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Recommended Practices for Rail Transit Intra-System Electromagnetic Compatibility of Vehicular Electrical Power and Track Circuit Signalling Subsystems

Volume II: Conductive Recommended Practices

U.S. Department of Transportation
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Project Memorandum

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16. Abstract

Methods for detecting and quantifying the levels of conductive electromagnetic interference produced by solid state rapid transit propulsion equipment and the susceptibility of audio-frequency signalling systems to these emissions are presented. These methods include procedures for taking measurements in the field, in the laboratory and on track circuits.

As background, the mechanisms of inductive and conductive electromagnetic interference are described, as are audio-frequency track circuits and dc chopper control. Recording and documentation procedures for applying these recommended practices are provided.

Appendix A contains definitions of terms and systems of units. Appendix B contains sample outputs of tests using conductive recommended practices.

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PREFACE

These recommended practices have been prepared by the Rail Transit Electromagnetic Interference (EMI) Technical Working Group (TWG) as part of a cooperative effort between the Federal Government -- the Urban Mass Transportation Administration (UMTA) and the Transportation Systems Center (TSC) of the U.S. Department of Transportation -- and the transit industry to develop standard methods of analysis and testing to quantify and resolve issues of electromagnetic compatibility (EMC) in rail transit operation.

This is an ongoing activity that will keep pace with the development of new propulsion and signalling techniques. To date, a number of recommended practices have been extensively tested and applied in the process of assuring compatibility between propulsion and signalling for a number of new and upgraded U.S. rail transit systems. The experience thus gained has been incorporated, along with suggestions and comments received from the rail transit operator and supply industries and the consultants, in preparing the finished versions of these recommended practices.

The recommended practices which have reached this final form address compatibility between rail transit propulsion systems employing dc power and solid state power conditioned drives, and audio-frequency track circuits. This combination of propulsion and signalling is characteristic of the types of equipment currently or soon to be available for use in new and upgraded U.S. rail transit systems.

Three salient types of electrical interference are dealt with in the set of recommended practices in these documents -- conductive, inductive, and radiated -- since these have been found to be the major interference types that must be dealt with to date.

Work continues on additional recommended practices that may be issued at a later time, covering other forms of interference and other combinations of propulsion and signalling equipment.

It is important to note that these are working documents that are subject to change as better methods and techniques are developed, and as more advanced equipment becomes available. The Institute of Electrical and Electronic Engineers (IEEE), Land Transportation Committee, Standards and Foreign Practices Subcommittee have agreed to update these recommended practices periodically. The Rail Transit EMI Technical Working Group includes representatives from the following manufacturers of rail transit equipment:

- Boeing Aerospace Company
- Brown Boveri Company
- Garrett/AiResearch
- General Electric
- General Railway Signal Company
- Union Switch & Signal Division, American Standard, Inc.
- Westinghouse Electric Corporation

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EXECUTIVE SUMMARY

Electromagnetic interference, generated by rail transit propulsion equipment, can cause a transit property's audio-frequency signalling system to malfunction, resulting in potential reliability and safety problems. These problems have been complicated and increased by the introduction and growing use of new types of solid state power-conditioned drives.

Three types of electromagnetic interference -- inductive, conductive, and radiated -- have been found to be the major sources of difficulty leading to electromagnetic incompatibility between propulsion and signalling subsystems in rail transit operations. The mechanisms of inductive and conductive interference are described in Section 2 of both volumes one and two, as are audio-frequency track circuits and dc chopper propulsion control.

In response to the electromagnetic interference and compatibility problem, the Federal Government, the transit supply industry and their consultants, and the transit properties themselves have developed, refined, and extensively tested and applied a number of recommended practices to ensure compatibility between propulsion and signalling equipment on U.S. transit properties.

These practices are tested methods for determining the susceptibility of signalling systems to electromagnetic interference, for measuring the electromagnetic emissions of electrical power subsystems in the field, in the laboratory, and on track circuits.

Included in Volume I of the Recommended Practices are the methods for determining inductive interference and susceptibility in rail transit subsystems. Volume II contains conductive recommended practices. Work is continuing on the project to develop existing and new recommended practices which will respond to new combina-

tions of propulsion and signalling equipment and new designs of these subsystems.

Appendices to this report include definitions of terms and systems of units, and sample outputs of tests using the recommended practices.

SECTION 1. RECOMMENDED PRACTICE FORMATS, RECORDING AND DOCUMENTATION PROCEDURES

1.0 SCOPE

This section documents the formats and procedures used in formulating and applying these recommended practices.

2.0 FORMAT

The test method format shall be as specified in Table 1-1.

TABLE 1-1. TEST METHOD FORMAT

Test Method Number / Description Title / Frequency Range

1.0 PURPOSE
2.0 APPLICATION
3.0 TEST MEASUREMENT APPARATUS
4.0 TEST PROCEDURE
5.0 TABULATION OF RESULTS
6.0 NOTES

Test Method Numbering System

The test method numbering system shall be of the form RT/AAXXB. The prefix RT denotes RAIL TRANSIT; the suffix B is a letter issued sequentially (e.g., A, B, C, ...) to denote a test series for a fixed RT/AAXX where each test in the series has the same basic purpose, but where a test procedure has to be adapted to equipment of the same generic class, but independently developed. Table 1-2 lists the current test method classification AA, numbering XX allows possibilities (01 to 99).

TABLE 1-2. TEST METHOD CLASSIFICATIONS

METHOD AA	DESCRIPTION
IS	Inductive Susceptibility
IE	Inductive Emissions
CS	Conductive Susceptibility
CE	Conductive Emissions

3.0 TEST REPORTING REQUIREMENTS

Integral to the performance of each test method is the documentation of testing scenarios and test results. Table 1-3 contains a sample test report format outlining report requirements.

TABLE 1-3. TEST REPORT REQUIREMENTS

1.0 Photo or Diagram of Test Configuration

2.0 Test Scenario

Significant Details Concerning Variations from Specified Test Method

3.0 Measurement Equipment

a. Description, including manufacturer, model name and number, operating voltage and current, and frequency and voltage ranges used.

b. Serial number

c. Last Calibration Date

d. Transfer Characteristics and Calibration Factors for Measurement Sensors (i.e., probes, loops, antennas, etc.)

4.0 Measured Levels of Emission and/or Susceptibility for each Required Test Parameter and Condition

5.0 Graphs of Measured Data

6.0 Susceptibility Criteria

a. Circuits, Outputs, Displays to be monitored

b. Normal, Malfunction, and Degradation, Normal Performance Criteria

SECTION 2. INTRODUCTION TO INDUCTIVE AND CONDUCTIVE INTERFERENCE MECHANISMS IN SYSTEMS WITH CHOPPER-CONTROLLED DC PROPULSION AND JOINTLESS AUDIO-FREQUENCY TRACK CIRCUITS

1.0 INTRODUCTION

This presentation is a brief review of what is involved in the production of inductive and conductive interference in rail transit systems employing chopper-controlled dc propulsion and jointless audio-frequency track circuits.

2.0 AUDIO-FREQUENCY TRACK CIRCUITS

Figure 2-1 shows a typical jointless audio-frequency track circuit of the type employed at MARTA, WMATA, and portions of the MBTA, CTA, and Cleveland, as well as the new Baltimore and Miami systems. In this type of system, rate-coded bursts of audio-frequency current are injected by means of resonant impedance bonds at the transmitting ends of track blocks, and are received at the receiving ends of the blocks. A number of audio carrier frequencies are used cyclically down the track. Figure 2-2 shows typical track circuitry in detail.

3.0 DC CHOPPER PROPULSION CONTROL

Figure 2-3 shows a typical chopper circuit that might be used for dc propulsion control. In operation, propulsive power is controlled by varying the length of time that the main thyristor T_M stays on. T_M is gated on to initiate application of the line voltage to the motor. Some time later, T_C, the commutation thyristor, is gated on to trigger an oscillatory loop current around the T_M, T_C, L_C, C_C loop. At some point during the first cycle of this oscillatory loop current, the algebraic sum of motor current and oscillatory loop current through T_M will go to

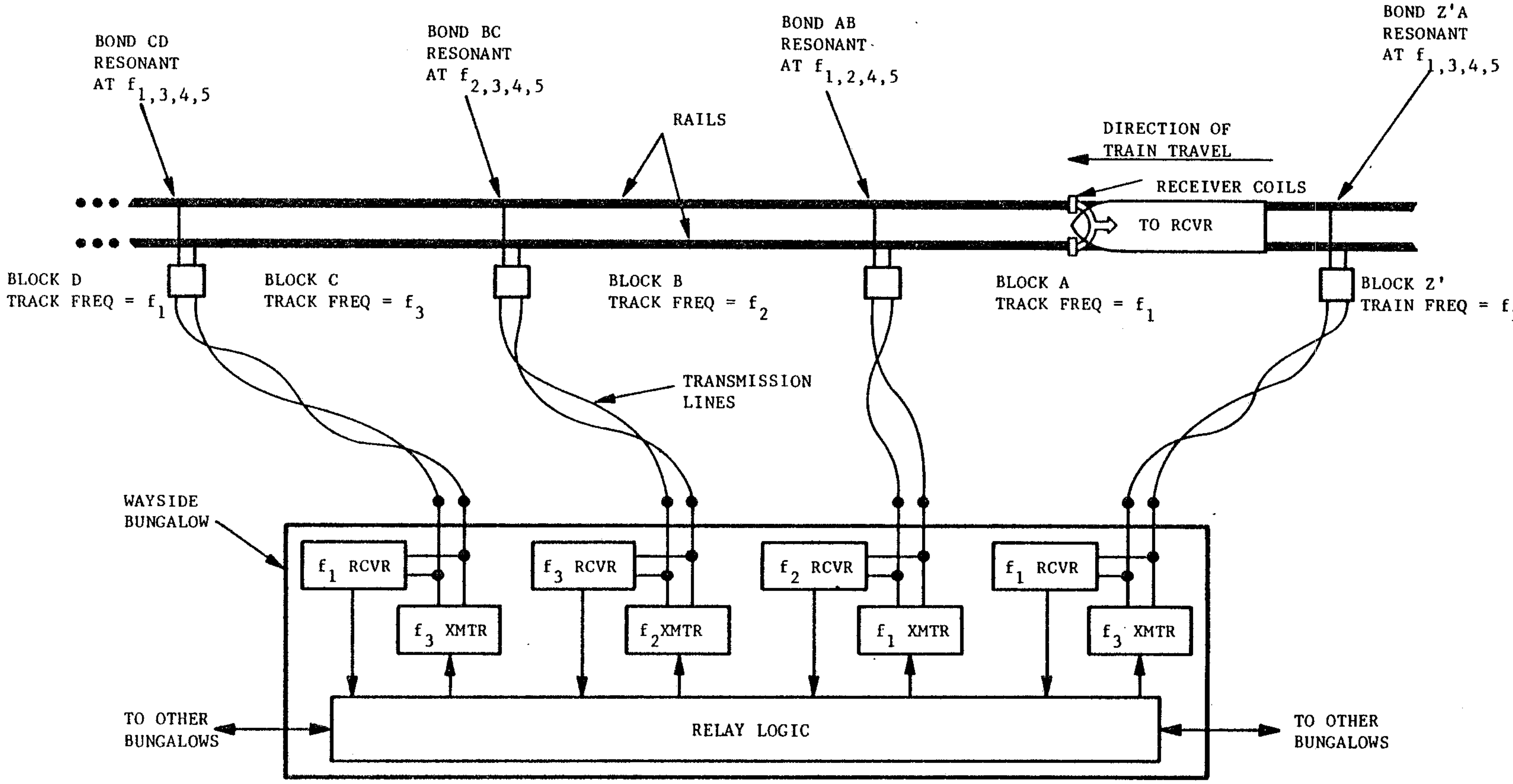


FIGURE 2-1. JOINTLESS AUDIO-FREQUENCY TRACK CIRCUIT

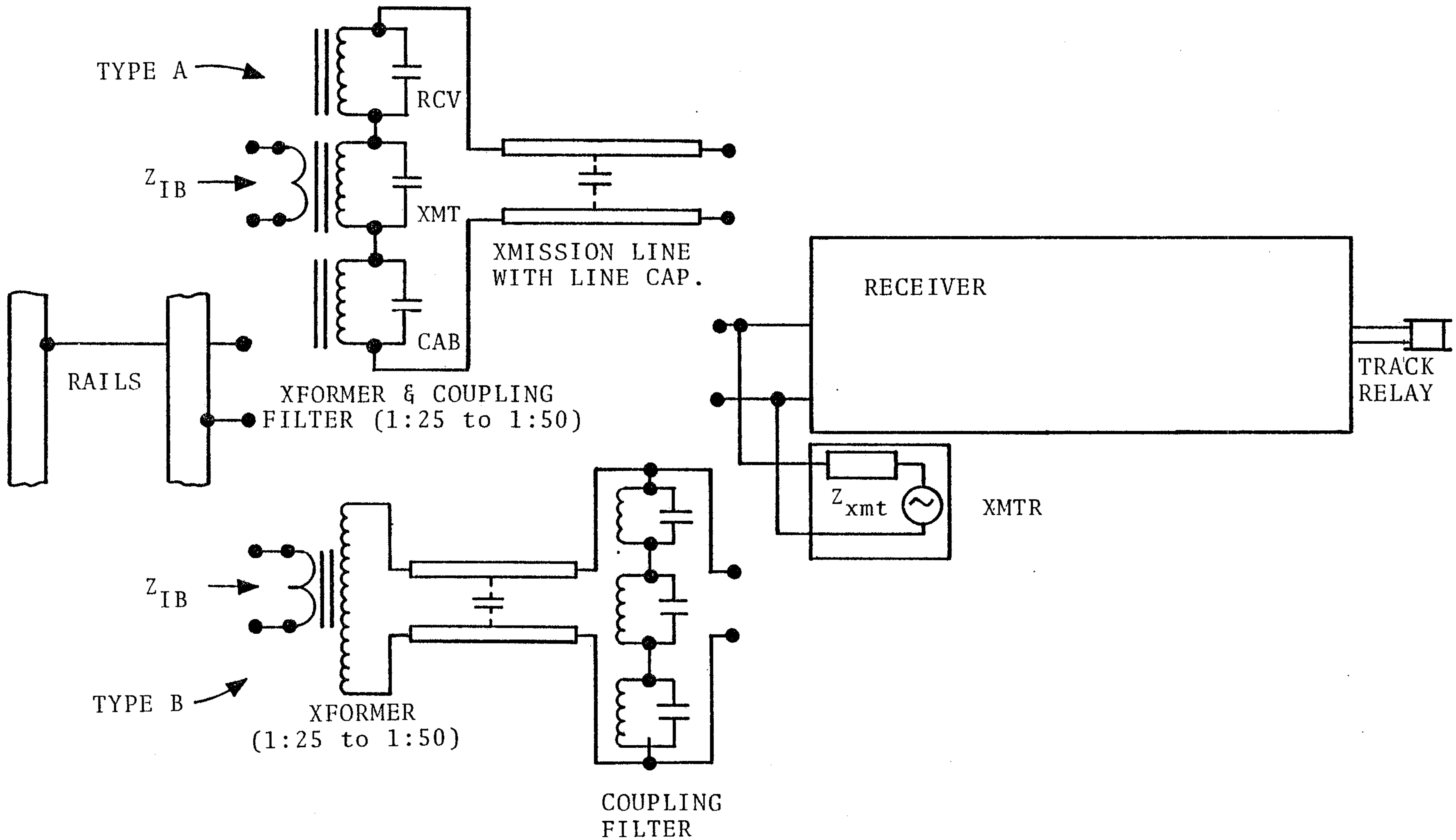


FIGURE 2-2. AUDIO-FREQUENCY TRACK CIRCUITRY

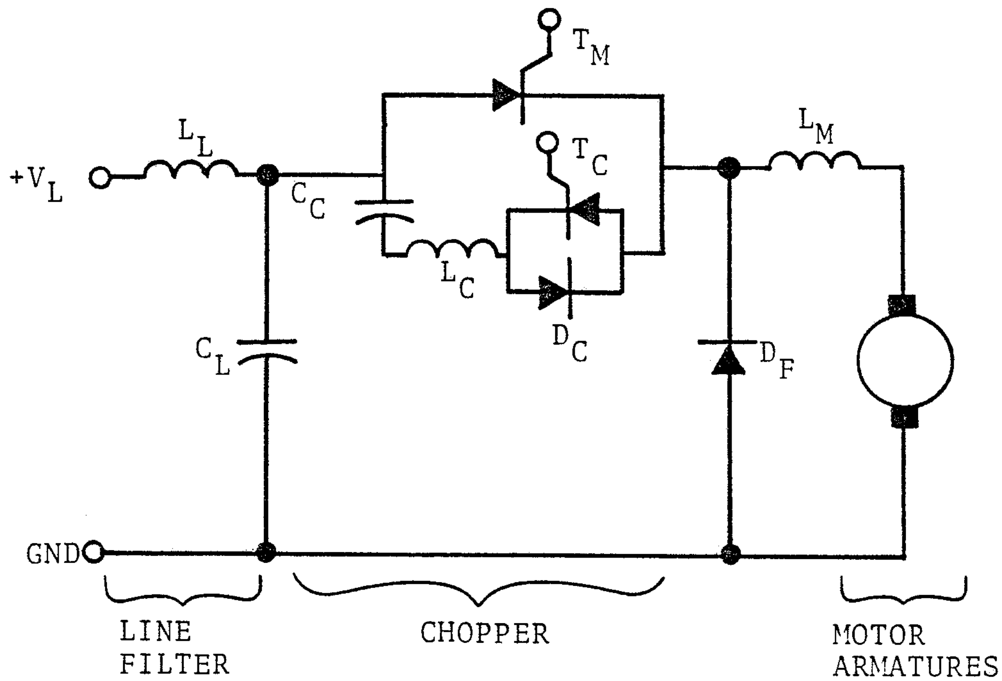


FIGURE 2-3. TYPICAL CHOPPER PROPULSION CONTROLLER

zero, allowing T_M to turn off. Repetition frequency for gating T_M on is typically in the 200-400 Hz range, and the oscillatory frequency provided by L_C and C_C is typically ten times as high.

