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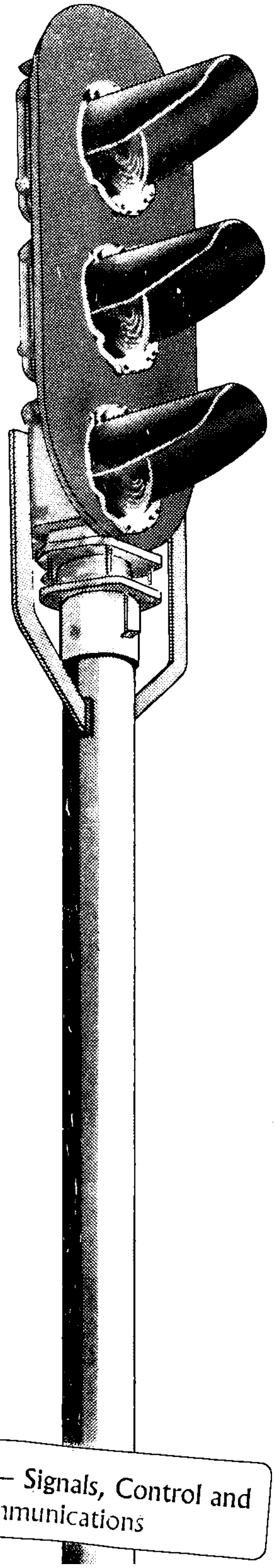

TASK 7
Summary and Final Report

September 1981

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16. Abstract

This report describes the objectives and procedures of the evaluation. It then summarizes the findings contained in each of six task reports. Those published reports are:

Task 1: Assessment of Signal/Control Technology and Literature Review
Task 2: Status of Present Signal/Control Equipment
Task 3: Standardization, Signal Types, Titles
Task 4: Electrical Noise Disturbance
Task 5: Economic Studies
Task 6: Specification Development

The report concludes with an analysis of the electromagnetic environment produced by electrification and proposes what steps should be taken to protect signal/control systems from harmful interference.

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TABLE OF CONTENTS

Section			Page
I	INTRODUCTION		1
II	STUDY PROCEDURES		4
III	TASK FINDINGS		7
	Task 1:	Assessment of Signal/Control Technology and Literature Review	7
	Task 2:	Status of Present Signal/Control Equipment	9
	Task 3:	Standardization, Signal Types, Titles	14
	Task 4:	Electrical Noise Disturbance	18
	Task 5:	Economic Studies	21
	Task 6:	Specification Development	25
IV	SIGNAL CONTROL SYSTEMS AND ELECTRIFICATION		29
	1.	Introduction	29
	2.	Sources of EMI	29
	3.	Effects of Interference on Signal Control Systems	34
	4.	Functional Requirements for EMI Control	37
V	SUMMARY OF PUBLISHED REPORTS		45

Section I

INTRODUCTION

This report summarizes the findings and recommendations of a study of intercity railroad signal and train control technology. It was supported by the Office of Research and Development of the Federal Railroad Administration under Contract No. DOT-FR-4236. The report concludes the program directed at the evaluating signal and control systems for 255 Km/h (160 MPH) maximum-speed passenger train operations on Amtrak intercity routes.

The key criterion of this program was that any candidate system should be based on current, state-of-the-art technology. The basis for this requirement was the need to avoid heavy expenditures in time and money to develop and implement a totally new technology. The broad purpose was to make a worldwide search of present railroad and rail transit signal/control technology to learn if one or more examples could fulfill the basic objective, namely to control and protect passenger trains operating in mixed traffic, up to speeds of 255 Km/h (160 MPH).

A number of other objectives were also considered:

(1) In specific applications, any new system would not necessarily replace an existing system, but complement it. This avoids the need to abandon technologically sound investments.

(2) The system should be fail-safe according to current signaling standards.

(3) A modular design should facilitate adaptation to all possible network configurations and permit direct, plug-in replacement of components without system adjustment.

(4) The system should be compatible with electrification.

Several types of signal systems have been found that exemplify alternative state-of-the-art technologies with characteristics meeting one or more program objectives. From that milestone, the study moved forward to narrow the range of available, basically off-the-shelf technologies to one or more that meets all objectives of the program. In accordance with contract requirements, the study has also set the stage for logical progression of the program into any future evaluation and testing.

The study was divided into seven tasks:

Task 1: Assessment of Signal/Control Technology and Literature Review

Task 2: Status of Present Signal/Control Equipment

Task 3: Standardization, Signal Types, Titles

Task 4: Electrical Noise Disturbance

Task 5: Economic Studies

Task 6: Specification Development

Task 7: Summary and Final Report

This report consists of a description of study procedures, a review of the six basic tasks, and a concluding focus on electromagnetic interference (EMI). There are a number of reasons for the emphasis on EMI:

(1) EMI presents serious obstacles to the adoption of new signal technology such as solid state hardware.

(2) A principal source of railroad EMI is the electric traction power distribution system.

(3) On a worldwide basis, high-speed passenger trains are universally powered by electricity distributed from remote sources.

(4) There is growing recognition of the need for independence from petroleum-based energy sources for both passenger and freight railroad operations.

Section II

STUDY PROCEDURES

Initial activity was concentrated on a review of existing literature. Bulletins of the Railroad Research Information Service (RRIS) were utilized to identify applicable documents in the time period from 1973 to 1979. Other sources of data were identified and utilized, such as the National Technical Information Service (NTIS) and various public, private, and university libraries. Several documents were available only through the International Union of Railways Office for Research and Experiments (UIC/ORE). These documents were obtained for the study by the FRA Technology Planning Office.

A total of over 400 documents were accumulated and reviewed. One-hundred and six are related to electromagnetic interference (EMI) and operation environments. Upon receipt, each document was screened and identified in a cross-reference index to denote its applicability to each of the program tasks.

While the literature search was being accomplished, a series of questionnaires was prepared to obtain additional data from selected railroads, transit properties, and suppliers of equipment. These questionnaires were sent to the 18 railroads over which Amtrak operates, 5 railroads and 3 transit systems overseas, 2 domestic transit systems, 7 domestic equipment suppliers, and 11 foreign suppliers.

The data obtained from the literature search and questionnaire responses were screened to establish a group of suppliers, transit properties, and railroads to which field survey trips were made in order to obtain additional information. The U.S. suppliers surveyed were: General Railway Signal Co. (GRS), Union Switch and Signal (US&S) Division of Westinghouse Airbrake Co. (WABCO), Westinghouse Electric Co. (WELCO), Harmon Electronics, Transcontrol Corp., Safetran Systems Corporation, and Thompson-Ramo-Woldridge (TRW).

The foreign suppliers surveyed were General Signal Company (GSC) Division of General Electric Company (GEC), and Westinghouse Brake and Signal in England, Siemens Corporation and Standard Electric Lorenz (SEL) in West Germany, and WABCO in Italy.

