ENSCO PUB. NO. DOT-FR-94-06

EMI TESTING OF A HIGH SPEED TRAINSET
GERMAN INTERCITY EXPRESS (ICE)

JUNE 1994

Prepared for:

Federal Railroad Administration
Office of Research and Development
Washington DC

Prepared by:

Robert F. Gray and Leedy G. Ambrose
ENSCO, INC.
5400 Port Royal Road
Springfield, VA 22151

TABLE OF CONTENTS

SECTION TITLE PAGE

SECTION 1.0 Introduction 1

SECTION 2.0 Railroad Signaling and Power Distribution. . . . 1

SECTION 3.0 EMI Testing. 4

  SECTION 3.1 Instrumentation. 4

  SECTION 3.2 Test Schedule 6

SECTION 4.0 Analysis of Results 7

  SECTION 4.1 Suggested EMI Limits 7

  SECTION 4.2 Conducted EMI at Pantograph and Cab Signaling System 8

  SECTION 4.3 Wayside Rail-to-Rail EMI Measurements . . 16

  SECTION 4.4 Lessons Learned. 18

SECTION 5.0 Conclusions. 19

SECTION 6.0 References 19

APPENDIX A ICE Protection Circuit 20

APPENDIX B EMI Consultant Memos 23

EMI Testing of a High Speed Trainset
German Inter-City Express (ICE)

1.0 Introduction

A series of tests were performed to investigate the potential for electromagnetic interference (EMI) from the operation of the German Inter-City Express (ICE), a high speed trainset, on the North-East Corridor (NEC). The primary objective of the testing and analysis effort was to determine if operation of the trainset would interfere with the railroad signaling system. Testing was also performed to determine the inductive EMI levels (rail-to-rail) from the ICE. The purpose of this paper is to document the testing and analysis procedures used and to describe the lessons learned from the effort.

A brief overview of the railroad signaling system and power distribution method is followed by a description of the tests performed on the trainset. The data are then analyzed to determine the potential of interference in the cab signaling system. The results of the inductive EMI testing at the rail wayside are also provided. Lessons learned from the conduct of these tests are then provided.

2.0 Railroad Signaling and Power Distribution

The trains currently in revenue service along the NEC all utilize DC traction motors. Single phase 25 Hz AC power is provided to the trains by means of an electrified overhead line with the rails serving as the ground return. The distribution of the return current in the rails is dependent on a number of factors including the track geometry (eg., switches, crossovers and road crossings) bonding and grounding variations and rail impedances. The effect of these conditions is to unbalance the current in the rails. Data will be presented to demonstrate this effect but statistics on the amount of unbalance that may occur are not developed.

The rails, as shown in Figure 1, are also an integral part of the train signaling system. The two rails are excited with a modulated signal. The modulation rate is a function of the allowed speed and varies from 0 pulses per minute (ppm) indicating stop or proceed with minimum speed to 180 ppm when the maximum speed is allowed. A simple model of the modulation system is shown in Figure 2. The carrier signal is switched on and off with a period T. The switching rate, 1/T, is dependent on the conditions within the signal block. The load is actually the impedance of two rails and the train wheels. The load impedance and therefore the signal current varies as the trainset approaches the transmitter. The nominal values for the carrier frequency and signal current along the NEC are 100 Hz and 1.5 amps respectively. Modulation rates are only up to 3 Hz (180 ppm) at this time, limiting the signaling system to a very narrow bandwidth. Other frequencies are of interest as presented in Section 4.1.

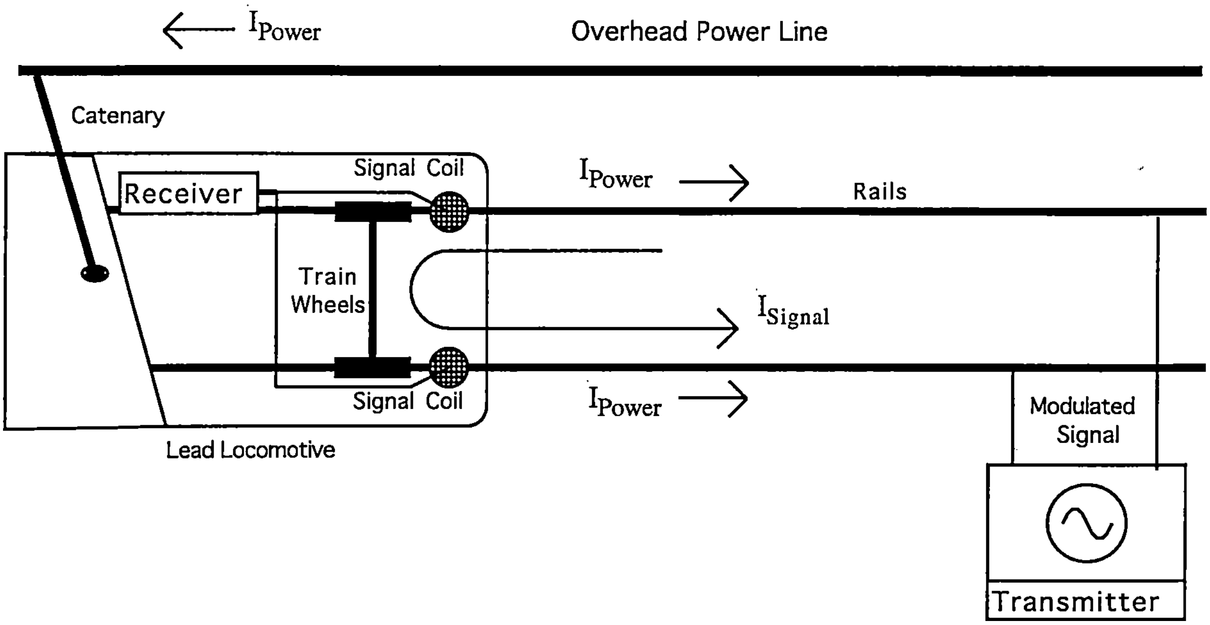


Figure 1 : Railroad Signaling Equipment.

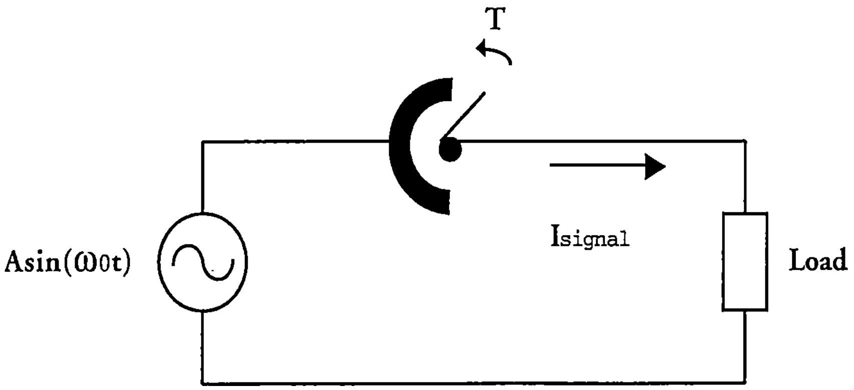


Figure 2: Transmitter Model.

When a train enters the block, its leading wheelset completes the signaling circuit causing a differential current to flow. The train detects the modulated signal in the rails through two signal coils located just in front of the lead wheelset. The coils are differentially connected as shown in Figure 3 to help reject any interference from the 25 Hz AC power harmonics. The signal is then filtered and amplified before going to a set of modulation detectors.

If AC power interference becomes too high due to adverse track geometries or other equipment problems, the signaling system will interpret the received signal as having 0 ppm modulation and will signal to stop or proceed with minimum speed. This signaling technique has years of proven service with traditional DC traction motors [1]. The introduction of AC traction motors and their accompanying variable frequency power regeneration creates a potential safety issue because the new frequencies may interfere with cabborne signaling equipment. The frequency generated by the on-board power inverters is a function of the train's speed. The primary concern is that the operation of the AC traction motors will generate large currents in the operating band of the cab signaling equipment, causing a false stop condition.

Test procedures [2] have been proposed for use in measuring the EMI produced by a trainset but they have not been established as formal standards. EMI limit levels have not been formally set.

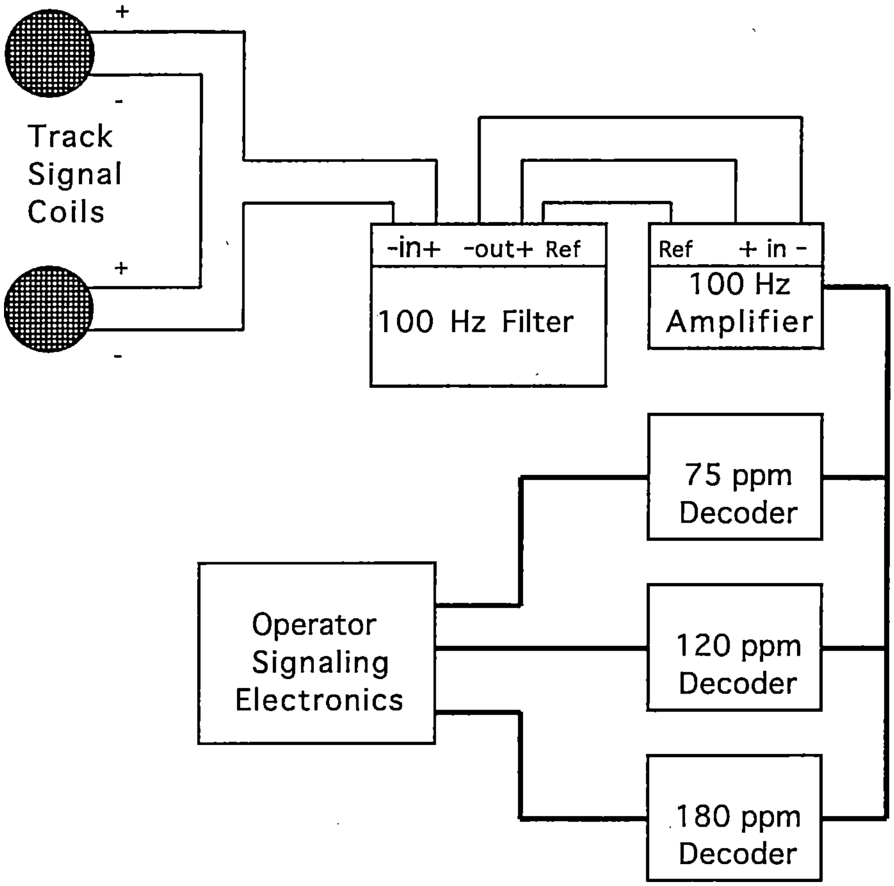


Figure 3 : Signaling Receiver Block Diagram.

3.0 EMI Testing

3.1 Instrumentation

EMI measurements were performed on an advanced high speed rail train using the test set up shown in Figure 4. The instrumentation allowed real-time observation of the critical circuits, such as the pantograph current and 100 Hz filter voltages. High quality, digital recordings of the signals were made and used for more detailed processing and analysis. The microphone was connected to the recorder to document the train speed, location and acceleration. The equipment set-up varied slightly depending on the direction of the train. The trainset tested used two locomotives, one in front (lead) and one in the rear. Measurements were made with the train traveling in both directions but always in the same locomotive. When the instrumented locomotive was in the rear of the train, the open circuit coil voltage was recorded instead of the filter input/output.

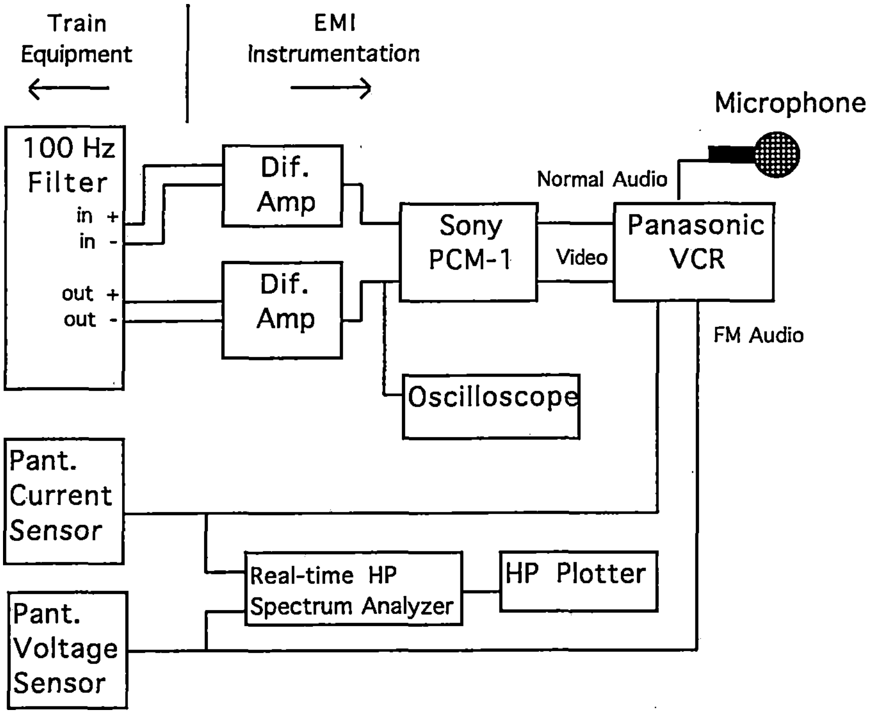


Figure 4 : Typical EMI Measurement Set-up.

A picture of the instrumentation in the train cab area is shown in Figure 5. The recording equipment is on the left, behind the patch panel used to connect to the trainset's pantograph voltage and current sensor outputs. The spectrum analyzer and oscilloscope are in the middle and the plotter is off to the right.