Two possible modes of audio-frequency interference are immediately evident. The first, called the <u>inductive</u> mode can arise because of high levels of stray flux rich in audio-frequency transients emanating from the inductive chopper circuit components. The second, called the <u>conductive</u> mode, can arise due to harmonics of the audio-frequency transient current waveforms present in the chopper circuit getting past the line filter (L_L, C_L). In both of these modes, interfering signals can be produced at harmonics of the fundamental chopper frequency, throughout the portion of the audio spectrum used for signalling.

4.0 INDUCTIVE INTERFERENCE

4.1 Inductive Interference Production

Figure 2-4 depicts the mechanism whereby magnetic flux from the magnetic components of the chopper induces interference voltage in the signalling system. When the rapid transit car is immediately over an impedance bond as shown in Figure 2-4, the signal current that would be received at that bond is shunted by the axles of the vehicle, thus normally causing the track relay to drop. However, magnetic flux lines from the chopper box, normally slung under the vehicle, can pass through the loops formed by rail, axle, and bond leads, and cause a transient-induced voltage across the track terminals of the impedance bond. Inductive interference is evidenced by the observation of abnormally high levels of rail-to-rail voltage observed at locations <u>under</u> the vehicle. This induced voltage has a harmonic spectrum that spans the frequency range typically used for audio-frequency signalling.

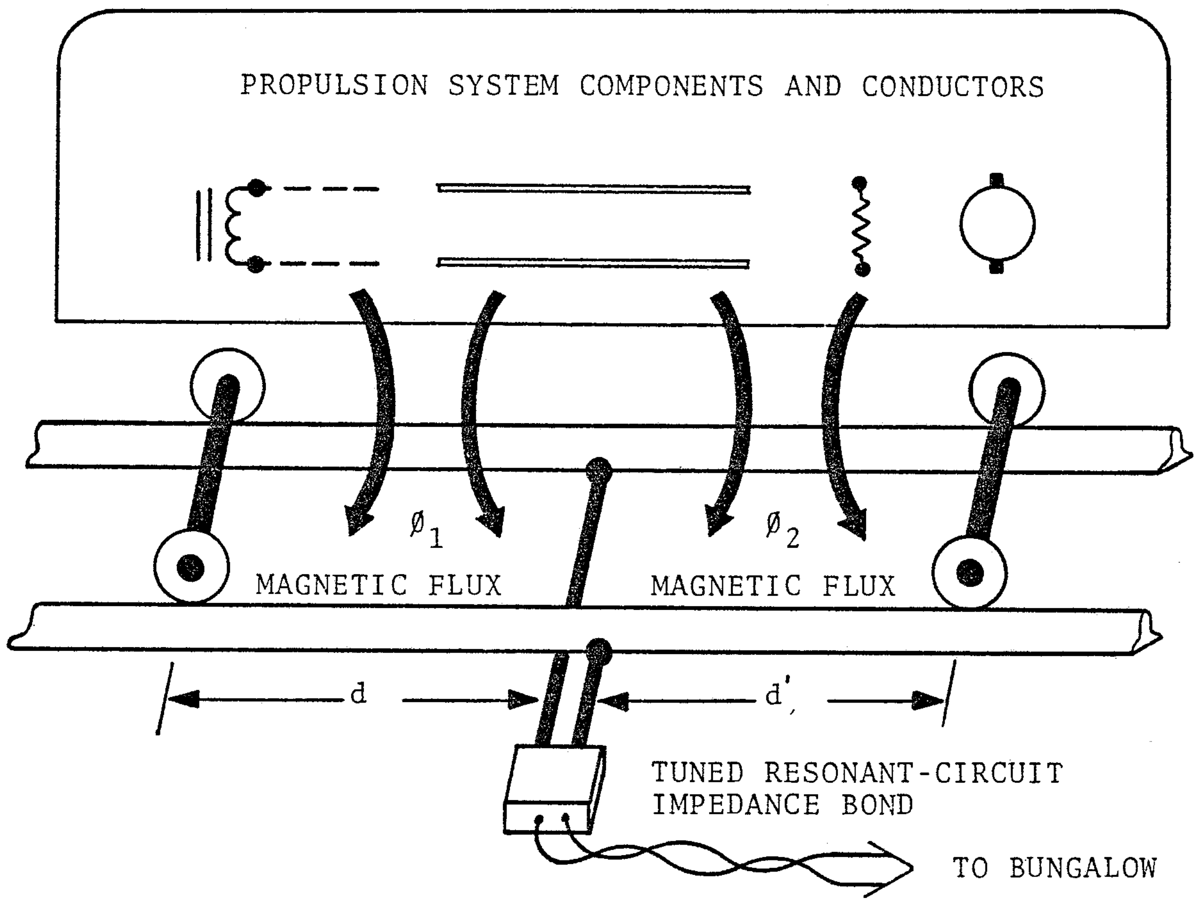


FIGURE 2-4. GENERATION OF INDUCTIVE INTERFERENCE

Different operational modes and speeds of the train, in acceleration, steady running, coasting, and braking, result in different amounts of observed interference. Such interference has been observed in actual transit operation in the U.S. and has been anticipated in new systems presently under construction.

Inductors such as commutation reactors and motor current smoothing reactors, propulsion and braking current buses, and dynamic braking resistor banks are sources of pulsed magnetic flux which pass through the closed loop formed by the rails and axles of the car. Other electrical equipment on the car can produce stray flux as well. The induced rail-to-rail voltage V_R depends on the following factors:

a. position of car over the interconnection point and the position of various components underneath the car relative to that point;

b. mode of operation of the car;

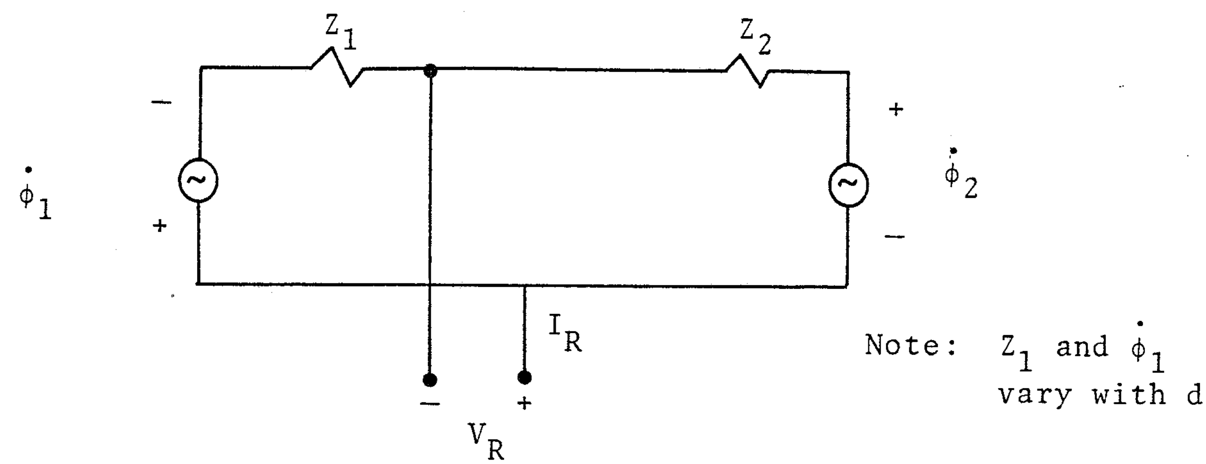
c. specific spectral characteristics of the time-varying fluxes $\phi_1(t)$ and $\phi_2(t)$ due to the mode of chopper operation, car speed, and train consist;

d. impedance characteristics of the two loops on opposite sides of the interconnection point;

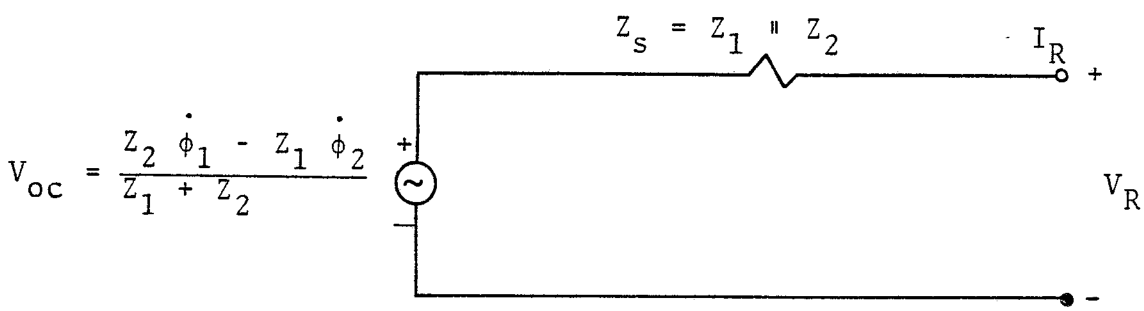
e. frequency-dependent impedance characteristics of track circuit receiver input at the rail connection points.

4.2 Equivalent Electrical Circuit

Figure 2-5(a&b) shows the equivalent electrical circuit which serves as the source of interfering signals. The impedances Z_1 and Z_2 account for the self-inductance of the rail-axle loops, series resistance of the axles, and rail-wheel contact resistances.



a) Loop equivalent



b) Thevenin Equivalent

FIGURE 2-5(a&b). EQUIVALENT ELECTRICAL CIRCUIT-INDUCTIVE EMISSION

When a car axle is near the bond, the corresponding values of Z_1 and Z_2 approach the shunting impedance -- a very small value, typically. As can be seen from Figure 2-5(b), the equivalent source voltage V_{OC} then gets very small, since either ϕ_1 and Z_2 are small, or vice versa. Since both fluxes ϕ_1 and ϕ_2 enter the expression for induced voltage, the peak-to-peak voltage swing will depend specifically upon the positioning, phase, direction, and polarity of various flux sources relative to the rail interconnection point at that time. A measurement indicative of the voltage induced into the impedance bond under these conditions can be acquired using the monitoring circuit as shown in Figure 2-5(c). Figure 2-6 shows a representative plot of the equivalent source impedance Z_s as a function of d, location of rail interconnection point under the vehicle.

Figure 2-7 shows typical waveforms of the rail-to-rail voltage recorded during the passage of a car over a measurement site at one particular rapid transit system. The voltage waveform has a rather complex shape, arising as the sum of contributions from a number of magnetic components. Different portions of the waveform change polarity at different times, as the components causing them cross the bond position.

4.3 Representative Observations of Inductive Interference

Figure 2-8 shows a complete spectral analysis that was obtained by use of an FFT analyzer to separate the contributions to the various harmonic components of the rail-to-rail voltage. As a car passes an observation point, the rail-to-rail voltage changes in shape and amplitude, and thus spectral plots taken at different times show different characteristics. Note in Figure 2-8, however, that strong contributions only exist at the harmonics of the 400 Hz fundamental chopper frequency.

Figure 2-9(a&b) shows an accurately calibrated plot of rail-to-rail voltage at its maximum amplitude, as well as a plot of the

