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of Transportation
**Urban Mass
Transportation
Administration**

The UMTA Rail Transit EMI/EMC Program:
An Overview and Summary

Transportation Systems Center
Cambridge, MA 02142

February 1987
Final Report

UMTA Technical Assistance Program

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16. Abstract

A history of the UMTA Rail Transit Electromagnetic Interference and Electromagnetic Compatibility (EMI/EMC) program, together with a listing of significant achievements over the life of the program, is presented. This is the lead volume of a nine volume set dealing with the theory, problems and solutions of electromagnetic incompatibility between solid state power systems and rail transit signaling systems. Specifics of conductive, inductive and radiated interference theory, data, tests and suggested test procedures are described in detail in the remaining volumes of this set.

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PREFACE

Compatibility between rail transit signaling systems and vehicle subsystems has been an industry concern since the introduction of solid state power control equipment to rail transit. Initial compatibility problems between signal circuits and chopper propulsion systems led to the formation of the Electromagnetic Interference and Compatibility (EMI/EMC) Technical Working Group (TWG) consisting of senior technical personnel from Government, rail signal and propulsion system suppliers and industry consultants. The TWG process assembled some of the Nation's foremost talents to find solutions to these pressing problems by first analyzing the mechanisms by which interference could be coupled to the signaling system, modeling these coupling mechanisms, developing test procedures to measure the emissions from vehicle systems, and finally, suggesting design and/or retrofit techniques to eliminate or mitigate the interference. The UMTA EMI/EMC program was a highly successful element of the UMTA Technical Assistance Program. Test procedures developed in the EMI/EMC program are now available to the industry through the National Technical Information Service (NTIS) and will soon be available as Institute of Electrical and Electronic Engineers (IEEE) standards.

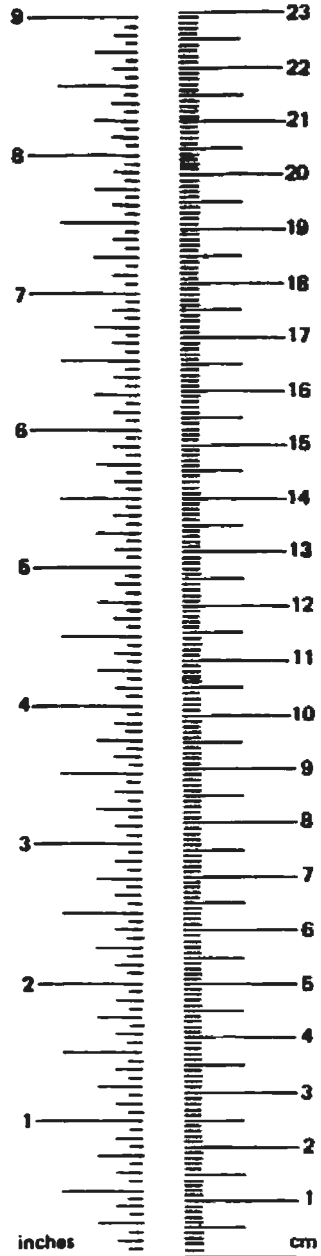
None of the successes of the EMI/EMC program would have been possible without the efforts and co-operation of the many individuals who brought their talents to the solution of the problems. The UMTA Office of Technical Assistance is grateful to the many technical experts who participated in the activities of the TWG, to their parent firms for providing the manpower and resources for the program and to the transit authorities who contributed time and facilities to help develop and validate the theories and test procedures described in separate reports listed in Section 9.3 of this document.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

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

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



Approximate Conversions from Metric Measures

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

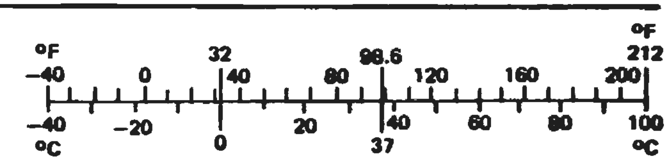


TABLE OF CONTENTS

LIST OF FIGURES

1. BACKGROUND

From the early 1900s until the mid-1970s, subway (rapid transit) vehicles used rheostatic motor controllers, called cam controllers, to control the operation of vehicle propulsion motors. In the mid-1970s, solid-state motor controllers called "choppers" were introduced in several transit systems. The choppers provided smoother operation, more efficient energy usage through regeneration, and lower maintenance, since they have fewer moving parts than cam controllers.

At one transit system, a supplier of propulsion controllers conducted tests of their chopper and found that electromagnetic interference (EMI) caused problems with the existing audio frequency signaling system, exposing the system to potential safety and reliability problems. In an attempt to achieve electromagnetic compatibility (EMC), the supplier tried shielding the chopper with thick metal sheets to contain the EMI emanations. However, the weight of the sheets and their hardware attachment created unacceptable maintenance problems.

At this point, the Urban Mass Transportation Administration (UMTA) initiated the EMI/EMC program to thoroughly investigate rail transit EMI and to provide technically sound procedures for assuring the electromagnetic compatibility of rail transit electronic systems. UMTA, through the Transportation Systems Center, also undertook an extensive review of existing EMI/EMC standards developed in other industries to ascertain their applicability to mitigating rail transit EMI. Under the EMI/EMC program, a technical working group (TWG) consisting of electronics specialists from UMTA, TSC, and the U.S. and Canadian signaling and propulsion suppliers was formed. In the late 1970s, the TWG initially set out to define how EMI endangered the safety and reliability of transit systems.

The major EMI/EMC program elements included the following:

- o Description and definition of the operation of power-frequency and audio-frequency signaling systems.
- o Definition of EMI impact, and description of EMI in terms of three interference types: Inductive, Conductive, and Radiated.
- o Description of approaches to manage the impact of EMI.
- o Development of theory and modeling of Inductive and Conductive EMI.
- o Development and validation of Suggested Test Procedures.
- o Application of the theory and test procedures to the Subsystems Technology Application to Rail Systems (STARS) AC propulsion project.

Work under the EMI/EMC program resulted in development of extensive knowledge in audio-frequency signaling system EMI, inductive and conductive EMI coupling and radiated EMI. Results of the program are presented in this overview to illustrate how chopper-controlled rail vehicles operating with an audio-frequency signaling system can cause false signals. An overview of radiated EMI, the third potential harmful EMI source, is also presented.

The knowledge acquired in the EMI/EMC program was compiled into a series of EMI test procedures (listed in Section 9.3) which were validated and approved by the signaling/propulsion suppliers and the rail transit authorities. These are technically sound procedures which have been applied to evaluate and solve EMI reliability and safety problems encountered by many U.S. transit authorities in recent years. The procedures are now available to the transit industry (through the NTIS, Springfield, Virginia) for their use in planning, designing, procuring and testing new systems; diagnosing/solving EMI problems on operational systems and improving the maintenance of electrical/electronic equipment. This program was successful in solving many electromagnetic compatibility problems faced by rail transit operators in the 1970s and 1980s.