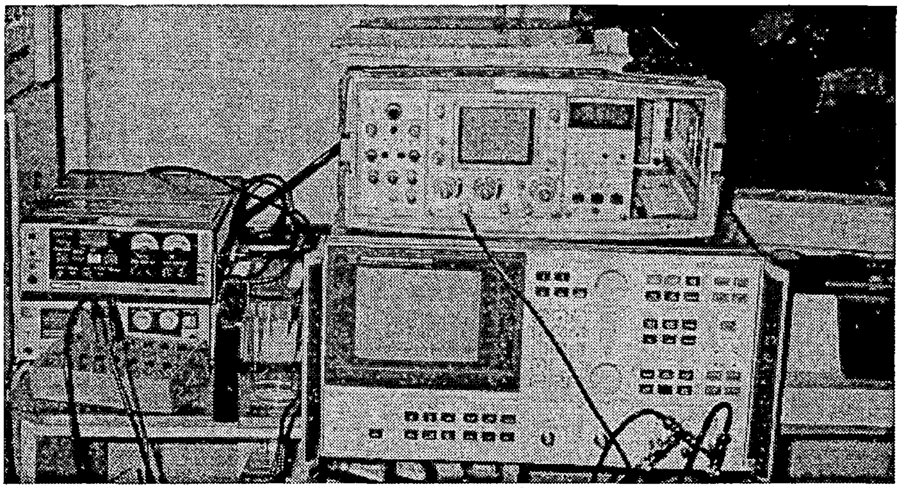


Figure 5: EMI Instrumentation Setup.

High impedance differential amplifiers were used to measure the signal voltages (filter input/output and open circuit) as shown in Figure 6. The amplifiers ensured that the signaling system circuits were not affected by the instrumentation.

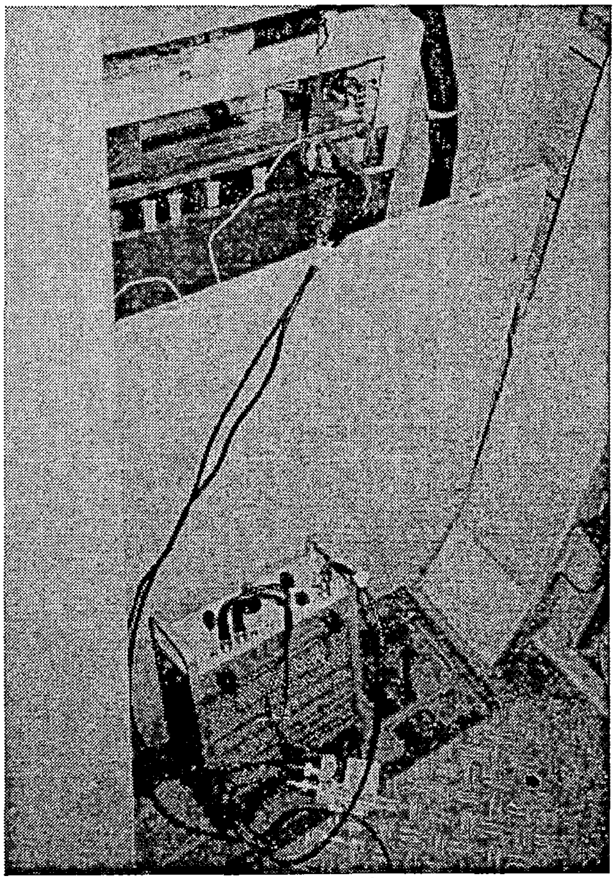


Figure 6: Track Coil Open Circuit Voltage Measurement.

Processing of the data included compensation for the instrumentation (recorder gain, probe factors, etc.) and spectrum analysis to obtain the frequency characteristics of the pantograph currents. The spectrum analyzer provides an estimate of the rms value of the data at each of its frequency bins. Since the frequency spectrum analyzer has a finite resolution bandwidth, the analyzer normalizes the output by the bandwidth yielding units of either volts^2/Hz or amps^2/Hz. Taking the square root of a spectrum results in data units of volts/$\sqrt{}$Hz or amps/$\sqrt{}$Hz.

If a narrowband tone with peak value of 1 amp rms is processed by the analyzer, it would be seen at the frequency bin containing the source frequency with a peak value of 1 amp/$\sqrt{}$Hz. In the analysis that follows, the EMI limits are given in amps but they can be compared directly with the spectrum analyzer data (in amps/$\sqrt{}$Hz) for the frequency of interest because the measurements were made with bin widths (frequency resolution) capable of resolving the spectrum into narrowband tone.

3.2 Test Schedule

Measurements for conducted EMI were performed on three different sets of runs along the NEC between Washington, D.C. and New York, NY. The tests included multiple starts and stops as well as high speed running. The acceleration rates varied greatly depending on the track conditions. The trainset typically used regeneration during braking but at least one high speed stop was made using only the air-actuated disk brakes. Spectrums of the AC current and voltage and the time domain waveforms of the signal circuits were monitored in real-time during these runs. The recorded data were then processed in the laboratory to further investigate the potential EMI effects on the signaling circuit. Representative results for the operational conditions of stopped, accelerating, running at speed and braking, are presented in the next section.

The test runs for conducted EMI were performed on the following dates:

July 9 - 10, 1993
July 22, 1993
October 1, 1993.

Inductive EMI measurements were performed at the rail wayside on Track 3 just North of Baltimore, MD. The experiments were performed on July 12, 1993. The data presented were processed in real-time at the wayside. No post-processing was performed.

4.0 Analysis of Results

4.1 Suggested EMI Limits

Based on a knowledge of EMI levels for existing trains, the following values were suggested as reasonable EMI limits. These values were established during the pre-test planning [3, 4]. The validity of the EMI limits given below is a major concern and future work is needed to verify their adequacy. It is noted that the nominal loop current for the 100 Hz signaling system is 1.5 amps. Therefore, the differential signal should be at least 50% greater than the interference. The common mode rejection of the signaling system will further enhance the modulated signal waveform, allowing the cab signal receiver to accurately resolve the correct signal. This indicates that the 100 Hz limit is reasonable. Comparable limits are used for the future signaling bands. The broadband limit (500 Hz to 20 kHz) is based on past EMI testing of audio frequency track circuits.

Conducted EMI Limits at the Pantograph (Single Power Unit)

90-103 Hz	1.0 A rms*	(NEC signal band)
145-165 Hz	1.0 A rms	(future band)
245-255 Hz	0.5 A rms	(future band)
500 Hz - 20 kHz	0.04 A rms	

Notes: 1. Double Limits for Total Train (2 Power Units)
2. Assume guard-band of +/- 10% of center frequency outside each of these bands (up to 20 dB increased levels at extremes of the band).
* This was initially set at 0.9 Amps rms. The ICE has a protection circuit designed to keep the 100 Hz current at or below 1 Amp rms. This circuit is described in Appendix A.

Cab Signal Interference (Carborne)

90-103 Hz	0.5 A rms (Equivalent Rail Loop Current)
245-255 Hz	0.25 A rms (Equivalent Rail Loop Current)

Note: Assume the same guard-bands as above.

Inductive EMI (Wayside/Under-Train)

0-500 Hz	100 mV rms
500 Hz - 20 kHz	20 mV rms

It is assumed that if the ICE EMI levels are below these limits then the critical signaling and other rail control systems will function properly when the ICE is on the NEC.

4.2 Conducted EMI at Pantograph and Cab Signaling System

The spectrum of the pantograph current with the train stopped is given in Figure 7. The hotel power systems such as lights and air conditioning were operating during this period. The peak input current at 25 Hz is only 10 amps (with a measured line voltage of 11.4 kV) and the 100 Hz (150 Hz) tone is less than 0.1 amp (0.25 amp). This spectrum was generated by processing 34 separate spectrums and retaining the peak value for each spectral bin.

A typical spectrum of the incoming AC current with the train accelerating is shown in Figure 8. The spectrum was obtained using the peak hold function on the spectrum analyzer over 34 input records (about 2.5 minutes of data). The current at 100 Hz and 150 Hz is nearly 1 amp. The series of slightly stronger peaks in the 35 Hz to 60 Hz range are actually the same tone that increased in frequency as the train accelerated.

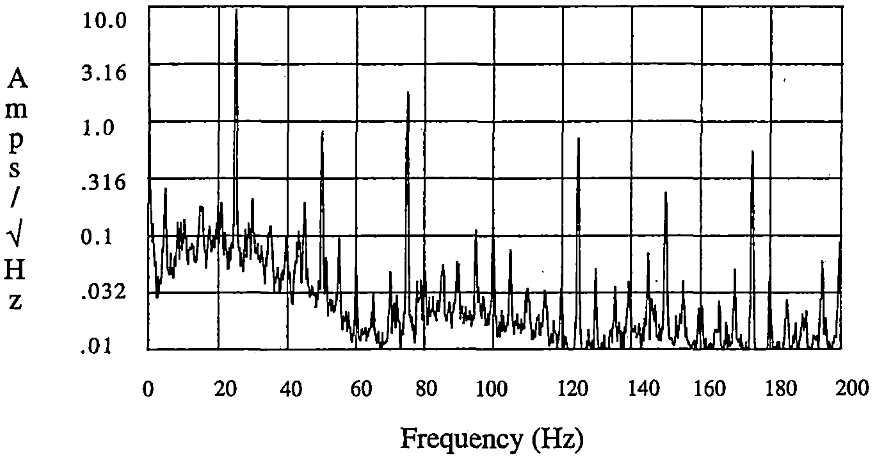


Figure 7: Pantograph Peak Current Spectrum with Train Stopped.

The same run was also processed using the stable mean option on the spectrum analyzer. The result is shown in Figure 9. As expected, the mean values are lower than the peak values shown in Figure 8. The 100 Hz tone is less than 0.6 amps while the 150 Hz level is 0.5 amp. The average signal levels in Figure 9 are about a factor of 2 to 5 lower than the peak signal shown in Figure 8.

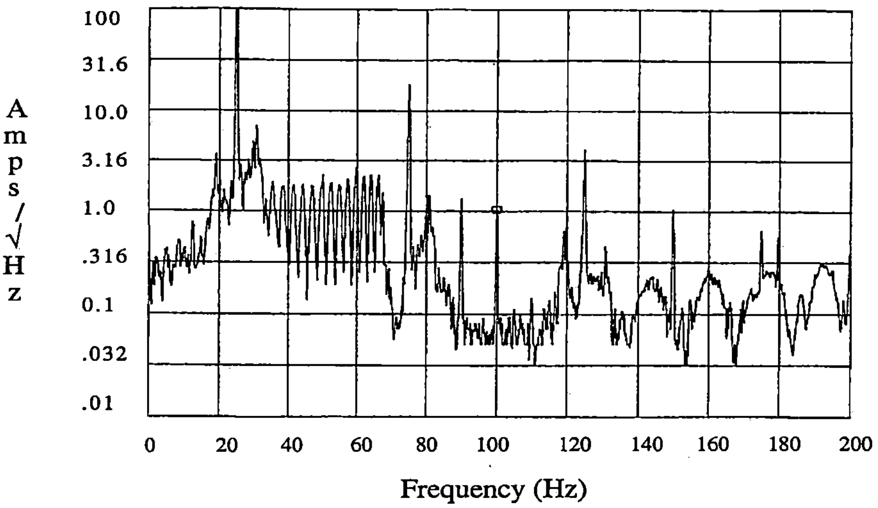


Figure 8: Pantograph Current Peak Spectrum with Train Accelerating.

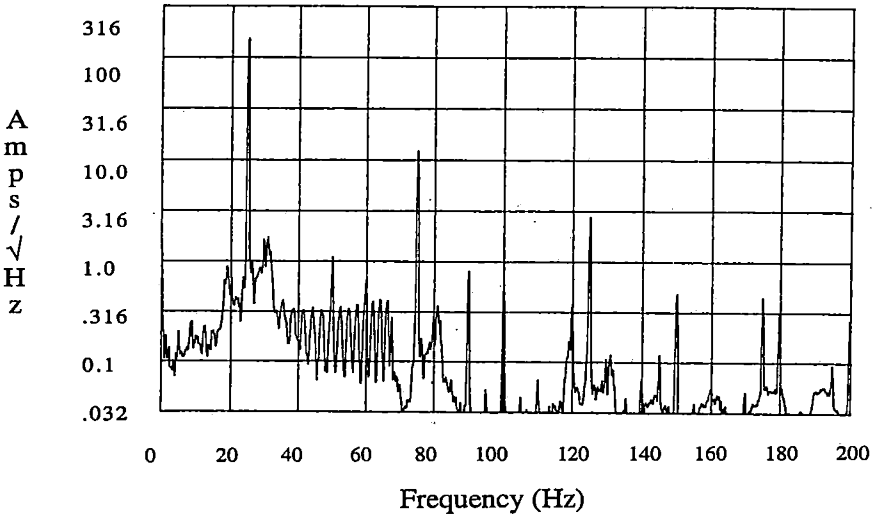


Figure 9: Pantograph Current Spectrum with Train Accelerating - Stable Mean Processing.

Similar results were obtained for the operational condition of running at high speed, as shown in Figure 10. This peak hold spectrum was generated by processing about 1 minute of data. The train was running at a nearly constant speed of 125 MPH. The 100 Hz and 150 Hz signals are slightly less than 0.7 amps. There are two tones in the frequency range of 245 to 255 Hz with amplitudes of 0.5 and 0.7 amps. The 250 Hz tone at 0.7 amps is higher than the limit presented in Section 4.1 The moving line seen during acceleration (Figures 8 and 9) is absent in Figure 10. This spectrum also shows an increase in the pantograph current from about 200 Hz to 400 Hz. This rise at the higher frequencies is most likely due to the operation of other electrical systems on the trainset.

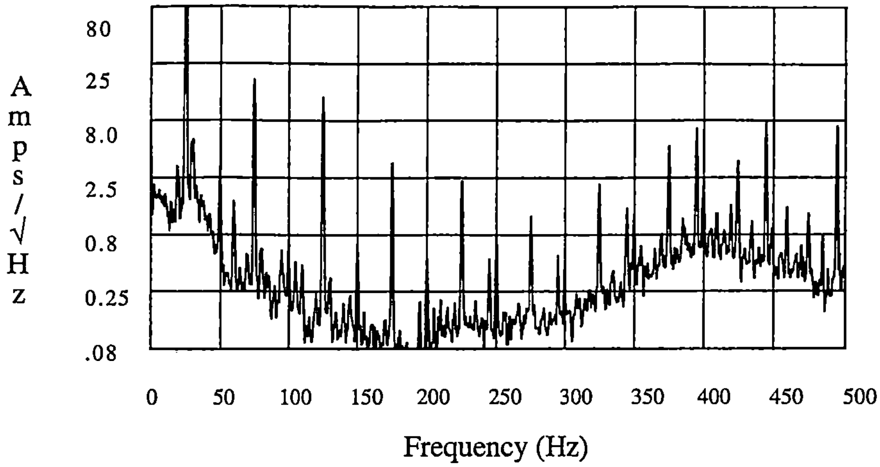


Figure 10: Pantograph Peak Current Spectrum
with Train Running at 125 MPH.

