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POTENTIAL MEANS OF COST REDUCTION IN GRADE CROSSING MOTORIST-WARNING CONTROL EQUIPMENT

Volume I: Overview, Technology Survey and Relay Alternatives

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FINAL REPORT

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16. Abstract

The results of a recent study of railroad-highway grade crossing warning system technology are presented. Emphasis in the investigation was placed on the determination of the potential for significant reduction in equipment, installation and maintenance costs through improvements sought within a framework of the basic (track circuit) system concepts now prevalent. This study comprises a comprehensive survey of current practices and hardware, an analysis of all major cost elements, and a consideration of potentially beneficial technical changes. The effort is concentrated on the equipment involved in train detection and the activation of warning devices. Special attention is given to European practices. The applicability of European signal relays and of mercury-wetted reed relays to the North American situation is analysed.

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PREFACE

The work described in this report was part of an overall program at the Transportation Systems Center to provide a technical basis for the improvement of railroad-highway grade crossing safety. The program is sponsored by the Federal Railroad Administration, Office of Research and Development.

Volume I of this report includes an overview, and two separate studies carried out under contract, one relating to the overall technology and cost of grade crossing control subsystems, and the other exploring the use of relays other than the conventional railroad signal type. A detailed analysis of reliability aspects and assessment of the potential applicability of solid-state devices is contained in Volume II. The executive summary in Volume I covers both volumes.

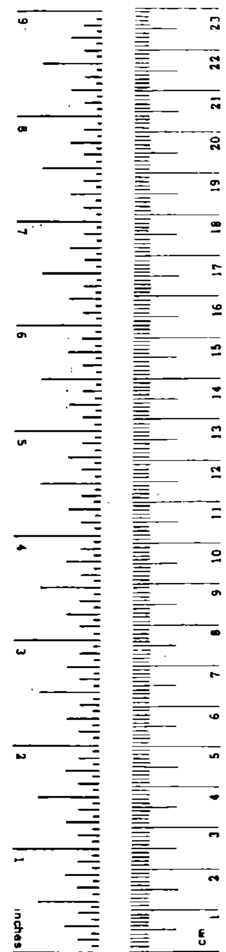
The work reported upon herein has benefitted greatly from the cooperation of many people in the railroad and railroad supply industry, as well as those in the commercial relay supply industry. In addition, the cooperation of European National Railway administrations and several prominent European manufacturers made a much better understanding of European practice possible.

The project is under the overall direction of Dr. John Hopkins, while management of the Transportation Systems Center grade crossing protection program is the responsibility of Mr. Robert Coulombere.

METRIC CONVERSION FACTORS

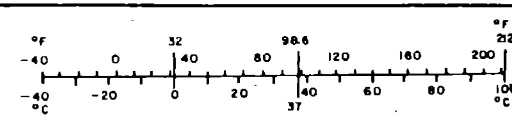
Approximate Conversions to Metric Measures

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



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	35	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



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1. PART I. OVERVIEW

JOHN B. HOPKINS
Transportation Systems Center

Grade crossing safety was identified as a serious concern of the Department of Transportation in 1967, with specific responsibility assigned to the Federal Railroad Administration in the Rail Safety Act of 1970. The reason for this attention is clear: at the time crossing accidents were claiming approximately 1500 lives every year. Although this was only 3 percent of motor vehicle occupant deaths, it represented approximately 2/3 of all rail-associated accidental fatalities. Although the causes of such accidents - estimated at 12,000 per year - are poorly understood, past studies and available statistics do offer some guidance as to the more promising means of achieving a significant reduction in casualties.

Of the approximately 225,000 public roadroad-highway grade crossings in the United States, fewer than 25 percent have train-activated motorist warnings. These almost always include pairs of alternately-flashing red lights, and nearly 10,000 are augmented by automatic gates. Numerous studies have shown that such warnings can achieve a marked decrease in accidents: 60 percent to 70 percent for lights alone, and 90 percent to 95 percent for gates. However, the substantial cost of these systems is a serious constraint upon their widespread installation.

The technology of this equipment is not new. Train detection is based upon some form of track circuit, with relay logic often utilized. The equipment now being used - like that for decades before - is highly reliable and virtually fail-safe. However, in recent years increasing interest has developed in the possibility of achieving significant reduction in the cost of grade crossing warning systems through application of recently developed electronic technology and design practices. The Highway Safety Act of 1973 and other actions have resulted in authorization of public (primarily Federal) expenditure of $50 million to $100 million per year for installation of motorist warning systems at grade crossings. In most states, financially hard-pressed railroads bear part or all of the cost of maintaining these systems, and face a dramatically increasing burden as the rate of installation is accelerated. Thus, even modest reduction in system cost - both installation and maintenance - could yield substantial benefits to both railroads and the public. Further, the impact of even very modest cost reduction can be significant; a 2 percent decrease in total installation cost would imply an annual savings of $1 million to $2 million, and it appears that even larger benefits are possible. Yet, uncertainties of product viability and acceptability, in a small market divided among numerous suppliers, make it extremely difficult for the existing equipment manufacturers to invest the necessary large sums into relatively speculative and long-term research projects.

In response to this situation, in 1974 the FRA, acting through TSC, initiated a number of contract research efforts to explore the possibility of significant cost reduction through application of alternative components and design and construction concepts. This report documents the studies directed toward the train-detection and motorist-warning control system portions of the overall installation. (Other FRA/TSC studies have addressed the warning devices themselves - flashing lights and gates - and are described in other reports.)[1,2] The studies described in this document have specifically been carried out within the context of conventional (track circuit) concepts; other projects exploring conceptually innovative approaches are reported elsewhere.)[3]

The initial focus of this work was the potential for system modularization. This is an approach which has proven effective in many electronic systems of greater complexity, and addressed the apparently complex array of elements typically found in equipment housings at grade crossings. A competitive procurement process resulted in award of an appropriate contract to Storch Engineers, Chestnut Hill, Massachusetts, for this investigation. The resulting report forms the second section of this document. That study necessarily began with an extensive survey of current equipment and practices, which has been included as an appendix. It is felt that this, alone, can prove valuable to the increasing number of individuals - in government and elsewhere - who are now, for the first time, having to become familiar with the esoteric world of grade crossing technology. The Storch report also includes extensive discussion of system costs and the constraints on innovation.

One early conclusion of the modularization study was the potential special importance to system cost and performance of relays other than the traditional railroad "vital" relay, and integrated solid-state circuitry. Accordingly, the Storch contract was expanded to include a thorough examination of relay technology, which inherently included examination of European practices. Additionally, an existing contract with the Lowell Technological Institute Research Foundation was modified to provide a study of the relevance of solid-state electronics to this application. These studies represent the third Section of Volume I and Volume II of this report.

To a large degree the separate studies speak for themselves. Taken as a whole, they bear out previous findings that the challenging operating environment and extremely demanding requirements of reliability and safety preclude any simple change or major reductions in system cost. On the other hand, the broad spectrum of possible variations in components and system design suggest that grade crossing control systems are likely to continue to evolve at a rate rather greater than that typical of railroad signal equipment in general, with continuing small but significant benefits possible in both installation and maintenance costs.

It is to be emphasized that the conclusions and recommendations found in the contractor studies are those of the authors, and do not necessarily represent the views or policies of the Department of Transportation, Federal Railroad Administration, or Transportation Systems Center. In general, given the limited scope and resources of the studies, those conclusions must be seen as preliminary judgements of technical viability and potential cost benefits.

Each of the several areas addressed in these studies appears to warrent further research activity; in particular, these include modularization, use of non-vital relays, and application of integrated circuits. However, it is important to understand the implications and potential consequences of a major research and development effort in this area. In a purely technical sense, the task is a large one. Although the initial design process can be limited in scope because the equipment is inherently simple in concept, the experience of both Government and industry research has invariably included a lengthy and expensive period of field testing and redesign, generally accompanied by a steady rise in system cost. The major constraints in this process are attainment of a mean time between safe failures of three to five years, and virtual exclusion of unsafe failures. Industry developments such as motion-sensitive train detection and solid-state audio frequency overlay equipment have typically required as long as ten years to move from the drawing board to widespread use. Some innovations, such as solid-state flashers, have failed to achieve a level of performance sufficient to generate full market acceptance.

Other factors can also impede utilization of improved equipment. Each railroad has a fully-developed maintenance system - procedures, trained personnel, and inventory. A broad variety of equipment types require changes to maintenance procedures which could limit the actual benefits of any improvement. Another limitation is the likelihood that alternative equipment will either fail to be covered by existing industry standards, or will be in some conflict with them.

The above considerations apply quite generally to the entire technology of railroad signalling. They are felt nowhere more strongly than in the area addressed by the studies reported here - train detection and control of motorist warnings. Thus, while the search for reduced cost of grade crossing warning systems is a worthy and important goal, to which a number of possible avenues have been identified, achieving that objective will require a large commitment of resources and time; research decisions must be made within this context.

On the other hand, the studies described here indicate that past constraints on innovation (largely economic) have left unexplored a number of potentially beneficial applications of recent technological development. Within the scope of the work reported here there appear to be a number of possible avenues toward equipment sufficiently lower in cost. Further, given the high level of national investment in crossing protection (of the order of $100 million per year), even a relatively small improvement can represent very large sums of money.

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2. St. Amant, A., Duttera, J., and Friedland, M., "Potential Means of Cost Reduction in Grade Crossing Automatic Gate Sytems-Two Studies," Report No. FRA/ORD-77-06.I&II, March 1977.

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2. PART II - TECHNOLOGY SURVEY

2.1 BACKGROUND

It is the express goal of the U.S. Department of Transportation to provide train activated vehicle warning systems at approximately 30,000 of the 235,000 public rail-highway grade crossings in the United States. This figure of 30,000 grade crossings is exclusive of additional DOT-sponsored grade separation/ crossing elimination projects. In the 1972 Report to Congress, DOT recommended that a 10-year, $700 million, program be initiated to sponsor improvements at those 30,000 high-risk grade crossings. The improvements recommended involve upgrading the warning devices in use. Where only passive devices such as stop signs or crossbucks are in use, it is intended to install active protection, such as train-activated flashing lights or automatic gates. The improvements would also involve, for crossings already equipped with active warning devices, the upgrading of existing active protection systems, as by adding automatic gates or crossing illumination to an existing flashing light crossing.

Responding to DOT's recommendation, Congress enacted the Highway Act of 1973 which, for the first time in history, allows the expenditure of Highway Trust Fund money specifically for rail-highway grade crossing safety projects. Section 203 of the Act authorizes the expenditure of $175 million over a three year period for grade crossing projects, and Section 230 of the Act authorizes the expenditure of an additional $250 million over the same three year period for Safer Roads Demonstration Projects, of which public grade crossing projects are considered a part.

Grade crossing protection has always been a rather expensive undertaking. The DOT estimate of the average cost to improve protection at each of the crossings is on the order of $25,000. This high cost is due, to some extent, to the fact that in the past, the installation and fabrication of grade crossing protective hardware has always tended to be a custom operation. The potential market for grade crossing protective devices has been relatively small, less than 1,500 installations per year, divided among several manufacturers. The wide diversity of street layouts at or adjacent to crossings and the necessity that all grade crossing hardware be compatible with a wide variety of existing railroad signaling practices and apparatus have further tended to customize the process. In addition, regulatory practices differ significantly among various jurisdictions and have not always been cost effective. For example, some states strongly favor the use of certain devices which are not permitted in other states.

The implementation of the DOT recommended plan will essentially double, and, in some cases, triple, the size of the present market for grade crossing protection devices. There may exist, therefore, new opportunities for potential cost savings through greater uniformity of hardware. An increased level of hardware uniformity could decrease the degree of customization at each grade crossing and might, therefore, lead to cost reductions. In June of 1974, the Department of Transportation's Transportation Systems Center contracted with Storch Engineers of Chestnut Hill, Massachusetts to perform a study of grade crossing protection hardware to determine whether or not there existed opportunities for cost reductions through hardware standardization, or other appropriate means. This report presents the findings of that study.

2.2 SCOPE

The scope of this study is limited essentially to existing grade crossing warning system methods and technologies. Concepts such as alternatives to track circuits which are well outside the scope of present practice have been given minimal consideration, and have been included only where necessary for completeness. The focus of the work has been on cost reduction through greater hardware uniformity and modular design.

2.3 APPROACH

During the course of this project, information on existing equipment and its application was obtained from several manufacturers and from a number of railroads. Visits were made to the offices and plants of several major equipment suppliers all of whom were most cooperative in supplying information. Letters requesting catalogue and technical information were addressed to the other suppliers. A substantial number of Class 1 railroads supplied valuable information. A number of state regulatory agencies, cooperated in supplying information on their regulations regarding grade crossing warning devices. The Communications and Signal Section of the Association of American Railroads was visited and provided our investigator with source material. A search was made of the trade literature.

A large fund of data was assembled. This was used to first develop an overview of present practices and then to create a "catalog" of systems, their components, and the hardware used, together with the costs involved. A major effort was directed to understanding the reasons why present practice was favored and what would limit the acceptibility of new concepts. From this information many different ideas were developed. These were quickly reduced to the set of concepts and their evaluation, the discussion of which forms the latter part of this report.

The recommendations resulting from this study are intended to present concepts which are both technically feasible with existing available technology and which should prove acceptable to at least a major part of the industry. Costs are based on an assumed production volume of equipment larger but of the same order of magnitude as present production. They have been developed within the limitations imposed by the practical "facts of life", which include not only limited production volumes, but also labor-management agreements, installation and maintenance limitations, the need to conserve power, and the necessity to maximize reliability with no compromise to safety.

The sections which follow include an overview of active grade crossing warning devices, a catalogue of grade crossing protection systems and practices, a summary of costs, a review of the factors limiting extent of change, a description of concepts, their evaluation, and a set of recommendations.

3. OVERVIEW OF GRADE CROSSING WARNING SYSTEMS AND PRACTICES

Grade crossing warning devices can be classified in accordance with the type of warning which is given to the user of the crossing. The simplest of such devices involve merely signs and are called passive warning devices. Such passive devices give no specific indication as to the approach of a train. They merely advise the driver that the roadway on which he is traveling is about to cross a railroad track. Such passive devices are suitable only where both road and rail traffic is light and where there is sufficient visibility for the road user to see an approaching train far enough away to be able to stop before entering upon the crossing. Where the number of potential conflicts between road users and trains is high, where the approach speed of trains is high, where visibility of approaching trains is restricted, and where experience has indicated that for whatever reason the incidence of accidents is high, additional warning in the form of some method of advising the motorist of the approach of a train is required. Any device which provides warning of the approaching of a train to the road user is called an active warning device.

There have evolved, over the 150-year history of the railroads, certain standards in warning devices, both of the passive and active type. American standards, in most recent years, have been set forth in the bulletins on grade crossings warning devices published by the Association of American Railroads. The latest of these bulletins is Bulletin No. 7, which is generally used by railroads and the cognizant governmental bodies as a standard. However, some regulatory authorities have modified requirements, or use earlier editions, in one case Bulletin 4.

The standardized American passive warning device consists of the so-called "crossbuck", mounted on each side of the crossing. Figure 1 shows a typical example of such a warning device.

Active warning systems consist of three or more parts and will be described in more detail in Section 3 of this report. All include means for either detecting a train at a certain point in its approach to the crossing or detecting the motion of a train towards the crossing; equipment generally located in a trackside cabinet which receives the information on the train's arrival or movement; and warning devices for the roadway users, which may consist of bells, lights and/or barriers.

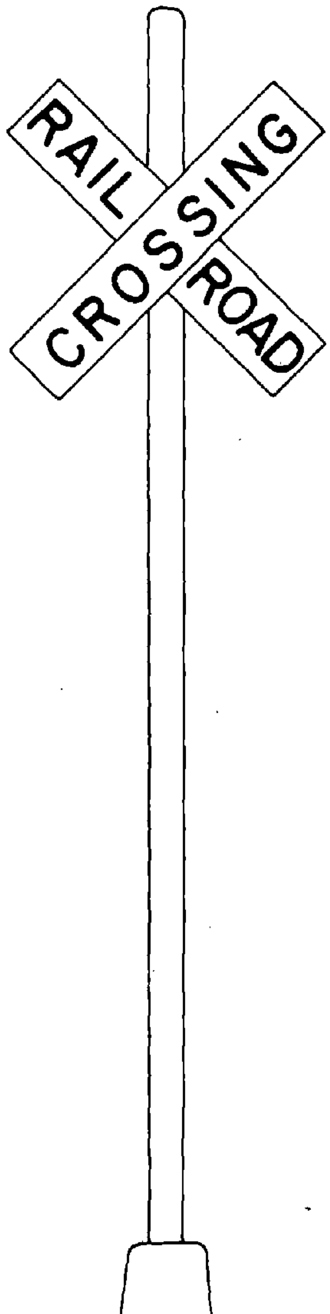


FIGURE 1. CROSSING WARNING SIGN

Many years ago, in a time when labor costs were low and reliable automatic devices had not yet been developed, the most common active warning device was a crossing tender who either stopped traffic with a red flag or a red lantern, or lowered manually-operated gates to prevent highway users from attempting to cross the tracks when a train was approaching. Originally, such crossing tenders provided protection upon hearing the locomotive whistle sounding or upon advice from a signal tower or telegraph operator that a train was approaching. With the advent of the use of track circuits, an annunciator was provided for the crossing tender which advised him of the train's approach. Warning bells were also provided at many crossings not having gates. The crossing tender was, of course, particularly effective in areas of switching movements since he was able to watch the movement and allow vehicles and pedestrians to cross the railroad safely during periods when the switch engine was moving away from the crossing or stopped, even though the engine and cars might be in fairly close proximity to the crossing. Today, very few manually-operated crossings remain, mainly because of the high value placed on human labor today.

As noted above, one of the means of providing manual protection at crossings was the tender, who swung a red lantern back and forth across the highway to warn vehicles and pedestrians to stop for an approaching train. It is not surprising that one of the first automatic devices to be developed simulated the motion of the tender's lamp. This is the so-called "Wig-Wag" signal, having a single red light swinging back and forth across the highway. Such "Wig-Wag" signals, while no longer recommended in AAR Bulletin No. 7 for new installations, are still in use at many crossings throughout the country. An example is shown in Figure 2.

The development of more reliable electrical components and the maintenance problems associated with moving parts over or alongside the highway resulted in the development of the present all-light warning signals as in Figure 3. However, the concept of the swinging lantern has been continued to this day in that the two red lights associated with each signal flash alternately, simulating the warning lantern. These red lights are normally placed approximately 30" apart and are located approximately 8 feet above the level of the highway.

Where the combination of volumes of rail and highway traffic, road geometry, and track layout resulted in unacceptably high hazard, gates were still needed. To eliminate

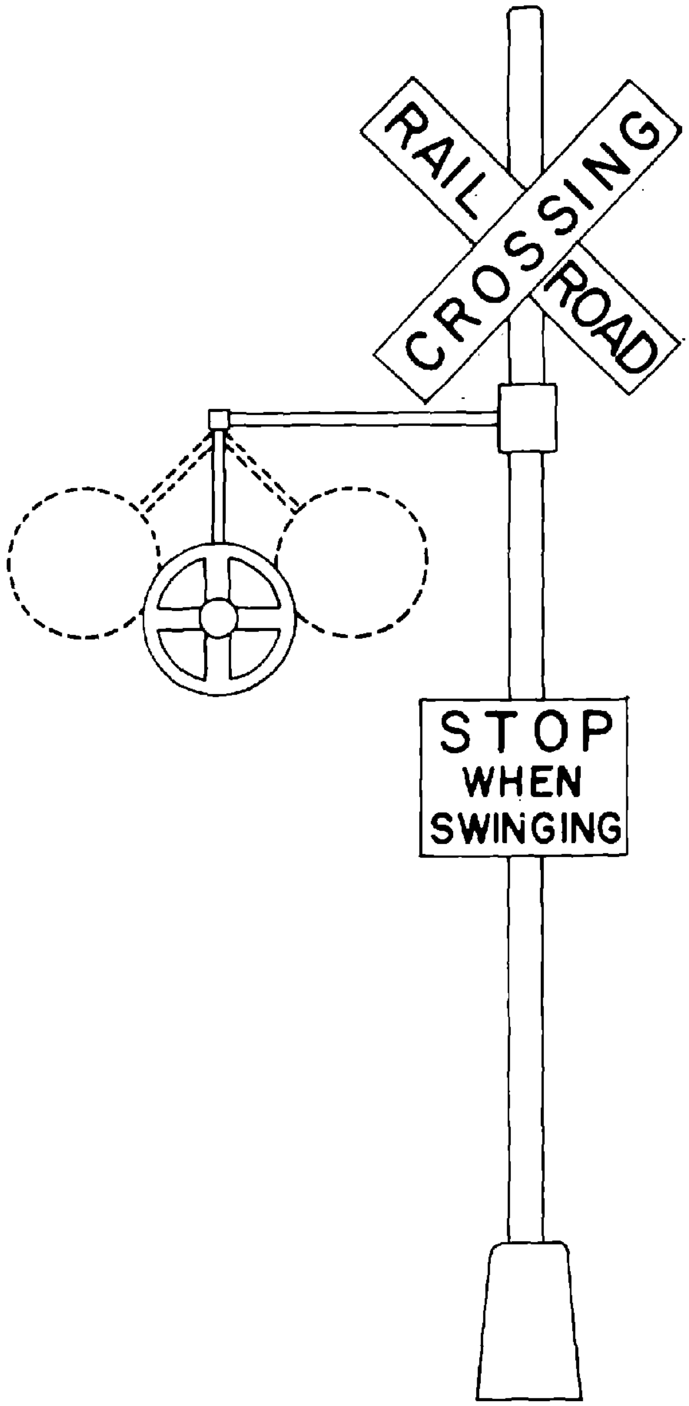


FIGURE 2. WIG WAG INSTALLATION

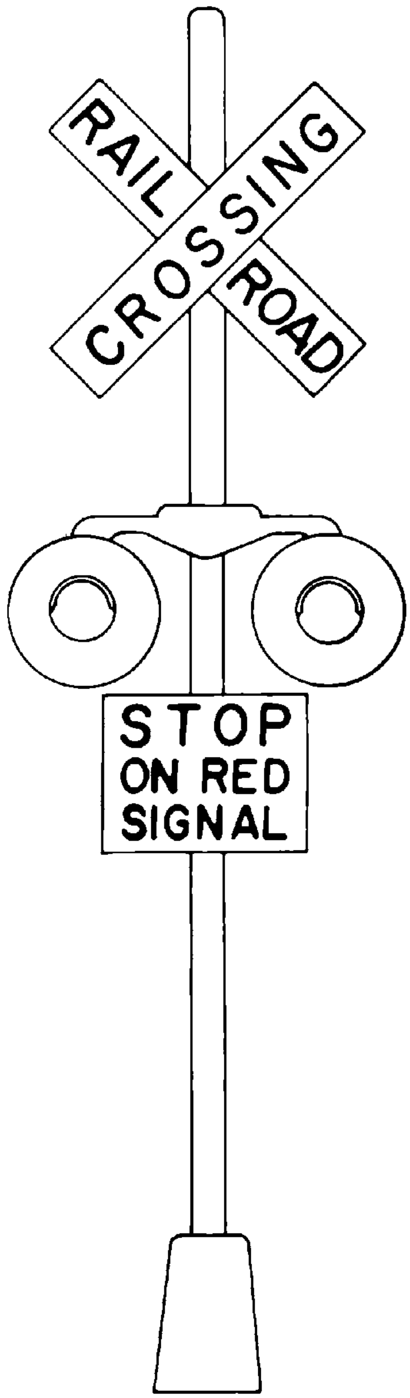


FIGURE 3. FLASHING LIGHT INSTALLATION

the cost of the gate keeper, the automatic gate was developed. Manual gates usually obstructed the entire road on both sides of the track. The gatetender would sequence the operation to allow a vehicle on the track to move clear. The automatic gate lowered a barrier across only the entering lanes. Thus, a vehicle on the crossing could always continue off and was never trapped. See an example in Figure 4.

In addition to the devices in common use, there were many which were tried and found to be of limited value. Some of these will be discussed. Many are lost in history. Some, such as the catcher of the Chicago North Shore and Milwaukee, were extremely elaborate. All are considered obsolete.

One of the paramount requirements of a grade crossing warning system is that it function 100% of the time. Safety demands this. The operation cannot be dependent on outside sources of electric power. Commercial power is the usual source, and interruptions do occur. Therefore, standby batteries are needed at all crossings. Primary batteries represent so much of a maintenance expense that their use is avoided. The usual requirements of regulatory agencies demand battery capacity for about 30 days of normal operation or 8 hours of continuous activation. All of this dictates a system design which keeps power consumption down to a minimum to keep the cost of batteries at an acceptable level.

In the typical flashing light warning installation the lights represent the major power drain. To minimize this, low wattage lamps, typically only 18 watts, are used. To get an effective warning at such low power levels requires the use of a good optical system which concentrates the available light in a narrow beam. This in turn requires rigid mounting hardware, careful aiming and considerable maintenance. It also requires extra lights, etc., where roads approach the tracks at odd angles, on curves, etc. Furthermore, the lense color used is a specific red color, which unfortunately transmits a very small percentage of the light from the lamp.

The typical roundel (the railroad name for the lense) used in a flashing light unit has an effective angle of visibility of about 30 degrees in the horizontal plane. This is called the spread angle. The beam has little upward dispersion and about 15 degrees downward angle, called the deflection angle. The beam has an intensity which ranges from virtually nothing at 15 degrees to the left of the axis of the beam to roughly 800 candelas at the axis, and back to nothing 15 degrees to the right. If a driver is only 20

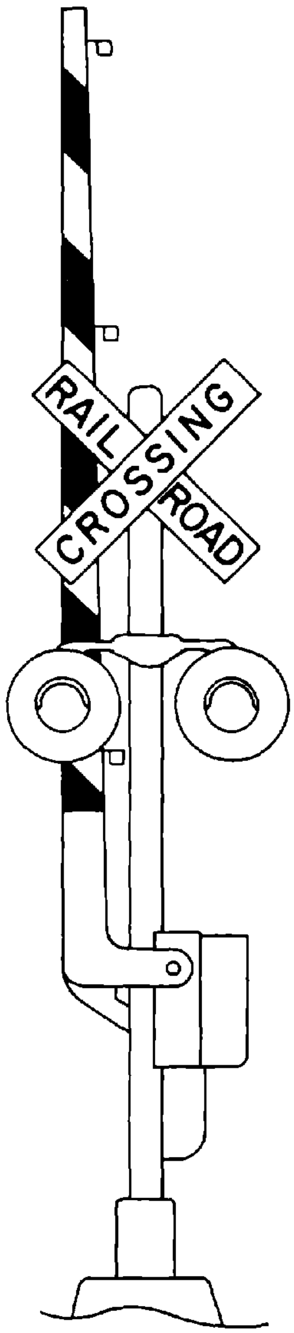


FIGURE 4. GATE AND FLASHING LIGHT INSTALLATION

feet to one side of the axis of the beam at a distance of 100 feet, the beam is down to about 400 candelas. The beam intensity for visibility in daylight is in the region of 100 to 400 candelas, so this example is approaching marginal visibility, indicating how important it is to aim the beam properly, and the major problems which may be faced if the road is wide or has several divergant approaches.

In contrast to the above, the conventional traffic signal has a much higher power lamp (65 to 150 watts) in an optical system having an angle of visibility of perhaps 90 degrees and using in the red indication a lense color which transmits up to 3 times as much of the lamp output. Rigid mounting and critical alignments is not needed. Span wire mounting is common. The great majority of vehicle traffic signals are mounted over the roadway, where they are much less subject to visibility problems. On the other hand, the power requirements are much higher, and no standby power is provided.

