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

Volume I: Inductive Recommended Practices

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Project Memorandum

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16. Abstract

Methods for detecting and quantifying the levels of inductive 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 inductive 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

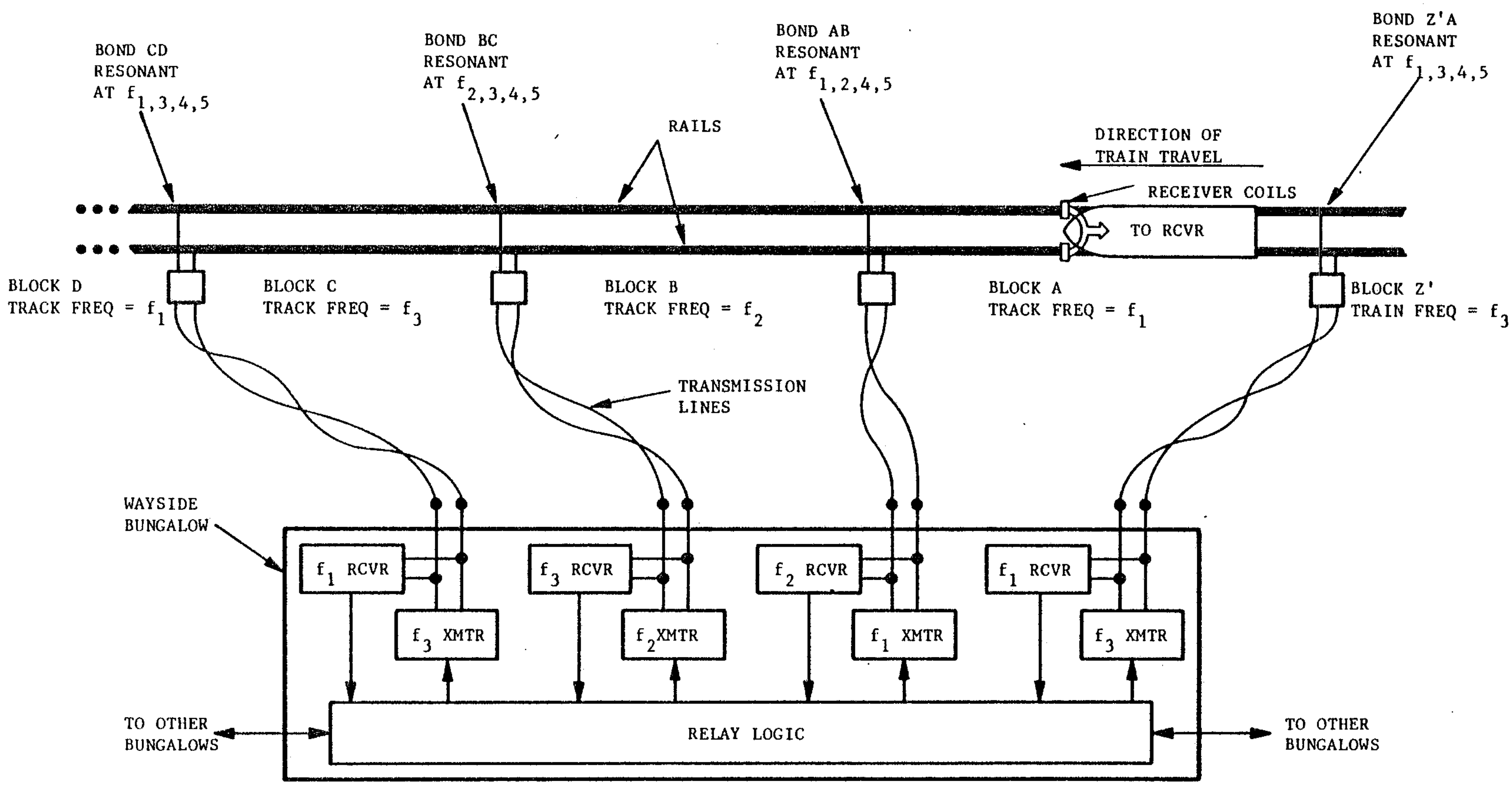


FIGURE 2-1. JOINTLESS AUDIO-FREQUENCY TRACK CIRCUIT

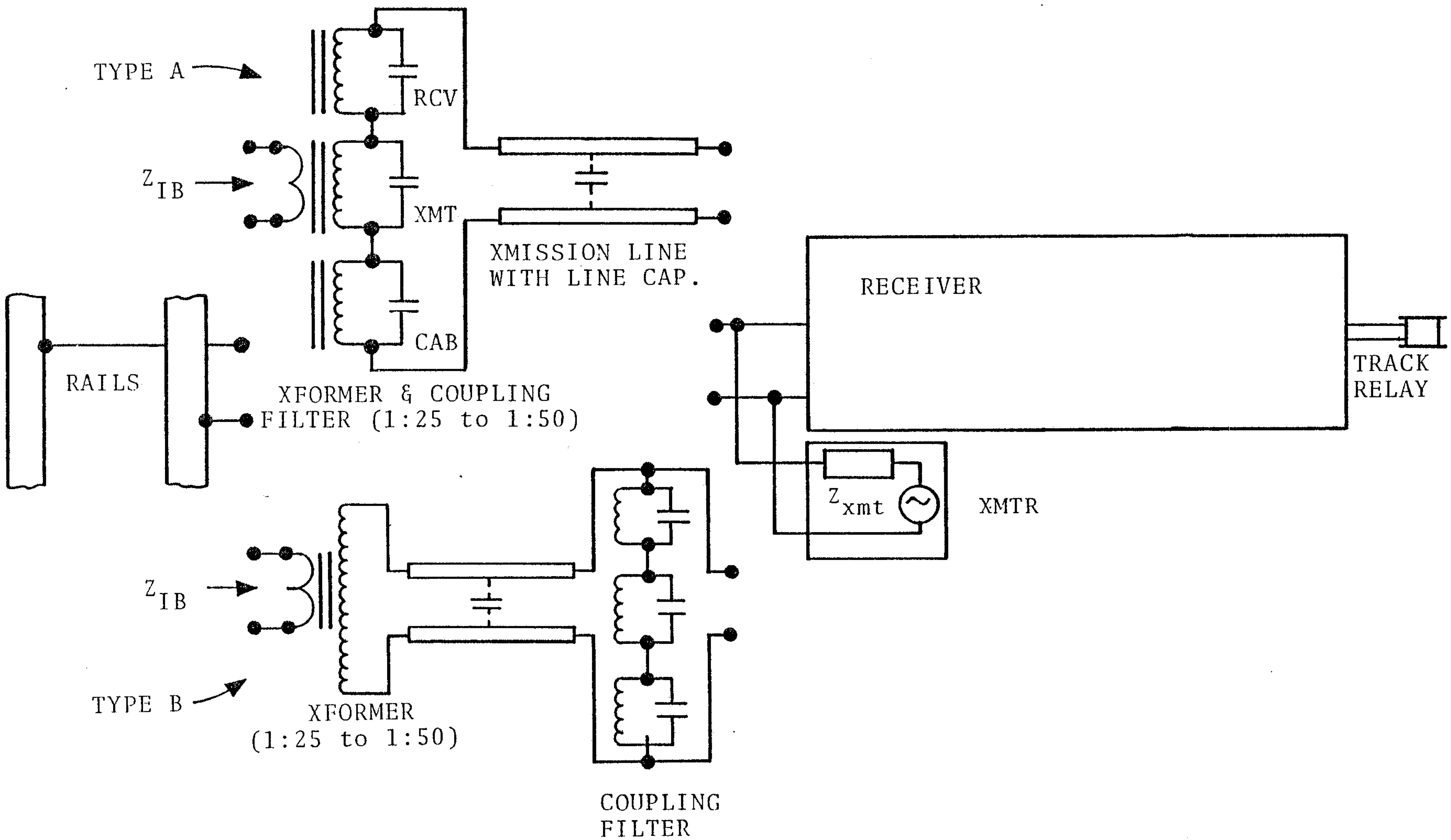


FIGURE 2-2. AUDIO-FREQUENCY TRACK CIRCUITRY

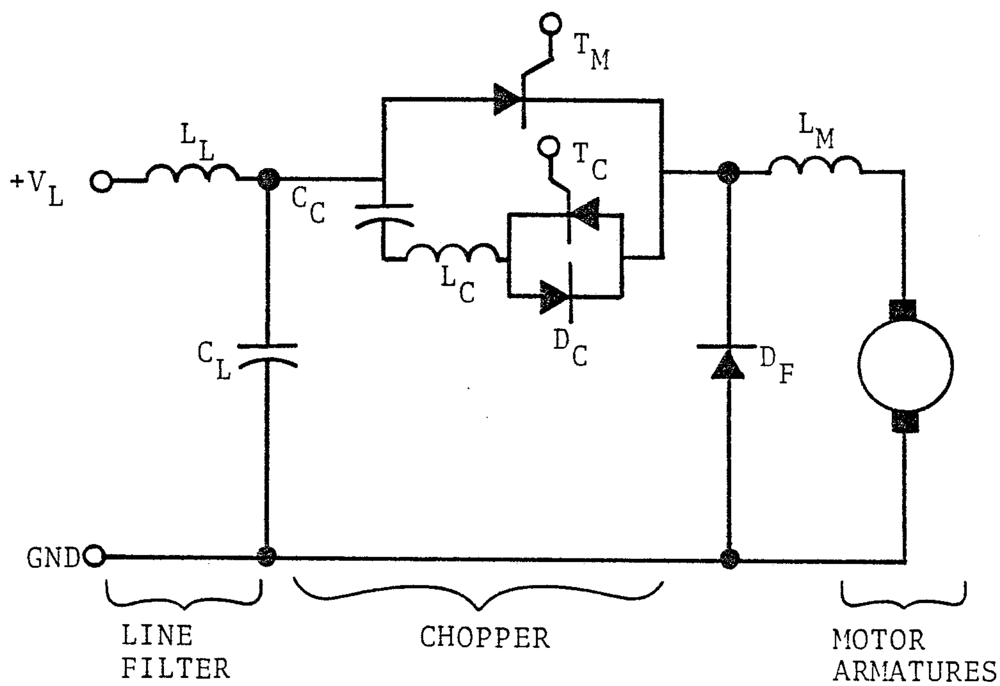


FIGURE 2-3. TYPICAL CHOPPER PROPULSION CONTROLLER

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 inductive 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 conductive 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 under the vehicle. This induced voltage has a harmonic spectrum that spans the frequency range typically used for audio-frequency signalling.

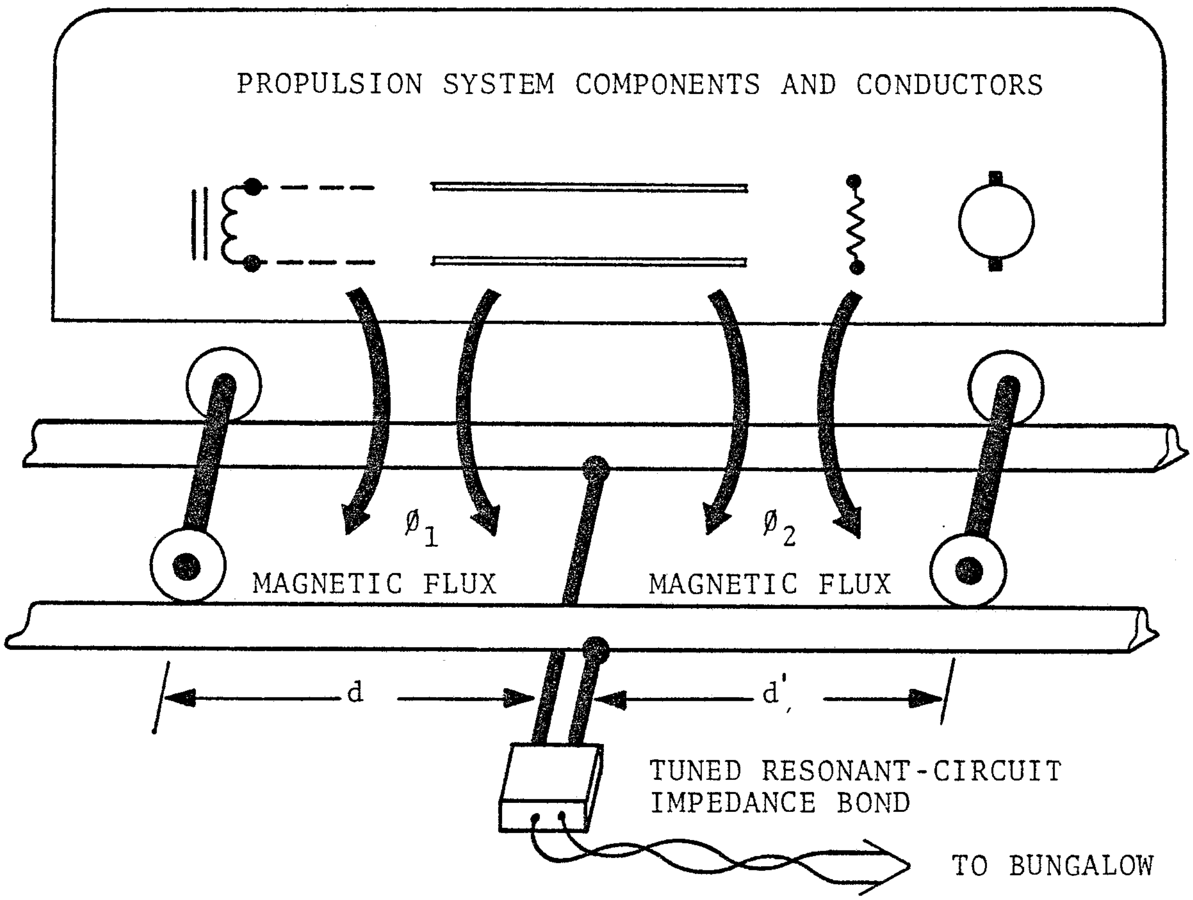


FIGURE 2-4. GENERATION OF INDUCTIVE INTERFERENCE

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;