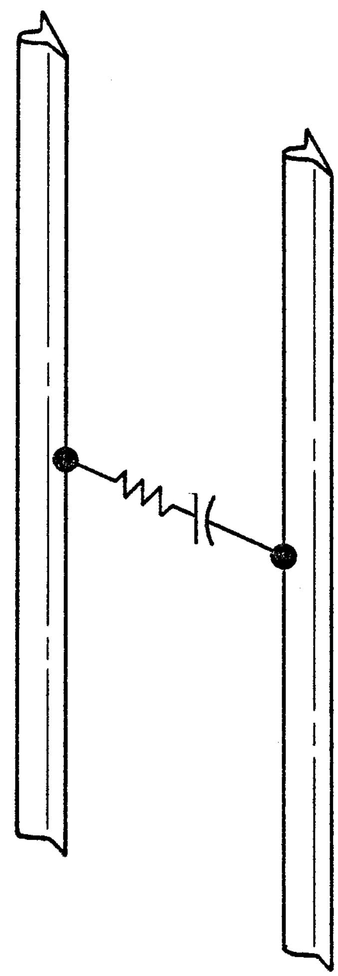


FIGURE 2-5C. TRACK MONITORING CIRCUIT

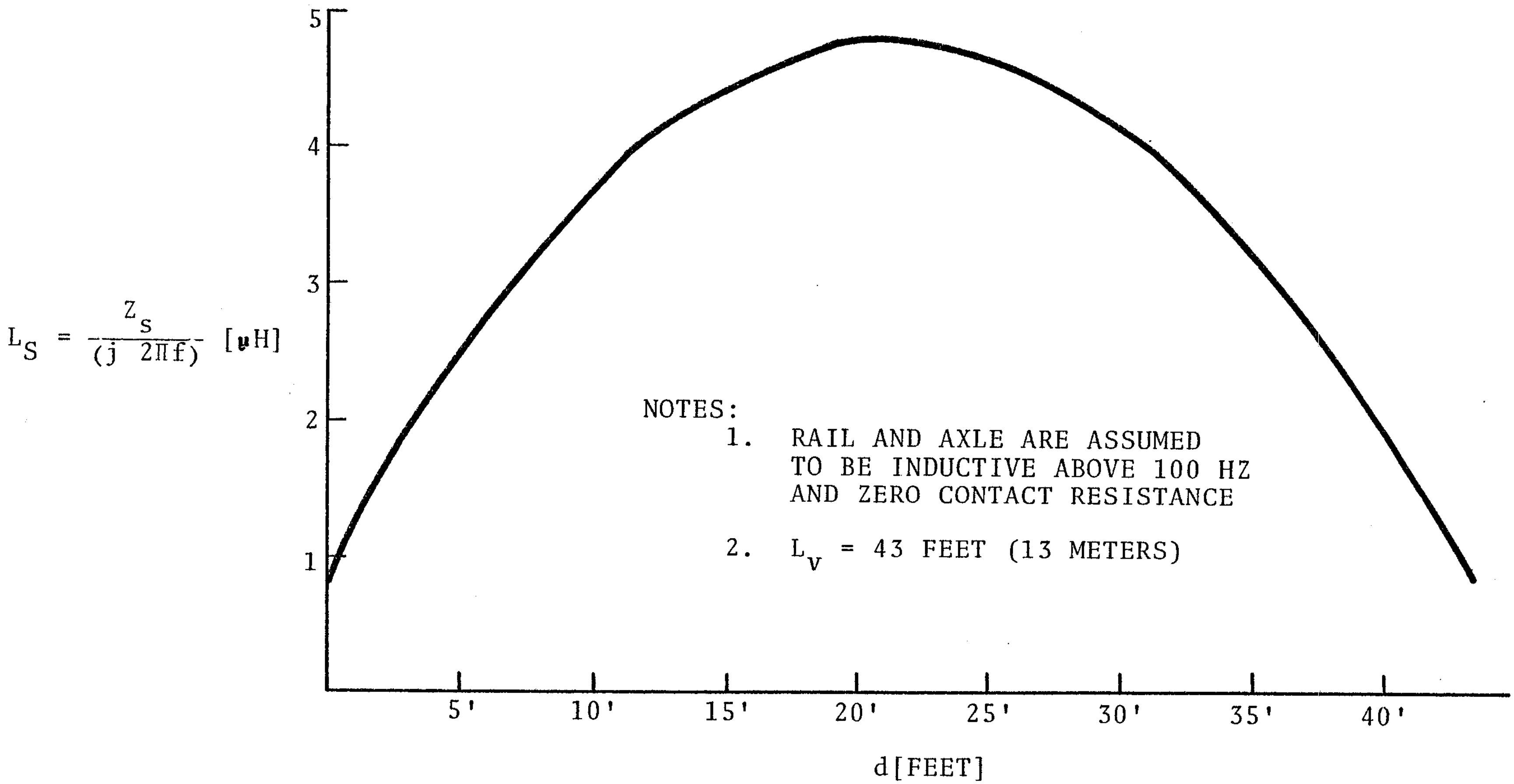
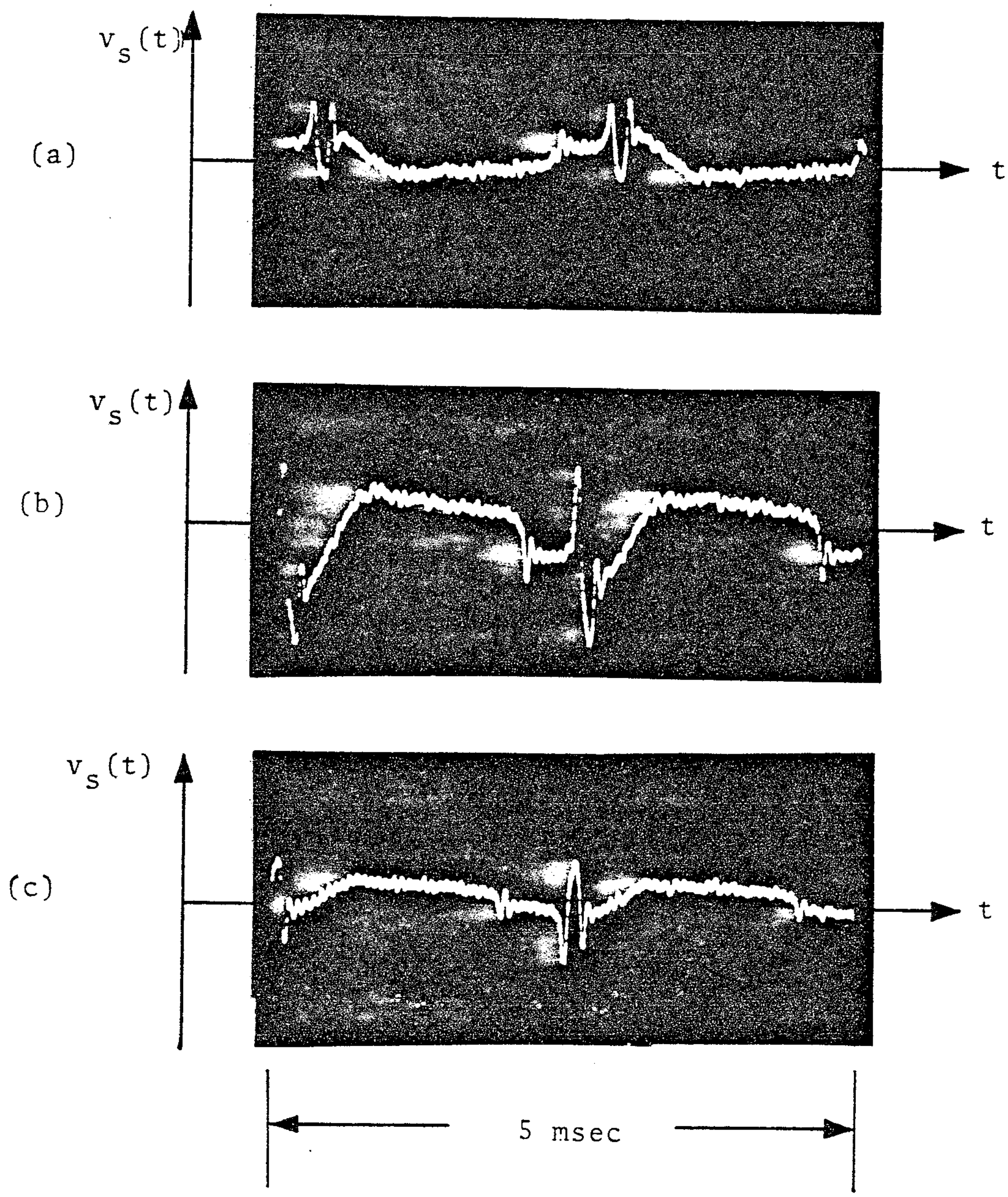


FIGURE 2-6. PLOT OF SOURCE INDUCTANCE VERSUS d



($v_s(t)$ IS IN ARBITRARY UNITS.
UNITS ARE SAME FOR (a)-(c).)

FIGURE 2-7. RAIL-TO-RAIL VOLTAGE AT THREE DIFFERENT TIMES DURING PASSAGE OF MARTA-CAR

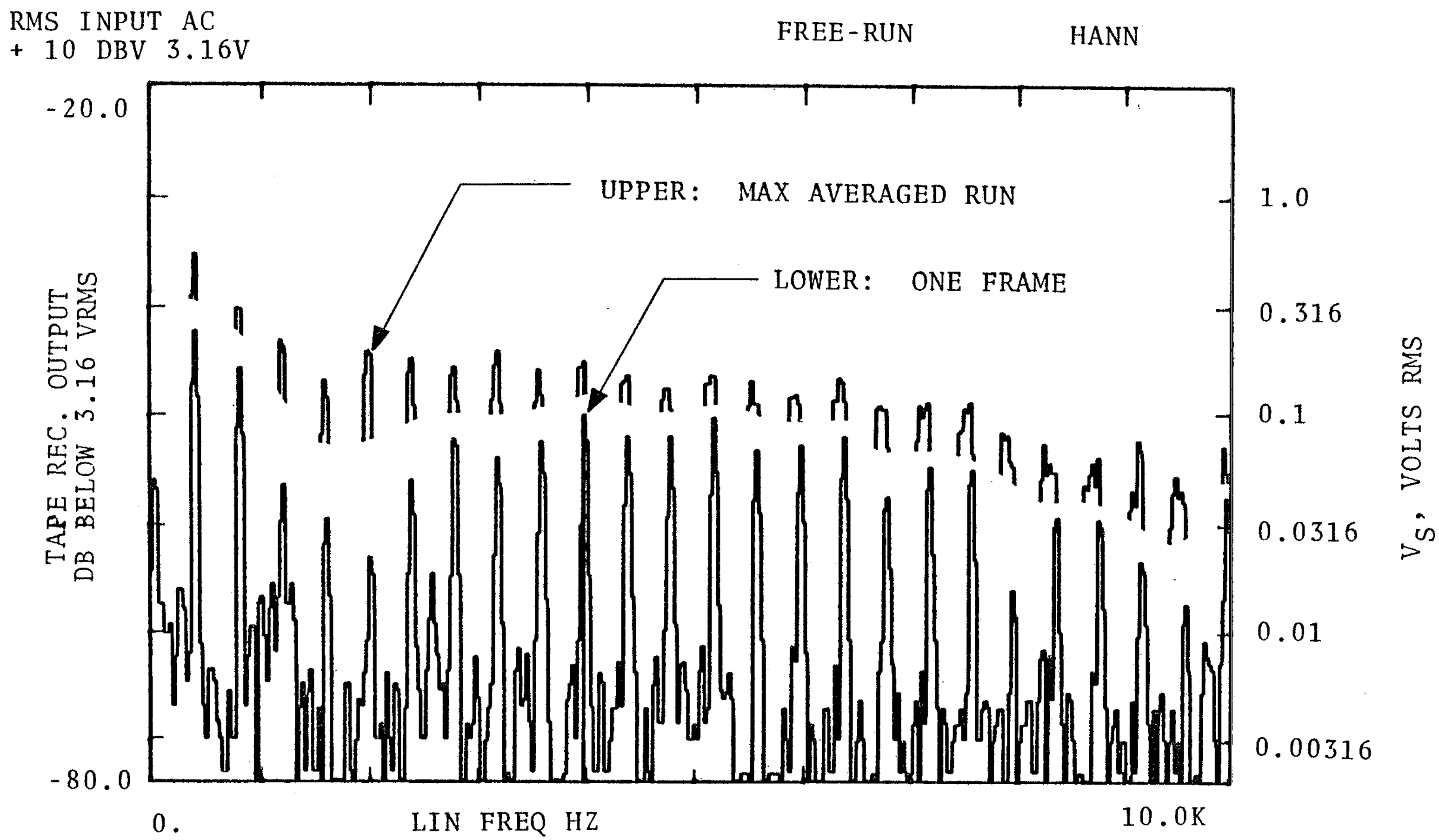
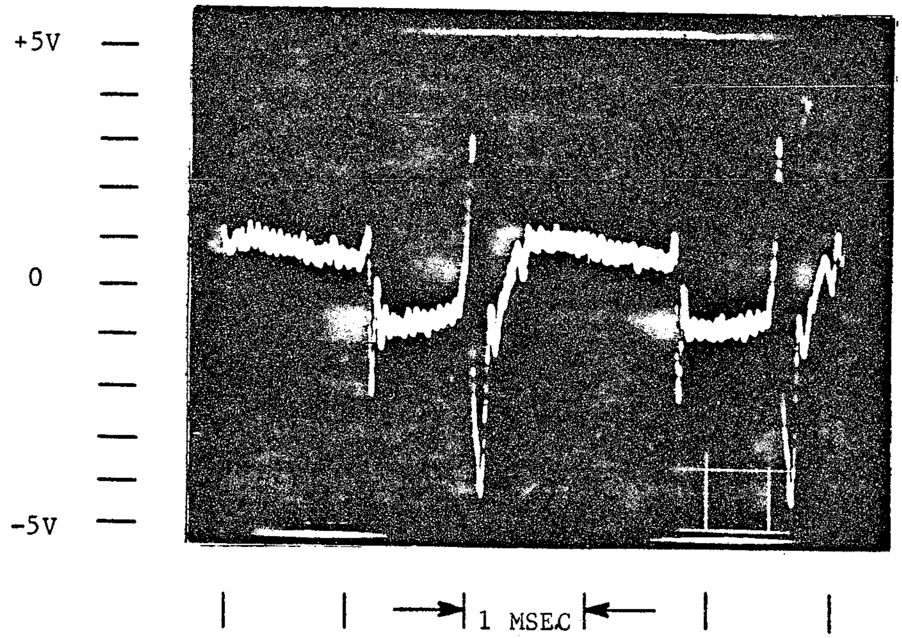
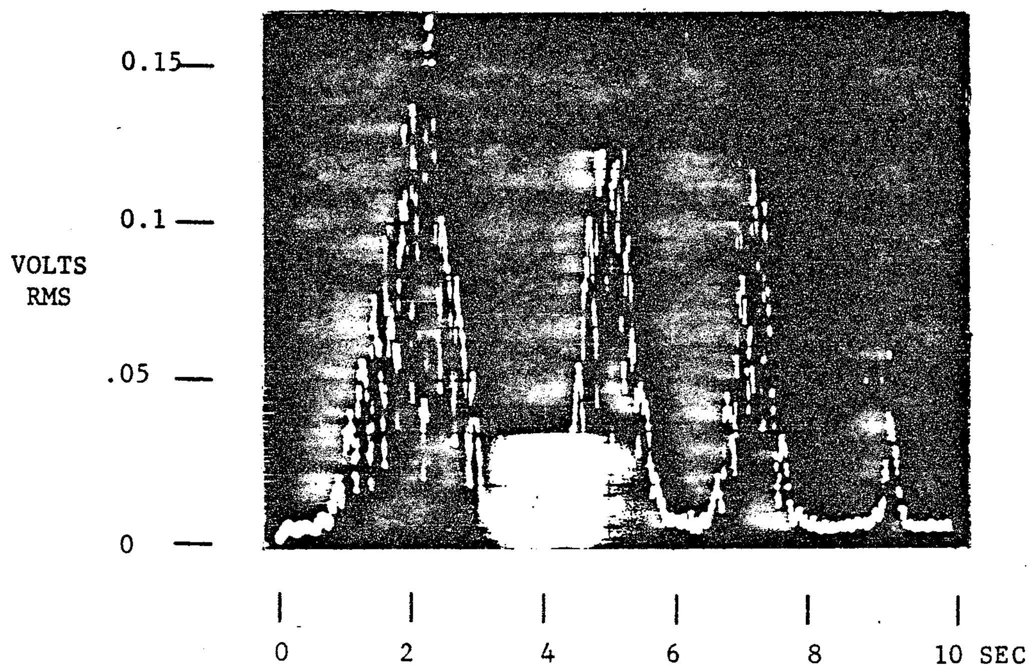


FIGURE 2-8. SPECTRUM OF RAIL-TO-RAIL VOLTAGE



a. RAIL-TO-RAIL VOLTAGE NEAR PEAK OF 1ST CAR



b. STRENGTH OF 9TH HARMONIC (3600 HZ) OF RAIL-TO-RAIL VOLTAGE AS TRAIN PASSES

FIGURE 2-9. MARTA RUN NO. 58 FULL POWER

time variation of the amplitude of a particular harmonic as a function of time during the passage of a four-car train. The rapid time variation of harmonic amplitude level is due to variation of chopper pulse width as the train accelerates, and the corresponding change in magnitude of the harmonic coefficients. Note that if the audio-frequency signalling system had a track frequency which was the same as or sufficiently close in value to a chopper harmonic frequency, and if the chopper harmonic in question reached sufficient amplitude, the track receiver could interpret a signal such as is pictured in Figure 2-9(b) as being a burst of coded track signal and could pick up the relay. This set of circumstances has in fact been observed in a number of instances.

5.0 CONDUCTIVE INTERFERENCE

A depiction of chopper-induced conductive interference in audio-frequency signalling is presented in Figure 2-10. The harmonics produced by the substation rectification system, as well as the harmonics produced by the chopper speed control and injected into the third rail by the car, can have measurable content in the audio-frequency range. The currents produced by these sources also flow back through the running rails. If the current which is in the audio-frequency range is divided equally between the running rails, no conductive signalling interference occurs. However, this is usually not the case. The third-rail current gives rise to magnetic flux which passes through the loop formed by the running rails, thus inducing circulating current in the loop formed by the running rails. The ratio of circulating current to third-rail current is given by the ratio of mutual inductance between third and running rails to running-rail loop self-inductance; this ratio is approximately 0.17 for typical third-rail geometries.

The audio-frequency signalling pickup coils on the car typically will be subjected to approximately 17 percent of the total conducted current in the audio-frequency range. Track receiver

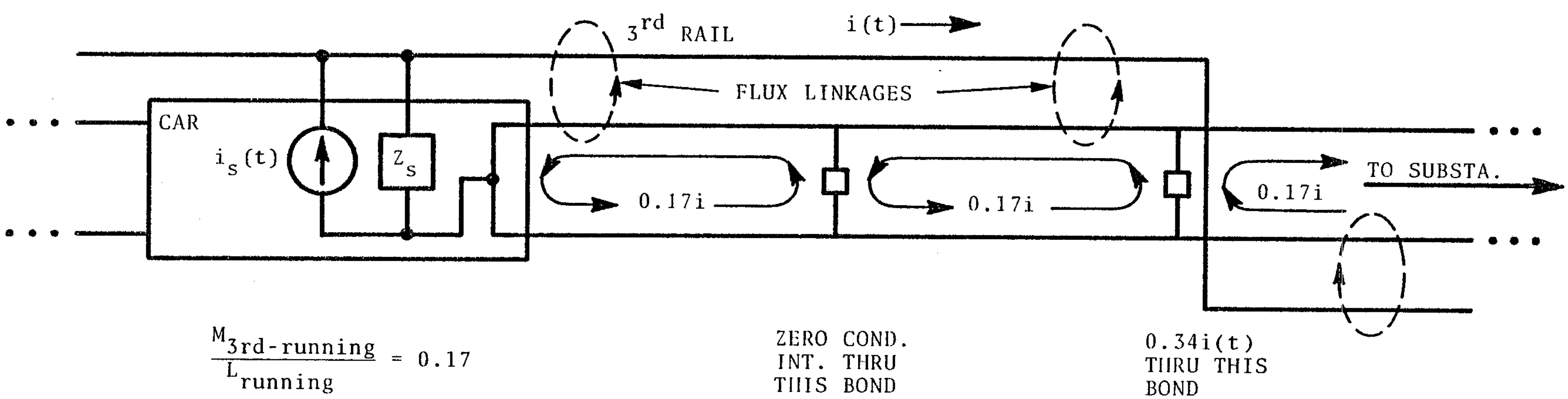


FIGURE 2-10. AUDIO-FREQUENCY CONDUCTIVE INTERFERENCE

impedance bonds can be subjected to between 0 and 34 percent of total conducted current in the audio-frequency range, depending on placement of bonds relative to locations where the third rail switches sides. Note that this inductive coupling between the third rail and running rails only accounts for a portion of conductive signalling interference that might occur in actual operation. Additional conductive interference can arise from unequal wheel-rail contact resistances or unequal bond lead impedances at cross-bonding locations. The coupling mechanism as outlined does establish a lower limit on expected levels of conducted interference.