2. OPERATION OF SIGNALING SYSTEMS

2.1 AUDIO-FREQUENCY SIGNALING SYSTEMS

Audio-frequency track circuits can be understood readily by examining the three major elements of the signaling system, as shown in Figure 1: the transmitter, the receiver and the rails electrically interconnecting them. The physical device that connects the running rails to the transmitter or receiver is the Impedance Bond. "Audio-frequency" refers to frequencies in the range of a few hundred to a few thousand Hertz.* In track circuits, an audio-frequency tone is modulated (turned on and off) at a selected "code rate." The result is an electrical current generated at audio frequency that pulsates at a selected code rate. A typical signal frequency is 1960 Hz and a typical code rate is 3 Hz. The receiver would be designed to be most sensitive to 1960 Hz signals. This frequency selectivity reduces the possibility that stray signals at other frequencies would pass through the first receiver circuit and cause false signaling. Further protection can be provided by code rate selectivity. In such a scheme, any tone operating near the receiver's design frequency would pass through the receiver to a decoder, which would be designed to react only to a code rate of 3 Hz. Thus the receiver would not react to false signals.

The section of running rail between the transmitter and the receiver bonds is defined as a block, as shown in Figure 1. When this system is in operation, a relay operated by the receiver will remain energized (picked) as long as the rate-coded tone is reaching the receiver. When a train enters this block, the wheel-axle sets serve as short circuits across the running rails between the transmitter and the receiver, and the signal can no longer reach the receiver.

*Hertz: The number of cycles per second -- abbrev. Hz.

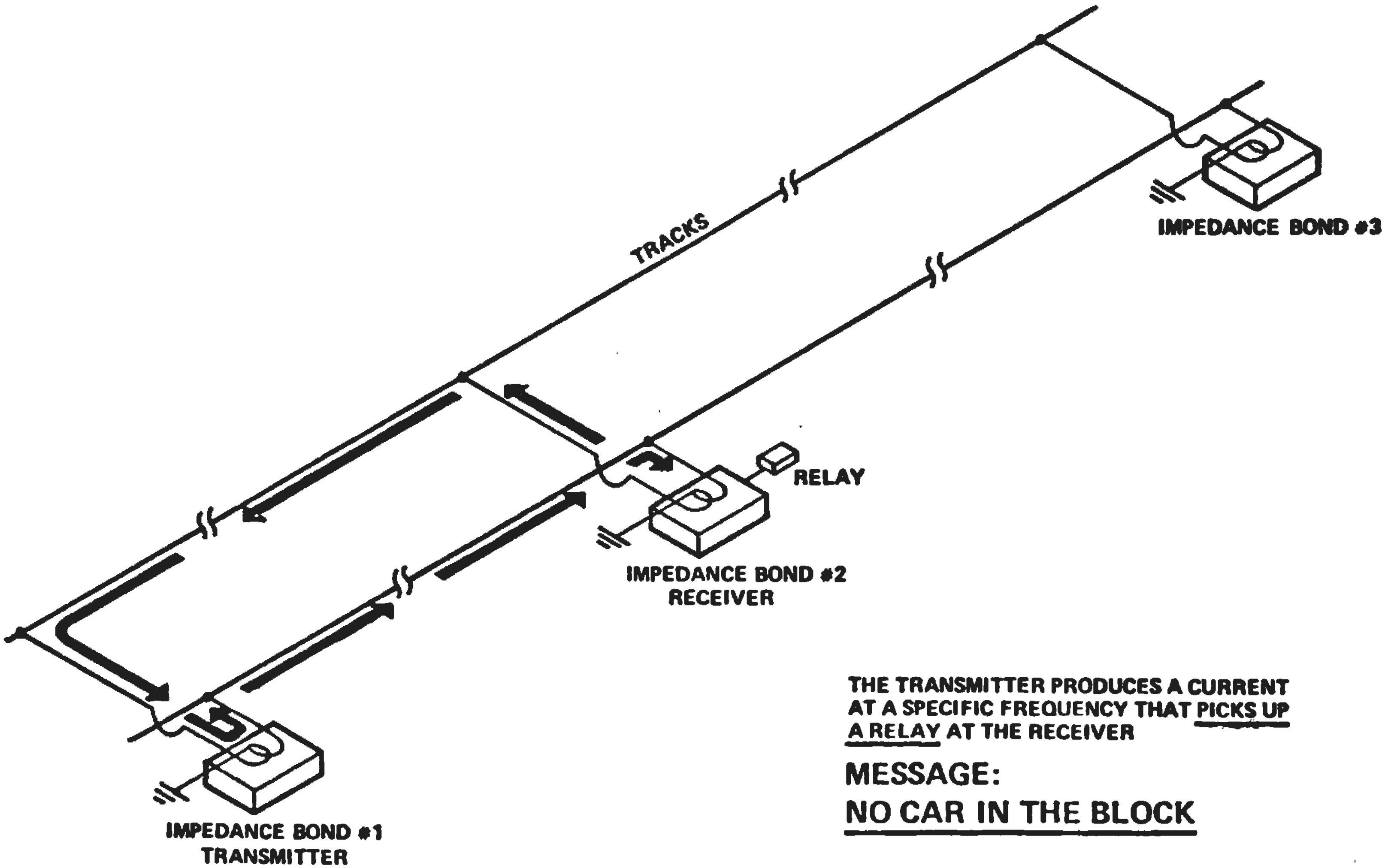


FIGURE 1. TRACK OCCUPANCY SIGNAL SYSTEM - SIMPLIFIED VERSION - NO TRAIN IN THE OCCUPANCY BLOCK

When this occurs, the receiver relay will lose current and be deenergized (dropped) as shown in Figure 2. Some contacts on the relay can be used to turn signal aspect lights on or off. Other contacts can be used to operate other electrical equipment at remote locations, such as cab signals in trains or status indicators at Central Control.

Adjacent blocks are delineated physically by the impedance bonds that transmit and receive signals at specific carrier frequencies. In a given signaling system, 3 to 8 signaling carrier frequencies are used with carrier frequency varying cyclically from block to block. The impedance bonds also transmit control signals to trains. Train signal currents in the rails are sensed by coils (antennas) mounted in front of the leading axles of trains, a few inches above the running rails.

The newer rapid transit signaling systems use audio-frequency track circuits, which are more adaptable for automatic train control and continuous cab signaling. These circuits improve operations by allowing higher average train speeds. Audio-frequency circuits also are used on track made up of continuous welded rail, which provides a smoother ride and requires less maintenance and lower installation costs than the older power-frequency track circuits described in Section 2.2.