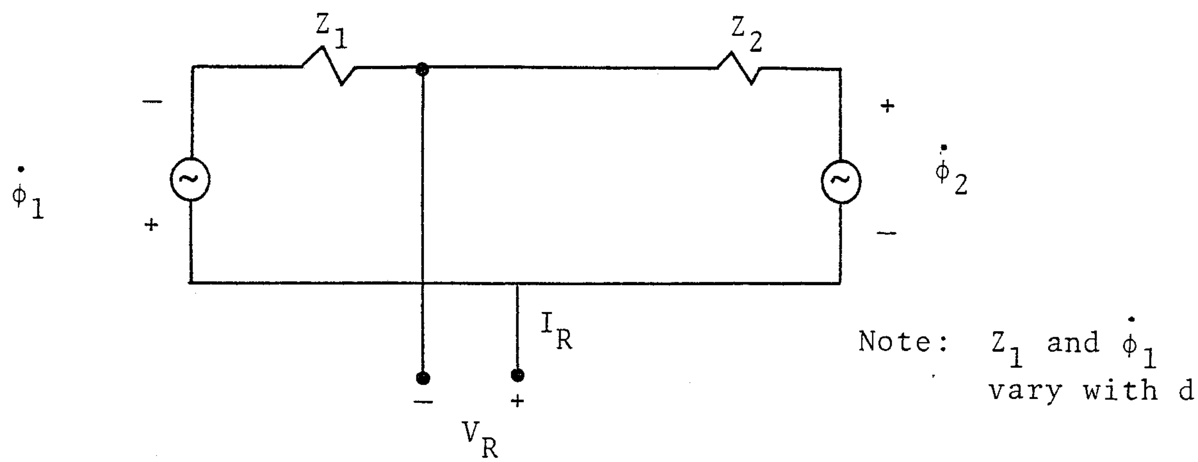
c. specific spectral characteristics of the time-varying fluxes $\phi_1(t)$ and $\phi_2(t)$ due to the mode of chopper operation, car speed, and train consist;

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

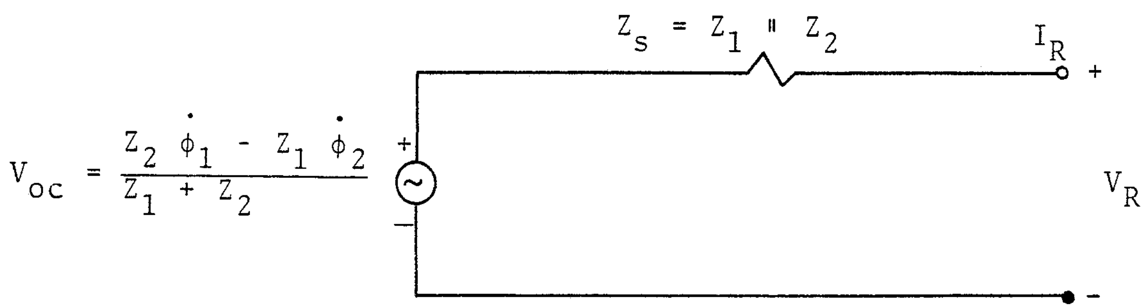
e. frequency-dependent impedance characteristics of track circuit receiver input at the rail connection points.

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

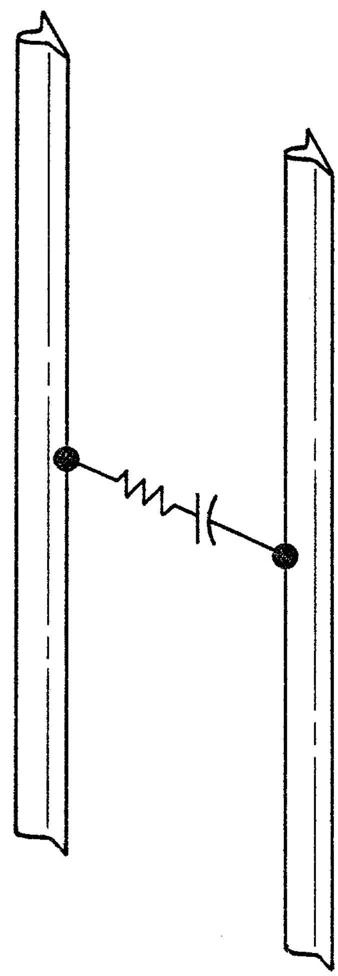


FIGURE 2-5C. TRACK MONITORING CIRCUIT

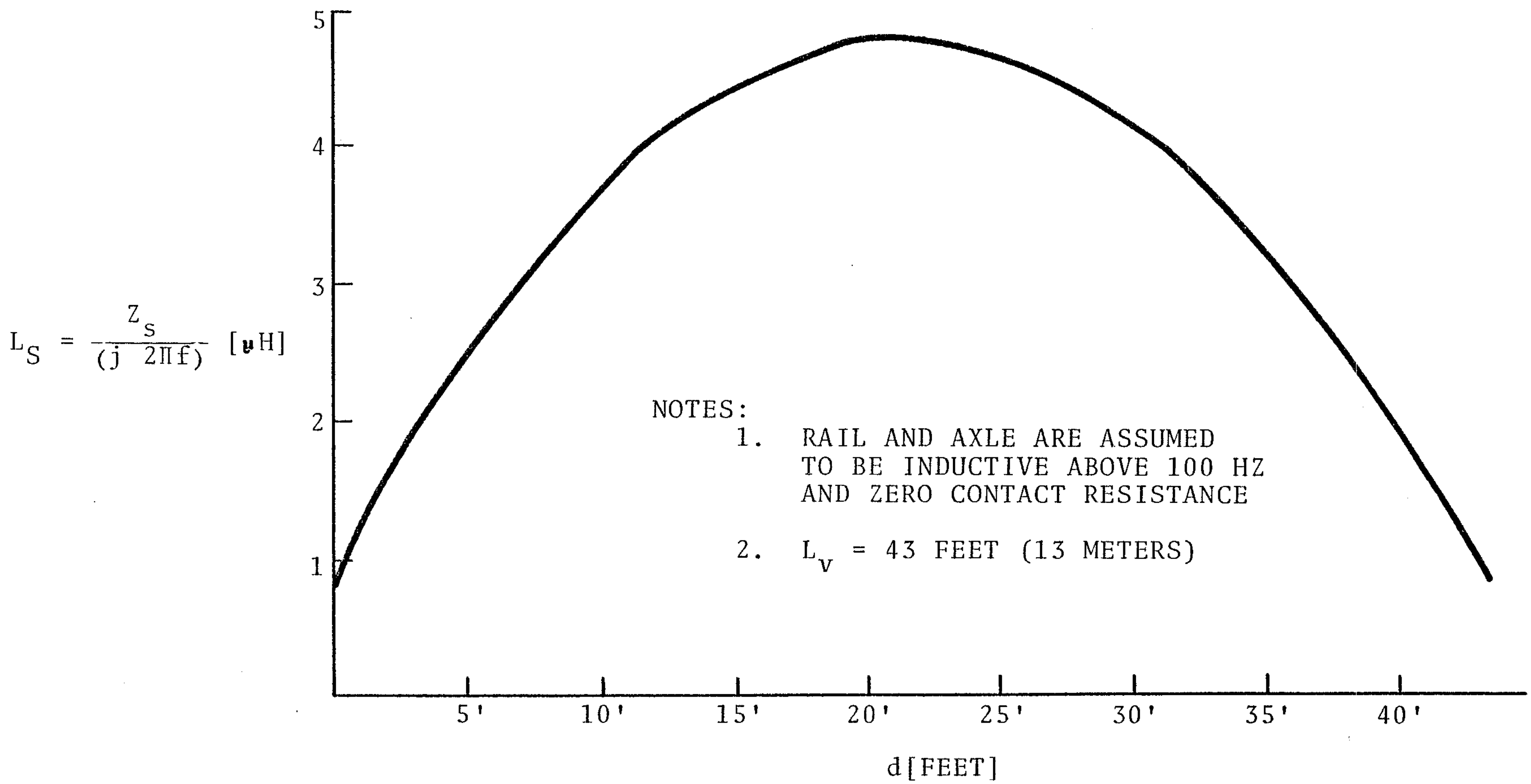
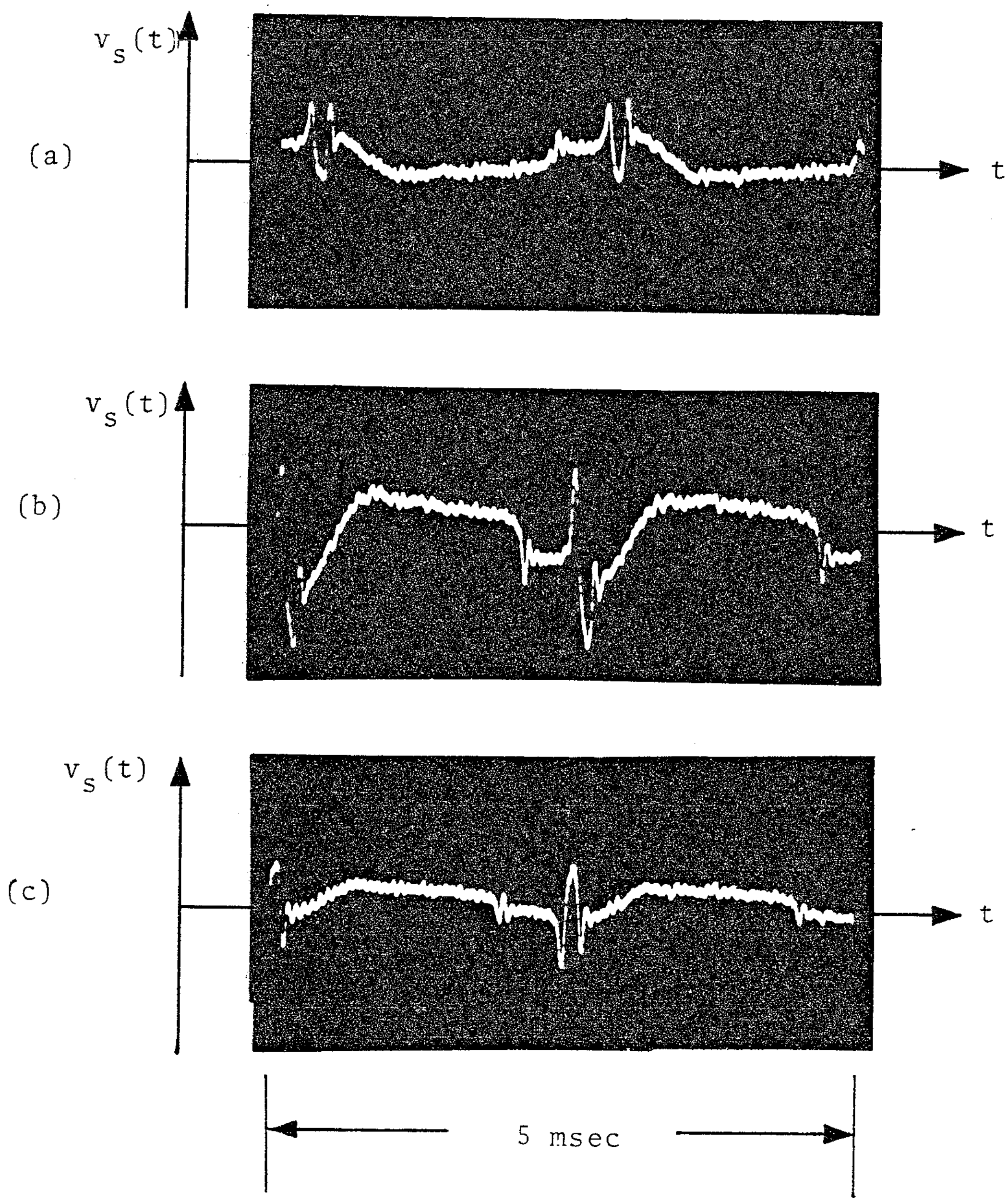