Conductive interference is evidenced by interference signals present at bond locations ahead of or behind the train, and potentially can cause two types of false responses: false pick-up of a dropped track relay; or false dropping of a picked-up track relay.

Recent investigation of chopper conducted interference levels for multi-car trains has led to the realization that these levels are of a statistical nature. Figure 2-11 depicts the phasor addition of contributions from separate cars of a multi-car train at a particular harmonic frequency. While it is possible for all of these separate contributions to add up very nearly in phase, that will happen only rarely. A statistical distribution of overall harmonic amplitude results, with the rms value of current increasing as $N^{1/2}$, and the maximum value of current increasing as N, where N is the number of cars in a train.

6. CONCLUSIONS

At this time, both inductive and conductive interference mechanisms are well understood. In addition to the extensive observations that have been made in the field under actual operating conditions, procedures now exist for observing interference levels in the laboratory for choppers and track circuits

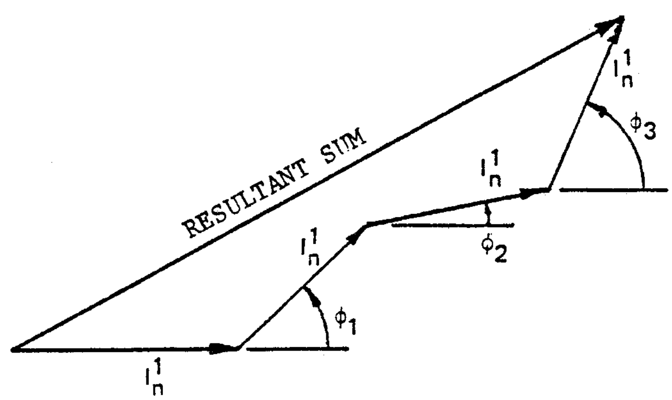


FIGURE 2-11. ADDITION OF SEPARATE n^{th}-HARMONIC COMPONENTS FOR A MULTI-CAR TRAIN

which are still in the engineering stage of development. Use of these procedures has proven beneficial in assuring compatibility of propulsion and signalling equipment for rapid transit systems currently under development, as described in the Recommended Practices that follow.

SECTION 3. CONDUCTIVE RECOMMENDED PRACTICES

METHOD RT/CS01A
CONDUCTIVE SUSCEPTIBILITY OF AUDIO-FREQUENCY RATE-CODED SIGNALLING SYSTEMS FROM 300 Hz TO 10 kHz

1.0 PURPOSE

The purpose of this test is to determine the susceptibility of audio-frequency rate-coded track circuit receivers to types of interference caused by conductive emissions.

2.0 APPLICATION

This method is applicable to all audio-frequency track circuit equipment operating at frequencies between 300 Hz to 10 kHz in which the operating signal waveform consists of amplitude modulated audio-frequency tones modulated at a selectable discrete rate (i.e., code rate). The test procedure has not been formally applied; its feasibility is presently being evaluated.

3.0 APPARATUS

The test apparatus consists of the following:

a. amplitude-modulated audio-frequency signal generator, Wavetek Model 146 or equal

b. low-output impedance amplifier

c. oscilloscope

d. RMS voltmeter

4.0 TEST PROCEDURE

To evaluate the effects of conductive interference, two distinct operating conditions must be considered:

Case I - track circuit occupied by vehicle
Case II - track circuit unoccupied

Only test procedures for Case II are presented here. The test procedures of Method RT/IS01A (Inductive Susceptibility), where the track circuit transmitter rail output has been disabled, are directly applicable to Case I conductive susceptibility.

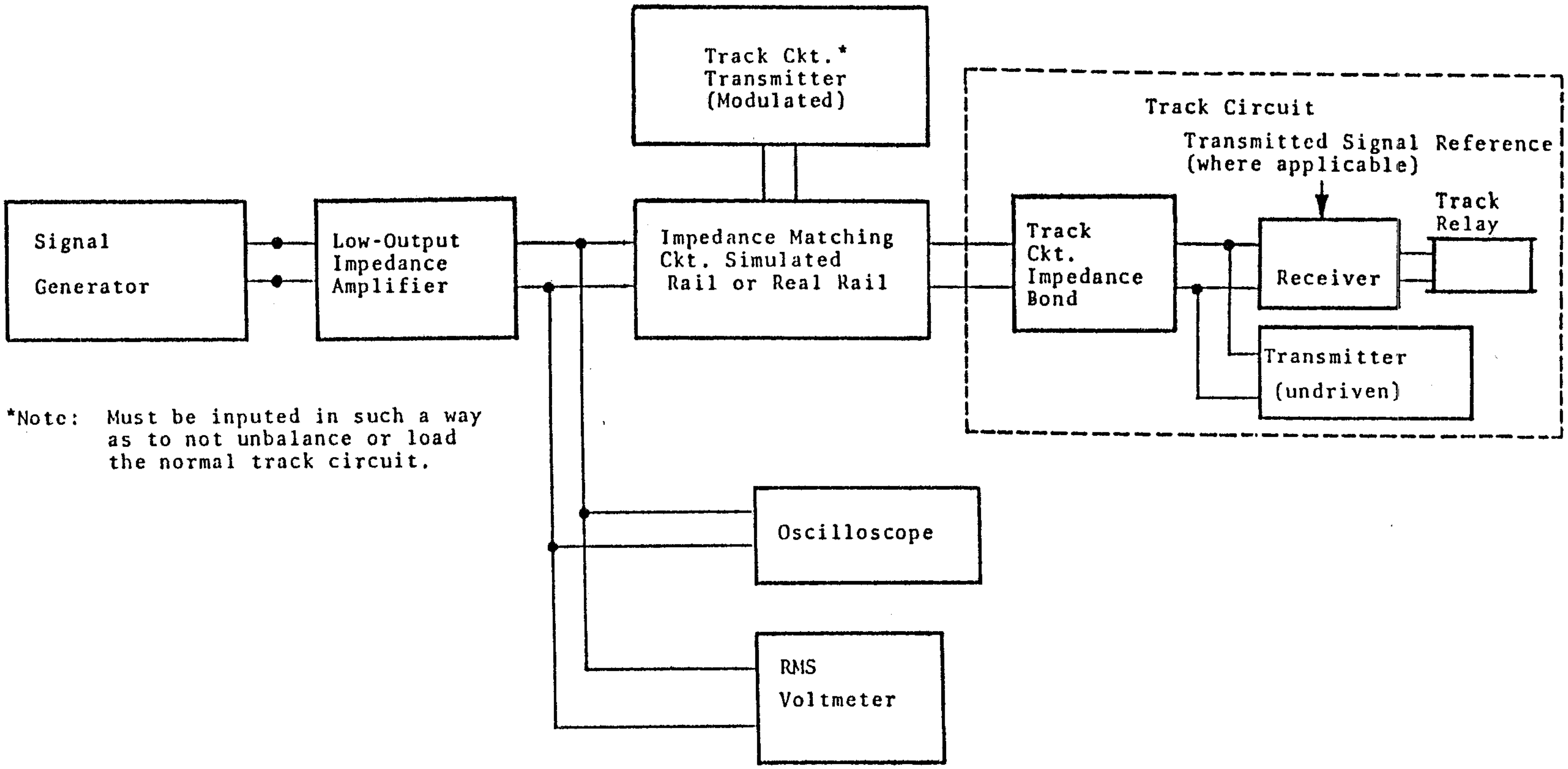
Therefore, in the susceptibility tests which follow, the track circuit transmitter track output remains connected and operational with the simulated or pre-recorded conductive interference source attached in parallel. Note that the susceptibility criteria is <u>track circuit occupied</u> (e.g., track relay dropped).

4.1 Verification Of Nominal Track Circuit Operation

Verify that the track circuit receiver is working according to manufacturer specifications, with the transmitter and receiver properly loaded, and with the transmitter track signal and references supplied to the receiver as required. Then, set up the equipment as shown in Figure RT/CS01A-1. Adjust the receiver threshold so that it is at its least sensitive position (minimum gain). Complete the test procedure and then repeat it with the receiver at its most sensitive (maximum) gain.

4.2 Continuous Wave (CW) Test

Turn on the track circuit transmitter to output a valid carrier and code rate. Adjust the carrier frequency of the audio-frequency signal generator to the specified operating frequency



*Note: Must be inputed in such a way as to not unbalance or load the normal track circuit.

FIGURE RT/CS01A-1. ARRANGEMENT OF TEST APPARATUS FOR PERFORMING MEASUREMENT OF INDUCTIVE SUSCEPTIBILITY (CASE II) OF SIGNALLING SYSTEMS of the receiver of the track circuit under test. Adjust the modulation index to 100 percent. Adjust the modulation frequency to 0 Hz (CW operation) and slowly increase the applied voltage until the track circuit indicates occupied (e.g., track relay drops). Record this value which is the CW Interference Susceptibility Level, Vrms, at center frequency. Adjust the carrier frequency of the signal generator in 10 Hz increments above and below the specified operating frequency. For each increment, slowly vary the applied voltage to establish the threshold for dropping the relay (record the frequency and level for each increment). Continue incrementing the carrier frequency followed by varying the applied voltage until the threshold is in excess of 0.5 Vrms. Repeat this test for all valid track circuit transmitter carrier and code rate frequencies which can be present in an unoccupied track circuit.

5.0 TABULATION OF RESULTS

Record the susceptibility results on a data sheet; where actual recorded signals are used, the results should be presented in a narrative form including the source of the noise, the tape identification and its storage location, the test method followed in producing the tape, the scale factor, and the resultant effect the noise had on the track circuit.

6.0 NOTES

6.1 Note that some erratic receiver behavior may occur in the CW test of section 4.2 when the CW interference frequency is near the signalling frequency. This is normal due to extra modulation components caused by the beat between interference and normal track signals. Increase the interference level slowly. The threshold (lowest level signal which causes the relay to drop away) should be recorded.

6.2 The interference susceptibility as measured in this test method is representative of the magnitude and characteristics of the unbalanced current in the running rails to which the track circuit receiver is susceptible.

METHOD RT/CE01A

CONDUCTIVE EMISSION TEST, SUBSTATION

1.0 PURPOSE

The purpose of this test is to measure the conductive emissions existent on the propulsion power supply feeder.

2.0 APPLICABILITY

The test is applicable to propulsion systems using dc input power. The test measures the conductive emissions produced by the vehicle(s) together with those caused by the substation. Under some conditions, it may be difficult or impossible to separate these two effects. This test method has been successfully applied and an example of the results is presented in Appendix B.

3.0 TEST EQUIPMENT AND FACILITIES

3.1 Test Facility

The test facility shall consist of a section of dry test track fed at one end by a power substation. The portion of track required for train acceleration should be without power gaps in order to avoid transients which can affect the data. It shall be possible to isolate the test section from all other power substations and from all other loads which can produce audio-frequency signals.

3.2 Apparatus

The following equipment is required:

a. suitable current sensor and associated signal conditioning (See RT/CE01A Exhibit A).

b. FFT spectrum analyzer, GEN RAD Model 2512 or similar

c. X-Y plotter compatible with the spectrum analyzer

d. tape recorder (optional)

e. strip-chart recorder and adjunct instrumentation, as required to record essential vehicle operating parameters (see paragraph 4.1)

f. means to assure proper calibration of the installed arrangement of current sensor, preamplifier, and amplifier

g. communication equipment to coordinate train operation with the substation test crew

4.0 TEST PROCEDURE

The test train consist(s) shall be as specified by the Authority and shall include a maximum-length train. The tests shall be conducted at empty vehicle weight (AWO)[1] and for the acceleration mode only. If required, the data can be adjusted for other weights and other operating modes, such as dynamic or regenerative braking, in accordance with known characteristics of the propulsion equipment. The tests shall be conducted with the objective of obtaining worst-case data.

4.1 Vehicle Instrumentation

Appropriate instrumentation and a strip-chart recorder shall be installed in one of the test vehicles to record the following information during each test:

---

[1]AWO - Actual Weight Zero Loading.

- dc line voltage or input filter capacitor-bank dc voltage
- propulsion system dc input current
- vehicle speed
- armature current on one traction motor
- dc-link voltage and current if ac drive
- field current
- P-Signal (or other train command signal)

4.2 Substation Instrumentation

In order to assess stray pickup the current sensor, at first, shall be installed immediately adjacent to the positive bus of the power substation. The entire instrumentation set-up shall be calibrated by injecting, using a known number of ampere-turns, a sine-wave signal whose frequency is in the band of interest but not coincident with a chopper or substation harmonic, and by observing the corresponding output level on the spectrum analyzer. All harmonic amplitudes shall be referenced to this level.

For purposes of assuring proper operation of the instrumentation, a calculation shall be made of the expected amplitude of the spectral display due to the calibration signal. Agreement should be within ± 1 dB. (See Note 6.2.)

With the output terminals of the current sensor shorted, a maximum-length train shall be accelerated to verify satisfactory noise immunity of the instrumentation exclusive of the current sensor.

A preliminary run as described in 4.3 shall then be made with all instrumentation active, and with the current sensor still adjacent to the positive bus instead of in the positive bus, in order to assess stray pickup. If stray pickup is believed to be excessive, cabling and equipment placement shall be altered to reduce stray levels.

4.3 Emission Test

The current sensor shall be installed in the positive bus. The test train shall be placed with its trailing end at the dc return to the substation and then accelerated under maximum power away from the power substation. The spectrum analyzer, in peak-average ("max") mode and in Hann windowing configuration, shall acquire data throughout the acceleration cycle. In order to avoid obscuring the data by transients, data acquisition should be delayed until after all train contactor closures related to initial power application have taken place. In order to assess the effects of initial chopper sweeping or pulse-skipping, data shall be recorded twice: first, beginning immediately after contact closure, and again beginning at a train speed above which chopper frequency sweeping or pulse-skipping ceases. The spectrum analyzer data shall be plotted and fully annotated upon completion of each run. The on-board instrumentation shall also acquire data throughout each test run. In addition, the maximum current registered by the substation dc meter shall be recorded. Results shall be checked against the noise immunity runs described in 4.2 to assure that stray pickup does not degrade accuracy more than a tolerable amount. (For example, stray pickup 20 dB below an actually observed harmonic line introduces an uncertainty of ±1 dB in the amplitude of that line.

5.0 TABULATION OF RESULTS

The results shall be summarized in tabular form. The table shall contain the following minimum information:

a. test description (e.g., 2-car train, outbound)

b. maximum reading of station ammeter

c. vehicle data: maximum speed, minimum line voltage, maximum line current, maximum motor current

d. frequency and level of measured emissions in signalling band.

In addition, the following data shall be presented:

a. all spectral plots made, fully annotated

b. strip charts of vehicle parameters

c. test equipment certification information

6.0 NOTES

6.1 The spectra plotted in accordance with 4.3 display only the maximum instantaneous magnitude that any harmonic has reached during the test. Additional information may be obtained by later analysis of the tape recorded data. Analysis such as the application of frequency expansion techniques may be helpful in discriminating between propulsion and power supply harmonics.

6.2 Some spectrum analyzers, including the one suggested herein (Item 3.2 b), do not automatically correct for the amplitude reduction associated with hanning. In that event, the data as recorded with the spectrum analyzer shall be adjusted by +1.8 dB, in order to obtain actual levels. This correction must be made to correctly correlate the actual level of the injected reference signal with its amplitude as measured by the spectrum analyzer.

6.3 The measurement resulting from this test method reflects the characteristics and loading of the specific substation as well as the characteristics of the vehicle used. It is important that the tests be conducted as closely as possible to a substation in order to:

(1) minimize the possibility of spurious results due to frequency-dependent impedence characteristics of the rail loop, and

(2) minimize error due to the finite source impedance of the car.

6.4 The test results also reflect the effects of vehicle auxiliaries, depending in detail on the exact equipment configuration in effect.

