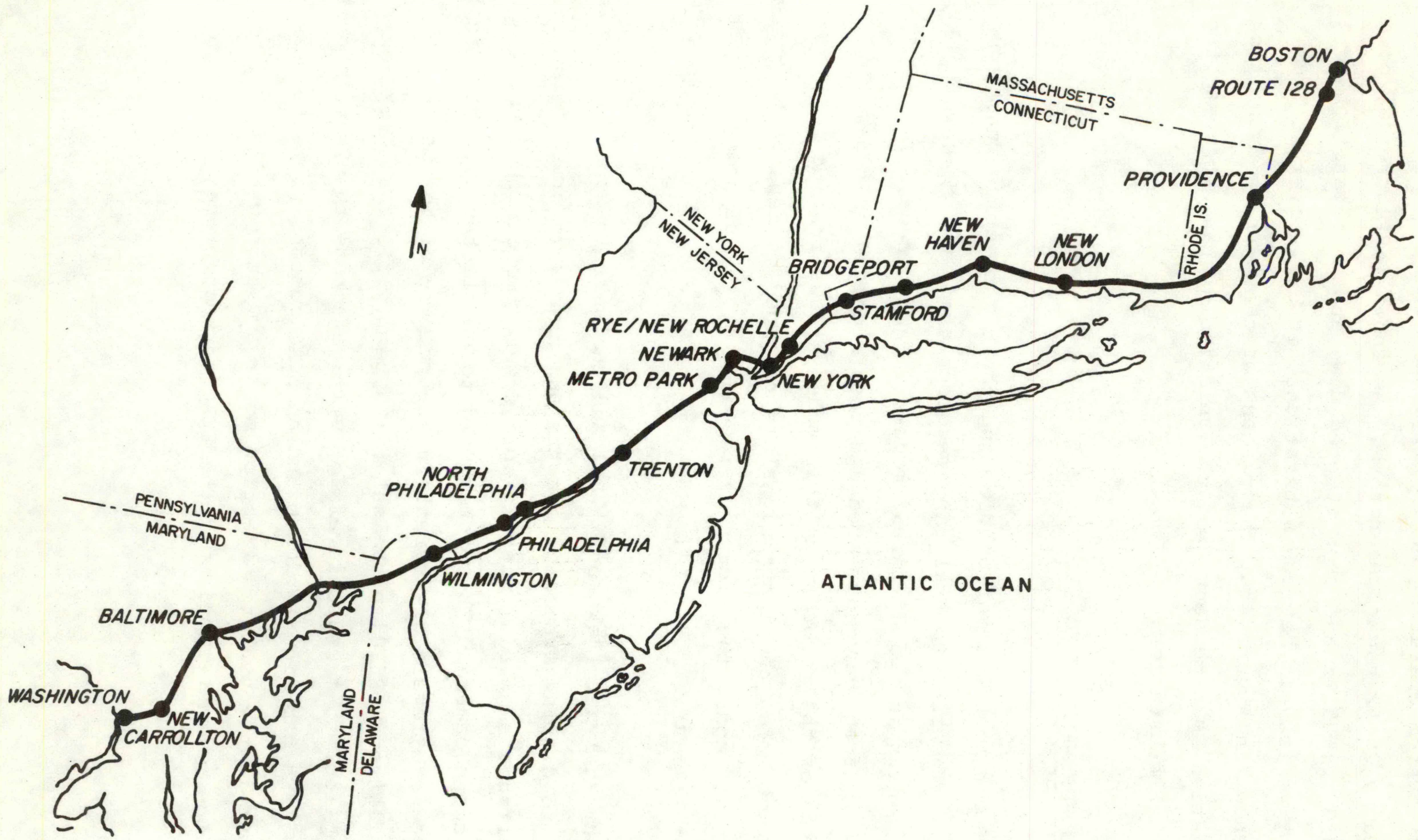


FIGURE 3. MAP OF THE NORTHEAST CORRIDOR.

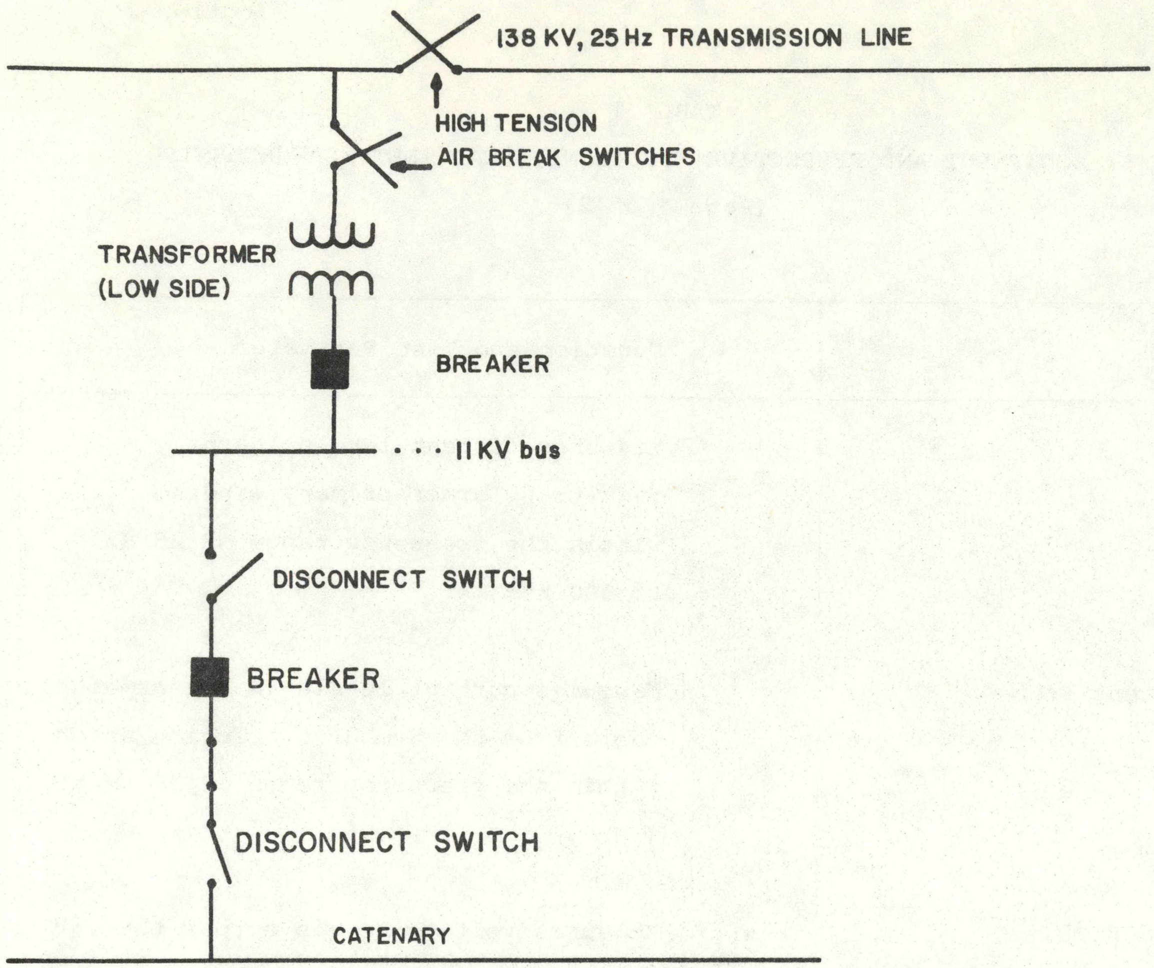


FIGURE 4a. SIMPLIFIED DIAGRAM OF THE MULTIPLE FEED SYSTEM FROM WASHINGTON TO NEW YORK.

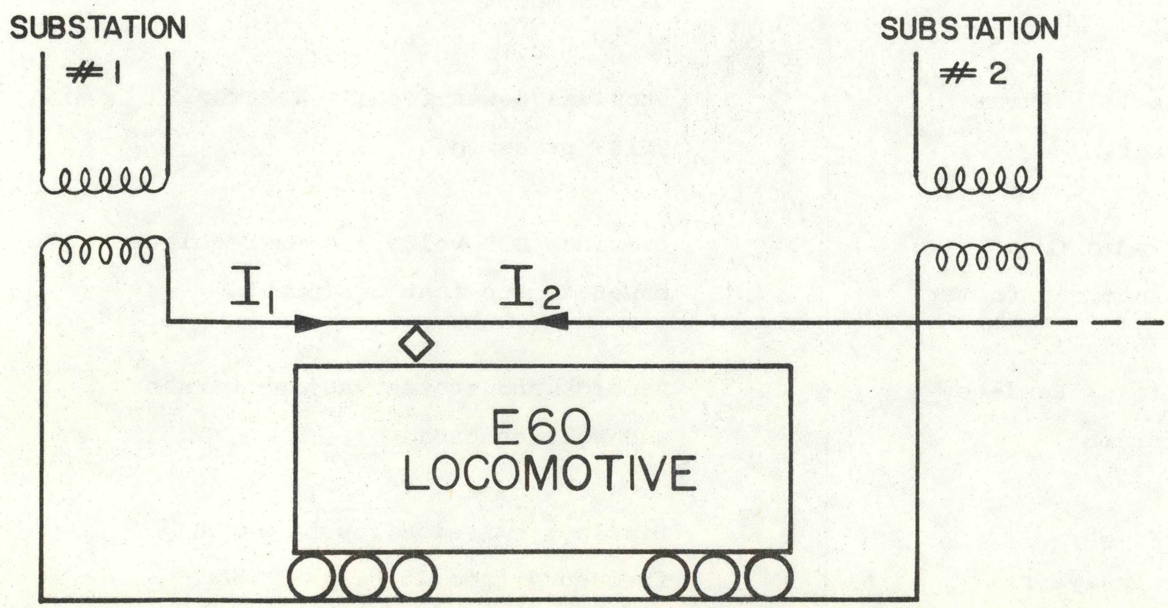


FIGURE 4b. SIMPLIFIED SKETCH OF A DOUBLE END FEED SYSTEM.

TABLE 1

TEST EQUIPMENT AND RESPECTIVE FUNCTIONS, ROAD TEST MEASUREMENTS

(Page 1 of 2)

Equipments	Function and Test Parameter
AMPROBE	Measures current levels in the main transformer primary winding within the frequency range of 25 Hz to 300 kHz.
ECAC Current Probe	Measures current levels in the armature cable from the number 5 traction motor within the frequency range of 25 Hz to 1 MHz.
Tektronix P6201 Probe Set and Terminations	Measures voltage levels across the cab signal pickup, 74-volt dc bus, and N-P test points (frequency range of dc to 500 MHz).
Tektronix 1101 Probe Power Supply	Provides power for the Tektronix P6201 probe set.
General Radio Corp W10MT3W Autotransformer	Provides 120 volts, 60-Hz regulated power to run test equipment.
Honeywell 101 Reel-to-Reel Recorder	Records and stores various current and voltage data.
Tektronix 7L5 Spectrum Analyzer	Displays emission levels versus frequency from 25 Hz to 5 MHz.

TABLE 1

(Page 2 of 2)

Equipments	Function and Test Parameter
Tektronix 7844/7B72/7A24 Mainframe/Oscilloscope	Displays emission levels versus time.
Tektronix C-53 Scope Camera	Photographs spectrum analyzer and oscilloscope displays.

Figure 5 is a block diagram showing the test equipment and the associated connections in the locomotive (969). Referring to Figure 5, five circuits were sampled. Emission data collected from these circuits was recorded on five 14-inch diameter reels of tape using the Honeywell recorder operating at 15 inches per second. The recorder was equipped with 8 recording channels (5 FM and 3 direct). The main transformer current and the 74-volt dc bus voltage levels were recorded in both FM and direct channels so as to acquire emission data within the frequency range of dc to 75 kHz. Channel 8 (direct channel) was used for voice recording of pertinent information such as milepost markings, dc truck current, speed, etc.

In addition to recording data on tape, the emissions were also randomly monitored on the spectrum analyzer/oscilloscope through the use of a 5-position selector switch. Since the probes, spectrum analyzer, and oscilloscope all had bandwidths greater than the tape recorder, photographs of the displays were taken to directly extend the frequency range of the collected data.

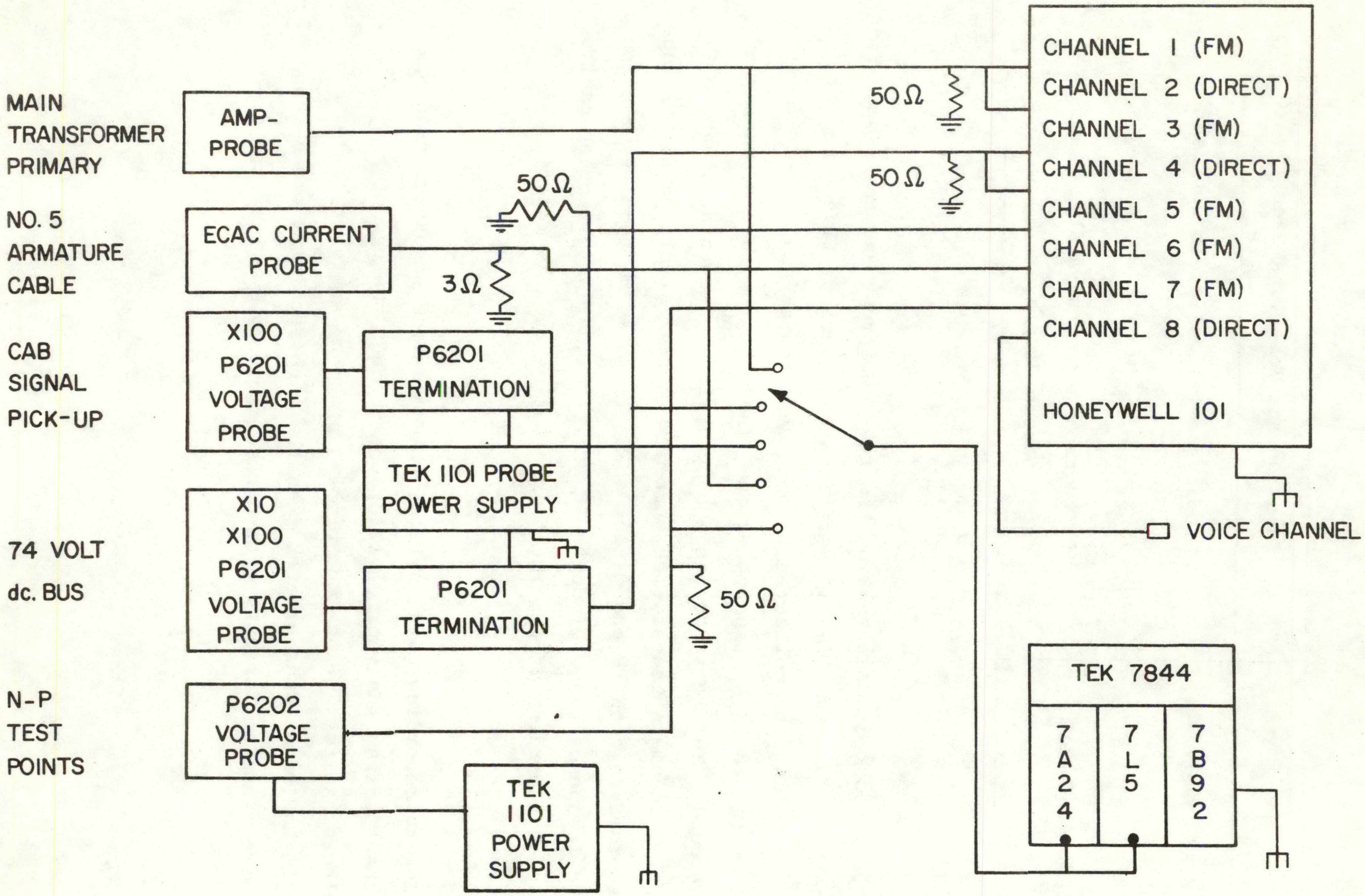


FIGURE 5. BLOCK DIAGRAM OF PROBE CONNECTIONS.