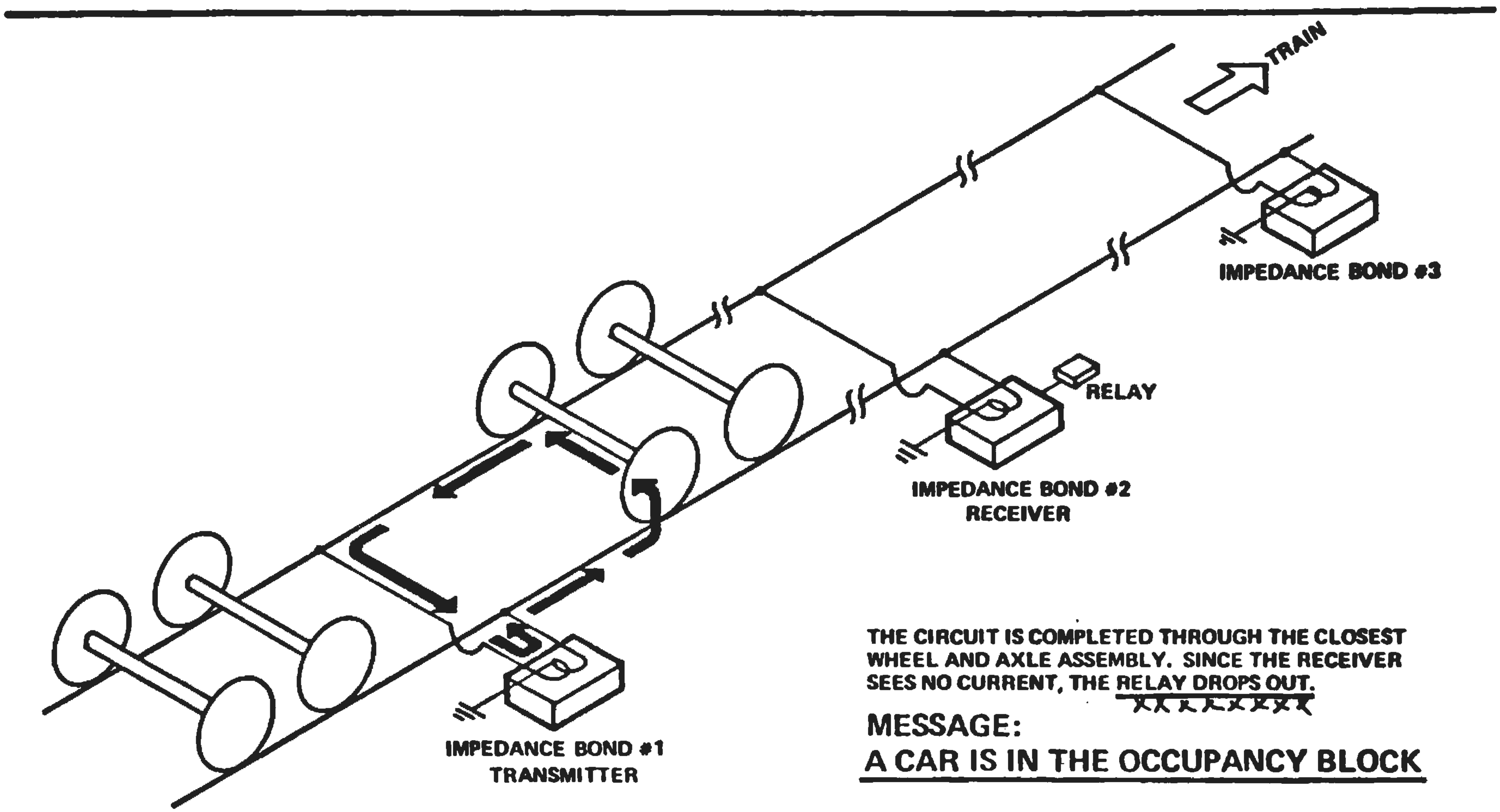


FIGURE 2. TRACK OCCUPANCY SIGNAL SYSTEM - SIMPLIFIED VERSION - TRAIN IN THE OCCUPANCY BLOCK

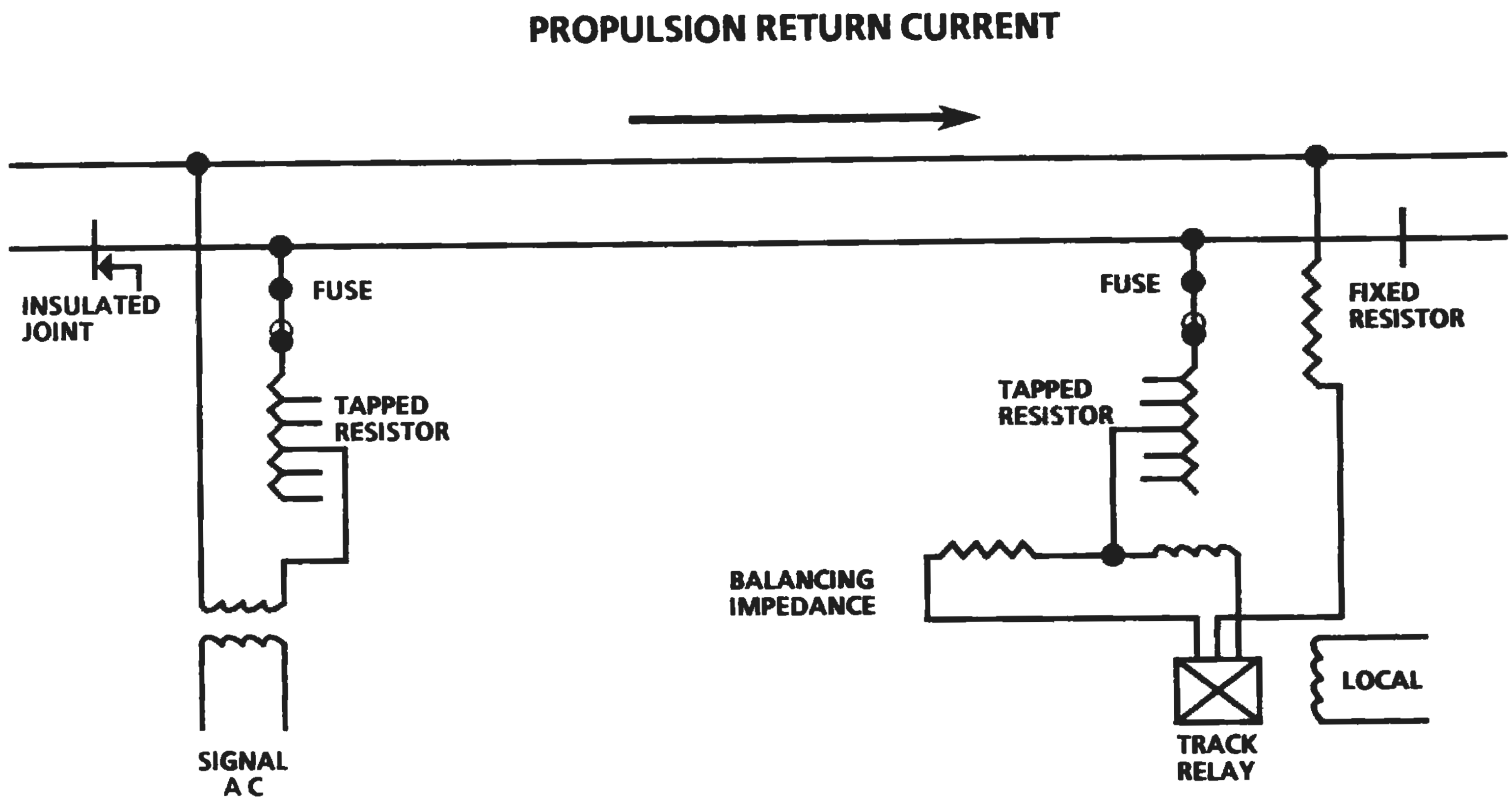
2.2 POWER-FREQUENCY SIGNALING SYSTEMS

Track circuits operating in the frequency range from 25 Hz to 300 Hz are referred to as power-frequency track circuits. Power-frequency track circuits were developed concurrently with the growth of DC electric propulsion and have been in use for many decades. Power-frequency circuits in use today are mostly 60 Hz circuits, but some 25 Hz circuits still can be found in older systems.