The moving line returned during periods of braking as shown in Figure 11. This spectrum was obtained during braking without regeneration from a speed of 125 MPH. The series of 1 amp peaks seen in the 80 to 105 Hz range are from a single tone that started at the highest frequency and moved down as the train slowed under braking. When the train accelerated, the line increased in frequency. The 150 Hz EMI is below the suggested limits.

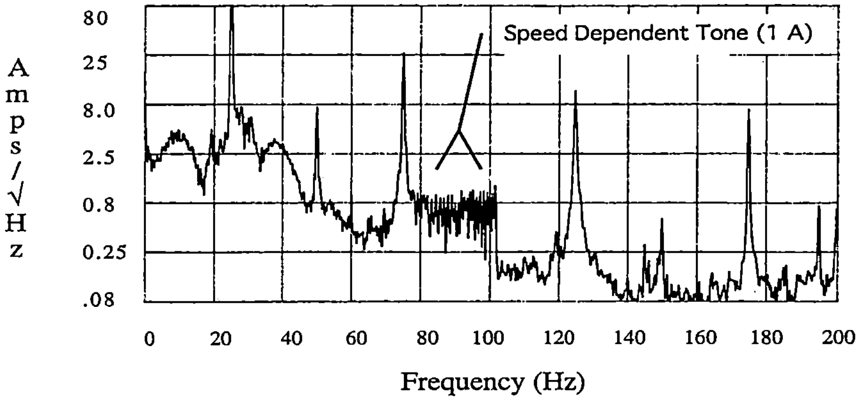


Figure 11: Pantograph Peak Current Spectrum
during Braking.

The dependence of the spectral lines on train acceleration or deceleration is best seen in the waterfall spectrogram shown in Figure 12. Here the tone is at much lower frequencies but its movement over time is very clear. The plot shows multiple spectrums of the incoming current during acceleration. The successive spectrums are shifted slightly upward to allow easier viewing. The oldest spectrum is on the bottom of the graph just above the frequency axis. The newest spectrum is at the top of the graph. The train was under moderate acceleration as indicated by the peak primary current of only 140 amps. The speed dependent tone starts out at a few Hz and increases continuously to a frequency of about 35 Hz in the top spectrum. The moving tone has an amplitude of 0.6 amps (determined from single line graphs).

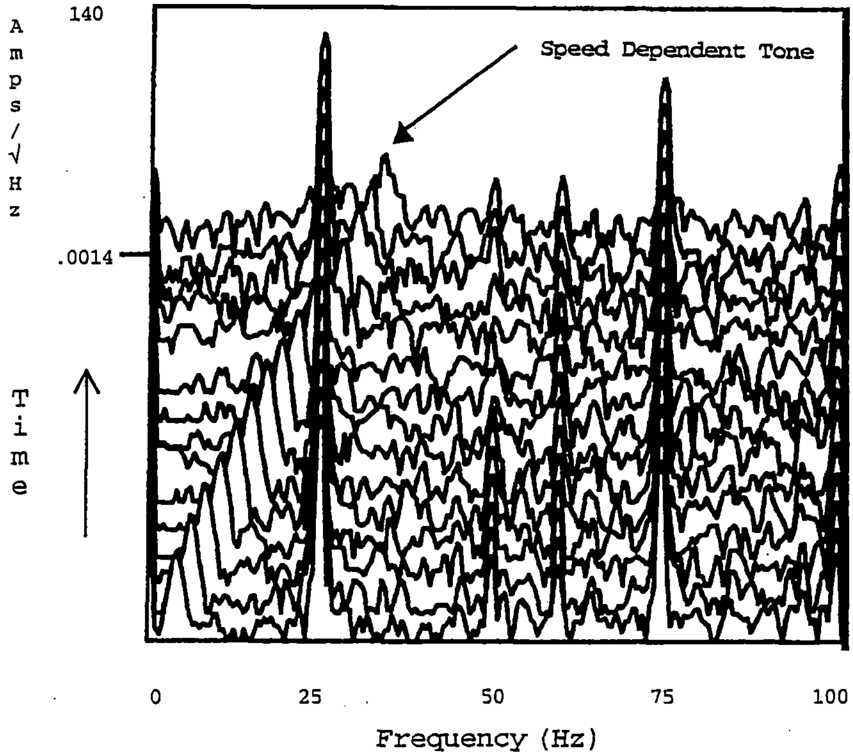


Figure 12: Spectrogram Showing Moving Tone.

The spectrum shown in Figure 13 was taken with the ICE running at speed. The Figure demonstrates that the suggested EMI levels for frequencies above 500 Hz are exceeded. Exceeding the suggested EMI levels at the higher frequencies will not affect the cab signaling system operation.

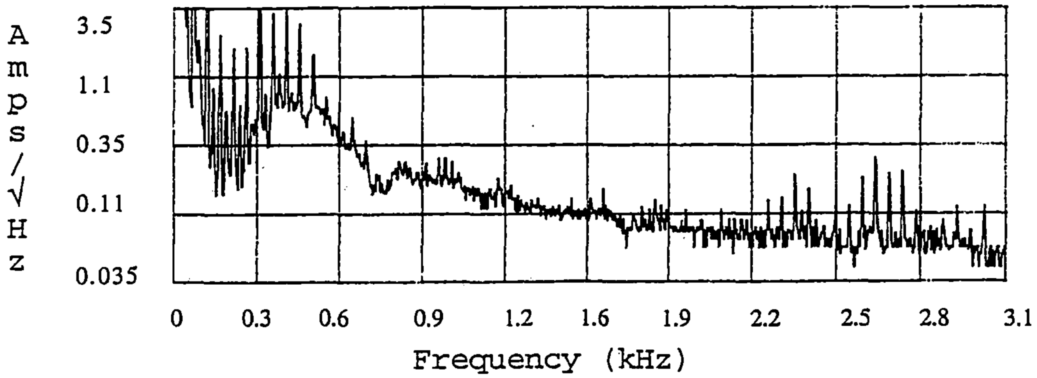


Figure 13: High Frequency Pantograph Current Spectrum.

The cab signal voltages were examined in the time domain to see if any EMI from the operation of the traction motors could be observed. A typical filter output voltage signal is shown in Figure 14. The data were collected during a period of acceleration. The voltage increase is due to the movement of the train. As the train gets closer to the transmitter, the differential current goes up because the impedance decreases. Similar results were obtained for the other operating conditions. The voltage signal time scale is expanded in Figure 15. The on and off periods are clearly defined. The signal during the off periods is actually related to the primary power line with a frequency of 25 Hz.

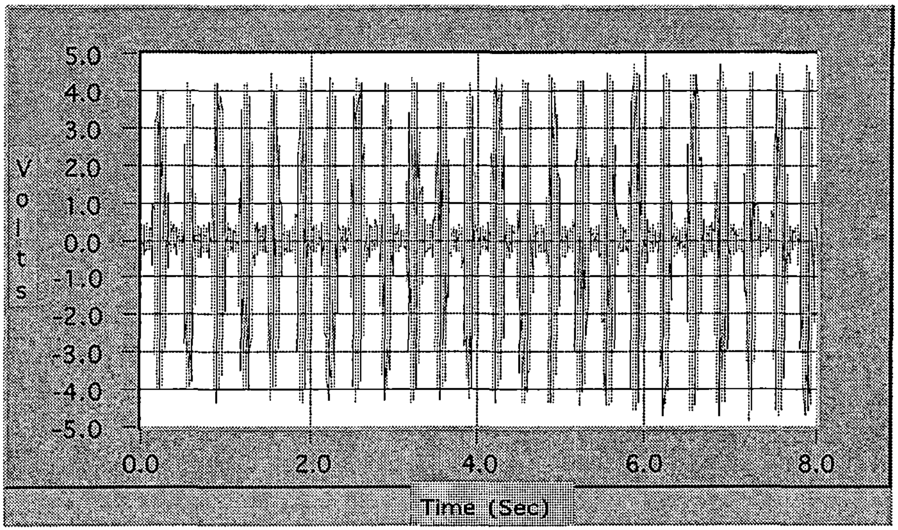


Figure 14: Filter Output Voltage During Acceleration.

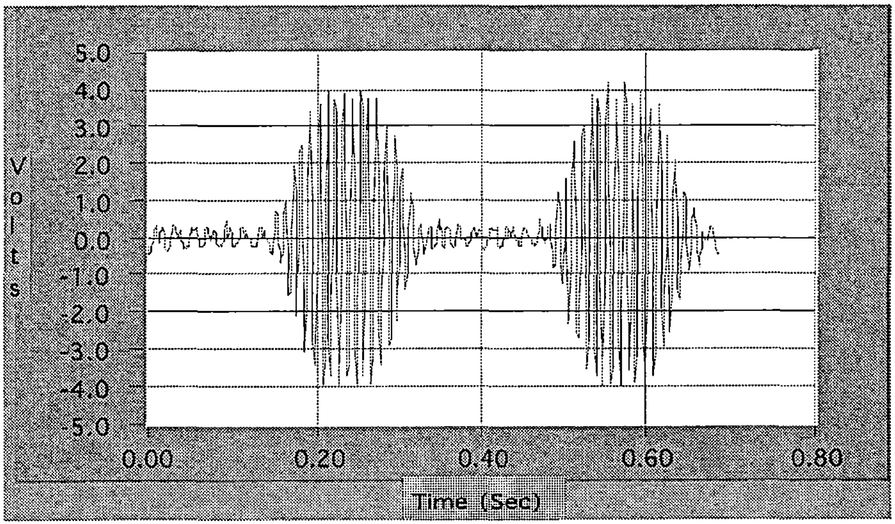


Figure 15: Expanded View of Filter Output Voltage.

The open circuit coil voltage, V(oc), with the train stopped and the transmitter on is shown in Figure 16. The voltage waveform is similar to the filter output voltage of Figure 14 except that it has not been filtered. The spectrum of the signal in Figure 16 is given in Figure 17. The 100 Hz tone is seen but the noise makes it difficult to detect the modulation signal.

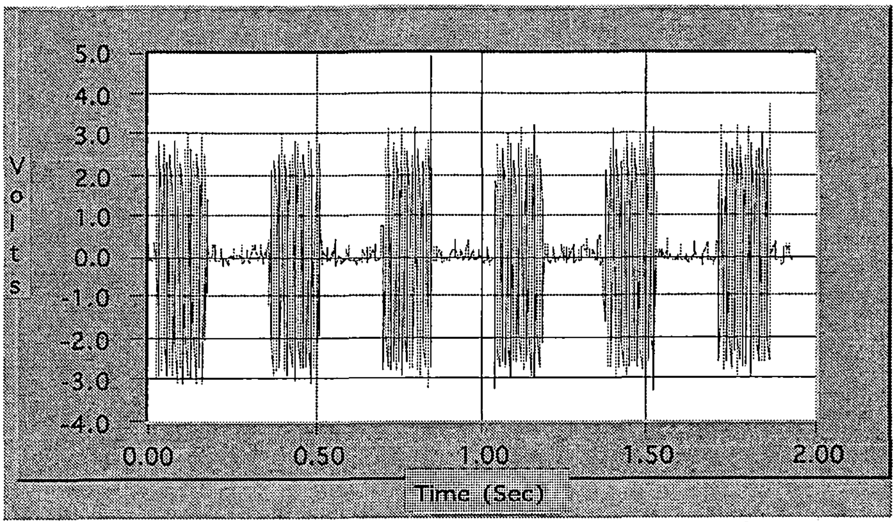


Figure 16: Open Circuit Coil Voltage with the Train Stopped and Transmitter On.

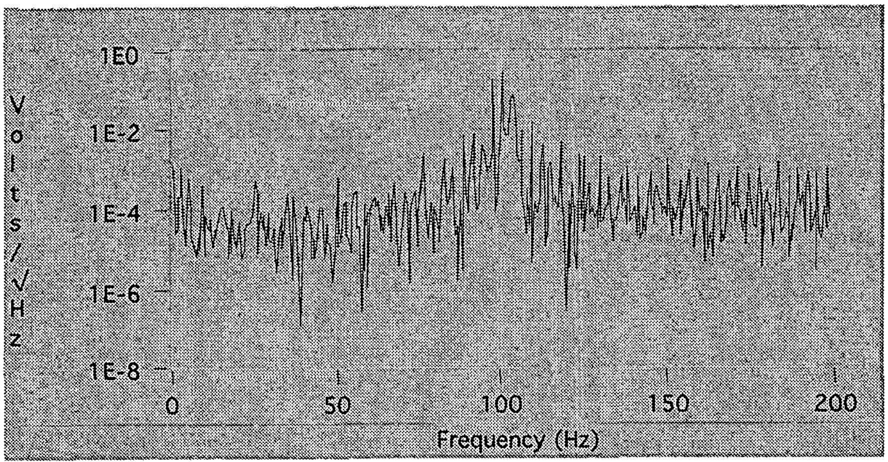


Figure 17: Spectrum of V(oc) in Figure 16.

The simple model of the signal transmitter in Figure 3, generates an open circuit voltage as shown in Figure 18. The modulation rate was set to 180 ppm (3 Hz). The waveform compares well with the measured signal in Figure 16. The frequency spectrum of the transmitter model, given in Figure 19, also correlates well with the measured spectrum shown in Figure 17. These comparisons add to the confidence level of the open circuit voltage measurements.

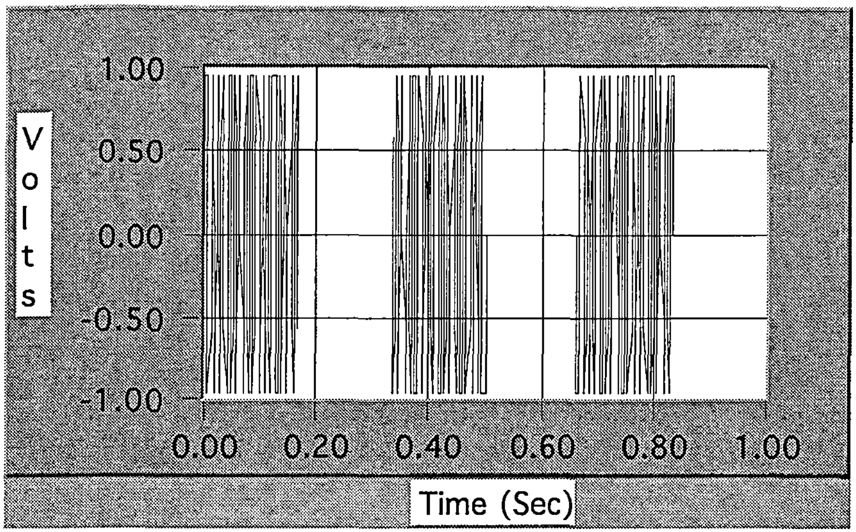


Figure 18: Open Circuit Voltage for Circuit in Figure 3 (180 ppm).