The domestic railroads that were visited included the Chessie System, Southern Pacific, and Union Pacific; transit properties included Chicago Transit Authority and the Bay Area Rapid Transit System. The European properties visited included: British Rail (BR), London Transport, French National Railroads (SNCF), German Federal Railroads (DB), the Munich U-Bahn system, and Italian State Railways (FS).

As a result of analyzing the literature, questionnaire and field survey data, six candidate technologies were identified. From these one was selected: continuous cab signaling actuated by coded ac with capability to accommodate five aspects using the standard code rates of 0, 75, 120, 180 and 270 ppm.

At the same time three levels of system capability were postulated in order to provide flexibility in the future implementation of a system. The three are identified as categories "A," "B," and "C":

- Category A: Cab Signaling Only
- Category B: Cab Signaling plus Central Monitoring
- Category C: Cab Signaling plus Central Monitoring and Control.

A third basic product of the study is a functional specification that must be met (as determined in the test and demonstration phases) if the signal/control system is to fulfill program objectives.

Section III

TASK FINDINGS

Task 1: Assessment of Signal/Control Technology and Literature Review

In two respects Task 1 serves as the foundation for the entire Phase I study. First, within its allocated level-of-effort most of the data gathering, described above, was carried out. Second, the Task 1 report provides valuable (for some readers -- essential) preliminary information to anyone making use of the entire Phase I series of reports.

The report begins with a review of train detection techniques. In addition to axle counters, the various track circuit systems are described including continuous and coded dc, ac, audio frequency, and high-voltage impulse.

The report then analyzed the various systems of cab signaling. The basis for this appears at the beginning of the analysis where it is stated that when train speed exceeds 160 Km/h (100 MPH) reliance on wayside signaling becomes impractical because of limited viewing time, excessive time intervals between information updates, and the limited amount of information that can be transferred by a stationary device. The report describes U.S. and European continuous and European intermittent cab signal systems. At this point, the report also describes the unique Location-Identification-Control system operated by the British Columbia Railway. Through a UHF radio link supplemented by passive wayside transponders, information and instructions are exchanged between trains and the central dispatcher.

The next subject covered is automatic blocksignaling. The report notes that the safety and operating efficiency of automatic blocksignaling has been verified for several decades; and as a consequence, 50% of all track mileage and 95% of all multiple track mileage are so equipped. The report then considers the options for coping with significantly higher speeds of some trains operating in mixed traffic. It suggests that the French approach of adding another aspect would be preferable to altering block lengths from both operating and eonomic standpoints.

The final system component considered by the Task 1 report is remote traffic control, which would comprise the heart of a category C level of implementation, described above. After a brief international survey, the report dwells at length on the traffic control system operated by the Southern Pacific from a control center at Houston, Texas. It is described as the most advanced system surveyed. Hardware includes process control computers, microwave communication, and color TV and cathode ray tube (CRT) console displays. Both manual and automatic control modes are available. With the latter, trains operating normally will automatically clear signals ahead of themselves, and the dispatcher is free to concentrate on difficult or abnormal conditions.

The section concludes by noting that although several railroad systems have installed dual computers to provide fail-operational capability, the primary uses of the back-up computer have been for software production and checkout.

The Task 1 report concludes with a technical and cost comparison of the several technologies. In summary of the technical portion, train detection can utilize coded ac or audio frequency track circuits. An axle counter system is a plausible candidate where supplemental broken rail protection is provided. Coded ac track circuits, wayside transponders, and continuous inductive loop techniques are all acceptable for cab signaling. Remote traffic control systems meriting consideration will utilize computer logic, CRT display and keyboard data entry for maximum growth capability. If growth capability is not critical and/or operating philosophy dictates, a hardwired modular display may be used in lieu of -- or in combination with -- CRT displays.

As to the costs of the train detection techniques evaluated, the axle counters would be lowest but would provide only intermittent train detection and no broken rail detection. The least expensive cab signaling implementation is the intermittent transponder. In the implementation of the continuous system, the choice of ac coded or continuous automatic train control (CATC) may be influenced by the probability of future electrification. In the area of traffic control systems and communication, the choice is primarily influenced by system size, with computers, CRT displays and microwave communications becoming more cost effective as system size increases.

Task 2: Status of Present Signal/Control Equipment

Task 1 described generic signal technologies. This task surveys specific, state-of-the-art applications of those technologies. The report covers all significant examples in the United States and foreign countries, but the primary focus is on Amtrak, to avoid the recommendation of a signal system that would be incompatible with existing systems or future electrification.

The task report establishes a foundation by presenting a brief chronology of the past 35 years which compares developments in the United States to those in Europe and Japan. In this country, Government-mandated cab signal systems were mostly dismantled as high-speed passenger service succumbed to competition. On the other hand, a freight productivity drive stimulated widespread development and installation of centralized traffic control systems.

During the same period, events in Europe and Japan moved in the opposite direction. Short distances aided the competitiveness of passenger service. Technology responded to the needs for higher speeds and closer headways with new train detection and cab signal systems. It was therefore recognized in the formulation of the study program that a complete survey of signal/control technology would have to be worldwide even though U.S. industry is capable of producing systems with the highest levels of sophistication.

Four United States and four foreign systems were selected for evaluation. They represent distinctly different technologies, all of which have been operationally proven in service.

The four U.S. systems are:

1. Amtrak Northeast Corridor. The line is equipped with a continuous Automatic Train Protection (ATP) system. It is a baseline system representing widely employed U.S. cab signal technology supplemented with wayside signals and enforced braking. The line is the only electrified railroad with both 25 Hz and 60 Hz propulsion supply.

2. Southern Pacific. The Flatonia-Belen, Texas, main line was selected because its signal system represents U.S. state-of-the-art in traffic control technology. It employed dc track circuits, wayside signals, and no cab signal control. The system utilizes microwave for all transmissions and a computer

for basic dispatching such as meet decisions and advance clearing.

3. Bay Area Rapid Transit. Although it is not a railroad, this system represents the highest degree of technology implementation in the United States. Speed regulation is provided by on-board control equipment which responds to wayside computer-generated corrective commands. Station stopping is achieved by a separate wayside antenna system that provides the vehicle with distance-to-go information.

4. Dallas/Ft. Worth Airport Airtrans. Although it is a small system, Airtrans represents the highest level of technology implemented in this country within present constraints of FRA and AAR standards. A conventional block system has steady dc track circuits for driverless train detection coupled with overlaid frequency shift keyed audio frequency carriers for train control. Automatic train operation functions include speed regulation, station stopping, door opening and closing, and train routing.

The four foreign systems are:

5. British Rail. The London-Glasgow line will see conventional trains operate at 167 Km/h (105 MPH) and the Advanced Passenger Train (APT) operate at 240 Km/h (150 MPH). To avoid confusion between conventional and APT-allowed civil speed limits, an intermittent cab signal system was installed for use by the

APT's only. In the event of equipment failure the cab signals will go out, and the APT will be required to operate at speeds established by wayside signals.

6. Japanese National Railways. The initial Shinkansen line has been site of a planned evolution from conventional, gravity-operated relay signal circuits to a "state-of-the-art," fully automated train control system. Initially, train speed was controlled by the operator. The present system is totally automatic through the use of on-board, triple redundant microprocessors, and central supervisory equipment. Fail-safe operation is achieved through majority voting.