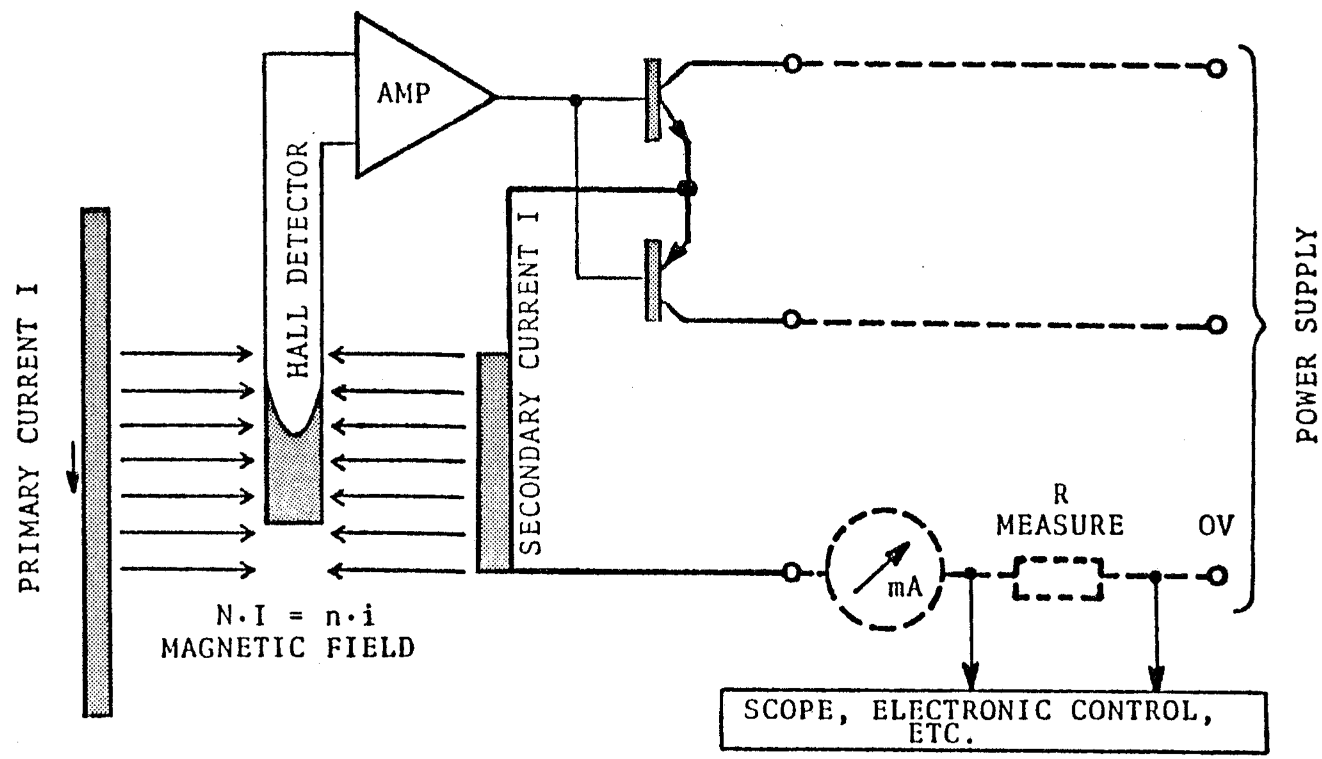


FIGURE RT/CE02A-A-1. LEM TRANSFOSHUNT

Other essential characteristics are:

- Measuring range - 1500 ampere-turns
- Output sensitivity - 2 mV/amp (10 ohm measuring resistor)

An elementary schematic of the complete instrumentation is shown in Figure RT/CE02A-A-2. The Transfoshunt is placed in the propulsion positive feed line, with the preamplifier/line-driver nearby. A 4-pole Butterworth filter is used to split the signal into two frequency ranges in order not to exceed the dynamic range capability of the tape deck and, on occasion, of the spectrum analyzer. In the latter event, each test is performed twice: once without the filter, and once with the filter at the spectrum analyzer input. The audio oscillator is used for spot calibration and checkout of the equipment.

NOTES: The Transfoshunt can become magnetized by primary current if the power supply is off. This may result in erroneous readings. Usually, operating the device through a normal operating cycle clears the problem. Otherwise, the sensor can be readily demagnetized by conventional means.

The harmonic distortion produced by the test equipment has not been fully characterized. Such distortion can lead to the perception of higher emissions than actually produced. However, the harmonic distortion of the test equipment has been determined to be sufficiently low to permit specification compliance testing to a specified emission level of 17 ma.

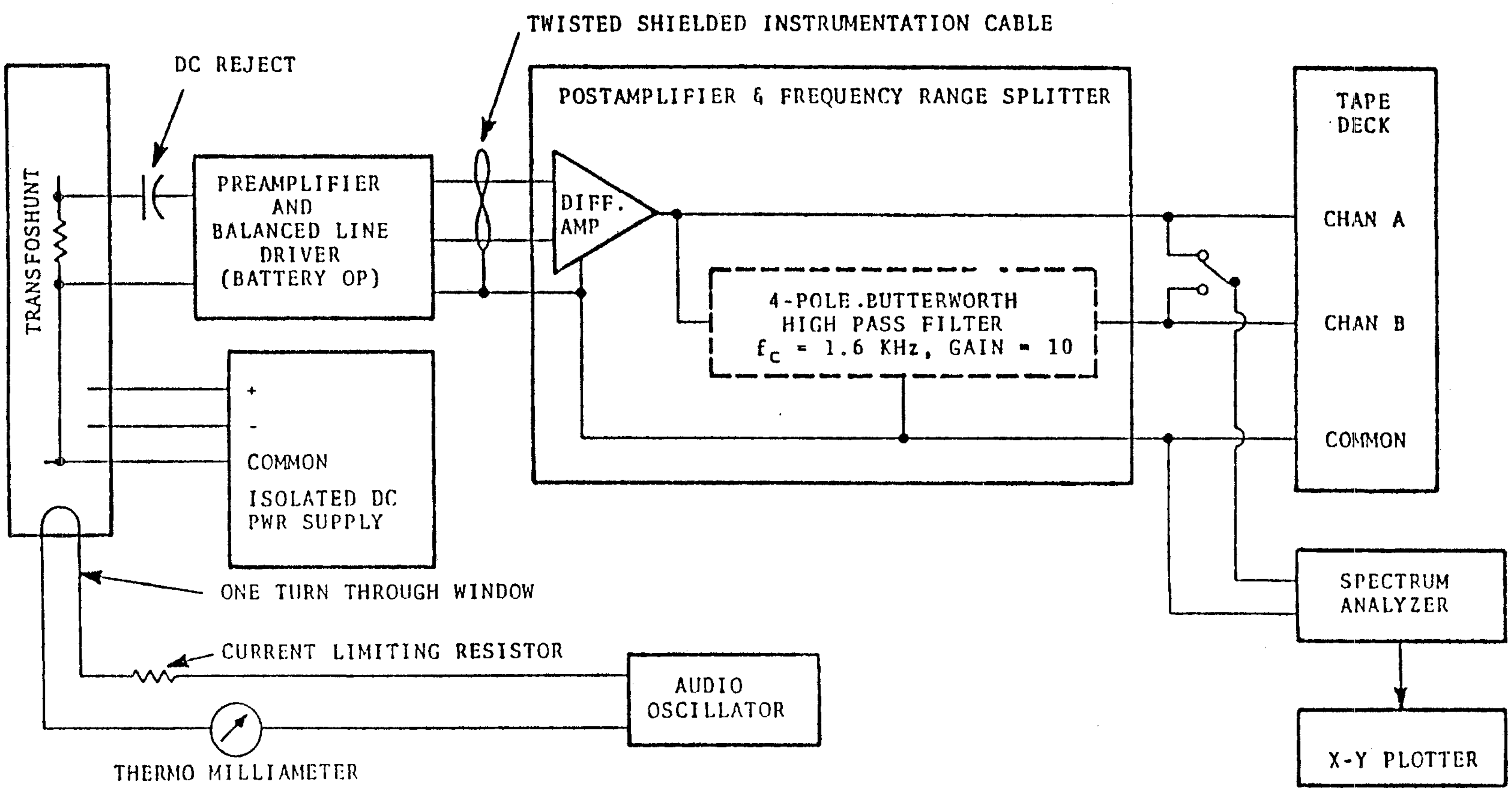


FIGURE RT/CE02A-A-2.
ELEMENTARY INSTRUMENTATION SCHEMATIC CONDUCTIVE
EMISSION TEST

METHOD RT/OC01A

AUDIO FREQUENCY RATE-CODED TRACK CIRCUIT RECEIVER OPERATING CHARACTERISTICS FROM 300 Hz TO 10 kHz

1.0 PURPOSE

The purpose of this test is to determine the receiver operating characteristics at the rail interface for audio-frequency rate-coded track circuits in support of interference susceptibility assessments.

2.0 APPLICATION

This method is applicable to all audio frequency track circuit equipment operating at frequencies between 300 Hz to 10 kHz in which the operating signal waveform consists of amplitude modulated frequency tones modulated at a selectable rate (i.e., code rate). This method has been successfully applied and an example is presented in Appendix B.

3.0 APPARATUS

(See specific equipment requirements in paragraph 4.0 to 4.3).

4.0 TEST PROCEDURE

To evaluate the susceptibility of audio-frequency signalling systems to interference, it is necessary to determine the following track circuit receiver operating characteristics at the rail interface:

a. frequency selective input sensitivity
b. input impedance

4.1 Verification of Nominal Track Circuit Operation

Verify according to track circuit manufacturer's instructions that the track circuit receiver is properly tuned and adjusted. Apparatus shall be as per manufacturer's specifications. Items to be verified include, but are not limited to:

a. tuning of resonant track coupling units

b. adjustment of variable receiver sensitivity levels

c. verification of proper value of transmission line compensation capacitor.

For purposes of this test, in those cases where the receiver sensitivity level is adjustable in the field (e.g., by means of a variable potentiometer or switch, as opposed to selection of soldered-in components), the receiver sensitivity level will be set at its most sensitive level. This sensitivity level will be maintained for the entire test.

4.2 Frequency Selective Input Sensitivity Test

4.2.1 Assemble the apparatus as shown in Figure RT/OC01A-1.

The apparatus includes the following:

- o oscilloscope
- o RMS--reading audio-frequency voltmeter
- o Wavetek modulated function generator Model 146 or equivalent

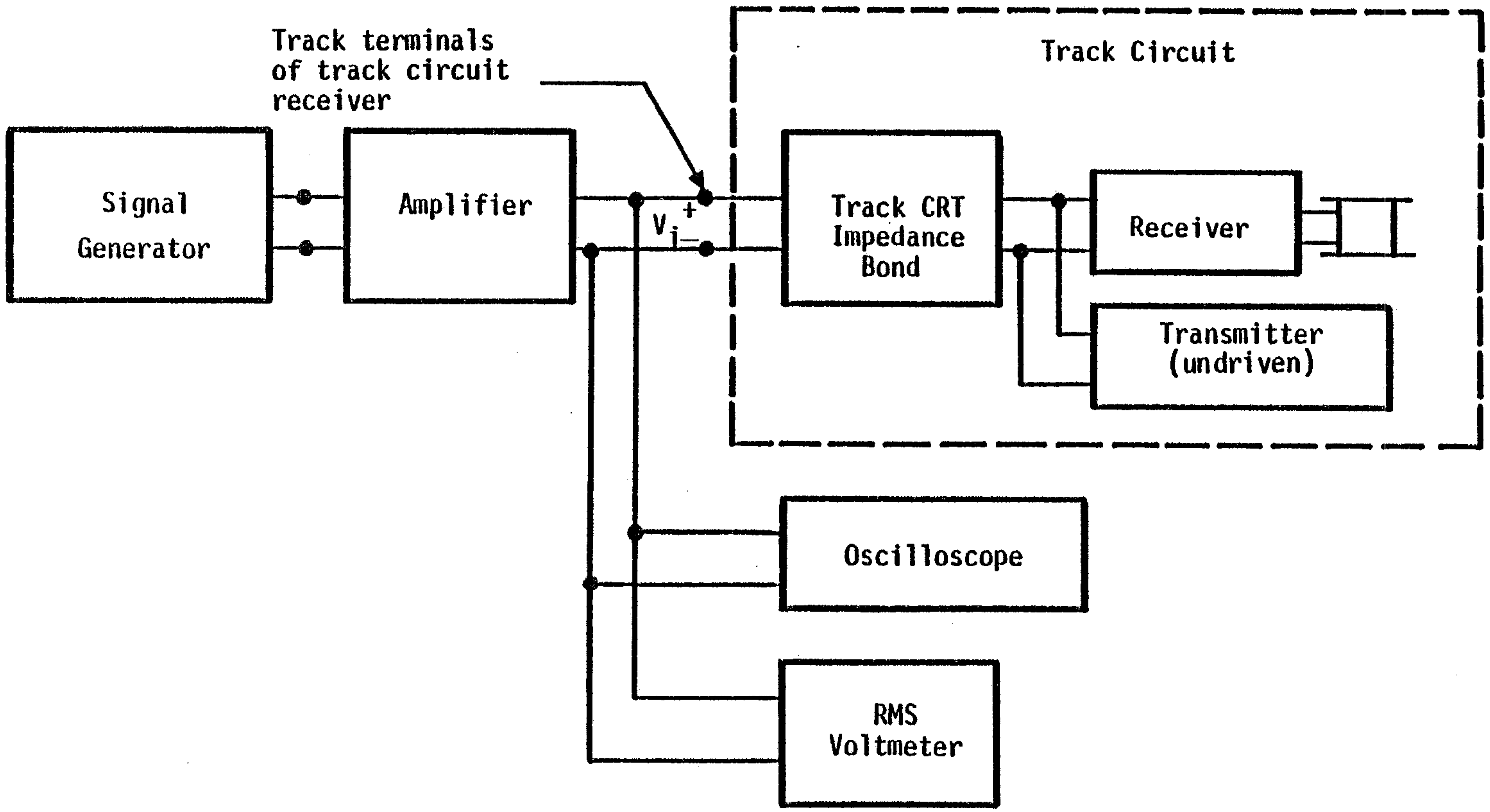


FIGURE RT/OC01A-1. ARRANGEMENT OF TEST APPARATUS FOR MEASURING FREQUENCY SELECTIVE INPUT SENSITIVITY OF TRACK TERMINAL OF TRACK CIRCUIT RECEIVER

- MacIntosh Model MC-60 audio-frequency power amplifier or equivalent

- frequency counter

4.2.2 In order to properly account for the effects of transmitter output impedance on circuit tuning, the transmitter's output impedance must be included in the circuit while the transmitter output is disabled. The transmitter output is disabled by removing the track signal and train signal oscillator boards from the track circuit module's card file. This method works when the transmitter output impedance is the same under driven and un-driven conditions.

4.2.3 Determination of Code Rates - The lowest normally used code rate is the minimum code rate. The highest normally used code rate is the maximum code rate. Determine the normally used code rate which is the closest to the geometric mean of the minimum and maximum code rates [i.e., the normally used code rate nearest in value to (minimum code rate) (maximum code rate)] 1/2. This is the intermediate code rate.

4.2.4 Determination of Test Frequency Increment Δf - Using the maximum code rate and square-wave modulation, determine the carrier frequency ranges between 300 Hz and 10 kHz over which the track relay picked up for a signal level less than or equal to 0.5 Vrms (1.4 Vpp). The frequency range that contains the specified operating frequency is the principal frequency range. Other frequency ranges that may exist are subsidiary frequency ranges. The lowest frequency of the principal frequency range is f_1. The highest frequency of the principal frequency range is f_2. (Care must be taken not to apply signals that exceed the manufacturer's recommended maximum levels within the principal frequency range, or equipment may be permanently damaged.) Determine the frequency increment Δf by rounding the value $(f_2 - f_1)/16$ to the next highest number divisible by 5 Hz.

4.2.5 With the signal generator operating CW, adjust its frequency to the specified operating frequency of the track circuit receiver. Square-wave modulate the test signal at the minimum code rate. Adjust the modulation to 100 percent. Slowly increase the level until the track relay picks up. Then, to measure amplitude, switch modulation to CW, and record the rms signal level at the track terminals.

4.2.6 Repeat 4.2.5 using frequencies Δf, $2\Delta f$, $3\Delta f$, etc., below the specified operating frequency until the lower limit of the principal frequency range f_1 is reached.

4.2.7 Repeat 4.2.5 using carrier frequencies Δf, $2\Delta f$, $3\Delta f$, etc., above the specified operating frequency until the upper limit of the principal frequency range f_2 is reached.