Where flashing lights alone are deemed inadequate to provide sufficient safety, gates are usually employed. Gates are particularly necessary at multi-track locations since there is a great propensity on the part of the roadway user to start across the crossing immediately behind a train even though the lights are still flashing. If a train happens to be approaching from the opposite direction, the driver often can neither see nor hear that train because it is hidden by the receding train. The use of gates discourages drivers from entering upon the tracks under these conditions. It should be remembered that gates are not designed to physically stop a vehicle but merely to provide a visible and psychological barrier.

The almost universal means of detecting the train is the track circuit. A typical single track crossing will have three, although there are other configurations having either more or less. The usual arrangement is to have a short track circuit including the crossing and its immediate approaches, (called the "island' or "x" circuit) and two others extending one in each direction from the end of the island circuit for the distance needed to get sufficient advanced warning. The far ends of these circuits are called the "ringing points", probably a holdover from the use of warning bells. The location of the ringing points is chosen to allow the desired 20 to 30 seconds advance warning of the fastest train to use the track. The exact warning time is often defined in state laws or regulations.

The track circuit itself is created by connecting an energy source between the rails at one end of the section of track and a compatible relay or receiver between the rails at the other. Any train or car which enters the section will short out the relay, dropping it out and indicating occupancy. Similarly a broken rail will drop the relay. Unfortunately, so will a piece of metal laid across the rails by a vandal.

No other detection method has been developed which exceeds the reliability of the track circuit, and there seems little probability that one will be developed in the foreseeable future which will find general application.

Where the speed of approaching trains varies widely, the length of time during which the warning is activated before a train arrives can become excessive. This time varies inversely as the speed. Hence an installation made to provide 25 seconds' warning at 60 miles per hour will provide an excessive 100 seconds if the train is moving at only 15 miles per hour. In addition, in some locations trains make station stops or do switching, which results in the train not entering the crossing at all, even though it has activated it. The first of these situations can be ameliorated by one of several special configurations of track circuits using timers, or by a sophisticated motion detector. The second type of situation is handled by motion detectors.

A motion detector is designed to measure the direction of motion of a train within its area of surveillance. It is connected to the rails at the crossing, and can by monitoring the impedance at that connection distinguish between a train moving toward the crossing, and one which is stopped or one which is moving away. In the first case, it activates the warning system, in the other it does not. Several methods of doing this have been developed by different manufacturers. Some have features which include a sensitivity to broken rails, etc. A particularly sophisticated form of motion detector will give a substantially constant time of warning over a wide range of speeds. Some others will approximate this to varying degrees.

A more detailed discussion of the track circuits and their operation and limitations will be found later in this report. This will include the motion detector, in its several forms.

As previously indicated, there is an assembly of components which performs the necessary logic functions required once an approach circuit is activated. This system is located in the relay cabinet which is adjacent to each crossing.

The major objective of this project is to study the technical and economic feasibility of modularization of components. As will be seen, this is particularly applicable to this logic function. To do this, it is necessary to define and catalog the components which make up this cabinet, and to consider the various constraints imposed by the environment, work rules, etc. An analysis of the costs of existing installations is also necessary. These subjects will be covered in detail in the subsequent sections.

4. COMPONENTS USED IN ACTIVE GRADE CROSSING WARNING SYSTEMS

4.1 INTRODUCTION

This section includes a list and brief description of the various component parts which can be assembled into a grade crossing warning system, together with some of the operational systems in use. This will place the areas on which this study will focus in context, and will provide a clearer overall picture against which to discuss the conclusions. A detailed listing of the hardware components will be found in Appendix A.

4.2 WARNING DEVICES

1. Visual

   a. Crossing Flasher (Fig. 3)

      One or more pairs lights flashed alternately, right & left.

   b. Wig-Wag Signal (Fig. 2)

      A device having a single light on a pendulum arm which is usually visible from both sides. Arm is swung perpendicular to highway on approach of train. One type extinguishes light and stops arm moving in vertical position in absense of train, while other types retract arm behind baffels when no warning is intended.

   c. Electric Stop Sign (Fig. 5)

      There are two types, one (shown) having four 8-3/8 inch diameter lamp units mounted vertically containing the letters "S" "T" "O" "P" from top to bottom, illuminated red on a black background. The other type uses a rotating metal sign, (not shown) usually reflectorized, lettered STOP.

   d. Advance Warning Signal

      A yellow lamp unit usually located 250 or more feet in approach of the track, on the right side of the roadway, and including a sign warning of the crossing. This usually reads"STOP Ahead At Railroad Crossing", or "STOP Ahead When Flashing". The light or

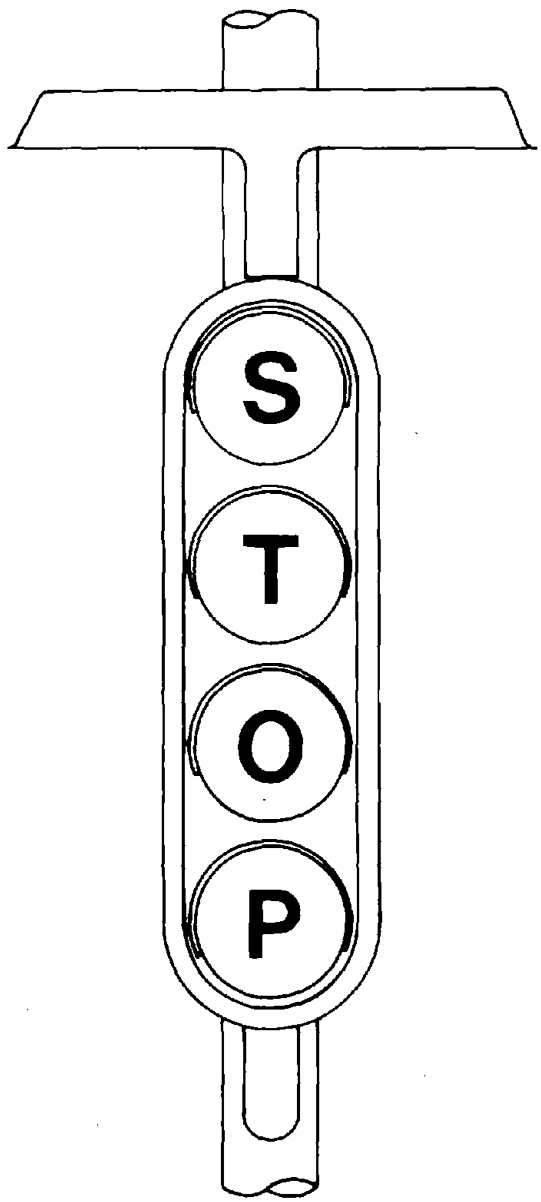


FIGURE 5. ILLUMINATED STOP SIGN

lights are flashed when a train is approaching the crossing. These signals are used where road alignment or speed precludes sufficient visibility of crossing signals to give adequate warning. Their location is ordinarily the same as the advance grade crossing warning sign W10-1, the round sign with the black "X" and letters "RR", as specified in the 1971 Manual of Uniform Traffic Control Devices.

e. Illuminated Sign (Fig. 6)

Sometimes used in conjunction with advanced warning signals, these are large light units having an opaque insert and cut out lettering to indicate to motorists when crossing is in use by a train. With single flashing light (usually yellow) they often warn against right or left turns onto tracks.

2. Audible

Bells (Fig. 7)

An electrically operated bell, mounted high on a post or mast to give an audible warning of approach of a train. A few crossings, where pedestrian warnings are the only problem, are provided with no other active warning device. A bell is also used as an added warning at crossings equipped with gates, to warn of the impending lowering of the gates.

3. Obstructive (Gates)

Though this form of protection physically blocks the roadway, it is not seriously intended that it actually prevent highway traffic from passing. Rather it is intended as a more visible and emphatic form of warning device.

a. Roadway Traffic Side Gate (Fig. 4)

A mechanically lowered wooden or metal bar equipped with reflectors and fixed and flashing lights usually used in conjunction with a flashing light signal, to obstruct that portion of the roadway over which highway traffic enters onto the tracks.

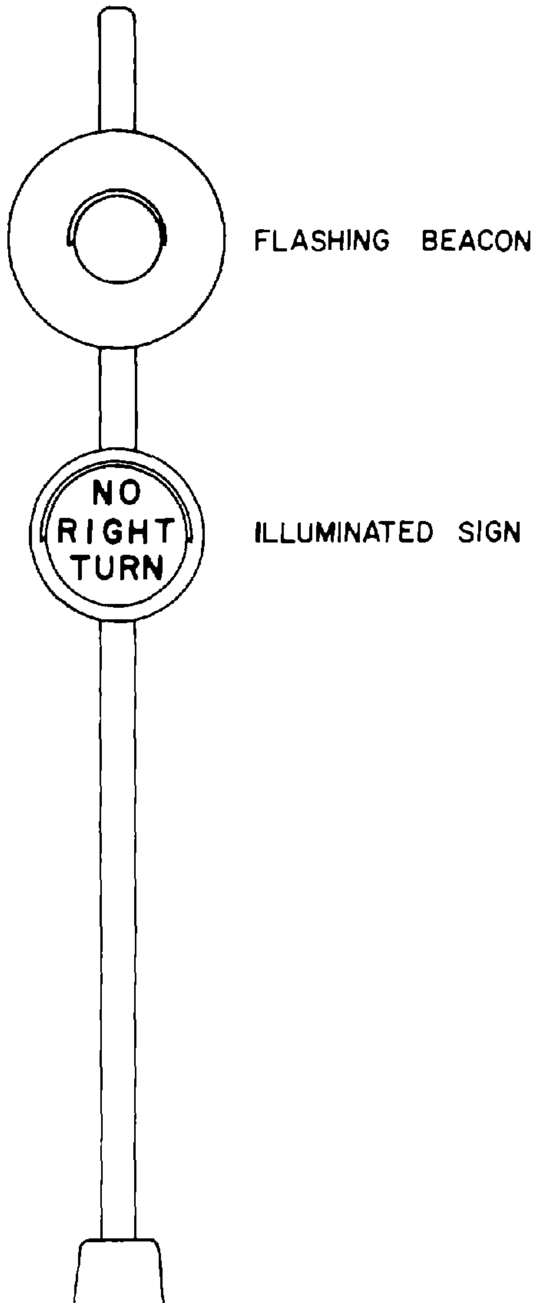


FIGURE 6. ILLUMINATED WARNING SIGN

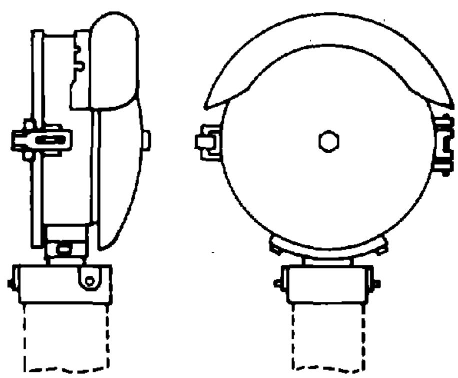


FIGURE 7. BELL

b. Off Side Gate

A device similar to traffic side gate but over which vehicular traffic leaves the crossing. Off side gates are not usually used except in those installations which are always manually controlled by train crew or gateman, because of the danger of trapping a vehicle on the tracks.

c. Sidewalk Gate

A short gate or combination of gates sometimes driven by the same mechanism as the roadway gate and sometimes driven by its own mechanism whose purpose is to obstruct the sidewalk or other pedestrian or bicycle way approaching the crossing. If sidewalk gates are used, each sidewalk is usually obstructed at each approach to the crossing.

4.3 ARRANGEMENTS OF WARNING DEVICES

The actual layout of any particular crossing will depend largely on local conditions and the requirements of the public authority having jurisdiction.

In addition to the figures referenced in this and the previous section of this report, there will be found in Bulletin #7 of the Communications and Signal Section of the Association of American Railroads a detailed description and illustrations which show recommended practice for a variety of roadway configurations. Some of these will be described below.

1. Mast Mounted Flashing Light Signals (Figure 3)

   Usually there are two sets of mast mounted lights, a set being located to the right of the road on the near side of the crossing in each direction. Each set normally consists of back-to-back pairs of lights, arranged to face in both directions along the road.

2. Cantilever Mounted Flashing Light Signals (Figure 8)

   The mast mounted signals are either supplemented or replaced by over-the-road flashing lights mounted on the cantilever. Usually the crossbuck and a set of flashing signals are mounted on the mast as shown in

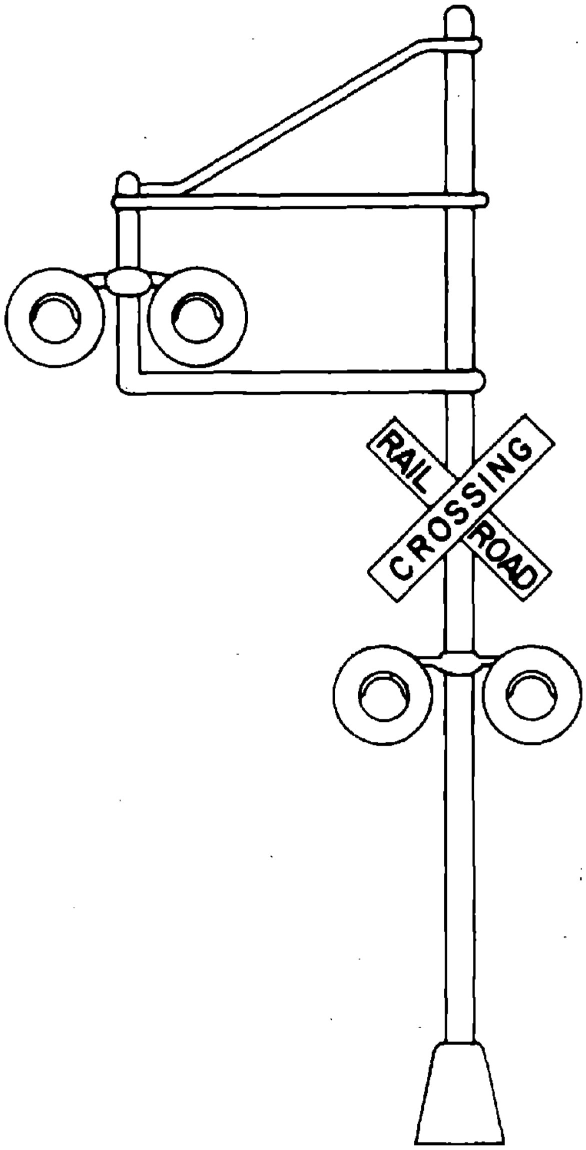


FIGURE 8. CANTILEVER FLASHING LIGHT INSTALLATION

Figure 8, but in some cases the mast is far back of the roadway edge and crossbuck is mounted on the arm. Many cantilevers are of the "walk out" type and are designed to support the weight of the signalman, while some rotate to the side for maintenance. In some areas where long cantilever arms are required, lighter arms are used, and signalmen do maintenance from bucket or ladder trucks or from extension ladders.

3. Flashing Light Signals and Gates (Figure 4)

Automatic gates normally supplement flashing light signals. Gates are usually equipped with three red lights, the outer one burning steadily whenever the gates are not in fully clear position, and the other two located at third points, alternating in unison with the regular flashing light signals.

4. Crossing Flashers with Gates and Cantilever

In this arrangement, the gate mechanisms are usually mounted on an independent stub mast between the cantilever mast and the track. In urban areas, this stub may be between the curb and the sidewalk.

5. Flashing Lights With or Without Gates and Supplemented By Illuminated Signs

Illuminated signs may be used in advance of the crossing or as supplemental warning at the crossing. Advance warning signs are usually used only at locations where approaching vehicles require earlier notice than when the warning devices at the crossing come into sight, such as on high speed roads where horizontal and/or vertical curvature of the roadway result in reduced sight distance to the crossing. Supplementary electrically illuminated stop signs at the crossing have been used along with flashers and gates, but are generally in disfavor because of the heavy power load involved, which results in the need for large and expensive standby batteries. Electrically illuminated stop signs have the advantage of providing high visibility at eye level, which can be particularly helpful to pedestrians with hearing impairment. Also used in cases of grade crossings close to highway intersections are illuminated signs, as shown in Figure 6. Such signs read either "NO RIGHT TURN" or "NO LEFT TURN" as appropriate and are associated with a yellow flashing light.

6. Warning Devices Supplemental To Traffic Signals

In numerous cases, highway intersections either are in very close proximity to or include the railroad grade crossing. Where such highway intersections are signalized, it is customary to provide for "preemption" of the traffic signals to prevent vehicles from being given a proceed indication in the direction of crossing the track or tracks during the period when the crossing warning devices are in operation. Where there is a chance of vehicles having stopped on the tracks in approach to the traffic signals, a "clear out" period in the traffic signal cycle is often scheduled to allow these vehicles to move off the crossing without violating the signals. Also, in certain cases, optically programmed signals are employed on the far side of the crossing, these signals being masked so that drivers cannot see the proceed signal of the clear out period unless they are close to or on the tracks. In such cases, a second set of traffic signals on the near side of the crossing displays red during this clear out period and until the train has cleared the crossing.

4.4 CONTROL SYSTEMS - FUNCTIONAL DESCRIPTION

4.4.1 Occupancy Detection

This is a system by which the protection is actuated and continues to function as long as a certain portion of track is occupied by a train.

1. Single Track Circuit

   A system having one long track circuit with the grade crossing at the center. These are usually used only where there are few train moves and at low train speed. Advantages are simplicity of circuit design. Uses a minimum of equipment. Disadvantage is the extended operation of protection as train leaves crossing. To keep this to a minimum, it is often necessary that the starting points for such a system be so close to the crossing as to require the train to stop.

2. Island Circuit with Manual Starting Switches

   An arrangement used nearly exclusively on industrial spurs and switching tracks, it is a system which assumes the train may often stop in the vicinity of a crossing or leave cars standing within the island circuit without obstructing the roadway. Occupancy of the island circuit alone does not activate the crossing warning. There are provided one or more manual control switches which, when operated, cause the warning to start, usually only if the island circuit is already occupied. These manual controls typically include a means of stopping the protection if the move clears the roadway, but not the island circuit. Advantages are more flexible train operation. Disadvantage is dependence on manual action, to initiate the warning and especially for manual action to terminate it.

3. Running Track Circuited For Train Movements In One Direction Only.

   A system frequently used on main lines of two or more tracks where there is a rigidly assigned direction of traffic. It is electrically similar to the island circuit, except for the use of additional relays for protecting 2 or more tracks at a single crossing. Advantage is simplicity and minimum equipment. Disadvantage is lack of automatic protection for reverse moves, which are frequently required for maintenance.

4. Multiple Direction Occupancy Detection

   A system involving the use of separate track circuits for each approach to the crossing and usually a short island circuit at the crossing. A train approaching from either direction on any track will cause the warning devices to operate. Operation of the warning devices will continue only until the train leaves the island circuit. A combination of track occupancy and directional memory relays are used to achieve this. This is the most widely used arrangement, and can be considered the "standard" treatment.

   The advantages of this system are protection for trains approaching on any track in either direction without causing warning devices to continue to operate after the train has passed over the crossing. One disadvantage is warning device lock-out which can occur if track circuit failure occurs under departing train and the next train arrives on the same track, moving in the opposite direction. However, this disadvantage can be minimized by several techniques. It presents no serious problem in territory which is signalized with Absolute-Permissive Block systems or in Centralized traffic Control areas, since track circuit failure will cause a red signal to be displayed for any approaching train, resulting in low speed train operation. It is a less serious problem in automatic block signal territory since trains operating against the current of traffic (the non-signalized direction) are usually operating at more restricted speeds anyway.

5. Proximity Detectors

A system, one implementation of which uses a loop in a figure 8 pattern, to detect the mass of the train. Loop detectors are limited to very slow speed installations, such as passenger switching yards, where frequent slow speed moves may be made across pedestrian walkways, and in other similar places, or at locations where track circuits cannot be installed because of steel ties, bridge construction, etc.

4.4.2 Speed Responsive Occupancy Detection

A system which combines occupancy detection with some form of speed detection so as to avoid excessively long periods of operation of the crossing warning devices in advance of a slow train, but providing proper warning time for a fast train.

The crossing is equipped with several points at which protection will start. In addition, there is a short track circuit in the approach to the first (fastest) starting point, whose function it is to determine the speed of an approaching train. This is accomplished with one or more timers which start running when this short speed-sensing circuit is occupied. If the train reaches the other end of this timing circuit before the timer runs out, the train is assumed to be fast and to require the full warning. This is accomplished with a time element stick relay and requires line wires along the entire length of the approach track circuits. Advantage is better, more creditable protection without use of exotic equipment. Usually can provide protection for departing moves which change direction before leaving higher speed approach zones. This is of obvious value in the vicinity of yards. Disadvantages are much more equipment and line wiring.

In order to assure that each timer runs its entire cycle, there is a relay which checks the timer at its beginning point in addition to the time element stick relay.

4.4.3 Motion Detection

This is a system in which the crossing protection is activated by equipment which senses that the motion of a train is toward the crossing, and within defined distance limits. If the train stops or backs away, the protection terminates. Only the portion of the track on and immediately adjacent to either side of the roadway has occupancy detection.

These devices are sophisticated pieces of electronic hardware which contain solid state devices. As such they are relatively more sensitive to lightning and other transients, and require substantially more effective transient protection. However, because they employ audio frequencies, they can be used without installing insulated joints in the rails. Insulated joints required for other reasons can be bypassed readily, making for ease of installation, and low maintenance costs.

1. Simple Directional Motion Detection

   This system employs an electronic device which monitors the approach to a grade crossing. When a train moves toward the crossing and is inside a defined limit, the device activates the warning devices. If the train stops, the device stops the warning. If the train now backs away, it is ignored. If it starts again toward the crossing, the warning is again activated. These devices can monitor both approaches at the same time, albeit with some loss in range and sensitivity.

2. Constant Warning Time Detection

   This system uses a more sophisticated and complex version of the Motion Detector. The device not only performs all functions of a Motion Detector described above, but measures the speed of the approaching train, and does not activate the warning devices until the train is at approximately the correct distance to give the desired (usually 25 second) warning time at that speed.

   It should be noted that some motion detectors give an approximation of this operation, while that of one manufacturer is designed to perform specifically in this manner.

4.4.4 Manual Control

1. Control Switches

   One or more manual control switches or buttons are located in the vicinity of the crossing, often on opposite sides of the roadway, to serve as the sole control of the protection. This type of control is usually restricted to switching tracks where trains are going to stop in the vicinity of the crossing and block and unblock the roadway frequently. Manual controls which cut out the warning devices to a crossing having automatic protection are sometimes used at stations and switching areas where trains may stop on an approach to the crossing. However, it is often difficult if not impossible to get train crews to properly use such devices.

2. Gate Towers or Gate Tender's Cabins

   These can be as simple as an attendant's shelter with suitable controls inside. Such installations also can be quite sophisticated, with an illuminated track diagram to show locations of trains and provide control over several crossings. Gate towers are sometimes used to provide an override of automatic protection to facilitate highway traffic in the vicinity of terminals and yards.

4.5 CONTROL SYSTEMS, TRAIN DETECTION FUNCTIONAL OPERATION

4.5.1 Train Detection by Occupancy

Any type of track circuit detection equipment can be used with almost any control system except motion detectors.

Regardless of the system used, each detector circuit must have an energy source such as a secondary battery and charging equipment, a primary battery, possibly a transformer, and if electronic, a transmitter. The energy source for the approach circuits will usually be located remote from the crossing. If an island circuit is used at the roadway, the energy source for this island circuit can be in a common equipment case at the crossing. The energy source is connected to the rails which form the conductors of an electric circuit.

At the other end of the track circuit from the energy source is the detector device. A vital circuit railway signal relay is normally used for the purpose. In the event that an audio frequency track circuit is used, a receiver, matched to the transmitter frequency, must be connected between the relay and the rails. The receiver detects the particular frequency and modulation of the source end transmitter and energizes the relay only if a strong enough input signal is present on the rails to indicate the absence of a train and an unbroken rail.

The presence of a train results in the wheel and axle assemblies acting as a rail-to-rail short circuit, thus preventing energy from the energy source reaching the other end of the track circuit, and causing the relay to drop out. Dropping out of the relay results in operation of the warning device. The wheel shunt condition could cause the energy source to be overloaded except for the presence of a current limiter. This limiter is usually a resistor on D.C. circuits and is the primary adjustment. In A.C. track circuits, resistors, variable reactors, or adjustable reactive transformers are all used, sometimes in combination. These devices provide both current limitation during train shunt and adjustment of the circuit. Electronic track circuit transmitters have built in current limitation and adjustment features.

Except in the case of electronic track circuits, which may use carrier frequency and modulation frequency as a means of separation between various track circuits, insulated rail joints in the track are the means of isolating track circuits. These insulated joints are usually installed at convenient joints in jointed rail or at special cuts in welded or continuous rail.

If insulated joints required for other signal controls fall in an electronic track circuit, a tuned coupler is used to pass the frequency of the electronic circuit around the insulated joints. This allows the use of overlay audio frequency electronic circuits installed on top of existing A.C. or D.C. track circuits. If non-electronic circuits are used and insulated joints fall in the approach zone, line circuits or repeater cut sections must be used in order to relay the approach zone occupancy information from one track circuit to the next.

In electrified territory, special techniques must be used to separate the large propulsion return currents from the track currents. Impedance (reactor) bonds which have low impedance for the propulsion current but much higher impedance for the higher frequency track circuits are one method of separating the two forms of energy. Track circuit relays which are selectively sensitive to the signaling frequency and highly insensitive to propulsion currents are used in such systems. A second method, particularly applicable in cases of D.C. propulsion, is to have one rail continuously bonded to provide the return path for the propulsion current and to provide insulated joints between signal track sections in the second rail. Special relays and balancing impedances are used in the latter method to prevent large propulsion currents from damaging the track circuit equipment. Such single rail track circuits are not considered as safe as more conventional approaches, hence are usually limited to the rapid transit field.

The components and functions of conventional closed track circuits have been described above. Other arrangements of track circuit components are possible, one of which produces a track circuit which, though closed, does not have the track between the power source and the relay. In this circuit, the power source is a transformer which feeds AC to two parallel branches. One branch consists of an adjusting resistor and DC vital circuits relay in series. The second branch consists of the two rails of the track circuit terminated by a half wave (single diode) rectifier at the end of the track section away from the relay. The transformer has the usual current limiting device, except that in this case a resistor must be used instead of the usual reactor.

When the track circuit is unoccupied, a DC current flows through the relay, picking it up. When a train enters, a low resistance short bypasses the rectifier. There is no longer a DC component of the current, and the relay drops out. The supply voltage is typically only a few volts, most of which then appears across the relay coil. But it takes 10 times this voltage to pull in the relay with AC, and the low AC voltage actually helps drop the relay out.

4.5.2 Motion Sensing

The motion detector or the constant warning time unit both make use of solid state electronic circuiting to monitor the position of a train, and to sense changes in the position. The motion detector in its simplest form will cause activation of the warning system if a train moves in the direction of the crossing but release the warning system if the train stops or moves away. The constant warning time unit does this also, but in addition calculates how fast the train is approaching and activates the warning system when the train is approximately 25 seconds (or whatever warning time it is set to give) away from the crossing. In practice, the motion detectors made by many manufacturers function somewhere between these extremes. They give a warning time which varies with train speed, but to lesser degree than could a normal track circuit operated system.

Motion detectors of all types work on the principle that the closer the train is to the crossing the lower the impedance (or inductance) of the track section from the point of measurement at the crossing to the train. The measurement of this impedance (or inductance) is made at audio frequencies, with both frequency and pulse modulation techniques used to improve accuracy and eliminate spurious signals.