Two distinct configurations for power-frequency circuits are single-rail and double-rail. Single-rail circuits employ one of the running rails as a continuous rail for propulsion return currents. The second running rail has insulated joints that define the blocks. Figure 3 illustrates a typical single-rail track circuit. In double-rail circuits, both running rails contain insulated joints defining the block. Figure 4 illustrates a typical double-rail track circuit.

Functionally, these track circuits are very similar. Power-frequency current is applied to the running rails at the transmitting end of the block. The running rails, acting as the signal path, carry the current to a relay at the receiving end of the block. As long as the current flows from transmitter to receiver, the relay remains energized and the wayside aspect signal remains green. When a train enters the block and is between the relay and the current source, the wheels and axle of the train shunt (short circuit) the signal current, preventing it from reaching the relay. The relay, now de-energized, drops, opening the contacts that energized the green aspect light and closing contacts that energize the red aspect light.

Most power-frequency circuits in use today utilize dual-element vane relays. Such relays operate in the following manner: Power to operate a relay comes from two sources. The first source is local current, provided directly



NOTE: BALANCING IMPEDANCE IS USED TO REDUCE THE EFFECT OF ANY PROPULSION RETURN CURRENTS ON THE RELAY COIL.

FIGURE 3. SIMPLIFIED SINGLE-RAIL TRACK CIRCUIT

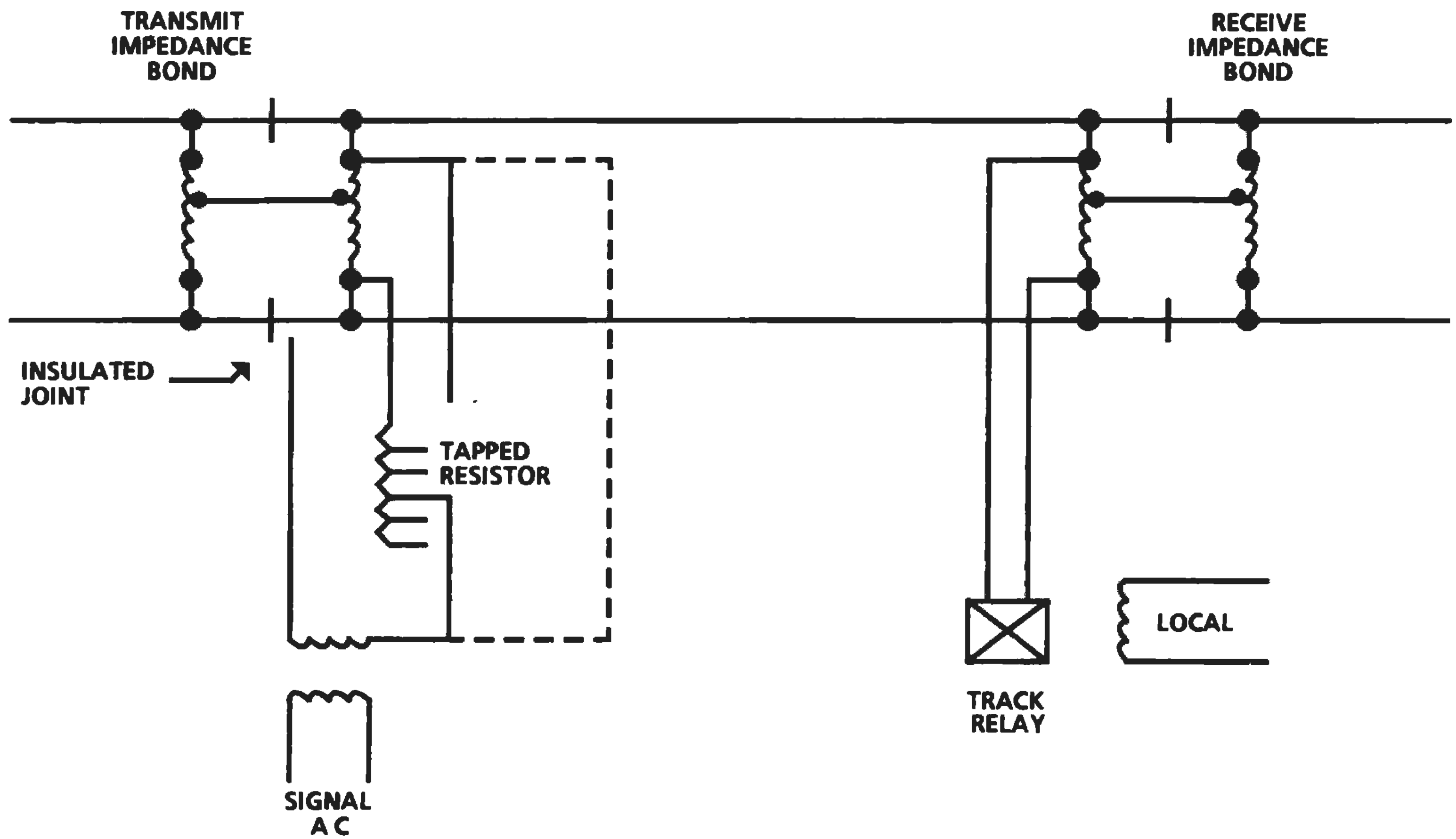


FIGURE 4. SIMPLIFIED DOUBLE-RAIL TRACK CIRCUIT

from the primary AC supply. The second source of current is the signal current, provided from the primary AC supply, but transmitted through the running rails from the end of the block. The signal current must be in proper phase with the local current to pick the relay. If either the local or track current is not present, because the wheel-axle sets of a train have shunted the current or there is a power or equipment failure, then the relay is de-energized and the signaling system fails in the safe mode, i.e., indicating that the block is occupied by a train.

Some relative advantages and disadvantages of power-frequency track circuits and audio-frequency track circuits are as follows: Power-frequency track circuits permit longer blocks, since rail impedance and signal attenuation is higher at audio frequencies than at power frequencies. However, power-frequency track circuits require insulated joints that must be maintained. Therefore, modern welded rail must be cut and insulated at the end of each block when power-frequency signaling is used. On the other hand, audio-frequency track circuits can take advantage of welded rails which provide a smoother and quieter ride. They also lend themselves more readily to use of continuous cab signaling and automatic train control and microprocessor control; thus, they are the choice for new or rehabilitated signal systems.

3. EMI THEORY AND MODELING ACTIVITY

3.1 SOURCES OF EMI

Electromagnetic Interference (EMI) is the result of unwanted electrical energy disrupting the normal operation of an electronic or electrical system. In rail transit, the sources of EMI can be emanations from rail transit propulsion or communication systems; or they may result from faulty operation of motors, generators or other electrically powered devices.

If unwanted electrical signals find their way into the running rails, and if these signals happen to fall at or near the signal frequency and are of sufficient strength, they can interfere with the proper operation of the signaling system. On modern transit vehicles, there are many potential sources of interfering signals that could be coupled into the running rails. Almost any high-current switching device can create EMI, e.g., solid-state chopper propulsion control, solid-state inverters, or traction power substations.