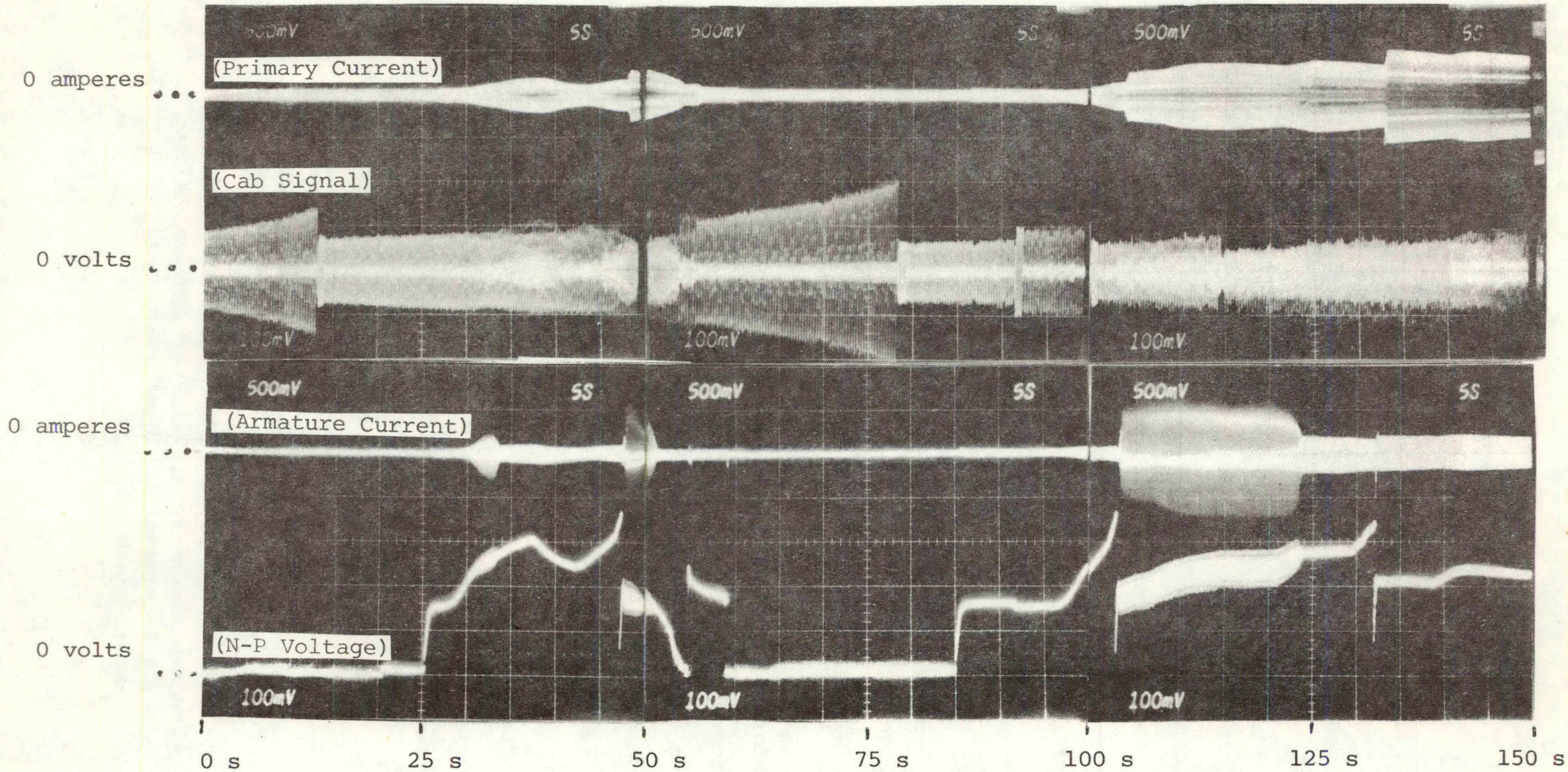
SECTION 3
DATA PRESENTATION

GENERAL

In all, approximately 24,800 seconds of data were recorded during the trip along with many real time photographs of emission waveforms and spectra. As a first step in reviewing the data, whenever the locomotive accelerated and began drawing a significant amount of current[a] in the main transformer primary, a sequence of photographs of the time waveform as displayed on an oscilloscope were taken over a 150-second time interval that included this large current level. In addition, the time waveforms of the cab signal voltage, the traction motor armature current, and the N-P reference comparator voltage, recorded at the same time were simultaneously displayed and photographed. In this manner, seventy-eight 150-second time intervals were photographed. One such data packet is given in Figure 6.

As can be seen in Figure 6, at the beginning of the interval (t = 0 seconds) the main transformer is drawing approximately 63 amperes peak-to-peak of current, and the locomotive is essentially coasting along. At this time, the cab signal is giving a "clear" indication (see subsection, Cab Signal Pickup). At t = 15 seconds, the locomotive passes through one cab signaling block and into the next block, as can be seen by the increased amplitude of the cab signal and then the sudden decrease. At t = 25 seconds, the thyristors begin to conduct (as can be seen by the increased voltage level across the N-P test points), and the locomotive starts to accelerate. By t = 33 seconds, the number 5 traction motor is drawing 892 amperes

[a]What is meant by a significant amount of current was somewhat subjective, but referred to levels of 300-700 amperes peak-to-peak versus a steady state current level of 30 to 60 amperes peak-to-peak.



time = 5 s/div.

PRIMARY CURRENT 315 A/div.
ARMATURE CURRENT 892 A/div.

CAB SIGNAL VOLTAGE 21 V/div.
N-P VOLTAGE 2.84 V/div.

FIGURE 6. ONE OF 78 DATA PACKETS.

peak-to-peak of current.[a] At this time, the dc ammeter in the cab indicated the locomotive was drawing 200 amperes dc.

At t = 47 seconds, the locomotive transitions into stage 2. At this time, the traction motor is drawing approximately 1800 amperes peak-to-peak of current, while the main transformer primary is drawing approximately 315 amperes peak-to-peak. The locomotive continues in stage 2 until t = 55 seconds, at which time the locomotive down-stages to stage 1. The thyristors are then retarded to near zero conduction.

The locomotive then coasts until t = 85 seconds, when the thyristors again begin to conduct. At t = 103 seconds, the traction motor amature is drawing approximately 1800 amperes peak-to-peak, and the main transformer is drawing 315 amperes peak-to-peak. As the locomotive continues to accelerate, the traction motor draws upwards to 2,100 amperes peak-to-peak and then transitions to stage 3, at which time the main transformer primary is drawing approximately 630 amperes peak-to-peak.

MAIN TRANSFORMER PRIMARY

The AMPROBE current probe was used to sample the current at the ground side of the primary winding of the main transformer. The AMPROBE was connected to a cable coming off of the ground side of the main transformer primary. This ground path was paralleled by another ground strap. Previous tests at AMTRAK's Wilmington Yard indicated that the ground strap carried between 50-60% of the current, while the ground cable carried 40-50% of the current. Therefore, in order to obtain an estimate of the total current, the current presented here must be multiplied by a factor of between 2.0 and 2.2. For purposes of this report, the data presented has not been multiplied by any such factor; however, a precise estimate of this factor will be determined when the data is analyzed.

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[a] It is important to note that the current waveform shown does not include dc but rather ac components from 25 Hz up to 10 kHz.

The current sampled was recorded on two channels (FM and direct); therefore, the components of the ac current were sampled up to 75 kHz. Generally, the levels of current sampled were found to be between 30 to 60 amperes peak-to-peak while the locomotive was coasting and up to a maximum (observed) of 312 amperes rms (882 amperes peak-to-peak) while the locomotive was accelerating in stage 3. In addition, "real time" photographs were taken of the main transformer primary current spectra up to 500 kHz. Examples of "real time" samplings are given in Figures 7, 8, and 9.

In Figure 7, the spectrum of the current was sampled between 25 and 500 Hz with the locomotive traveling at cruising speed (approximately 80 miles per hour). The spectrum shown was recorded with the analyzer in the peak-hold mode for approximately 10 to 15 minutes. From Figure 7, it is seen that the spectrum is dominated by odd harmonics of 25 Hz. The 25-Hz fundamental was recorded at 40 dBA (100 amperes rms). In Figure 8, the current spectra between 25 Hz and 1 kHz are displayed while the locomotive was accelerating from 0 to 80 miles per hour, and also while the locomotive was cruising. From Figure 8, the emission levels recorded for the locomotive accelerating appear to be approximately 4-6 dBA higher than the current levels recorded while the locomotive was cruising. In Figure 9, the average and peak current spectra between 1 and 500 kHz, sampled over many miles of track, are displayed.

The primary current time waveform and frequency spectrum shown in Figure 10 were recorded while the traction motor rectifier circuits were in stage 2. At this time, the train was traveling at a speed of approximately 50 miles per hour. The train was traveling towards a substation 3.5 miles west of the train's location. The previous substation was approximately 1 mile south-southeast of this location. The amplitude recorded was 277 amperes peak-to-peak; the corresponding frequency spectrum is displayed between 25 Hz and 50 kHz. In Figure 10, the odd harmonics predominate. For example, the 25-Hz component sampled was 43 dBA (141.25 amperes rms), while the 75-Hz component was 24 dBA (15.8 amperes rms). Conversely, the 50-Hz component sampled was 10 dBA (3.16 amperes rms) and the 100-Hz component was -3 dBA (0.71 amperes rms).

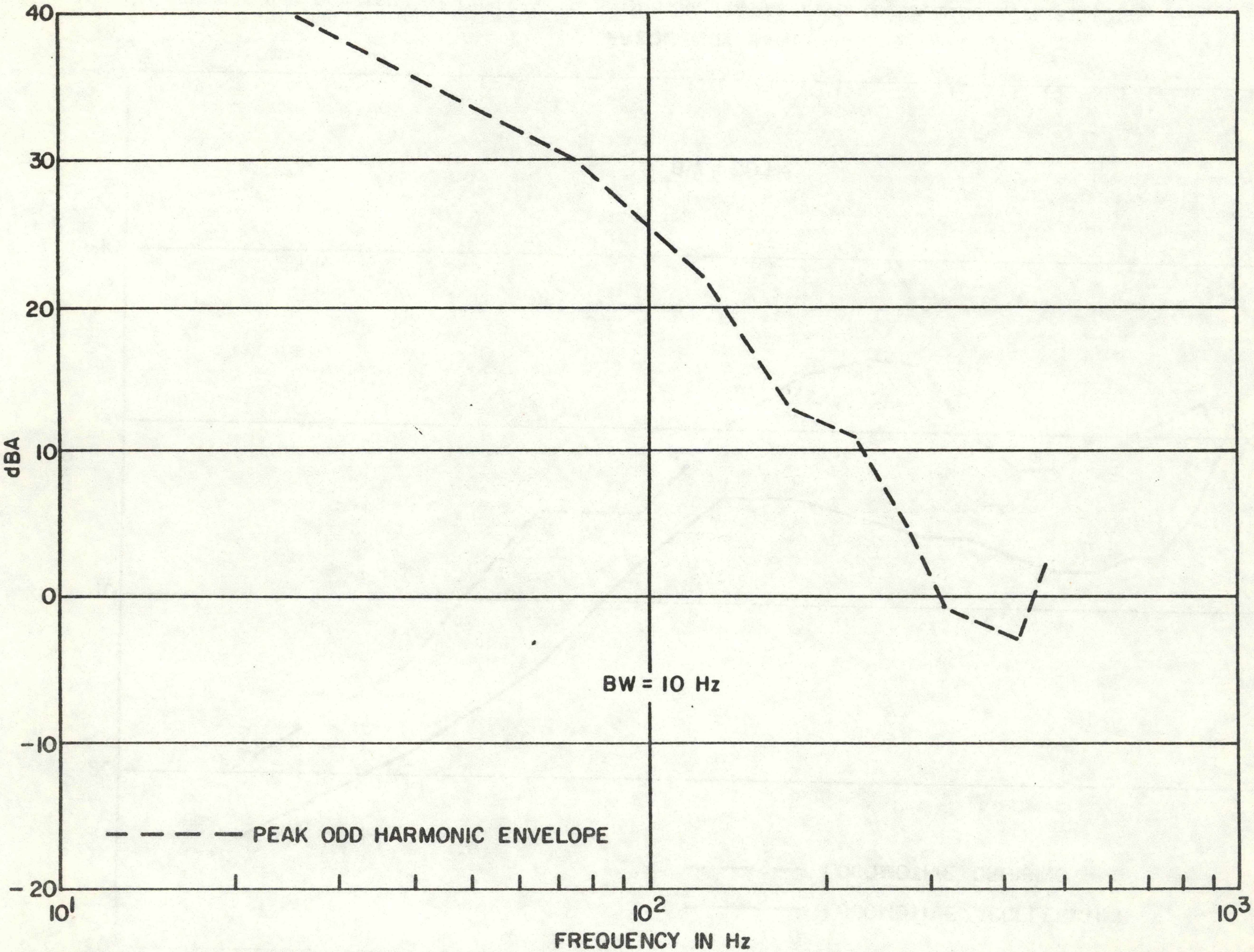


FIGURE 7. SPECTRUM OF CURRENT IN MAIN TRANSFORMER PRIMARY WITH LOCOMOTIVE RUNNING AT CRUISING SPEED.