Both a transmitter and a receiver are coupled to the rails at the crossing. Figure 9 shows the arrangement. When no train is present in the section, the signal in the receiver will indicate an impedance above a certain level. As the train enters and moves toward the crossing this measured impedance drops, slowly at first, then more rapidly as the train gets close. If the train stops, the impedance measurement remains constant. If the train moves away from the crossing, the measured impedance rises.

The electronic circuitry of the device monitors the measured impedance to distinguish a decreasing impedance signal from a constant or rising one. The apparatus is usually sensitive to motion toward the crossing at well under 2 miles per hour close to the crossing. The constant warning time unit further monitors the rate of change of the impedance measurement to predict the arrival of the train at the crossing and to initiate warning at a constant time before that event.

More recent designs of motion detectors will detect a broken rail because it causes an abnormally high impedance measurement. One design uses an inductance measurement rather then impedance measurement. The advantage of this is that ballast resistance (the leakage resistance through wet ballast) is almost a pure resistance, and can be eliminated.

The need for wraparound track circuits in conjunction with motion detectors was investigated. Wrap around track circuits are conventional occupancy circuits which are used to back up the motion sensing. It is clear that the decision as to whether or not to use a wraparound circuit in non signal territory is a management decision based on its view of the effect on liability. There appears to be no technical reason for requiring their use if the newer designs of motion detector which provide broken rail sensing are used and are applied within their operating limits.

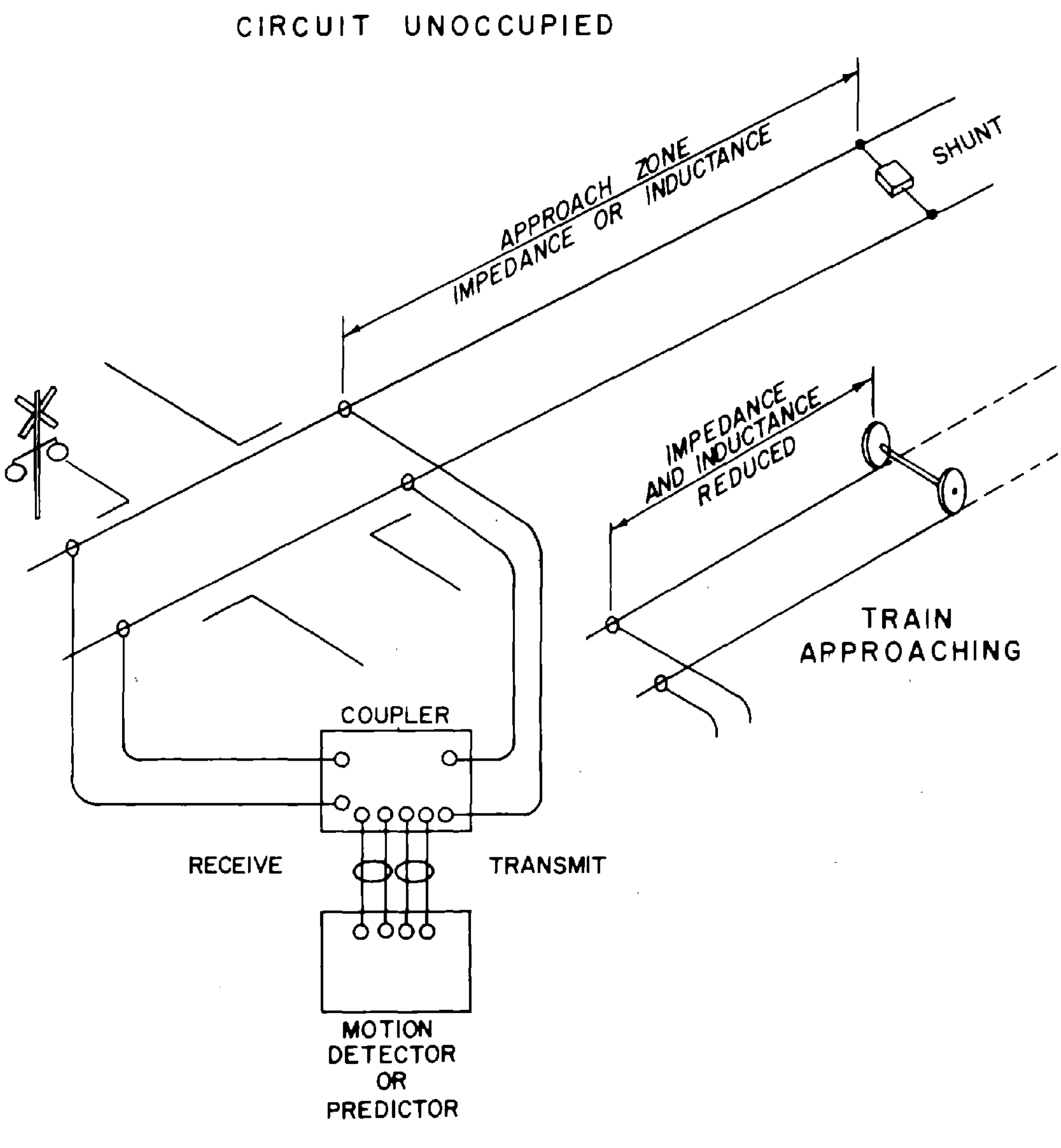


FIGURE 9. MOTION DETECTION

5. CONSTRAINTS ON INNOVATION

5.1 INTRODUCTION

The stated objective of this study is to determine the extent to which the costs of design, construction and upgrading of grade crossing warning systems can be reduced through modularization and standardization. The approach to be used is definition of constraints, and (in subsequent sections) investigation of the cost situation now prevailing, assessment of the potential for improvement, development of alternatives and, finally, generation of conclusions and recommendations.

The constraints which limit the range of alternatives will now be discussed in detail.

5.2 RAILROAD ACCEPTANCE - SAFETY AND LIABILITY

Safety is the guiding principle of railroad signalling. This extends even to failures, which, when they do occur, must result in safe conditions. This "Fail Safe" concept has resulted in the development of hardware practices and procedures which yield a signal system having an awesome safety record. Closely related is the burden of liability in the event of accident which the railroads have had to assume. The equipment for railroad-highway grade crossing warning systems is identical to that used in general signal work, and, with one notable exception, follows signal practice.

In just over 100 years since the invention of the track circuit, railroad signal hardware, practices, and procedures have been perfected to a high degree. It is most significant to note that this has been done by a direct attack on the causes of failure. The concepts of redundancy, self checking and similar ideas which have been used to improve reliability in such fields as space exploration have never found significant application in railroad signalling.

Liability is a very sensitive subject. It is obvious that a train, which may weigh 5,000 tons or more is travelling 60 miles per hour, must be given preemptive right to a highway grade crossing. In return, railroads provide warning of the approach of a train, so drivers of highway vehicles can keep clear. At certain crossings this has taken the form of active warning systems. The courts have assessed heavy damages against the railroads when these systems have failed to operate properly, even though the drivers may have behaved in a manner which is something less than cautious. The difficulties of defense under these conditions makes the railroad very conservative. Present practice has stood up to the test of many court cases. Deviation is avoided because of the inherently greater risks involved.

The area wherein grade crossing warning system practice does not follow general railroad signal philosophy concerns the warning given to the driver. In all other areas of railroad signal practice the absence of a signal means "Stop". This is not true at a grade crossing. Railroad people will say that the absence of a signal in this instance means proceed if the way is seen to be clear (and safe). The driver does not interpret it this way. The absence of a signal means "Go", usually without looking. He puts complete faith in the warning system, and the courts have generally supported this interpretation of the signal.

Highway traffic engineers often have a desire to apply highway intersection signal technology to railroad-highway grade crossing warning systems. This is in part the result of comparing the costs of highway signal installations with the costs of railroad-highway grade crossing warning system installations. The latter are usually higher despite a seemingly much lower complexity. There is unfortunately a general lack of appreciation of the complexities of the railroad side of these systems, and the special conditions the railroad faces, especially in the liability area.

It is very important to recognize the very different liability situation which applies to traffic signal installations. Almost all traffic signals are owned and operated by a government agency. Laws vary greatly, but it is fair to say that it is very difficult to collect damages from a government in a suit resulting from an accident at a signalized intersection. The burden of proof which the plaintiff must carry is significantly greater than in a suit involving a railroad.

There are of course other factors which have shaped the direction of highway signal technology. These include the much shorter stopping distances applicable to highway vehicles, the greater complexity and a smaller area of an intersection, and the much greater reliance on drivers' control of the vehicle. The much larger volumes of smaller and lighter vehicles which can be maneuvered without organized direction allows such operating approaches as fixed time signals, single point vehicle detection, permission of conflicting flows (example: left turns across opposing through movements), etc. which are totally unsafe when applied to a railroad.

Traffic signal control equipment design is greatly influenced by these factors of liability and environment. Standby power is never required. The extreme reliability and fail-safe design is not required. The equipment is therefore functionally totally different from a railroad signal hardware and will not meet the railroad signal standards.

The potential financial burden of the altered liability situation is one of the primary reasons for the general resistance of the railroads to the application of traffic signal technology to railroad-highway grade crossing warning systems. Many railroads are self insured, which further sensitizes them to increases in liability, so the reaction is as could be expected.

5.3 THE MARKET

With the exception of the vehicle warning hardware and a few special devices such as motion detectors, all the hardware used in grade crossing warning systems is identical to that used in railroad signal systems. The railroad signal market has a gross sales volume that has been estimated as $150 million per year. There are few statistics on the dollar size of the grade crossing warning system market. For one thing, much of the hardware and supplies are common to other signal work. The several suppliers asked indicated that annual sales of hardware only were about $6 million in 1973. For comparison, the vehicle traffic signal market is about $60 million annually. Further, no company of the eight suppliers derives more than half of its sales dollars from the sale of grade crossing hardware.

A further insight into the limited size of this market can be gained by looking at the installation rate. There are approximately 48,000 crossings equipped with active warning systems. New installations declined from 1010 in 1970 to 884 in 1973, according to figures supplied by a leading trade journal. This latter figure represents only a 1.8% change in the total number of actively protected crossings. Even if this number is tripled, it still would not be a large dollar amount.

This limited market, closely allied to a much larger signal equipment market means that there are strong economic advantages to using the hardware of the larger market. This means that only changes acceptable and economical in the signal market will be economically viable in the grade crossing market.

A serious constraint is the difficulty of gaining new product acceptance. Even if it is economical, a new product will be installed only on a trail basis until enough time has elapsed to gain experience as to its reliability and safety. This takes from months to years. The manufacturer must underwrite the cost of this work. Sales costs in the railroad business are very high, and this further increases the cost of introduction.

Competitive situations tend to hold prices down. Therefore, every supplier tries to make his product distinctive. If he can develop a product which he alone sells, he can price it higher and, theoretically at least, make a bigger profit, from which the costs of development and introudction to the market can be met. There is therefore an understandable reluctance to take a concept and develop it when it is known that there will be competition from the start.

The combination of a small volume, the considerable economic disadvantage of introduction of a new product solely for grade crossing warning systems, and the high investment with low return puts severe limitations on what is practical under this study. The probability of acceptance decreases very rapidly as the concept diverges from what is presently considered accepted practice in the industry. Or, saying it another way, a proposal which involves a very different concept must offer a major economic advantage without diminution of safety before it will even be considered.

5.4 THE ENVIRONMENT

Grade crossing warning system hardware shares with railroad signalling equipment and vehicle signalling equipment the distinction of having to operate in an extremely harsh environment. The equipment is installed in outdoor relay cases which have negligible internal heat. It is subjected to 40 degree below zero and lower temperatures in winter, and air temperatures over 120 degrees Fahrenheit in a blazing sun (which results in temperatures above 160 degrees inside the case), extreme dryness, humidity high enough to keep everything dripping wet, and extreme vibration, and must at least resist the attentions of hunters, vandals, and errant automobiles. In addition, the equipment must work under stress from all kinds of transients due to lightning and man-made sources. That it actually does work as reliably and safely as it does is a truly major achievement. Anyone who is familiar with the problems involved in environmentally hardening equipment will appreciate what an achievement the present level of reliability represents.

Lightning is a very special problem for the railroad industry. A railroad is spread out over long distances. The rails are a good, if highly inductive, conductor, and there are many parallel wires and many grounds. This creates a situation in which the very high ground potential differences caused by lightning can create dangerous surges which can propogate for long distances. Railroad signal hardware is normally designed to pass a 3000 volt breakdown test. The conventional lightning arrestors and equalizers are readily able to prevent transients of much over 1000 volts, unless the lightning strike is extremely close, so serious damage is minimized. Continuous maintenance is the main problem.

The use of solid state, (transistorized) equipment was long delayed because of the difficulties of providing suitable transient protection. Transistors are notably unforgiving of transients, in some cases of less than 1 volt. Lightning still represents a serious maintenance problem and the use of solid state equipment is generally limited to applications where other devices simply cannot be substituted.

The need to operate from a standby power source is another of the limitations on alternative solutions to the design of grade crossing warning systems. Because of the preemptive nature of the operation and the inability of the train engineer to stop short of a crossing when the warning systems are inoperative, no main line railroad will accept the potential liability resulting from inoperative grade crossing warnings because of an outage of commercial power. Some railroads, and especially electrified ones, have their own power distribution systems which minimizes this problem. Practically all crossings are equipped with a standby storage batteries which are charged from the power line, and which will operate the crossing for long periods. This is typically 30 days of average activity, or 8 hours of continuous operation. These long times are related to the long periods between inspections. It is conceivable that a fuse would blow 5 minutes after a miantainer had left, and put the installation on the batteries. It may be 3 weeks before he gets there again.

Attempts have been made to provide lights on top of the relay case to notify train crews that the equipment is operating on standby batteries so they could report it. This has generally not proven successful. Hunters use the lights for targets, and it is difficult to get train crews to look at the lights and report when they are illuminated.

5.5 FUNDING

There are two basic costs involved in the grade crossing system. These are the cost of installation and the cost of maintenance. The cost of installation is a one-time expense, which when paid, is over with. The cost of maintenance, on the other hand, is an ongoing expense. Since the equipment life is from 20 to 50 years, this represents a truly long term commitment, greatly affected by the vagaries of inflation, labor contracts, etc.

Sources of funding for the two cost elements are quite different. The initial installation cost, which at first was entirely paid by the railroads has been increasingly paid with public funds. Federal funding has been a major factor for work at grade crossings on highways which are designated as part of the Federal Aid System. This source has, since 1944, paid up to 100% of improvement costs, with the railroad's share limited to the value of actual benefits but not exceeding 10% of the cost. On non-Federal Aid roads, the picture is quite different. Figure 10 shows the degree of Railroad participation in both installation costs and maintenance costs, broken down by State. Note that the railroad share can be anything from zero to the entire cost, although 10% is a common figure, of the installation cost.

Both the funding and scope of Federal Aid has been increased greatly under Sections 203 and 230 of the Highway Act of 1973. This act has taken effect too recently to have any significant impact on either present hardware or practices.

The funding for maintenance and operation has not been handled in a like manner. No Federal aid funding has been available for maintenance. As shown in Table 1, only 8 states contribute anything toward maintenance and operation costs. Since the present worth of the annual maintenance costs at present high interest rates approximates 1/3 of the installation cost, this can be seen to be a heavy burden on the railroads, many of which are in severe financial difficulties.

The overall impact of the funding picture on Active Grade Crossing Warning system design has been to give the railroads a strong economic incentive to spend money on an installation (paid largely by Public funds) in ways which will reduce maintenance later (paid out of the railroad's pocket). Since the railroad is almost universally given the task of designing the installation as well as doing the actual construction work, the railroad has ample opportunity to make this tradeoff. This tends to increase the installation costs.

TABLE 1 USUAL ALLOCATIONS OF COST TO RAILROAD ON NON-FEFERAL-AID RAILROAD-HIGHWAY PROJECTS

State	Grade Crossing Protection Installation	For Maintenance and Operation of Protection
Alabama	100%	100%
Arizona	50%	100%
Arkansas	100%	100%
California	50%	100% & (50% if made after 10/1/65)
Colorado	10%	100%
Connecticut	50%	100%
Delaware	50%	100% & 50%
Florida	0-100%	100% & (50% if made after 2/3/71)
Georgia	50%	100%
Idaho	20%	100%
Illinois	10%	100%
Indiana	50% (St.Rds. only)	100%
Iowa	10% (St.Rds. only)	100%
Kansas	25-50%	100%
Kentucky	10%	100% & (0% if made after 6/58)
Louisiana	50%	100%
Maine	50-100%	100%
Maryland	50-100%	100%
Massachusetts		100%
Michigan	50% for Flashing Lights 100% for Gates	100% - $120/yr.
Minnesota	10%	100%
Mississippi	10-100%	100%
Missouri	50%	100%
Montana	100%	100%
Nebraska	25%	100%
Nevada	13%	50% if made after 4/16/71
New Hampshire	100%	100%
New Jersey	5%	100%
New Mexico	50%	100%
New York	50%	100%
North Carolina	10%	100% (50% on St. Rds. or if after 1/1/72)
North Dakota	10%	100%
Ohio	10%	100%
Oklahoma	10-25%	100%
Oregon	50%	100%
Pennsylvania	0-20%	100%
Rhode Island	100%	100%
South Carolina	100%	100%
South Dakota	10%	100%
Tennessee	0-100%	100%
Texas	10%	100% ($100-$150, if St. Maint. Rd)
Utah	10%	100%
Vermont	10%	100%
Virginia	25%	50%
Washington	10%	100% (75% new only)
West Virginia	10%	100%
Wisconsin	30-32%	100%
Wyoming	10%	100%
Dist. of Columbia	100%	100%

Source: U. S. DOT Report to Congress
Railroad-Highway Safety
Part II (August, 1972)

The effect of this situation on this study is to limit the options which will be acceptable to railroads to those which tend to minimize maintenance.

5.6 THE NEED FOR COMPATIBILITY AND ADAPTABILITY

Because grade crossing warning systems are in effect superimposed on railroad signal systems, they cannot disrupt the signal system, and must not be disrupted by it. To find general use, grade crossing warning systems must be readily adaptable to work with the wide range of track patterns, types of signal systems etc. This requirement has its greatest bearing on the train detection and control functions.

The railroad plant in the vicinity of a grade crossing can include switches, sidings, stations, signals, interlocking plants and other grade crossings. The equipment used for any one grade crossing system must be compatible and adaptable to the application. Some idea of the complications which must be faced can be seen if two rather common situations are examined.

Assume that a crossing is entirely within one signal block, and simple DC track circuits are in use. Each of the three track circuits of the crossing warning system (the two approaches and the island) are a part of the block. Therefore the track relays for each must, in addition to operating the grade crossing warning, also open the line control to the signals. If this is a single track with an Absolute-Permissive Block system, three wires are involved.

Another example is one in which there is a signal at or near the crossing. Here not only must the track circuits serve double functions, but there must be a separate circuit for that part of the approach in the second block.

The necessity to function as a part of a signal system dictates use of signal-system-grade hardware, and the advantages of minimization of inventories of spare parts dictates that it <u>be</u> signal system hardware.

5.7 WORK RULES

A railroad is a large and highly organized operation. The workers are unionized along craft lines, with each Union having a contract restricting work in a specific area to its members. These contracts generally prohibit the railroad from using outside contractors except under certain limited conditions. The exact provisions vary, but in general they are quite restrictive.

The work involved in installation and maintenance of railroad grade crossing warning systems is within the province of the Brotherhood of Railway Signalmen. This union has negotiated contracts which permit certain railroads to subcontract relay case wiring. Other contracts allow purchase of prewired equipment, while others put limits even on this. There are relatively few restrictions on purchased components.

In summary, work rules are most restrictive about field installation work, but in general pose only a limited restriction on modules, provided they are complete units.

5.8 PRACTICES AND PROCEDURES

Railroad equipment is substantially different from what is commonly called commercial-industrial hardware. Therefore, it is not available through normal distribution channels. This extends to such things as the universal use of 14-24 Terminal screws, a size virtually unknown elsewhere. Each railroad must therefore maintain a large inventory of spare parts to be able to quickly restore operation of all kinds of equipment. Furthermore, because a railroad is spread out over great distances and maintenance personnel must spend much time just travelling from one point to another, each maintainer must be provided with a supply of spare equipment. A large investment in spares is inevitable.

It is interesting to note that the costs of carrying this inventory of spares and of the administration of records, etc. is not always charged directly to the equipment, but is absorbed into the general overhead.

The organization of construction and maintenance forces also has an effect on the acceptability of new things. Union rules require use of railroad forces for vitually all work. But a railroad covers a wide area. It is difficult to economically to justify moving equipment long distances with the resultant high costs for only a small job. Furthermore, much of a railroad's right of way is not readily accessible from a road. Obviously the grade crossing itself always is. But other signal equipment is not so conveniently located. This has more to do with controlling the designs simply because there is more signal equipment.

The effect of this situation is to limit hardware to pieces that can be handled by a typical four man gang. Foundations are made in several parts, often of cast iron. Everything is relatively portable. About the only exception in general is the relay case.

Because maintenance expense is such a large item, and because non-railroad funds are available for construction, railroads will do such things as bury loops of cable in the ground where a cable enters the cabinet. If the cable gets damaged above ground, it is only necessary to dig up this loop to get cable enough for repairs. The cable itself is specially fabricated for railroad use and is direct burial cable. The life of some of this material is extremely long. Cable 50 years old and still in perfect condition is not unusual. Such cable was expensive when purchased but has proven economical to maintain.

6. COSTS ASSOCIATED WITH PRESENT PRACTICES

6.1 INTRODUCTION

On first examination, different grade crossing warning systems appear to have more differences than similarities. However, upon further analysis the great diversity can be seen to be almost entirely in detail. There is a very high degree of uniformity in both design and construction practices among different railroads. It is possible, therefore, to look at typical installation and get a reasonably accurate picture of the costs involved.

Actual costs for a new installation, at a location which has not previously been equipped with active warning devices, can run from less than $10,000 to in excess of $100,000. It is virtually impossible to document the figure, but it appears that a median cost figure for all degrees of complexity would be about $25,000. Factors which tend to increase costs include the presence of a signal system, multiple tracks, sidings, high train speeds, approaches which overlap other crossings, etc. Wide highways, heavy traffic volumes, high vehicle speeds, and complex road geometry are also factors which tend to raise costs. There is a growing tendency toward use of gates, especially at multiple track crossings, and this also increases installation costs, as does the use of cantilevers.

Normally, the rebuilding or upgrading of an existing installation of active protection would cost less than a new installation to the extent that existing facilities could be reused. This, however, is not always true. The bonding of track, existing foundations and possibly existing cable can often be continued in service. However, a common reason for upgrading is the installation of welded rail. It then becomes highly desirable to eliminate insulated joints so a conversion to audio frequency overlay equipment, or to a motion detector (which requires no active components at the two ringing points) is frequently made. The costs involved in equipment removal, tamporary connections, etc. will sometimes push the overall cost of upgrading above the cost of a new installation.

6.2 COMPONENTS FOR COST ANALYSIS

For the purposes of cost analysis the grade crossing warning system can be broken up into four major subsystems. These are the Train Detection, the Control, the Vehicle Warning, and the Interconnection subsystems. These are illustrated in Figure 10.

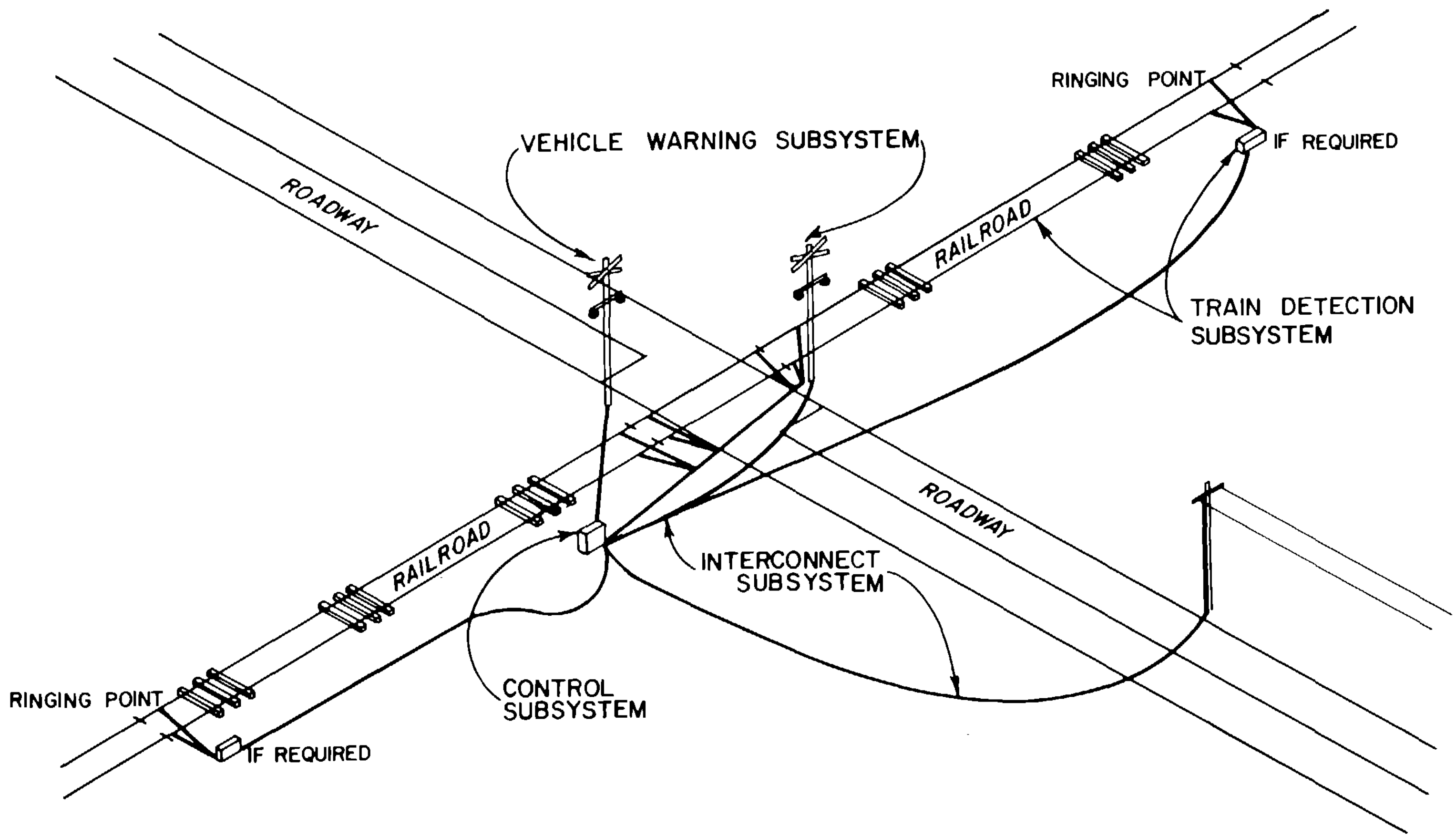


FIGURE 10. COST ELEMENTS

The Train Detection subsystem consists of the track circuits and such components and hardware as may be located at the ringing point. Strictly speaking, it should include the track relays and other related components in the relay case, but these have been included with the Control subsystem to simplify cost determination. The function of this subsystem is to detect the approach of a train and the occupancy of the crossing by that train.

The Control subsystem is essentially the relay case and contents, including relay, batteries, chargers, wiring etc. Its function is to respond to the approach of a train by properly sequencing the operation of the warning system, and keeping it in active condition until the train has cleared the crossing.

The Vehicle Warning subsystem consists of the flashing lights with gates if they are used, and related hardware. Its function is to warn the driver that a train is approaching.

The Interconnection subsystem is the final one. It consists of all the wire and cable, most of which is buried, which connects the parts of the system together. This is defined as a separate subsystem because of the high cost and because of the difficulty of alocating the costs elsewhere.