FIGURE 2-6. PLOT OF SOURCE INDUCTANCE VERSUS d



($v_s(t)$ 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

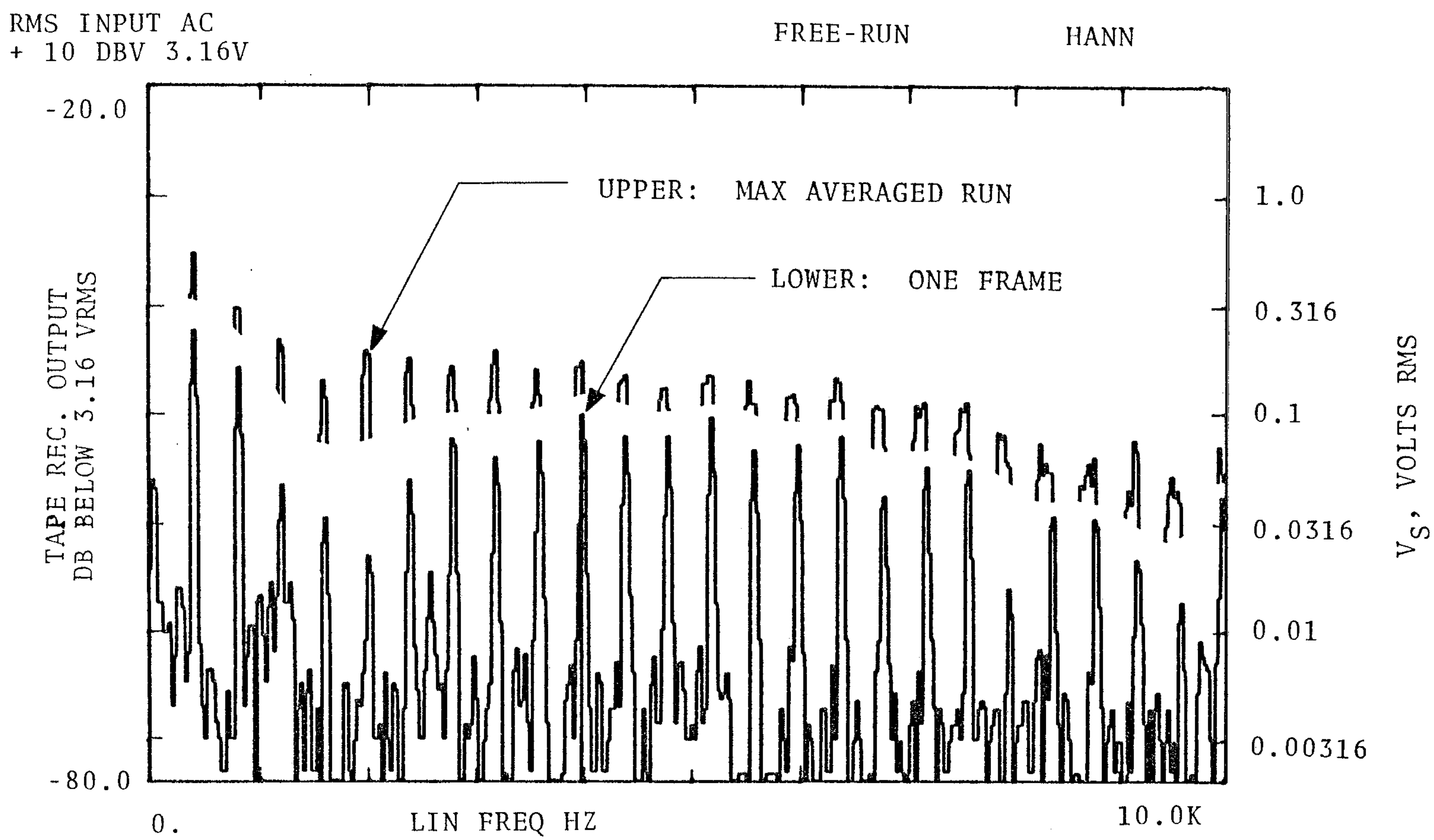
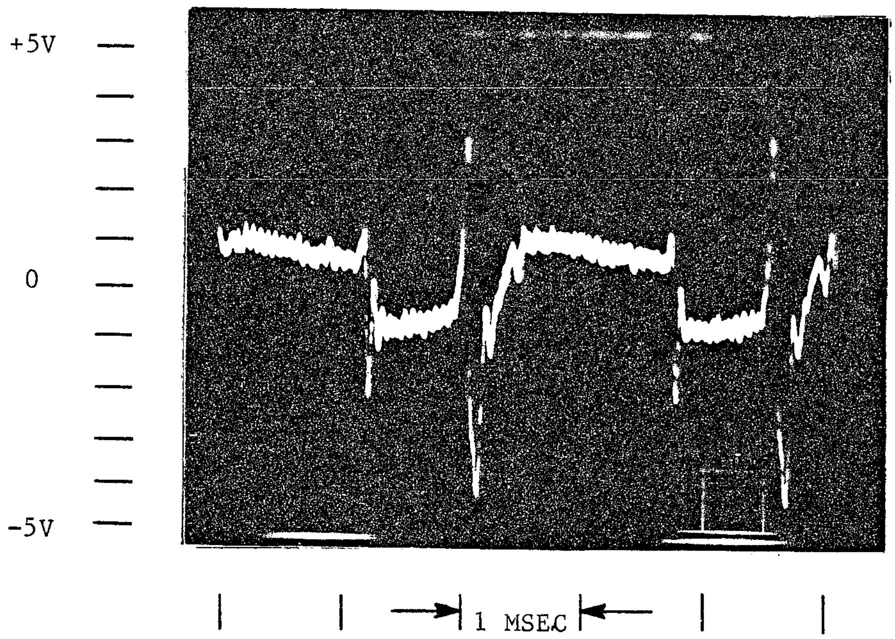
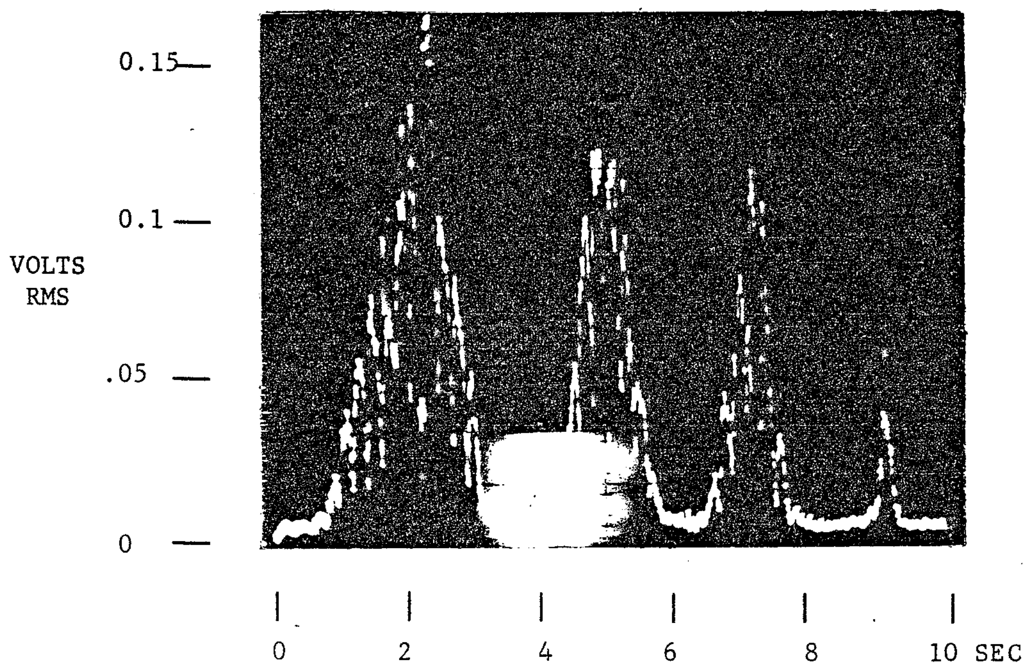


FIGURE 2-8. SPECTRUM OF RAIL-TO-RAIL VOLTAGE



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

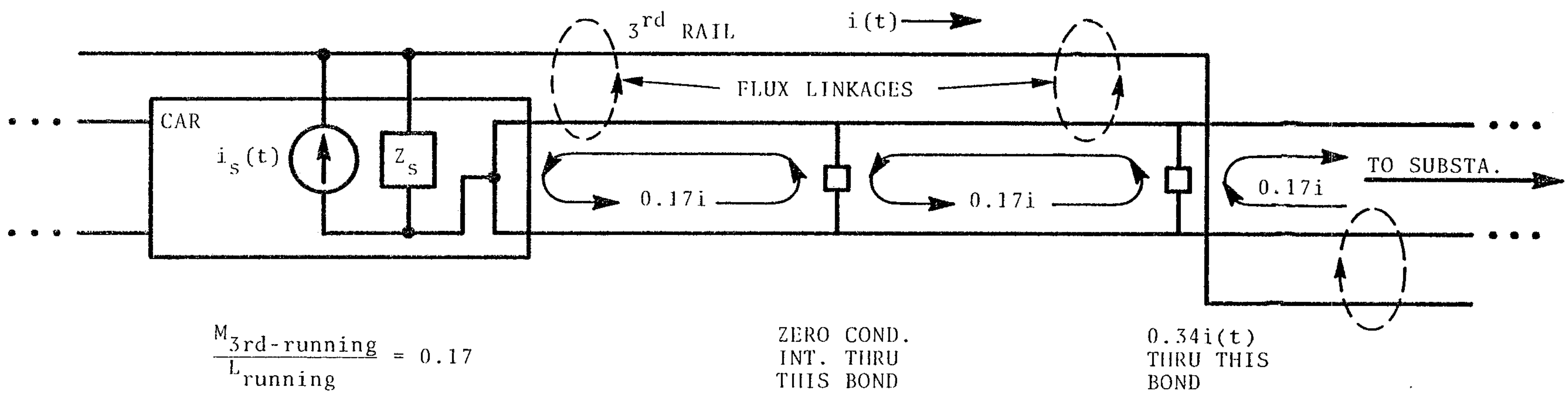


FIGURE 2-10. AUDIO-FREQUENCY CONDUCTIVE INTERFERENCE

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

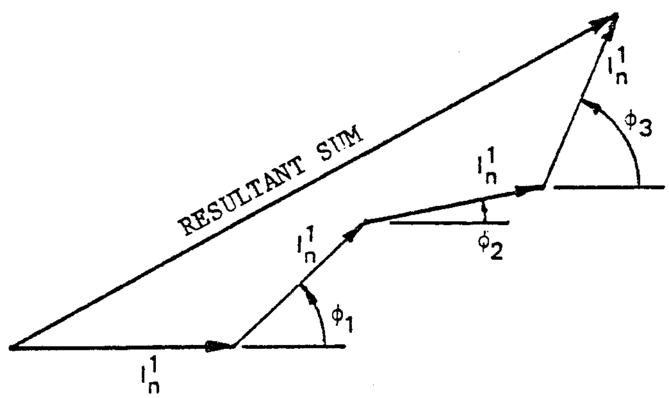


FIGURE 2-11. ADDITION OF SEPARATE n^{th}-HARMONIC COMPONENTS FOR A MULTI-CAR TRAIN

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. INDUCTIVE RECOMMENDED PRACTICES

METHOD RT/IS01A
INDUCTIVE SUSCEPTIBILITY OF AUDIO-FREQUENCY RATE-CODED SIGNALLING SYSTEMS FROM 30 Hz TO 10 kHz

1.0 PURPOSE

The purpose of this test is to determine the susceptibility of the audio-frequency rate-coded track circuits to the inductive interference voltage induced from rail-to-rail by the passage of a rail transit vehicle.

2.0 APPLICATION

This method is applicable to all audio-frequency track circuit equipment operating at frequencies between 300 Hz and 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). This test method has been applied, and an example of the results is presented in Appendix B.

3.0 APPARATUS

The test apparatus shall consist of the following:

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

b. audio-frequency amplifier, McIntosh MC 240 or equal (See Note 6.2)

c. oscilloscope

d. true RMS audio-frequency voltmeter

4.0 TEST PROCEDURE

The test shall be performed as specified herein. For inductive interference to be present the vehicle must pass over the point at which the track circuit receiver is electrically connected to the rails. Therefore, the test assumes that the track circuit is occupied (i.e., track circuit shunted between its transmitting end and receiving end).

4.1 Verification of Nominal Track Circuit Operation

Verify that the track circuit receiver is working according to manufacturer's specifications, with the transmitter output impedance included in the circuit as required for proper impedance matching and with the transmitted track signal and/or reference signals supplied to receiver when required. Then, set up the equipment as shown in Figure RT/IS01A-1. If the receiver has adjustable sensitivity, adjust the receiver equipment to its most sensitive operating threshold.