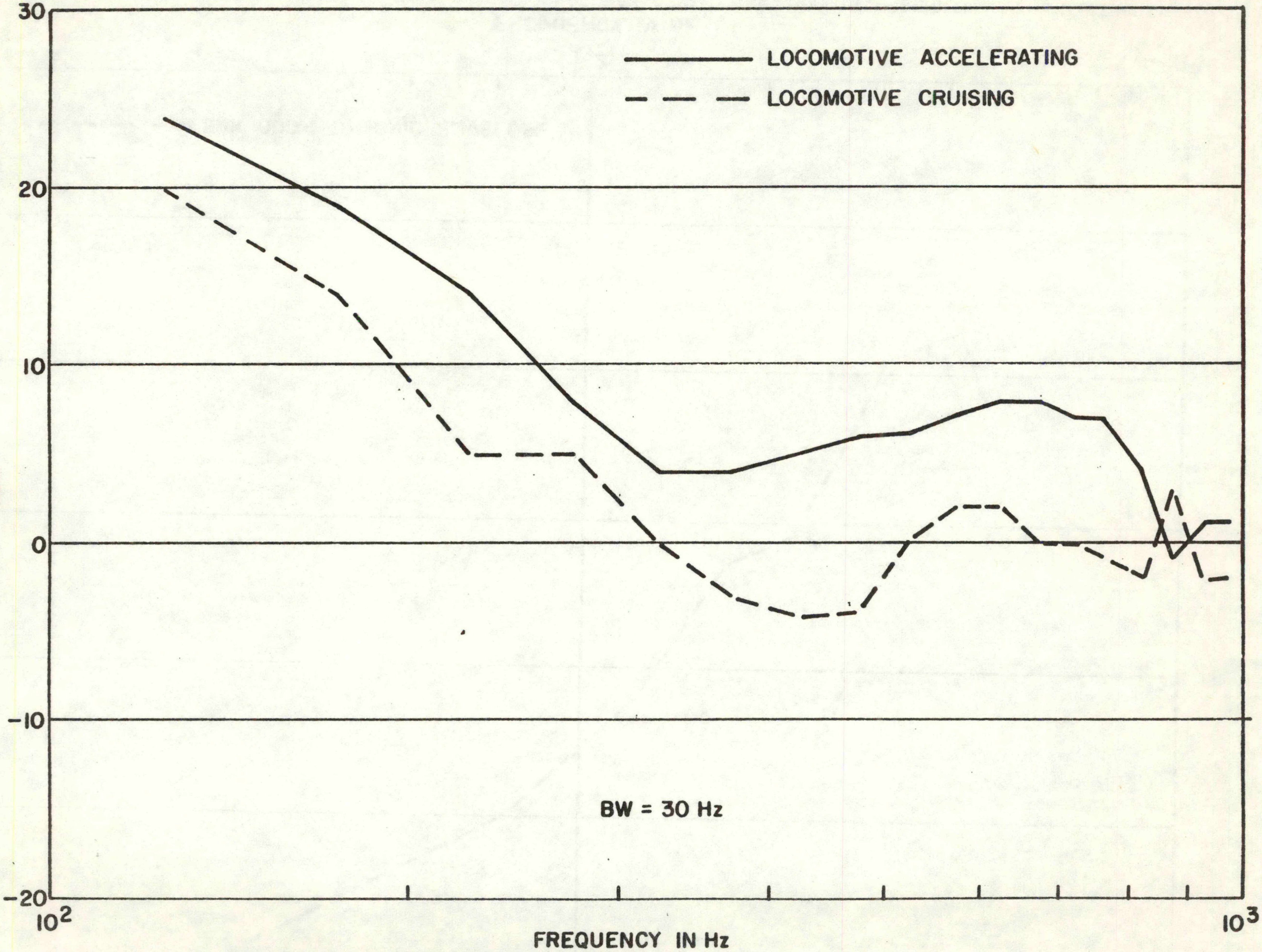


FIGURE 8. SPECTRUM OF CURRENT IN MAIN TRANSFORMER WITH LOCOMOTIVE ACCELERATING.

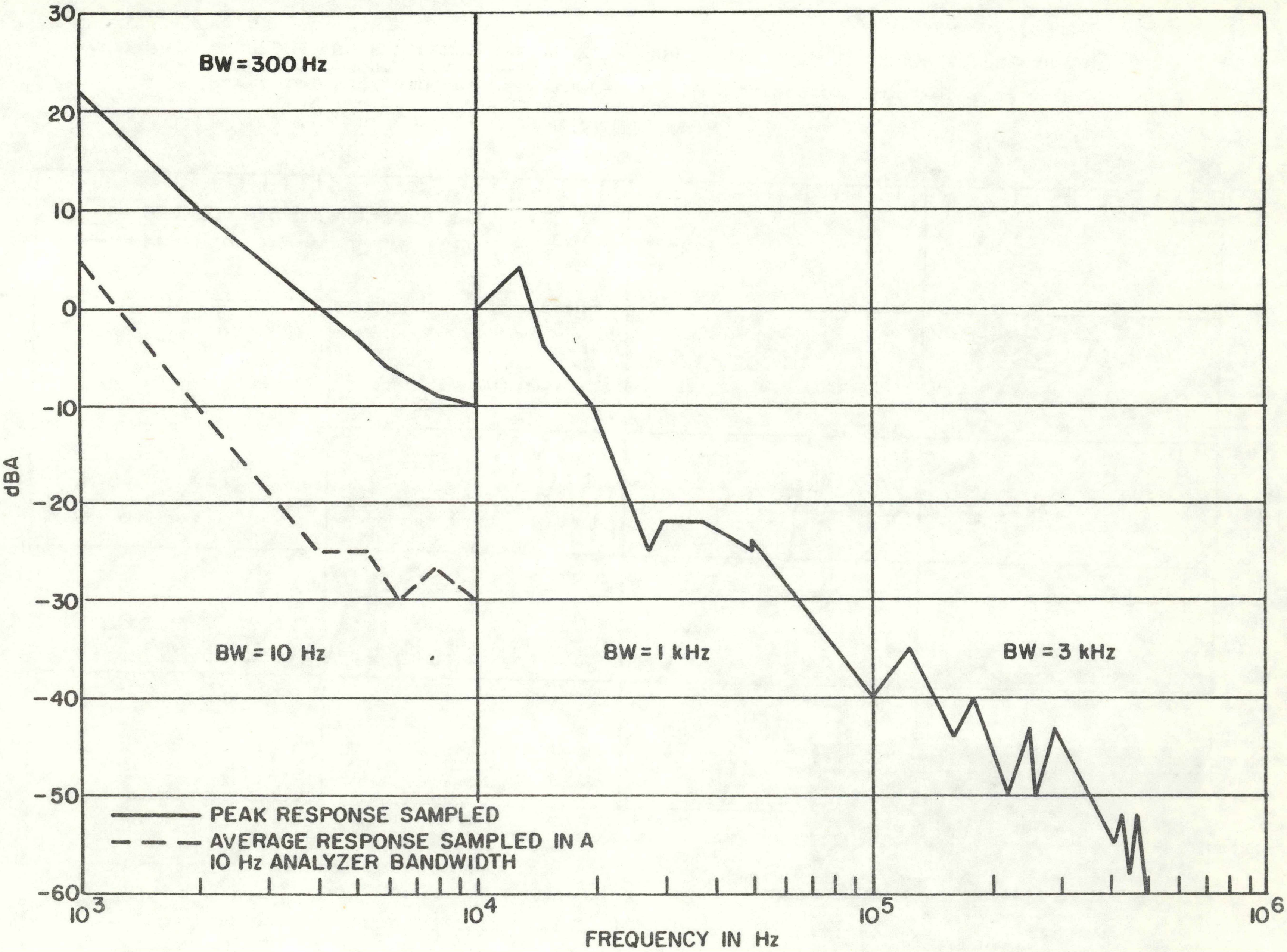
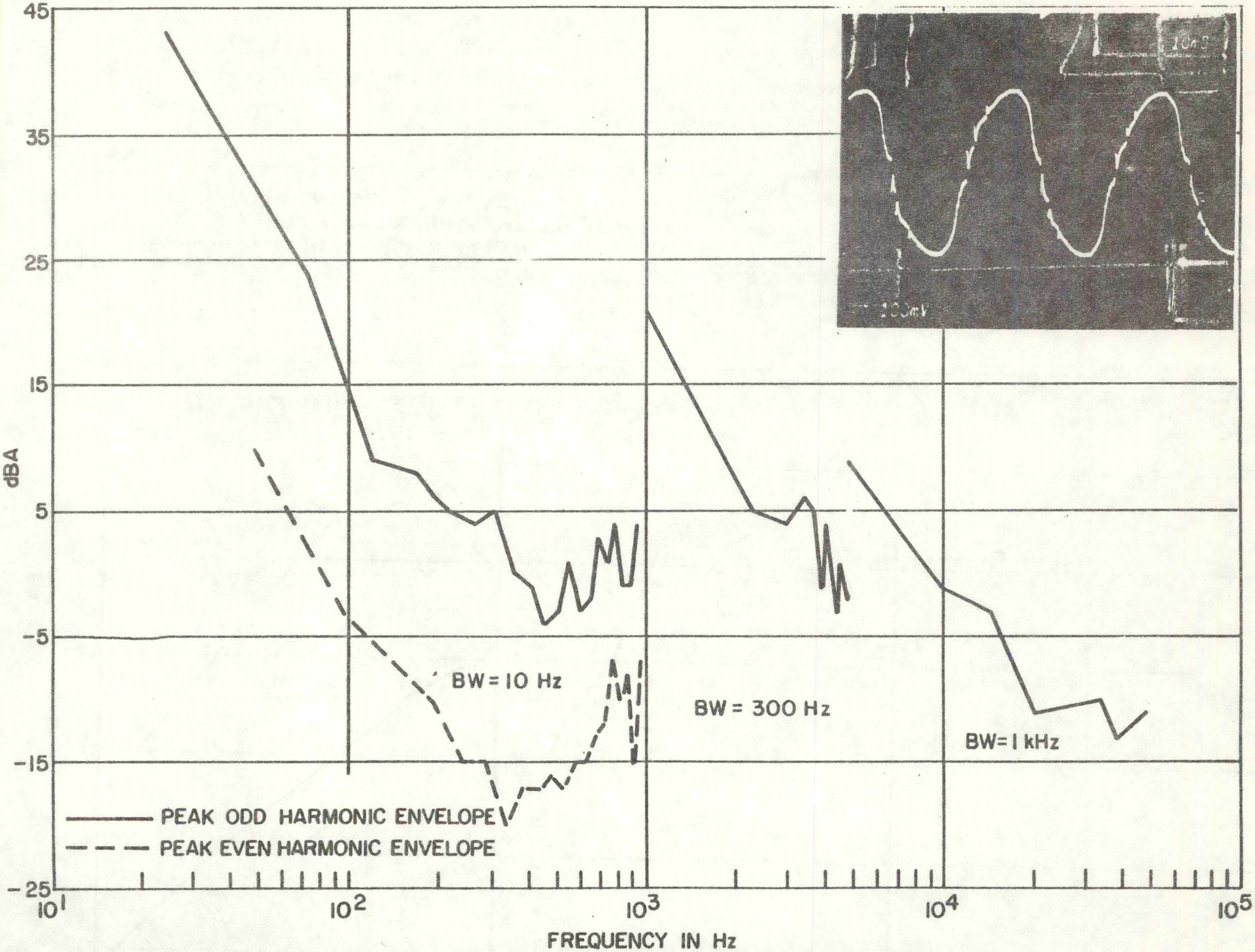


FIGURE 9. SPECTRUM OF CURRENT IN MAIN TRANSFORMER, SAMPLED OVER MANY MILES OF TRACK.



(waveform: 277 amperes peak-to-peak; 100 millisecond time interval)

FIGURE 10. WAVEFORM AND FREQUENCY SPECTRUM OF CURRENT IN MAIN TRANSFORMER PRIMARY, STAGE 2.

Approximatey 30 seconds after the data shown in Figure 10 was recorded, the locomotive shifted into stage 3. The time waveform and frequency spectrum of the current sampled just prior to this transition are given in Figure 11. Comparing the waveforms in Figures 10 and 11, the current level in Figure 11 appears to be slightly higher then in Figure 10 (302 amperes peak-to-peak as compared to 277 amperes peak-to-peak). Comparing the frequency spectra in Figures 10 and 11, the 75- and 125-Hz components appear to be 3 and 10 dBA higher, respectively, in Figure 11 than they do in Figure 10.

The waveform and spectrum recorded just after the locomotive shifted into stage 3 are presented in Figure 12. The amplitude of the current waveform recorded is approximately 485 amperes peak-to-peak as compared with 277 amperes peak-to-peak when the locomotive shifted into stage 2 (see Figure 10). Referring to the spectrum, the odd harmonics appear to predominate. The 25-Hz component recorded, for example, was 45 dBA (177.8 amperes rms) as compared to 30 dBA (31.6 amperes rms) for the 50-Hz component.

TRACTION MOTOR ARMATURE

The recorded dc truck current data indicated that when the locomotive was coasting (bridge tap switches 2, 3, 5, and 6 open), the traction motor drew 0 amperes of dc current.[a] However, the data recorded using the ECAC probe indicated that at this time ac current was still being drawn by the traction motor armature (approximately 90 amperes peak-to-peak). Conversely, when the locomotive was accelerating, up to 700 amperes of dc current and 3100 amperes peak-to-peak of ac current were drawn by the armature winding.

In Figure 13, the current waveform recorded while the rectifiers were in stage 1 is given. The amplitude recorded was approximately 356 amperes peak-to-peak.