6.3 COSTS OF TYPICAL INSTALLATIONS

It is informative to examine the cost distribution for installation of grade crossing warning systems. To highlight the important material, two typical examples have been chosen. The costs for each subsystem have been estimated, and each will be analyzed.

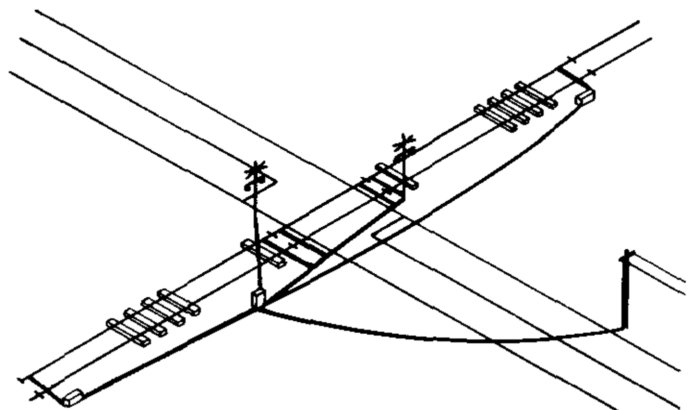
It was necessary to estimate costs for each example because railroad accounting procedures do not provide a cost breakdown in the manner desired. Furthermore, there is only a limited data base of individual installation costs. Those that are available have various differences in detail which obscure the main points. Three major railroads, in different sections of the country were most helpful in furnishing what cost information was available, and aided in developing the estimates used. A comparison with price information furnished by equipment suppliers varified that the figures are reasonable. To facilitate interpretation, costs have been rounded to the nearest $100. The expense of engineering and such miscellaneous charges as transportation, taxes, etc. are not a major part of the cost of an installation, and have been prorated into the costs of the four subsystems.

The two examples chosen are reasonably representative of the majority of the simpler installations. In each case it has been assumed that no major track work has been required. This would include ballasting, crossing surface repairs and similar work.

The first typical installation is a crossing of a single track line. Protection is provided for train movements in either direction. The line is not signalized, and the crossing is equipped with flashing lights only. This is typical of many rural crossings. The estimated cost is $15,000. Figure 11 shows this system, and contains a circular chart which shows the division of costs of material and labor among the four subsystems.

The second example is the crossing of a double track rail line. Simple block signalling is assumed, with the entire length of both approaches in the same block on each track. In keeping with present practice, both tracks are equipped for train movements in both directions. The crossing is equipped with flashing lights and gates, but does not have cantilevers or any other advanced types of warning equipment. An installation of this type is estimated to cost $25,000. Figure 12 shows the details and contains a circular chart giving the distribution of costs between material and labor for each of the subsystems.

A chart showing the cost breakdown of both examples for direct comparison will be found in Table 2. It is interesting to note that the double track example has more interconnect but other costs are about the same proportion. Also shown in this figure is the amount to be added for each cantilever. The range given covers various types, with the upper figures a heavy walkout type. The additional cost for installation of a motion detector for each track is also shown. This range covers a simple installation up to a constant warning time device. The costs for adding a cantilever and motion detector must be used with caution, as there are many types having widely varying costs in both categories.



COST RANGE $10,000 TO $40,000
ESTIMATED MEDIAN COST $15,000

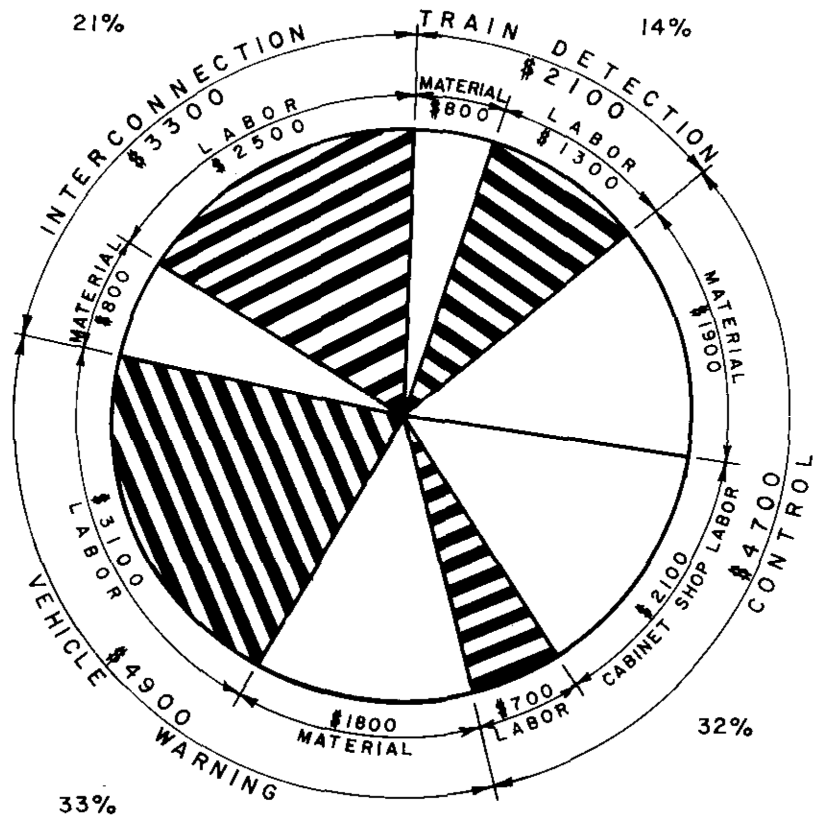
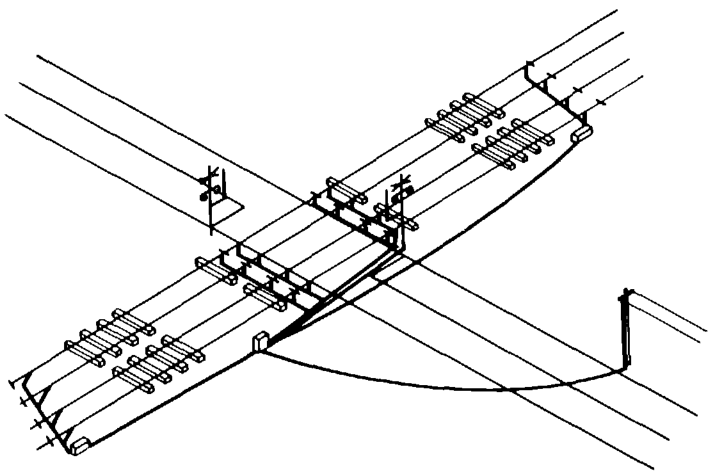
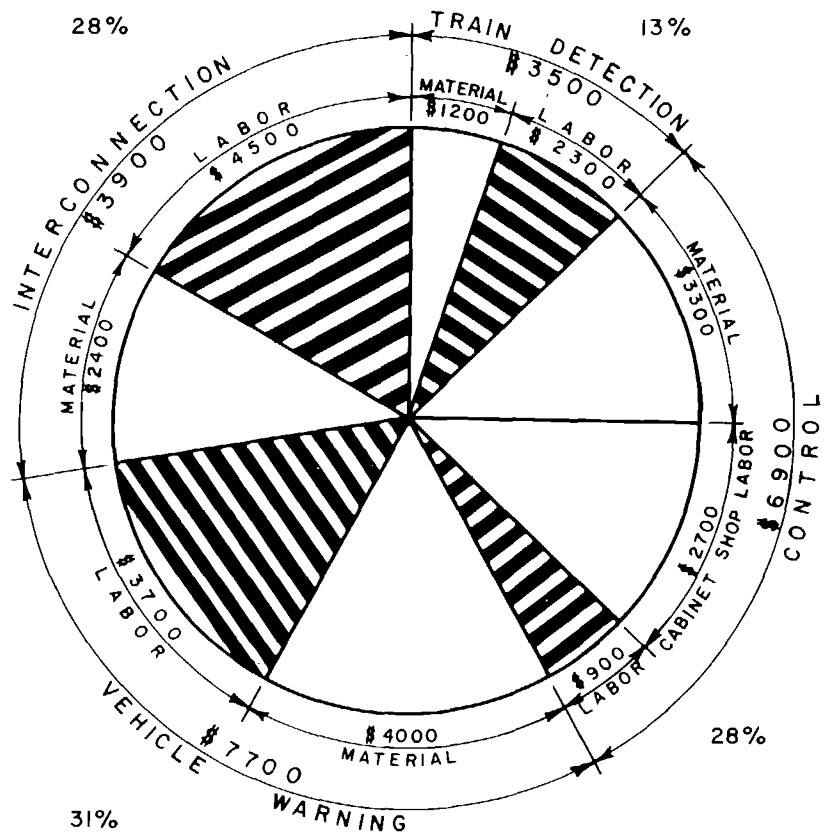


FIGURE 11. ONE-TRACK CROSSING WITH FLASHING LIGHTS





COST RANGE $15,000 TO $90,000
ESTIMATED MEDIAN COST $25,000

FIGURE 12. TWO-TRACK CROSSING WITH GATES AND FLASHING LIGHTS

TABLE 2 COMPARISON OF COSTS

Subsystem	Single Track Warning System		2 Track Warning System	
	Est.$	% of Total	Est.$	% of Total
Train Detection Subsystem				
Labor (field)	$1300		$2300	
Material	800		1200	
Total	$2100	14%	$3500	13%
Control Subsystem				
Labor (field)	$ 700		$ 900	
Labor (shop)	1900		3300	
Material	2100		2700	
Total	$4700	32%	$6900	28%
Vehicle Warning Subsystem				
Labor (field)	$3100		$3700	
Material	1800		4000	
Total	$4900	33%	$7700	31%
Interconnection Subsystem				
Labor (field)	$2500		$4500	
Material	800		2400	
Total	$3300	21%	$6900	28%
Total Installation Cost	$15,000	100%	$25,000	100%
	Simple		Complex	
Cantilever - add				
Labor	$ 800		$1200	
Material	1000		3000	
Total	$1800		$4200	
	Simple		Constant Warning Time	
Motion Detector - add				
Labor	$2000		$12000	
Material	1500		10000	
Total	$3500		$22000	

7. THE POTENTIAL FOR COST REDUCTION

7.1 INTRODUCTION

Meaningful cost reduction programs must be based on a prior determination that potential for cost reduction exists. Unless such a potential exists, it is futile to expend effort. Each of the subsystems of the grade crossing warning system will be examined to determine the potential for cost reduction within the scope of this project.

7.2 COST REDUCTION POTENTIAL IN THE TRAIN DETECTION SUBSYSTEM

The train detection subsystem uses the equipment and practices of railroad signalling. It functions in the same manner as a signal system. Indeed, in many installations it IS a part of the signal system, in addition to its function in the grade crossing warning system. Under these conditions it must meet the rigorous safety standards of railroad signalling. The hardware must conform to all the many laws and regulations applying to such equipment. Even when not a part of a signal system, the hardware functions the same. The same hardware and practices are used. The grade crossing use is a small one compared to the railroad signal field, hence the design and specifications are determined by the larger and more critical use. The grade crossing warning system use is distinctly secondary.

Any change in this subsystem must meet all the safety requirements of the signal system. No changes of consequence can be made in existing hardware and practices. The only avenue possible is to replace the signal system hardware with something else which is equally safe. However, this would result in the need for maintaining separate inventories of parts, which is very unattractive economically. The usual costs of carrying inventory varies greatly with accounting practices but a figure of between 15% and 25% per year is a realistic one in this era of high interest. In addition, this inventory would have to be large in proportion to the value of the installations because installations are new and few.

In view of the above, it seems safe to say that the potential for improvement in the train detection subsystem is very small. To be worth considering, a change would have to offer a substantial saving in excess of the extra inventory costs. Subjectively this would probably mean in the range of 25% to 50% of present costs. Achievement of this seems very unlikely.

7.3 COST REDUCTION POTENTIAL IN THE CONTROL SUBSYSTEM

The Control Subsystem presents a very different picture. While the circuitry is quite standardized, there is a fairly diverse selection of components which can be arranged in many configurations and interconnected using a number of wiring methods. Further, the components are purchased parts, some of which are elaborate assemblies already. Most of the wiring can be and in fact usually is, done in a signal shop. Some railroads can, under terms of their contracts with the Brotherhood of Railway Signalmen buy cases which have been prewired, and some can buy relay cases completely assembled, wired, and tested. Those railroads which can use these approaches find them distinctly economical.

Clearly there is a potential for cost reduction through modularization and adoption of more uniform design and fabrication procedures, especially through use of more factory assemblies.

7.4 COST REDUCTION POTENTIAL IN THE VEHICLE WARNING SUBSYSTEM

The Vehicle Warning subsystem consists primarily of hardware which functions in a prescribed manner. The lights must give a beam which is of a required size and shape and aimed exactly and rigidly. The gate, if present, must operate in a prescribed manner. The functional specifications are spelled out in laws and regulations which have been sanctified by many court rulings. The supporting structures are specially designed for this purpose. The design has been developed over a long period to meet the need to hold the lights rigidly, carry the gates and their driving mechanism and miscellaneous signs, etc., and be easily handled and installed. The tooling for making the parts is probably paid for, and each manufacturer has his own minor variations. Even the foundations offer little potential for change.

It is apparent that there is little opportunity to reduce the costs of the elements of this subsystem within the scope of this study. Other DOT studies are in process to evaluate improvements in the gate mechanism and to study ways to improve the flashing lights, but these are outside the scope of this project.

7.5 COST REDUCTION POTENTIAL IN THE INTERCONNECTION SUBSYSTEM

The Interconnection Subsystem consists of electric wire and cable, much of which is buried. The size of wire and type of insulation are chosen as dictated by long experience. In general this is specially insulated wire in order to withstand the vibration, ballast, cinders, and general abuse of railroad service. There is cable of this type which has survived in continuous use for 60 years and more.

It is clear that within the scope of this project there is little if any potential for cost reduction in this subsystem. There is certainly reason to question the economic justification for some of the practices used, but it is not possible to investigate these within the scope of this study.

7.6 SUMMARY OF IMPROVEMENT POTENTIAL

The Train Detection, Vehicle Warning, and Interconnection Subsystems all show very limited potential for cost reduction within the scope of this study. All of these subsystems can be characterized by cost inputs made up largely of materials which are relatively simple, and large amounts of field labor. Significant cost reductions require breakthroughs in technology. The labor which bulks so large in present costs is inherent in present technology. The present labor contracts, with the built in restrictions on who may work on the railroad right of way have their effect, but technological changes not now foreseeable are needed to produce major cost reductions in these subsystems.

The Control Subsystem differs from the others in that it alone has a significant amount of labor input which is <u>not</u> field labor. Further, this subsystem is less affected by the physical layout of the grade crossing than are any of the others. It therefore offers enough potential for cost reduction to merit further study.

8. ALTERNATIVE SUBSYSTEM CONCEPTS

8.1 INTRODUCTION

In this section six alternative concepts will be described. Each will be discussed, and some cost estimates will be made. These six alternatives are the final alternatives remaining after the study and selection process described was completed.

8.2 ALTERNATIVE CONCEPT GENERATION AND SELECTION

To aid in the generation of ideas, a study was made of the functional operation of the Control Subsystem. When the functions are defined and these are blocked off on circuit diagrams found in various AAR Signal Section publications or furnished by several railroads, it will be found that things fall very neatly into three blocks. Figure 13 shows these blocks marked on the diagram of a very commonly used circuit. This circuit diagram shows a two track grade crossing warning system, the same system previously used for cost analyses. As can be seen, there are two identical blocks each of which contains the three track circuit and two directional stick relays associated with a track. An additional block contains the relays and circuitry associated with the gates, while the last contains the relays and circuitry associated with the flashing lights. The relay case of an actual installation contains, in addition to the above the power supplies, batteries, lightning protection, etc. These have been omitted for clarity. A single track crossing having only flashers would need only one track block and the flasher block. A four track crossing would have four track blocks, etc.

After definition of functional blocks, the implementation of the subsystem using present hardware was studied. Alternative hardware configurations using present components as well as using different components were considered. In addition the possibilities which might be realized through application of new technology were studied.

The outcome of this process was a long list of candidate concepts. To reduce this number, a selection process was used which was designed to eliminate those which were outside the scope of this study and to combine those which were essentially similar. Those remaining were further evaluated and any which offered no significant contrast to what is standard practice on at least one major railroad were discarded. The result of this winnowing was the selection of six alternative concepts which will be defined and discussed

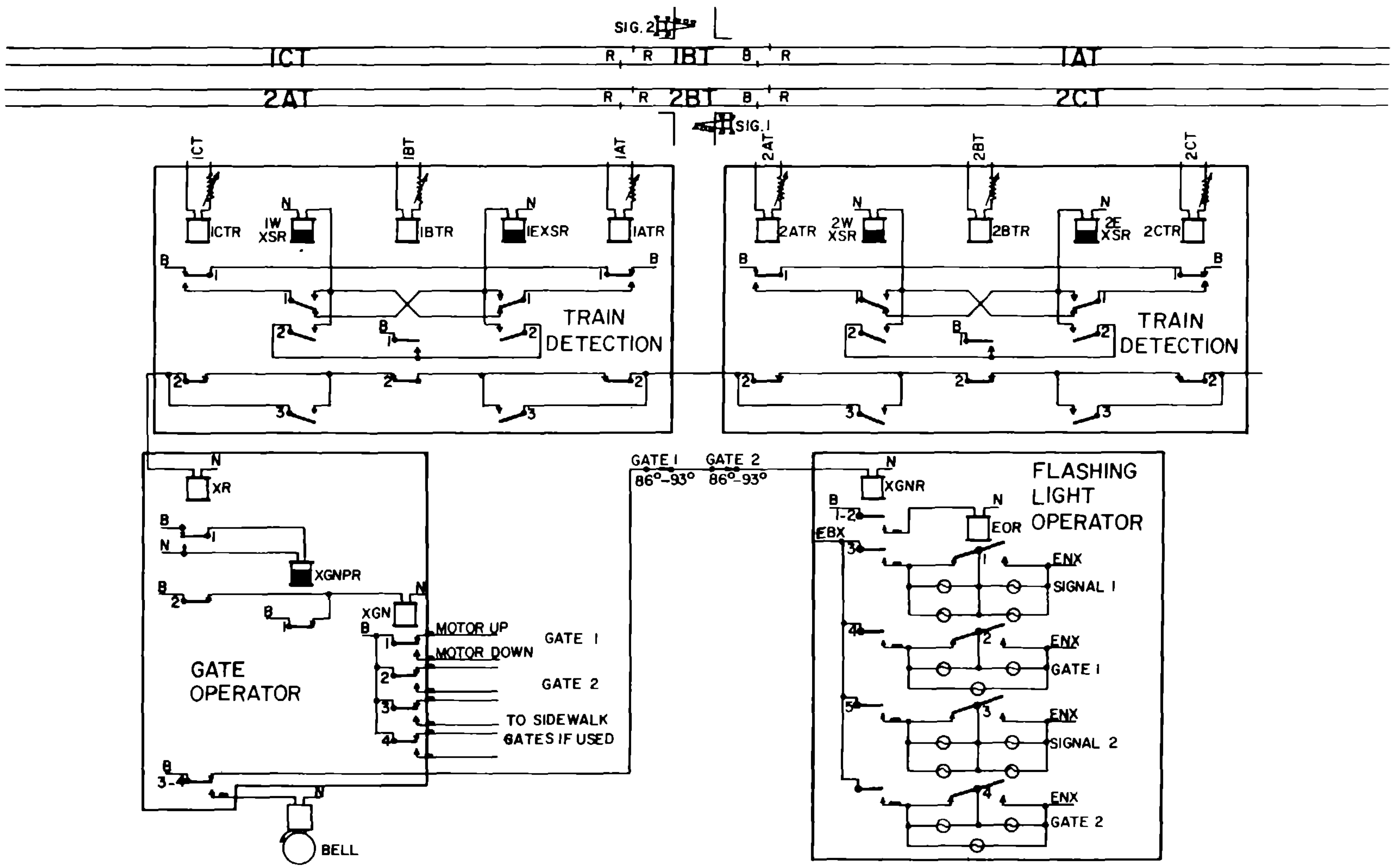


FIGURE 13. MODULARIZED CIRCUIT FOR CROSSING WARNING OPERATOR

8.3 ALTERNATIVE CONCEPTS

The following list of concepts has been arranged in an order which reflects the divergence from present practice. The first two concepts are essentially present practice. The next two incorporate present technology in advanced form, while the last two use a new implementation and new technology. A summary of comparative costs is shown in Table 3.

1. Universal use of shelf-type relays.

2. Universal use of plug-in type relays.

3. Development of a set of universal modules.

4. Development of a set of easily serviced modules.

5. Use of non-vital but highly reliable relays.

6. Development of a solid state substitute for present logic.

8.4 DISCUSSION OF EACH CONCEPT

1. Universal Use of Shelf-type Relays

This concept would use the conventional standard shelf-type relay in all application. This would basically be a step backwards. Shelf-type relays are larger, cost more, and except to trouble shoot are more difficult to work with than plug in relays. This is a very unattractive solution on all counts except that it is a known and technically acceptable solution.

One of the major disadvantages of this alternative is the fact that shelf-type relays cost about $100 more than plug-in relays.

2. Universal Use of Plug-in Relays.

This alternative would simply make universal what is now standard practice on a number of railroads. Hardware and wiring techniques are known and understood. Where one relay design in a limited number of contact and coil combinations has become the standard on a particular railroad, substantial cost savings in parts inventory and service have resulted. The major objection raised by railroad signal engineers to this concept is that trouble shooting is made difficult unless done by two men. In a conventional installation the relays are plugged into sockets in the backboard, and all wiring is behind this panel. It is therefore a problem to find trouble unless one man is on each side of the case. The concept is otherwise technically acceptable, and in view of the approximately $100 cost advantage per relay over shelf type, is economical.

3. Development of a Set of Universal Modules.

It is readily seen that, given the functional blocks defined above, a generally applicable design would result if the circuitry and components of each of the three functional blocks were incorporated into a module. A preliminary design for such a set of modules was developed. The overall construction is shown in Figure 14 while a photograph of a mockup of such a set is shown in Figure 15.

As conceived, each module would be an assembly of plug-in relays. All wiring would be done with conventional Tower and Case wire to AAR standard terminal blocks on either end of the unit. The unit would be fully cased, and could either sit on a shelf or be hung on a backboard. The case wires could be connected directly to the terminal blocks, or conventional links used to connect the module to a set of fixed AAR terminal strips mounted in the relay case to which the case wiring would be connected. The module will accept sockets for any of the three major designs of plug-in relays of the two largest manufacturers.

It appears that a set of modules such as described would have application in a large percentage of installations. The track module has available circuits for signal line control. If line rather than direct track circuit input is required, the only modification required is to change the keying for the different coil resistance of the relays involved. While it is not possible to determine the exact application of such a module set, it seems reasonable to expect that upwards of 50% of all installations would be candidates for the track module, and a considerably higher percentage could use the gate module and the flasher module.

This type of module can be assembled in a manufacturing plant using conventional assembly methods. The only installation work is to equip the cabinet to receive the units and connect them up. The relays within the unit are plug-in and can be serviced by replacement with similar units. It is not necessary to replace the entire module. Trouble shooting is done from the front by disconnecting links or wires. There are two sources of savings. First, all wiring can be done at the manufacturing plant using assembly techniques, tools, and facilities associated with electrical and electronic equipment production, which is a more cost effective use of personnel and material than field or signal shop wiring. Secondly, it uses plug-in relays, which cost substantially less than shelf-type relays.

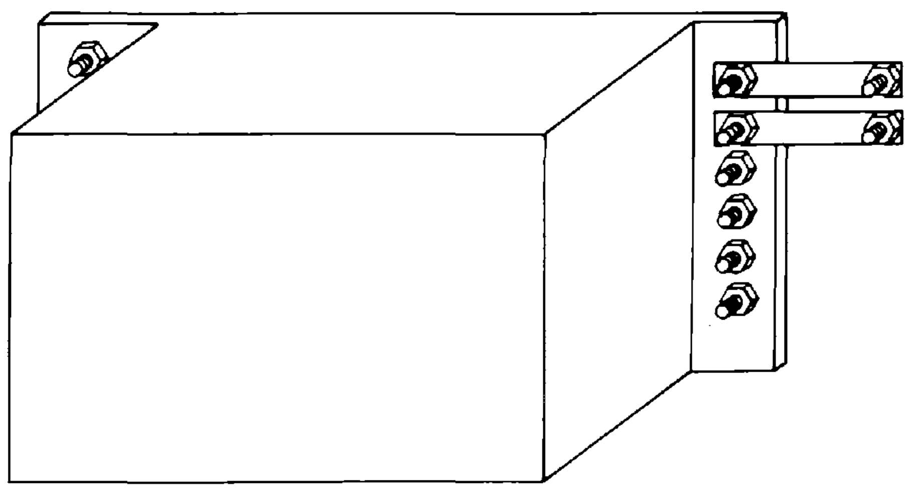


FIGURE 14. CONCEPT OF A MODULE

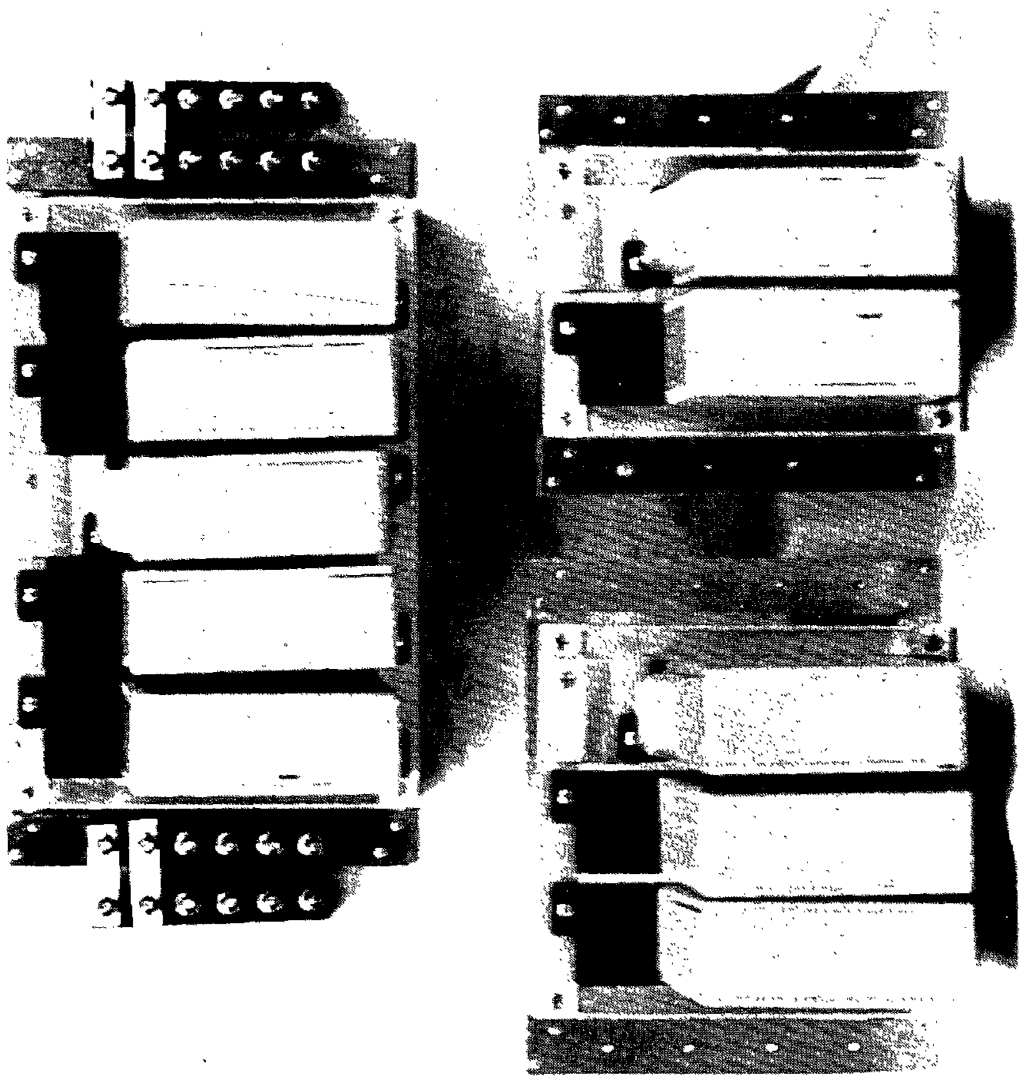


FIGURE 15. MOCKUP OF A SET OF 3 MODULES

Cost estimates indicate that for a single track crossing with flashing lights only and no complications, the modules would cost $1550 as compared to a conventionally wired plug-in relay cabinet at $1720, and a shelf relay assembly at $2400. The cost of relays is included in these figures. The cost estimate for a two-track installation which includes gates would be $3360 as compared to a conventionally wired plug-in relay equivalent at $3790 and a shelf relay assembly at $4980. Note that all three cost estimates include only the relays and related items. All other equipment in the relay case which is not affected by the type of module or relay, such as batteries, transfer relay, lightning arrestors, the case itself, etc., are not included. The costs do reflect conventional practice, such as use of No. 16 wire within modules. Should the railroads be willing to accept a printed circuit for wiring within the module, another $30 per module could be saved. These costs are summarized in a table in Table 3.