4.2 Inductive Susceptibilty Test

4.2.1 Adjust the signal generator to sine wave output, 100 percent square-wave modulation, 0.1-Hz modulation rate (hereafter referred to as code rate), and carrier frequency equal to the nominal operating frequency f_0 of the receiver under test. Adjust the signal level at the track terminals of the impedance bond to 0.5 Vrms during the on-portion of the signal (1.4Vp-p). [CAUTION - See Note 6.1.] Note which of the following response modes occurs:

a. track relay remains down

b. track relay momentarily picks up one or more times during each code rate cycle, and then drops

c. track relay picks up and stays up continuously

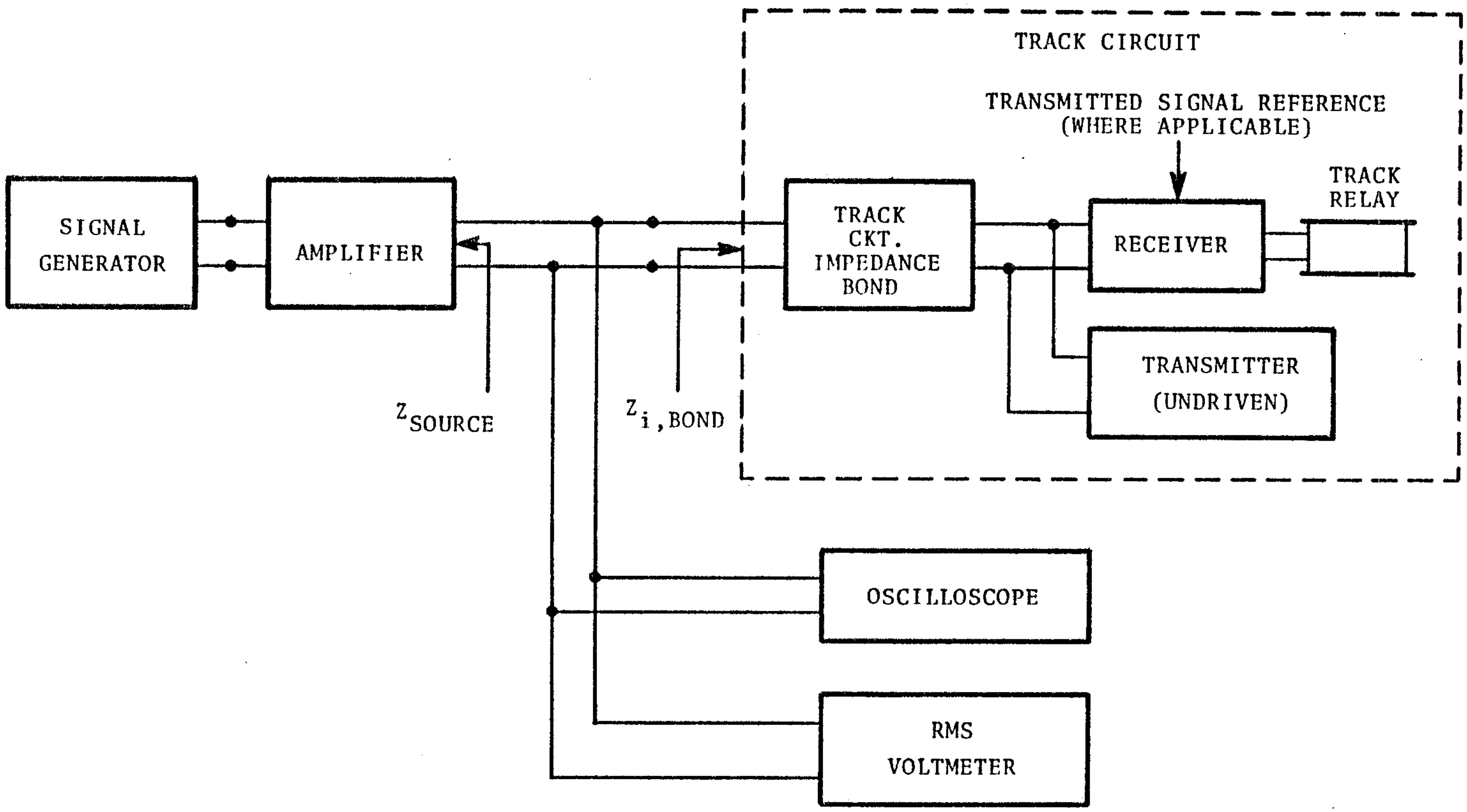


FIGURE RT/IS01A-1. ARRANGEMENT OF TEST APPARATUS FOR PERFORMING MEASUREMENT OF INDUCTIVE SUSCEPTIBILITY OF SIGNALLING SYSTEMS

Slowly increase the carrier frequency from f_O to 10 kHz, and then slowly decrease the carrier frequency from f_O to 300 Hz. Determine to the nearest 5 Hz the frequencies at which response mode changes. Tabulate the various frequency intervals between 300 Hz and 10 kHz in which the different response modes occur. Care must be taken to maintain constant bond input amplitude as frequency is detuned from f_O.

4.2.2 Change the signal amplitude at track terminals of the impedance bond to 0.25 Vrms (half of 0.5 Vrms), and repeat 4.2.1. Repeat 4.2.1 at each of the following signal levels given in Vrms: 0.125, 0.0625, 0.0313, 0.0156. If response mode (b) or (c) occurs for any frequency in the 300 Hz to 10 kHz range at the 0.0156 vrms signal level, continue by repeating 4.2.1 at successive signal levels that are half the previous level, until a level is reached at which response mode (a) is observed for all frequencies in the 300 Hz to 10 kHz range. (The signal levels used above correspond to -6 dBV, -12 dBV, -18 dBV, etc.)

4.2.3 Change the code rate to 0.2 Hz, and repeat 4.2.1 to 4.2.2. Repeat 4.2.1 to 4.2.2 again at each of the following code rates given in Hz: 0.5, 1.0, 2.0, 5.0, 10, 20, 50. If, after having increased the code rate to 50 Hz, response modes other than (a) are occurring for any frequency between 300 Hz and 10 kHz and any of the specified signal levels, continue increasing the code rates using decade multiples until only response mode (a) occurs. When a code rate is reached at which only response (a) occurs, note the previously used code rate. Repeat 4.2.1 to 4.2.2 at code rates that are 1.25, 1.5, 1.75, etc., times the previously used code rate. Stop when a code rate is reached at which only response (a) occurs.

5.0 TABULATION OF RESULTS

Tabulate data on a sheet or sheets as shown in Figure RT/IS01A-2.

SYSTEM TESTED: ____________________ FIELD LOCATION: ____________________

TEST PERFORMED: ____________________ BY WHOM: ____________________

DATE: ____________________ OPERATING FREQUENCY: f_o =

V_I = INTERFERENCE LEVEL IN mV RMS

V_I	CODE RATE - HZ															
500																
250																
125																
62.5																
31.3																
15.6																

FREQUENCY - HZ

—: NO-PICK OF RELAY

* : MOMENTARY PICK OF RELAY

N : RELAY PICKS IN NARROW RANGE OF FREQUENCIES NEAR THIS VALUE

FIGURE RT/IS01A-2. SAMPLE DATA SHEET

6.0 NOTES

6.1 When performing the tests in 4.2, do not exceed manufacturer's stated maximum allowable signal level in any frequency range. Modify test procedures as required to stay within allowable signal levels.

6.2 The test procedure described in 4.2 -- Amplitude Modulation Test -- has been specified with square-wave modulation (50 percent duty cycle). This test does not include measurement of receiver sensitivity as a function of duty cycle. If duty cycle is believed to be an important parameter, the entire test procedure may be performed using duty cycles other than 50 percent as well.

6.3 Ordinarily, when driving the track circuit impedance bond with a signal that has the prescribed voltage wave-form, a signal source with very low output impedance should be used. However, the tests specified in 4.2 use signals of sufficiently narrow bandwidth that acceptable results can be obtained using a signal source with higher output impedance, such as the 4-ohm output taps of a McIntosh Model MC 240 amplifier. The narrow bandwidth of the applied signal assures that the gain reduction factor due to impedance match, $(Z_{i,bond}/Z_{source})$, is approximately constant over the entire signal bandwidth, for any fixed carrier frequency. Furthermore, since the receiver filter bandwidth is typically much narrower than the impedance peak of the impedance bond near the nominal receiver frequency, there generally will not be an appreciable variation in V_I across the bandwidth of the receiver filter.

METHOD RT/IE01A

INDUCTIVE EMISSION OF VEHICULAR ELECTRICAL POWER SUBSYSTEM, RAIL-TO-RAIL VOLTAGE FROM 20 Hz TO 20 kHz

1.0 PURPOSE

This method is used for measuring amplitudes of the harmonic components of interference voltage from 20 Hz to 20 kHz, measured from rail to rail during the passage of a rail transit vehicle.

2.0 APPLICABILITY

The test is primarily intended for rail transit vehicles equipped with chopper propulsion control systems, but may be performed for other types of rail transit vehicles as well, where applicable. Inductive interference is caused by the time-varying magnetic flux lines emanating from propulsion equipment and other electrical equipment on the vehicle passing through the rail-axle loop under the vehicle. Its presence is evident by the observation of abnormally high levels of rail-to-rail voltage observed at locations under the vehicle. The passage of a vehicle over a fixed location induces a transient interference voltage from rail to rail, the harmonics of which can have measurable amplitude throughout the audio-frequency spectrum. The induced voltages can be coupled into audio-frequency track circuit apparatus and disrupt the normal operation of such equipment. The procedure described below has been successfully applied and an example of the results is presented in Appendix B.

3.0 APPARATUS

Test apparatus shall consist of the following:

a. GenRad Model 2512 Spectrum Analyzer, or equal (FFT spectrum analyzer capable of real-time spectral analysis at

20 kHz, with 400 evenly spaced frequency increments from 0 Hz to maximum of range used)

b. oscilloscope camera for spectrum analyzer

c. tape recorder, SE Model Eight-Four, or equivalent. (IRIG Intermediate Band, Direct Record, 15 ips, with at least two channels)

d. X-Y plotter, Esterline-Angus Model XY575, or equal

e. portable audio-frequency signal generator

f. true RMS voltmeter

g. 1:1 isolation transformer (UTC Model LS-33 200 ohm/200 ohm, or equal), 4 μf-1500 V capacitor, and 220 ohm-2 watt resistor; or other suitable means for assuring dc isolation

h. rail clamps

4.0 TEST SET-UP AND PROCEDURE

4.1 Test Set-Up for Data Collection

The test set-up data collection shall be as shown in Figure RT/IE01A-1.

4.2 Procedure for Data Collection

This procedure shall be performed for each different operating mode of the rail transit vehicle, e.g., each different propulsion setting, and each different brake rate that the vehicle can be operated in, with the objective of obtaining worst case data.

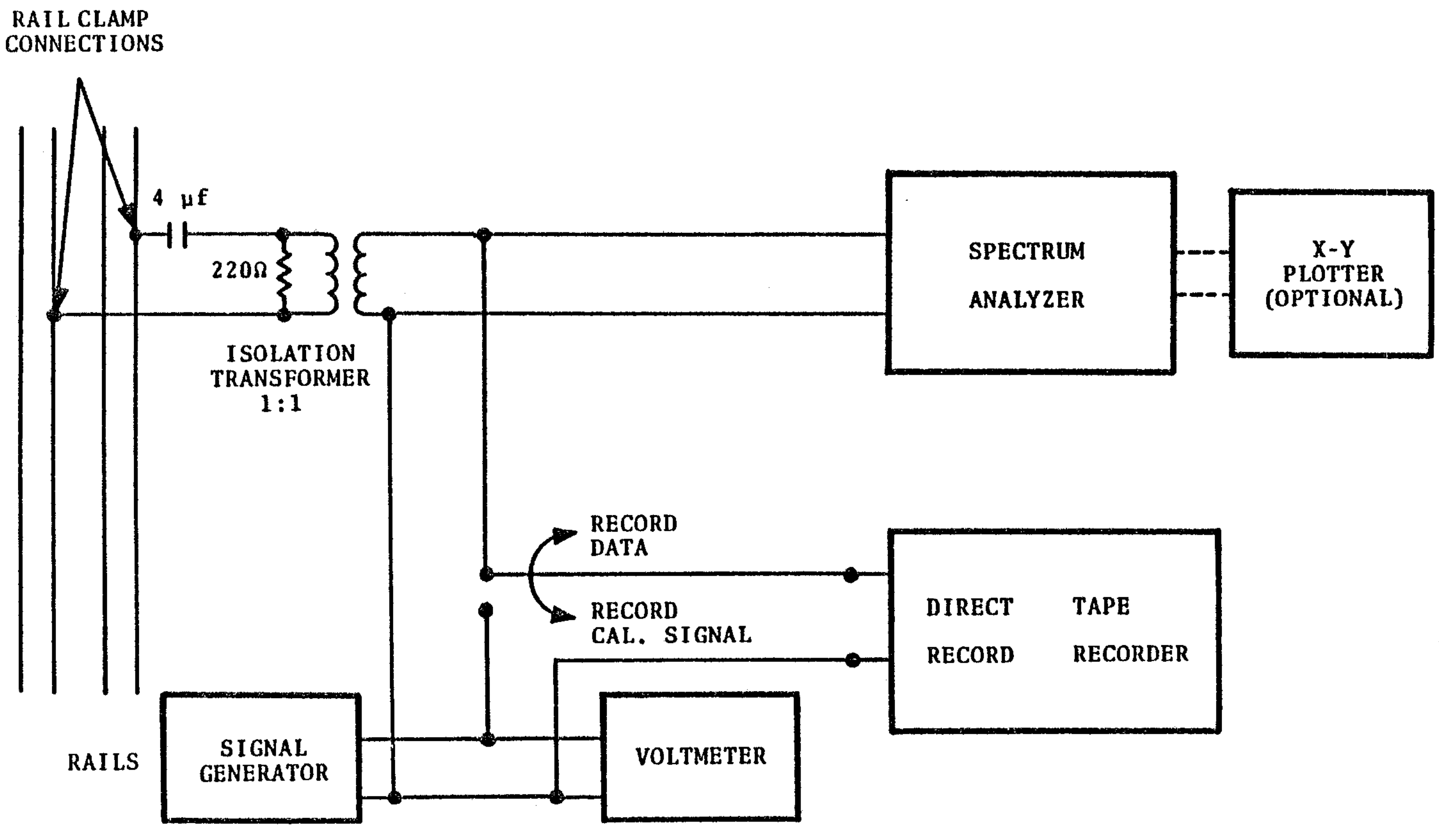


FIGURE RT/IE01A-1. TEST SET-UP FOR DATA COLLECTION

4.2.1 Initial Preparation of Tape Recorder - Using the 1:1 taps on the isolation transformer, apply a number of amplitude calibration signals of known amplitude to the track terminals of the isolation transformer, for recording onto the tape recorder immediately prior to recording of data. Be careful not to disturb any of the amplitude controls of the tape recorder after this is done. Use a separate recording channel to record a voice narrative giving frequency and amplitude data for each reference signal being recorded. During initial runs, verify that the tape recording is being made within the correct dynamic range of the recorder. Also note and record the gain factor of the isolation transformer by use of spectrum analyzer. (See Note 6.2.)