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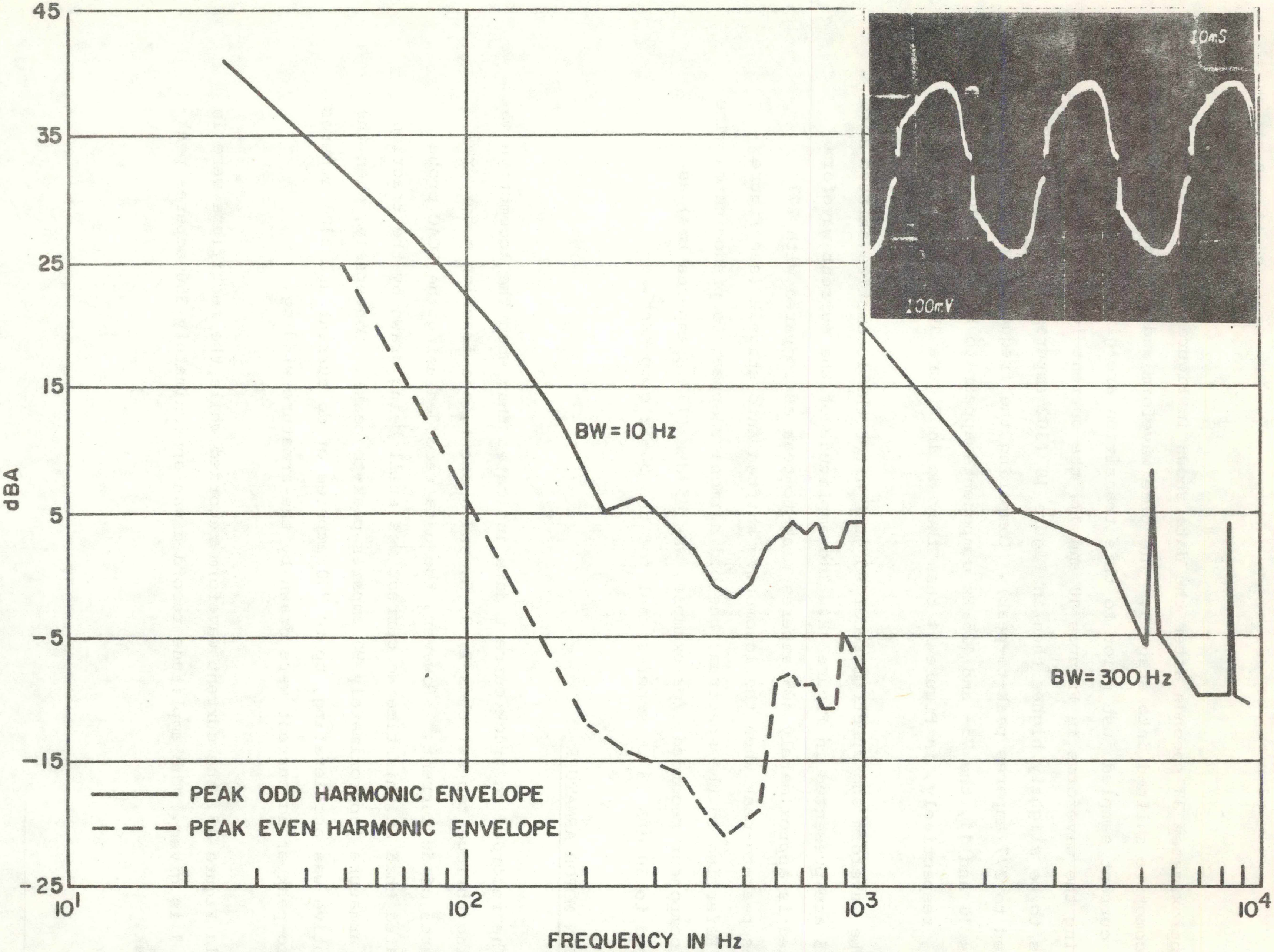
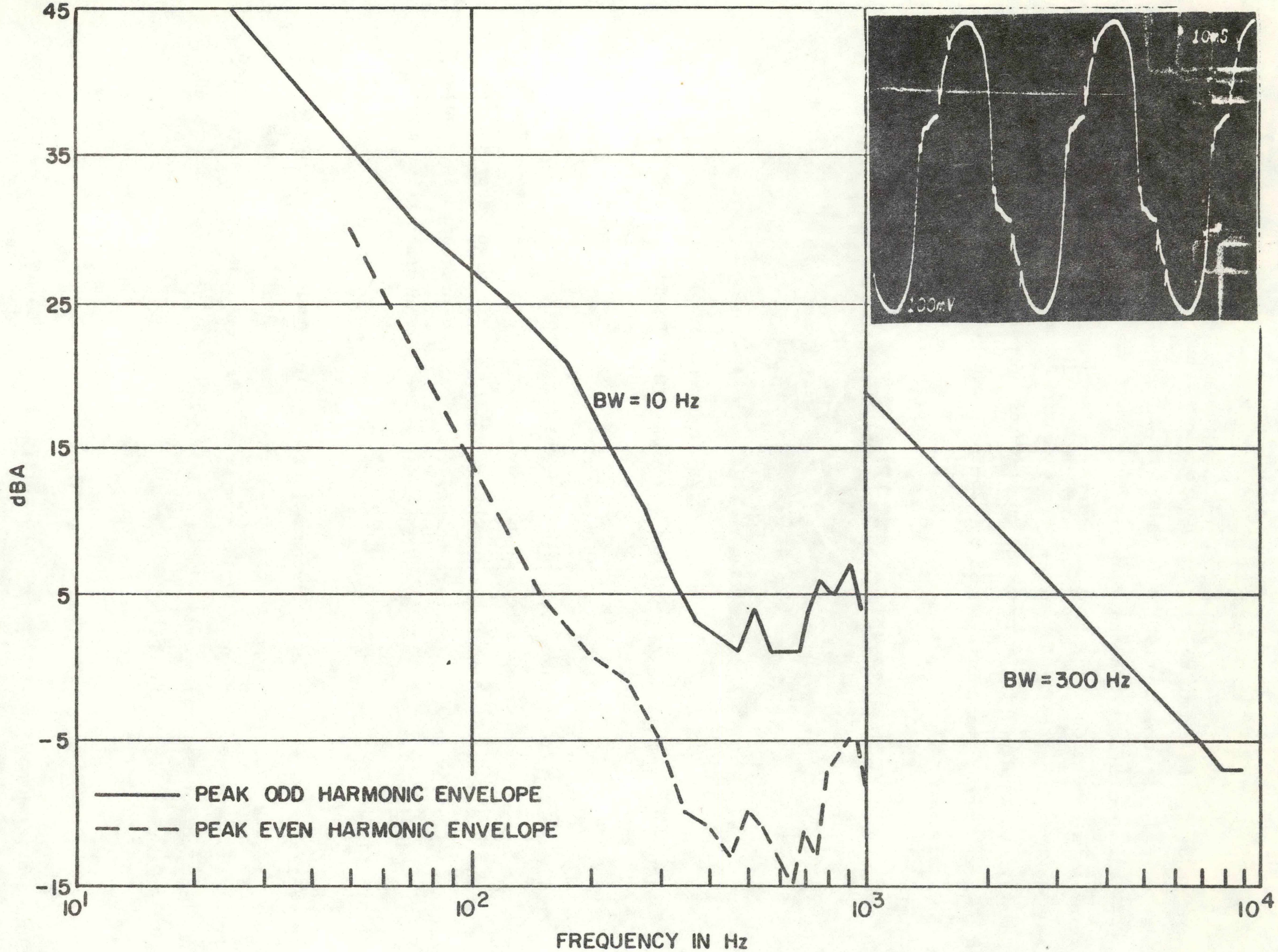
[a]This data was read off of the ammeter in the cab of the locomotive.



(waveform: 63 amperes/div., 10 ms/div.)

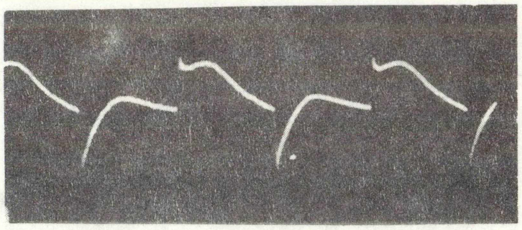
FIGURE 11. WAVEFORM AND FREQUENCY SPECTRUM OF CURRENT IN MAIN TRANSFORMER PRIMARY JUST PRIOR TO TRANSITION TO STAGE 3.



(waveform: 485 amperes peak-to-peak, 100 millisecond time interval)

FIGURE 12. WAVEFORM AND FREQUENCY SPECTRUM OF CURRENT IN MAIN TRANSFORMER PRIMARY, STAGE 3.

In stage 2, the armature current waveform was found to go through two typical shapes. As the thyristors first began to conduct, the current spectrum was dominated by odd harmonics. The term stage 2-odd is used to describe this condition. The time waveform and frequency spectrum between 25 Hz and 50 kHz of a stage 2-odd current are given in Figure 14.[a] In Figure 14, the peak-to-peak value of the recorded current was approximately 2285 amperes (808 amperes rms). The amplitude of the 25-Hz component of the current was 54 dBA (501 amperes rms).



(waveform: 178 amperes/div., 10 ms/div.)

FIGURE 13. WAVEFORM OF TRACTION MOTOR ARMATURE CURRENT, STAGE 1.

The second typical shape occurred when the thyristors conducted fully. When this happened, increased levels of even harmonics were observed. The term stage 2-even is used to describe this condition. The time waveform and frequency spectrum of a typical stage 2-even current are presented in Figure 15. In comparing Figures 14 and 15, a rounding out of the armature current waveform in Figure 15 is observed.

Typical time waveforms and frequency spectra for stage 3 are given in Figures 16 and 17. In comparing the waveforms, some rounding off of the waveform is observed in Figure 17 (as compared with Figure 16). In Figure 17, the 50-Hz component sampled was 49 dBA (282 amperes rms) as compared with 45 dBA (178 amperes rms) in Figure 16.

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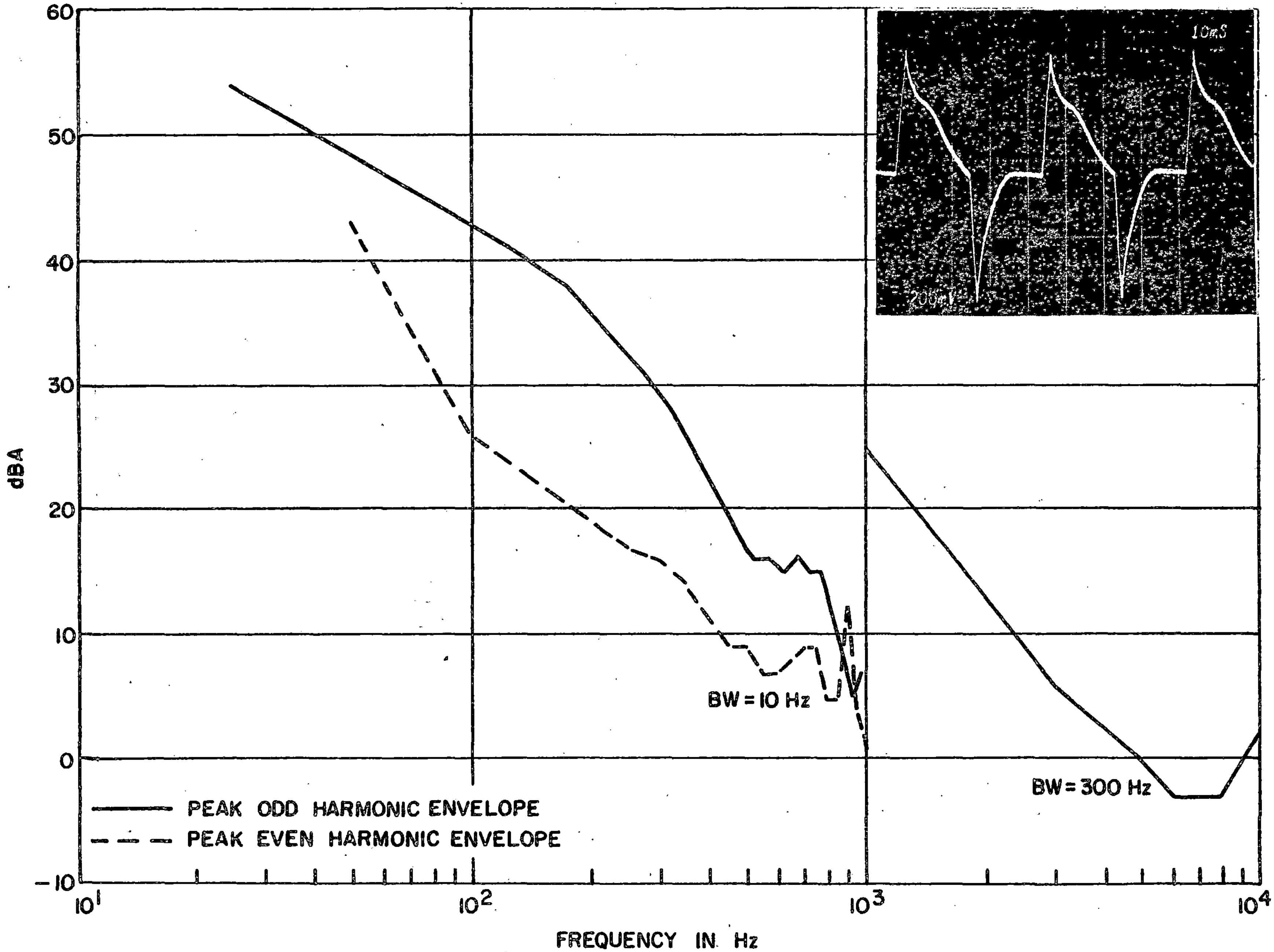
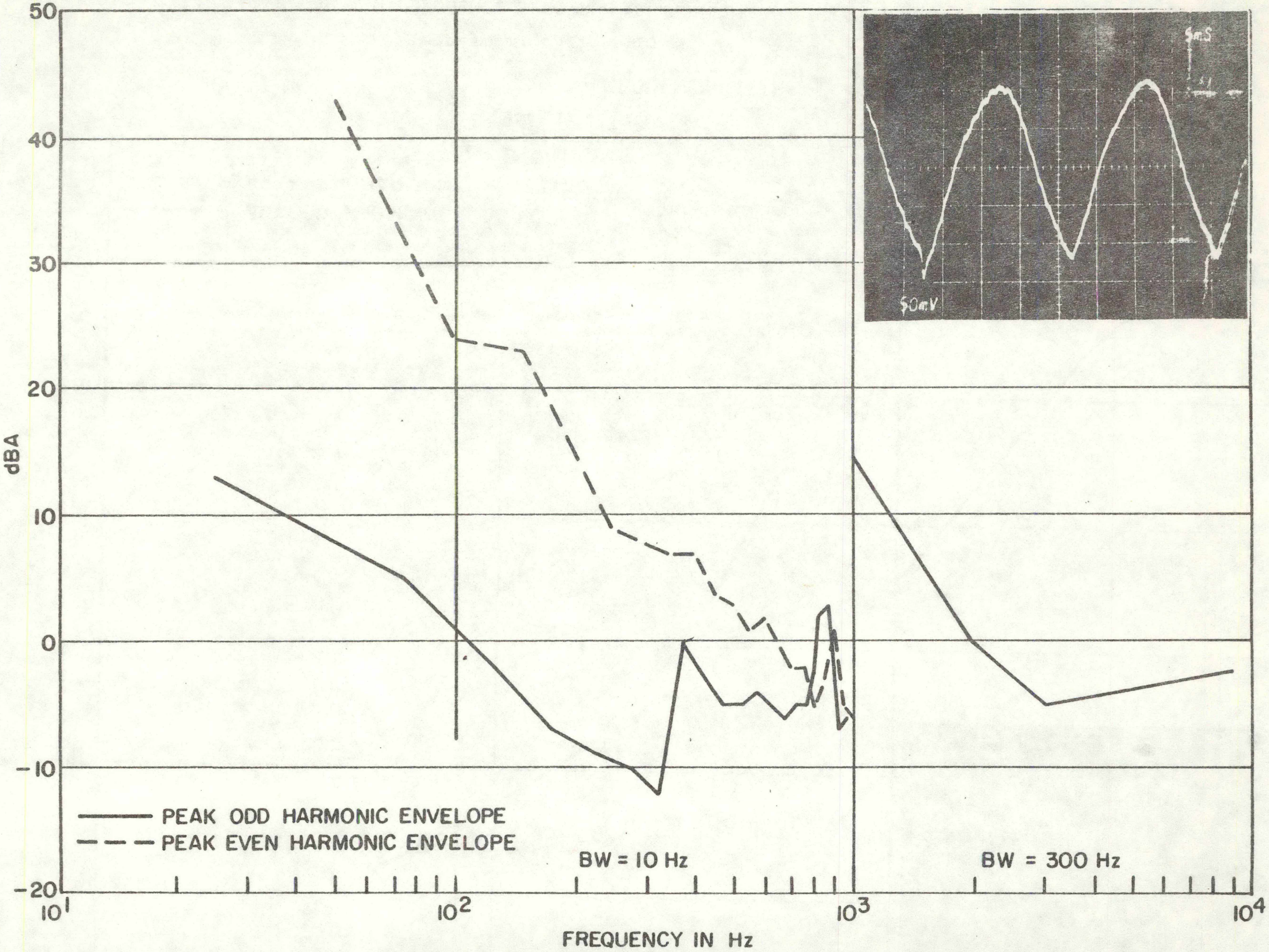
[a]The data presented in Figures 14 through 17 was recorded at the same location and under the same conditions as the data in Figures 10 through 12.