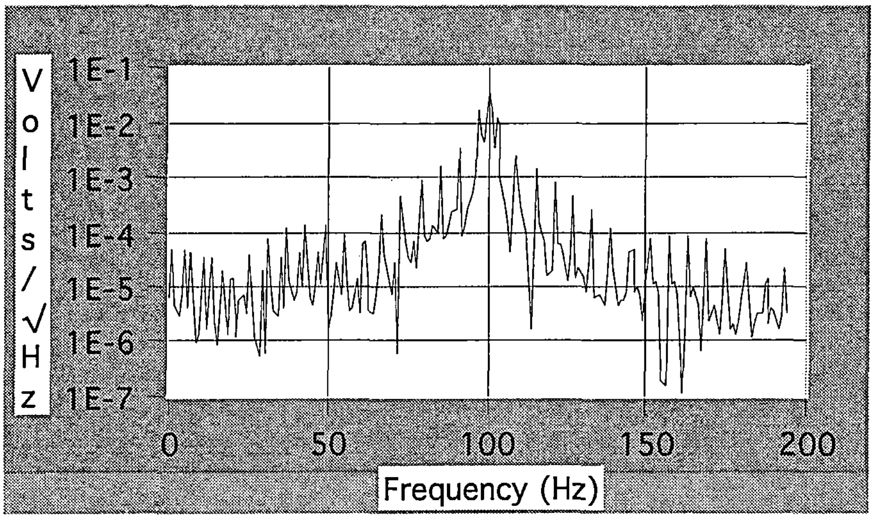


Figure 19: Spectrum of V(oc) in Figure 18.

The open circuit voltage data shown in Figure 20 were obtained during acceleration. The instrumented locomotive was in the rear of the train. The 100 Hz transmitter signal is not present in this data because the lead locomotive shorts it out. The 25 Hz power line signal is seen in the data as the .02 second crossovers. The 25 Hz signal would be much larger if the signal coils were not connected differentially. The spectrum of the open circuit voltage waveform of Figure 20 is presented in Figure 21. Comparison of the spectrums in Figures 17 and 21 shows that the transmitter excites the coil with a signal that is about 10 times larger than the power line interference.

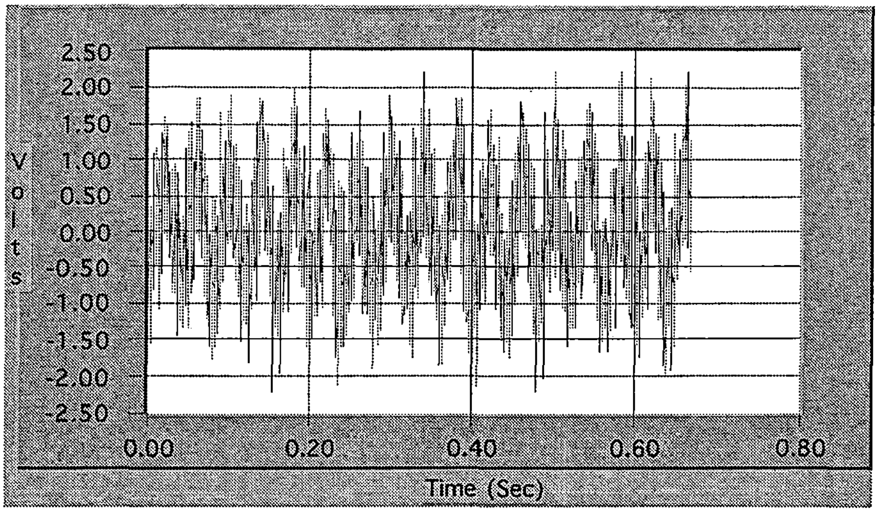


Figure 20: Open Circuit Coil Voltage Under Acceleration.

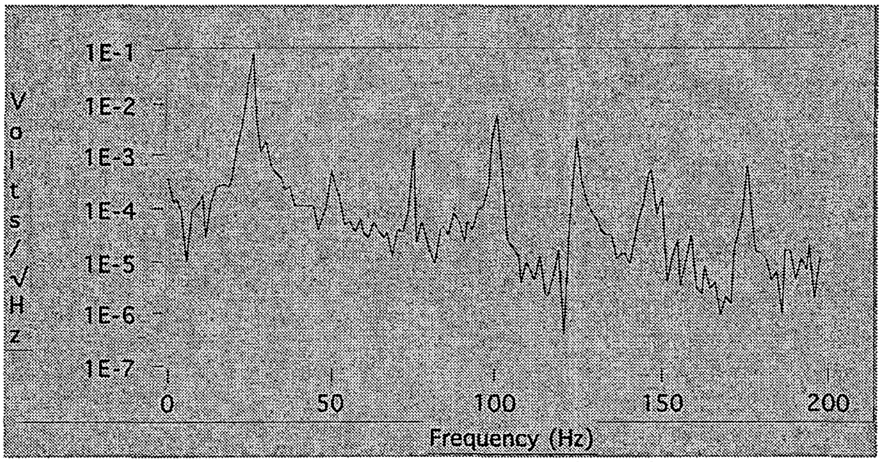


Figure 21: Spectrum of V(oc) in Figure 20.

The effects of track conditions on the signal coil voltage are demonstrated in Figure 22. The data coincide with the train passing over a switch. The current obviously becomes unbalanced during this period due to the different rail geometry. The change in signal is not caused by the operation of the inverters in the high speed trainset. Rather this effect is normal for all types of trainsets and demonstrates that the cab signaling system can operate in less than ideal conditions. Short term disruption in the balance of the rail currents will not create a false alarm. This is significant because it indicates that the generation of short lived EMI, such as the moving tones discussed above, can be tolerated by the cab signal system.

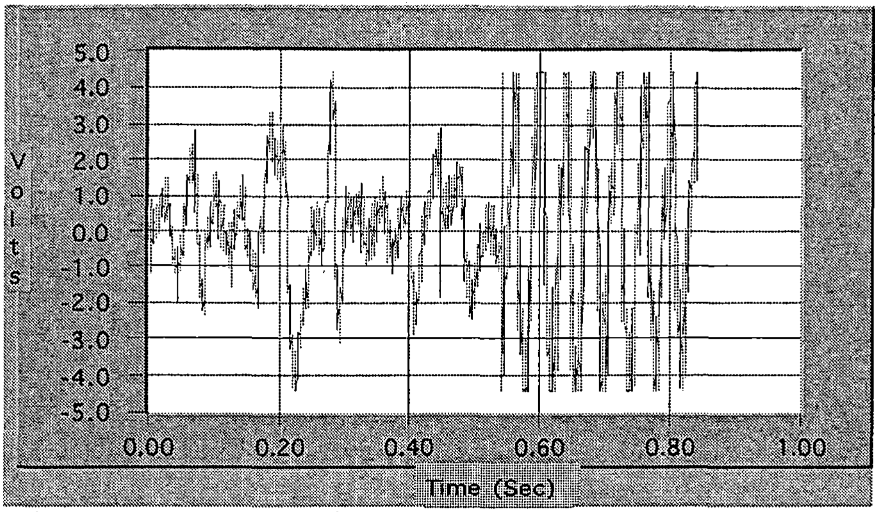


Figure 22: Transient V(oc) Due to Rail Geometry.

4.3 Wayside Rail-to-Rail EMI Measurements

The wayside measurements consisted of measuring the rail-to-rail voltages at a commuter stop north of Baltimore. The rail-to-rail voltage signals were obtained using rail clamps connected to the test track (Track Number 3). The track voltages were recorded on the digital tape unit and simultaneously viewed with a spectrum analyzer. These track voltage measurements were not processed in the lab. Averaged measurements were made with the spectrum analyzer and plotted during selected periods of the ICE Train activity. Electrical power was supplied with a portable ac generator.

Measurements at the wayside location were made with the train stopped, passing at speed, accelerating, and braking. Spectrum plots of the rail-to-rail voltages under the different test configurations are provided. Figure 23 was collected with the ICE train passing southbound at 50 to 60 mph. The ICE train was traveling northbound at 40 mph, and then stopped over the test point under maximum braking when the spectrum in Figure 24 was collected. Figure 25 shows the rail-to-rail voltage measured when the ICE train was over the test point and accelerating with maximum power. With the exception of the signal at the power line frequency (25 Hz), none of the measured results exceed the suggested limits given in Section 4.1.

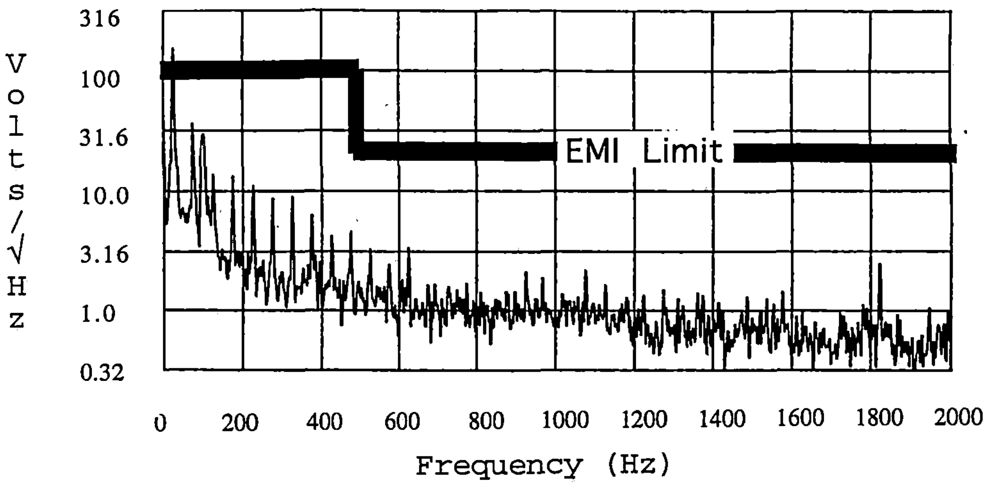


Figure 23: Rail-to-Rail EMI with ICE at Constant Speed.

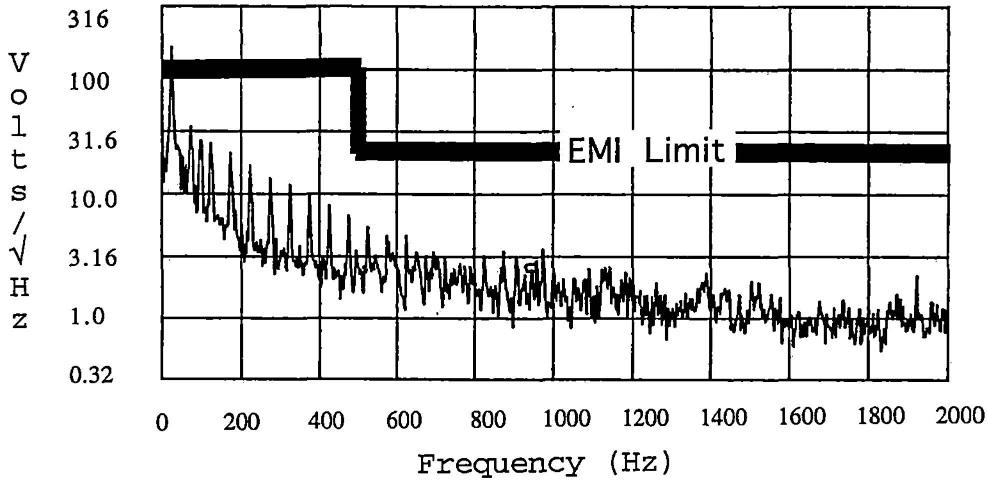


Figure 24: Rail-to-Rail EMI During Braking.

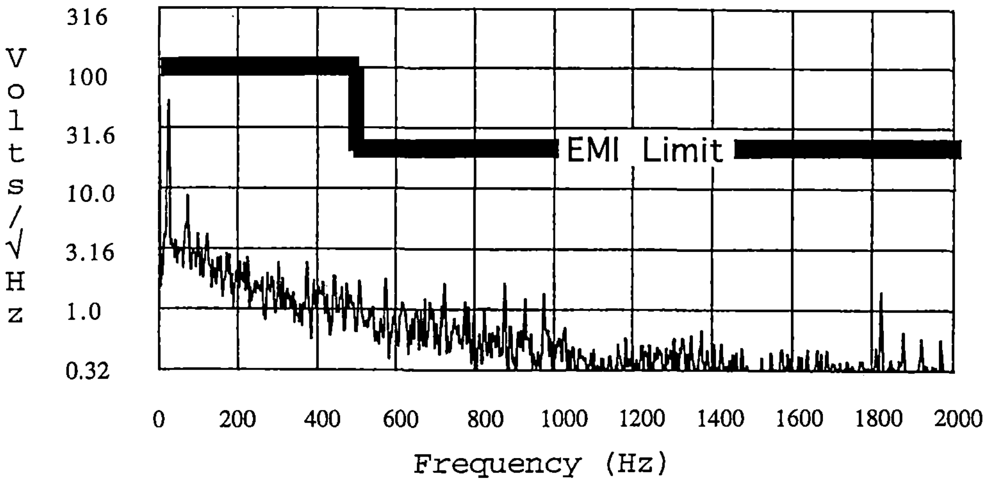


Figure 25: Rail-to-Rail EMI During Maximum Acceleration.

4.4 Lessons Learned

The conduct of the EMI tests on the ICE provided several important lessons that will be useful in future testing efforts on high speed rail trainsets.

1. A microphone was used to record test comments and train activity on the test data tape. This proved to be a valuable tool during post test data processing.

2. Real-time analysis was complemented with record/playback post test analysis, allowing better characterization and assessment of the EMI effects.