7. German Federal Railroad. High-speed lines have a CATC system which was first placed in operation in 1966. The unique feature is a continuous series of 7.8-mile-long wire loops placed between track rails. Information and command data are exchanged between the loop and a train-borne antenna. The system control center regulates the speed and routing of all trains and provides operational and statistical data to train operators.

8. Italian State Railways. Large portions of the system are equipped with intermittent train control, while other parts have continuous train control. An overlaid continuous automatic train protection system has been developed to achieve compatibility between the two former systems and to provide additional speed regulation points for intermixed high-speed

passenger trains. Trainborne equipment will sense the type of signal system on which it is operating and automatically switch to it.

Most of the Task 2 report is devoted to Amtrak and how a new signal system could be compatible with it. There is an inventory of the many types of signal systems on the privately owned and Amtrak-owned lines which comprise the national network. The analysis is prompted by the previously stated requirement that any proposed signal/control system should overlay an existing system and not replace it.

Section II of this Summary Report noted that any proposed system should be described at three levels of capability:

(1) Category A: Cab Signaling Only
(2) Category B: Cab Signaling Plus Central Monitoring
(3) Category C: Cab Signaling Plus Central Monitoring and Control

The systems described above incorporate technologies that are attractive candidates for a new cab signal system, and they can be grouped into three types:

(1) Intermittent
(2) Coded ac
(3) Continuous automatic train control (CATC)

Costs are estimated for overlaying each of the three candidate types on each of six types of existing systems, such as steady dc automatic block signal and time table and train order. Costs are then developed for expanding capability to the B and C categories.

In summary, the report finds that the intermittent systems are the simplest and most economical. However, achievable headways are limited to those obtainable with existing fixed wayside signals. Expansion to category B or C implementation levels requires the addition of data collection and encoding and decoding equipment. The coded ac systems provide closer achievable headways because they detect aspect changes at any point within a signal block. This increase in performance results in an intermediate cost level. Expansion to category B or C implementation still required the addition of data collection and encoding and decoding equipment. The CATC system, while the highest cost candidate, provides the most performance and growth flexibility. Since it already incorporates two-way data exchange between train and wayside, it can be expanded to category B or C implementation levels without additional equipment.

Task 3: Standardization, Signal Types, Titles

The subjects of Task 3 are signal aspects, signal indications, and operating rules. After a survey of representative railroads in the United States and the systems of the United Kingdom, West Germany, and the U.S.S.R., the task report recommends national standards for wayside and cab signal aspects and indications. It also recommends revisions to the Federal Rules, Standards and Instructions (RS&I).

In their operating and signal practices, all U.S. railroads are governed by the requirements of the Signal Inspection Act enacted in 1937. Signal requirements are spelled out in a section of the Act (Part 236 of the Code of Federal Regulations) entitled Rules, Standards and Instructions. The railroad industry must conform to the RS&I in the installation, inspection, and maintenance of signal systems. The regulations mandate practices that insure adequate levels of safety. In adhering to these practices the railroads are free to install hardware and promulgate operating rules of their own choosing.

The history of U.S. signal development can be characterized as highly diverse, since over the years each private railroad independently established its own policies on operating rules and signal aspects and their indications. Today, any effort toward standardization is impeded by the heavy investment in hardware which could only be replaced at high cost without a justification of obsolescence.

The task report traces the development of signaling from its beginning in 1832 with the installation of the first fixed signal system. Each significant milestone, such as the first train-actuated signal system and the first mechanical interlocking, is noted, down to current state-of-the-art technology. The report then catalogues all types of signal hardware, aspects, and indications found on U.S. railroads. The basic information is supplemented by three appendices which show the complete series of aspects, indications, and rules in effect on each of the 18 railroads over which Amtrak operates. In addition to comparing domestic systems to each other, the report provides greater perspective by showing all aspects and indications of the railroads of the United Kingdom, West Germany, and the U.S.S.R.

As previously noted, the industry has followed a wide range of policies in developing signal hardware, aspects, titles, indications and operating rules. There have been attempts toward standardization; in 1889, the industry association adopted a set of operating rules entitled <u>The Standard Code</u>. It has been updated several times to reflect technological change, but it has never been compulsory. The railroads have complied in a general way, but their variations beyond the recommended standard series are numerous. Many deviations have resulted from changes found necessary by specific situations in which physical alterations to the signal system were neither practical nor economical.

In recognition of the national scope of railroad passenger operations, the Federal Railroad Administration (FRA) has sought consideration of standards for signal hardware, aspects, titles, and indications to be used throughout the network. Such standards would eliminate multiple train-borne signal packages, reduce the learning requirements of train operators, simplify hardware requirements, and enhance safety enforcement. The main objective of Task 3 is to propose such standards for a system which would overlay existing signal systems until such time as conversion to the new system would be economically sound.

A nine-aspect standard is proposed as the optimum wayside signal system. Alternative, interim standards of 11 and 15 aspects, respectively, are also proposed. The 15-aspect system approximates a composite of existing systems. Its adoption would therefore require the lowest initial investment. While the least desirable from the standpoints of maintenance and train operator comprehension, it could serve as a foundation for evolutionary development toward systems with fewer aspects and simpler hardware.

The 11-aspect standard is a logical step toward simplicity but requires more hardware alterations. Adoption of it or the ultimate nine-aspect standard could be carried out on a segment-by-segment basis as worn-out or obsolete hardware is replaced. It is recommended that the systems incorporate signal heads with two lights each containing two filaments with an automatic changeover when the active filament burns out. This redundant arrangement minimizes the occurrence of dark signals.

Because passenger trains will operate at higher speeds than freight trains with identical signal aspects, it is proposed that a system of illuminated wayside markers be established to provide fixed speed limits for interlockings, diverging routes, or civil restrictions.

A standard is also proposed for cab signaling. Aspects would be displayed in two ways. The primary system is a quantitative display providing speed and control data in a numerical format. The secondary system is a repeat of standard wayside signals. It would function in the absence of an overlay carrier for passenger service.

The proposals for standard aspects, titles, and indications were developed against the background of previously described government regulations. There have been suggestions to modify certain of these to increase safety and facilitate technological change. In February 1979, the FRA conducted a public hearing on the subject. An appendix to the Task 3 report provides a summary of the proceedings. All parties agreed that safety should be the ultimate goal of signal systems. However, the railroad industry asked for removal of what it termed unnecessarily restrictive rules, while the National Transportation Safety Board proposed more extensive signal systems and improved enforcement of regulations.

Analysis of the RS&I was part of the Task 3 effort. While the RS&I is found to be basically adequate, recommendations are made for changes to accommodate the proposed signal system. For example, the RS&I requires a direct interconnection between a wayside signal and the train to produce an automatic brake application. For the very high speed train operations contemplated in this study, brake action would have to be initiated in progressive steps ahead of the signal so the requirements should be modified to recognize this condition.