4.2.8 Repeat 4.2.5 at all frequencies lying in the subsidiary frequency ranges that are spaced from the specified operating frequency by integral multiples of Δf.

4.2.9 Adjust the code rate to intermediate code rate and repeat 4.2.5-4.2.8. Then adjust the code rate to the maximum code rate and repeat 4.2.5-4.2.8 again.

4.3 Input Impedance Test

The impedance characteristics versus frequency of a track circuit can be obtained as follows:

Using an Audio Frequency Spectrum and Network Analyzer, HP Model 3582A, an audio-frequency power amp and an X-Y plotter, the impedance characteristics can be obtained by applying the white noise generator output of the analyzer through the power amp to the input terminals of the impedance bond (the wayside components must be configured as shown in Figure RT/OC01A-2, with the transmission line compensating capacitor adjusted as per manufacturer's specifications). As shown in Figure RT-OC01A-2, the current through a 1-ohm reference resistor and the current into the track circuit are measured using matched current probes. The complex ratio of these currents is measured by the analyzer, and the impedance plot is thus obtained.

5.0 TABULATION OF RESULTS

5.1 Frequency Selective Input Sensitivity Test

Tabulate data on a sheet or sheets as shown in Figure RT/OC01A-3.

5.2 Input Impedance Test

Annotated X-Y Plot from Analyzer.

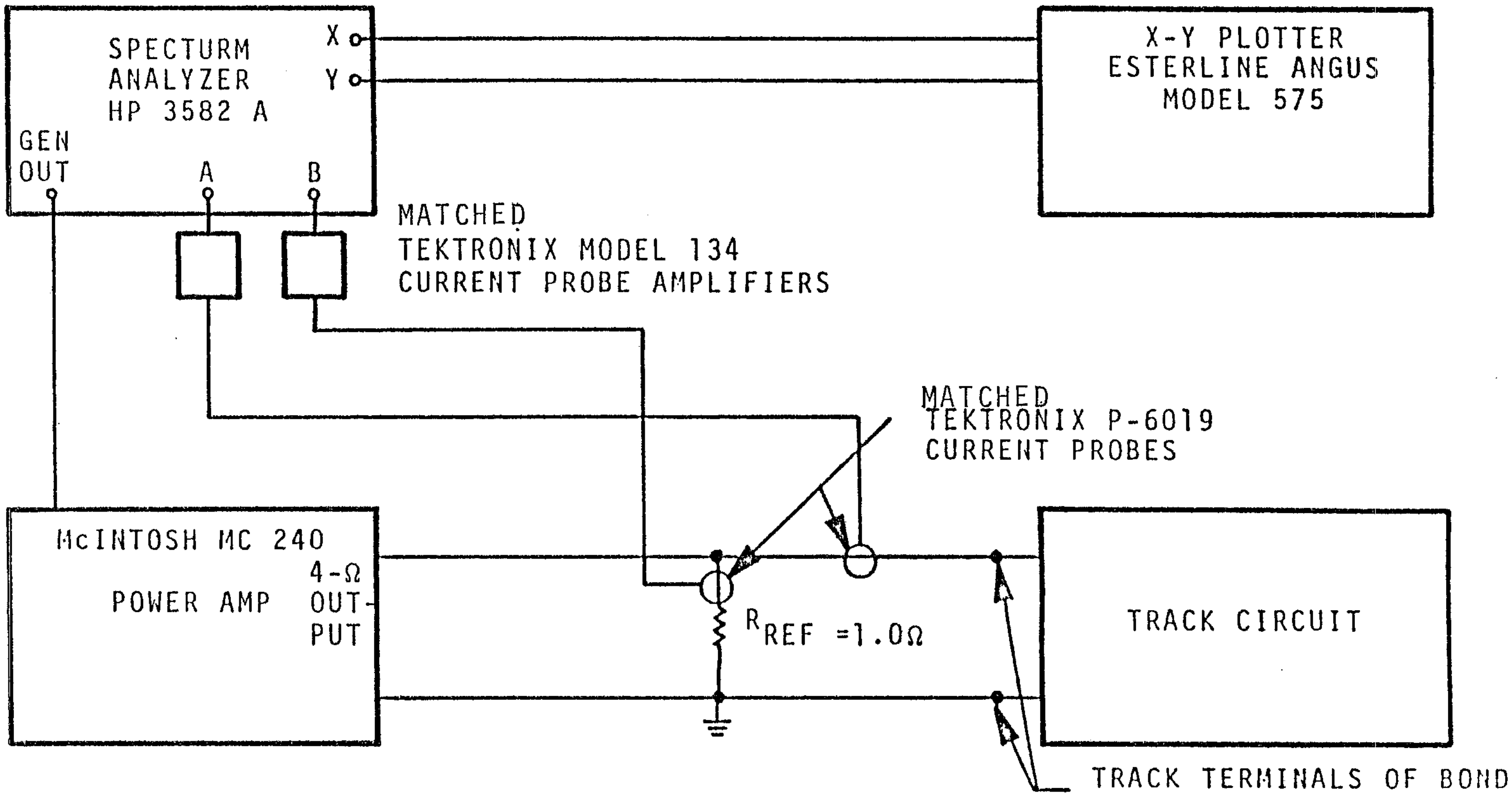


FIGURE RT/OC01A-2. INPUT IMPEDANCE TEST SET-UP

System Tested: ___________________

Test Performed: ________________

Date: ____________________________

OPERATING FREQUENCY f_o = Hz

MAXIMUM CODE RATE = Hz

INTERMEDIATE CODE RATES = Hz

MINIMUM CODE RATE = Hz

* - DENOTES THAT NO VALUE OF V_i LESS THAN 0.5 VRMS
(1.4 VP-P) CAUSED TRACK RELAY TO PICK UP

THRESHOLD VALUES OF V_i FOR WHICH TRACK RELAY PICKS UP IN mV RMS																		
Frequency																		
MIN. CODE RATE																		
INTERMEDIATE CODE RATE																		
MAX CODE RATE																		

NOTES:

FIGURE RT/OC01A-3. SAMPLE DATA TABLE

APPENDIX A
DEFINITIONS AND SYSTEMS OF UNITS

1.0 SCOPE - This section provides standard definitions and a system of units for the recommended practice.

2.0 GENERAL INFORMATION

2.1 <u>Definitions</u> - Definition of terms used in this recommended practice shall be determined by using the references in the order specified below:

a. Section 3.0 (next section)
b. MIL-STD-463A
c. IEEE Standard Dictionary (Second Edition, 1977)

2.2 <u>System of Units</u> - System of units shall conform to IEEE standards.

3.0 DEFINITIONS - An index of defined terms follows:

(1) code rate
(2) emission, inductive
(3) flux mapping
(4) frequency, track circuit
(5) interference, conductive
(6) interference, inductive
(7) rail-to-rail voltage
(8) susceptibility, conductive
(9) susceptibility, inductive
(10) susceptibility threshold
(11) track circuit, audio-frequency
(12) track circuit, power frequency
(13) track circuit signalling, audio-frequency
(14) track circuit signalling, power frequency
(15) vehicular electrical power subsystem

DEFINITIONS

(1) CODE RATE - The frequency at which the track circuit signal is modulated.

(2) EMISSION, INDUCTIVE - Desired or undesired magnetic flux which is propagated through space.

(3) FLUX MAPPING - The process of determining the spatial distribution of a magnetic field emanating from a source.

(4) FREQUENCY, TRACK CIRCUIT - A sinusoidal audio-frequency signal occurring during the on-portion of the code-rate cycle.

(5) INTERFERENCE, CONDUCTIVE - Interference requiring a common ohmic path between the emission source and the susceptible circuit.

(6) INTERFERENCE, INDUCTIVE - Interference caused by inductive emission.

(7) RAIL-TO-RAIL VOLTAGE - Rail-to-rail voltage is the voltage occurring at a point on one rail with respect to the opposing point on the adjacent rail.

(8) SUSCEPTIBILITY, CONDUCTIVE - The degree to which equipment, together with all conductors associated with its intended function, evidences undesired end responses caused by conductive emissions to which it is exposed.

(9) SUSCEPTIBILITY, INDUCTIVE - The degree to which equipment, together with all conductors associated with its intended function, evidences undesired end responses caused by inductive emissions to which it is exposed.

(10) SUSCEPTIBILITY THRESHOLD - Limiting characteristics of an interfering signal which caused an undesired response under defined operating conditions.

(11) TRACK CIRCUIT, AUDIO-FREQUENCY - A train detection and communication scheme generally operating above 300 Hz using the rails as the transmission link. These track circuits do not require, but may use insulated joints to establish their boundaries, and are in rail transit applications, generally

less than 2000 feet in length. Also, they generally operate at receiving-end current levels of less than 1.0 amperes.

(12) TRACK CIRCUIT, POWER FREQUENCY - A train detection and communications scheme operating in the 0 Hz to 300 Hz range using the rails as the transmission link. These track circuits require the use of insulated joints to provide the track circuit boundaries, and are generally used where long track circuits are required. Also, they generally operate at current levels in the ampere range.

(13) TRACK CIRCUIT SIGNALLING, AUDIO-FREQUENCY - The system employed to vitally control safe train movement, using audio-frequency track circuits. The functions of train detection and train separation control are involved. Cab signalling, overspeed detection, and other ATP related parameters may also be involved.

(14) TRACK CIRCUIT SIGNALLING, POWER FREQUENCY - The system employed to vitally control safe train movement, using power frequency track circuits. The functions of train detection and train separation are involved. Cab signalling, overspeed, and other ATP related parameters may also be involved.

(15) VEHICULAR ELECTRICAL POWER SUBSYSTEM - Those transit vehicle devices involved in converting the prime power into forms for utilization by the car, viz., inverters, converters, propulsion controllers, etc.

APPENDIX B

Sample Test Outputs Using Conductive Recommended Practices

SYSTEM TESTED: MARTA
TEST PERFORMED: RT/CE01A
COMMENTS:

FIELD LOCATION: CANDLER PARK SUBSTATION
BY WHOM: R. RUDICH (GARRETT)

DATE: 8/26/79

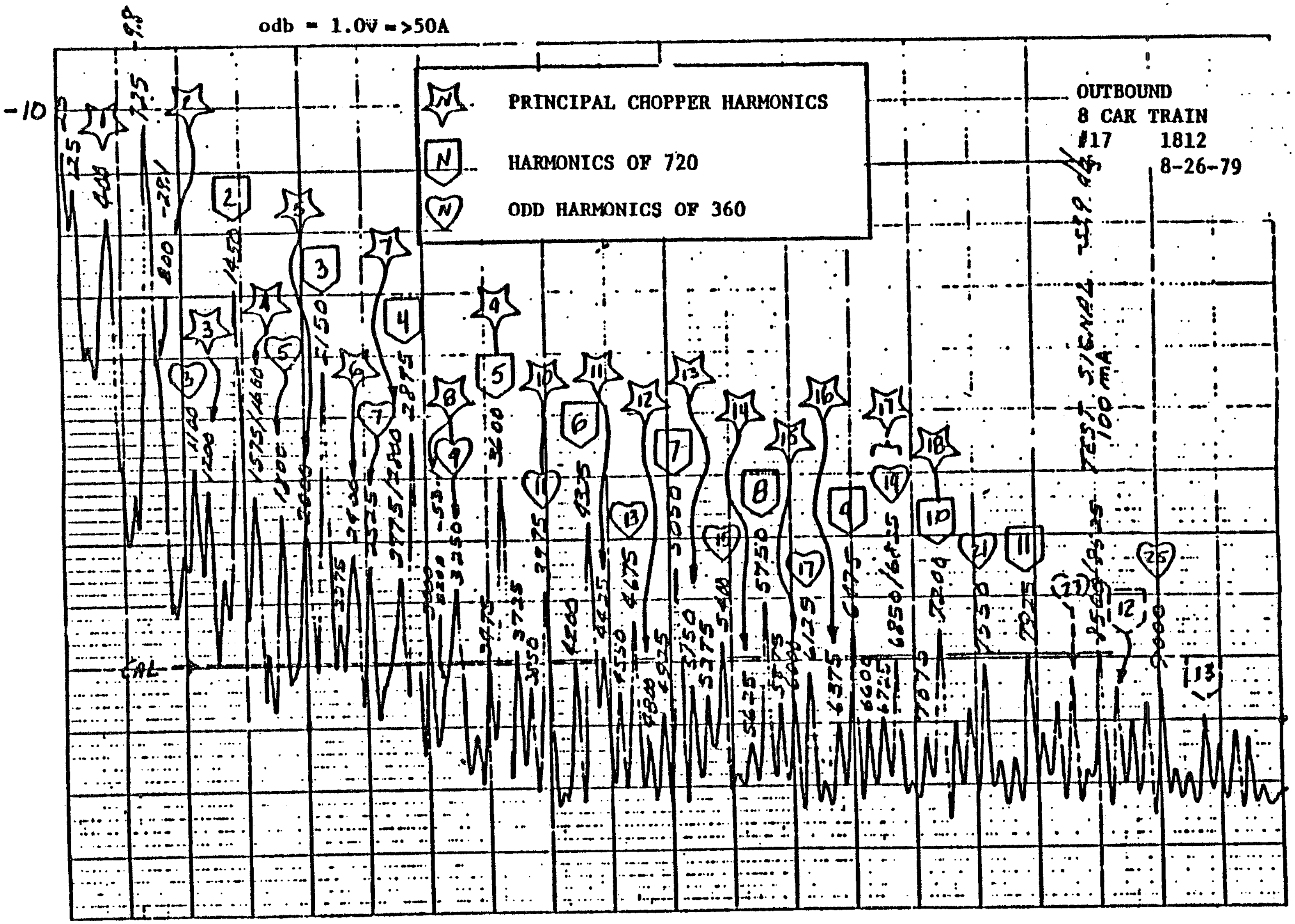
RUN #	INSTRUMENT SETTINGS	SCENARIO
17		SEE PARA 4.0 RT/CE01A 8 CAR

APPARATUS USED: SEE PARA 3.2 RT/CE01A

DIAGRAM: TEST MEASUREMENT

SEE FIGURE RT/CE01A A-2 EXHIBIT

NOTE 1
NOTE 2
NOTE 3
NOTE 4



odb = 1.0V = >50A
PRINCIPAL CHOPPER HARMONICS
HARMONICS OF 720
ODD HARMONICS OF 360
OUTBOUND
8 CAR TRAIN
#17 1812
8-26-79
TEST SIGNAL
100 mA
CAL

SYSTEM TESTED: GRS (BRAINTREE EXTENSION)

FIELD LOCATION: MBTA CABOT SIGNAL BLD

TEST PERFORMED: RT/OC01A FREQUENCY SELECTIVE INPUT

BY WHOM: R. GAGNON & J. CADIGAN (DOT/TSC)

COMMENTS: TRACK CIRCUIT DRAWING #58521-7 (MAINTENANCE TEST UNIT)

DATE: 3/25/80

RUN #	INSTRUMENT SETTINGS	SCENARIO
18	SELECT PROPER CODE RATE AND CARRIER FREQUENCY	SEE PROCEDURE RT/OC01A PARAGRAPH 4.2

APPARATUS USED: SIGNAL GENERATOR (NOTE 3). AMPLIFIER (McINTOSH 240). FREQUENCY COUNTER (H/P 5327B) RMS VOLTMETER (H/P 3403A). OSCILLOSCOPE (H/P 1701B)

DIAGRAM: TEST MEASUREMENT

S E E   F I G U R E   RT/OC01A-1 (NOTE 1 AND NOTE 2)

NOTE 1 UNMODULATED TRANSMITTER REPLACED BY 14mh COIL AND 400Ω RESISTOR IN PARALLEL

NOTE 2 0.1 μfd CAPACITOR PLACED ACROSS RECEIVER TERMINALS FOR LINE COMPENSATION

NOTE 3 A ROCKLAND SYNTHESIZER MODEL 5100, MODULATED AT THE CODE RATES, USED IN PLACE OF SPECIFIED SIGNAL GENERATOR.