4. Development of a Set of Easily Serviced Plug-in Relay Rack Type Modules.

Of all of the existing technology, the use of plug-in relays offers the most economical solution to construction of grade crossing control systems, both in terms of money and of relay case space. One of the major objections voiced to the universal use of such relays has been that, with ordinary construction in which the sockets are mounted on a rack or in holes in the backboard and all wiring is behind the backboard, it is very difficult for one man to trouble shoot an installation. The maintainer cannot see the relays when he is working on the wires. Other than this, and the lack of standardization of relays between manufacturers, plug-in relays are considered a highly desirable component.

In light of the above, an effort was made to develop a solution to the one man service problem. It appears that such a solution is easy and practical. Figure 16 illustrates this concept while Figure 17 shows a mockup. By mounting the relays in racks which can swing out, access to both sides can easily be had and one man servicing is practical. It turns out that this concept is not new to the railroad signal field, since it has been used in some narrow bungalos at interlocking plants.

This concept was modelled, and a preliminary design made, from which a cost estimate was prepared. Two swinging racks would be required for up to a two track crossing with gates. The cost estimate for a single track assembly with flashers only is $1560 and a two track assembly with gates is estimated at $3250, both figures including the cost of the relays, sockets, and all wiring. Again, the costs

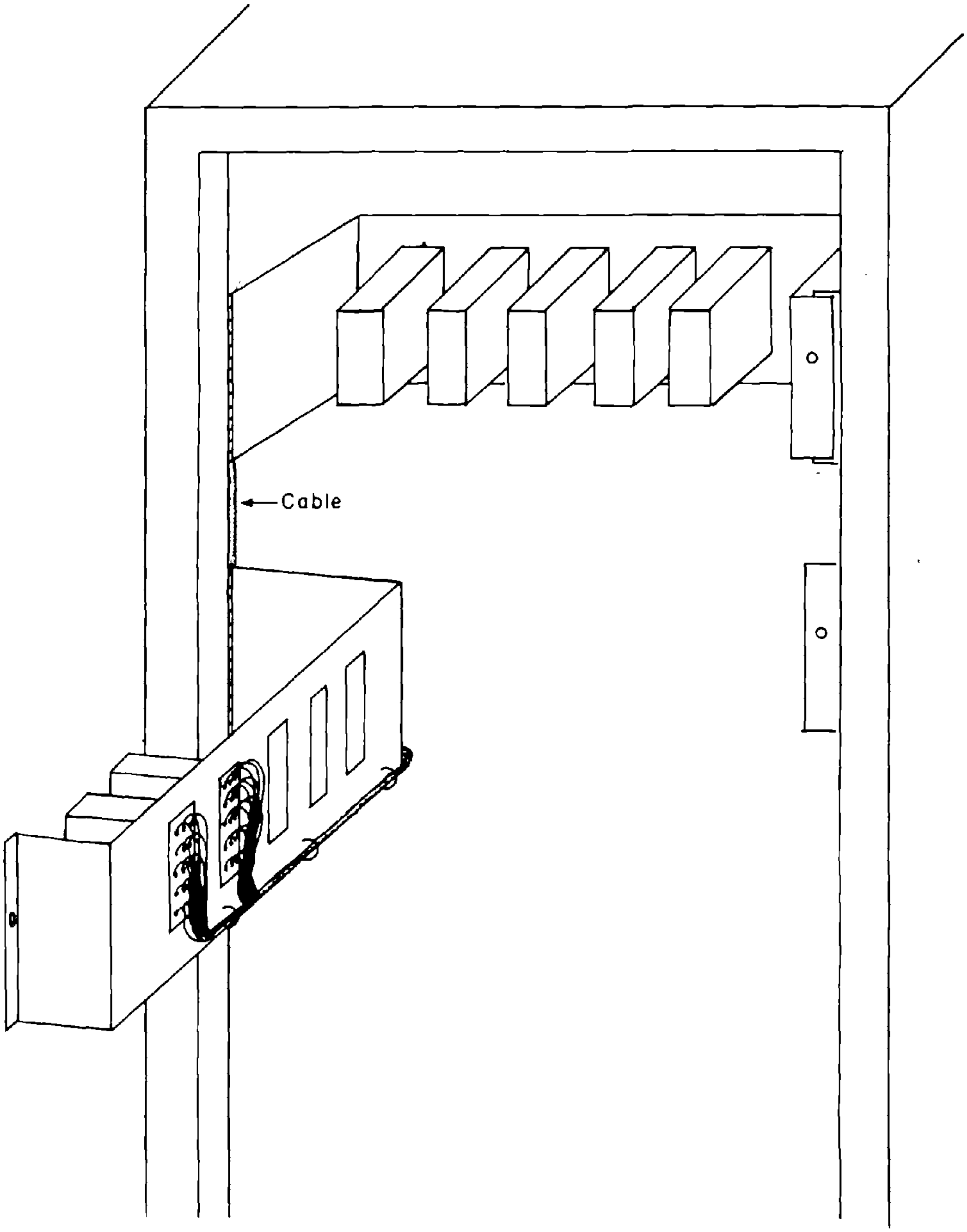


FIGURE 16. CONCEPT OF SWINGING MOUNTING RACK

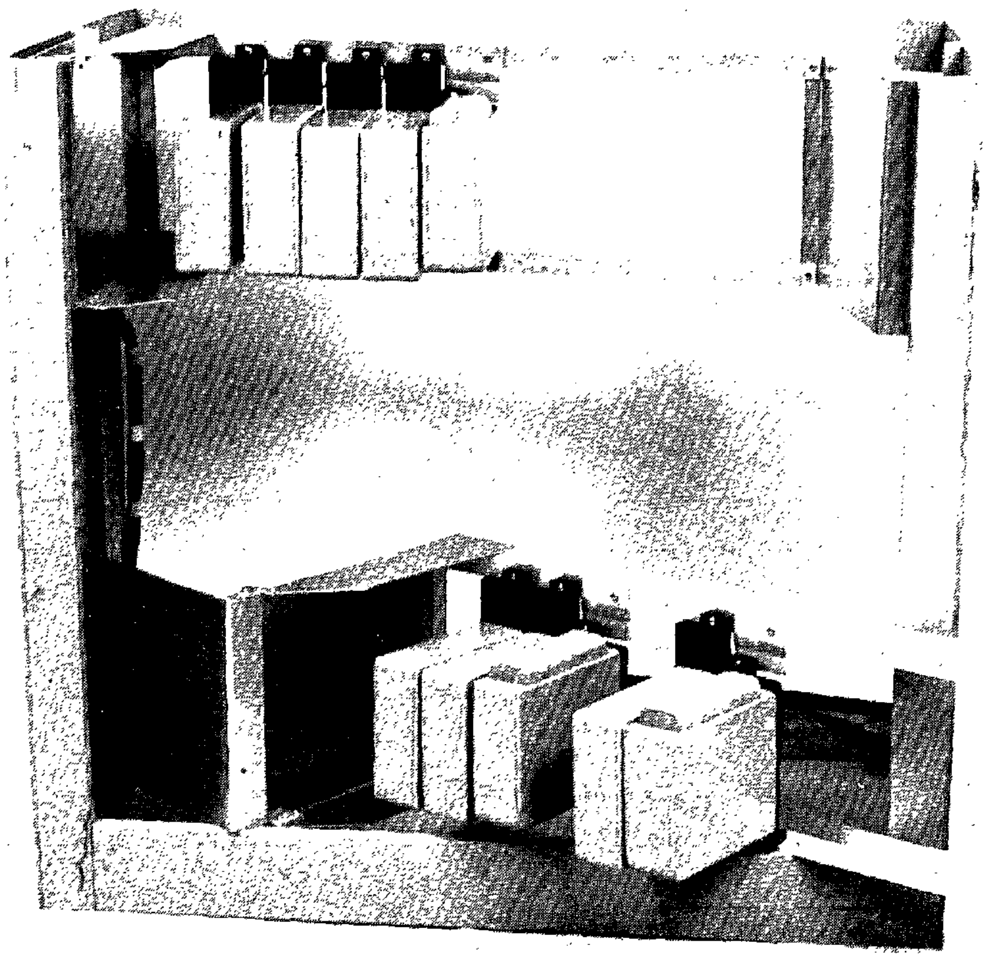


FIGURE 17. MOCKUP OF A SWINGING MOUNTING RACK

reflect only those parts of the relay case directly affected, and do not include the case itself, nor such things as the batteries, charger, lightning protection, etc. In this case also, if the railroad industry would accept a printed circuit board for most of the wiring, further savings of $25 per module could be effected. These figures will be found summarized in the table of Table 3.

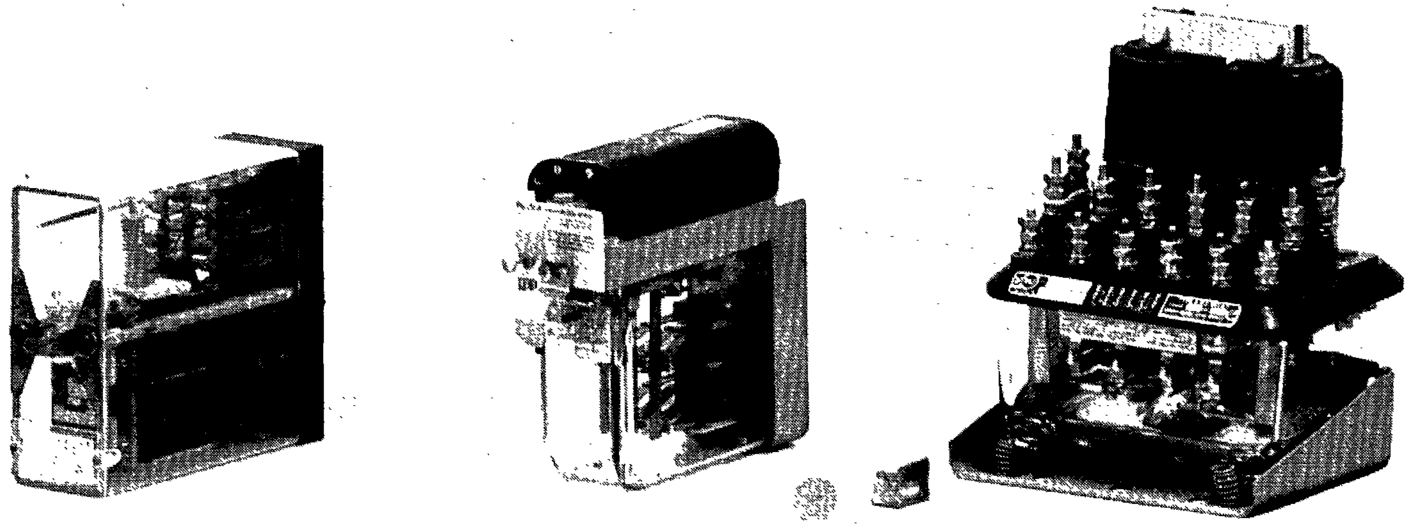
5. Use of Non-vital but Highly Reliable Relays

The substitution of different hardware for the presently used vital relays in a control subsystem package having the same functional inputs and outputs as present assemblies has been investigated. The resulting package would of necessity have at least the same fail safe reliability of present hardware.

There are two approaches which can be used. One is to obtain relays with the reliability and fail-safe characteristics needed using conventional circuits. The other is to use highly reliable relays in circuit configurations designed to protect against those types of failures which could be unsafe. The first approach requires a relay of extremely safe characteristics. Availability of such devices has not been investigated. The second is a different philosophical approach to circuit design, and reflects present European signal practice. Interestingly, a major Eastern railroad has three interlocking plants in New York State which have been in operation for some years, and which use a German-made relay circuited in this way. The results appear satisfactory.

Given that a suitable combination of relays and circuitry having the required reliability and fail-safe characteristics is obtainable, the space advantage and cost savings appear impressive. Figure 18 shows typical vital relays and a commercial relay. For comparison a 25 cent piece is also pictured. The non-vital relay can be seen to be much smaller. Conceivably the entire assembly of logic might be not much larger than a single plug-in type vital relay. Such a small unit would require interface relays to handle such power consuming circuits as those to the gate motor and to the flashing lights.

Without a detailed circuit it is of course very difficult to estimate costs. However, a rough circuit was prepared and the cost estimated. This was compared with the probable cost of using the same approach as that of the three interlocking plants described above, and was found comparable. It was estimated that the basic logic function assembly



LEFT TO RIGHT:
2 Vital Circuit Plug-in Relays, a 25¢ Piece, a Commercial Relay, a Vital Circuit Shelf Type Relay

FIGURE 18. TYPES OF RELAYS

would cost about $300, with the interface adding another $200 for a total of $500. Power requirements would be approximately the same as present systems.

Overall, this is a very attractive approach. It would, however, require an extensive development program which would include vigorous testing for several years to prove that the system was as fail-safe and reliable or better than present systems.

6. Development of a Solid State Substitute for Present Logic

Modern solid state technology and production techniques have produced extremely reliable and rugged solid state equipment. The basic logic of a grade crossing warning system is very simple. A single large scale integrated circuit unit (an LSI) an inch long and costing perhaps $40 would do the main part of the job. This would of necessity require considerable interfacing, both to operate the flashing lights and gates if used, and to tie into an existing signal system. Conceivably most of the electronics for Audio Frequency Overlay track circuits and possibly even motion detectors could be incorporated. The total package cost would probably be on the order of $100. The LSI would be a throw-away unit.

While this alternative has great potential, it also faces enormous problems. Making such a device acceptably immune to lightning-generated transients would be a major problem. An extensive development program and years of field testing would be needed to demonstrate that the unit was safe and reliable. It would, despite its advanced technology, be servicable by present maintenance personnel because service would effectively be limited to chip replacement. Development costs for the LSI are estimated to be between $100,000 and $500,000. This would raise serious economic questions in the present market.

TABLE 3 COST COMPARISON OF ALTERNATIVES 5 AND 6

	Single Track Flashing Lights Only	Double Track With Gates
Present Practice		
Shelf Relays	$2400	$4980
Plug-in Relays	$1720	$3790
Shelf Type Modules	$1550	$3360
Saving over present plug-in	$ 170 (10%)	$ 430 (11%)
Swing Rack	$1560	$3250
Saving over present plug-in	$ 160 (9%)	$ 540 (14%)

Cost Comparison of shelf modules and swing rack assemblies with present practice only affected costs are shown.

9. CHARACTERIZATION OF ALTERNATIVES

9.1 INTRODUCTION

Each of the alternatives previously defined will be characterized in terms of the constraints discussed previously. Of necessity the judgments made must be largely subjective, since in matters such as user acceptability, benefit/cost analysis, and some aspects of technical feasibility, a definitive evaluation cannot be made without an extensive development-test-evaluation program which is beyond the scope of this study. Each alternative is discussed below, and the characterization is summarized in Table 4.

9.2 ALTERNATIVE 1 - UNIVERSAL USE OF SHELF-TYPE RELAYS

This alternative meets all technical constraints and would be generally acceptable, but it is the least attractive economically. Since there are other alternatives which satisfy the technical constraints yet offer distinct economic advantage, this is the least desirable.

9.3 ALTERNATIVE 2 - UNIVERSAL USE OF PLUG-IN RELAYS

This alternative fully meets all technical constraints. It is in fact present practice on several progressive railroads. The only objections raised are that in conventional installations where the relay sockets are mounted on the backboard, two men are needed to efficiently trouble shoot problems and that some railroads would have a problem in inventorying spare parts because they now have large inventories of shelf relays. Since maintenance is a major cost to the railroads, this alternative is acceptable, but not desired by many lines.

9.4 ALTERNATIVE 3 - DEVELOPMENT OF STANDARD MODULES

This concept, since it uses standard plug-in relays meets all technical constraints as to safety, environmental resistance, etc. The design proposed would provide the circuits needed for adaptability to almost all signal systems. The approach uses existing technology and gains its economic advantage from substitution of factory assembly for field labor. Maintenance and spare parts will not present problems to many railroads. There is actually little that is different enough to create problems. The concept appears to be easily developed and proven and should find acceptance relatively quickly.

The development cost and test-demonstration costs should not be very high. This is a very acceptable concept. The only weakness is the relatively modest cost reduction it offers.

9.5 ALTERNATIVE 4 - DEVELOPMENT OF PLUG-IN RELAY RACK TYPE MODULES

This alternative is also based on existing technology. Plug-in relays are assembled into modules which can be swung out for service by one man. In this respect it meets all tachnical constraints. It has the same advantages as Alternative 3, and essentially the same disadvantages, including the low economic advantage. It would be likely to require the same level of effort to complete development testing and demonstration as the latter.

9.6 ALTERNATIVE 5 - USE OF NON-VITAL BUT HIGHLY RELIABLE RELAYS

This alternative requires a move away from present accepted practice, and as such would require overwhelming proof of safety and reliability before acceptance.

This alternative involves replacement of a known component with one not well known, and a system of such components replacing an old familiar one. The major problem will be to convince the railroads that the system is as "Fail Safe" as present practice. Because unsafe failures are so rare, this would require long periods of test. Because of the liability involved, the field tests must conclusively demonstrate safety, ease of maintenance, and reliability that are better than existing practice.

This alternative offers considerable economic advantage, even when the problem of added inventory costs is considered. There are several approaches possible, and further study is needed. The cost of the necessary development, testing, and demonstration program appears to be fairly large, but it is difficult to precisely define it at this stage.

9.7 ALTERNATIVE 6 - DEVELOPMENT OF A SOLID STATE SUBSTITUTE FOR PRESENT LOGIC

This alternative, which is the one farthest removed from present practice, offers the potential for the greatest cost reduction, but has the greatest problems. Since the resulting device would be relatively low in cost, both initial installation and maintenance would be small costs. However, there are major problems in the interfacing of the device to the track and to the vehicle warning devices as well as to signal systems. In addition the provision of effective transient protection will be difficult. In other aspects of environmental hardening there are no problems which modern solid state technology cannot solve.

Development cost is the major disadvantage of this alternative. Once the above mentioned design difficulties were overcome, a long test and demonstration program is required to prove conclusively that it was at least as reliable and fail-safe as existing hardware. Since unsafe failures are so rare, such a program would take several years. Only thereafter could the device be incorporated into the design of new installations.

It is very difficult to see how the high cost of development of this alternative could be underwritten except through some sort of joint program of the Government and the railroad industry.

It is apparent that this alternative is in need of a feasibility study to define the costs and benefits more closely. It is not a presently usable approach.

9.8 SUMMARY

In summary, alternatives 1 and 2 offer no significant advantages over present practice. Alternatives 3 and 4 are an advance over present practice which does offer a significant though small economic gain. Alternative 5 potentially offers a significant cost improvement, but requires extensive development, while alternative 6 requires a major design and development program which needs cooperative effort, hence is the most difficult to carry out. The characterization has been summarized in Table 4 for convenience.

TABLE 4 COMPARISION ACCEPTABILITIES

SUMMARY OF CHARACTERIZATION OF ALTERNATIVES						
ALTERNATE NO. Definition	1	2	3	4	5	6
Characteristics	Universal Use of Shelf Relays	Universal Use of Plug-In Relays	Development of Standard Modules	Development of Plug-In Relay Rack Type Modules	Use of Non-Vital Relays	Development Of a Solid State Substitute for Present Logic
Safety - Liability	Excellent	Excellent	Excellent	Excellent	Unproven	Unproven
Marketability	Good	Excellent	Good	Good	Poor	Very Poor
Degree of Environmental Hardness	Excellent	Excellent	Excellent	Excellent	Unproven	Unproven
Compatibility to Existing Systems	Excellent	Excellent	Excellent	Excellent	Feasible but Unproven	Feasible but Unproven
Present Acceptability	Very Good	Very Good	Good	Good	None	None
Effort Required to Gain Acceptance	Medium	Small	Medium	Medium	Great	Very Great
Probability of Early Acceptance	Medium	Excellent	High	High	Low	Very Low
Potential Reduction in Installation Costs	Negative	Small	Small	Small	Medium	Large
Potential Reduction in Maintenance Costs	None	None	Small	Small	Small	Large
Magnitude of Development Cost	None	None	Medium	Medium	Large	Very Large
Magnitude of Test and Demonstration Effort	None	None	Medium	Medium	Large	Very Large

10. CONCLUSIONS AND RECOMMENDATIONS - (CONTROL SYSTEMS)

In this section the conclusions to be drawn from the foregoing problem analysis will be discussed, and recommendations will be made. Reference should be made to Table 4.

10.1 CONCLUSIONS

It can be seen from the foregoing that the present practices which control the design and hence the cost of grade crossing warning systems do have a potential for small but significant cost reductions. The present technology has evolved over about a hundred years and has been the result of much careful thinking and many mistakes. It is therefore based on a solid foundation, and is not to be changed without careful engineering study. However improvements can and should be made. These changes should be evolutionary in nature, in order to take fullest advantage of the fund of knowledge already gained.

10.2 RECOMMENDATIONS

On the basis of the constraints, cost estimates, and characterization previously considered, it is recommended that the following steps be taken to improve the cost effectiveness of grade crossing warning systems.

1. Develop the two modular concepts, alternatives 3 and 4. This requires that the design be finalized, pilot models built, and a test installation made.

2. Encourage development of an American National Standard Plug-in type vital circuit relay. This can best be achieved through a cooperative effort involving the Government and the railroad industry.

3. Initiate a study to establish more precisely the technical viability, the probable development costs, and the potential installation costs and benefits to be derived from the use of non-vital but highly reliable relays and appropriate safety circuitry.

4. Explore further the technical and economic feasibility of the development of a solid state logic unit, particularly in respect to the magnitude of the development effort required in comparison to the probable benefits.

11. TOPICS OUTSIDE THE SCOPE OF THIS STUDY

11.1 INTRODUCTION

In the course of this study, a number of areas were identified in which, in the opinion of the authors, further research might offer significant benefits. These topics, which are outside the scope of this project, have not been explored in depth, and conclusions or recommendations concerning them are not appropriate. However, they are presented here in order to stimulate consideration of their possible relevance to the goal of improved crossing safety.

11.2 THE ABSENCE OF A FAIL SAFE VEHICLE WARNING DISPLAY

It is a notable peculiarity of the vehicle warning devices used at grade crossings is that, unlike all other railroad signal devices, the absence of a signal is not the most restrictive indication, but the least. It is universal railroad signal practice to interpret the absence of a signal as a stop indication. At a grade crossing, the vehicle driver is required to stop only when a signal is activated. He may proceed in the absence of a signal. Technically, he is expected to do so with caution, but this is not always adhered to. It appears reasonable to investigate the possible benefits of a better warning system in which the driver can distinguish an inoperative warning system from an operative (but not activated) one.

11.3 CREDIBILITY

When a driver approaches a grade crossing and finds the warning system activated, he stops and waits. He will not wait indefinitely however. After about a minute he will edge up to the crossing, and if there is no obvious danger, will ignore the warning and cross. Note particularly the word "obvious". In one instance observed by one of the authors, a train waiting to enter a yard was stopped with the engine just clear of the crossing. What made this latter example particularly illustrative was that one set of flashers was protecting a crossing of three parallel railroads. A high speed train approaching on either of the other lines would have set the stage for a serious accident, because drivers approaching the crossing saw the stopped train, saw the "obvious" reason for the warning, which was "obviously" false, and did not even slow down or look both ways, before driving across the track.

Consider another situation. A local freight comes into a town at about the same time each day and does extensive switching, in the process activating the grade crossing warning signals unnecessarily on many occasions. People who regularly use the affected crossing observe this and quickly learn to ignore the signals. But then the day comes when the warning is activated for a high speed freight. The local people still "know" the warning is due to the local freight, and may be false. The potential for a serious accident is obvious.

What may not be as obvious in the above situations is that the drivers learned that they could ignore a grade crossing warning. They will, when confronted with such a warning 50 miles away have less respect for it, increasing the accident potential.

Railroads have taken many positive steps to improve the accuracy of their warning devices. These include use of motion detectors, constant-warning-time devices, and operating rules which require crews to flag traffic across the tracks. However, research directed toward identification of the potential benefits and alternative means of achieving reduced unnecessary delays and activations appears to be warranted.

11.4 ALARM SYSTEM FOR UNWANTED WARNING ACTIVATION

The unwarranted activation of the vehicle warning devices due to train operation which was described above is basically the result of the limitations in the sophistication of the control subsystem. In addition, unwarranted activation of the warning devices can result from vandalism or from actual hardware failure. Unfortunately it is also true that it is impossible to distinguish some of these failures from normal operation, at least for some period of time.

It is obvious that the sooner the maintainer can reach the scene, the shorter will be the duration of the false warning. However, the railroads generally must rely on engine crews, local employees, or the public to call attention to such false operation. This is not always satisfactory. Engine crews, aside from being occupied with other duties, cannot always tell whether the warning system was activated by their train or had been on for hours. The long interval between trains on some lines also tends to reduce the effectiveness of this approach. The modern trend to centralization of operations has removed most of the local railroad employees who could detect a false activation or through whom the public could report such an event. The use of indicator lights on relay cases has been tried, but these lights have been subject to vandalism and it has been very difficult to get train crews to see and report when the lights are on.

What appears to be needed is a simple, reliable, and cost effective system which can detect an unwarranted activation as soon as possible and send an alarm to a point on the railroad from which corrective action can be initiated. Because of the great variety of grade crossing warning systems, the problem of recognition of a false activation, the absence of line wires in some areas, and the long distances over which the alarm may have to be transmitted, it seems likely that several systems would be needed.

11.5 DEVELOPMENT OF A TRAIN INDICATOR SYSTEM

In the course of the development of the alternatives for this project, considerable thought was given to the functioning of the grade crossing warning system. The plot of Figure 19 was made. This shows a typical curve of stopping distance vs. speed for a train, and the distance travelled in 20 and 30 seconds time at constant speed. The scales are not important to this concept. What is important is that there is a critical speed below which the train can stop if the crossing warning fails to function and the train's engineer can be notified soon enough. There are many hundreds of crossings where the fastest train approaches below this critical speed, which is in the range of 20 to 30 mph in many cases. If a device such as a train indicator were placed in such a way as to properly notify the engineer of the condition of the crossing warning system, the system becomes effectively fail safe even though the components are not. This opens up a large area for cost reductions. The system is fundamentally safe even if there is no standby power at all, so long as the train indicator gives its warning to the train crew. This approach might allow simpler train detection devices (for example, magnetometers) to be used, possibly leading to substantial cost reductions. Systems of this type have had very limited use in the United States, but are in quite general use in Europe, even on high speed trackage.