Task 4: Electrical Noise Disturbance

This task examines electromagnetic interference (EMI) generated by power equipment related to railroad electrification. The task report describes the adverse effects of EMI on existing and potentially applicable signal and control systems. The report then defines the functional requirements for the control of EMI and also recommends follow-on testing activity.

All adverse electromagnetic phenomena that may cause false signal indications are collectively defined as the EMI environment. It is created by many sources such as locomotive traction control equipment, the contact wire and feed system, short circuits, lightning, power faults, and adjacent high-voltage distribution lines.

The primary EMI source is the electrification power circuit which consists of the catenary, locomotive traction control system, and the current return path. The power circuit will conduct, inductively couple, and radiate power fundamental, harmonics, transients and broadband interferences. Variable phase traction control systems will produce harmonics of the fundamental, while variable frequency traction control systems currently under development will vary the frequency of the current pulses to the drive motors.

The most severe transients on the power circuit are caused by short circuits. Direct lightning strikes on the catenary and parallel, cloud-to-cloud discharges will also induce transients. Other interference sources include abrupt load changes by the utility, catenary and power line coronas, parallel high-voltage transmission lines, ignition and industrial noise, and high-power communication transmitters.

The second part of Task 4 indentifies the many components of a signal/control system which can be affected by EMI. The track circuit is one. Phase selective 100 Hz circuits are compatible with 60 Hz electrification and locomotive phase control power modulation. However, the variable frequency power modulator, now under development, has a second harmonic at 50 Hz which would swamp the locomotive cab signal pickup coils as would the fundamental at 100 Hz. The false indications caused by this circuit disruption would be totally unacceptable.

With 60 Hz high-voltage (25 - 50 kV) catenary power, the effects of radiated interference on wayside equipment are unpredictable because of dynamic and environmental variables. Additional research is required. Traffic control and communication systems are unlikely to be affected by high-voltage electrification except in isolated cases where open wire pole lines are close to the right-of-way.

The third and final part of Task 4 proposes functional requirements for controlling EMI. They are guidelines in developing design and installation specifications for signal/control equipment. Such equipment is affected by both conducted and radiated interference. Conducted interference can occur between equipment via power, signal and control conductors, or it may be conducted from a source and subsequently radiated to susceptible equipment and cables. Conducted interference is primarily controlled by filtering, isolation, and decoupling.

Protection of on-board equipment against radiated interference can be accomplished by various shielding practices. The enclosures or housings for both signal/train control and traction control equipment can provide substantial shielding if all openings and discontinuities are properly treated. In addition, the separation of signal/train control equipment from traction control equipment by ferrous metal-shielding partitions or compartment walls has been found to be effective. Such shielding can be applied to cabling as well. Wayside equipment and cables should also be shielded against the inductive field created by the catenary feed and return current as well as lightning current.

To state that EMI must be controlled by shielding and other procedures serves only to introduce a complex and as yet incomplete process to accomplish assured protection. The degree of protection should not exceed the need, yet there is no complete and reliable definition of the electromagnetic environment. The development of a definition has been found to be an iterative process requiring continued measurement, study, and evaluation. To date, measurements performed in various government and industry projects have not been totally consistent, and in many instances the direct application of results has not been found to be feasible. Even if greater success were evident, future electrification projects will pose new problems that have not been previously addressed.

In two appendices the task report reviews the history of EMI testing and proposes a plan for future testing which includes both methodology and devices. Current technology is adequate for measuring conducted and radiated interference from locomotive and electrification sources. However, the duplication of the electrification environment for equipment susceptibility testing in the laboratory may be difficult. Conventional EMI testing hardware has not been designed to effectively develop the fundamental, harmonic, and transient interferences actually found in on-board and wayside environments. In light of this problem three alternative approaches are possible: (1) perform tests in actual operating environments; (2) develop or adapt testing devices for the laboratory; and (3) design signal and control equipment with a conservative margin of safety. The task report recommends that at least initially all three alternatives be pursued.

Task 5: Economic Studies

Task 5 develops capital, operating, and maintenance costs of six candidate system technologies which Task 2 described as falling into three types. The six technologies are:

1. Northeast Corridor 5-Aspect (100 Hz)
2. British Rail Intermittent
3. German Federal Railroads Intermittent
4. Italian State Railways Intermittent
5. Italian State Railways Dual Carrier
6. German Federal Railroads Inductive Loop Continuous

Capital costs are determined not only by the physical characteristics of each candidate technology but also by the characteristics of the existing systems which the new technologies are to overlay. For cost comparison purposes, the Task 5 report presents the six most common systems now in service:

1. Steady DC
2. Coded DC

3. Steady AC
4. Coded AC
5. Audio
6. Timetable and Train Order

A complete comparison of the six candidate technologies with the six common U.S. systems forms a matrix of 36 elements. Within each element are three cumulative cost components: (1) per route-mile; (2) per track-mile; and (3) per locomotive. Capital costs are stated in ranges. As an example of a complete element, overlaying Italian State Railways dual carrier continuous on-coded ac would cost \$28,000 - \$30,000 per route-mile, plus \$7,000 - \$13,000 per track-mile, plus \$67,000 - \$72,000 per locomotive.

It may be recalled from Section II that total costs were to be developed for three levels of system capability identified as categories A through C. Categories B and C represent incrementally greater capability at additional cost. The task report goes on to develop these costs. Continuing with the example of overlaying dual carrier continuous on-coded ac, the costs to add train-to-central information systems would be \$17,000 per route-mile and zero per locomotive. The costs to add central-to-train information systems (category C) would be \$2,700 per route-mile and \$13,000 per locomotive.

It is noted at another point in the report that where operations on a line are governed only by timetable and train order (TT&TO), a signal system would have to be installed as a prerequisite foundation for any of the candidate technologies. All cost estimates for TT&TO territory include this factor.

To give the cost data some utility, an existing Amtrak route was selected and the unit costs were applied to it. This produced total costs for installing each of the six candidate technologies on a segment of actual railroad. The route selected is the 2,041-mile Southern Pacific line between New Orleans and Los Angeles. Signaling is predominantly automatic block signal (ABS) and traffic control system (TCS) with coded dc track circuits. However, a state-of-the-art, computer-controlled signal/control system using an audio frequency overlay was installed on a substantial portion of the line.

The total cost of overlaying the Italian dual carrier continuous technology at the category C level of capability would be $132,579,000 or $65,000 per route-mile. This dual carrier system is near the high end of the cost spectrum of the six candidates. At the low end is the German intermittent system. Its total installation cost at the category C level would be $41,384,000 or $20,300 per route-mile. These summary costs presented in the text of the task report are supported by 26 tables of detailed cost estimates in an appendix.

The other costs analyzed in Task 5 are operations and maintenance. In a prelude to the presentation of cost data, the task report examines reliability/maintainability and training requirements. Unfortunately, most of the candidate system technologies are new entries in the field, and even though all are currently in use none has been in service long enough to establish in-use reliability trends. Since reliability will determine the magnitude of recurrent maintenance costs, the report recommends a thorough investigation of this aspect.