3. Simple analytical models helped to understand the results and added confidence to the conclusions.

4. The lack of standardized EMI limits complicates the evaluation of high speed rail systems.

5. A more compact and automated approach to acquiring and analyzing the EMI data is needed. The deployment of the instrumentation needed to perform real-time analysis in the constrained area of a locomotive cab is difficult at best. Only about 20 % of the recorded data were processed during the post-test analysis. Both issues could be alleviated with a different instrumentation approach.

5.0 Conclusions

Testing was performed on the ICE trainset to determine if operation of the AC traction system would affect the on-board signaling system. The incoming AC power and the cab signal voltages were measured during three different test periods. Spectrum analysis of the in-coming power line current indicated that the peak levels in the critical frequency band of 90 to 110 Hz were typically at or below 1 amp. The 150 Hz pantograph current levels were at or below the suggested level of 1 amp rms but the 250 Hz responses were typically above the 0.5 amp level. This finding indicates that the ICE may interfere with future cab signaling systems operating at 250 Hz. The ICE has an effective and critical 100 Hz protection circuit as described in Appendix A. A similar protection module could be developed for 250 Hz.

Similarly, the pantograph current levels exceeded the suggested limit of 0.04 Amps rms in the range of 500 Hz to about 700 Hz. The higher than specified levels may interfere with track circuits such as grade crossing and other audio frequency overlay circuits planned to be installed on the future electrified New Haven - Boston NEC section.

The 100 Hz cab signal voltage waveforms were found to be free of interference related to the operation of the trainset. This assessment is limited to the trainset under investigation and should not be extended to other similar systems.

The wayside rail-to-rail measurements indicated that the inductive EMI produced by the ICE was well below the suggested limit.

Future research will study other trainsets including DC traction motor locomotives that currently operate along the NEC. An in depth study of the susceptibility of the cab signal system to EMI is also needed. The lack of concise EMI limits for the input current versus frequency makes the testing of new trainsets very difficult.

6.0 References

1. Elements of Railroad Signaling, Handbook 50, General Railway Signal Company, June 1954.

2. Conductive Interference in Rapid Transit Signaling Systems, Volume II: Suggested Test Procedures, UMTA-MA-06-0153-85-6 (DOT-TSC-UMTA-86-7), June 1986.

3. Frasco, L., Technical Memo: Recommendations for EMI/EMC Certification Testing - German ICE Train HST Demonstration - Amtrak Northeast Corridor Operation, July 5, 1993.

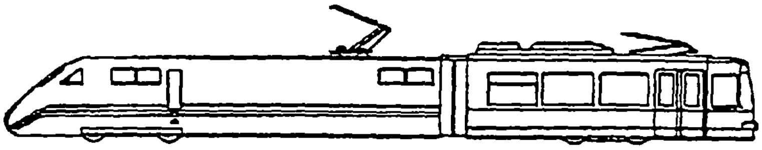
4. EMI Test for Certification of the German Inter-City Express Trainset, ENSCO, Inc., July 9, 1993.

APPENDIX A

ICE Protection Circuit

SIEMENS

Verkehrstechnik
Postfach 3240 D-8520 Erlangen



TELEFAX

An/To:	ENSCO, Inc.	Von/From:	Siemens AG
Abt./Dept.:		Abt./Dept.:	VT 623
Ort/Place:	Springfield, Virginia	Ort/Place:	Erlangen
Name:	Mr. Dale Stout	Name:	Prem
Tel./Phone:	001-703-321-4715	Tel./Phone:	09131-7-28009
Fax Nr./Fax No.:	001-703-321-7619	Fax Nr./Fax No.:	09131-7-21365
		Seiten/Pages:	1 von 5

Betreff/Subject **Outstanding EMI Tests** Datum/Date: **28.09.93**

Dear Dale,

thank you for the facsimiles you have sent to me concerning the open issues of the EMI tests. Unfortunately I was on vacation last week and my collegue was joining the ICE-Train on the National Tour. Therefore please apologize the delay of the required answers.

The requested information can be given as followed:

1. The calibration of the voltage probes given by the traction control unit was okay. The transmission behavior of these transformers is correct up to frequencies of at least 2000 Hz.

   Refering the current probes we have some concerns that the calibration was not absolutely correct because of our primary current transformer. This transformer might have had an overburdening because of the higher frequency (25 Hz instead of 16 2/3 Hz)
   Therefore we will replace this 15 VA-current transformer by a 30 VA-transformer on one power car for the additional EMI-tests this week. So we can make sure that all frequencies are represented exactly.

2. The 100 Hz-protection relay is set at 1 A. Please find enclosed the fax I have sent to Ed Lombardi in July concerning the 100 Hz-relay. In addition I have enclosed a disription and the technical data of this relay.

3. I'm sorry that I'm not able to be in the U.S. for the final tests this week. But Mr. Klüpfel will arrive in Washington on Wednesday. He will take care of the requested EMI-tests and will supply the necessary equipment as he did in July.

Concerning the "Outstanding EMI Items", Point 3, we hope to give you a sufficient information about the source and the possibilities to mitigate the high levels of the current harmonics in the low audio frequency range (500 - 1500 Hz).

Best regards

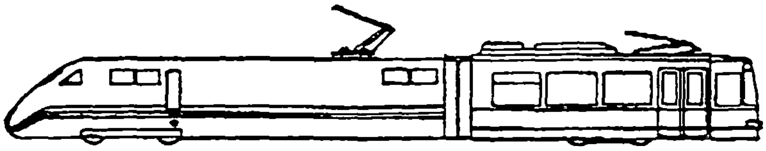
J. Prem

copy to

Frasco + Ass. Inc.
Belmont MA
Mr. Lou Frasco
Phone: 001-617-489-8413
Fax: 001-617-484-5176

SIEMENS

Verkehrstechnik
Postfach 3240 D-8520 Erlangen



TELEFAX

An/To:	Amtrak	Von/From:	Siemens AG
Abt/Dept.:	Engineering & Testing	Abt/Dept.:	VT 623
Ort/Place:	Philadelphia	Ort/Place:	Erlangen
Name:	Mr. Ed Lombardi	Name:	Prem
Tel./Phone:	001-215-349-2748	Tel./Phone:	09131-7-28009
Fax Nr./Fax No.:	001-215-349-2767	Fax Nr./Fax No.:	09131-7-21365
		Seiten/Pages:	1 von 1

Betreff/Subject: **Siemens ICE/USA 057** Datum/Date: **01.07.93**

Dear Ed,

the item concerning the 100 Hz-protection we discussed in our last meeting in Philadelphia, can now be answered.

The traction control unit has an active control to reduce 100 Hz-currents in the catenary. This active control is able to achieve a 3 dB-damping for all currents between 95 and 105 Hz, that means to halve the amplitudes. For lower and higher frequencies (83-94 Hz and 106-116 Hz) the 100 Hz-control is still working, but the achievable damping is less than 3dB.

In addition the ICE has a 100 Hz-protection relay, which applies and cuts the MCB off, when currents with a frequency of 99 to 101 Hz exceed a level of 1 A. For currents with lower and higher frequencies the apply-levels increase with a gradient of 40 dB/dec. (i.e. 2A for 98 Hz/102 Hz-currents and 10 A for 97 Hz/103 Hz - currents).

I hope this facts will help you and I'm looking forward to meet you next week in Washington

Best regards

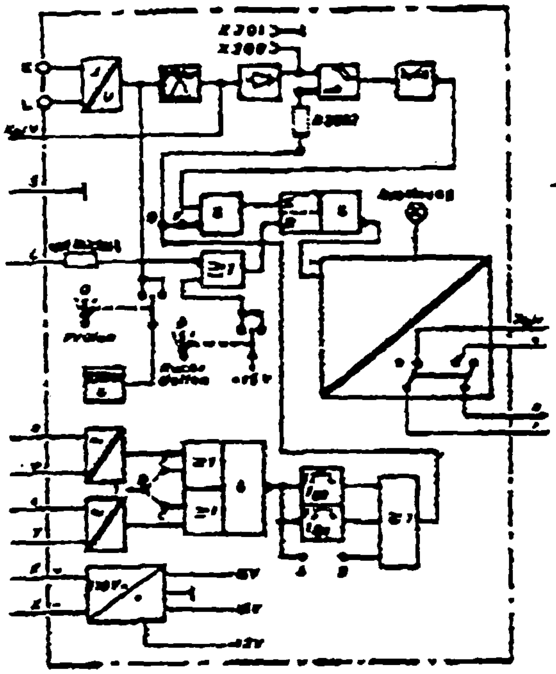
J. Prem

J. Prem

Frequenzüberwachung
10 HC 06 b-E

Elektronik

GERÄTESCHALTZEICHEN



BESCHREIBUNG

Das Gerät 10HC06 ist ein Spezialgerät der Baureihe 3C-V. Es hat die Aufgabe, den im Oberstrom von Fahrdrahtlokomotiven auftretenden 100Hz-Anteil zu erfassen, auszuwerten und bei Überschreiten eines unzulässigen Grenzwertes die Anlage abzuschalten.

FUNKTIONSBESCHREIBUNG

Der Oberstrom wird über einen Stromwandler im Fahrzeug dem Gerät zugeführt. Mit einem Aktivfilter wird der 100Hz-Anteil ausgefiltert, gleichgerichtet und an einem Komparator mit einer einstellbaren Spannung (Überschreitung des Stromgrenzwertes) verglichen. Das abgegebene binäre Signal durchläuft ein einstellbares Verzögerungsglied (Überschreitung der Grenzzeit) und wird anschließend gespeichert.

Das gespeicherte Signal sperrt eine Relais-Schaltstufe. Das Relais, welches im störungsfreien Zustand angezogen ist, fällt ab und löst den Hauptschalter aus. Gleichzeitig wird die Störung an der Frontplatte des Gerätes durch eine rote Leuchtdiode angezeigt.

Steht kein Störsignal mehr an, kann der betriebsbereite Zustand durch Betätigung der Rückstelltaste wieder hergestellt werden.

PRÜFEINRICHTUNG

Zum Prüfen des Gerätes wird ein im Gerät erzeugtes 100Hz-Signal über die Prüftaste auf den Eingang des Filters gelegt. Die Höhe des Signalpegels ist einstellbar (Poti, R110) und kann somit dem eingestellten Ansprechwert angepaßt werden.

An den Meßbuchsen (X200–X201) steht eine Gleichspannung an, die proportional dem 100Hz-Strom bzw. dem 100Hz-Prüfsignal ist.

RUSHSCHUTZ

Um ein Ansprechen des Gerätes durch den Einschaltrush des Haupttransformators zu vermeiden, ist eine Rushschutzeinrichtung vorgesehen. Beim Ein- und Ausschalten des Trafos wird ein einstellbarer Zeitblock abgeleitet, der den Ansprechwert hochsetzt oder bei (F-G gebrückt) das Ansprechsignal sperrt. Abgeleitet wird der Block entweder aus der Fahrdrahtspannung (X_b/e – <U) und der Hauptschaltermeldung (X_b/co-T), oder aus den einzelnen Signalen: die Auswahl erfolgt über die Brücken D-C bzw. D-E.

Der erhöhte Ansprechwert kann am Widerstand R2002, die Blockzeit an den Widerständen R1001 und R1002 eingestellt werden.

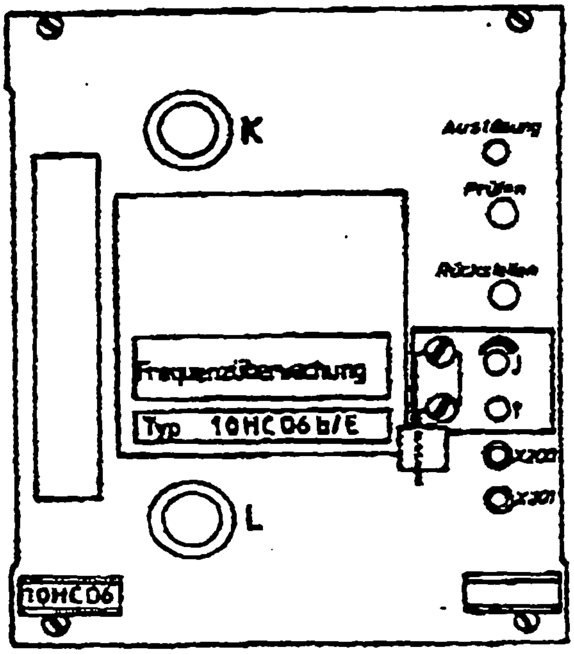


Abb. 1: Gerätefrontplatte

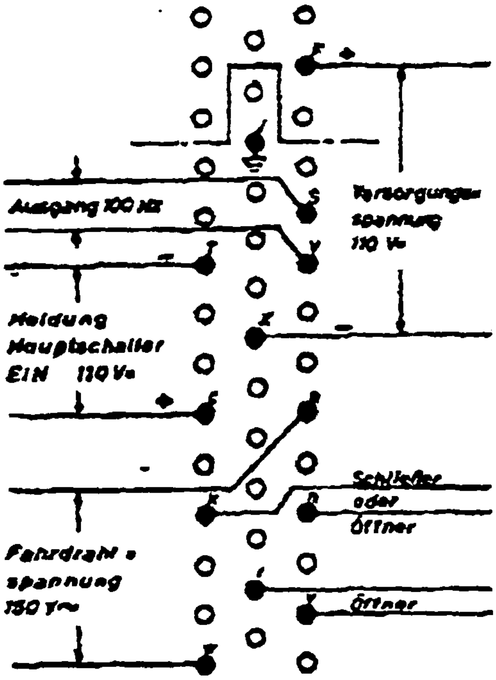


Abb. 2: Kontaktbelegung des Frontsteckers

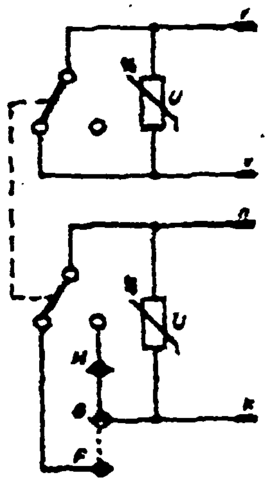


Abb. 3: Schaltung des Ausgangskreises

MECHANISCHER AUFBAU

Doppelsteckplatte 3U. 20R   Gewicht: ca.
mit Steckplatte in R1 und R15
ohne Anschlußstecker (Xa).