4.2.2 Initial Preparation of the Spectrum Analyzer - Place the averaging selection of the spectrum in the "Max" mode, select the appropriate frequency range and set the sensitivity setting at 0 dBV. Put the frequency scale on "linear," the amplitude scale on 10 dB per division, and the hanning filter "on."

4.2.3 Performance of Test - Turn on the tape recorder to record interference produced, activate the spectrum analyzer, and have the vehicle run past the observation point. When the vehicle is clear of the observation point, store the display of the FFT spectrum analyzer. If the input signal overdrive light remained off during the passage of the vehicle, the data is valid. If the input signal overdrive light flashed or remained on during the passage of the vehicle, change the sensitivity setting to +10 dBV and repeat 4.2.3. Increase sensitivity setting up to 20 dBV and repeat this procedure if the input overdrive light does not remain off during passage of the vehicle. If further desensitization is required, change taps on the coupling transformer to achieve the required input voltage reduction, and repeat 4.2.1-4.2.3. Use voice channel to record salient operating characteristics of the run, e.g., starting point or stopping point of train, propulsion or braking mode, and speed when the front of train reaches measurement point.

4.2.4 Field Reduction of Data - With the display stored in the spectrum analyzer, move the frequency cursor across the screen and record the amplitudes of the peak values of harmonic components. Photograph the display. (If convenient, immediately generate an X-Y plot of spectrum analyzer display using X-Y plotter. Use measured isolation transformer throughput gain factor to determine plotted amplitudes.)

4.2.5 Repeat 4.2.3 and 4.2.4 for each acceleration mode and braking mode. Multiple runs in each mode will be required if a 1-car train is used, in order to obtain data for train passing measuring point at a variety of speeds.

4.3 Procedure for Laboratory Reduction of Data

4.3.1 Test Set-Up for Laboratory Reduction of Data - The test set-up shall be as shown in Figure RT/IE01A-2.

4.3.2 Data Reduction - Play back the recorded test signals and observe their amplitude on a RMS-reading voltmeter and on the FFT spectrum analyzer. Use an X-Y plotter to obtain a plot of each spectrum analyzer display. Calculate the ratio of output (played-back) to the input (recorded) test signal, for each amplitude level recorded. Convert these ratios to dB. The results should all be within 1 dB of each other. The average of the dB values is the instrumentation throughput gain factor, of the isolation transformer plus tape recorder, expressed in dB. It can be either greater or less than 0 dB.

Prepare the spectrum analyzer as described in 4.2.2. Play back the recorded interference signals into the spectrum analyzer, following procedures outlined 4.2.3. Repeat 4.2.4. Using X-Y plotter, operate the spectrum analyzer in the "plot" mode to produce a large-scale graphical record of the interference voltage spectrum. Use the instrumentation throughput gain factor and plots of the played-back reference signals to correctly label

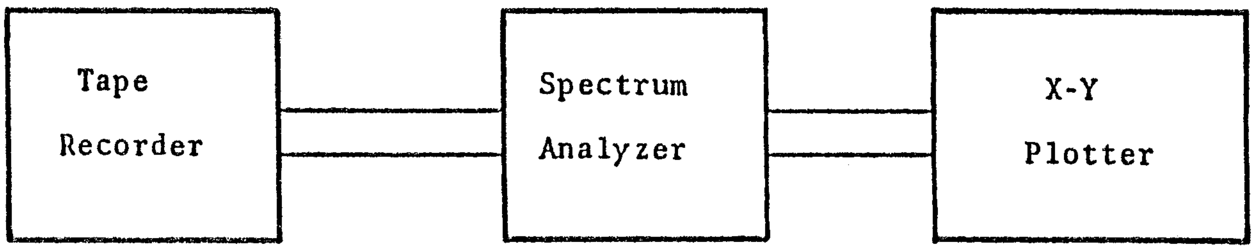


FIGURE RT/IE01A-2: TEST SET-UP FOR LAB REDUCTION OF DATA the amplitude scale of plotted graphs. Compare the interference signal plots with the X-Y plots or photos of the spectrum analyzer display from the field to verify validity of the tape recorded data.

5.0 TABULATION OF RESULTS

5.1 Tape Recordings

The tape recording shall be stored for future use and analysis, along with a written index of its contents, in the form of tape distance indications for various runs, and information on type of tape recorder used.

5.2 Index of Runs

An index giving pertinent information of each run shall be prepared, with runs numbered consecutively.

5.3 Spectrum Analyzer Photographs

Spectrum analyzer photographs taken in the field according to Section 4.2.4 shall be numbered by run and stored in a permanent manner.

5.4 Spectrum Analyzer X-Y Plots

Spectrum analyzer X-Y plots generated from plotter outputs of spectrum analyzer in the field, and those generated from spectrum analyzer in the lab, according to Section 4.3.2, shall be numbered by run and stored in a permanent manner.

6.0 NOTES

6.1 It should be noted that the tape-recorded signal (i.e., rail-to-rail voltage) is equivalent to the open-circuit voltage across the rails, and is the Thevenin equivalent source voltage of the rail-axle loop. It does not account for additional voltage drops due to the rail and wheel-axle impedances that would occur due to current flow caused by actual track circuitry connected across the rails. Depending on the value of rail and wheel-axle impedances with respect to the track circuit input impedance, this effect may be significant.

6.2 Some spectrum analyzers, including the one specified herein (Item 3.0 a), 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 adding +1.8 dB, in order to obtain actual levels. This correction must be made especially to correlate level of injected reference signal with its amplitude measured with spectrum analyzer.

METHOD RT/IEO4A

INDUCTIVE EMISSIONS OF VEHICULAR ELECTRICAL POWER SUBSYSTEM, EMULATED TRACK CIRCUIT

1.0 PURPOSE

The purpose of this test is to reproduce inductive emissions of transit vehicle electrical power equipment in the laboratory under emulated track circuit conditions.

2.0 APPLICABILITY

This test is applicable to all electric power equipment used on transit vehicles which utilize steel wheels and steel rails for guidance, signalling, and train control. The passage of a vehicle over a fixed location may induce a transient rail-to-rail interference voltage, the harmonics of which can have measurable amplitude throughout the audio-frequency spectrum. The induced voltages can be coupled into the track circuit signalling apparatus and disrupt the normal operation of such equipment. Three test conditions are possible:

- TEST CONDITION A - with simulated in-band resistance of the track circuit impedance bond
- TEST CONDITION B - with actual signalling equipment
- TEST CONDITION C - recorded open-circuit voltage of the rail-axle loop, i.e., the Thevenin equivalent source voltage as per Figure 2-2

Unless otherwise specified, TEST CONDITION A shall apply, and this procedure details that test condition. Test conditions A, B and C have been applied and an example of the test results for TEST CONDITION A is presented in Appendix B.

3.0 APPARATUS

The following equipment is required:

a. a complete operating set of vehicular electrical equipment suspected of producing inductive emissions.

b. aluminum tubing, grade 6061-T6 or similar, 95 mm (3.75 inches) outside diameter and 0.89 mm (0.35 inch) minimum wall thickness (see Note 6.4 for modifications), and length equal to the interior wheelbase of the car (see Note 6.5 for modification). The tubing is used to simulate running rail.

c. aluminum tubing, grade 6061-T6 or similar, 15.9 mm (0.625 inch) outside diameter and 0.89 mm (0.035 inch) wall thickness, or equivalent conductor. This conductor is used to simulate the vehicle axle reactance.

d. a specified resistor R_B to simulate the in-band resistance of the track circuit impedance bond.

e. copper wire, AWG No. 6 or heavier, to connect the resistor RB (item 3.0. d) to the test apparatus.

f. FFT spectrum analyzer, GEN RAD model 2512 or equivalent.

g. X-Y plotter compatible with spectrum analyzer (Esterline-Angus Model XY575, or equivalent).

h. a specified resistor R_A to simulate rolling axle resistance. The resistance shall not be greater than is specified for track signal shunting. If unspecified, the R_A shall be 0.12 ohms (noninductive), 2 watts.

i. strip-chart recorder and adjunct instrumentation as required to record essential operating parameters of propulsion equipment.

j. tape recorder (optional), SE Model Eight-Four, or equivalent (IRIG, intermediate band, direct-record, 15 ips).

k. Wayside Track Circuit Signalling Equipment (TEST CONDITION B).

4.0 TEST PROCEDURE

The apparatus shall be set up in accordance with Figure RT/IE04A-1. The arrangement of vehicle equipment shall conform as closely as possible to the undercar configuration. Traction motors may be located remotely (see Note 6.5). The tubes used to emulate the running rails shall be marked in equal increments 0.4 meters apart, and the increment boundaries marked in numerical sequence 0, 1, 2, 3, ... etc., starting at one axle. These are called bond positions.

4.1 Zero Added Axle Resistance

Starting with resistor R_B in position 1, and resistor R_A replaced by a short circuit, the propulsion equipment shall be exercised through all its operating modes (e.g., acceleration, dynamic, and regenerative braking), under predetermined worst case conditions (usually maximum dc propulsion line voltage and maximum propulsion current). Nonpropulsion equipment shall also be operated under worse case conditions, if possible. The spectrum analyzer shall be operated in peak holding (maximum) and hanning time-windowing modes. The spectrum analyzer shall acquire data throughout each operating cycle, and the cumulative spectrum shall be photographed and plotted (see Note 6.3). This sequence shall be repeated at alternate (odd numbered) bond positions, except in the neighborhood of response maxima, where data shall

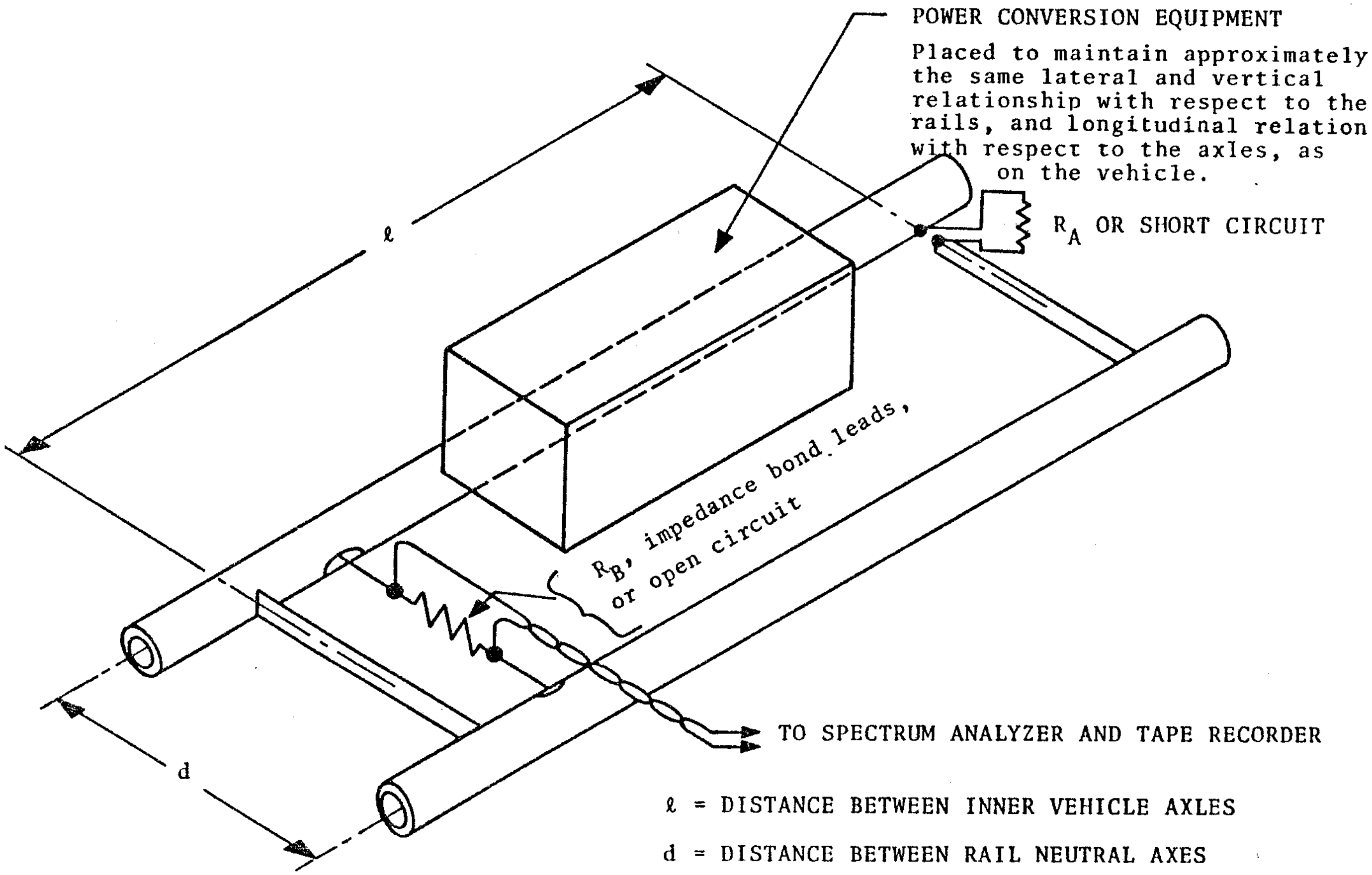


FIGURE RT/IE04A-1. TEST SET-UP

be obtained at all bond positions as well as at intermediate positions if needed. As the test progresses, a graph of the greatest amplitude of any spectral line in the signalling band versus bond position shall be generated.