Maintenance training for most of the candidate systems will have to extend over several weeks and will require maintenance manuals and other training aids. The technologies that they incorporate differ from existing systems and in some cases may require a different maintenance philosophy. For example, maintenance personnel will have to learn the techniques of locating problem areas and isolating replacement modules.

Training will also be necessary for operators. It would be conducted for both on-board and wayside positions. All candidate technologies have cab signal equipment that should be relatively easy to operate. The task report estimates that no more than two days' training will be required for any technology under consideration.

The task report presents operations and maintenance costs by first calculating the national average 'normalized' expense. Normalized is defined as the average annual cost over the long term to maintain the signal plant in a condition adequate to support an efficient transportation service. Costs are then developed for each of the six candidate technologies at the three levels of system capability. The last of several tables shows the percentage increase in operations and maintenance costs of the combined categories A through C. Again, using as an example the Italian dual carrier continuous inductive loop, the increase over current costs would be 40%.

The task 5 report concludes with a number of recommendations. The first is that the continuous inductive loop candidate should be dropped from consideration at this time because of its high capital and maintenance costs and susceptibility to vandalism. Another is that the FRA should consider a revision of the RS&I to eliminate the requirement that all locomotives must be cab signal-equipped if cab signaling exists anywhere within a specific territory. A third recommendation is that more definitive cost evaluations should be carried out in subsequent phases of the program.

Task 6: Specification Development

Task 6 is a functional specification of the requirements for a signal and train control system that meets the criteria described in Section I of this summary report. The specification, itself, is preceded by an introduction that states that the only generic technology meeting the criteria at reasonable cost is coded ac. It is found in the United States on the Northeast Corridor.

The specification begins with a description of the proposed system. It is a continuous cab signaling system with an integrated command center to direct and supervise all equipped trains from a remote location. This is the Category C level of capability. Data processing and sensors would be required on trains and at the command center. The basic concept of the system would be that the command center would acquire knowledge as to the position and velocity of all trains in the system and supply virtually continuous speed commands to them.

Train position would be established and maintained at all times. A unique coordination system would be established so that the exact location of each train would be known in terms of a transportation zone, rail line, section, and mile post. An identifier would be used to differentiate between tracks in areas of multiple trackage and sidings. In block signal territory the block or track circuit would be identified as part of the locational data. Where the block system is not present, wayside markers, transponders, or other unique wayside monuments would be used to establish absolute train position. Train velocity would be measured by passive, vital tachometer probes. The data from this on-board source would be verified by the positional data generated by the wayside sources.

A data communication link between all equipped trains and the command center would transmit information from the trains and return commands to them. Handshake and cryptographic techniques would be used to identify the data between trains and the command center and to provide security. Data transmitted from trains would consist of train identification, last command from the center, last absolute position, present indicated position, present velocity, and other train functions. The coding and deciphering system would ensure that only the intended train would respond to a command.

To protect against failure, the command center's data processor would have a redundant triplex configuration with parallel and serially redundant switchover apparatus. A single switchover failure would not inhibit proper functioning of the fail-operational mode by the two remaining processors. Majority voting would be used to determine the failure of one of the three processors and initiate an automatic exclusion of it. It would also be possible for an operator to take any one of the processors off line without disrupting any system functions.

With regard to on-board responses to equipment failure, all equipped trains would have two fallback modes of operation. First, a command center failure would cause a transition to the conventional cab signals. Second, a cab signal failure would be offset by reversion to wayside signals as the train made a mandatory reduction in maximum speed to 130 Km/h (80 MPH).

System performance would be evaluated in terms of headway capability and of estimating, refining, and maintaining train schedules. The control of train movements would be carried out by generating speed commands at the command center. Outside factors, such as a track obstruction or an abnormal station delay, must be considered for their impact on the ability of the system to modify train performance, and the means to respond to these factors should be included in the design. Performance modification is essentially a block-to-block process, and if the entire Amtrak system is to be considered as the basis for design, then data from approximately 16,000 blocks would have to be analyzed as part of the task to establish information for generating speed commands. In addition, the system design should include a capability to manage approximately 1,000 trains and, as a minimum requirement, there should be a complete monitor and command sweep of the entire fleet within one-half second.

The specification calls for the system developer to establish a reliability program plan which will include participation by reliability specialists in design reviews and the preparation of reliability test and demonstration plans. The developer would have to maintain a procedure for collecting and analyzing information derived from all failures and discrepancies that occur in all phases of testing, fabricating, and inspecting the signal and control system commencing with components of the research model and extending through design, production, and testing.

With regard to maintainability, the specification states that the system design should follow as a guide the requirements set forth in the military standard document, MIL-STD-470, Maintainability Program Requirements (For Systems and Equipment). A plan should be developed to ensure that the final system is comprised of components that can be analyzed, repaired, and checked out by relatively unskilled personnel. An objective of system design should be to minimize manual procedures for troubleshooting and should use self-diagnostic programs and built-in failure indicators to isolate malfunctions at the unit, or "black box," level. When the system is operating on-line, the maintenance requirements should be reduced to simply replacing failed units.

A final section of the specification deals with safety. It requires the developer to establish a system safety program that would be integrated into all phases of system development. The program should provide a disciplined approach to methodically evaluate the safety aspects of the signal and control system design, to identify hazards and to prescribe corrective action in a timely, cost-effective manner. The program should also prescribe a formal approach to the elimination of hazards through design, education, management policy, and supervisory control of conditions and practices.

Section IV

SIGNAL/CONTROL SYSTEMS AND ELECTRIFICATION

1. Introduction

The expansion of electrification on U.S. railroads is expected to produce a number of benefits. However, electrification creates certain problems that must be recognized if it is to be successfully implemented on a large scale. One of these is the characteristic environment of electromagnetic interference (EMI) that can adversely affect the functioning of signal/control systems and thereby create serious safety problems. This section will review the sources of EMI and its effects on signal/control systems. It will then outline functional requirements for effective control.

2. Sources of EMI

The EMI environment is defined as the aggregate of all internal and external conditions in which signal/control systems must function. The environment is created by many interference sources such as locomotive traction control equipment, contact wire, the catenary feed system, lightning, power faults, and adjacent high-voltage distribution lines.

The primary EMI sources are the electrification power circuit and the locomotive traction control system. The electrification power circuit may conduct, inductively couple, and radiate the power fundamental, harmonics, and transients. The likelihood of this occurring will be governed by soil conductivity, the character of adjacent terrain, the presence of parallel tracks, and many other factors.

Variable phase traction control systems will produce harmonics of the fundamental, whereas the variable frequency traction control system currently being developed will vary the frequency of the current pulses to the drive motors and will produce harmonics of the instantaneous operating frequency. Both systems produce silicon controlled rectifier (SCR) switching transients that will be conducted and radiated by all power circuit elements including the catenary line and return current path.