SYSTEM TESTED: GRS (BRAINTREE EXTENSION) BY WHOM: R. GAGNON & J. CADIGAN (DOT/TSC)

TEST PERFORMED: RT/0C01A FREQUENCY SELECTIVE INPUT WHERE: MBTA CABOT SIGNAL BLD

DATE: 3/25/80

VIS = INTERFERENCE SUSCEPTIBILITY LEVEL IN MVrms

OPERATING FREQUENCY: F_O = 3060Hz

CODE RATE HZ			2710	2760	2810	2860	2910	2960	3010	F_O 3060	3110	3160	3210	3260	3310	3360	3410	3460	
1.25						Δ	292	39.5	32.1	27.2	28.5	33.0	230	Δ					
3.0						Δ	265	36.8	31.3	26.9	28.2	32.8	221	451	Δ				
6.83			Δ	494	401	332	148	38.4	32.2	26.2	27.7	32.6	114	236	293	343	445	Δ	

Δ NO PICK OF RELAY AT 0.5 VRMS

FIELD

SYSTEM TESTED: GRS (BRAINTREE EXTENSION)

LOCATION: MBTA CABOT SIGNAL BLD

TEST PERFORMED: RT/OC01A INPUT IMPEDANCE

BY WHOM: R. GAGNON & J. CADIGAN (DOT/TSC)

COMMENTS: RECEIVER OPERATING FREQUENCY = 3060 Hz

TRACK CIRCUIT DRAWING #58521-7 (MAINTENANCE TEST UNIT)

DATE: 4/1/80

RUN #	INSTRUMENT SETTINGS	SCENARIO
38	CAREFULLY SET SENSITIVITY LEVELS OF CHANNELS A & B OF SPEC. ANAL. PER INSTRUCTION MANUAL	SEE RT/OC01A PARAGRAPH 4.3

APPARATUS USED: SPECTRUM ANALYSER (H/P 3582A), TEKTRONIX P-6019 PROBES & 134 AMPLIFIERS, X-Y PLOTTER (EATERLINE ANGUS MODEL 575), AMPLIFIER (McINTOSH - MC-240

DIAGRAM: TEST MEASUREMENT

S E E F I G U R E RT/OC01A-3 (NOTE 1 AND NOTE 2)

NOTE 1 UNMODULATED TRANSMITTER REPLACED BY 14 mh COIL AND 400 Ω RESISTOR in PARALLEL

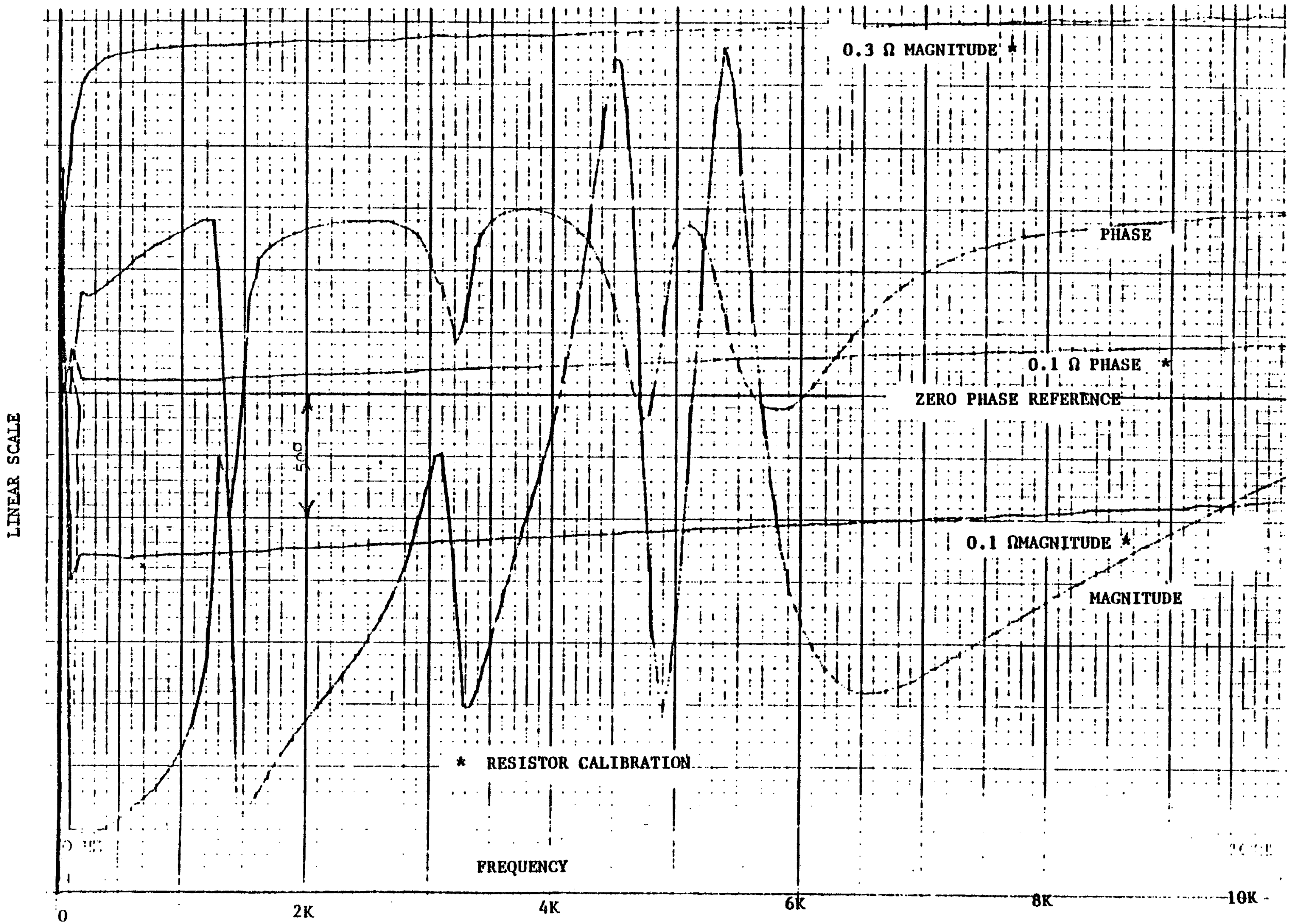
NOTE 2 0.1 μfd CAPACITOR PLACED ACROSS RECEIVER TERMINALS FOR LINE COMPENSATION

NOTE 3

NOTE 4

SYSTEM TESTED: GRS (BRAINTREE EXTENSION)
TEST PERFORMED: RT/OC01A INPUT IMPEDANCE
RECEIVER OPERATING FREQUENCY: 3060 Hz

FIELD LOCATION: MBTA CABOT SIGNAL BLDG
BY WHOM: R. GAGNON & J. CADIGAN (DOT/TSC)
DATE: 4/1/80



SYSTEM TESTED: US&S (Haymarket North)
TEST PERFORMED: RT/OCOIA Frequency Selective Input
COMMENTS: Track Circuit AF-200

FIELD LOCATION: MBTA Cabot Signal Building
BY WHOM: R. Gagnon & J. Cadigan (DOT/TSC)
DATE: 3/25/80

RUN #	INSTRUMENT SETTINGS	SCENARIO
23	Select Proper Code Rate and Carrier Frequency	See Test Method RT/OCOIA Procedure Para. 4.2

APPARATUS USED: Signal Generator (Note 1), Amplifier (McIntosh-MC240), Frequency Counter (H/P 5327B), RMS Voltmeter (HIP3403A), Oscilloscope (H/P1701B)

DIAGRAM: TEST MEASUREMENT

See Figure RT/OCO1A-1

NOTE 1 Rockland Synthesizer Model 5100 Modulated at the Code Rates was used in place of specified Signal Generator
NOTE 2
NOTE 3

SYSTEM TESTED: US&S (Haymarket North) BY WHOM: R. Gagnon & S. Cadigan (DOT/TSC

TEST PERFORMED: RT/OCO1A Frequency Selective Input WHERE: MBTA Cabot Signal Boulevard

DATE: 3/25/80

VIS = INTERFERENCE SUSCEPTIBILITY LEVEL IN MVrms

OPERATING FREQUENCY: F_O = 1590

CODE RATE HZ			1470	1490	1510	1530	1550	1570	F_O 1590	1610	1630	1650	1670	1690	1710	1730		
5.0				Δ	411	249	102	74.5	70.2	78.1	162	335	461	Δ				
10.8			Δ	474	329	203	98.1	69.1	65.4	74.2	139	253	345	439	Δ			
20.4			Δ	498	329	208	103	71.7	63.0	78.0	143	255	328	450	490	Δ		

Δ No pick of relay at 0.5 VRMS

SYSTEM TESTED: US&S (Haymarket North)
TEST PERFORMED: RT/ OC01A Input Impedance
COMMENTS: Receiver Operating Frequency = 1590 Hz
Track Circuit AF-200

FIELD LOCATION: MBTA Cabot Signal Bldg
BY WHOM: R. Gagnon & S. Cadigan (DOT/TSC)
DATE: 3/31/80

RUN #	INSTRUMENT SETTINGS	SCENARIO
43	Carefully set sensitivity levels of Channels A&B of Spec Anal. per Instruction Manual	See RT/OC01A Paragraph 4.3

APPARATUS USED: Spectrum analyzer (H/P 3582A). Tek Tronix P-6019 Probes & 134 Amplifiers. X-Y Plotter (Esterline Angus Model 575). Amplifier (McIntosh-MC240)

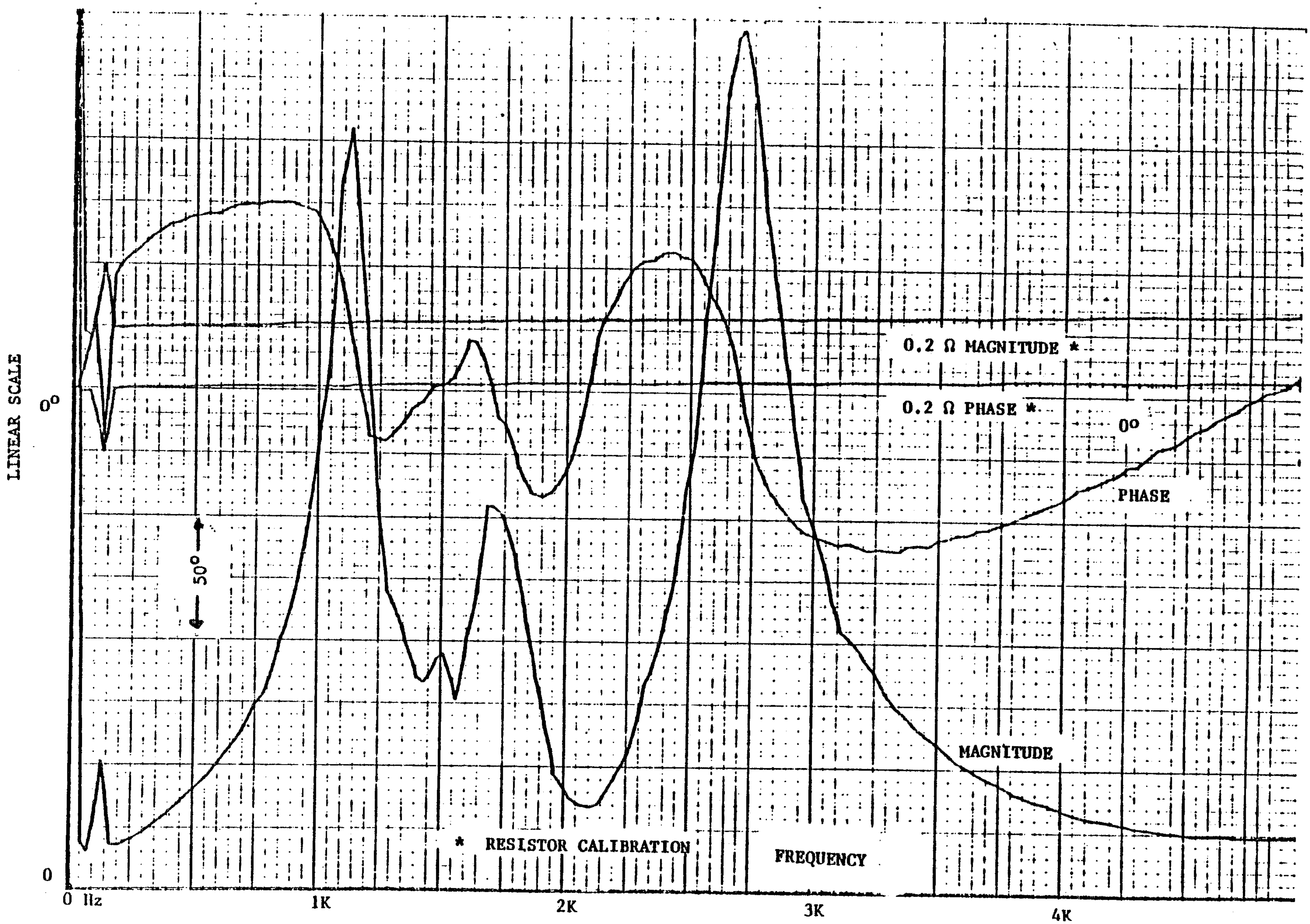
DIAGRAM: TEST MEASUREMENT

See Figure RT/OC01A-3 (Note 1)

NOTE 1 Include Unmodulated Transmitter as in RT/OC01A Procedure Para 4.2
NOTE 2
NOTE 3
NOTE 4

SYSTEM TESTED: US & S (HAYMARKET NORTH)
TEST PERFORMED: RT/OC01A INPUT IMPEDANCE
RECEIVER OPERATING FREQUENCY: 1590 Hz

FIELD LOCATION: MBTA CABOT SIGNAL BLDG
BY WHOM: R. GAGNON & J. CADIGAN (DOT/TSC)
DATE: 3/31/80



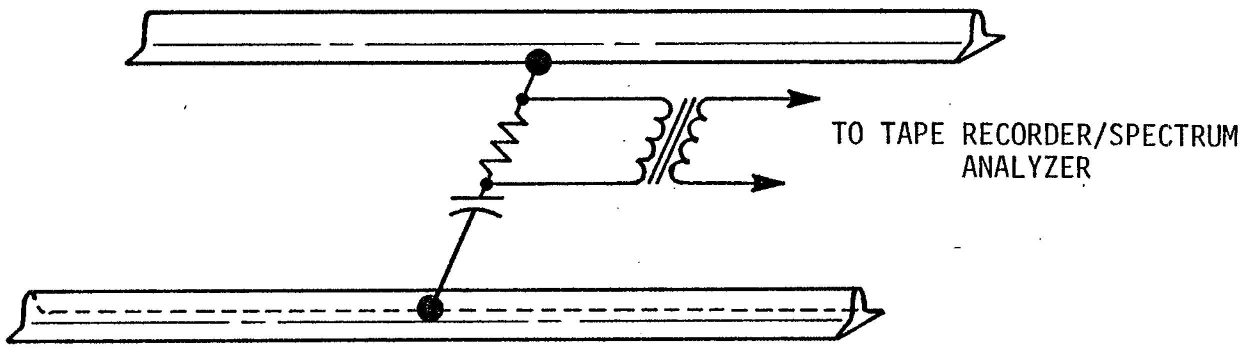


FIGURE 2-5C. TRACK MONITORING CIRCUIT

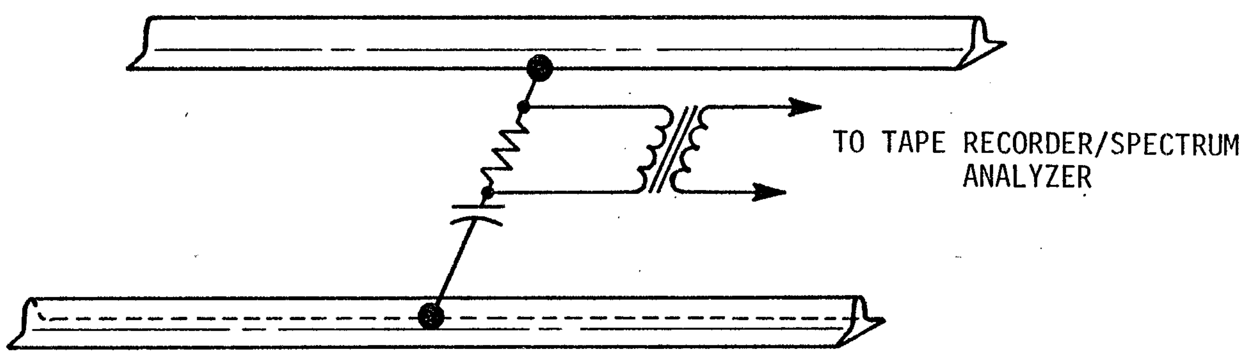


FIGURE 2-5C. TRACK MONITORING CIRCUIT

METHOD RT/CE01A

EXHIBIT A: SUGGESTED INSTRUMENTATION

The measurement of conductive emissions is difficult due to the rich spectra, wide signal range, and the high-noise environment. The set-up presented herein has been successfully applied.

CURRENT SENSORS

The suggested current sensor is an LEM type LA 10000-S Transfoshunt.[1] The Transfoshunt (see Figure RT/CE01A-A-1) consists of: 1) a gapped iron core with primary and secondary windings; 2) a Hall sensor, which is placed in the gap; and 3) a servo amplifier to drive the secondary winding.