Interfering emissions and the methods through which they are coupled into electrical circuits have been analyzed theoretically. The theoretical examination of emissions has defined the different coupling mechanisms that are referred to throughout this document. These coupling mechanisms are Conductive, Inductive and Radiated. Conductive and inductive coupling are the two primary mechanisms by which EMI is coupled into the running rails.

Based on the theories of the three coupling mechanisms, analytical models have been developed and applied to determine the magnitude of EMI that can be expected to be present in specific operating systems. This modeling has permitted evaluation of the potential for interference presented by these unwanted signal sources. Development of theory and models was the first step toward understanding the effect of EMI on rail transit signaling systems. It has been found that both inductive and conductive EMI can have a serious impact on rail transit systems, while radiated EMI generally may impact radio communication systems both within the transit system and at the wayside.

3.2 INDUCTIVELY COUPLED EMI

When a vehicle is directly over the receiving impedance bond, the signal current that would be received by the bond is shunted (short circuited) by the axles of the vehicle, causing the track relay to be de-energized (dropped). However, potentially interfering signals from equipment mounted under the vehicle, can be magnetically coupled into the loop formed by the rails, axle and bond cables, and cause EMI voltage to appear between the track terminals of the impedance bond (see Figure 5). Inductive interference is evidenced by abnormally high levels of voltage measured from rail to rail at locations under the vehicle. These magnetically induced signals can exist throughout the frequency range typically used for audio frequency signaling. If any one of these EMI signals falls within the selected frequency of the signal receiver then the track relay may be energized (picked) and cause a false "block clear," signal to appear. This can create a safety problem since a following train could then enter an already occupied block.

3.3 CONDUCTIVELY COUPLED EMI

Interfering signals produced by traction power substations and electrical equipment on vehicles can be conducted directly into the third rail which supplies electrical power to the train. The EMI signal currents flow back through the running rails. These signals can have significant strength in the

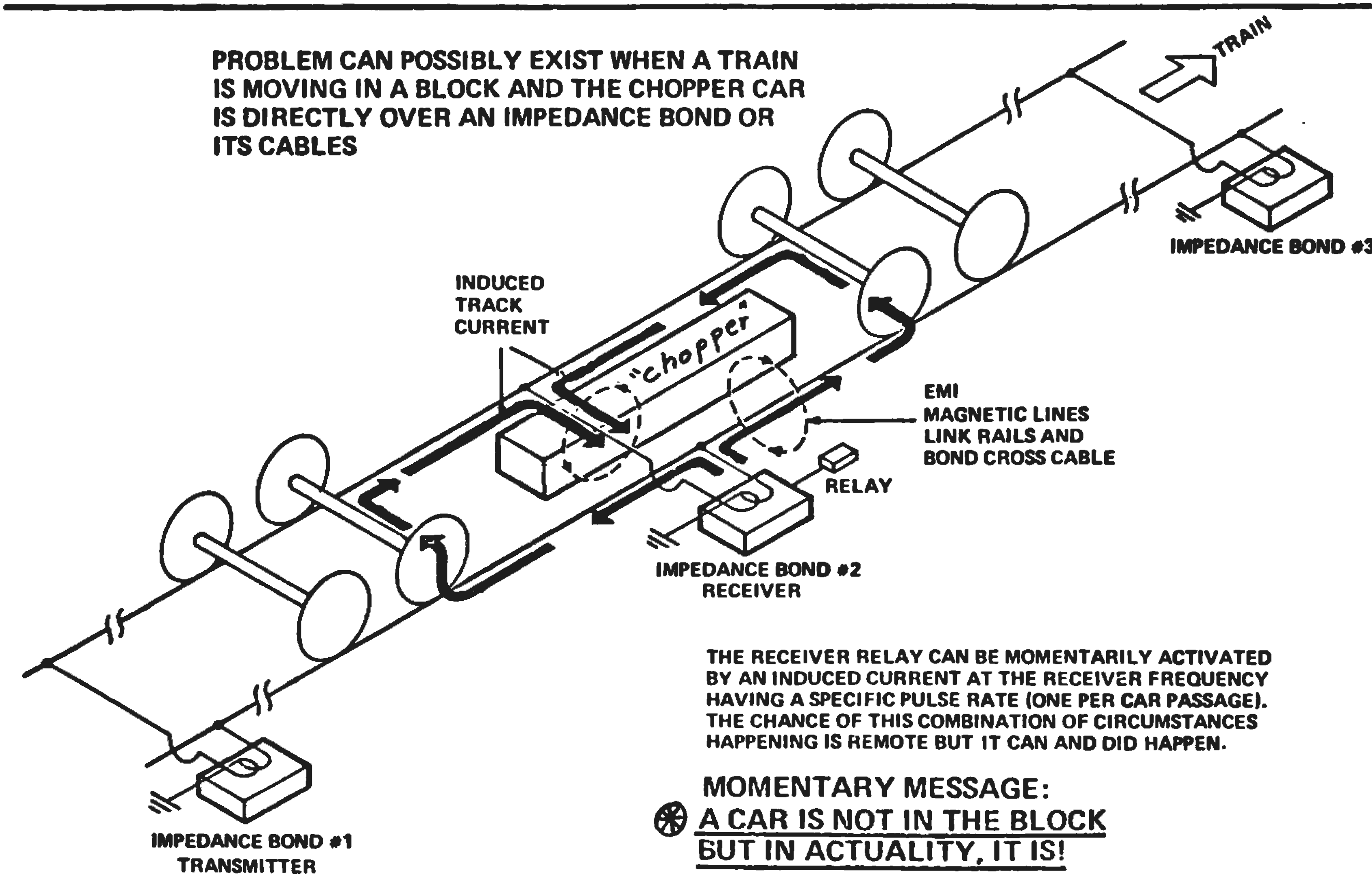


FIGURE 5. RAIL TRANSIT INDUCTIVE INTERFERENCE

audio frequency range. If EMI currents are divided equally between the running rails, no conductive interference occurs. However, this is not the usual case. Magnetic coupling between the third rail and running rails naturally causes unequal current division. In addition, conductive interference can arise from unequal wheel-rail contact resistance or unequal bond-rail connection resistance, which create unbalanced current flow in the running rails.

Conductive EMI is evidenced by strong interfering signals at bond locations ahead of or behind the vehicle, and can cause both false pick-up (block clear indication) of a dropped track relay or false dropping (block occupied indication) of a picked-up track relay.

3.4 RADIATED EMISSIONS

Radiated emissions from rapid transit rail vehicles are a third potential source of EMI. These emissions are much like the unwanted electrical energy that causes static and noise on our radios or "snow" on our television sets. Radio frequency noise, produced by many electrical devices, is radiated through space rather than traveling down rails or wires. Experience has indicated that these emissions are not likely to interfere with rail transit subsystems other than radio communications. The problems caused by radiated emissions from rail transit subsystems are mostly external to the transit system. Interference with AM radio reception near the right-of-way is possible. Potentially, these emissions can interfere with emergency communications such as police and fire radio communications. (See Figure 6.)