<ins>The Electrification Power Circuit.</ins> The distributed inductance and capacitance in the catenary and running rails, as measured from any one point in the system to the train, will vary with the position of the train. The combination of inductance and capacitance will resonate at different frequencies with train motion, and such resonance can cause widely varying changes in the amplitude of induced noise at the resonant frequencies. The distributed capacitance and resistance from rail to earth will vary widely with climatic conditions. When the ballast becomes frozen, the resistance will become very high and capacitance will increase drastically. There will even be some change in inductance as a consequence of current which causes a magnetostrictive effect (dimensional changes of material attending magnetization).

Transients are produced by a number of sources. The most severe transients on the electrification power circuit can result from faults and direct lightning strikes to the catenary line. Similarly, cloud-to-cloud lightning discharges paralleling the catenary lines will induce a transient. Other abrupt load changes on the power grid and switching of sources by the power company will also produce transients and surges in the catenary. Other possible sources of interference include catenary and power line voronas, ignition noise, industrial noise, high-power communication transmitters, and radars.

A modern catenary system is usually installed utilizing a grounded return conductor mounted near the top of the catenary support structures. This provides signaling and some communication systems with a lightning protection that they have not experienced before. The grounded return conductor is well within the 30° cone of protection for the track circuit, and since the electrification controls, breakers, and substation equipment are designed to deal with high voltages and relatively high currents, they have no difficulty dealing with direct lightning strikes.

A short circuit current is potentially the most harmful. It can occur when the catenary system is accidentally grounded and the maximum current permissible by the breaker controlling a section is in the circuit before the circuit breaker opens and trips that circuit. Under such a condition, relatively heavy currents are trying to find their paths back to the traction power substation. When this happens, some recommended protections, such as grounding the conductors on both ends, can, in fact, create more problems than they solve.

<u>Traction Control Systems.</u> There are electric locomotives in the United States that modulate the power supplied to the drive motors by using SCR thyristors to vary the conduction phase angle of the power fundamental. Variable phase traction control will produce high-level harmonics of the ac fundamental frequency as well as SCR switching transients. The variable frequency traction control modulates the power supplied to the drive motors by varying the frequency and pulse width using SCR's. This type of system (variable frequency traction control) will produce a spectrum of harmonics when going from start-up to full traction power and will also produce SCR switching transients. This report assumes both variable frequency and

variable phase traction control systems will be used in the near future on electrification projects.

The Silicon Control Rectifier Thyristor. The name thyristor defines a family of semiconductor switches whose bistable action depends on p-n-p-n regenerative feedback. Thyristors can be two, three, or four-terminal devices, and both undirectional and bidirectional devices have been produced. The silicon controlled rectifier is by far the best known of all thyristor devices.

Each time a thyristor is triggered in a resistive circuit, the load current goes from zero to the load-limited current value in a very few micro-seconds (limited only by the snubber circuit). A frequency analysis of such a step function of current would show an infinite spectrum of energy, with an amplitude inversely proportional to frequency. With full wave phase control and 60 Hz electrification, there is a pulse of this noise 120 times each second. In phase control locomotive applications, the amplitude of these noise bursts is maximum during maximum current which, in turn, is during starting. Under starting conditions the conducting phase angle is low, but the current is very high since the back electromagnetic field (EMF) from the traction motor is zero. As the locomotive picks up speed, the conduction angle increases but the current begins to decrease since the motors are not generating a back EMF. In a locomotive environment where several control circuits may be involved, these noise pulses could cause interaction between control circuits or other cab equipment and wayside equipment.

Conducted and Radiated Interference. There are two basic forms of EMI. The first (and most commonly measured) is conducted EMI. In this form, the high-frequency energy generated by the thyristor switching transients propagates through the power system which acts as a transmission system. By using standard methods and equipment, quantitative measurements may be easily obtained.

Since thyristors generate essentially a step function of current when they are turned on in a resistive load, the conducted interference has the frequency distribution of a step function, that is, a continuous spectrum of noise with an amplitude that decreases with increasing frequency at a rate of 20 db per decade. This indicates that even unfiltered thyristor circuits would show very little tendency to interfere with such VHF service as television or FM broadcasting.

In the electric propulsion locomotive environment very little can be done in the design of the control circuitry to reduce conducted EMI. At best, only a few microhenries of inductance can be added because of the high currents involved. The designer can do little more than add only inductance (and capacitance) necessary to control dI/dt in the switching. Even so, these inductors become very large and expensive. The noise currents in these inductors can be many times greater in magnitude than the line current.

The second form of thyristor generated interference is radiated EMI. This is the rf energy radiated directly from the equipment. In most cases, and especially with locomotives where weight is not a factor, the radiated EMI is significant compared to the re-radiation of conducted EMI from the large antenna formed by the catenary.

The minimization of radiated EMI is as much a matter of good construction practice as anything else. In a locomotive it is simple enough to virtually eliminate radiated EMI by proper shielding of the power modulation circuitry, transformers, conductors, etc. Re-radiation of conducted EMI by the catenary cannot be completely eliminated. However, by the use of autotransformers or a return current conductor, the catenary feed system can be designed to minimize inductive and radiated interference.

High-Voltage Transmission Lines. Power transmission lines parallel to the tracks can cause interference with track circuits, as well as wayside lines and cable which are not adequately protected. Induced current can also break down the lubricating barrier between journals and bearings causing hotboxes. In many instances railroad rights-of-way have been the most economical location for high-voltage transmission lines. When these lines create interference, modification or replacement of track circuits and wayside cables will be required to solve compatibility problems.

3. Effects of Interference on Signal Control Systems

This section is devoted to the effects of EMI on various systems and hardware. The discussion will focus on EMI generated by thyristor power-modulated electric locomotives. Further, since locomotives have operated without difficulty for years on 25 Hz electrification, emphasis will be placed on difficulties that may be encountered with 60 Hz power at 25 kV and 50 kV.

Train Detection. Track circuits in electrified territory are typically either 60 Hz or 100 Hz coded. It is obvious that a 60-Hz track circuit is not compatible with 60-Hz electrification power. On the other hand, phase selective 100-Hz circuits are compatible with 60-Hz electrification and locomotive phase control power modulation. The fundamental interference frequency is 120 Hz, and with a high Q detection circuit, EMI problems will not degrade equipment performance. This will not be the case, however, when the variable frequency power modulator, now under development, goes into service. Its second harmonic at 50 Hz would swamp the pickup coils as would the fundamental at 100 Hz. The false indications on track circuit may be totally unacceptable with this propulsion system.

A similar situation exists with audio frequency overlays employed for highway grade crossing protection. An operating frequency can be selected that would not be susceptible to interference from phase control propulsion. However, the interference from variable frequency controllers will render audio frequency overlays inoperative at certain frequencies. A modification of the track circuit to utilize frequency modulation would cause it to be insensitive to either propulsion control system. Frequency modulation could take the form of frequency shift keying (FSK), or it could be a subaudible analog modulation. The latter could easily be demodulated with a phase locked loop-type receiving circuit.