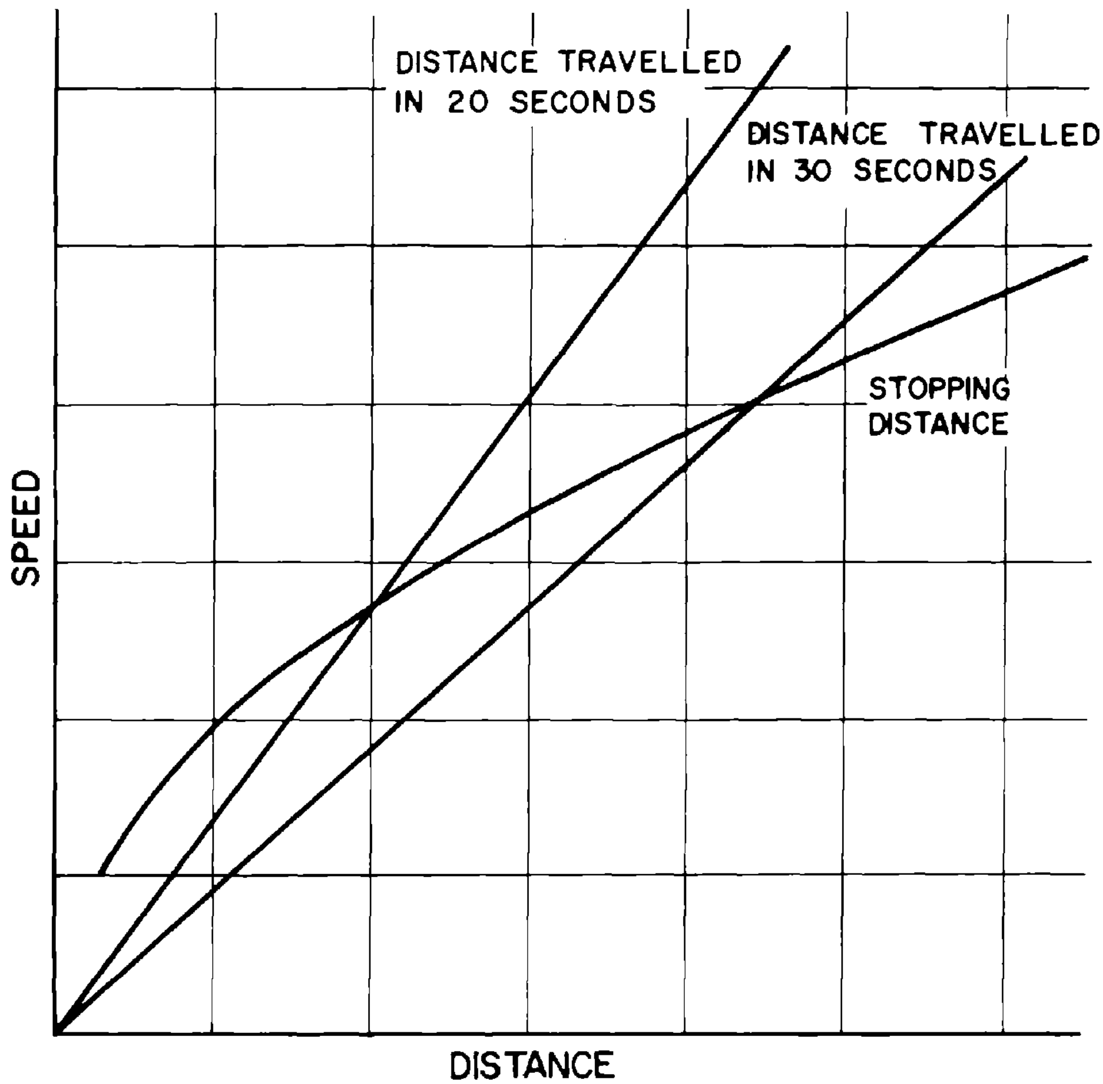


FIGURE 19. SPEED-DISTANCE CURVE

12. PART III. RELAY ALTERNATIVES

This report records the results of a study of the technical and economic viability of using non-vital circuit components in the assembly of automatic grade crossing warning system circuits. The scope of this study has been limited to investigation of techniques and components which are presently available. The principle focus has been on possible alternatives to the conventional vital relay. A review of European practice has been made to determine if there are components in use in Europe which might be applicable to American practice.

This report contains an Introduction (Section 13), followed by a review of Conventional United States Practice (Section 14). The latter contains a brief overview and a detailed functional description of two of the most common circuits used for new applications, followed by a discussion of conventional hardware.

The problems on which this study focuses are reviewed in Section 15. Included are a discussion of the Mean Time Before Failure (MTBF) and Mean Operations Before Failure (MOBF) of vital relays. There is also a discussion of the track circuit and its associated track relay, which is a critical component. Another problem discussed is that of Electrical Transients. Transients are a key problem, since one of the characteristics which clearly distinguishes the vital relay from other relays is that the front (normally open) contacts are made of material which cannot weld. Without electrical transients of sufficient magnitude, welding cannot occur.

A comprehensive review of European practice has been made. This is covered in Section 16. There is a review of the background of European Practice. It is noted that the development of railroads occurred in an area already densely populated. Construction was of a higher order, railroad train density and road vehicle density were both substantially greater, making both signal system development and grade crossing protection development more urgent. This led to manual systems for both, as automatic technology was not yet up to the demand. As a result a different type of relay, called a safety relay, and a different circuit design philosophy based on checking or proving circuits has arisen. Train detection is most commonly by a mechanical trip called a "pedal", a device which has virtually no chance of use in North America. The gate operating mechanisms are frequently hydraulic. It was found that the above mentioned safety relay is a component worth further consideration.

The alternative components considered will be found discussed in Section 17. There is a general overview (Section 17.1) and a discussion of the limitations imposed by compliance with existing standards (Sec. 17.2). This is followed by a review of some less attractive components (Sec. 17.3) and a discussion of the characteristics of the telephone relay (sec.17.4). This relay has some desirable properties, but is found not suitable for this application. After a brief and negative consideration of the several non-vital relays manufactured by present vital relay suppliers (Sec. 17.5), the European signal relay is discussed (Sec. 17.6), as is the Mercury Wetted Reed Relay (Sec. 17.7). The latter two devices are found to be likely candidates.

In Section 18 there is a discussion of circuits which includes some general comments (Sec. 18.1), and a review of signal circuit design principles applicable to grade crossing control circuits (Sec. 18.2). The application of these principles and the possible application of redundancy is discussed (Sec. 18.3). Redundancy is found to be not economically advantageous.

In Section 19 the alternatives developed are considered. After a brief general comment (Sec. 19.1) the alternatives are considered (Sec. 19.2). These included a package installation (not presently possible), the possible use of the "C" circuit (which is described in detail), development of low cost vital relays (found uneconomical), the possibilities of transient protection specification modification, and the results of an inspection of an existing American all-relay interlocking installation using European safety relays. This is followed by a detailed discussion (Sec. 19.3) of Alternative I, a system using European safety relay which is available in this country. A circuit design is presented, including all the modules needed for a complete system with or without gates. This is followed by a detailed description of a system using mercury wetted reed relays (Sec. 19.4). These relays have limitations in that they can freeze, are position sensitive, and must be conditioned on starting, but exhibit such superior reliabiltiy that they make a viable alternative possible. A comparison of alternatives is made (Sec. 19.5), and it is found that practical alternatives have been developed.

The conclusions and recommendations are summarized in Section 20.

13. INTRODUCTION

13.1 SCOPE

The scope of this study is the investigation of the economic and technical viability of using non-vital circuit components in the fabrication of active grade crossing protective circuits. The particular focus of the study is the possible alternative types of relays and a review of European practice.

The economic and technical viability of the substitution on non-vital circuit components in the fabrication of active grade crossing warning systems essentially hinges on the development of an assembly having safety equal to or better than present assemblies using the conventional vital relay. The resulting assembly must be enough lower in cost to justify the added expense of stocking spare components different from standard signal components. It must also have a service and maintenance cost lower than present practice. An important consideration in this respect is the degree of immunity to damage by electrical transients.

13.2 TYPICAL SYSTEMS

Automatic grade crossing warning systems occupy a unique position at the point of intersection of two very different transportation modes, rail and highway, and as such have two faces, one toward each mode.

The automatic grade crossing system as seen by the driver of a highway vehicle is highly standardized. Over 85% of all such systems use two or more pairs of alternately flashing red lights, and at many locations these are augmented by automatic gates. The standardized flashing light warning may be further supplemented by other devices such as illuminated signs and preempted traffic signals to further increase safety. While the flashing lights may be mounted on cantilever arms or bridges to place them where they may be more readily seen by the driver, the warning is common and control hardware falls essentially into one of two classes, flashing lights only, or flashing lights with gates.

The railroad face of the automatic grade crossing warning system has many variations. These are made necessary by the presence of one, two, or more main tracks along with sidings, switches, and other track configurations, the operating practices in the vicinity of the crossing which include station stops, single or bi-directional operation, and switching; and the presence of a signal system in one of numerous variations. However, since the presence of additional tracks simply requires repeating one group of components, and since the inclusion of switches and other variants does not change the basic equipment requirements, the following study is limited for clarity to a single bi-directional track without switches or other complications within the limits of either approach. Since much high speed trackage is signalized, provision for signal system interface will be considered.

14. CONVENTIONAL PRACTICE

14.1 AN OVERVIEW

In the United States, automatic railroad-highway grade crossing warning systems, with minimal exceptions, basically conform to the standards of the Association of American Railroads Communications and Signal Section. While there is some diversity among these installations in the various states as a result of interpretations and modifications by the cognizant state regulatory authorities, there is a far larger measure of agreement and a very substantial degree of similarity in functional requirements. The few exceptions are generally to be found on rapid transit and industrial railroads, and will not be considered here.

That part of the overall automatic grade crossing warning system directly within the scope of this study includes the circuitry and components which detect the approach of a train, activate, and if necessary sequence, the operation of the vehicle warning devices, and deactivate them at the proper time.

While the overall operation of the system is rather simply stated, the complications in detail can be substantial. The additional components and circuitry needed effectively to warn vehicles at a specific crossing, where problems related to approach speeds, street layout or other traffic conditions exist, and the complications introduced by railroad operating practices and the presence of sidings, crossovers, switches, etc. can be major indeed. Even the presence of other grade crossings presents difficulties. It should be remembered that the distance to the "ringing point" (the point of first detection of an approaching train) is 1835 feet if a 25 second minimum warning is to be provided where the maximum train speed is 50 miles per hour. The presence of another crossing within this distance would require special design attention. Situations such as this are among the many causes of engineering problems which plague grade crossing warning system design and which have often led to a new design for each crossing.

What is very important to recognize is that while there are many complications in design, many of these result in quite superficial changes to the circuitry of the crossing control logic. An example of this is the substitution of a line relay for a track relay. A properly designed set of standard circuits will accommodate such changes, and be applicable to an estimated 60% of all installations.

14.2 COMMONLY USED CIRCUITS

There are many different circuit configurations currently in use for automatic grade crossing warning systems. However, there are only a few which are in common use for new installations. It is general practice to provide full bi-directional operation for all tracks, even where there is an established current of traffic as on each track of many double track lines. This is done because modern maintenance of track requires that the track be taken out of service, and the need for manual crossing protection for reverse running is burdensome.

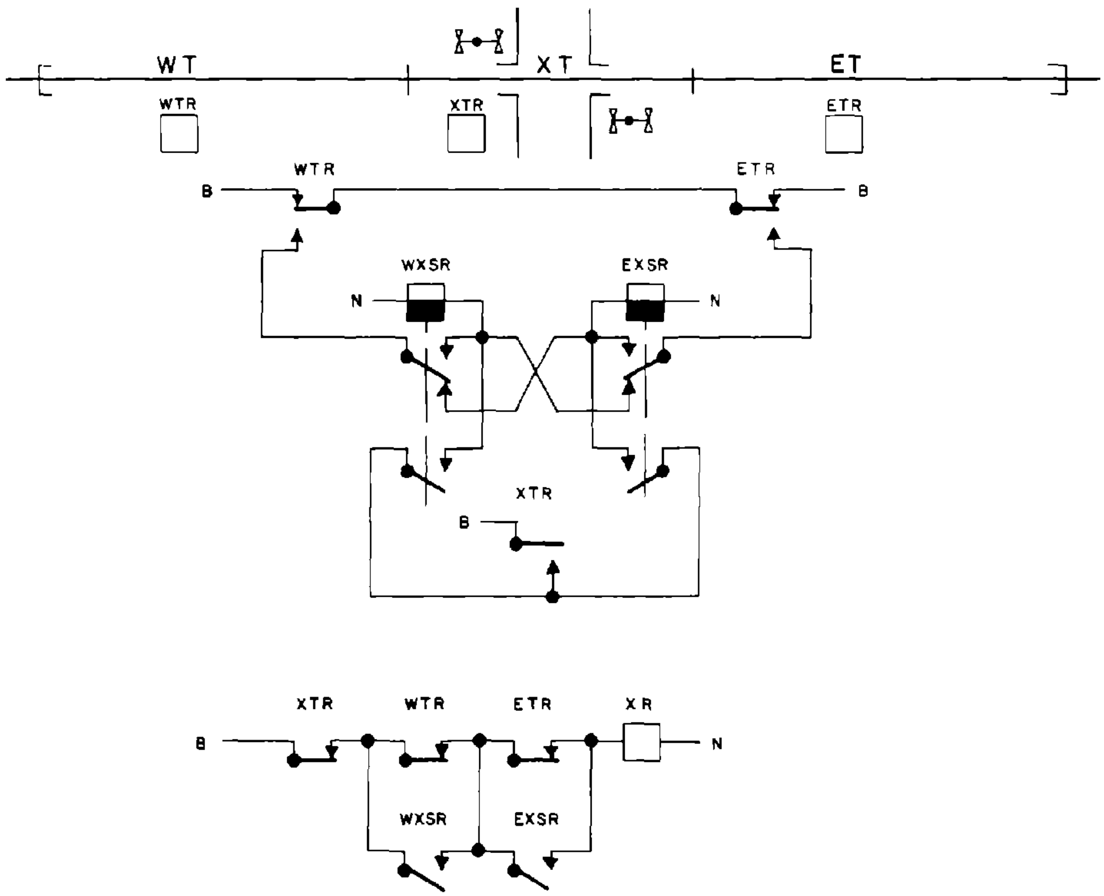
The circuits used for this bi-directional operation are fairly well standardized. Interlocking relays are no longer used in new installations. The systems using one of the several arrangements requiring only two DC or AC track circuits are likewise no longer used for new installation work. Audio overlay and motion sensing systems are in general use. However, the former has an output that is the direct equivalent of a line control circuit, and the latter is a complete device in and of itself, requiring virtually none of the logic being considered in this study.

All of the circuits discussed in present practice will be found in the publication "Typical Circuits Representing Current Practice for Railway Signalling" of the Communication and Signal Section of the Association of American Railways.

The choice of the particular circuit to be used in an installation is a matter of engineering judgment. This choice is influenced by a knowledge of local conditions and past experience, among other things. No attempt will therefore be made to comment on the advantages and disadvantages of individual circuits.

In discussing circuits, only that circuitry associated with the track, the directional relays, and the crossing control relay will be reviewed. The circuitry used to flash the lamps, and that needed properly to sequence the gate operation where gates are used is substantially standard and is independent of the control and directional functions.

The circuit which is probably the most used configuration is shown in Figure 20. This configuration uses three track circuits, a west approach (WT) circuit, an Island or Crossing Circuit (XT), and an east approach (ET) circuit. Referring to Figure 20, this operates as follows:



Ref. AAR Sig. Sec. Dwg. 8053C
Scheme I Stick Circuit

FIGURE 20. A COMMON CIRCUIT

Step 1 Crossing circuit is at rest, track relays, ETR, WTR and XTR, as well as crossing control relay, XR are picked up. Directional stick relays WXSR and EXSR are dropped away.

Step 2 Eastward train enters WT track circuit. WTR drops away. Positive energy (B) is connected through ETR front contact, WTR back contact and WXSR back contact to the coil of EXSR. EXSR picks up. The circuit from B through front contacts of XTR, WTR and ETR to XR is broken at open front contacts of WTR and WXSR in parallel, causing XR to drop away to start warning system operating.

Step 3 Train enters XT track circuit. XTR drops away sticking EXSR from B through XTR back contact and front contact of EXSR to EXSR relay coil. XR relay circuit is also opened at XTR front contact.

Step 4 Rear end of train leaves WT track circuit. WTR picks up. EXSR is sustained only by XTR closed back and EXSR closed front contacts. XR remains dropped away due to open circuit at XTR front contact. Note: Step 4 occurs at this point in the sequence only if the train is short enough to occupy XT track circuit exclusively, otherwise it will occur after Step 5.

Step 5 Train enters ET track circuit. ETR drops away. When Step 4 has occurred, this causes EXSR to remain picked up from B through WTR front contact, ETR back contact and EXSR front contact to EXSR coil. Until Step 4 is complete, EXSR sticks up in accordance with Step 3.

Step 6 Rear end of train leaves XT track circuit. XTR picks up. EXSR remains stuck up as in accordance with Step 5. XR picks up from B through XTR front, WTR front and EXSR front which shunts ETR open front contact. This stops the protection from operating. Note: If a second train enters WT track circuit and passes across the crossing into ET track circuit before the first train leaves the ET circuit, the second train will start the warning system as usual, but the presence of both trains will preclude establishing direction for the second train since EXSR will be dropped away when the second train enters the WT track circuit.

This feature is of value since it breaks the control circuit of the stick relay open if a track relay fails to pick up after a train, when another train passes in the same direction.

Step 7 The rear end of the train now leaves the ET track circuit. ETR picks up. The circuit from B through WTR front contact, ETR back contact and EXSR front contact to EXSR coil is opened at ETR back contact. EXSR drops away. XR relay remains picked up from B through XTR front contact, WTR front contact and ETR front contact instead of EXSR front contact now open.

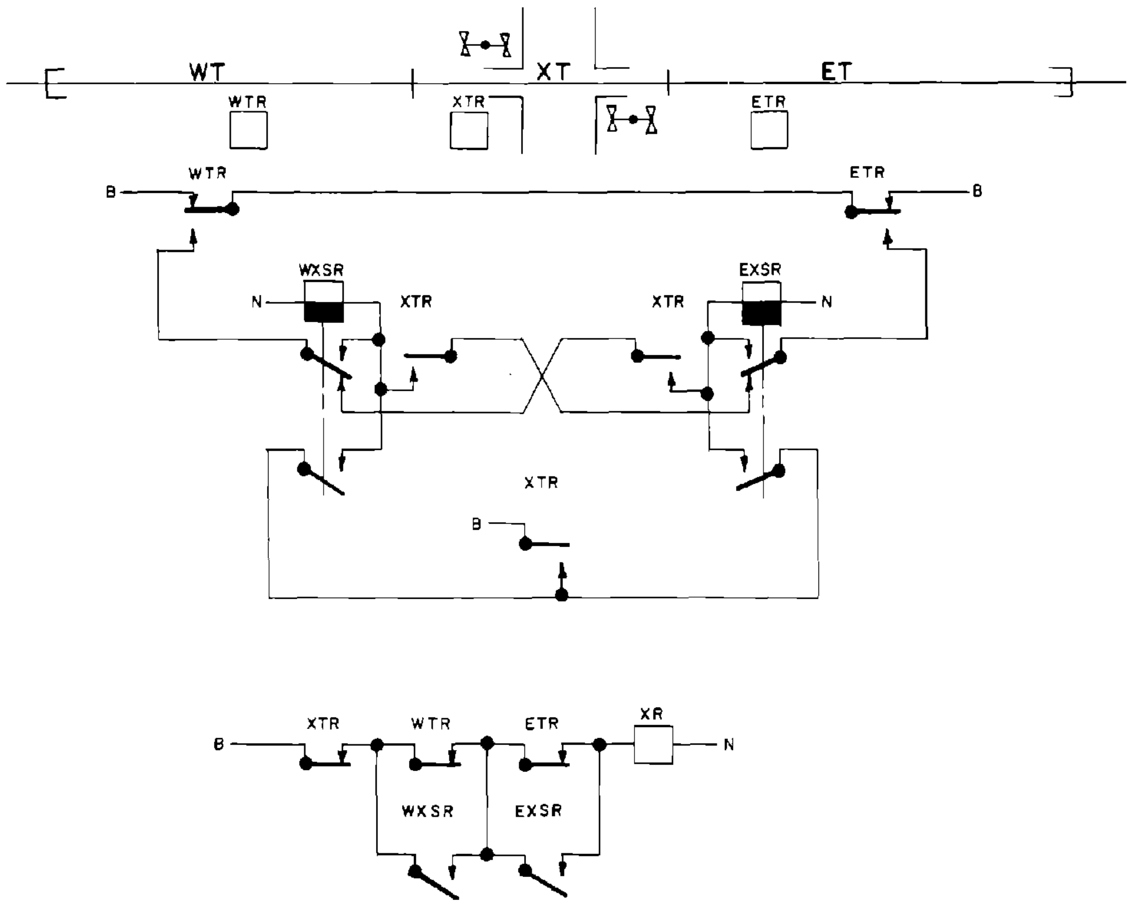
A second and also very common circuit is that shown in Figure No. 2. This is basically the same as the previous circuit, but has two additional XTR contacts which interrupt the pickup circuits to relays WXSR and EXSR. This functions as follows:

Step 1 Crossing circuit is at rest. Track relays ETR, XTR and WTR, as well as crossing control relay XR are picked up. Directional stick relays EXSR and WXSR are dropped away.

Step 2 Eastward train enters WT track circuit. WTR drops away. Positive energy (B) through XTR front contact WTR front contact and ETR front contact to XR coil is interrupted at WTR open front contact. XR drops away to start warning system operating.

Step 3 Train enters XT track circuit. XTR drops away. B is connected through ETR front contact, WTR back contact, WXSR back contact and XTR back contact to EXSR coil. EXSR picks up. EXSR stick circuit from B through XTR back contact and EXSR front is also established. XR relay remains dropped away due to XTR open front contact.

Step 4 Rear end of train leaves WT track circuit. WTR picks up. EXSR is sustained by the stick



REF AAR SIGNAL SECTION DWG. 8090B SHEET NO. 3

FIGURE 21. AN ALTERNATIVE CIRCUIT

circuit established in Step 3 only. XR remains dropped away due to XTR open front contact only. Note: Step 4 occurs at this point in the sequence only if the train is short enough to occupy XT track circuit exclusively, otherwise it will occur after Step 5.

Step 5 Train enters ET track circuit, ETR drops away. As soon as Step 4 has occurred, EXSR is stuck up from B through WTR front contact, ETR back contact and EXSR front contact to EXSR coil. This is in addition to stick established in Step 3.

Step 6 Rear end of train leaves XT track circuit. XTR picks up. EXSR remains stuck up as established in Step 5. The circuit from B through XTR front contact, WTR front contact and EXSR front contact bridging ETR open front contact to XR coils picks up XR to stop warning system operating. Note: If a following train should enter the WT track circuit and pass over the crossing before Step 7 occurs, the second train would operate the warning system as usual though the presence of the two trains would preclude the establishment of direction for the second train, since EXSR would drop away when the following train enters the WT track circuit.

Step 7 Rear end of train leaves ET track circuit. ETR picks up. EXSR stick circuit established under Step 5 is broken at ETR open back contact. EXSR drops away. XR is sustained from B through XTR front contact, WTR front contact and ETR front contact (now closed) instead of EXSR front contact (now open).

14.3 CONVENTIONAL HARDWARE

For all practical purposes all present installations of automatic grade crossing warning systems use vital relays. The complete system may include electronic components for such functions as audio frequency overlay, motion sensing and the like, but the output of the electronic equipment drives a vital relay which is part of the sequence and logic function. For purposes of this study it is therefore possible to ignore the electronic equipment. Insofar as the logic of operation is concerned, it makes no difference whether the input relay is a track relay controlled directly from the track circuit, a line relay controlled by a line, or a line relay driven from an electronic unit. The latter two cases may even use the same relay.

"Vital Relay", a term which will be found throughout this report, is commonly used in the literature and spoken word by those associated with American railway signalling. In railroad signal parlance, this term denotes a relay of the type whose design has been refined over many decades to minimize failures, and particularly to minimize those failures which might cause a front contact to remain closed with the coil deenergized.

Failure of any relay, whether it is vital or non-vital, to drop away and open its front contacts when deenergized can result from mechanical binding of the armature, loss of spring tension where a spring is used to open the front contacts, magnetic problems, or the welding of contacts.

Mechanical binding of the armature is prevented by careful design and proper production quality control. Life testing of relays will usually show any such problems up.

The possibility of loss of spring tension as a cause of failure to drop is eliminated in a vital relay by using gravity instead of a spring. This does make the relay position sensitive, and while accidents have resulted from relays being turned over, they have been extremely rare.

Magnetic problems which cause failure to drop out result from development of residual (i.e. permanent) magnetization of components in the magnetic circuit. Standard specifications for vital relays require a .013 inch residual gap, maintained by use of a bronze residual stud, and a backup stud or studs guaranteeing a .010 gap. The component parts of the relay magnetic structure are very carefully made and heat treated to minimize development of residual magnetism. Failures of vital circuit relays due to this type of problem are exceedingly rare.

The contact welding problem is one which has been met head on in the design of vital relays. Front contacts are made of non-welding materials. One of the two contacts is made of carbon or a silver impregnated carbon. The other is metallic, usually silver. These contacts will not weld. Back contacts are both silver, and can weld. However, this is a safe failure because of circuit design methods used.

It is important to recognize that it is critical to safe operation that the track circuit relay drop (go to the deenergized position) when the track circuit is shunted by a train. There is no practical way of checking on the operation of this relay, particularly in grade crossing warning systems. If trains travel smoothly along a track, it is possible to check the sequence of operation of successive track circuits, but all kinds of unusual moves are possible, and with the possible exception of rapid transit lines, are likely to happen. Further, as applied to grade crossing warning systems, it would require additional track circuits, the cost of which would wipe out all savings from other sources.

While there are specifications for vital relays which cover some of the more critical points, the great difficulty in establishing that a design or a change in design is as safe as previous designs has placed a great emphasis on competence of design and quality control in manufacture. Acceptance testing can reveal only some of the possible problems with a relay. Such tests will not reveal some of the more exotic problems that can cause relay failures, particularly those which occur only after extended use. The railroads have therefore tended to rely on suppliers who have been in the business for long periods of time and whose product has been found consistently good.

Except for those features which characterize a vital relay as such, the relays used in automatic grade crossing are for the most part ordinary DC neutral relays. The contact arrangements vary, some require coil slugs to control operating characteristics, etc., but those are not characteristics found only in the vital relay. The interlocking relay (a device containing two relays which are mechanically interlocked so that if one is down, the other can only drop halfway) is no longer used in new installations. The flasher relay is of a very special design. However, today it is often replaced with a vital relay driven by an electronic flashing device, and can also be replaced by a pair of relays which operate as a multivibrator. The track relay, however, is another matter. This relay must have two characteristics, a low operating power and a high ratio of dropout to pickup. In addition, there is a special type of relay, called a biased neutral relay, which has a magnetic structure containing a permanent magnet. This makes the relay almost totally insensitive to current of one polarity while responding normally to that of the other. In addition the ratio of dropout to pickup current is raised. This type of relay has no commercial equivalent. Where local conditions require its use, there is no alternative to the use of a biased type vital relay.