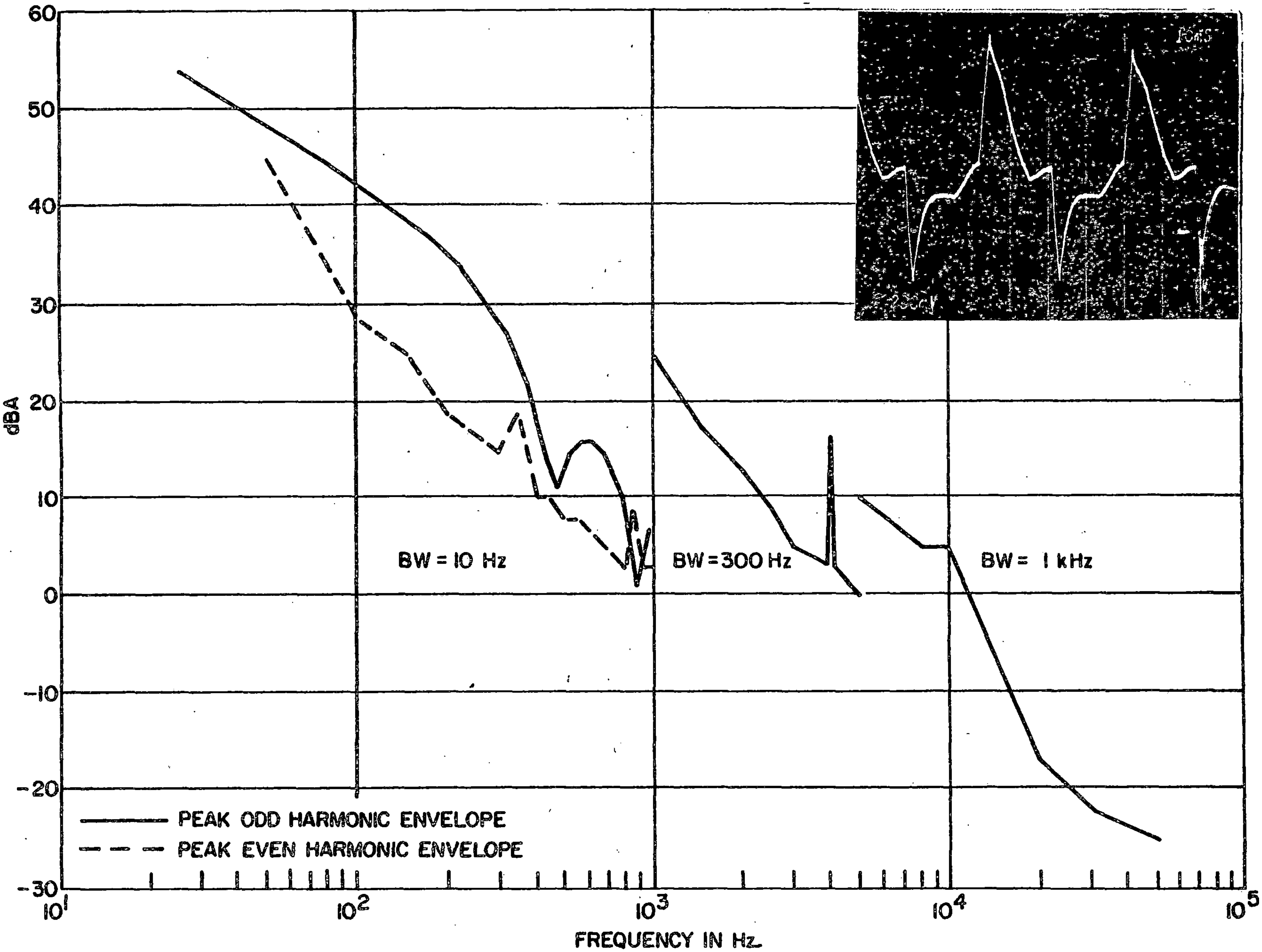
(waveform: 375 amperes/div., 10 ms/div.)

FIGURE 14. WAVEFORM AND FREQUENCY SPECTRUM OF CURRENT IN TRACTION MOTOR ARMATURE, STAGE 2-ODD.



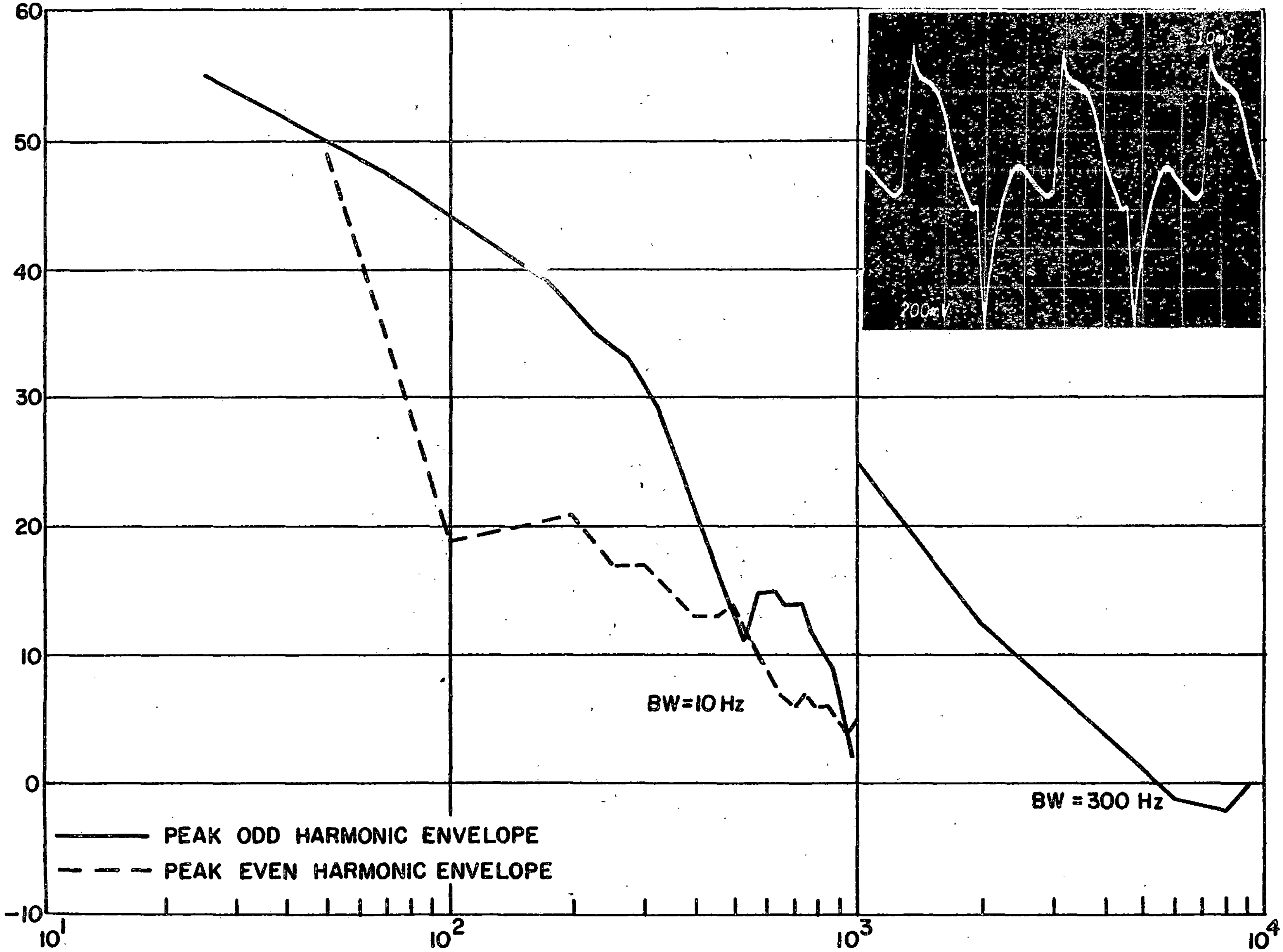
(waveform: 89 amperes/div., 5 ms/div.)

FIGURE 15. WAVEFORM AND FREQUENCY SPECTRUM OF CURRENT IN THE ARMATURE WINDING OF THE TRACTION MOTOR, STAGE 2-EVEN.



(waveform: 357 amperes/div., 10 ms/div.)

FIGURE 16. WAVEFORM AND FREQUENCY SPECTRUM OF CURRENT IN TRACTION MOTOR ARMATURE AS LOCOMOTIVE SHIFTS INTO STAGE 3.



(waveform: 357 amperes/div., 10 ms/div.)

FIGURE 17. WAVEFORM AND FREQUENCY SPECTRUM OF CURRENT IN THE ARMATURE WINDING OF THE TRACTION MOTOR, STAGE 3 (TAKEN JUST AFTER FIGURE 16).

Section 3

CAB SIGNAL PICKUP

General

The cab signaling system in use on the Northeast Corridor is a four aspect, 4-speed system incorporating a 100-Hz carrier signal. The carrier signal is pulse coded into one of four pulse repetition frequencies, each pulse code indicating a specific maximum safe speed at which the train may travel. A pulse repetition frequency of 0 pulse per minute (ppm) is used to designate a most restrictive aspect (corresponding to a maximum speed of 15 miles per hour). The other codes and corresponding speed limits are 75 ppm (called approach medium aspect) with a maximum speed of 30 miles per hour (mph), 120 ppm (called approach aspect) corresponding to a speed limit of 45 mph, and 180 ppm (called a clear aspect) for a maximum speed presently set at 95 mph.[a] Examples of the 75, 120, and 180 ppm codes are presented in Figures 18 and 19.

In Figure 18, the cab signal transmitter initially conveys a code of 120 ppm. After approximately 4.8 seconds, the code rate changes to 75 pulses per minute (measured to be approximately 90 ppm). The amplitude of the 120-ppm cab signal sampled was approximately 90 volts peak-to-peak, while the amplitude of the 75 ppm signal was approximately 46 volts peak-to-peak. In Figure 19, the cab signal changes from 120 ppm to 180 ppm. The amplitude of the 180-ppm signal sampled was approximately 86 volts peak-to-peak. The amplitude of the 120-ppm signal recorded at this time was 67 volts peak-to-peak.

In general, the cab signal received during the road test measurements was relatively free of interference. An example of the spectrum, between 25 and 500 Hz, of a "clean" cab signal is given in Figure 20. In this figure, the amplitude of the desired 100-Hz cab signal present is 24 dBV (15.85 volts

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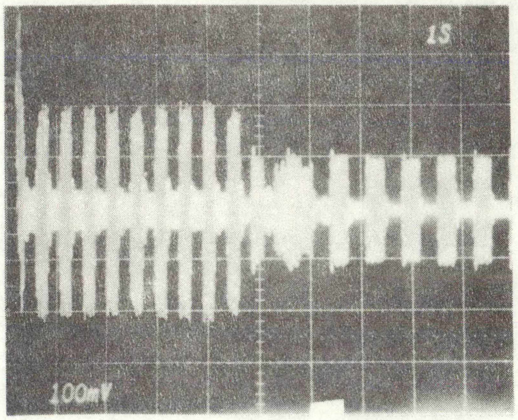
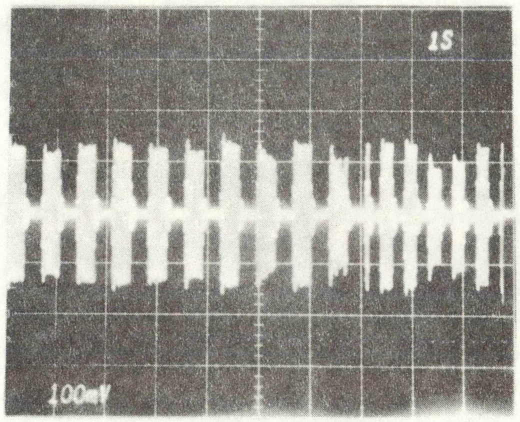
[a]That is, the maximum safe speed for the particular section of track up to a maximum of 95 miles per hour.



(21 volts/div., 1 s/div.)

FIGURE 18. 120 ppm CODE CHANGING TO 75 ppm.



(21 volts/div., 1 s/div.)

FIGURE 19. 120 ppm CODE CHANGING TO 180 ppm.

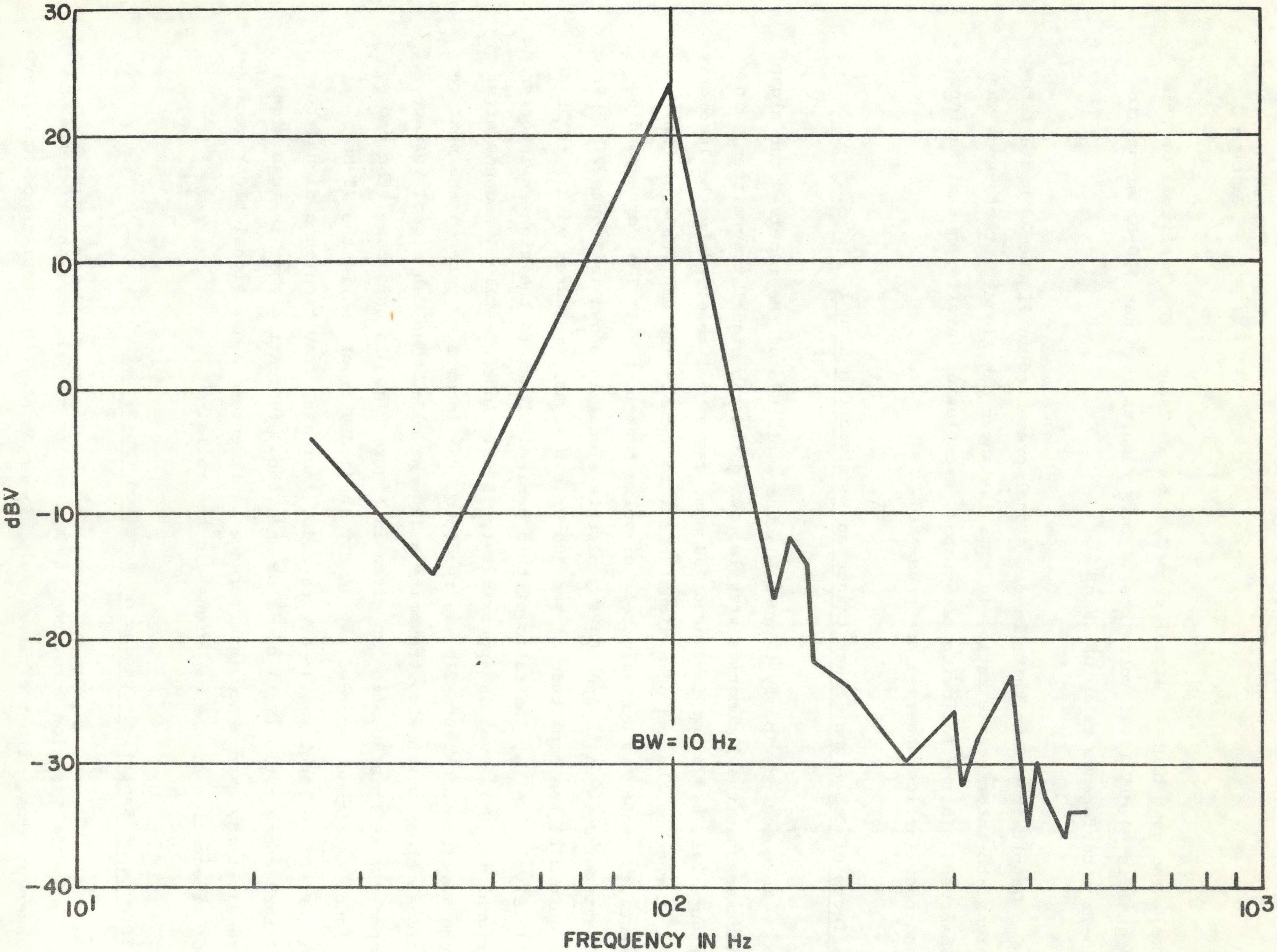


FIGURE 20. SPECTRUM OF "CLEAN" CAB SIGNAL.

rms). The next highest signal recorded was at 25 Hz. The amplitude of this signal is -4 dBV (0.25 volts rms). This results in a net 100-Hz signal to 25-Hz interference ratio of 28 dB.