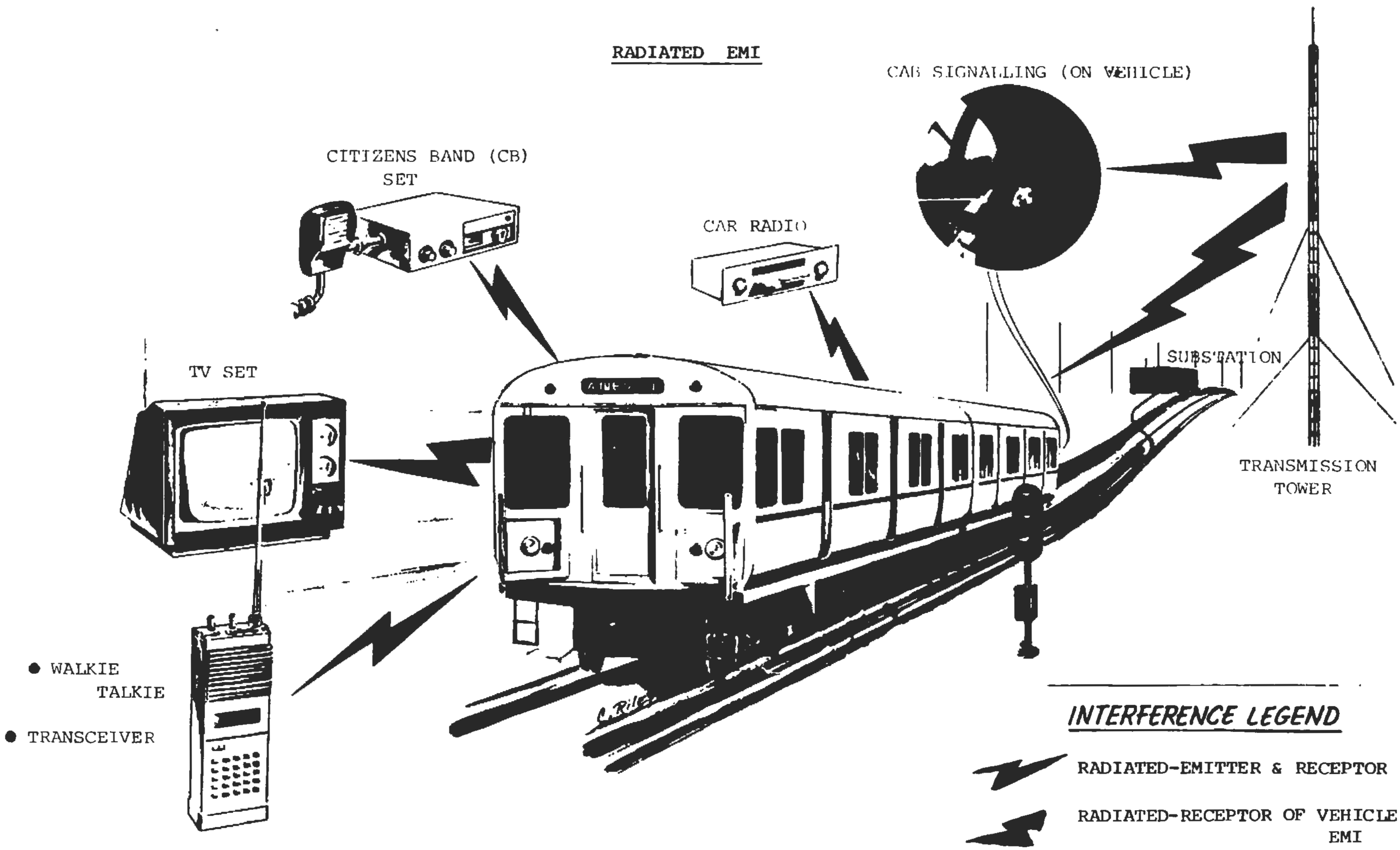


FIGURE 6. RAIL TRANSIT ELECTROMAGNETIC INTERFERENCE

Several EMC standards were examined to determine their applicability to the measurement of radiated emissions from rail rapid transit vehicles. They are:

1. MIL STD 461-462
2. SAE J551F
3. CISPR 2 and 18
4. VDE 871/3.68, 877/1/12.59, 877/2/12.55
5. FCC DOCKETS 20780 and 80284
6. ANSI C63.4
7. IEEE STD 302-1969

These standards were reviewed by the National Bureau of Standards (NBSIR 82-1669) to determine their applicability to measuring EMI from a moving electrically powered rail vehicle. It was concluded that none of these standards can be applied directly to assess EMI on a rail vehicle for the following reasons:

1. Existing standards only provide for testing stationary objects. Only limited power can be applied to a stationary electrically powered rail vehicle. Electromagnetic radiation usually increases as more power is applied, giving worst-case EMI levels at maximum vehicle acceleration (or deceleration dynamic or for regenerative braking). This requires testing a moving vehicle.
2. Rails are EMI transmission lines and form part of a car-rail radiating structure. None of the existing standards provide for testing vehicles on rails.

MIL-STD-461A contains a chart, "LIMIT FOR BROADBAND EMISSIONS," that must be met by military systems that may emit undesirable radiated energy. This chart is neither a necessary nor a sufficient condition for civil applications under FCC jurisdiction. The FCC criterion is that the vehicle and its equipment shall not cause interference either on board or at wayside. The most important element of this standard is that non-broadcast radiated emissions must not interfere with legal radio communications. If interference occurs, then the FCC can require the source of the interfering emissions to be shut down.

In developing a Suggested Test Procedure for measuring radiated emissions from rail rapid transit vehicles, elements of recognized standards were adopted and/or modified to meet the specific need. In addition, where required, new elements were introduced. The result is a series of validated test procedures that may be applied to the measurement of radiated emissions from a moving rail rapid transit vehicle.

4. DEVELOPMENT AND VALIDATION OF TEST PROCEDURES

Once the inductive and conductive coupling mechanisms and radiated emissions effects were understood, the TWG developed test procedures and methods for data reduction and analysis that then were compiled into the Inductive, Conductive and Radiated EMI Recommended Practices (see Section 9.2 for complete listing).

The development of these Recommended Practices started with analytical modeling of systems to be tested. From these models, preliminary draft Suggested Test Procedures were written. When the drafts had been reviewed and updated by the various members of the TWG, the procedures were taken into the field to cooperating transit authority facilities for validation. This is an iterative process requiring several tests. Validation of the Test Procedures was completed at a number of locations including: Washington DC, San Francisco, Atlanta, Miami, Boston, Baltimore, Buffalo, Cleveland. When the Suggested Test Procedures were finally revised, validated and reviewed, they were handed off to the Institute of Electrical and Electronics Engineers (IEEE) as draft Recommended Practices.

The UMTA Suggested Test Procedures and/or the IEEE Recommended Procedures are available for use by transit authorities and their consultants as tools for resolving EMI and compatibility concerns.

Transit industry vendors apply the Practices as a means of assuring that new subsystems will be compatible with the current operating environment of a transit system. The transit signaling and propulsion suppliers have been applying EMI mitigation techniques as well as frequency management methods to the design of new propulsion and signaling systems. Test procedures developed and approved by the members of the TWG were applied to the measurement and quantification of emissions and signaling system susceptibility.