Present hardware can be seen as a highly developed, thoroughly tested technology which for the most part has its equivalent components in other fields.

15. PROBLEM DEFINITION AND ANALYSIS

15.1 GENERAL

This study is directed toward determining if there are practical and beneficial alternatives to the present vital relay in the assembly of automatic grade crossing warning systems. To be viable, any such alternative must equal or exceed present safety standards, and must be substantially less costly.

The matter of safety is paramount. But it is necessary to define this in less subjective terms. The ordinary measures of system reliability are Mean Time Before Failure (MTBF) and Mean Operations Before Failure (MOBF). However, in a railroad system of this type there are really two such measures, one the MTBF or MOBF to a failure of any sort, and the second and more important one, the MTBF or MOBF to an <u>unsafe</u> failure. It has been found extremely difficult to get any data on which to base determination of these figures.

With regard to the components of the grade crossing warning system, the most critical is the track relay. This relay must drop when the track circuit is shunted. Because of various limitations in its operation, including low power, there is virtually no way of checking its operation. It is not possible to use a sequence logic type of check at a grade crossing because of the probability of unusual train movements. The problems of the track circuit and track relay will be discussed in detail, as this represents one of the major problems to be dealt with.

A problem which must be faced in any design of a system of control such as that for a grade crossing which is to be installed outdoors, is the problem of electrical transients. Lightning is a major source of these, but switching transients and fault currents in high tension power lines can also create severe problems. Such externally generated surge currents are the primary cause of contact welding, and are a reason for use of the carbon or silver impregnated carbon front contacts on vital relays. This subject will be discussed further below.

15.2 MTBF AND MOBF

To compare the alternative systems with present automatic grade crossing warning systems, a measuring method is needed. This should be as non-subjective as possible. The Mean Time Before Failure (MTBF) and Mean Operations Before Failure (MOBF) are generally accepted measures of the required type. They are applicable to this study provided the MTBF and MOBF of existing practice is known or can be reasonably estimated.

As was pointed out above, the paramount importance of safety in the type of system under study leads to the existence of two such measures, one to a failure of any sort, and the second to unsafe failures.

A study has been made to define the MTBF and MOBF as well as the MTBF and MOBF to unsafe failures. The latter will be referred to as MTBF/U and MOBF/U to distinguish them from the former, which are of course the normal or conventional measures of reliability.

It was rather quickly established that MTBF or MOBF on present equipment was not available. The liability problems involved made knowledgeable people unwilling to reveal any data which may have been accumulated. There is good reason to believe that in fact little or no such information has actually been assembled. It was rather difficult to get many responsible people to admit that any such failures occur. They are reluctant to use the word at all. A further problem is the relatively few operations per day of equipment of the subject type. Few railroad lines support more than 50 trains a day. Railroad signal relays are normally checked, and serviced if required, every two years. Life expectancy is extremely long in time (40 to 50 years). Yet at 50 trains per day there are less than 1 million operations in 50 years.

In an effort to get some kind of a basis for estimating the needed reliability measures, a large rapid transit operating agency which uses vital relays in its signal system was approached.

Because of the large number of movements, these relays are subjected to much greater use than is normal, and it was hoped that data could be obtained. An estimate was obtained that a failure of a relay occurred about once in 20,000,000 operations, with an unsafe failure estimated at under 1% of all failures. This is an MOBF of 20×10^6 and an MOBF/U of 20×10^8. At even 100,000 operations a year almost 300 per day, the MTBF is 200 years and an MTBF/U of 20,000 years, a number so small as to be statistically indeterminate.

In an attempt to collect further information, a major suburban commuter railroad was contacted. Again, it was impossible to get exact factual data, but it was determined that of the roughly 20,000 vital relays in use, about 500 were serviced by the relay shop per year. If all were shopped for failure, this would be an MTBF of 40 years. However, included in the 500 relays are many which are serviced for reasons other than an in-service failure (equipment replacement or change in operating specification, to name two). It seems probable that the MTBF is as least 100 years. No data on unsafe failures could be obtained.

In view of the lack of factual data, one is reluctant to state any numbers for reliability, but in view of the need for such a basis, it seems reasonable to use the rapid transit figures.

These are:

MTBF	200 years	MBTF/U	20,000 years
MOBF	20×10^6	MOBF/U	20×10^8

It must be emphasized that, since hard statistical data is not available, it was necessary to base the above figures on estimates of responsible signal engineering personnel. These figures should therefore be used with great caution. They do, however, tend to substantiate the general assumption that these are extremely reliable devices.

15.3 THE TRACK CIRCUIT AND THE TRACK RELAY

The key input element to the automatic grade crossing warning system is the track circuit and its relay. To better understand the limitations on the operation of this relay, it is necessary to understand the operation of a track circuit and see how this operation is affected by weather and other factors.

A track circuit at first view is a disarmingly simple device. In its simple DC form it consists of a battery, a relay and a section of track arranged as shown in Fig. 22 However, the two rails are un-insulated conductors on very poor insulators, and make up one of the poorest transmission lines imaginable.

This discussion will be confined to the simple DC track circuit both because of its very widespread use, and because AC circuits and special DC circuits require relays of a very special design which make substitution of components all but impossible.

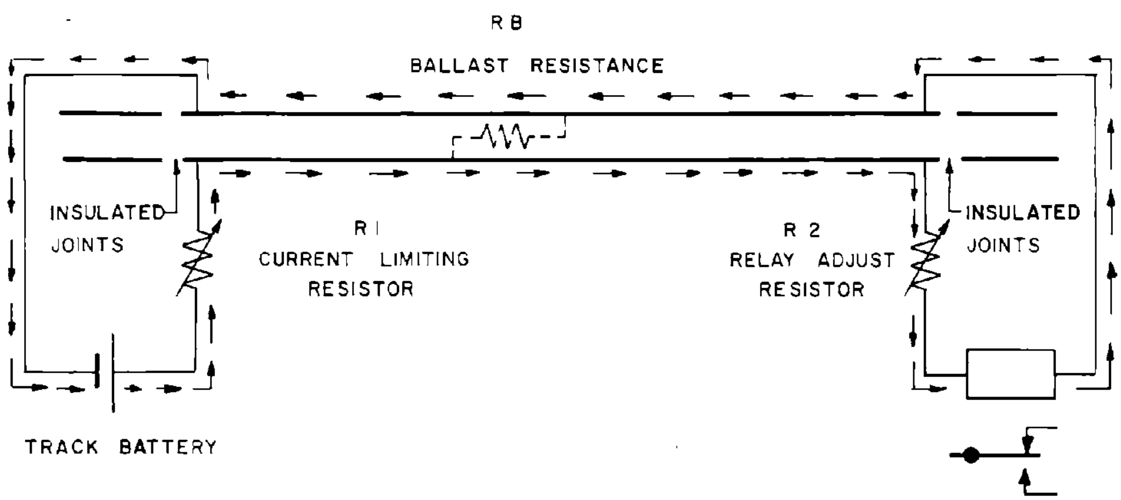


FIGURE 22. SIMPLE DC TRACK CIRCUIT-
NO TRAIN IN CIRCUIT.

The DC track circuit, in its present closed circuit form, was conceived by Dr. William Robinson and first installed on the Philadelphia and Erie R.R. at Kinzua, in the northwestern part of Pennsylvania, in 1872. Dr. Robinson also invented the rail bond at the same time. Alternative arrangements such as AC, and coded track circuits have been developed since, but the basic concept has not changed. Figure 22 shows the fundamental elements.

The operation of a track circuit is simple. When there is no train present a current flows from the positive battery terminal through the limiting resistor R1 to the first rail, along that rail to the other end of the section, through the adjusting resistor, R2, through the relay coil to the second rail, and returns through that rail to the battery. Refer to Figure 22.

When a train enters the circuit its wheels short the two rails together. A train at the battery end is shown in Fig. 23. Here current flows directly from the positive battery terminal through the limiting resistor R1 to the first rail, directly through the axle to the second rail, and back to the battery. Resistor R1 is adjusted to limit the current under these conditions to reduce battery drain. Because of the low resistance of the shunt applied to the rail by the wheels (less than .06 ohm), very little current reaches the relay coil and it becomes deenergized.

As the train moves toward the relay end of the circuit the current from the battery continues to be diverted through the axles and the relay remains deenergized. When the train is at the relay end of the seciton, conditions are as shown in Figure 24. When the train clears the section, conditions return to those of Figure 22 and the relay pulls in. Note that a broken rail interrupts the current and drops the relay.

While the operation of a track circuit is simple and easily comprehended, designing and adjusting one turns out to be a very complex operation. Each track circuit has 9 parameters, and a compromise must be reached which will allow for safe operation while these vary through a range of values. These 9 parameters are:

1. Battery Voltage.
2. Resistance of the current limiting resistance (R1 in Fig. 22).
3. The Rail Resistance.
4. The Ballast Resistance (RB in Figure 22).
5. The resistance of the adjusting resistor (R2 in Figure 22).
6. Relay Coil Resistance.
7. Relay Pickup Current.
8. Relay Drop Out Current.
9. The shunting resistance of a train.

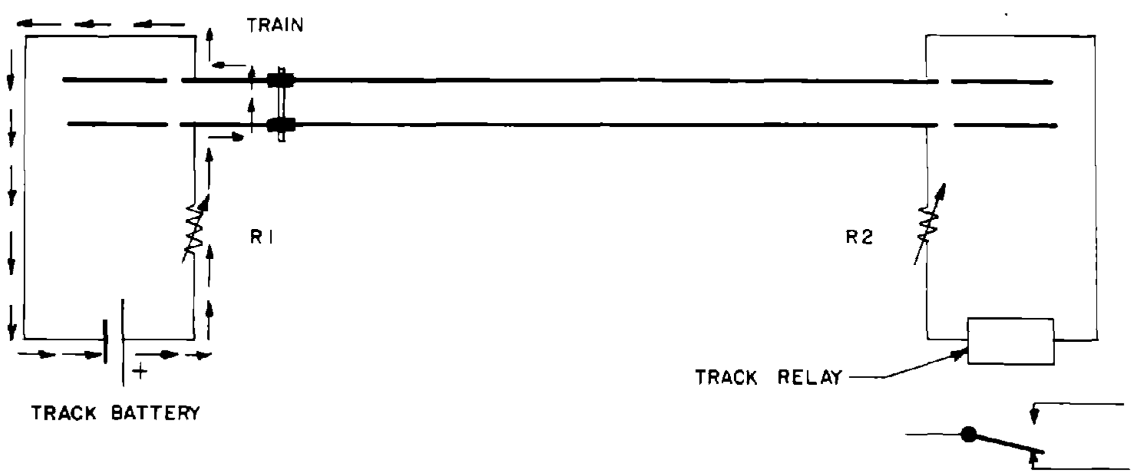


FIGURE 23. SIMPLE DC TRACK CIRCUIT-
TRAIN AT BATTERY END.

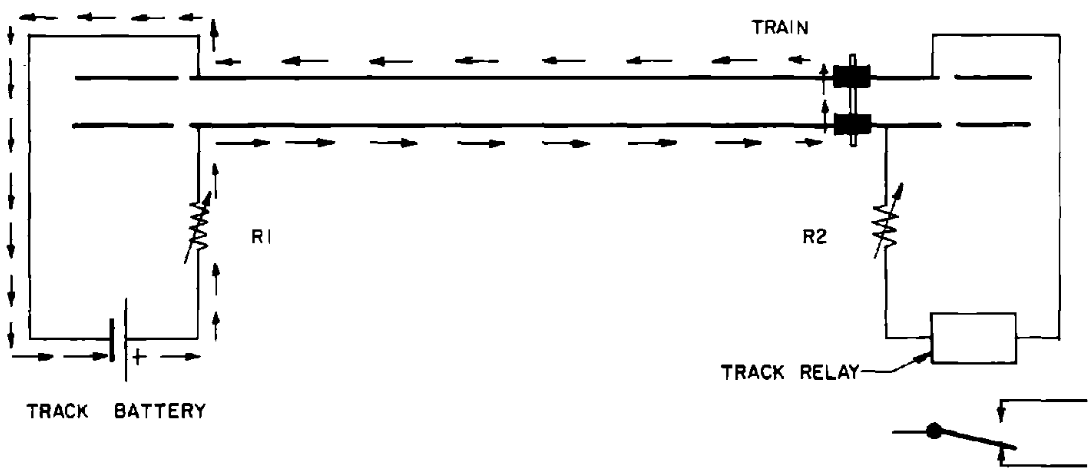


FIGURE 24. SIMPLE DC TRACK CIRCUIT-
TRAIN AT RELAY END.

Of these 9 parameters, Nos. 2 and 5, the current limiting adjustment resistors, are the means by which a circuit is adjusted for operation. No. 3, the rail resistance is a reasonably stable value for a given circuit, and Numbers 6, 7 and 8 are fixed by the relay chosen. This usually has a 2 ohm or 4 ohm coil with pickup and dropout characteristics shown in Fig. 25. Note the power required to pick up, only 21 milliwatts. Of the remaining three parameters, battery voltage, ballast resistance, and shunt resistance, the ballast resistance is the most troublesome and limiting. It will be discussed separately. The battery voltage varies with the state of charge of the battery, and must be kept low enough to limit power in the circuit while being as high as possible to improve shunting. Shunting resistance is largely the resistance of the contact of the wheel and rail. This varies greatly depending on the length of time and weather since the last train, use of brakes, type of brakes used, weight on the axle, etc. Rust greatly increases the shunt resistance, as does a film of fine dirt. Despite the great weight on the wheels and consequent high pressures, the value of this resistance is surprisingly unstable. For example, a single unit RDC type car will occasionally fail to properly shunt a track circuit on a main line if the line has been idle say from midnight to this train's arrival at 6:00 a.m.

The parameter which complicates the design and adjustment of a track circuit more than any other is the ballast resistance. It is the equivalent resistance of all the leakage paths between the rails over the surface of the ties and through the ballast. It is usually expressed in ohms for one thousand feet of track. The value varies from a high of 200 or more ohms when the ballast is frozen to 2 ohms or less. Track maintenance greatly affects ballast resistance, as clean well-drained ballast properly graded has a much higher resistance, even when wet, than does dirty, weed choked ballast. The dust resulting from brake applications and salt used to melt snow on crossings can reduce ballast resistance to very low values. It is customary to design for a minimum ballast resistance of 2 ohms per 1000 feet, but short track circuits, such as are common in grade crossing warning systems, can function with lower values.

A proper compromise on the adjustment of a track circuit is one in which the relay will always drop when the highest resistance shunt is placed at any point in the section with battery voltage and ballast resistance both at maximum, while still being able to pick up the relay when there is no shunt with battery voltage and ballast resistance at minimum values. The range of adjustment between these two requirements is larger as minimum ballast resistance increases and the length of the track circuit is reduced.

Specifications (4 Contact Relays)	AAR Specifications		Signal Manufacturers Specifications	
Coil Resistance (ohms)	2	4	2	4
Minimum Dropout Current (amps)	.053	.037	.053	.037
Maximum Pickup Current (amps)	.105	.070	.103	.070
Derived Characteristics				
Minimum Dropout Volts	.106	.148		
Maximum Pickup Volts	.210	.280		
Minimum Dropout Current as % of Pickup Current	50.5%	52.9%		
Power to Pickup (watts)	.021	.020		

FIGURE 25. TYPICAL RELAY SPECIFICATIONS

The art in adjusting a track circuit comes in determining the conditions at the time of adjustment and estimating where in the range of conditions for that track circuit they fall, so that the adjustment may be properly biased. It requires substantial skill on the part of the maintainer to do this correctly.

The track relay characteristics have a substantial effect in the ease of achievement of proper adjustment. The relays are designed so that the drop out current is a high percentage of the pickup. Special relays have been developed which have magnetic structures incorporating permanent magnets which make the relay pull in on one and only one polarity of current and drop out at currents as high as 70% of the pickup value. These relays make marginal track currents work reliably and greatly increase the margin for adjustment.

For reference, Fig. 25 also contains specifications for a track relay taken from major manufacturer's catalogs. It will be noted that, as expected, these relays fall within the AAR specifications. The important point to observe is that power requirements are very low, and that dropout is a high percentage of pickup. These are the characteristics which will most critically affect the results of this study.

15.4 ELECTRICAL TRANSIENTS

Electrical transients pose a severe threat to the proper operation of railroad signal equipment, grade crossing warning systems included. While the major source of destructive transients is lightning, transients which are the result of man-made events such as power line switching and the fault currents resulting from breaks in power lines, cross shorts, etc., can be very destructive.

Transient protection in the sense of preventing any damage or malfunction due to a transient from any source is impossible. The protective devices simply improve the odds of survival. This concept may be visualized by assuming that a lightning bolt of a given intensity will strike in a given area once in 5 years. If a strike of this intensity originally will be destructive within 100 feet of a relay case, and the transient protective gear is then improved so that such a strike must be within 50 feet before destructive damage will result, the area within which a strike will be destructive is now only 1/4 as great, and the mean time between strikes which are destructive is 4 times as long. Again, no amount of protection will prevent total destruction from a direct hit by lightning, contact with a 100 KV high tension line, or similar event.

Transient protection requires careful design. It is not enough simply to install protective devices. It is vitally important to arrange the wiring of the relay case to provide a proper ground for the protector. This ground circuit must NOT have impedances (and remember that all wire is quite inductive to the high frequency components present in all transients) which are common to other circuits. Such common impedances will couple transients into other circuits and cause damage as though no protective device was present.

One particular point which must be remembered when considering transients is that the rate of rise of the transient voltage has a great deal to do with the effectiveness of protection. All transient protective devices have a rated breakdown voltage, but all will limit transients to this level only if the rate of rise is below a specified rate, which, except for some very new devices, is much lower than the rate of rise of the transients resulting from many lightning strikes. If this rate of rise is exceeded, then the protector will limit at some higher voltage. The faster the rise, the higher this limit will be. This effect is due to the finite time required to establish the breakover path. This is a major reason for the high (3KV) insulation breakdown test in AAR specifications It is also a major reason for the required use of non-weldable front contacts on vital relays, since the surge current that accompanies the transient voltage is the cause of the contact welding.

Transient protective devices have, in addition to their breakdown rating, a rating of the amount of current they may carry for a specified time period. If this current-time product is exceeded, enough energy will be dissipated in the device to destroy it.

Another rating which must be considered in design involving transient protection is the ability of the device to interrupt the discharge current after the transient energy has dissipated. Unless the protective device is used to blow a fuse (a so-called crowbar), it must restore the drain circuit to pre-transient conditions as soon as the voltage drops to safe levels. Again, it takes a finite time to do so. The maintaining voltage rating of the protective device must be higher than any steady voltage appearing on the circuit it is protecting. This is normally not a problem in signal work, where voltages are usually quite low, but it must be considered.

A requirement which restricts the choice of transient protective devices is the requirement of Federal Regulations governing the safety aspects of railroad signalling which specifies that a resistance of at least 1 megohm be maintained to ground on all signal circuits except those connected to the track. This eliminates a number of commercially available devices which have otherwise excellent characteristics.

The magnitude of the transients which can pass through the normal transient protective devices, while low enough to prevent damage to relay type equipment of present design, is much too severe for solid state equipment. To cope with this, solid state equipment is provided with secondary protection. Such secondary protective devices generally lack the high energy dissipation capacity of the primary devices, but are much faster and are designed to further attenuate the transients to levels which will not damage the solid state equipment. All of this is, of course, conditional on the incoming transient not being excessively severe. Provisions for this secondary protection are highly relevant to the topic of this study.

15.5 MAINTENANCE

Once an automatic grade crossing warning system is installed, it must be maintained. The cost of this is an ongoing expense. The life of the equipment, given reasonable maintenance, is in the range of 40 to 50 years, so maintenance must be expected to continue for a long time.

The cost of maintenance of an automatic grade crossing warning system varies greatly. It is affected by such obvious factors as the complexity of the installation, vandalism, and exposure to lightning. The number of trains, their speed, and the level of maintenance of the railroad track also are factors. However, there are really two costs involved. One is predictable and covers the routine work such as visual inspection, testing, and such activities as putting water in the batteries. The second is not predictable to any significant degree, and includes repairing the damage resulting from catastrophic events such as lightning and automobile accidents. The latter can only be allowed for over a number of crossings and over a long time period.

The frequency of trouble calls will vary widely. Some crossings give little or no trouble while others cannot go a month between trouble calls. Estimates of an average frequency of trouble calls range from 3 to 6 months. Major causes are vandalism, lightning, hunters using the equipment as a target, and automobiles which stray off the road. Dragging equipment, poor ballast conditions, and pollution problems are less frequent causes.

The repair of damage is, of course, dependent on the nature and extent of the damage. The cost can be held down through control of component costs and through use of easily replaceable modules, allowing later shop repair of damaged modules using adequate test equipment. Such a process is much more economical than the usual system where all testing, circuit checking and repair, except to the relays themselves, is done in the field.

The routine maintenance of a crossing will ordinarily require monthly visits by the maintainer, and periodic inspection by the maintenance foreman, and by a relay inspector. For a simple single track crossing with no gates and no complications, the direct cost of this labor is estimated to be approximately \$360 per year. A proportionate share of the cost of equipping the maintainer with a truck, test equipment and other supplies, and for such expenses as electric power, replacement lamps, battery depreciation, etc., would add roughly \$180. Another \$100 provides for insurance against catastrophic events, either through actual insurance or some form of contingency reserve fund. The total is approximately \$640 per year, rising to \$1200 or more where a complex installation in a vandal prone area is involved, all in 1974 dollars.

The impact of maintenance costs on this study is relatively minor. While such costs rise with inflation, the difference in total maintenance costs between the same installation using existing technology and the same un-molularized system with other components is likely to be small. Modularization, if it used plug-in relays, would substantially lower trouble shooting time. However, this is a small part of the total. It must also be remembered that this is traded off against a higher investment in inventory and in handling of spare parts.

16. EUROPEAN PRACTICES

16.1 GENERAL

Europe, with its extensive network of rail lines carrying dense traffic through a land area with a generally higher population than most of North America, has developed a railway signal technology which is substantially different from that of North America. Automatic grade crossing warning systems are also quite different. These have been investigated as a possible source of new components and alternative approaches.

To provide a better understanding of European technology, it is helpful to review some of the historical and geographical background as it affected automatic grade crossing warning system design.

16.2 BACKGROUND

The railroad network of Europe was built in an area which was well populated and which had a large volume of trade. This is in sharp contrast to North America, where the railroads often preceeded the population. As a result, the volume of traffic in Europe was high from the start. Financing for a higher level of design was possible. Double-tracking at initial construction was common. Since a highway system had already been built and was carrying a heavy commerce, grade crossings were a problem from the very beginning. They were avoided if possible. Indeed, many of the original laws required complete fencing of the right of way. Public safety was a more serious problem because of the greater density of both people and trains. As a result, the railroads did not occupy as unrestricted a position as they often did in North America.

The use of gates at most crossings was mandated by law very early in the railroad era. Manually operated swinging gates, identical to those used on a farm, were standard. They were normally closed across the tracks and railroad right-of-way until a train approached, excluding the public and its livestock from the right of way. On approach of a train, the gates were swung across the road to clear the path for the train and block road traffic.

The large population provided a plentiful supply of cheap labor to operate these gates. This factor, combined with a need for signalling on railroad lines which was felt before the technology for providing automatic signals was available, led to development of manual systems and a philosophical reluctance to use automatic equipment. In fact, it was many years before the automatic equipment was improved to the point where it was as safe and reliable as the manual systems, and as long as the necessary labor was available at reasonable cost, there was little reason to change to automatic operation.

The generally conservative thinking of European railway management is nowhere more clearly evident that in the application of the track circuit. Construction standards were generally quite good, and maintenance was excellent. Rail was heavier in proportion to the weight of trains. Broken rails were not the accident problem they were in North America. Further the high cost of wood ties (called sleepers in Europe) led to frequent use of steel ties, and later to reinforced concrete ties. All of these practices combined to reduce the advantages of the track circuit and at the same time make its application more difficult. As a result, there was a general distrust of them, and they were avoided.

The reluctance to use track circuits did occasionally result in accidents. Towermen did forget that a locomotive was waiting at the signal and cleared a block for an express (Hawes Jnc. 1915 for example), resulting in a major accident. But this kind of man-failure accident was infrequent enough that track circuits were not considered necessary as a general rule.

As labor costs rose and labor became more difficult to obtain, the use of automatic signal systems grew. However, the axle counter became an often used alternative to the track circuit. However, automatic block signal systems are basically recent technology in Europe compared to their long history in North America.

The concept of interlocking signals and switches was invented and developed in Europe. The first installations were mechanical, and many plants of over 200 levers are still in use. The size and complexity of the plants required the use of power at an early date. Compressed air was used, and when suitable electric motors became available, electric operation of switches and signals was developed. In Europe, as in North America, early power operated interlocking plans might be termed "power assisted" installations, as the usual arrangement was to use a small scale mechanical interlocking which controlled power switch machines and signals and in turn was locked by electric latches which repeated the positions of the switches and signals. Track circuits were seldom used. The old and long obsolete (in America) detector bars were used. Such a plant requires few relays. However, in Europe the development of large interlockings encouraged use of all relay systems, as they were physically smaller and faster, and required fewer people to operate.

The development of the all relay interlocking in Europe came at a time when the track circuit was still a rarity. Therefore relay designs were optimized for their use in interlocking plants rather than for track circuits. The problem of welded contacts was bypassed by use of checking circuits instead of non-welding contacts. The relays resulting from this design approach are much smaller, and are installed in clean, dust-free rooms to eliminate the need for individual enclosures. Groups of relays are often assembled into modules which may be replaced as a unit if trouble develops, greatly reducing the time an interlocking is out of service when trouble occurs.

In contrast, in North America interlockings were fewer and on the average smaller in proportion to the miles of railroad. The use of track circuits was much more general, and the ancestor of the present vital relay had been developed into a reliable and safe device by the time all relay interlocking installations became popular. It was natural and convenient to expand the use of the vital relay so familiar as a track relay into the new field. Since these relays had non-welding contacts, no checking circuitry was needed. They were, however, larger. A typical plant might be two to three times as large as its European equivalent, but would draw only 1/5 the power. Maintenance is on a relay replacement level.

Operating practices in Europe are also quite different from those in North America. Train weight is much less. Nowhere in Europe is there anything like the 10,000 ton train travelling at 70 miles per hour. Passenger trains are fast but have excellent brakes. Freight trains (called good trains) until recently had no train brakes, but were sufficiently limited in weight and speed so that stopping distances were short. As a result, on signalized lines, it is often possible to tie the automatic grade crossing warning system into the signal system without requiring excessively long warning times. A failure of the crossing warning system is arranged to prevent clearing of the signal for the train. Obviously this arrangement cannot be used on railway lines having very high speed trains or in non-signal territory. In fact, strong efforts are made to eliminate all grade crossings where train speeds exceed roughly 50 miles per hour.

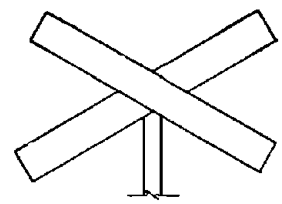
In summary, the differences in the time of development of signal systems and different operating practice has resulted in a different hardware development. Interestingly, the European track circuit relay, like the vital relay, has non-weldable contacts and many of the characteristics (including its high price) of its American equivalent.