Despite the fact that the cab signal presented in Figure 20 had a large signal-to-interference ratio, in some instances cab signal interference was observed. In the following paragraphs, examples of interference situations and peculiarties observed are presented.

Effects of Cab Signal Block Change on Received Cab Signal

As noted previously (Figure 6), the amplitude of the received cab signal increases as the locomotive travels toward the cab signal transmitter. In Figure 21a, a 120 ppm (measured 130 ppm) cab signal received by the locomotive as it reaches the end of a signal block is shown. The amplitude of the received signal is approximately 63 volts peak-to-peak. The corresponding spectrum, between 25 and 500 Hz, of this signal is shown in Figure 21b. From Figure 21b, the amplitude of the 100-Hz cab signal (measured 98 Hz) is 25 dBV (17.8 volts rm ,. The ratio of this desired signal to the highest interfering signal (75 Hz) level is approximately 13 dB. Approximately 4 seconds after the waveform of Figure 21b was recorded, the locomotive entered the next cab signal block which also transmits a 120-ppm code. The cab signal voltage spectrum at this location is given in Figure 21c. In this case, the cab signal amplitude recorded was 14 dBV (a 11 dBV drop), while the 75-Hz interference level was 16 dBV (a 2 dBV increase) resulting in a signal-to-interference ratio (S/I) of -2 dB and, thus, indicating that the cab signal receiver may experience interference as it enters a new signal block because of attenuation of the cab signal in the rails.

Effects of Rectifier Staging on Received Cab Signal

As the traction motor rectifier circuits staged, some interference was observed along with the cab signal. Examples of such interference are given in Figures 22a, 22b, 22c, and 22d. Initially, the locomotive was entering a

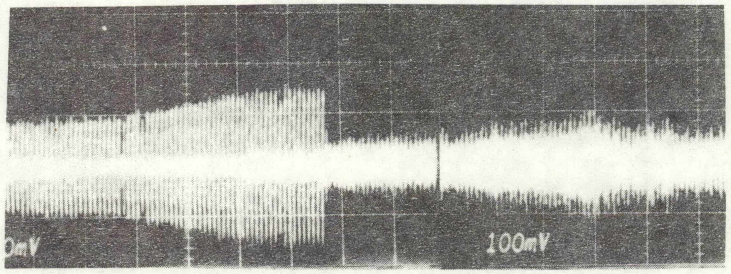


FIGURE 21a. WAVEFORM OF CAB SIGNAL AS LOCOMOTIVE PASSES THROUGH ONE CAB SIGNAL BLOCK AND INTO ANOTHER.

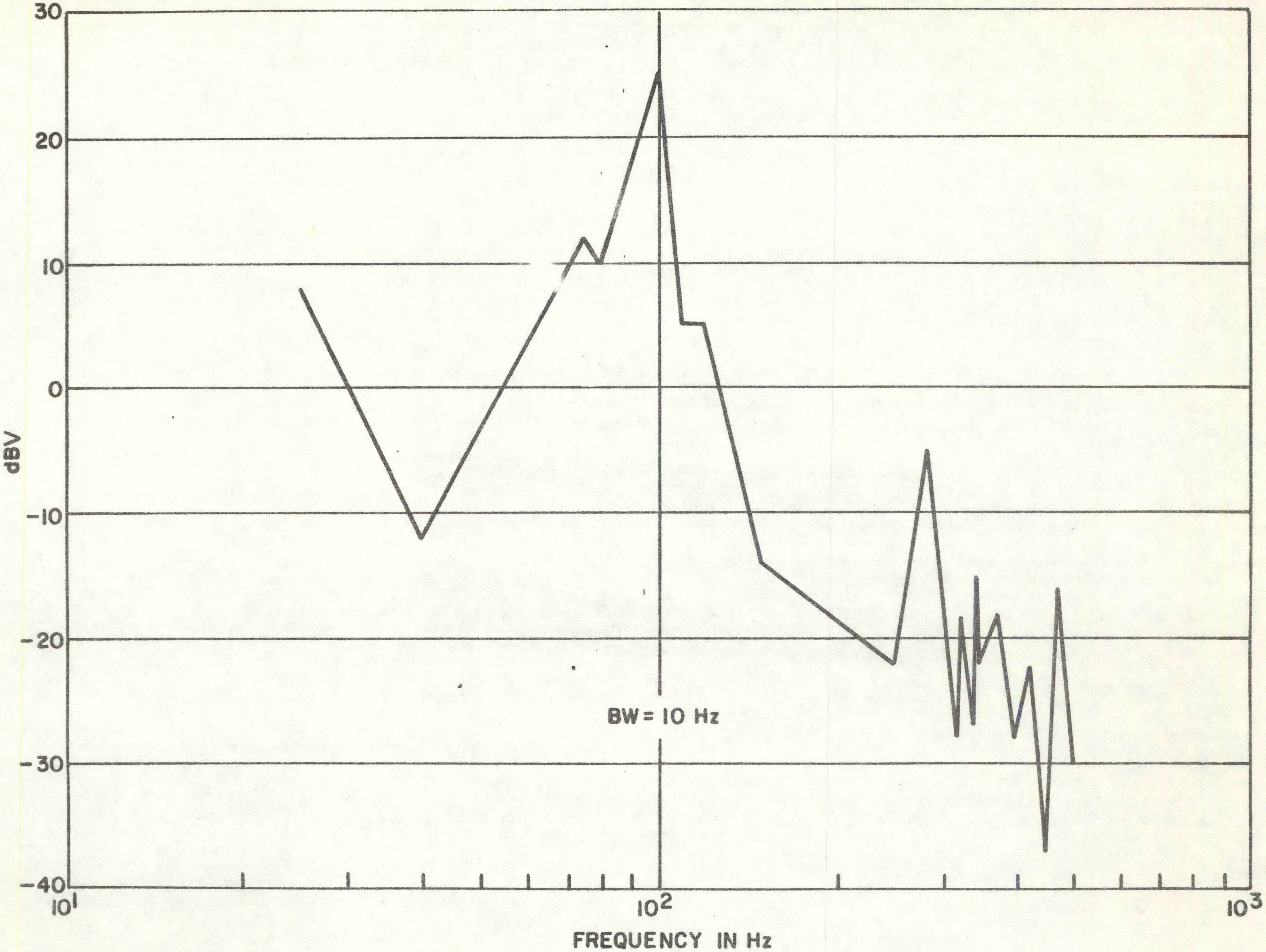


FIGURE 21b. SPECTRUM OF VOLTAGE ACROSS CAB SIGNAL PICKUP PRIOR TO CAB SIGNAL BLOCK CHANGE.

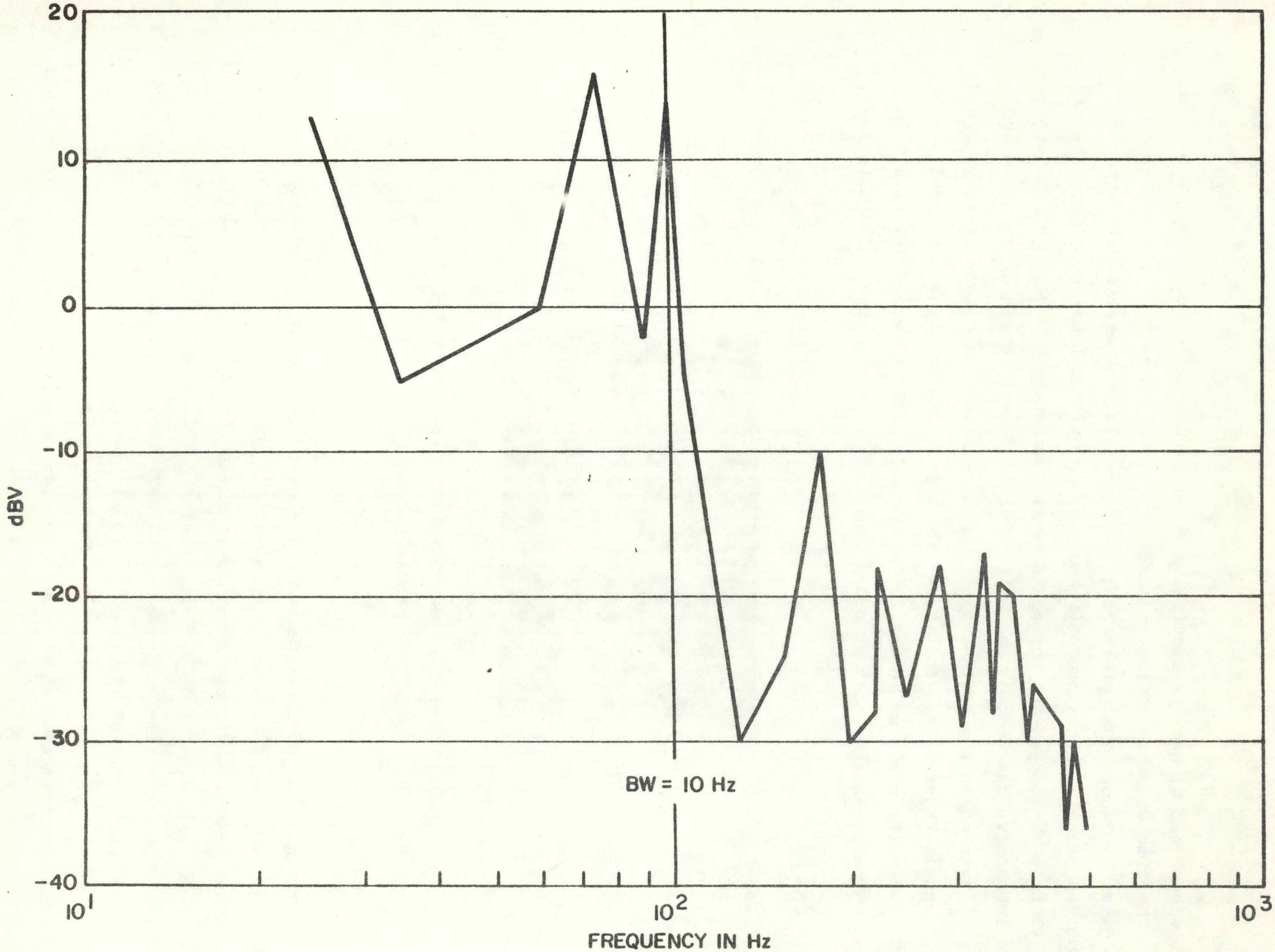
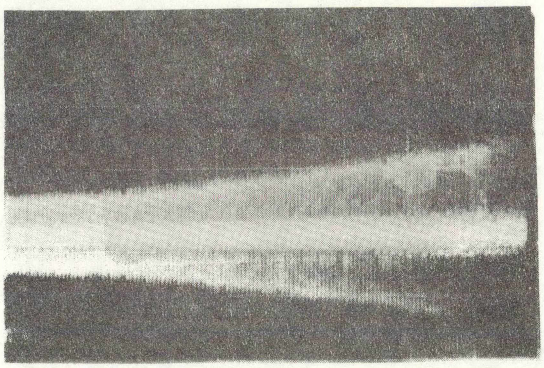


FIGURE 21c. SPECTRUM OF VOLTAGE ACROSS CAB SIGNAL PICKUP AFTER CAB SIGNAL BLOCK CHANGE.

cab signal block, and the rectifiers were transitioning from stage 1 to stage 2. The time waveform of the received cab signal throughout the signal block is given in Figure 22a. Referring to Figure 22a, the amplitude of the received signal as the locomotive entered the signal block was approximately 27 volts peak-to-peak and increased to approximately 63 volts peak-to-peak as the locomotive reached the end of the block. The spectrum of the received signal sampled at the beginning of the block (traction motors in stage 2-odd) is given in Figure 22b. In Figure 22b, the 95-Hz cab signal recorded was 18 dBV (7.9 volts rms), while the 25-Hz component sampled was 6 dBV (2.0 volts rms). The 50-Hz component recorded at this time was -7 dBV (.45 volts rms).



(21 volts/div., 5 s/div.)

FIGURE 22a. WAVEFORM OF VOLTAGE ACROSS CAB SIGNAL PICKUP.

The spectrum of the received cab signal with the traction motor rectifier circuits in stage 2-even are displayed in Figure 22c. In this figure, the recorded 95-Hz cab signal increased to 22 dBV (12.6 volts rms) while the 25-Hz component decreased to 3 dBV (approximately 1.4 volts rms). The 50-Hz component at this time increased to -5 dBV (0.56 volts rms). Beyond 300 Hz, the emission levels of Figures 22b and 22c appear equivalent.

The spectrum sampled as the locomotive rectifiers changed to stage 3-odd is given in Figure 22d. Here, the 25-Hz component increased from 3 dBV

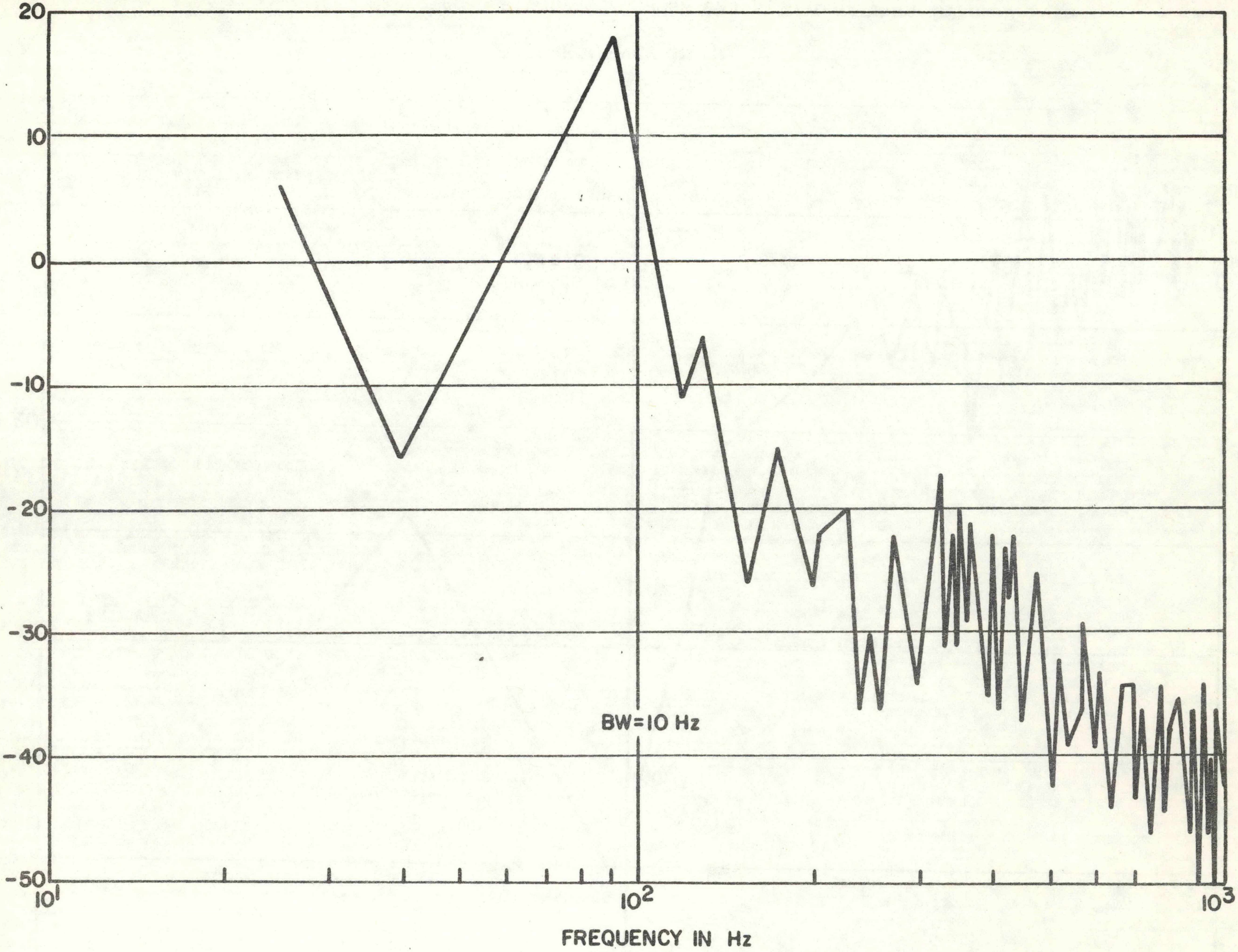


FIGURE 22b. SPECTRUM OF VOLTAGE ACROSS CAB SIGNAL PICKUP, STAGE 2-ODD.