5. EMI MANAGEMENT

5.1 EMI MANAGEMENT TECHNIQUES

As noted in Section 1, in 1979 a supplier of propulsion control systems conducted tests at a transit property and found that electromagnetic emissions from their chopper caused the signaling system to malfunction in modes that could cause safety and operational reliability problems. Their initial attempts to eliminate the interfering emissions involved shielding the propulsion control system. To reduce emissions to an acceptable level, the shielding was fabricated from thick aluminum sheets that were bolted to the controller housing and other components of the system. The weight of the shielding and the number of bolts sealing and securing the shielding in place created an unacceptably difficult maintenance problem. A different approach was required.

Through the initial investigations conducted under the EMI/EMC program, three basic methods emerged for reducing the possibility of these energy sources interfering with a signaling system. The first method involves frequency management techniques. In this method, the frequencies of the electrical energy sources (e.g., propulsion chopper control) are selected so that they do not generate harmonics near any of the signaling carrier frequencies. Conversely, the signal frequencies may be selected to avoid harmonic frequencies of the chopper. The second method of control involves reduction of the level of EMI from the circuit components, thus reducing the magnitude of unwanted signals coupled into the running rails. This procedure requires careful selection of the design, location, and orientation under the vehicle of the circuit components that generate the unwanted induced EMI. The magnitude of conducted EMI is controlled by the design of the propulsion system input filter.

The third control technique involves the design and use of more sophisticated track circuit receivers that are capable of discriminating between true track circuit signals and EMI. Three different approaches have been taken to design of more sophisticated audio-frequency track circuits by three different U.S. manufacturers. Westinghouse Electric's track circuits used at BART employ frequency-shift keyed (FSK) track signals with multi-bit digitally encoded "words" whose bit patterns carry train speed information. Only reception of a valid code word by a track receiver will lift a track relay. The probability that an interfering signal would do so is exceedingly remote.

GRS developed a dual code rate system employed first at MARTA. In their scheme, the audio-frequency track carrier signal and train carrier signals are square-wave modulated at separate rates. The track signal is modulated at a fixed rate of approximately 1 Hz, and the track receiver has a narrow-band filter that looks selectively for the specific modulation frequency.

Union Switch & Signal developed a technique, first employed at Baltimore and Miami, in which the code rate signal recovered at the receiving end of a track circuit is compared with the specific code rate waveform transmitted from the transmitting end.

The Westinghouse technique, developed first, and the GRS and US&S techniques that followed all solve the safety problem associated with spurious signals picking up a dropped track relay in an occupied block.

To date, radiated emissions have not caused EMI problems adversely affecting signaling systems. However, it is important to determine that they do not cause external radios, TVs, computers, or other communication systems to malfunction.

5.2 A CASE HISTORY

To illustrate the need for careful EMI management, we can look briefly at a recent case history from a major transit authority.

The authority had ordered new transit vehicles with chopper controlled propulsion systems. EMI testing of this prototype propulsion system was conducted by the propulsion vendor in his laboratory and with the prototype propulsion system mounted on a flatcar and towed around the transit authority system. The testing indicated that emissions from the completed vehicle would be well within the specifications.

Frequency management methods had been applied to chopper design; and chopper harmonic frequencies were well removed from signaling frequencies. Under the transient conditions of startup, EMI was generated at frequencies between the normal harmonics and near signaling frequencies. However, specification of the design, placement, and wiring of electrical components that generated EMI assured that EMI levels would not affect signaling.

When the first new vehicles were delivered to the transit authority, they were subjected to EMI tests. It quickly was discovered that chopper harmonic EMI levels of the production vehicles were significantly higher than those of the prototypes, as were the transient EMI levels at frequencies between the normal chopper harmonics and near the signaling frequencies. Normal operation of the signaling system most likely would have been affected.

It was discovered that a number of critical propulsion system components, mounted under the vehicle, had been moved several inches from the locations established in the laboratory. Certain induction coils that were to be wired so their stray magnetic fluxes cancelled, were actually wired so their fluxes added.

The wiring errors were corrected. However, the equipment mounting locations could not easily be changed. Weeks of intensive EMI testing and modifications were required to reduce EMI emissions to specification levels. Changes included modification of chopper operation under transient startup conditions to reduce interference at signaling frequencies.

Exercising careful control over the design, testing, fabrication, installation and inspection of transit equipment can help avoid expensive modifications and delays in delivery.

6. EMI/EMC PROGRAM TEST EQUIPMENT

The EMI/EMC Program maintains an extensive array of specialized instrumentation for the purpose of laboratory and field testing. The equipment is capable of measuring and recording inductive, conductive and radiated emissions of transit subsystems. Additional equipment is available for the reduction and analysis of data. This equipment is available to a transit authority for use by authority personnel and their consultants on a loan basis.

Interested parties should write to the following organizations:

Office of Technical Assistance
Urban Mass Transportation Administration (UMTA)
U.S. Department of Transportation
400-7th Street, S.W.
Washington D.C 20590
and
Rail Transit EMI/EMC Program Manager
Infrastructure Systems and Technology Division
Transportation Systems Center
Kendall Square
Cambridge, MA 02142

6.1 AVAILABLE TEST EQUIPMENT

Some of the unique test equipment available for loan from UMTA/TSC is listed below.

1. Liaisons Electroniques Mechaniques, S.A. (LEM) Transfoshunts for use in sensing ripple currents during emissions testing of transit vehicles and substations.
2. GENRAD 2512 Spectrum Analyzer with a range from DC to 100 KHz.
3. Rockland 5100 Frequency Synthesizer for calibration of test set-up.
4. Digital (VCR) tape recorder, 2 tracks plus voice, capable of recording signals from DC to 20 KHz, flat within approximately .2 dB.
5. Tape recorder, 4 track, B&K, battery and line operated.

6. Dual Krohm-Hite variable band filters.
7. Various pre-amplifiers, filters, line drivers, voltage dividers and other specialized test equipment designed and assembled by TSC.
8. Hewlett-Packard 9845 Controller
9. Hewlett-Packard 8568A Spectrum Analyzer
10. Antennas: 14KHz-30MHz H field sensor Loop Antenna
    14KHz-30MHz E field sensor Rod Antenna
    30MHz-200MHz E field sensor Biconical Antenna
    200MHz-1GHz E field sensor Log Periodic Antenna
11. Hewlett-Packard High Speed Plotter.

7. AC PROPULSION

In August 1979, DOT approved the AC propulsion (ACP) project as a high priority element of the Subsystem Technology Application for Rail Systems (STARS) program. AC traction motors promise lower maintenance, more efficient energy usage, and smoother performance than the DC motors which have been used for decades by rail transit operators. In March 1982, two contractors (Garrett & Westinghouse) were funded by UMTA to design, build and laboratory test their versions of an ACP system (Phase I of ACP project). In October 1983, the Garrett Corporation completed their laboratory tests, and in March 1984 UMTA selected Garrett to continue into the Phase II vehicle installation and system test program. Garrett installed ACP systems on two NYCTA R-44 vehicles.