Axle counters or wheel detectors may or may not be affected by electrification at 60 Hz, especially under phase-controlled propulsion modulators. The inherent nature of their operations would permit the selection of a frequency at which little or no interference would exist. However, variable frequency power controllers are another matter. Also, electromagnetic induction as well as the dc component of relatively high-current/high-voltage return currents could affect the operation of these devices. Until such time as interference levels can be measured, it is not possible to predict the performance of these devices. It may be assumed that photo-optical and certain RF detectors would not experience EMI problems. These types of detectors are not extensively used by the railroad industry.

Cab Signaling Systems. The performance of cab signaling systems that derive the speed aspects from track circuits will, of course, depend upon the compatibility of the track circuits with electrification and the locomotive traction control system. Cab signaling systems that use continuous inductive loops or fixed transponders, as well as VHF and UHF links for data and voice transmissions with the traffic control center, can be implemented for compatibility with both varible phase and frequency traction control systems.

Wayside Equipment. With 60 Hz high-voltage catenary power (25-50 kv) the effects of radiated interference on wayside equipment and devices will be unpredictable because of dynamic and environment variables. The Electromagnetic Compatibility Analysis Center (ECAC), Annapolis, Maryland, has identified a number of classification yard wayside devices that are potentially susceptible to EMI. These are:

60-Hz Track Circuits
Speed Radars
Presence Detectors
Automatic Car Identification Systems
Wheel Detectors
Optical Isolators

The initial measurements were made in three freight classification yards. As electrification progresses it may be expected that other wayside equipment will be found susceptible to EMI such as the hotbox and dragging-equipment detector. Although signal/control equipment is not used, EMI measurements were made on the Navajo Power Company's 50 kV 60 Hz, Black Mesa and Lake Powell Railroad in Page, Arizona.

A high-voltage catenary (25-50 kV) can introduce considerable voltage into pole lines, although the amount will be dependent upon a number of factors such as the amount of separation between the catenary and the parallel line and whether or not a return wire is used. Under extreme circumstances the energy may be sufficient to cause malfunction of a circuit or a system and can create a shock hazard to personnel. Signal transmission lines can be immunized by conversion to coaxial cables or run underground in conduit. The need for this can be determined from an analysis of the specific variables in a given situation.

Pole lines are rapidly disappearing on U.S. railroads, and most communications are carried over dedicated microwave and VHF/UHF which are not affected by EMI. Other communications are carried over AT&T-switched and non-switched circuits that normally would not be sufficiently close to the source of interference to be affected. There will, of course, be some exceptions, but correcting these deficiencies should not be difficult.

4. Functional Requirements for EMI Control

This section addresses the functional design, EMI practices, and testing requirements for the compatible operation of signal/control systems in the electrification environment. An abundance of reports relating theoretical and measured results for specific electrification EMI environments on both U.S. and foreign properties is available. Analyses of these reports have provided considerable insight into the nature of interference problems to be expected with signal/control and telecommunication systems.

In recent years, a number of EMI control methods have been developed. What is now necessary is the development of a standard to bring about an effective and uniform application of these methods. Such a standard can only be achieved through adequate testing procedures. Testing is necessary in order to define the degree of filtering, shielding, and other practices that are required for the functional compatibility of signal control systems. Future research should be governed by the policy that it is not mandatory or economically prudent to develop protective devices and practices that are effective under all conditions. Therefore, effort must be made to establish what portions of a signal/control system cannot withstand any interruption at all and identify all other systems and components that could receive some interference (interruption) and still perform. Of course, it will be important and necessary to establish the level of interference (interruption) they can receive without significantly degrading their performance.

Functional Compatibility. One of the primary requirements in the design of signal/control systems is functional compatibility with the electrification environment. A basic example is the functional compatibility of frequency-modulated signals as compared to amplitude-modulated signals that could be degraded by the electrification environment. Fiber optic cables are immune from interference and are recommended even though their electro-optic conversion units are susceptible and may require protection. Similarly, microwave transmission links can be considered functionally compatible. Existing track circuits may be functionally compatible with variable phase traction control, but in all probability they will not be compatible with variable frequency traction control. An exception is 60-Hz track circuits, which are not compatible with 60-Hz electrification regardless of the traction system used.

Interference Control Practices. Interference control practices encompass many design disciplines and technologies. The specification of equipment design and installation requirements must include EMI requirements to assure compatibility. An EMI standard would normally include requirements for testing based on existing military standards such as 461A and 462. However, complete specifications including limits for signal/control system susceptibility testing cannot be developed until tests and measurements of the electrification environment are complete. After tests and measurements of the electrification environment, definitive EMI environment design levels can be incorporated into the standard.

Conducted Interference. Conducted interference can occur between equipment components via power, signal, and control conductors, or it may be conducted from a source and re-radiated to susceptible equipment and cables. Conducted interference is primarily controlled by filtering, isolation, and decoupling.

Filtering is required to minimize conducted interference and to protect susceptible hardware. As a general rule, an RFI filter will be required for each phase and neutral conductor at the power line entrance to the signal/control equipment. If only dc voltages are required for operation of on-board signal/control equipment, the negative or return side should be grounded only at the source and carried with the dc voltage line to equiment with both voltage and return lines filtered at the equipment enclosures.

Control and signal lines must be analyzed individually to determine their filtering requirements. Typically, dc and low-frequency cables can be filtered as required. For pulse, digital, audio, and rf cables, filtering must be designed and functionally tested to verify that signals or data performance are not degraded.

In addition to filtering, per se, conducted interference can be minimized by isolation transformers and decoupling techniques. Isolation transformers may be used in parallel telecommunication circuits to limit induced voltages to acceptable levels. Insulators to break the circuitry of right-of-way fences serve the same purpose. Relays can serve as decoupling devices for the transmission of on-off control and indication signals.

Radiated Interference. Protection of on-board signal/control equipment against radiated interference requires elaborate shielding measures. The enclosures or housings for both signal/control and traction control equipment can provide substantial shielding if all openings and discontinuities are properly treated. In addition, the separation of signal/control equipment from traction control equipment by ferrous metal shielding partitions or compartment walls is recommended. Shielding including partition separation applies equally to both functional equipment and cables.

Wayside signal/control equipment and cables should be shielded against the potential inductive field created by the catenary feed and return current including the fundamentals, harmonics, and transients produced by traction control systems. Wayside equipment and especially cables paralleling the catenary are also vulnerable to lightning currents and the inductive field created by power faults. Thus, shielding design must consider the total EMI environment.

The radiated EMI envionment for remotely located signal/control equipment will normally be less severe than within the electrification environment. However, shielding should be provided for equipment as necessary for compatible operation of all collocated equipment. The use of lighter gauge ferrous materials for equipment enclosures at remote facilities is possible. The shielding continuity for apertures and openings with small dimensions can be less stringent except for rf equipment. Copper braid and tape may be adequate for the shielding of conductors and cable inside central control facilities, whereas ferrous materials are needed for the immediate areas within the electrification environment.

Susceptibility Test Requirements. The measurement of conducted and radiated levels of interference from electrification and locomotive sources can be accomplished using available equipment and technology. However, the duplication of the electrification environment for susceptibility testing of signal/control equipment will be more difficult. Conventional EMI test equipment is not designed to efficiently develop the fundamental, harmonic, and transient types of interference which would be expected in the on-board and wayside signal/control environments. Alternatives are: to test equipment in an operational environment; to develop or adapt equipment for testing; or to design signal/control equipment with a conservative margin of safety. At least initially, all three alternatives are recommended.