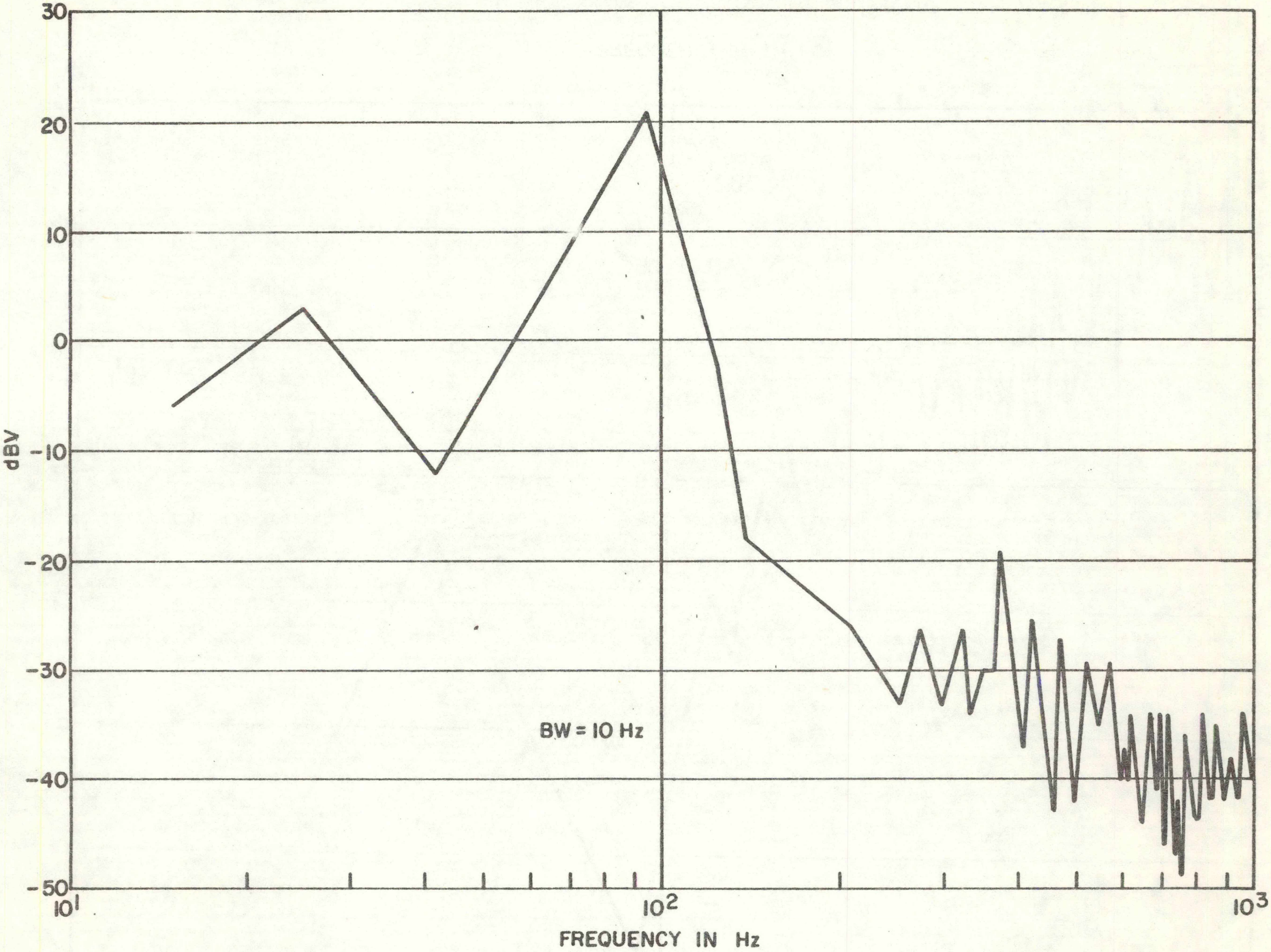


FIGURE 22c. SPECTRUM OF VOLTAGE ACROSS CAB SIGNAL PICKUP, STAGE 2-EVEN.

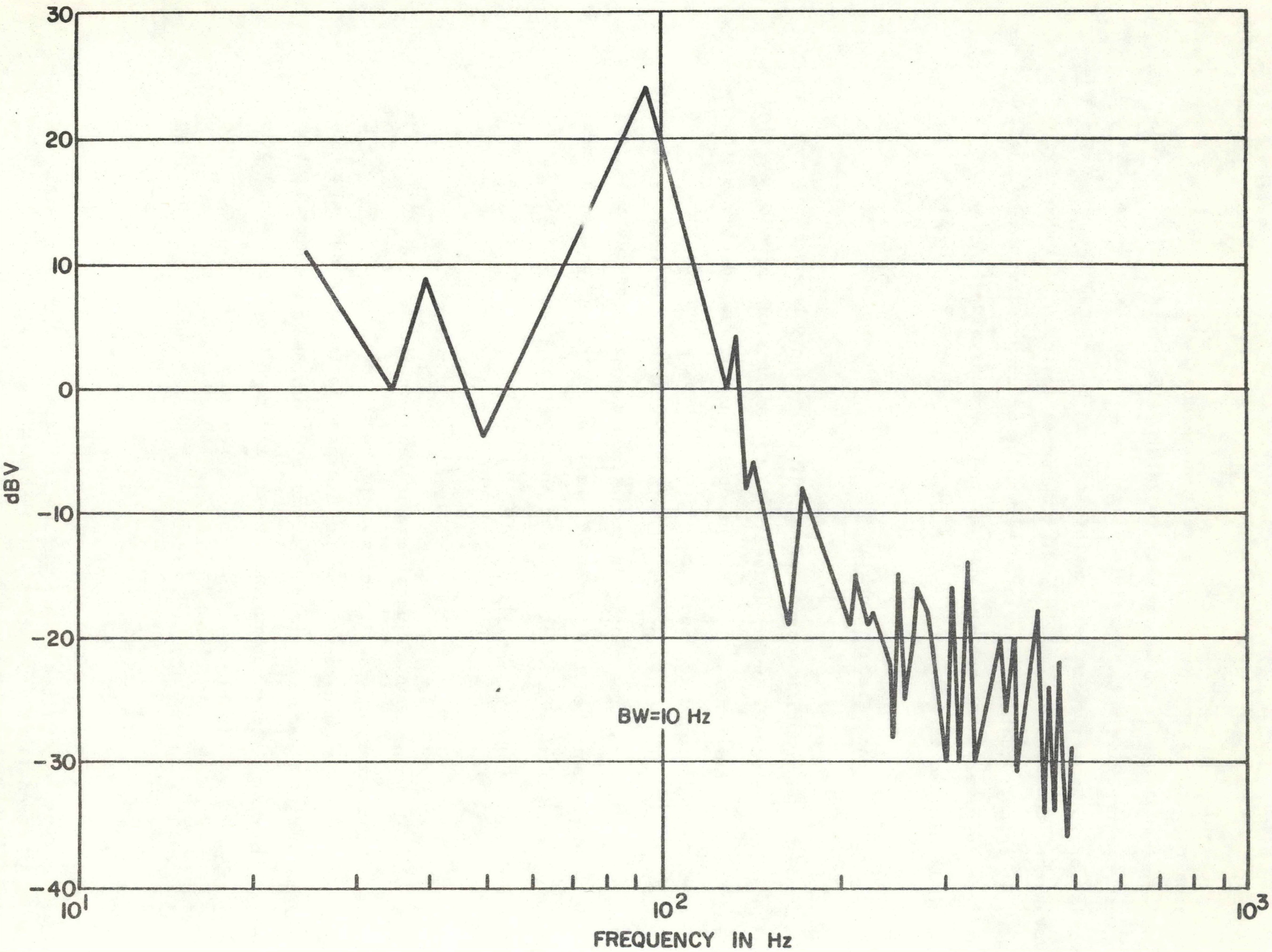


FIGURE 22d. SPECTRUM OF VOLTAGE ACROSS CAB SIGNAL PICKUP, STAGE 3.

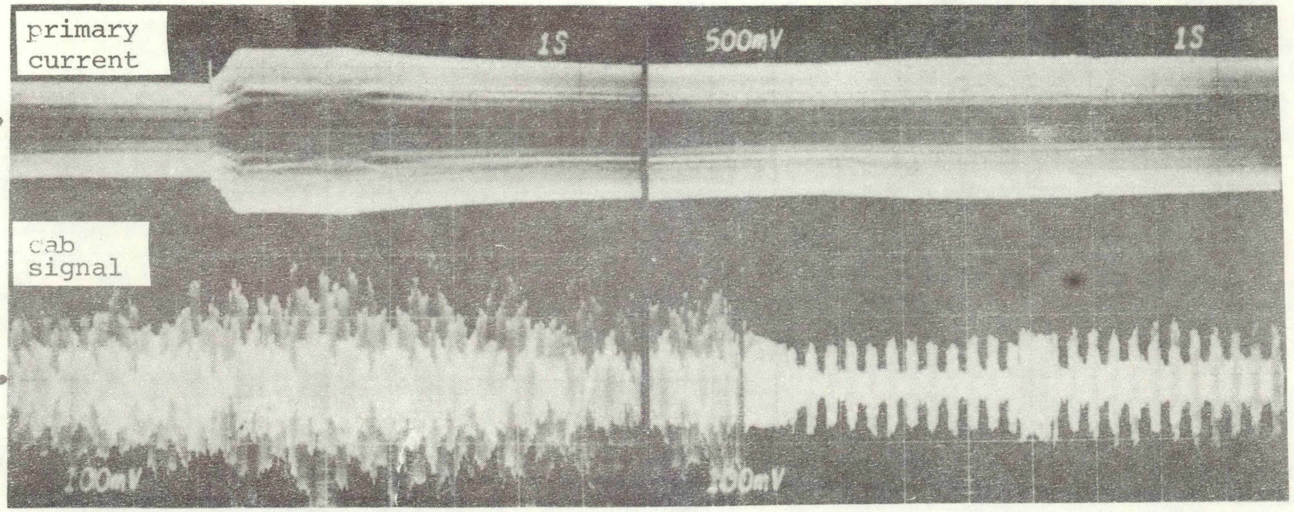
(1.4 volts rms) to 11 dBV (3.55 volts rms) while the 95-Hz cab signal increased from 22 dBV (12.6 volts rms) to 24 dBV (15.8 volts rms). As was the case when the traction motor rectifier circuits were in stage 2-odd, the odd harmonics of 25 Hz is predominant in the spectrum beyond 100 Hz (roughly 5 to 10 dBV higher than the even harmonics). In summation, as the locomotive stages, it appears that the levels of harmonics of 25 Hz detected by the cab signal receiver vary. On the average, as the locomotive up-stages, the harmonic levels increase.

Case of Possible Track Circuit Unbalance

Ideally, the traction return current divides evenly between the two running rails. However, in some cases, greater amounts of current may flow in one rail then in the other. This may be due to unequal impedances in the two rails, unbalanced ground bonding, or adjacent catenary interference. When this occurs, the net result appears to be a circulating interference current in the track circuit. The magnitude and harmonic content of the interfering current is dependent upon the degree of traction return current unbalance, type of motive power, characteristics of the traction power distribution circuit, and impedance of the track circuit (including track, source, and load).[3]

A possible case of track unbalance is shown in Figure 23. In the first 3 seconds of the interval, the traction motor rectifiers are in stage 2 and then change to stage 3 as can be seen by the increase in primary current. At approximately 11.4 seconds, the cab signal suddenly becomes recognizable as a 180-ppm cab signal. The cab signal spectra recorded just before and after the signal became recognizable are given in Figures 24 and 25, respectively.

[3]Stark, Donald, E., "Interference Susceptibility of the Signaling System - Part I Cab Signaling," presentation to AAR/IEEE/AREA Railroad Electromagnetic Compatability Working Group, June 1979.



0 amperes

0 volts

(primary: 315 amperes/div., cab signal: 21 volts/div., time: 1 s/div.)

FIGURE 23. WAVEFORM OF PRIMARY CURRENT AND CAB SIGNAL WHERE TRACK UNBALANCE IS SUSPECTED.