At the start of the ACP project, UMTA realized that a major consideration in operating the ACP-equipped R-44 cars at the NYCTA will be the electromagnetic compatibility of the propulsion system with the existing signaling and other wayside systems. As a result, under the EMI/EMC program, a laboratory and NYCTA field test program was initiated to measure the susceptibility of NYCTA power-frequency signaling systems to ACP systems EMI. These tests produced plots of the EMI susceptibility envelopes of each of the 11 NYCTA track circuits which would be operating with the ACP-equipped R-44 vehicles. In addition, tests were conducted to develop data that could be used in the construction of analytical models of rail transit signaling systems. These models are required for the analysis of potential interference to signaling caused by AC propulsion systems. They will permit the development of EMI countermeasures that will assure electromagnetic compatibility. A detailed technical description of these tests is given in the report, "Laboratory and Field Testing of NYCTA Power Frequency Track Circuits," (see Section 14).

In late 1986, a comprehensive EMI/EMC test program of the ACP system on the R-44 cars was conducted at the Morrison Knudsen (MK) test track in Hornell, NY. As part of the overall ACP system evaluation, the test program included system testing with power frequency track circuits used on the NYCTA, and measurements of radiated emissions. These tests at the MK test track were followed with testing on the NYCTA Sea Beach Line test track.

8. MICROPROCESSOR TECHNOLOGY

Microprocessors are appearing in more and more applications in both industrial and commercial systems. They are applied whenever a digital control process can improve the performance, safety or reliability of a device or subsystem. We now find microprocessors in refrigerators, dishwashers, stereo tape decks, automobile ignition systems and automobile fuel systems as well as in systems that control industrial processes. They are used both as stand-alone controllers and in concert with larger computers. Microprocessors are used in rail transit systems including ATC, propulsion and braking, and door systems.

As microprocessors become smaller and faster, they are designed to operate at lower voltages which tend to make them more susceptible to external EMI. The high-frequency switching transients produced by microprocessor-based systems can also become a source of radiated EMI that could effect other nearby subsystems.

Microprocessor controls and other developments should be monitored to assure that safe and reliable operation of American rail rapid transit systems will continue.

9. CONCLUSIONS AND RECOMMENDATIONS

9.1 CONCLUSIONS

The EMI/EMC program was a highly successful element of the UMTA Technical Assistance program. It was completed through the dedicated cooperation between signaling/propulsion suppliers, government and the rail transit authorities that provided the expertise and resources to develop the test procedures. Since 1979, the EMI program has provided engineering guidance to transit authorities in using these procedures to solve EMI problems at WMATA (Washington, DC), MTA/MD (Baltimore), DCTA (Miami), MBTA (Boston), NYCTA (New York), GCRTA (Cleveland), NFTA (Buffalo) and others. These efforts have saved the authorities well over $50 million by improving safety, reliability, maintenance and reducing retrofit and revenue service disruption costs.

The EMI/EMC program produced the EMI test procedures which are now available to the transit industry through the National Technical Information Service (NTIS). These procedures have been accepted by major suppliers of rail transit signaling/propulsion subsystems and rail transit authorities. The procedures can be used to evaluate and solve electromagnetic compatibility problems on existing or proposed rail systems. They may also allow signaling and propulsion suppliers to demonstrate that their subsystems comply with EMC specifications prepared by the procuring transit authority.

The inductive and conductive test procedures are being combined into the Institute of Electrical and Electronic Engineers (IEEE) Standard 985, an IEEE recommended practice for rail transit electromagnetic compatibility of vehicular electrical/electronic subsystems. The proposed Standard 985 is currently undergoing the IEEE review process. The IEEE will update/revise Standard 985 as new and improved EMI mitigation techniques are developed.

9.2 RECOMMENDATIONS

9.2.1 Early Recognition of Potential Problems

The development of EMI test procedures involved extensive field testing to validate the electromagnetic compatibility of new types and different combinations of equipment. This has increased the industry's awareness of potential EMI problems arising whenever changes in hardware occur. It is therefore recommended that potential EMI problems be considered early in the planning, design and procurement phases of a system to avoid future costly redesigns or retrofits, adverse safety or reliability problems and loss of system revenues.

9.2.2 Specification of EMI Susceptibility Levels

Transit authorities purchasing new equipment should identify levels of interference susceptibility and specific margins to be achieved between all electrical and electronic subsystem interfaces. The control of frequencies and emitted amplitudes constitute a major element of assuring system electromagnetic compatibility. In addition, the specific test procedures to be applied in verifying that the purchased equipment meets EMC specifications should be identified as part of System Test and Acceptance Criteria.

9.2.3 Ongoing Testing as a Maintenance Tool

Consideration of potential electromagnetic interference by transit authorities purchasing new equipment should not stop with the procurement of a compatible subsystem. They should be aware that any device placed into service will require certain preventive maintenance for it to remain productive and trouble free. Transit systems present a harsh environment. Electro-mechanical, electrical and electronic subsystems are subject to deterioration due to the environment as well as normal aging.

A procedure to periodically measure the emissions from vehicular subsystems should be established. These periodic measurements may be compared to system emissions specifications , and any significant variations should trigger further examination of the subsystem.

It is possible to use periodically collected data to plot trends in the deterioration of a subsystem and to alert the maintenance department to potential EMI before it becomes a concern of safety or operational reliability. Measurement of emissions may also be of value after maintenance has been performed on electrical or electronic vehicular subsystems.

Additional benefits from periodic testing for emissions may be the ability to identify a weak component before it fails. This allows preventive maintenance to reduce the risk of failure during revenue service.

There are many methods for measuring electromagnetic emissions and subsystem susceptibility. The Recommended Practices (Suggested Test Procedures) identified in the following series of eight documents are intended as tools to be applied by transit authorities in assuring successful system integration of new subsystems. These procedures have been developed and validated by the UMTA EMI/EMC program with the cooperation of the major vendors of rail transit subsystems. Therefore, they will allow a signaling vendor and propulsion vendor to utilize procedures acceptable to both parties, in the laboratory and in the field, for collecting the data required to demonstrate that their equipment performs to EMC specifications.

9.3 LIST OF SUGGESTED TEST PROCEDURES AND TEST REPORTS FOR EMI PROGRAM

The following eight documents describe, in considerable technical detail, the Recommended Practices and the NYCTA ACP laboratory and field tests:

*CONDUCTIVE INTERFERENCE IN RAPID TRANSIT SIGNALLING SYSTEMS;

UMTA-MA-06-0153-85-5 - VOLUME I: Theory and Data

UMTA-MA-06-0153-85-6 - VOLUME II: Suggested Test Procedures

* INDUCTIVE INTERFERENCE IN RAPID TRANSIT SIGNALLING SYSTEMS;

UMTA-MA-06-0153-85-7 - VOLUME I: Theory and Background

UMTA-MA-06-0153-85-8 - VOLUME II: Suggested Test Procedures

UMTA-MA-06-0153-85-9 - VOLUME III: Data and Test Results

* RADIATED INTERFERENCE IN RAPID TRANSIT SYSTEMS;

UMTA-MA-06-0153-85-10 - VOLUME I: Theory and Data

UMTA-MA-06-0153-85-11 - VOLUME II: Suggested Test Procedures

* LABORATORY AND FIELD TESTING OF NYCTA POWER FREQUENCY TRACK CIRCUITS

UMTA-MA-06-0153-85-12

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