Existing signal/control equipment that is functionally compatible with existing and new electrification systems should be tested at operational test sites with available locomotives. Methods and equipment to simulate the electrification environment in the laboratory should be investigated as may be practical. Additionally, the specification and design of off-the-shelf selection of signal/control equipment with a conservative margin for compatible operation in the electrification environment is recommended. This simply means that provision should be made for possible increase in severity of the EMI environment with future expansion of electrification and commercialization of wayside areas.

Susceptibility testing in a "conventional" EMI laboratory consists of exposing the equipment in an operating configuration to various levels of conducted and radiated interference by means of sweep oscillators and linear amplifiers. The equipment is observed for proper operation, while selected points within the equipment are monitored for conducted and radiation-induced signal levels. The monitors may be of the spectrum analyzer type or they may be tuneable receivers. Regardless of the method used, the ultimate consideration is whether the device under test performed in accordance with the design specifications.

The development of a facility that would accurately duplicate the environment produced by thyristor and other propulsion controllers is a formidable problem that must be resolved at the beginning of any program. However the environment is created, the methods are those for susceptibility testing of signal/control systems in the laboratory. Operational testing in electrified environments is the obvious alternative.

Interference Test Requirements. While the costs of establishing or even simulating the environment for susceptibility testing may be excessive, the initial costs of interference measurements in an existing operational environment will be minimal. Industrial interference and high-voltage transmission lines will add to the electrification environment. However, these sources are best measured at known or suspected problem locations.

Signal/Control Systems. Interference measurement is recommended for signal/control systems designed or planned for use in electrification environments. Military Standards 461A and 462 requirements are considered adequate for laboratory measurements of conducted and radiated interference levels. Testing of existing signal/control systems will be required to resolve questions concerning their compatibility and to validate modifications for electrification. Testing in place in any existing electrification environment or in the laboratory may be appropriate depending on the nature of expected or potential problems.

Traction Control Systems. The continuous developmental testing of traction control systems for current and future U.S. electrification projects is recommended. There is a need for the development of new designs and the modification or improvement of existing design to minimize and limit harmonics, transients and interference. Testing and research for improvement of traction control systems is recommended as the responsibility of system designers and suppliers. Standardization of tests and measurements is recommended to assure comparative results for tests performed for different traction control systems.

Testing of locomotive traction control systems is recommended to provide:

a. Comparison of available traction control systems and development of modifications to reduce harmonics and transients.

b. Comparison of different filtering and shielding configurations.

c. Measurement of radiated and inductive field levels inside the cab, in personnel compartments and at signal, control, display, and communication equipment locations.

d. Measurement of radiated and inductive field levels at external locomotive locations for antennas, interrogators/transponders, etc.

e. Measurement of harmonics, transients, and other interference conducted by the catenary or supply line.

f. Measurement of inductive field and radiated interference levels at 10 meters (30 ft) from locomotive. Ten meters is recommended as a standard distance for comparison; measurement at other distances may be appropriate for individual electrification projects requiring fences or having parallel lines at other distances from the track center-line.

Additional tests may be required for power line reactors, drive motors, regenerative braking, and other motive power interference sources. Possible locations for traction system tests include the facilities of suppliers, railroad properties, the Northeast Corridor, and the Pueblo Transportation Test Center.

Catenary Feed Systems. The configuration of the catenary feed system, including the use of booster transformers, autotransformers, return current conductors, and rail bonding directly influences the magnitude of electrostatic and inductive fields and the level of radiated interference. The continued use of many existing signal, control and communication sytems including wayside lines and cables will depend upon the catenary feed system configuration. Comparative testing would benefit the design of future electrification projects. However, the establishment of a test facility with the different types of catenary feed systems in location is not considered economically feasible at this time. On the other hand, the measurement of magnetic field levels and radiated and interference generated by existing and near future electrification systems is both feasible and recommended for comparison with theoretical studies and as input to future designs.

SUMMARY OF PUBLISHED REPORTS

for

"Evaluation of Signal/Control System Equipment and Technology"

Contractor: STV, Inc. Pottstown, Pa.

Contract No.: DOT-FR-773-4236

Performance Period: Sept. 1977 to Dec. 1981

Summary: The status of present-day signal/control equipment and technology both in the United States and abroad was evaluated. The results have been publicized and recommendations made for further developments and fabrications of a prototype system using the most advanced techniques. One goal of the program was to provide a standardized system for use on passenger routes with emphasis on using the best techniques of present day technology as used throughout the world.

Reports:

1. Task 1: "Assessment of Signal/Control Technology and Literature Review," Dec. 1978; Taylor, SF; Marshall, JF; Schultz, CM; Whalen, RB, STV, Inc., Kentron, Inc., Dyer (TK), Inc.--Available NTIS, FRA/ORD-78/39.1, 195 pages, PB-296494/AS, Cost $15.00 (A09)

2. Task 2: "Status of Present Signal/Control Equipment," Jan. 1979; Taylor, SF; Marshall, JF; Schultz, CM; Whalen, RB, STV, Inc., Kentron, Inc., Dyer (TK), Inc., Available NTIS, FRA/ORD-78/39.2, 122 pages, PB-299891/AS, Cost $11.00 (A06)

3. Task 3: "Standardization, Signals Types, Titles", Dec. 1979; Taylor, SF; Marshall, JF; Schultz, CM; Whalen, RB, STV, Inc., Kentron, Inc., Dyer (TK), Inc., Available NTIS, FRA/ORD-78/39.3, 356 pages, PB-80-142441, Cost $26.00 (A16)

4. Task 4: "Electrical Noise Disturbance", July 1980; Taylor, SF; Marshall, JF; Schultz, CM; Whalen, RB, STV, Inc., Kentron, Inc., Dyer (TK), Inc., Available NTIS, FRA/ORD-78/39.4, 132 pages, PB-81-111130, Cost $12.50 (A07)

5. Task 5: "Economic Studies", Dec. 1980; Taylor, SF; Marshall, JF; Schultz, CM; Whalen, RB, STV, Inc., Kentron, Inc., Dyer (TK), Inc., Available NTIS, FRA/ORD-78/39.5, 141 pages, PB-81-190209, Cost $12.00 (A07)

6. Task 6: "Specification Development", Jan. 1981; Taylor, SF; Marshall, JF; Schultz, CM; Whalen, RB, STV, Inc., Kentron, Inc., Dyer (TK), Inc., Available NTIS, FRA/ORD-78/39.6, 117 pages, PB-81-194318, Cost $11.00 (A06)

7. Task 7: "Summary Report" Taylor, SF, STV, Inc., To be published mid 1982

Evaluation of Signal/Control Systems Equipment
and Techniques, Task 7: Summary and Final
Report, US DOT, FRA, 1981 -06-Signals, Control &
Communications