At maximum response, and last bond position, the following system parameters shall be recorded on the strip chart:

- input filter capacitor bank voltage
- propulsion system input current
- traction motor current
- field supply current (if separately excited)
- vehicle speed
- pertinent parameters of the auxiliaries (if included)

4.2 With Added Axle Resistance

The test shall be repeated with the specified axle resistance R_A inserted first at one axle and then at the other axle.

4.3 Auxiliaries Only

If applicable, the procedure shall be repeated with auxiliaries only (propulsion off) to obtain emission signature of a stationary vehicle.

5.0 TABULATION OF RESULTS

The tabulation of results for these tests shall include the following:

a. all spectral plots fully annotated

b. tabulated harmonic amplitudes (where spectral plots are not made)

c. annotated strip charts of the propulsion system parameters

d. test equipment identification, serial numbers, and certification information

6.0 NOTES

6.1 Some spectrum analyzers, including the one specified herein (item 3.0 f), do not automatically correct for the amplitude reduction associated with use of the hanning function. In that event, the data for amplitudes of chopper harmonics shall be adjusted by adding to each observed reading a factor of +1.8 dB.

6.2 In the event that a tape recorder is used for recording data for later analysis, the tape recorder shall initially be set up according to the procedures outlined in RT/IE01A, Section 4.2.1. Recorded tapes shall be documented as set forth in RT/IE01A, Section 5.1.

6.3 Spectral plotting is time-consuming and is usually not required at each position because the character of the spectrum changes only as the bond comes under the influence of different major flux sources. Experience has shown that all the needed information can be obtained by making spectral plots at a few representative positions, and by reading and recording the following data directly with the aid of the cursor at each position:

a. frequency and amplitude of the spectral line nearest the low-frequency end of the signalling band

b. frequency and amplitude of the spectral line nearest the high-frequency end of the signalling band

c. frequency and amplitude of the maximum-amplitude spectral line in the signalling band

6.4 Although 3.75 inch of tubing allows a formally correct simulation of the running rails, experience has shown that tubing as small as 1 inch OD can be used under appropriate circumstances. The rationale for this approach, together with an example, are given in RT/IEO4A-Exhibit A.

6.5 A loop of tubing whose length is equal to the interior wheel-base of the car may be unwieldly under cramped laboratory conditions. It has been found that a shorter loop provides essentially unchanged results, provided the loop is sufficiently long to capture essentially all of the magnetic flux that would be captured by a full-length loop. Since a shorter loop has lower inductance than a longer loop, at times it may be desirable to compensate for this lower inductance by adding lumped series inductances to the ends of the loop. A few turns of heavy copper wire wound on a nonconducting mandrel of approximately 1.5 inch diameter are generally sufficient.

6.6 To date, dc traction motors have not been observed to produce inductive audio-frequency interference in track circuits. However, if they are suspected of being a significant source of induction into the rails, they must be tested separately under conditions that appropriately emulate the motor-truck-track circuit relationship.

6.7 The recorded results of TEST CONDITION A serve as an indication of interference voltage levels that occur within the passband of a track receiver filter. Track circuit impedance bonds are generally tuned to resonance at or very near receiver frequencies. The bandwidth of the resonance peak in bond input impedance is typically greater than the bandwidth of the receiver filter. Therefore, across the passband of the track receiver filter, the input impedance to the track terminals of the impedance bond will typically be approximately constant and resistive. The value of this resistance is typically a few tenths of an ohm.

6.8 TEST CONDITION B provides the most accurate modelling possible in the lab of the effects of inductive interference on track circuitry. During the conduct of tests using TEST CONDITION B, the actual response of track circuit receivers can be observed and recorded. The dynamic response of the track circuit receiver can be observed as the carborne power equipment is cycled through various operational modes.

6.9 TEST CONDITION C provides the most general measure of inductive interference voltage, since it directly measures V_{OC}, the Thevenin-equivalent open-circuit voltage of the circuit that serves as the source of inductive interference to the track circuitry. This knowledge can be used in conjunction with wheel-axle, rail, and bond input impedances to calculate levels of inductive interference in track circuits under arbitrary conditions.

6.10 Note that this test method is a static laboratory test insofar as the effects of car motion on observed rail-to-rail voltages as a function of time cannot be observed.

METHOD RT/IE04A

EXHIBIT A SIMULATION OF RAIL-WHEEL-AXLE IMPEDANCE

1.0 The electrical characteristics of the rail-wheel-axle loop under a rail car can be accurately simulated by use of aluminum tubing, since at audio-frequencies the loop impedance is largely inductive. Furthermore, the inductance is approximately constant across the range of track circuit signalling frequencies due to the fact that skin effect prevents fields from penetrating into the interior of conductors, yielding essentially equal inductive characteristics for solid steel and tubular aluminum conductors. This exhibit outlines the electrical characteristics of actual and simulated rail-wheel-axle loops.

2.0 AXLE IMPEDANCE

Axle impedance is nearly all inductive, with inductance lying in the range of 1.2 to 1.8 h at audio-frequencies. Skin effect causes inductance to decrease as frequency increases. Aluminum tubing can be used to simulate this inductance.

The inductance of a straight nonmagnetic tubular conductor is given by the relation:

$$L_A = 0.2\ [\log_e(2\ell/r) - 1 + \alpha]\ \text{h/meter}$$

where ℓ is length, r is outer radius, and α is a function of ID/OD ratio and skin depth. The parameter α is approximately zero for a thin shell or for zero skin depth, and approximately 0.25 for a solid conductor whose radius is much less than skin depth.

An aluminum tube with 1.59 cm (0.625 inch) OD, 0.09 cm(0.035 inch) wall, length of 1.4 m, and with $\alpha = 0$, has an inductance of 1.4 μh. Because of the slowly varying nature of the log function in the above equation, a tube of 2.54 cm (1 inch) diameter, for example, has an inductance of 1.2 μh -- a figure which provides sufficient accuracy in most instances.

The resistance of a conductor at dc and 20° C is given by the relation:

$$R = (0.1754/\sigma' A)\text{milliohms/meter}$$

where σ' is the conductivity relative to copper at 20° C, and A is the crossection in cm^2. For 6061-T6 aluminum, $\sigma' = 0.43$. A 6061-T6 aluminum tube having 1.59 cm OD, 0.09 cm wall thickness and 1.4 m length would have a dc resistance of 1.3 milliohms. Since the wall thickness is small with respect to the skin depth, resistance would only increase by 6 percent at 10 kHz.[1] Since inductive reactance is approximately 9 milliohms at 1 kHz and even greater at higher frequencies, this resistance is negligible. The resistance of a rolling wheel-axle set is a complex function of wheel and track condition, of frequency, and of current through the wheel. Since for frequencies above 500 Hz the value of actual axle resistance measured tread to tread is always larger than the 1.3 milliohm figure given above, the effects of actual axle resistance and wheel-rail contact resistance both can be accounted for by addition of series lumped resistance, as shown in Figure RT/IE04A-A1.

3.0 RAIL IMPEDANCE

At audio-frequencies, rail impedance is essentially inductive, with a value of X/R typically greater than 9 at a frequency as low as 1 kHz. Running rails behave electrically at audio-frequencies as if they were cylinders with effective radius of 4.7 cm, or diameter of 9.4 cm (3.7 inches).

[1] Dwight, Electrical Coils and Conductors, McGraw-Hill, 1945.

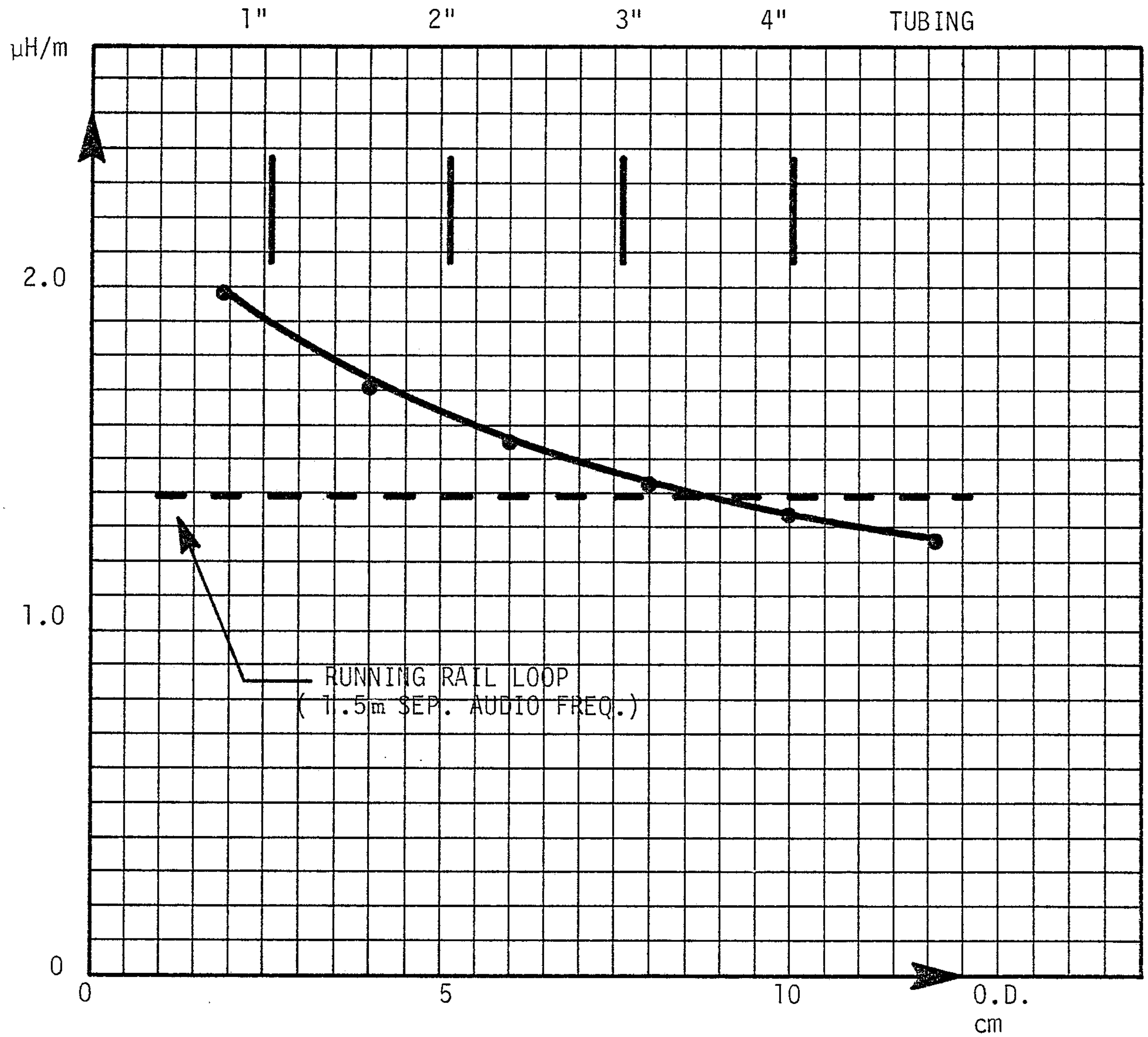


FIGURE RT/IE04A-A1. INDUCTANCE OF LONG RETURN CIRCUIT

The inductance of a return circuit of identical straight parallel cylindrical conductors is given by the relation:

$$L_R = 0.4\ [\log_e(d/r)-(d/\ell)+(d/\ell)^2/4\ ...]\ \text{h/meter}$$

where ℓ is the length of the conductors, d the distance between their axes, and r their radius.[2] Because of the log function, inductance is only weakly dependent on radius, and frequently tubes with a diameter less than 9.4 cm can be used to simulate running rails. (See Figure RT/IE04A-A1.) At times, tubes as small as 2.54 cm (1 inch) in diameter have been used successfully.

The minimum diameter of a tube used to simulate the electrical characteristics of the rails depends directly upon the input impedance to the track circuit impedance bond at frequencies within the passband of track circuit receiver filters. That input impedance is typically in the range of 0.2 ohms to 0.5 ohms, and is resistive. If a tube with too small a diameter is chosen, results from Method RT/IE04A under TEST CONDITIONS A or B will predict erroneously low values of inductive interference. The error results from an unrealistically high ratio of simulated rail-wheel-axle impedance to bond input impedance.

The actual source inductance L_S seen by an impedance bond in Figure RT/IE04A-1 is maximum when the bond is attached to the rails midway between the interior axles of the car. For a car with an interior wheelbase of 16 meters, resting on standard-gage track with d = 1.5 meters, the bond sees a source inductance due to two paralleled loops of length 8 meters each terminated by an axle, plus the series inductance of the bond leads. Bond lead inductance L_B is typically approximately 1.5 μh. Assuming then that each loop has inductance equal to:

[2] Trueblood & Wascheck, "Investigation of Rail Impedances," Electrical Engineering, December 1933.

$$L_R(d=1.5m,\ r=4.7cm,\ \ =8m)+L_A$$

where L_A = 1.4 μh, the total source inductance is equal to:

$$L_S=(L_R+L_A)/2 + L_B=7.7\ \mu h$$

This value of inductance, taken with an in-band bond input resistance R_B = 0.5 ohms yields an upper half-power frequency for attenuation of interference signals of $f_H = R_B/2\pi L_S$ = 10 kHz. (See Figure RT/IEO4A-A2.) As long as this frequency is sufficiently higher than any signalling frequency of interest, tube diameter can be reduced without producing erroneously optimistic results, provided R_B is in the range of 0.5 ohms. However, in the case of much smaller R_B, for instance 0.15 ohms, the corresponding value of f_H becomes 3.5 kHz -- right in the middle of the audio-frequency signalling range, and tube diameter cannot be reduced.