Bestellangaben: GJR 2 3566 R1. (E120)
R2. (EL17)
R3. (Rn1063)

Anschlußelemente:

Gerätefrontseite: 41-poliger RDM-Stecker X_b. Für den Anschluß des Meßstromes sind zwei Durchführungsklemmen R6 mit der Bezeichnung K und L vorhanden..

Frontplatte nach Abb. 1.

TECHNISCHE DATEN

Neben den charakteristischen Werten der Baureihe JC-V gelten folgende Daten:

Stromversorgung		
Speisespannung		
Eingang X_b/F(+) u. X(-)		110V ± 30 %
Stromaufnahme		≤ 60mA
Verlustleistung		≤ 6,6W
Eingangswerte		
Meßstrom bei 16 2/3 Hz		
Klemme K-L		0 ... 6A
Einstellbereich		
für 100Hz-Auslösestrom (R203)		4 ... 125mA
Einstellbereich		
für Auslösezeit (R216)		0,5 ... 10s
Filterkurve		
Dämpfung	100Hz ≙ 2Hz	- 36dB
	100Hz ≙ 10Hz	-36dB
	100Hz ≙ 25Hz	-30dB
	16 2/3 Hz	-...
Rückstellung		Rückstelltaste
extern durch Signalblock		
($-U_{Batt.}$) an X_b/L		≥ 500ms
Ruhschutz		
Meldung Hauptschalter EIN		
Eingangsspannung		
Eingang X_b/E(+)-X(-)		110V= ± 30 %
Stromaufnahme		≤ 15 mA
Fahrdrahtspannung		
Eingangsspannung		
Eingang X_b/e - b		150V - 20%-30%
Stromaufnahme		≤ 5 mA

APPENDIX B

EMI Consultant Memos

FRASCO & ASSOCIATES, INC.
24 HORACE ROAD
BELMONT, MASSACHUSETTS 02178

TELEPHONE
(617) 484-8413

German ICE Train HST Demonstration
Amtrak Northeast Corridor Operation
EMC Status

General Summary & Conclusions

Initial EMI testing has recently been completed to assure ICE Train compatible operation on the Amtrak Northeast Corridor (NEC). The testing was performed as part of the intial ICE train performance tests on the NEC during the period July 9-13, 1993 and conformed with recommendations for EMI/EMC certification testing (Cf: Recommendations for EMI/EMC Certification testing, German ICE Train HST Demonstration, Amtrak Northeast Corridor Operation; L. A. Frasco, Frasco & Associates; July 4, 1993).

The results of these initial tests appear positive and support compatible NEC operation. However, due to the safety criticality of EMC certification, some additional EMI testing is required to repeat the measurement of catenary/pantograph harmonic levels in the critial Amtrak power frequency signalling band. This testing must be performed, following completion of ICE performance testing and optimization, and prior to the start of the ICE NEC revenue demonstration program. In addition, certain supporting technical data is required of Siemens regarding their 100 Hz protection circuitry.

Technical Summary of Initial EMI Testing

During this initial testing sequence, both onboard and wayside EMI testing was performed. These tests included carborne measurement of voltage/current pantograph ripple harmonic levels, wayside measurement of undercar rail-to-rail induced voltage levels, and carborne monitoring of cab signal interference levels.

Figure 1 is a representative plot of the pantograph ripple current harmonic spectrum measured onboard on ICE power car. Levels in the critical 100 Hz range are below the 1A (RMS) recommended limit; the measured level at 100 Hz is .8A (RMS), sidebands in the 90-103 Hz range are at least 6 db below this; the level at 150 Hz is less than .5A (RMS). The measured level at the proposed future cab signal frequency of 250 Hz is .5A (RMS), acceptable but right at the recommended limit. Also, maximum levels measured in the low audio frequency (AF) range (500 Hz - 1500 Hz) are around 700 ma (RMS); it should be noted that with these levels the potential exists for interference with grade-crossing and other AF overlay circuits planned to be installed on the future electrified New Haven - Boston NEC section. [Finally, it should be noted that during these pantograph ripple current measurements, transient transitions at 100 Hz, above the 1A level, occurred. These transients were of short duration and have also been observed during earlier testing of AC/DC locomotives and are not unique to AC/AC traction. This earlier testing has identified the primary cause of transients of this type to be pantograph bounce, saturating the main transformer. It should also be noted that these transients were not of sufficient duration to trip the Siemens 100 Hz protection relay, which we understand to be set at 1A.]

Cab signal interference levels were also monitored onboard. Several runs (max power/max braking, 0-125 mph) were made with cab signal levels at the carborne antenna/filter output monitored with no measurable signs of interference (e.g. no cab signal "fill-in", etc.).

Figures 2-4 are typical plots of undercar rail-to-rail voltage measurements made while the ICE Train passed over the measurement point. Testing concentrated on low speed runs (i.e. 60 mph or less - speeds at which the interference time duration would be at least 250 msec). The test plots include low speed creep, max power @ 50-60 mph, and max brake to 0 mph. As can be implied from these representative plots, in all test scenarios, measured levels were well below recommended levels.

Outstanding EMC Items

Before introducing the ICE Train into demonstration revenue service, the following outstanding items must be completed:

1. Following ICE train performance testing & optimization, additional onboard EMI testing is required to repeat the measurement of pantograph ripple voltage/current harmonic levels at the critical Amtrak signalling frequencies.

   These measurements will be performed during a simulated revenue run between Union Station/DC and Penn Station/NYC; the test scenario will also include 0-max speed, max power/max braking cycles.

2. Siemens will provide technical information on their 100 Hz protection relay circuit (e.g. relay type/spec, application circuit, and level setting/bandwidth (1A/2Hz?)).

Finally, while not necessary for present Amtrak NEC compatible operation, it is recommended that Siemens identify the source and any proposed methods of mitigation of the high levels (1A range) of pantograph current harmonics in the low audio frequency range (500 Hz - 1500 Hz).

Louis A. Frasco
Belmont, Massachusetts
August 1, 1993

(3)

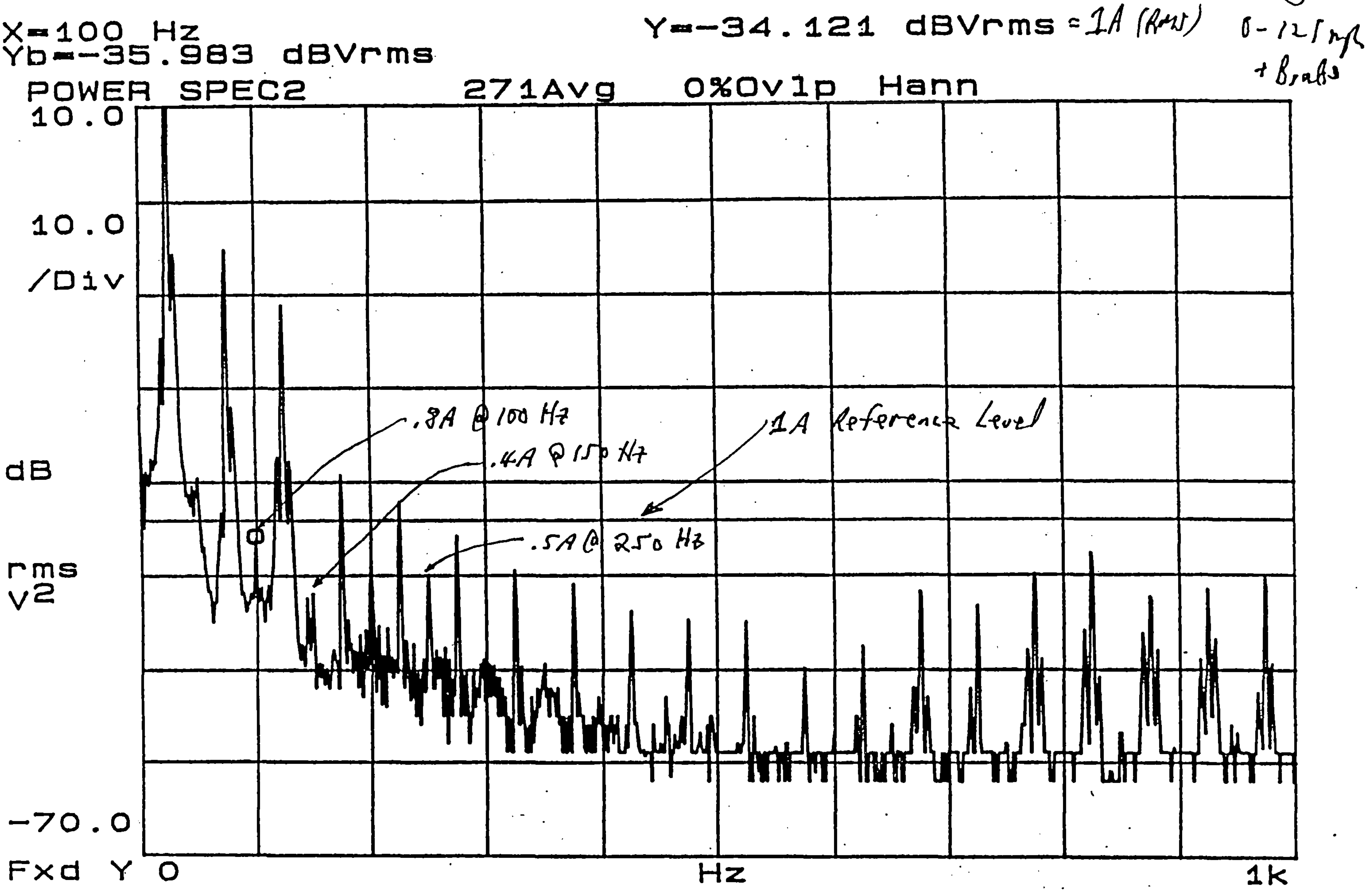


Figure 1 ICE Pantograph Current Harmonics Spectrum (Max Pwr/Max Brake 0-125 mph).

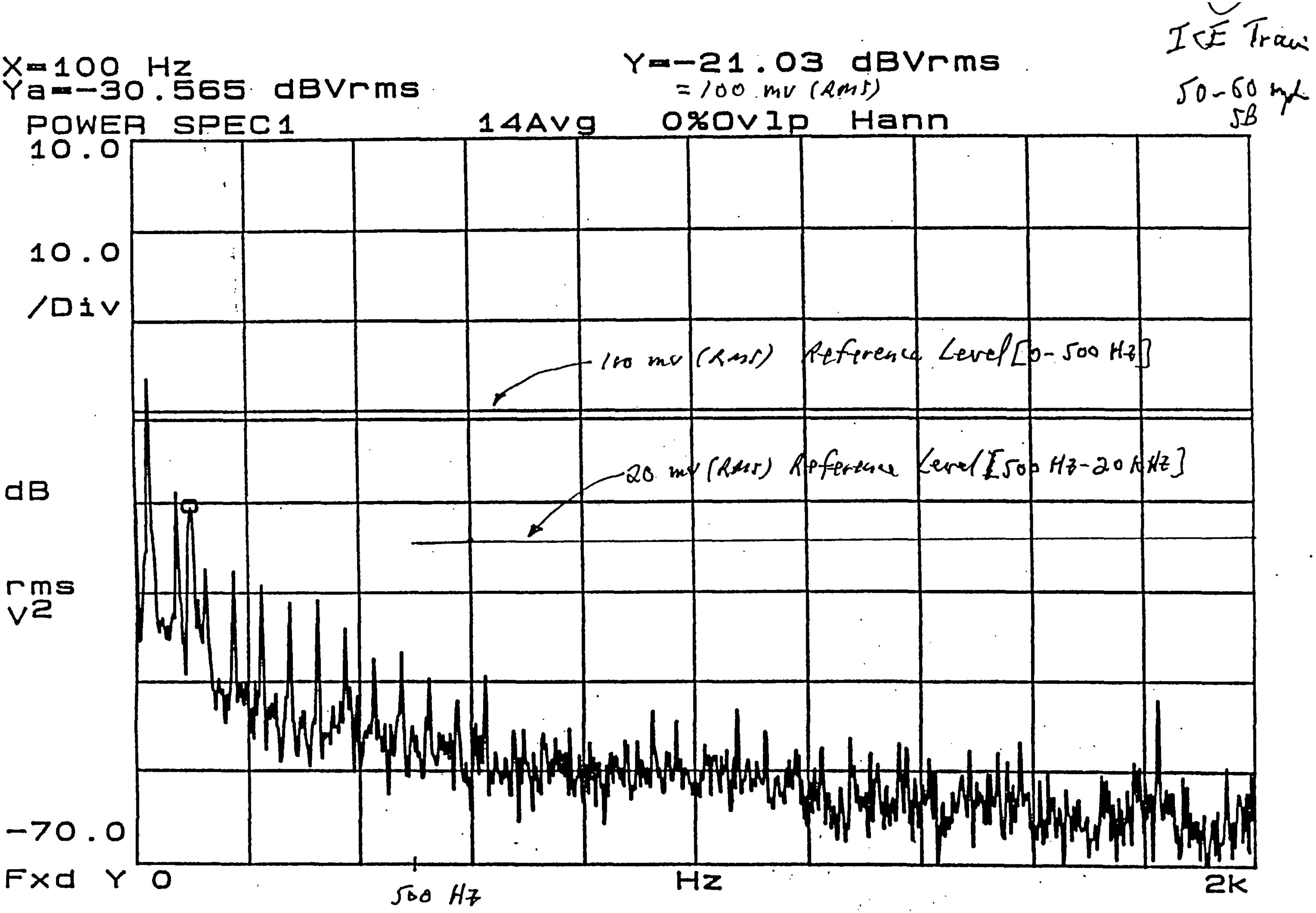


Figure 3 ICE Undercar Rail-to-Rail Voltage
(Max Power, 50-60 mph)

(6)