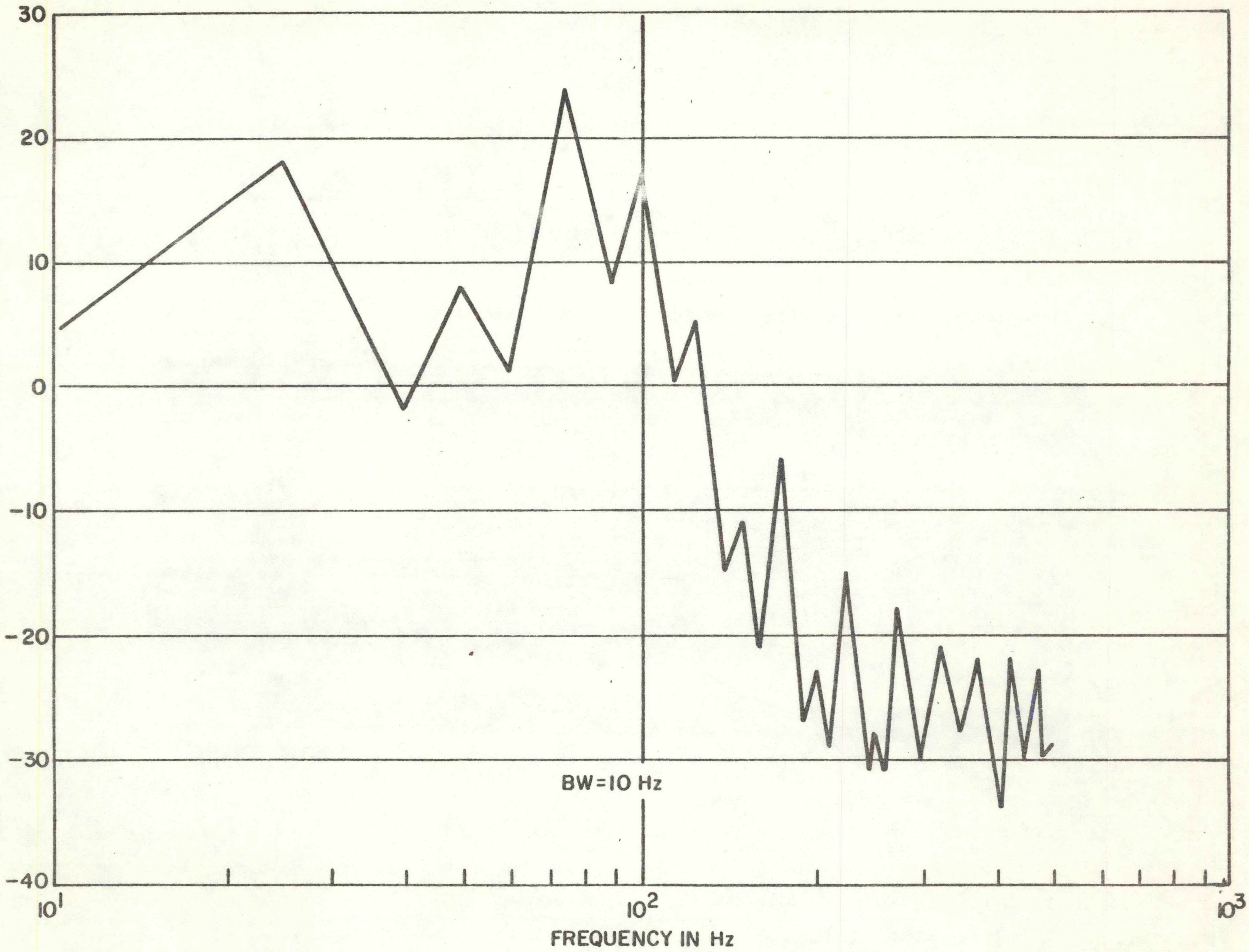


FIGURE 24. SPECTRUM OF CAB SIGNAL JUST BEFORE SIGNAL CODE BECOMES RECOGNIZABLE.

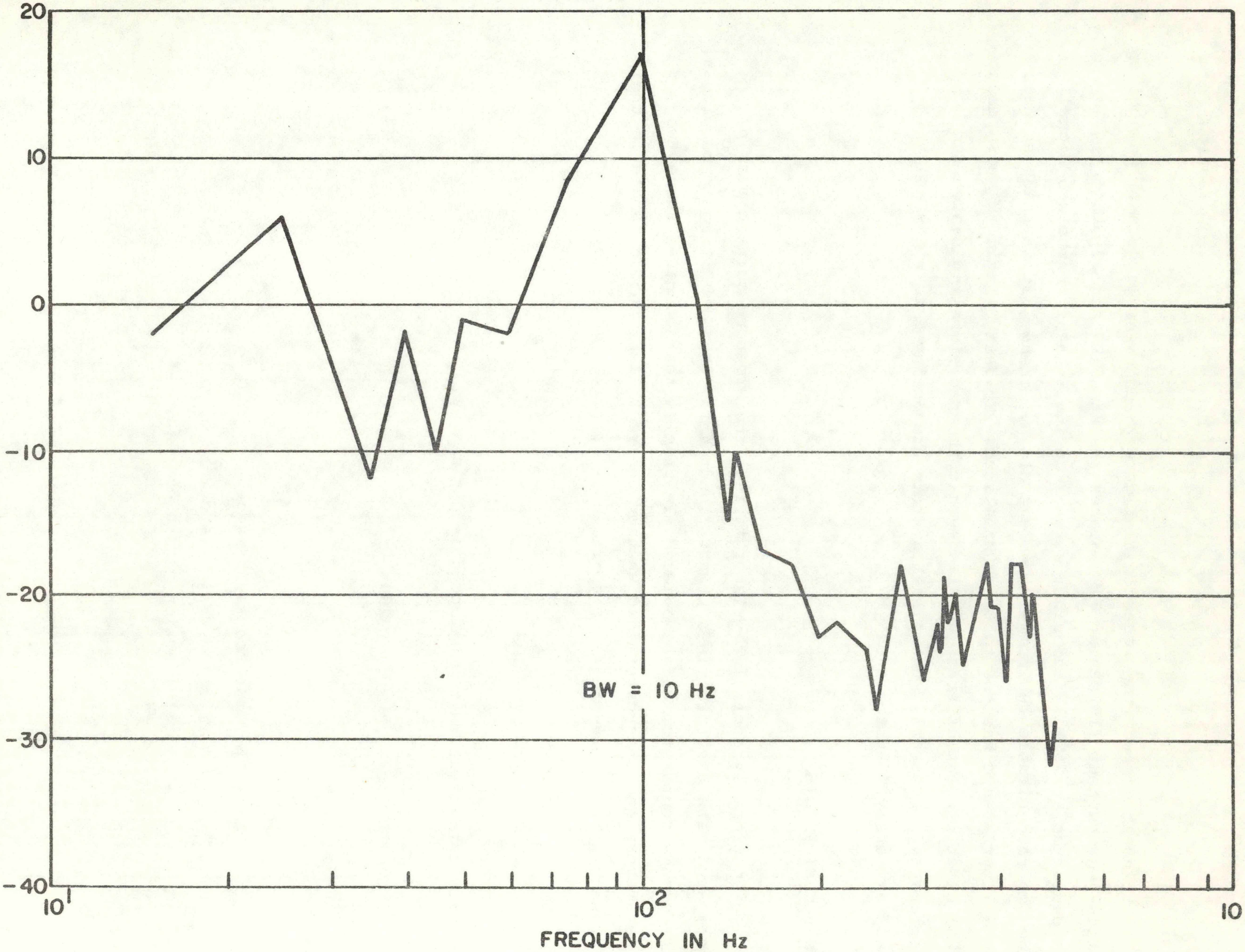


FIGURE 25. SPECTRUM OF CAB SIGNAL JUST AFTER SIGNAL CODE BECOMES RECOGNIZABLE.

Since the spectrum presented in Figure 25 contains large amplitude of 25- and 75-Hz current (19 dBA or 8.9 amperes rms at 25 Hz and 23 dBA or 14.13 amperes rms at 75 Hz), and since before, during, and after the cab signal became recognizable the primary current did not change, it is reasoned that the interference was due to track unbalance. To date, little is known about the exact percent of track unbalance that the cab signaling system can tolerate.[a] Presently, the signal systems are designed to withstand approximately 10% unbalance.

N-P TEST POINTS

To properly control thyristor firing, the armature current must be compared with the throttle setting. To do this, the E-60 is equipped with a reference comparator and associated electronics that compares these two parameters and then determines whether the rectifiers should remain in their present stage, down-stage, or up-stage.

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[a]Percent track circuit unbalanced is defined as:

$$U_T = \frac{I_1 - I_2}{I\ total} \times 100\% \qquad (1)$$

where

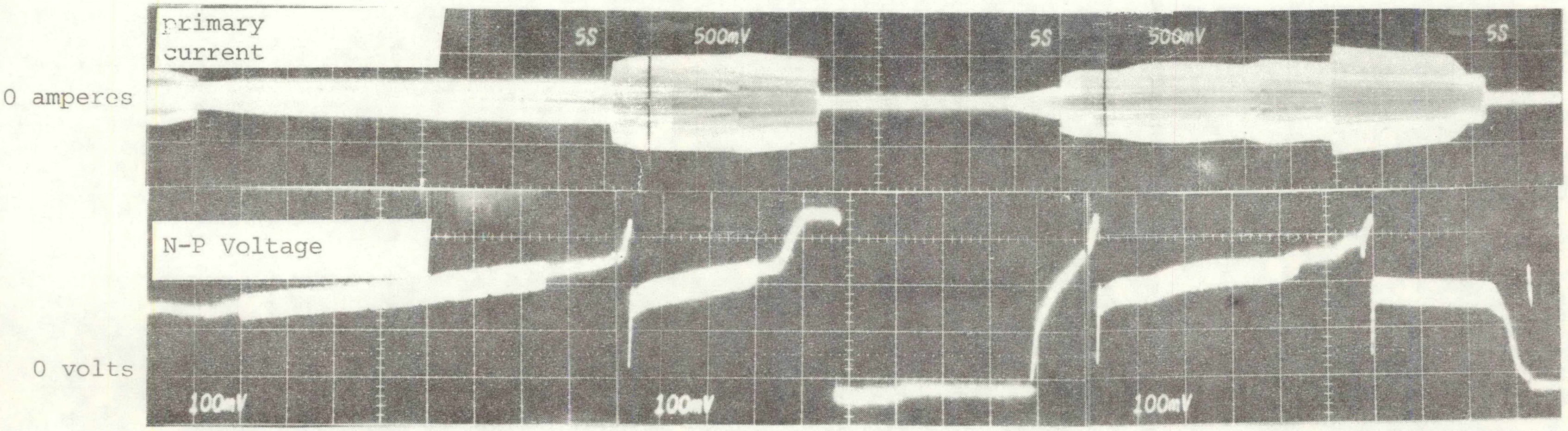
U_T = percent track unbalance
I_1, I_2 = current in rails 1 and 2
I total = total traction return current.

The output of the reference comparator (card #859) was sampled across the N-P test points and the data recorded in an FM channel of the Honeywell tape recorder. A sample of the data obtained is shown in Figure 26. As the locomotive began accelerating (as can be seen by the increased current in the main transformer), the N-P voltage quickly goes from approximately -0.5 volts dc to 9.6 volts dc. The rectifiers then change into stage 2 and the voltage drops to 5.7 volts dc increasing to 9.6 volts dc before the rectifiers shift into stage 3. In stage 3, the locomotive's speed starts to level off as is indicated by the relatively constant primary current (630 amperes peak-to-peak) and N-P voltage (5.8 volts dc).

An example of the voltage spectrum sampled across the N-P test points is presented in Figure 27. The curve shows the peak voltage spectrum recorded while the locomotive traveled over many miles.

74-VOLT dc BUS

The voltage across the 74 volt bus was recorded on an FM channel of the Honeywell recorder. During playback, much distortion was observed. It is felt that this distortion was due to equipment malfunction (most probably the probe).



(primary: 315 amperes/div., N-P voltage: 2.84 volts/div., time: 5 s/div.)

FIGURE 26. N-P VOLTAGE WAVEFORM AS THE TRACTION MOTOR RECTIFIERS STAGE.

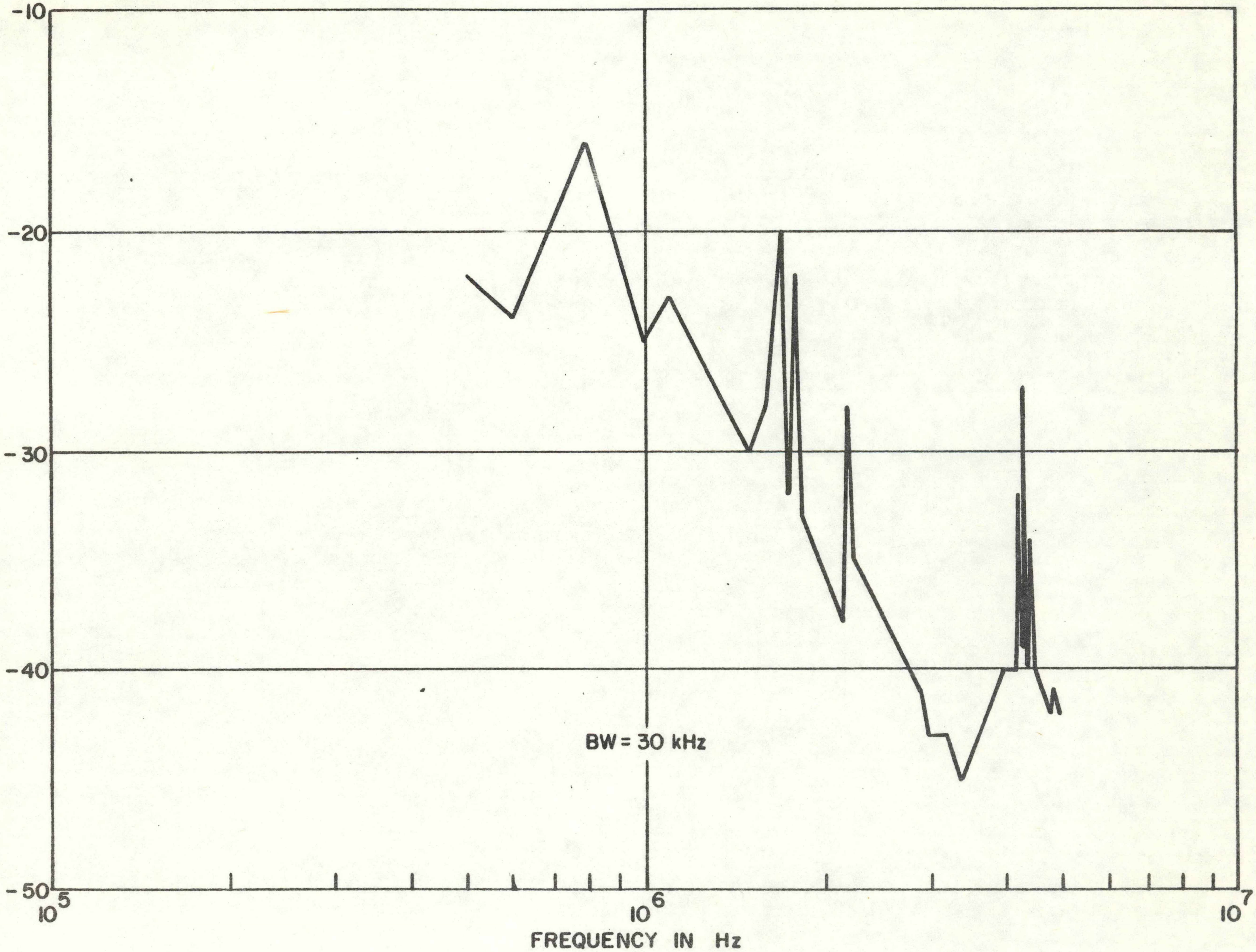


FIGURE 27. SPECTRUM OF VOLTAGE ACROSS N-P TEST POINTS.

SECTION 4

SUMMARY

In the preceding pages, examples of pertinent emission data obtained along with the controlling parameters and the measurement methodology employed during the revenue runs are presented. This data presented here together with the rest of the data collected during the road test and the data obtained at the Wilmington Yard will be analyzed, and a characterization of the locomotive 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 will be a report on locomotive emission levels tentatively scheduled for publication in fiscal year 1982.

Railroad Electromagnetic Compatability Locomotive, Volume II - Summary of E-60 CP Road Test Electromagnetic Emission Measurements, 1980 - US DOT, FRA, Daniel J O'Neill of ITT Research Institute