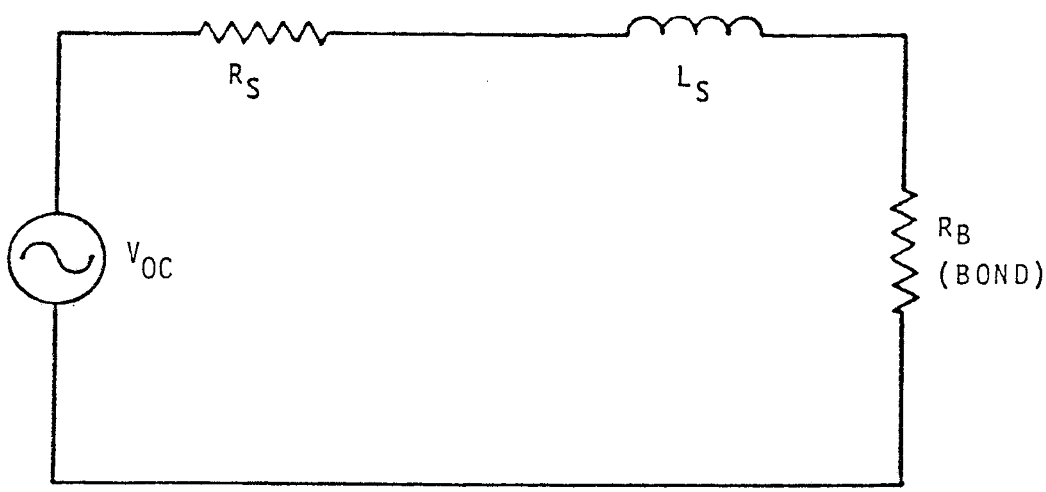


FIGURE RT/IE04A-A2. EQUIVALENT CIRCUIT OF UNDERCAR NETWORK

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 Inductive Recommended Practices

SYSTEM TESTED: GRS (BRAINTREE EXTENSION)
TEST PERFORMED: RT/IS01A
COMMENTS: TRACK CIRCUIT DRAWING # 58521-7 (MAINTENACE TEST UNIT)

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

RUN #	INSTRUMENT SETTINGS	SCENARIO
28	SELECT PROPER CODE RATE AND FREQUENCY CARRIER	SEE PROCEDURE RT/IS01A PARAGRAPH 4

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

DIAGRAM: TEST MEASUREMENT

SEE FIGURE RT/IS01A-1 (NOTE 1 AND NOTE 2)

NOTE 1 UNMODULATED TRANSMITTER REPLACED BY 14 mh COIL AND 400 Ω RESISTOR IN PARALLEL
NOTE 2 0.1 μ fd CAPACITOR PLACED ACROSS RECEIVED 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) FIELD LOCATION: MBTA CABOT SIGNAL BLD
TEST PERFORMED: RT/ ISOIA BY WHOM: R. GAGNON + J. CADIGAN
DATE: 4/22/80 OPERATING FREQUENCY: f_0 = 3060Hz

V_I = INTERFERENCE LEVEL IN mV RMS

V_I	CODE RATE - HZ															
	0.1	0.2	0.5	1.0	2.0	5.0	10	20	50	100	100	200	200	500	275	
500	-	-	-	2895	2895	2860	2705	2600	2395	N 2455	N 3670	N 2625	N 3720	-	-	
	-	-	-	3220	3220	3285	3450	3575	3705	N 2455	N 3670	N 2625	N 3725	-	-	
250	-	-	-	2920	2920	2910	2880	2840	2785	N 2810		N 3345		-	-	
	-	-	-	3200	3200	3215	3270	3350	3420	N 2810		N 3355		-	-	
125	-	-	-	2935	2935	2925	2920	2915	2895	-		N 3270		-	-	
	-	-	-	3195	3195	3200	3210	3220	3240	-		N 3290		-	-	
62.5	-	-	-	2955	2955	2955	2955	2955	2950	2960		-		-	-	
	-	-	-	3170	3170	3170	3170	3175	3200	3170		-		-	-	
31.3	-	-	-	-	-	-	-	-	-	-		-		-	-	
	-	-	-	-	-	-	-	-	-	-		-		-	-	
15.6	-	-	-	-	-	-	-	-	-	-		-		-	-	
	-	-	-	-	-	-	-	-	-	-		-		-	-	

FREQUENCY - HZ

—: NO-PICK OF RELAY
* : MOMENTARY PICK OF RELAY
N : RELAY PICKS IN NARROW RANGE OF FREQUENCIES NEAR THIS VALUE

SYSTEM TESTED: U S & S (HAYMARKET NORTH)
TEST PERFORMED: RT/ISO1A
COMMENTS: TRACK CIRCUIT AF-200

FIELD LOCATION: MBTA CABOT SIGNAL BLD
BY WHOM: R. GAGNON & J. CADIGAN (DOT/TSC)
DATE: 3/28/80

RUN #	INSTRUMENT SETTINGS	SCENARIO
33	SELECT PROPER CODE RATE AND CARRIER FREQUENCY	SEE PROCEDURE RT/ISO1A PARAGRAPH 4

APPARATUS USED: SIGNAL GENERATOR (NOTE 1). AMPLIFIER (McINTOSH - Mc240) FREQUENCY COUNTER (HVP 5327B). RMS VOLTMETER (H/P 3403A). OSCILLOSCOPE (H/P 1701B)

DIAGRAM: TEST MEASUREMENT

SEE FIGURE RT/ISO1A - 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) FIELD LOCATION: MBTA CABOT SIGNAL BLD

TEST PERFORMED: RT/IS01A BY WHOM: R. GAGNON & J. CADIGAN (DOT/TSC)

DATE: 4/17/80 OPERATING FREQUENCY: f_0 =

V_I = INTERFERENCE LEVEL IN mV RMS

V_I	CODE RATE - HZ															
	0.1	0.2	0.5	1.0	2.0	5.0	10	20	50	100	62.5	75				
500	* 1530	* 1530	* 1530	—	—	1495	1485	1490	1520	—	1595	—				
	* 1645	* 1640	* 1640	—	—	1675	1700	1700	1590	—	1660	—				
250	* 1540	* 1540	* 1540	—	—	1530	1525	1525	1525	—	1570	—				
	* 1630	* 1630	* 1630	—	—	1630	1650	1650	1605	—	1645	—				
125	* 1540	* 1550	* 1550	—	—	1550	1545	1545	1550	—	—	—				
	* 1625	* 1625	* 1620	—	—	1630	1625	1625	1570	—	—	—				
62.5	—	—	—	—	—	—	—	N 1580	—	—	—	—				
	—	—	—	—	—	—	—	N 1590	—	—	—	—				
31.3	—	—	—	—	—	—	—	—	—	—	—	—				
	—	—	—	—	—	—	—	—	—	—	—	—				
15.6	—	—	—	—	—	—	—	—	—	—	—	—				
	—	—	—	—	—	—	—	—	—	—	—	—				

FREQUENCY - HZ

—: NO-PICK OF RELAY

* : MOMENTARY PICK OF RELAY

N : RELAY PICKS IN NARROW RANGE OF FREQUENCIES NEAR THIS VALUE

SYSTEM TESTED: MARTA
TEST PERFORMED: RT/IE01A
CARS IN CONSIST: 4 CAR CONSIST

FIELD LOCATION: EASTLAKE STATION
BY WHOM: R. GAGNON (DOT/TSC)
WEATHER: FAIR

COMMENTS: RAIL TO RAIL CONNECTION MADE IN TRACK CIRCUIT ER-261
NO FLAT WHEELS

DATE: 8/22/79

RUN #	START FOOTAGE	STOP FOOTAGE	CAR SPEED	DIRECTION	SCENARIO
58	969'	978'	~10MPH	WEST BOUND	P4 TRAIN STARTED JUST AT ENTRANCE TO BLOCK. SEE RT/IE01A PARA 4 NOTE 1

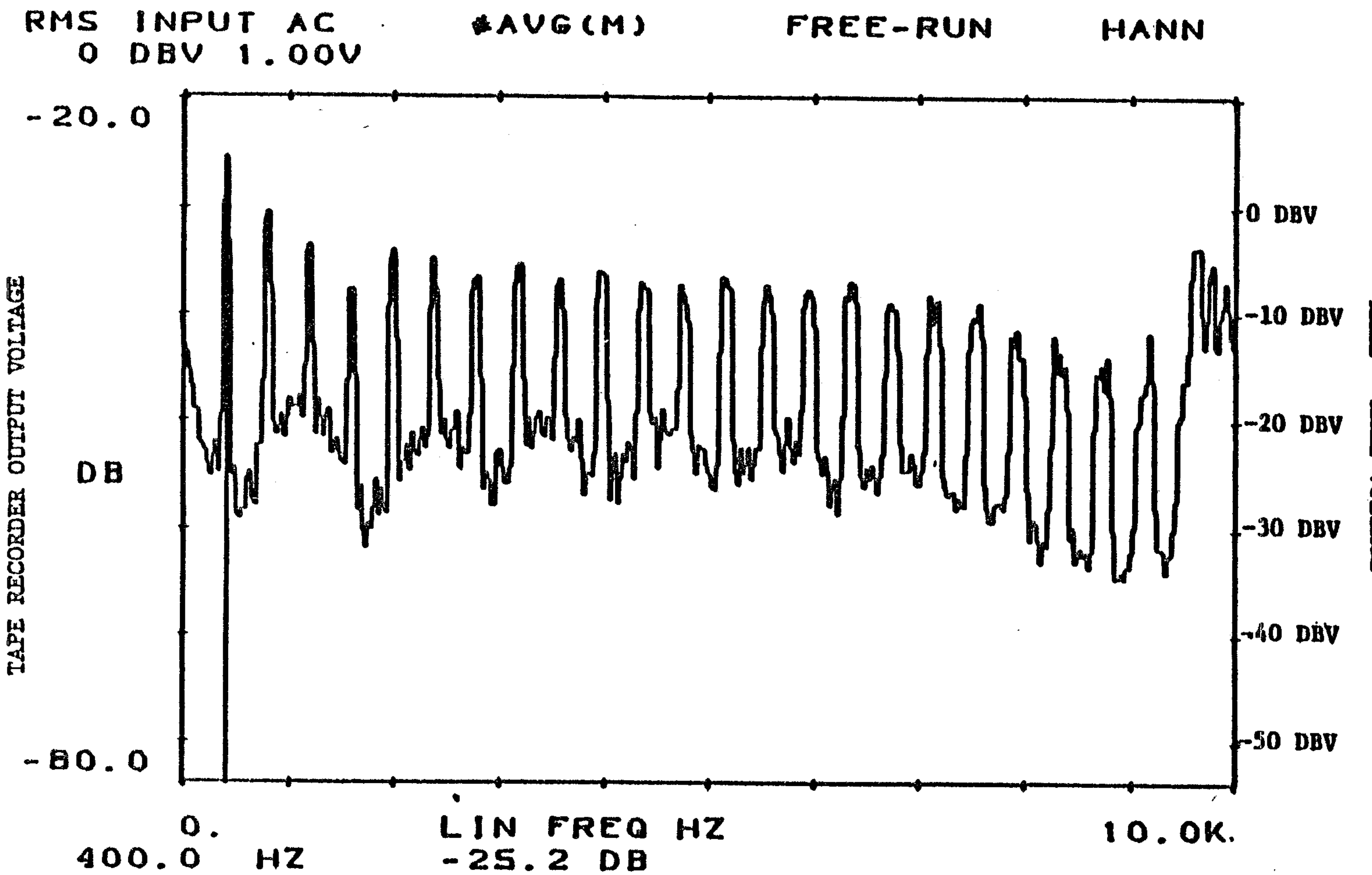
APPARATUS USED: AS SPECIFIED IN RT/IE01A

DIAGRAM: TEST MEASUREMENT

SEE FIGURE RT/IE01A-1

NOTE 1 MARTA TAPE #1
NOTE 2
NOTE 3
NOTE 4

NOTE: DISREGARD SPURIOUS MEASUREMENT RESPONSE AT ZERO HZ



HZ	DB
400	-25.2
800	-30.0
1.2K	-32.9
1.6K	-37.3
2.0K	-33.9
2.4K	-37.1
2.8K	-35.4
3.2K	-34.6
3.6K	-38.7
4.0K	-35.5
4.4K	-37.0
4.8K	-39.7
5.2K	-36.6
5.6K	-38.7