Low Speed Creep
Pwr Unit

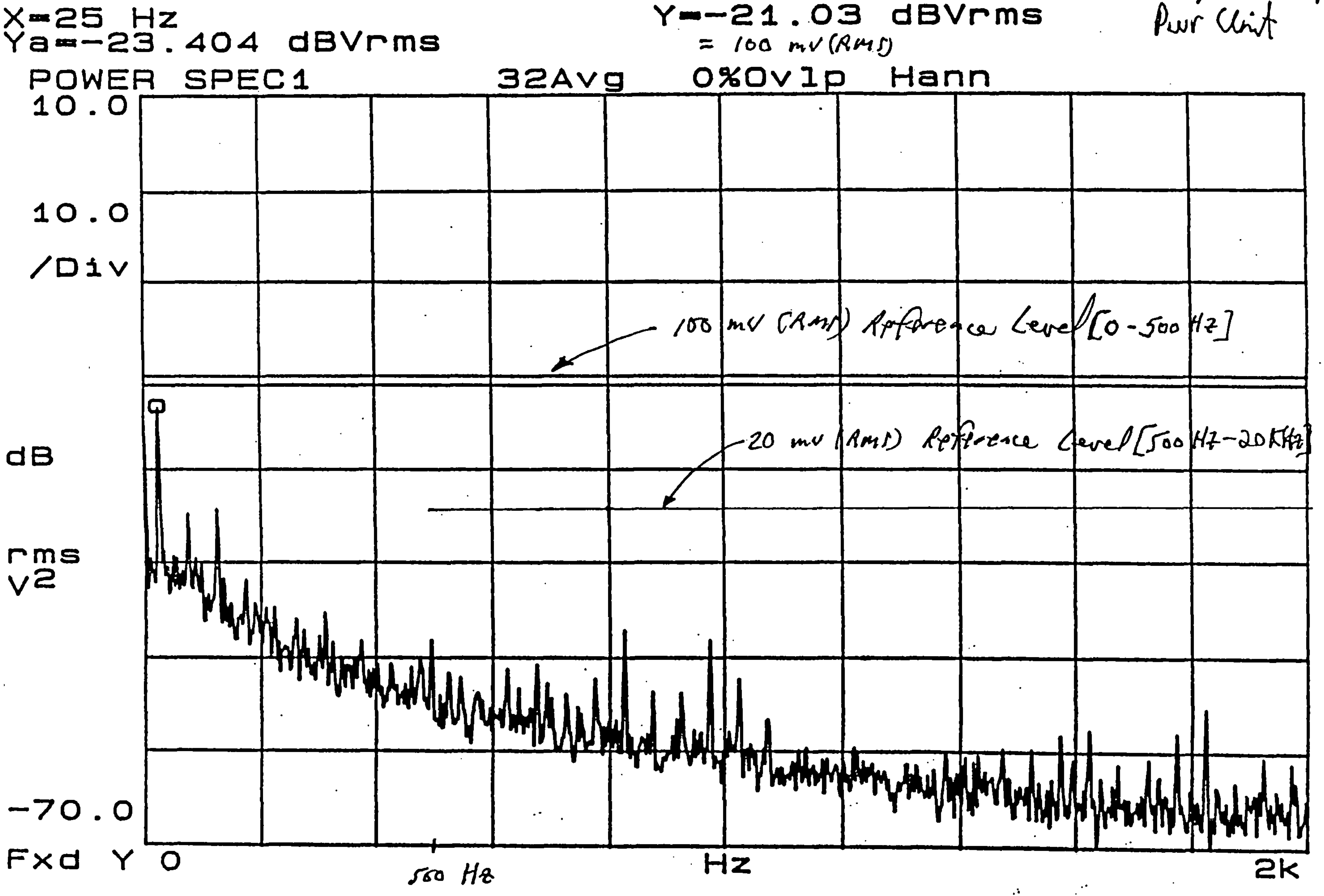


Figure 2 ICE Undercar Rail-to-Rail Voltage
(Low Speed Creep; Pwr Unit)

MAX BRAKE
to 0 MPH

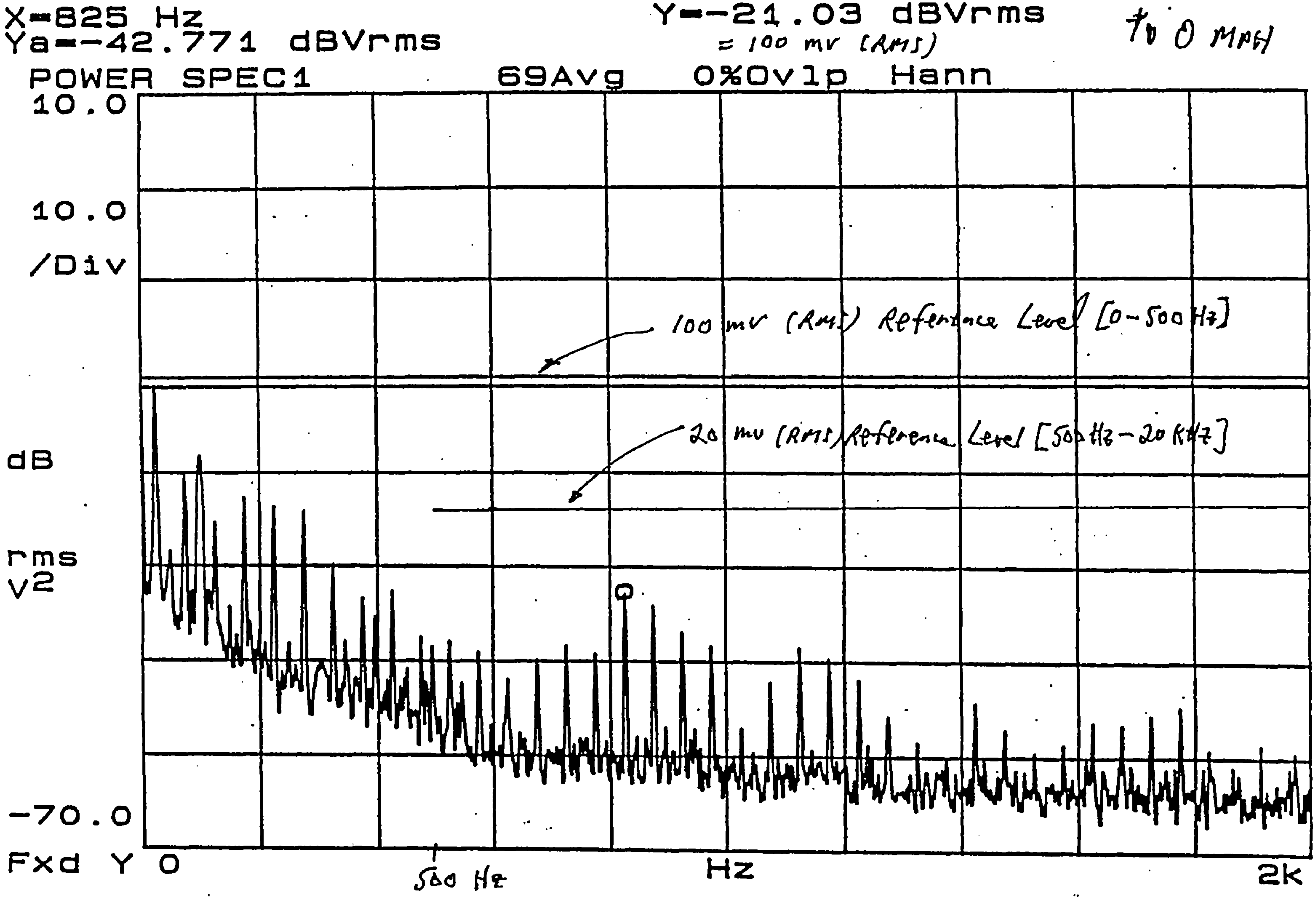


Figure 4 ICE Undercar Rail-to-Rail Voltage
(Max Brake to 0 mph)

FRASCO & ASSOCIATES, INC.
24 HORACE ROAD
BELMONT, MASSACHUSETTS 02178

TELEPHONE
(617) 484-8413

German ICE Train HST Demonstration
Amtrak Northeast Corridor Operation
Final EMC Status

General Summary & Conclusions

Final ICE EMI testing was performed on October 1, 1993 during an Amtrak training run prior to placing the trainset into demonstration revenue service on the NEC beginning October 4, 1993. The purpose was to gain additional confidence in earlier safety-critical measurements (i.e. 100 Hz harmonic current levels, etc.), to retest/spot-check those levels following completion of ICE performance testing and optimization, and finally, to perform all this during a simulated NEC revenue service run between Washington, DC and NYC at revenue service speed profile and operating conditions.

Earlier EMI testing performed during the period July 9-13, 1993 as part of the initial ICE train performance tests on the NEC was reported on previously (Cf. German ICE Train HST Demonstration, Amtrak NEC Operation, EMC Status; August 1, 1993; L. A. Frasco). The Final EMI testing reported here supports the results and conclusions from this earlier testing. Based on the results of both testing sequences, we feel that compatible operation of the Amtrak ICE trainset in demonstration revenue service is assured.

While compatible with the existing NEC signalling infrastructure, ICE pantograph emission levels at Amtrak's future cab signal frequency (250 Hz) appear too high; also high emission levels exist in the audio frequency range (especially 500 Hz - 1500 Hz) with the potential for limiting application of audio-frequency overlay (AFO) circuits on the NEC, especially on the New Haven-Boston section scheduled to be electrified.

Finally, for additional security, the ICE (Siemens) has a vital protection relay circuit monitoring the level of pantograph 100 Hz harmonic ripple current in Amtrak's existing critical 100 Hz frequency range. It has been verified by Siemens that this circuit has been set at the recommended limit of 1A for each power car. This vital protection relay circuit module is independently supplied to Siemens by ABB. For future applications, it could also be supplied at 250 Hz.

Technical Summary of Final EMI Testing

During this final testing sequence prior to placing the ICE trainset in demonstration revenue service, pantograph ripple current and voltage were monitored during a simulated revenue service run on the NEC, roundtrip between Washington, DC and NYC.

Figure 1 is a representative plot of the pantograph ripple current harmonic spectrum measured onboard the ICE power car. Compared with the results from the earlier EMI testing sequence, levels at existing Amtrak critical signalling frequencies are within acceptable limits but appear somewhat higher. Levels at the new Amtrak frequency of 250 Hz have doubled and levels in the audio frequency (AFO) range while still too high are lower than earlier results.

Figure 2 is a plot of the pantograph ripple current harmonic spectrum when the train was stopped at Trenton. Note the low frequency "hump" in harmonic current levels with only auxiliary and "hotel" power loads, no tractive effort applied. Comparison with Figure 1 shows this same hump distorting the low frequency portion of the ICE traction inverter spectrum. Further comparison of Figure 1 with similar plot from earlier EMI tests shows a similar bump in the specturm, but shifted slightly higher in frequency, from 0-500 Hz range to 500-1000 Hz range. It appears that this effect accounts for the differences in measured levels at 250 Hz and in the low audio frequency range. Finally, based on the plot of Figure 2, it is important to note that these increased levels are not due to the ac traction system. A cursory analysis of this plot (and Figure 4 plot) suggest this effect may be due to ICE input line filter characteristics. Siemens should investigate.

Figure 3 is a representative plot of pantograph ripple current during regenerative braking. The traction inverter switching frequency harmonics (and inverter frequency sidebands) can be seen. These levels exceed recommended limits in the audio frequency range. The low frequency "hump" of Figures 1 & 2 is not present, since in the braking mode, the traction motors/inverter supply the aux and hotel power, not the catenary.

Finally, Figure 4 is a representative plot of the simultaneous measurement of pantograph voltage and current harmonic spectra; the measurement was made stopped at Union Station/DC. Measurements of this type can be used in the calculation of train input impedance and, together with time domain plots, to study the harmonic spectrum of the catenary voltage.

[Note: While not affecting the nature of our results, it should be noted that due to the use of a different spectrum analyzer for this test, the frequency resolution was lower than for the earlier tests; i.e. 400 line resolution versus previous 800 lines.]

Conclusions

Based on ICE EMI test results to date, conclusions can be reached concerning the present and future operation of the currently configured ICE trainset on the NEC.

At the present time, the ICE demonstration trainset can operate compatibly with the existing Amtrak signalling system. Measurements of pantograph harmonic currents, undertrain induced rail-to-rail harmonic voltages, and onboard cab signal input interference levels at critical Amtrak signalling frequencies supports this conclusion.

For future operation, however, measured levels appear too high at Amtrak's new 250 Hz cab signal frequency and in the low audio-frequency range of AFO circuits (with applications for grade-crossings and switch control). In the former case, the increased levels do not appear to be caused by ac traction, but by the interaction between catenary supply voltage harmonics and the ICE pantograph line filter. While this same effect has also been observed in the low audio frequency range, the effects of the traction inverter (i.e. inverter switching harmonics) can also be seen in this latter case. Figure 3 plot of regenerative braking clearly demonstrates this. Therefore, for the future, Siemens should address these two issues.