The current to be measured is applied to the primary, which consists of conductors passed through a window, as is done with conventional current transformers. The magneto-motive force (MMF) generated by the primary current produces a flux in the air gap. The flux is sensed by the Hall sensor, the voltage generated by the sensor is applied to the amplifier, and the amplifier drives the secondary of the transformer via a measuring resistor so as to null the air gap flux. Consequently, the voltage developed across the measuring resistor replicates the primary current, differing from it only by the small errors inherent in the Hall sensor and the amplifier and by the ability of the amplifier to drive the secondary at the required rates. The measured frequency response was flat to 7 kHz, rising +6 dB at 10 kHz.

[1]Mfg. by Liaisons Electroniques Mechaniques S.A., 14F route de Saint-Julier, CH-1227 Carouge/Geneve, Switzerland. A sensor with compensation optimized for maximally flat frequency response should be specified.

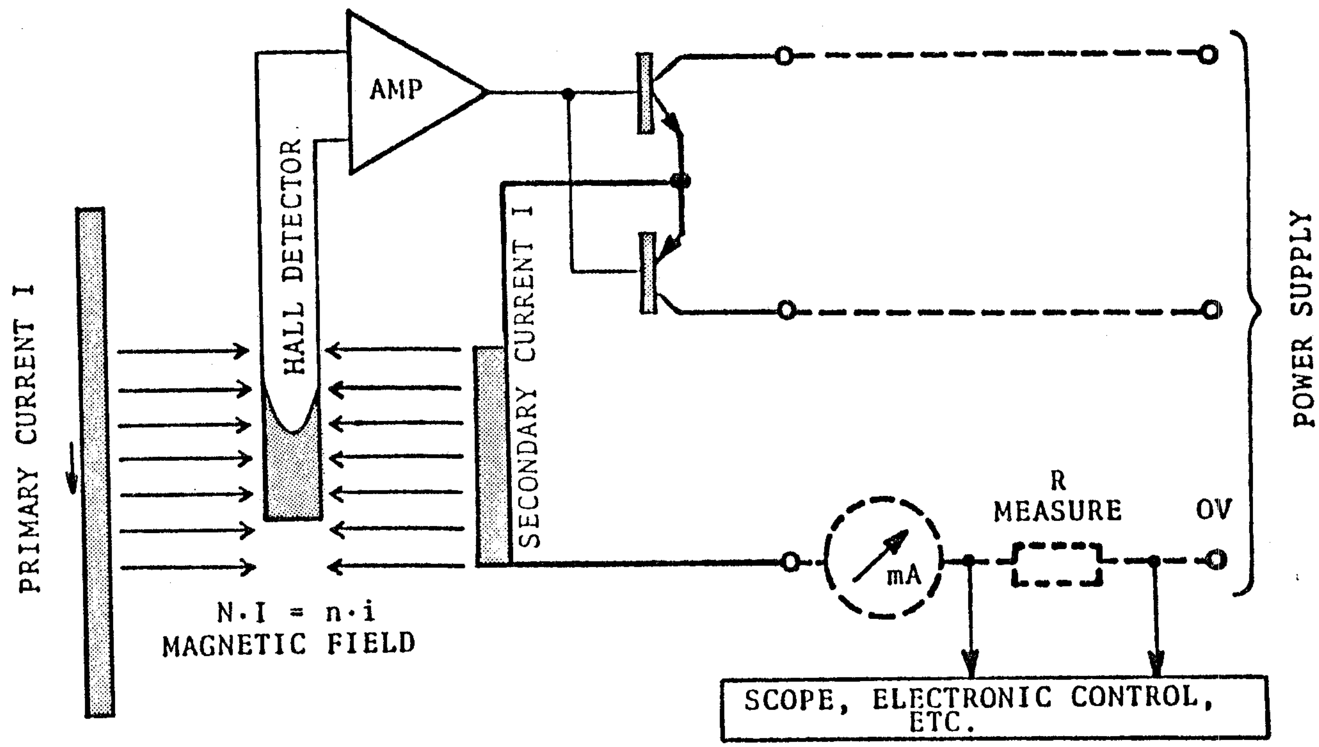


FIGURE RT/CE01A-A-1. LEM TRANSFOSHUNT

Other essential characteristics are:

- o Measuring range - 10,000 ampere-turns
- o Output sensitivity - 500 μV/amp
- o Window area - 208 sq cm

An elementary schematic of the complete instrumentation is shown in Figure RT/CE01A-A-2. The Transfoshunt is placed in a substation circuit breaker enclosure, with the preamplifier/line driver nearby. A 4-pole Butterworth filter is used to split the signal into two frequency ranges in order not to exceed the dynamic range capability of the tape deck and, on occasion, of the spectrum analyzer. In the later event, each test is performed twice: once without the filter, and once with the filter at the spectrum analyzer input. The audio oscillator is used for spot calibration and checkout of the equipment.

NOTES: The Transfoshunt can become magnetized by primary current if the power supply is off. This may result in erroneous readings. Usually, operating the device through a normal duty cycle clears the problem. Otherwise, the sensor can be readily demagnetized by conventional means.

The harmonic distortion produced by the test equipment has not been fully characterized. Such distortion can lead to the perception of higher emissions than actually produced. However, the harmonic distortion of the test equipment has been determined to be sufficiently low to permit specification compliance testing to a specified emission level of 50 ma.

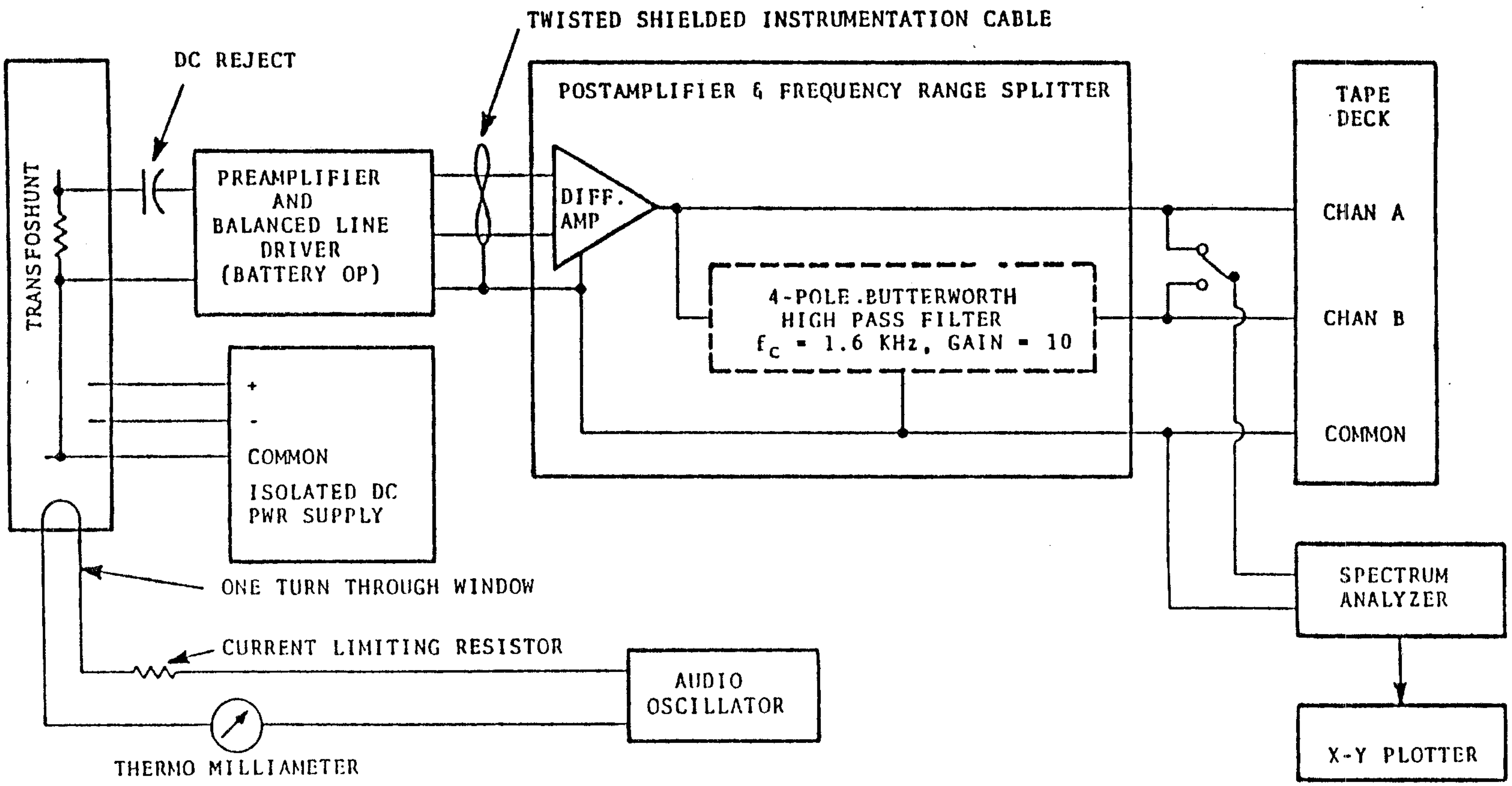


FIGURE RT/CE01A-A-2. ELEMENTARY INSTRUMENTATION SCHEMATIC CONDUCTIVE EMISSION TEST

METHOD RT/CE02A

CONDUCTIVE EMISSION TEST, VEHICLE

1.0 PURPOSE

The purpose of this test is to measure, on board, the conductive emissions of a single transit vehicle.

2.0 APPLICABILITY

This test is applicable to propulsion systems using dc input power. The test measures the conductive emissions produced by propulsion together with those caused by the substation harmonics, under some conditions it may be difficult or impossible to separate these two effects. The test procedure has been successfully applied and an example of the results is presented in Appendix B. The procedure has also been applied in the laboratory, with the propulsion equipment driving a simulated load.

3.0 TEST EQUIPMENT AND FACILITIES

3.1 Test Facility

The test facility shall consist of a section of dry test track fed at one end by a power substation. The portion of track required for train acceleration should be without power gaps in order to avoid transients which can obscure the data. The test section shall be isolated from all other power substations or the test should be conducted when or where no other traffic can contribute signal components.

3.2 Apparatus

The apparatus required for this test is as follows:

a. suitable current sensor and associated signal conditioning (see RT/CE02A EXHIBIT A)

b. FFT spectrum analyzer, GEN RAD Model 2512 or similar

c. X-Y plotter compatible with the spectrum analyzer

d. tape recorder (optional)

e. strip-chart recorder and adjunct instrumentation, as required to record essential vehicle operating parameters, as stated in paragraph 4.1

f. means to assure proper calibration of the installed arrangement of current sensor, preamplifier, and amplifier.

4.0 TEST PROCEDURE

The test shall be conducted with a single transit vehicle. If a 2-car consist must be used, the other car shall be off, i.e. with its line switch or circuit breaker open. The tests shall be conducted at empty vehicle weight (AWO) and for acceleration mode only. If required, the data shall be adjusted for other weights and other modes, such as dynamic and regenerative braking, in accordance with known characteristics of the propulsion equipment. The tests shall be conducted with the objective of obtaining worst-case data.

4.1 Vehicle Performance Instrumentation

Appropriate instrumentation and a strip-chart recorder shall be installed on the test vehicle to record the following minimum information during the test:

- dc line voltage or input filter capacitor-bank dc voltage
- propulsion system dc input current
- vehicle speed
- armature current of one traction motor
- dc-link voltage and current if ac drive
- field current
- P-Signal (or other train command signal).

4.2 Conductive Emission Instrumentation

In order to assess stray pickup the current sensor and its pre-amplifier shall be, at first, installed immediately adjacent to the conductor in which the current will be sensed i.e., the positive input line of the propulsion subsystem.[2]

The entire instrumentation set-up shall be calibrated by injecting, using a known number of ampere-turns, a sine-wave signal whose frequency is in the band of interest but not coincident with a chopper or substation harmonic, and by observing the corresponding output level on the spectrum analyzer. All harmonic amplitudes shall then be determined by reference to this level.

For purposes of assuring proper operation of the instrumentation, calculation shall be made of the expected amplitude of the spectral display due to the calibration signal. Agreement should be within ±1 dB. (See Note 6.2.)

With the output terminals of the current sensor shorted, the test train shall be accelerated to verify satisfactory noise immunity of the instrumentation, exclusive of the current sensor.

[2]It is necessary that the sensor be placed in the positive line, in order to avoid possible ground loops, conductive and/or capacitive.

A preliminary run as described in 4.3 shall then be made with all instrumentation active, and with the current sensor still adjacent to the dc power line instead of in the line in order to assess stray pickup. If stray pickup is believed to be excessive, cabling and equipment placement shall be altered to reduce stray levels.

4.3 Emission Test

The current sensor shall be placed in the dc power line. The test train shall be placed with its trailing end at the dc return to the substation and then accelerated under maximum power away from the power substation. The spectrum analyzer, in peak-averaging ("max") mode and in Hann windowing configuration, shall acquire data throughout the acceleration cycle. In order to avoid obscuring the data by transients, data acquisition should be delayed until after all train contactor closures related to initial power application have taken place. In order to assess the effects of initial chopper sweeping or pulse-skipping, data shall be recorded twice: first, beginning immediately after contact closure, and again beginning at a train speed above which chopper frequency sweeping or pulse-skipping ceases. The spectrum analyzer data shall be plotted and fully annotated upon completion of each run. The data specified in 4.1 shall also be acquired throughout each test run.

Results shall be checked against the noise immunity test runs described in 4.2 to assure that stray pickup does not degrade accuracy more than a tolerable amount. (For example, stray pickup 20 dB below an actually observed harmonic line introduces an uncertainty of ± 1 dB in the amplitude of that line.

5.0 TABULATION OF RESULTS - The results shall be summarized in a table containing the following information:

a. maximum vehicle speed

b. minimum line voltage

c. maximum line current

d. maximum motor current

e. frequency and level of measured emissions in the signalling band

The following additional data shall be presented:

a. fully annotated spectral plots

b. strip charts of vehicle parameters

c. test equipment certification information

6.0 NOTES

6.1 The spectra plotted in accordance with 4.3 display only the maximum instantaneous magnitude that any harmonic has reached during the test. Additional information may be obtained by later analysis of the tape recorded data. Analysis such as the application of frequency expansion techniques may be helpful in discriminating between propulsion and power supply harmonics.

6.2 Some spectrum analyzers, including the one suggested herein (3.2 b), do not automatically correct for the amplitude reduction associated with Hanning. In that event, the data as recorded with the spectrum analyzer shall be adjusted by +1.8 dB, in order to obtain actual levels. This correction must be made to correctly correlate the actual level of the injected reference signal with its amplitude as measured by the spectrum analyzer.

6.3 The measurement resulting from this test method reflects the characteristics and loading of the specific substation as well as the characteristics of the vehicle used. It is important that the tests be conducted as closely as possible to a substation in order to:

(1) minimize the possibility of spurious results due to frequency-dependent impedance characteristics of the rail loop and

(2) minimize error due to the finite source impedance of the car.

6.4 The test results also reflect the effects of vehicle auxiliaries, depending in detail on the exact equipment configuration in effect.

METHOD RT/CE02A

EXHIBIT A: SUGGESTED INSTRUMENTATION

The measurement of conductive emissions is difficult due to the rich spectra, wide signal range, and the high-noise environment. The set-up presented herein has been successfully applied.

CURRENT SENSORS

The current sensor is an LEM type LA 600 Transfoshunt.[3] The Transfoshunt (See Figure RT/CE02A-A-1) consists of: (1 a gapped iron core with primary and secondary windings; (2 a Hall sensor, which is placed in the gap; and (3 a servo amplifier to drive the secondary winding.

The current to be measured is applied to the primary, which consists of conductors passed through a window, as is done with conventional current transformers. The MMF generated by the primary current produces a flux in the air gap. The flux is sensed by the Hall sensor, the voltage generated by the sensor is applied to the amplifier, and the amplifier drives the secondary of the transformer via a measuring resistor so as to null the air gap flux. Consequently, the voltage developed across the measuring resistor replicates the primary current, differing from it only by the small errors inherent in the Hall sensor and the amplifier and by the ability of the amplifier to drive the secondary at the required rates. The measured frequency response of a particular unit tested was essentially flat ($\pm$0.5 dB) to 10 kHz.

[3]Mfg. by Liaisons Electroniques Mechaniques S.A., 14E route de Saint-Julien, CH-1227 Carouge/Geneve, Switzerland. A sensor with compensation optimized for maximally flat frequency response should be specified.