RAIL - RAIL VOLTAGE FOR MARTA RUN NO. 58. P4 POWER SETTING,
MEASUREMENT SYSTEM THROUGHPUT FACTOR = -18.6DB

SYSTEM TESTED: BART
TEST PERFORMED: RT/IE01A
CARS IN CONSIST: 4 CAR CONSIST
COMMENTS: NO FLAT WHEELS

FIELD LOCATION: HAYWARD TEST TRACK
BY WHOM: R. GAGNON
WEATHER: DAMP MISTY

DATE: 1/16/80

RUN#	START FOOTAGE	STOP FOOTAGE	CAR SPEED	DIRECTION	SCENARIO
21	674'	705'	24 MPH	SOUTHBOUND	FULL POWER MANUAL RUN STARTED 120' FROM MEASUREMENT POINT. NOTE 1 SEE RT/IE01A PARA 4

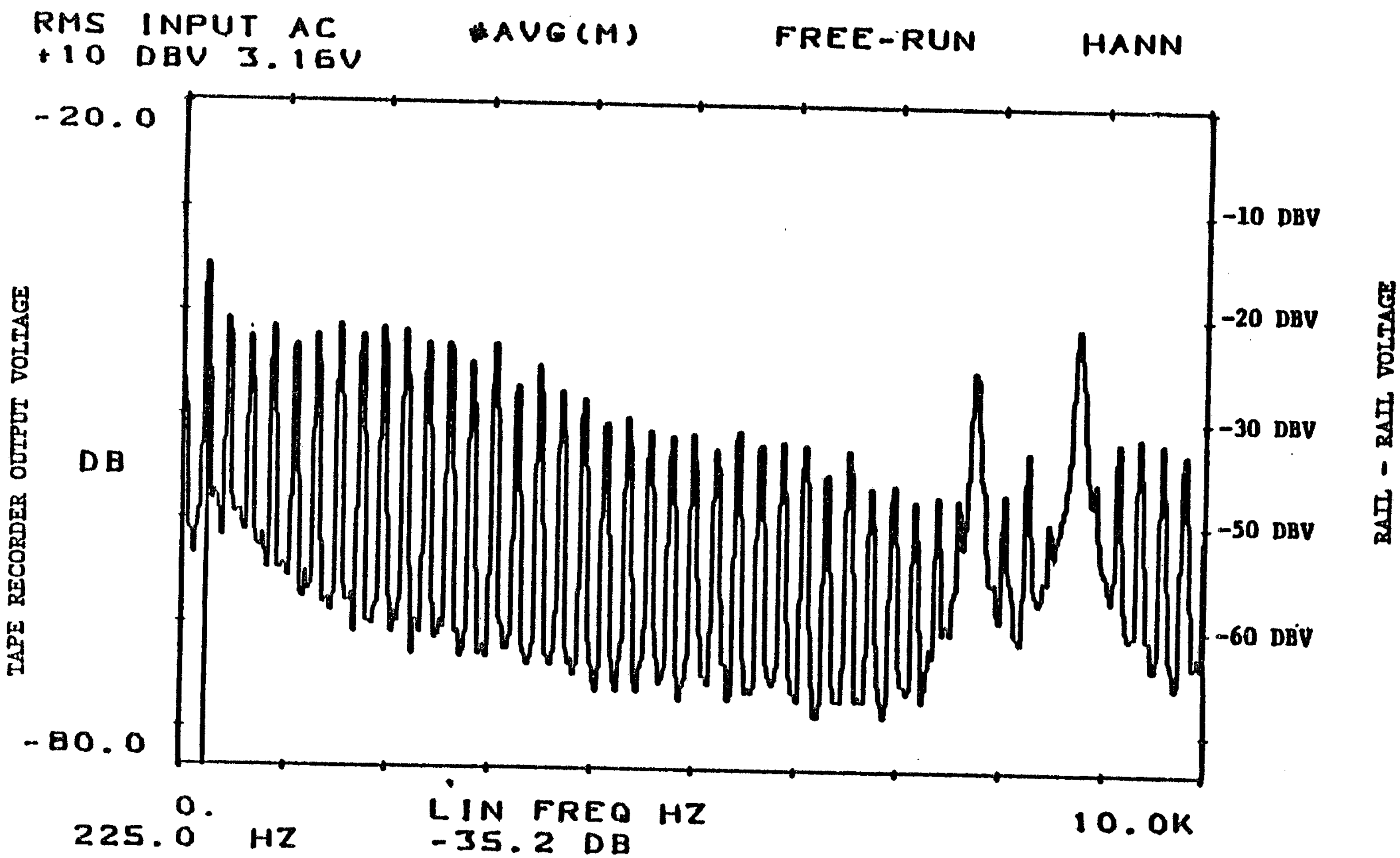
APPARATUS USED: AS SPECIFIED IN RT/IE01A

DIAGRAM: TEST MEASUREMENT

S E E F I G U R E RT/IE01A

NOTE 1 BART TAPE #1
NOTE 2
NOTE 3
NOTE 4

NOTE: DISREGARD SPURIOUS MEASUREMENT RESPONSE AT ZERO HZ
MEASUREMENT SYSTEM THROUGHPUT FACTOR = -13.2 DB



RAIL - RAIL VOLTAGE FOR BART RUN NO. 21. FULL POWER 24 M.P.H.

SYSTEM TESTED: EXPERIMENTAL CHOPPER

TEST PERFORMED: RT/IE04A TEST CONDITION A

COMMENTS: ZERO ADDED AXLE RESISTANCE

FIELD LOCATION: GARRETT TORRANCE CALIF.

BY WHOM: R. RUDICH (GARRETT)

DATE: 3/13/80

RUN #	INSTRUMENT SETTINGS	SCENARIO
10		RT/IE04A PARA 4.0 TEST CONDITION "A"

APPARATUS USED: AS SPECIFIED IN PARA. 3.0 OF RT/IE04A

DIAGRAM: TEST MEASUREMENT

S E E F I G U R E RT/IE04A-1

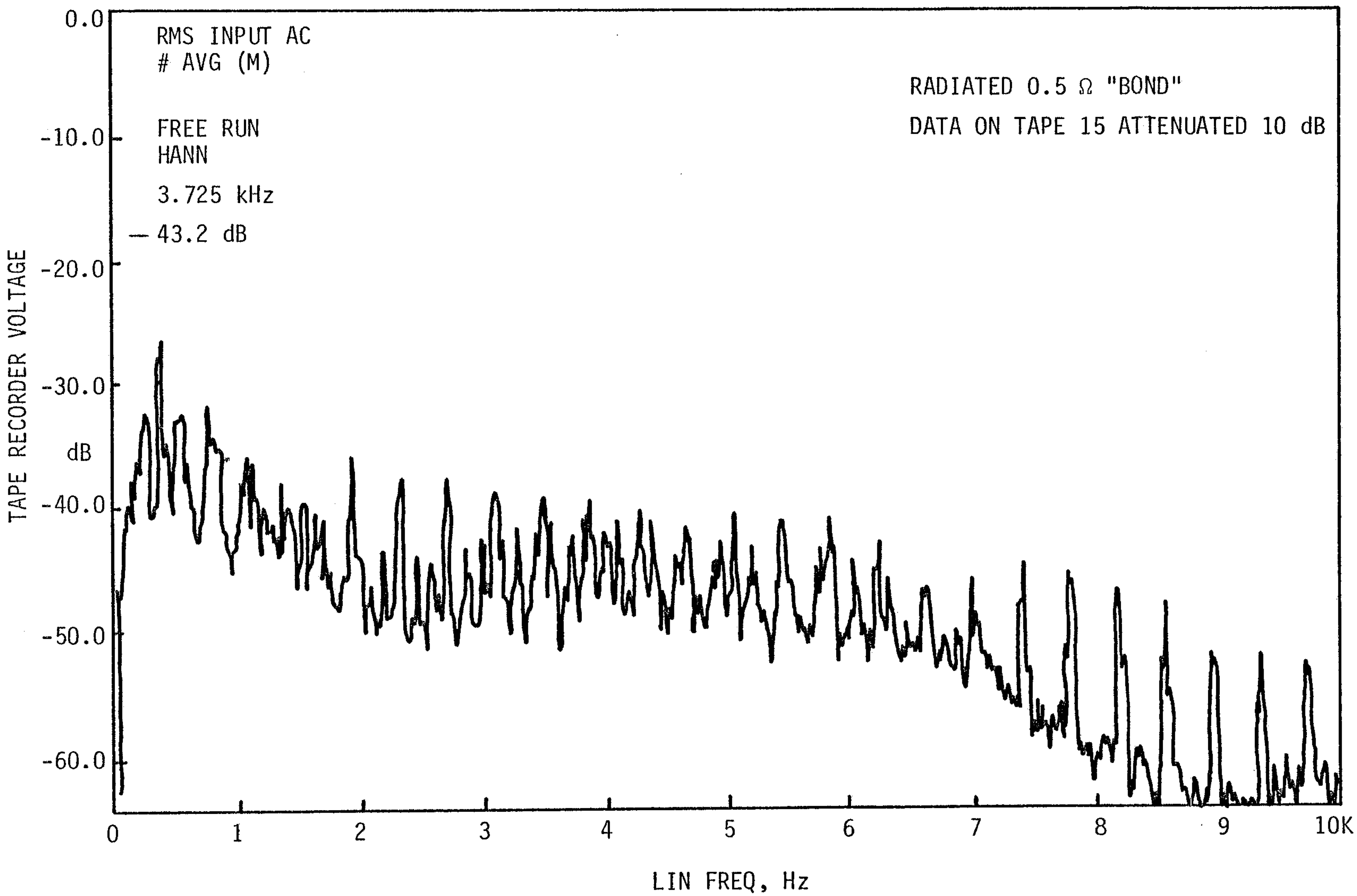
NOTE 1

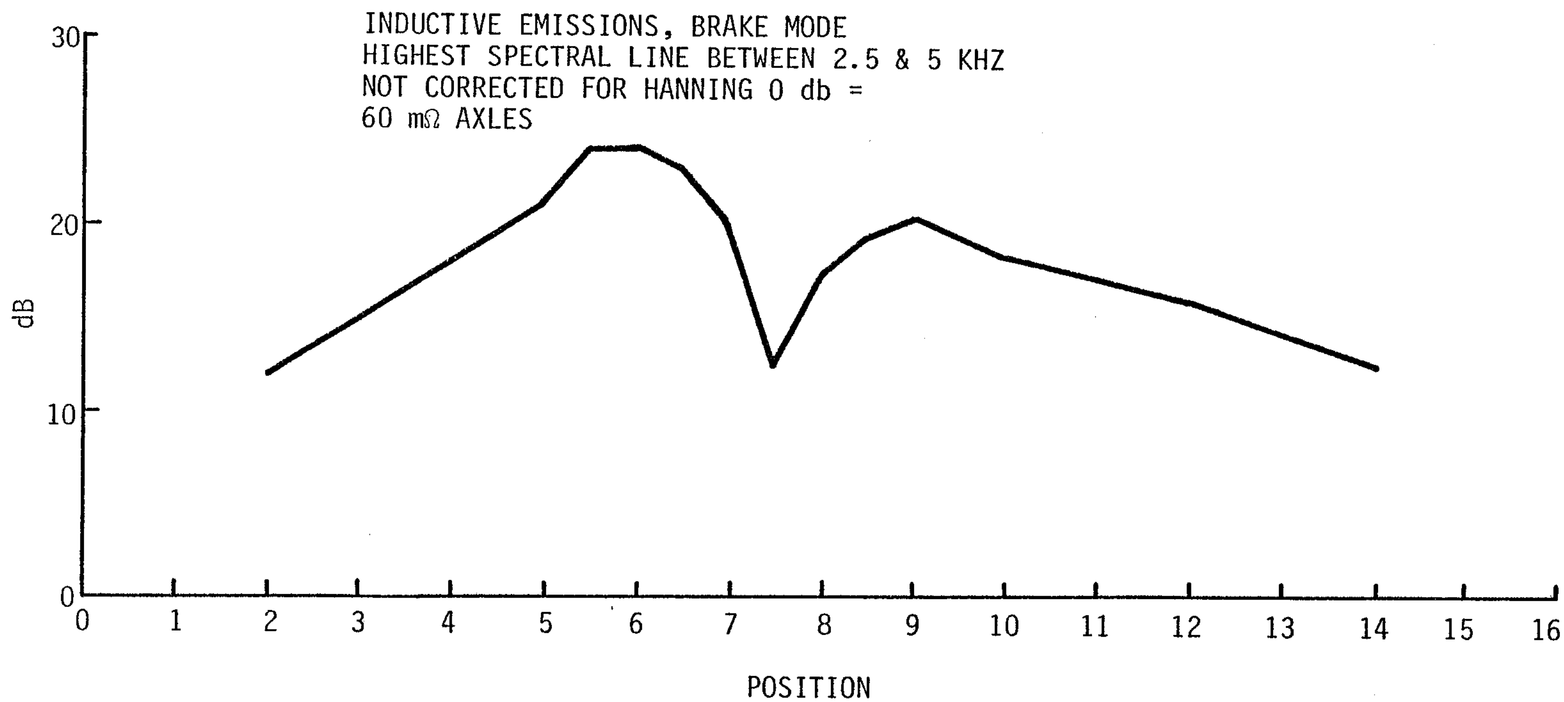
NOTE 2

NOTE 3

NOTE 4

NOTE: DISREGARD SPURIOUS MEASUREMENT RESPONSE AT ZERO Hz





INDUCTIVE EMISSIONS, BRAKE MODE
HIGHEST SPECTRAL LINE BETWEEN 2.5 & 5 KHZ
NOT CORRECTED FOR HANNING 0 db =
60 mΩ AXLES
30
20
10
0
dB
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
POSITION