Louis A. Frasco

Louis A. Frasco
Belmont, Massachusetts
January 1, 1994

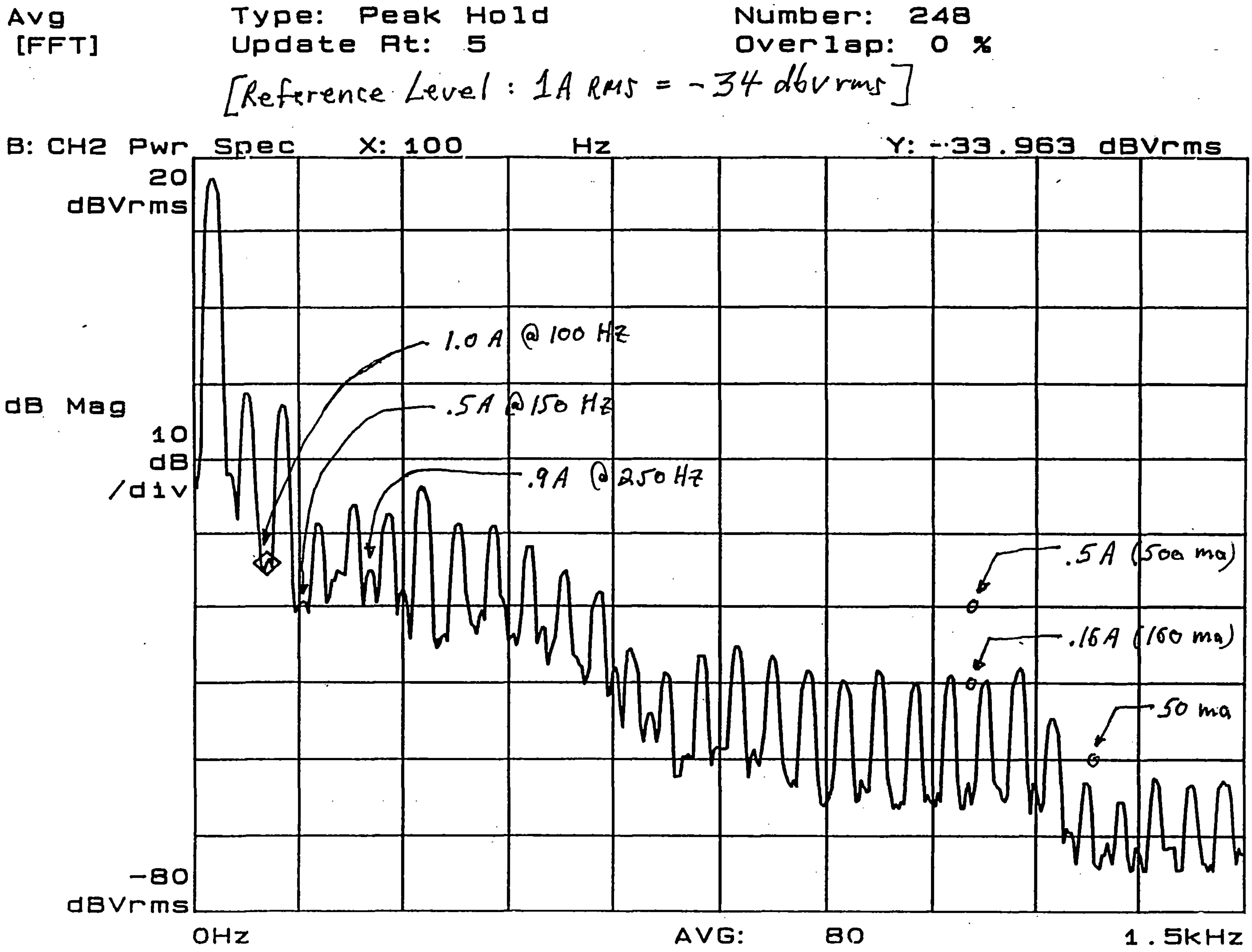


Figure 1 ICE Pantograph Current Harmonics Spectrum
(Max Pwr/Max Brake, 0-125 mph)

Avg Type: Peak Hold Number: 248
[FFT] Update Rt: 5 Overlap: 0 %

Stopped at Trenton

[Reference Level: 1A Rms = -34 dbvrms]

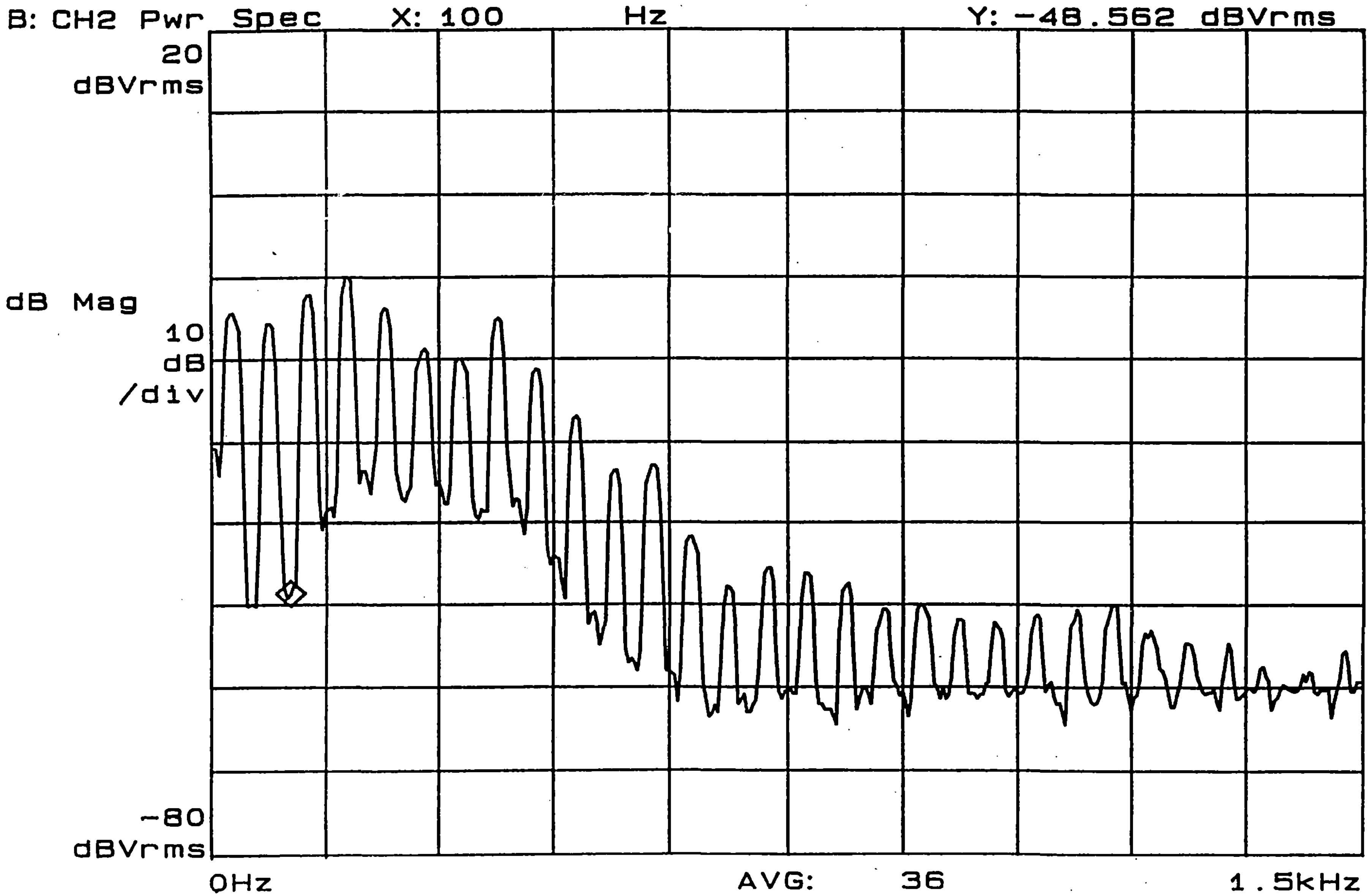


Figure 2 ICE Pantograph Current Harmonics Spectrum
(Stopped at Trenton)

Braking

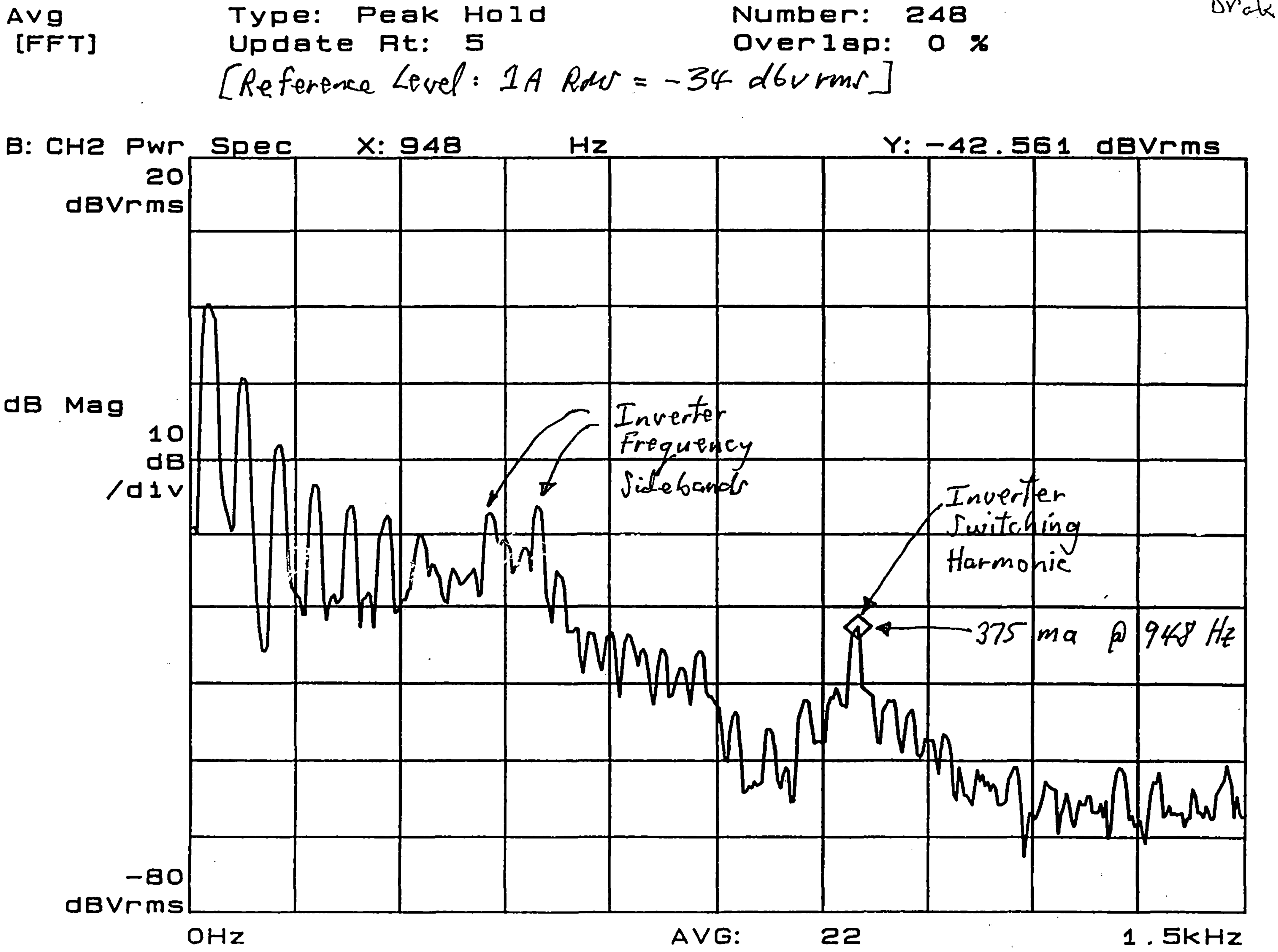
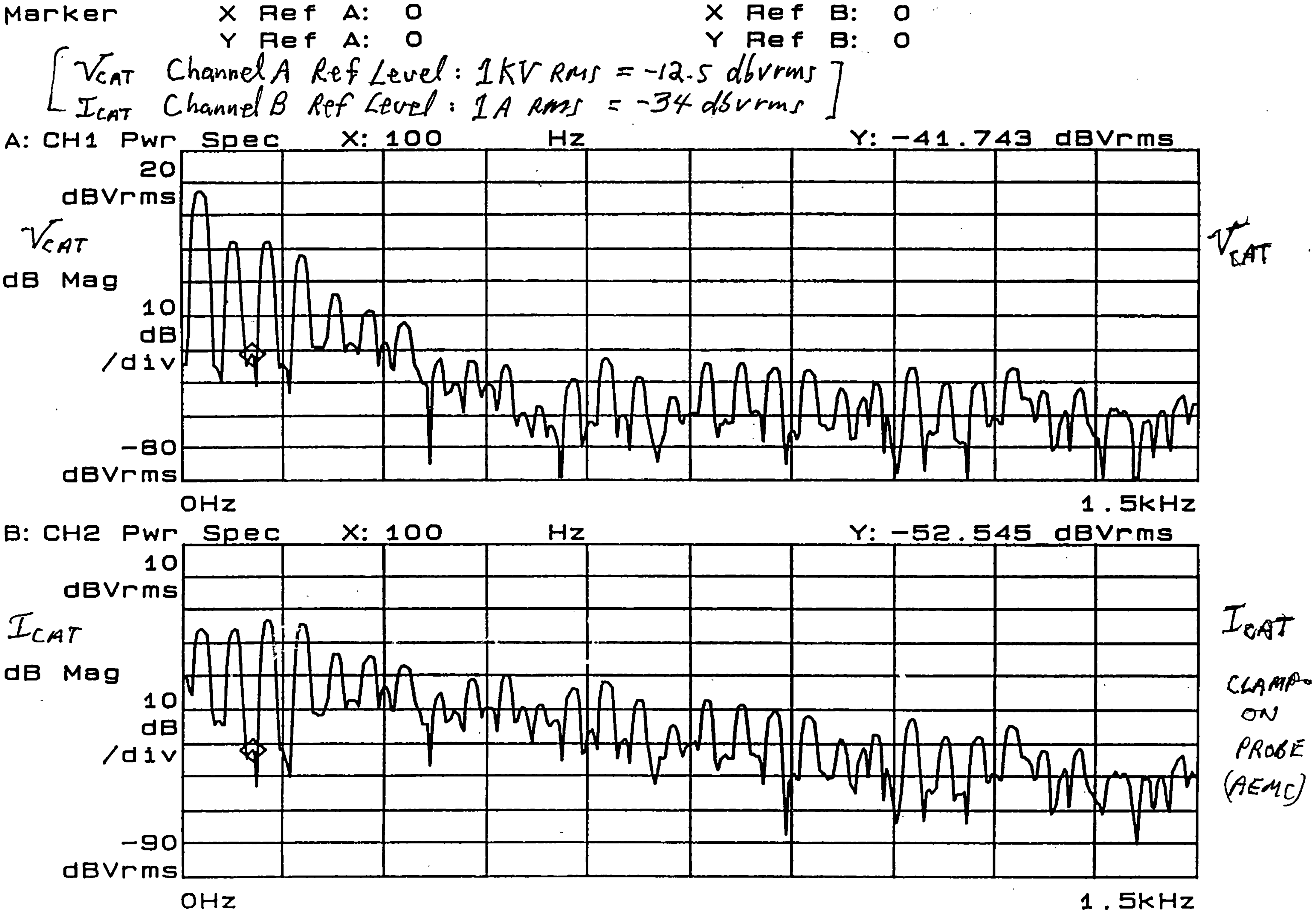


Figure 3 ICE Pantograph Current Harmonics Spectrum
(Regenerative Braking)



[VCAT Channel A Ref Level: 1KV RMS = -12.5 dbvrms]
[ICAT Channel B Ref Level: 1A RMS = -34 dbvrms]

CLAMP ON PROBE (AEMC)

Figure 4 ICE Pantograph Voltage/Current Harmonics Spectra
(Stopped @ Union Station/DC)

4379 EMI Testing of a High Speed Trainset German Intercity Express
03-Rail Vehicles & Components