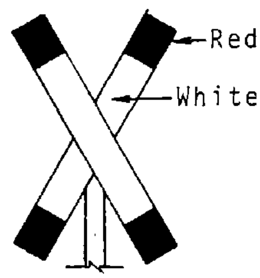
16.3 EUROPEAN PRACTICES

The investigation of current European practice was conducted through interviews with the officials in charge of grade crossing protection in the central administrations of the National Railways of France, Switzerland, Germany and England. In addition, two European manufacturers were contacted and a literature search was made. The information collected was detailed but of necessity general in nature. The review which follows is intended to provide an overview of current thinking. As in the United States, many crossings in Europe have warning systems which are obsolete, inadequate, or otherwise substandard. The upgrading process there is also limited by available funding. The intent of this discussion is to provide a general understanding of current thinking on what constitutes an acceptable automatic grade crossing warning system.

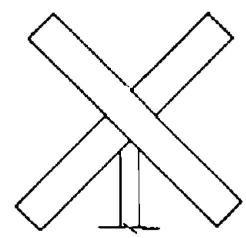
The basic European approach to crossing warning systems is to provide manual protection. Automatic systems are designed, as one railway official put it, to "function as though operated by a man". Since a crossing tender can exercise a substantial amount of judgment in operating the gates, and in providing additional warning, this is an objective that cannot be reached. However, the systems installed incorporate substantial sophistication in order to approach this objective. The intent is to provide the public with much more protection against its own ignorance and carelessness than in North America.

Each European country has its own standards governing signing and pavement markings on the roadway approaching a crossing. Despite the considerable degree of co-operation among European countries in railway and highway matters, there is substantial divergence in detail. Because of the language problem, symbolic signs are the rule. There is no universal agreement on such a basic sign as the passive crossbuck warning. As shown at right the common sign in some European countries is a flattened X, the same form as the older American practice. However, in Germany this sign takes the form of a more vertical X, as shown. The color of this sign is a much brighter red and white and the contrast with the background is much greater. This higher contrast is very noticeable in all of the signing in Europe. The advantage of the form of the German "crossbuck" is that it fits on the side of the road much better, where a wider sign would be partly obscurred by roadside obstruction such as trees and poles.


Typical European Sign
(old American design)



German Sign


Present American Sign

Grade crossings are quite common in Europe. The United States has almost 1 crossing per mile, equivalent to one every 1.6 kilometers. There is roughly one crossing for every kilometer (5/8 mile) in Switzerland and one every 1.1 kilometers in Belgium. Of these, from roughly 40% to 60% are provided with only passive protection. Automatic systems account for a very different portion in different countries, from perhaps 1/2% in England to 6% in Switzerland to 56% in Belgium. Manual operation accounts for the remaining crossings with active protection. The degree of protection provided is increased as maximum train speeds increase. On high speed lines a four barrier system is favored in most countries. Indeed, manual operation either by a gate tender, or remote controlled and aided by TV monitors, is preferred for the higher-speed lines. A strong effort is being made to eliminate all crossings on the highest speed and heaviest trafficked lines.

In England in particular, automatic grade crossing warning systems have been very slow in coming. By 1968 there were 278 installations on 18,750 km of railroad line. However, on January 6, 1968 there was a collision at Hixon, at a grade crossing equipped with an automatic warning system and half barrier gates (a typical American installation). This collision, which took 11 lives resulted from failure of the driver of a road transporter, (a low boy) to obtain prior clearance to use the crossing. He was moving a 120-ton transformer over the tracks at 2 mph when the train appeared. This accident called into question the adequacy of the automatic crossing warning systems as then installed. There was a long period during which no new installations were made. A new and much more elaborate set of standards for operation of automatic systems was promulgated by the British Government, and about 75 new installations have been made since 1968. The new standards require such things as longer ringing times, additional advance sensing of a second train (most lines are double track) and illuminated signs indicating that the second train is coming, and further extension of the telephone system required at all crossings.

The design of an automatic grade crossing warning system varies greatly from one country to another. However, some general points can be noted. Gates are more generally used than in North America. In part, this is due to a greater prevalence of multiple track railroad lines, but protection standards are generally higher also. Some form of flashing-light warning is universal, but it takes several forms. A single light is sometimes used, although two which flash alternately are probably the most often found. A white "clear" indication is also frequently given to road users. Back lights are however, not common. Signing is generally more elaborate and much more attention has been given to making the warning signs visible. Symbolic signs are universal. Moreover, colors are brighter and contrast much better. The flashing lights are mounted on a common large backboard which materially enhances their visibility, by improving the contrast with the background.

Gates used in Europe are of many designs. Some are single arms much like the standard North American design, although often with reflectors or targets to improve visibility. Another type of gate swings a large square target into the road. Frequent use is made of a collapsible hanging fence which prevents people from ducking under a lowered gate. This was sometimes used on manual gates in North America.

The gate operating mechanism in Europe is very commonly hydraulic, rather than straight electric. The gates operate faster, but often do not go up more than 60 degrees. The mechanism is often between the two sides of the gate on its own pedestal, rather than being mounted on the same mast as the flashing lights, as is commonly done in North America.

Not only are gates used in a larger proportion of automatic grade crossing warning systems, but the automatic four-gate type of installation, which is virtually unknown in North America, is common in Europe. The system using two gates which obstruct the entering lane on each side is referred to as one with "half barriers". Adding two additional gates which obstruct the leaving lanes as well is referred to as using "full barriers". In this system the entering gates are lowered first, and the leaving gates follow after a suitable time delay. Elaborate systems of light beams and radar have sometimes been installed to detect obstructions on the crossing as an aid to further safety in use of these leaving gates.

The detection of the approach of a train is perhaps the area where European practice differs the most from North American standards. As previously noted, track circuits do not find great favor with European signal engineers. The ordinary DC track circuit is seldom used. The much wider use of electric traction has made AC track circuits the prevalent type, but still not general. For example there are only 291 km of route signalled with track circuited automatic block of 2662 km total in Switzerland. Axle counters are used on 750 km of line, while the rest uses manual block. However, electronic track circuits (audio overlay) are becoming much more popular, especially in France, In this form track circuits are coming into more general use.

While axle counters, some of highly sophisticated design, are occasionally used for automatic train detection, the most commonly used device is a pedal which is depressed by the wheels of the train. This, by American standards, is a crude and unreliable device. European railway officials admit to mechanical reliability problems, and installation of a second pedal is frequently made. The axle counter is not used primarily because of its high cost.

Functionally, the circuitry used is generally quite complex. The operating principle of a pedal actuated system is simple. It resembles closely the systems activated by trolley contactors which were common on interurban roads some years ago. However, the simple system is surrounded by an elaborate hedge against failure and a general use of redundant circuitry. As a result, the control function is complex and costly.

16.4 EUROPEAN COMPONENTS OF INTEREST

In general, the components used in European automatic grade crossing warning systems are not applicable to North American service, either because they are not rugged or heavy enough, or because they require an amount of maintenance of a kind not acceptable to American railroads. This includes the gates, especially the pedals, and much of the rest of the hardware used.

The major exception to this is the signal relay. Called a security or safety relay by some, it comes in a number of configurations. The main characteristic which distinguishes this relay from common commercial relays is that the armature is a rigid assembly and the fixed contact springs have rigid stops. Silver to silver contacts are used, which can weld. But should a weld occur, the relay armature is prevented from causing any contact on the other side to make. For example, should a pair of front contacts weld, the armature cannot drop far enough to make any of the back contacts.

This type of relay is used in interlocking plants which are provided with checking circuits to detect and protect against false operation should a welding of contacts occur. European experience has indicated that this is a safe and reliable approach to signal system design. However, as applied to grade crossings, the limitations of input from the commonly used pedal are such that redundancy rather than checking is used.

16.5 CONCLUSIONS REGARDING EUROPEAN PRACTICE

The technology of European grade crossing protection is based on quite different concepts. Some of these, such as the pedal actuator, are unlikely ever to find acceptance in North America. The complex monitoring systems used may some day be used, but this is unlikely in the forseeable future.

The European signal relay could find a place in American practice, and is a viable candidate for lower cost automatic grade warning systems with uncompromised safety.

Another aspect of European technology which should be investigated further is the signing and the design of the warning light assembly. These devices appear to be much more visible than their American equivalents because of the use of brighter and higher contrast colors, as well as better proportions. This is especially true of the red and white cross bucks and the large single back plates for flashing lights.

17. ALTERNATIVE COMPONENTS CONSIDERED

17.1 GENERAL

There are many constraints which limit to varying degrees the probability of acceptance of alternative system components. In the course of this study an effort was made to define these and understand them. At the same time, an extensive search of available components was made, and each was considered against the various constraints. As will be discussed further, the choice was reduced to two alternatives.

It should be emphasized that the viability of any substitution of components is first of all dependent on the resulting assembly being at least as safe and preferably safer than present practice, and that it be proven so. It must then be sufficiently less costly to purchase and to maintain to justify the stocking by the railroads of the additional spare parts inventory necessitated by a new and different set of components. These are very demanding requirements.

The scope of work of this study defines it as an investigation of the technical and economic viability of use of non-vital components in automatic grade crossing systems. In a practical sense, this limits the study to alternative types of relays with such circuit changes as may be required or possible to optimize safety. Further, this review has been restricted to relays which are generally available. No attempt has been made to develop a special relay for this application. While such an effort has attractive aspects, it would require time and test facilities not available in this study.

It should be recognized that there are special types of vital relays which have been developed which will make marginal track circuits work reliably. Since there are no commercially available substitutes for these special biased and high-drop-away relays, it would be necessary to use them in cases where track conditions prevent use of other relays. This is true whether there is a signal system or not.

17.2 COMPLIANCE WITH EXISTING STANDARDS

The components of an automatic grade crossing warning system are, except in one respect, not subject to the stringent requirements of the Railroad Safety and Inspection Act and the many rules and regulations which derive from that Act. The exception, and it is very a very important one, is that all these requirements do apply to any component which serves a dual function as part of the signal system as well as part of the grade crossing warning system. The most common example of this is the track relay for a track circuit which is at the same time an approach circuit to a crossing and part of a block in a signal system. Such a relay must meet full RS&I requirements. Those relays not part of a signal system are not, legally at least, subject to these requirements.

The high cost of the vital-type track relay makes it appropriate that alternatives be sought. Two classes of alternatives will therefore be considered. The first will use vital track circuit relays and will contain provisions for being made a part of a signal system. The second class will not be subject to this restriction.

17.3 SOME LESS ATTRACTIVE COMPONENTS

In pursuit of this objective a careful review of the characteristics of all commonly available relays was conducted. This included a wide variety of the highest quality commercial components and relays made to military specifications. This review was designed to identify those relays which offered the possibility of a suitable level of safety.

In the process of seeking out alternative hardware for an automatic grade crossing warning system, consideration was given to use of Mil Spec components. However, these are generally not suited to this application for several reasons. The first is that they are generally very small relays which therefore require significant power to operate. As was pointed out, pickup power for a typical railroad track relay is under 20 milliwatts. In contrast, a typical Mil Spec relay will require an order of magnitude more power. Further, relays having the reliability levels needed are generally available only in the smaller types which have no advantage over other alternatives.

Of the many commercial-industrial relays available, most could quickly be eliminated because of poor reliability records. The only relays found worthy of further consideration were those used in telephone exchanges, the mercury wetted reed relay, and the European type railway signal relay. Each of these will be discussed separately. Dry reed relays, as distinguished from the mercury wetted type, while capable of billions of operations, are very easily welded, and are not acceptable for that reason.

17.4 TELEPHONE RELAYS

Special consideration was given to the telephone type relays. There are several types and sizes. The so-called long frame Strowger relay is the best of these. While there are several designs of relays used in Bell System exchanges, these are made only by Western Electric and are not generally available. The long frame telephone relay is a highly standardized design made by several excellent manufacturers. It has the needed flexibility of contact arrangement, acceptable power requirements, and an established record of reliability and long life. Its disadvantages are in the susceptability to welding of front contacts and the lack of a mechanical connection between moving contacts, which makes it possible for a welded front contact to remain closed while other back contacts are made properly. This makes a checking circuit very unreliable.

Contact materials of many types are available on long frame telephone relays. However, only tungsten and silver-cadmium oxide materials are resistant to welding from transients. Unfortunately neither are suitable for use in automatic grade crossing warning system logic circuits. Tungsten has the unfortunate property that it requires 40 to 60 volts to break through an insulating film which develops. It is an excellent material for high voltage circuits, but not for the 10 volts which is almost universal in grade crossing warning systems. Silver-cadmium-oxide is a material which, at least in theory, will weld with welds brittle enough to break readily. However, to be reliable, fairly high contact opening forces are needed, and this requires substantial power to overcome them when the relay is energized. Carbon type contacts such as are used on vital relays are not available on this type of relay for several reasons, including their large size and high resistance.

This type of relay, while having many desirable characteristics, is not suitable for this application.

17.5 NON-VITAL RELAYS MANUFACTURED BY PRESENT VITAL RELAY SUPPLIERS

There are several types of relays which are manufactured by vital relay makers for use in non-vital circuits such as route selecting and code control relays in CTC installations. Some of these are long lived and highly reliable, and should merit consideration as alternatives. However, it is virtually impossible to get adequate data on the reliability of any of these relays. The manufacturers are unwilling to discuss the type of application which is the focus of this study. Further, the cost of the most suitable of these relays is high, higher than other alternative approaches. These relays have therefore not been considered further.

17.6 EUROPEAN SIGNAL RELAYS

The European signal relay is specifically designed for railroad signal work. It has double series make silver alloy contacts. What makes it acceptable in this application is that the moving contacts are assembled rigidly to the armature and all contact springs have rigid stops so that should a contact weld, the relay armature is held in such a way as to prevent any of the opposite contacts to make. For example, should a front contact weld, no back contacts can make. This makes reliable check circuit operation possible.

17.7 MERCURY WETTED REED RELAYS

The mercury wetted reed relay is a highly reliable and very fast relay which has an exceedingly good reliability record. In this relay the contact is made between two films of liquid mercury. This is a clean and low resistance contact. The standard commercial relay has an ability to handle heavy surges. It is typically rated at 5 amperes at the voltage levels used in grade crossing warning systems. It can handle surges in excess of 50 amperes for short times. Before their contacts can weld the film of mercury must be evaporated by the power dissipated by the surge currents. After this, the contacts themselves (which are platinum or palladium) must be welded. This requires a substantial amount of energy. These relays are regularly used to discharge large capacitors without use of limiting resistors. The inductance of the capacitor itself and the inherent circuit resistance are enough to prevent relay damage.

The mercury wetted reed relay has three disadvantages. The first is that mercury freezes at -39 degrees. This is certainly not a limitation over most of North America. The areas in which temperatures can get this low are relatively limited. Even in these areas, a very small amount of insulation properly applied will retain enough of the heat of normal operation to prevent any freezing. A freeze would then only occur after a prolonged power failure, and would be inherently fail-safe in nature in a properly designed circuit.

The second disadvantage of the mercury wetted reed is that unless the relay is stored and transported in an upright position, it must be either tapped or operated in that position to drain excess mercury out of the contacts before it will function normally. This type of relay has been successfully used in railroad hotbox detector units and no major problems have arisen.

The third disadvantage is the limitation imposed by available contact capsules. There are essentially two types. One provides a contact arrangement having two front and two back contacts with a common moving contact. This is a make-before-break contact under ordinary use. The second is a heavier duty simple make-after-break contact structure.

Relays with multiple capsules are available, but they have the same problem as other relays in that there is no assurance that all contacts work together. However, this restriction can be avoided by suitable circuit design if the double contact form of the capsule is used.

This type of relay, because of the low power requirements, can function as a track circuit relay. However, the relay does not drop away until the coil current is reduced to a substantially smaller percentage of the pickup value than is characteristic of most track relays. This makes adjustment of the track circuit more critical. Track circuits associated with grade crossings are usually short, allowing more margin for adjustment, but it is still an undesirable characteristic, and will limit application of this relay as a track relay.

17.8 CONCLUSION

Of the many types of relays considered, only two have characteristics which are acceptable. These are the European railroad signal relay and the mercury wetted type of reed relay.

18. CIRCUITS

18.1 GENERAL

The circuits used in automatic grade crossing warning systems are quite numerous, if the many minor variations are considered. However they are all built on some very basic principles and it is this subject which will now be considered. Consideration will then be given to development of actual circuits in which these principles are applied to the relays in a way which will take advantage of the particular characteristics of each relay and overcome any disadvantages.

Signal circuit and system design in North America have developed within a framework of rigorously applied rules and practices, which have yielded systems proven to be safe in use. This design philosophy which matches component and circuit characteristics closely is discussed below.

18.2 PRINCIPLES

The guiding principle of railroad signal circuit design for much of the past 100 years has been "Fail Safe". It has always been recognized that things can go wrong with relays. Wires do break. Vandals do cause damage. But the concept of "Fail Safe" requires that any of these events result in a safe condition. In the case of a grade crossing warning system, this means that the warning is activated. The design of these circuits is quite straight forward. Relays are energized when in the clear condition. They are de-energized when the circuit is in the safe (i.e. most restrictive) condition. Note that the two stick relays WXSR and EXSR in the circuits of Figure 1 are normally de-energized. When one of these relays pulls in, one of the approach circuits no longer can control the warning. This is done to stop the warning as soon as the rear of a train clears the crossing. Therefore, if the relay does not pull in, the circuit for the receding track section is <u>not</u> cut out. This lengthens the warning which is a safe failure mode. Similarly circuits are arranged using a series of contacts, failure of any one of which will cause a safe condition, as will a broken wire.

18.3 CIRCUIT CONSIDERATIONS

Railroad signal circuit design is highly conservative. Both the components used and the way in which these components are interconnected is very carefully engineered to eliminate the occurrence of unsafe conditons which have been experienced in practice. Other technologies, notably the aerospace field, have been faced with the need for highly reliable systems. However, in these newer fields the cost of failure is frequently so great and the time for development so short that there has been no opportunity to perfect special components and systems. The use of redundancy has been the only way of achieving the required levels of reliability.

Fundamentally, redundancy is a means of achieving overall system reliability which is greater than that of the component subsystems alone. This, in terms of grade crossing warning systems, might be thought of as a system having two motion detector devices operating on two different and non-interferring frequencies at the same crossing, with either one able to initiate a warning. Assuming that failure modes are independent, if the probability of failure to detect by one device is 1 in 10^6 operations, the probability of both failing at the same time, which is the unsafe failure, is the product of the individual failure rates, or 1 in 10^{12} operations, a major improvement, and one which has been achieved by adding components of the same reliability. The cost of detection components has doubled, but reliability has been squared.

It must be recognized that this discussion is dealing with relay systems. Solid state systems are not within the scope of this study.

In considering redundancy as a means of achieving lower costs while maintaining or improving reliability, it must be recognized that it is economically advantageous only if the total cost of a system based on this concept is lower than the cost of one based on present practice. This cost must not only include the component cost but the labor of assembly, trouble shooting costs, added space, additional power, etc. The added labor, because it is costly, is a particular problem.

When costs of systems using components which meet minimum reliability requirements are studied, it is found that redundancy does not yield economic advantage. The components themselves are lower in cost, but the additional labor cost in particular more than offsets the savings in components over present practice. And further, components meeting all of the failure mode and environmental requirements have a reliability which gives simple systems not using redundancy a reliability approximating those based on present components. Redundancy therefore is not economically advantageous.

19. ALTERNATIVES

19.1 GENERAL

In the course of this study many alternatives to the use of vital relays were considered. As a part of a general quest for ideas the entire relay case as a system component was examined. The possibilities of changes in the system/component combination were analyzed. What follows is a general description of some of the alternatives considered and found inadequate, along with detailed descriptions of two systems which appear to have sufficient merit to warrant development of circuits and further investigation.

19.2 ALTERNATIVE APPROACHES

Consideration was given to the possibility of designing a package assembly which could be factory assembled and transported to the crossing, then simply wired to the track and the vehicle warning devices without consideration or modification of any signal system which might be present. Such an approach is not at present fully attainable. The nearest approach is the use of a motion sensing device. Disregarding the question of the safety of this device, about which there is substantial disagreement in the railroad industry, this approach requires modifications of signal equipment if coded track circuits are used. In any event shunts, to define the ringing points and tuned by-passes for any insulated joints are still needed. The major objection to this approach insofar as this study is concerned is the high cost of the motion detector.

Another method of achieving a particuarly simple installation might be the use of conventional track circuits of the so-called "C" type, shown in Fig. 26. This circuit is unique in that the relay is located at the same end of the track section as the power feed. The only objection to this circuit is that in its usual form it requires AC at all times, necessitating an inverter for use when the system is running on the standby battery. Inverters are rather trouble-prone devices, and are generally a heavy drain on the battery. However, a modification to this circuit, shown in Fig. 8 adds a battery and a resistor at the ringing point and a blocking capacitor. The battery can be either a storage cell or a primary cell of any type. Examples of this circuit are known to have been installed and to have given completely satisfactory service for at least 10 years. The only problem is that a battery well or case must be installed at the ringing point.

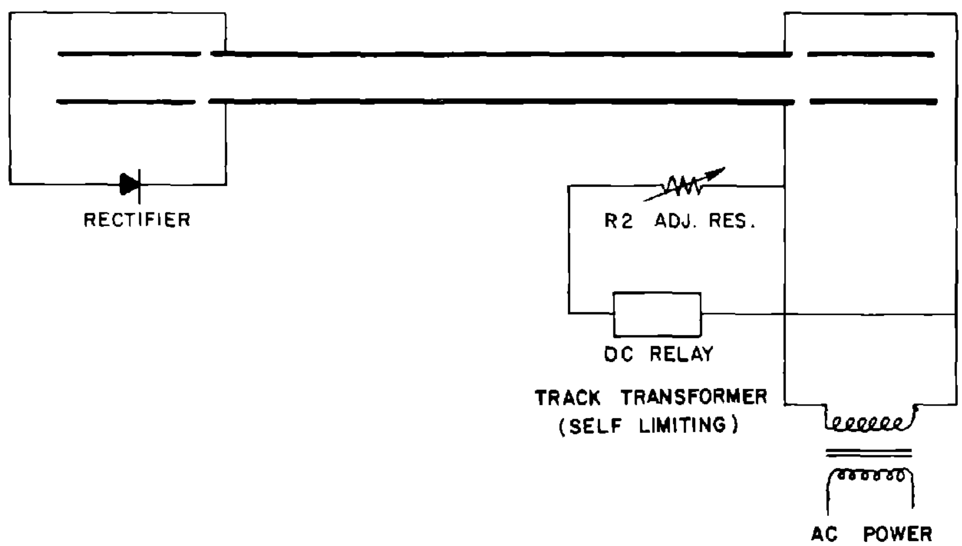


FIGURE 26. BASIC "C" CIRCUIT

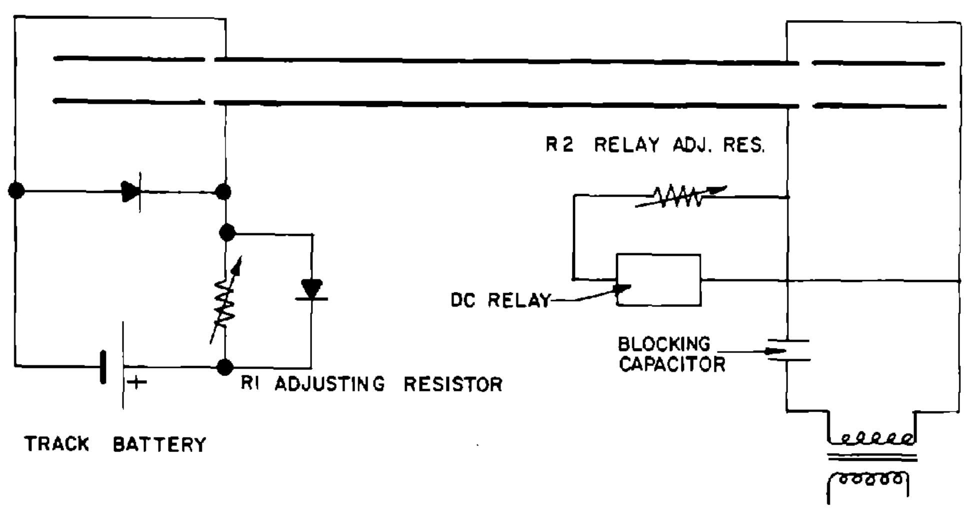


FIGURE 27. "C" CIRCUIT MODIFIED.
Modification to Eliminate Standby AC.

Unfortunately none of these alternatives really achieve the instant-installation objective, and so have been given no further consideration.

In the pursuit of this study, discussions were held with the signal engineers of several railroads. It was suggested to the investigator that a lower-cost vital relay be developed. This approach was given serious consideration, but has been found not to be a viable alternative. The present vital relay design is the culmination of one hundred years of effort to build a relay which will be fail safe. A great many ideas and "improvements" have been tried and found wanting in that time. The ancestors of the present relay had failure modes which did not appear until long after the relay was in service. In order to develop a new relay, a program to do extensive testing of designs, followed by years of field tests would be required. It requires 3 to 5 years to work out most of the design and manufacturing bugs in a commercial relay. Note that not all are eliminated. It would take at least twice this time to prove out a design meeting the requirements of a vital relay. Further, it would be very difficult, if not impossible, to predict how much of a saving would result. Such a program is not economically viable, although it is technically feasible.

No manufacturer will allow the investigation of costs of manufacture by non-company people which is the essential first step in such a project. It would be necessary, if such a program were to be successful, that all relays be built to a standard design to be manufactured by all companies. This would mean a loss of sales advantage which all companies will oppose. It must be remembered that the present relay has been refined for decades, and substantial amounts of money would be required in tooling up to produce a new design, even if all design and testing costs were Government supported. Further, it would be nearly impossible to predict what economies would result. This approach is fraught with such great uncertainties as not to be viable.

One of the most important characteristics which distinguish a vital relay is that it is equipped with non-weldable front contacts. One contact of each pair is made of carbon or a silver impregnated carbon material. The other is a metal contact, usually silver. A surge current which would spot weld two metal contacts together will only burn a pair of metal to carbon contacts. The relay will still drop when de-energized and the contacts will open properly. An alternative approach to achieving this vital Fail Safe feature in an automatic grade crossing warning system appears attractive. Doing so would expand the possible alternatives, by expanding the range of acceptable components.

There is essentially only one way that the possibility of welding can be eliminated. That is to eliminate the transients which cause it. In practice, this is difficult. However, in an automatic grade crossing system where reasonable design precautions can be taken to prevent entry of transients, the same result could be achieved if some circuit opening device, a fusible link, were to open the circuit to the protection relay if a transient sufficiently large to cause problems appeared. This possibility has been thoroughly investigated.

Transient protection requirements have been examined. In conventional practice, a protector is installed at the entry to the relay case on each wire. This primary protection provides for limiting the voltage to ground to approximately 300 volts. However, these arrestors, like all transient protective devices do not begin to conduct instantly but require a finite time to break down. A rapidly rising transient can reach voltages much in excess of 300 volts during this time. Short peaks of well over 1000 volts are easily reached.

It is present practice to provide no secondary transient protection except for solid state equipment. The relays are required to meet a 3000 volt insulation breakdown test, and reliance is placed on this to withstand whatever transient peaks occur before the primary protection breaks down and dissipates the transient.

The question has been raised as to whether the present practice places an unreasonable requirement on the relays, a requirement which might better be met with a lower test voltage for insulation resistance together with the use of secondary protection, as is now universal with solid state equipment. This has been fully investigated.

As has been noted previously, one of the likely candidate components has been the European signal relay. One such relay is available in the United States from the American division of its manufacturer. To get a better understanding of the characteristics of this relay, an inspection of an all relay interlocking plant using these relays for all functions except the track relays was arranged. The results of this inspection and discussion with the responsible signal engineering and maintenance people can be summed up as follows:

1. The circuit design is fail safe. The checking and abort circuitry provided is fully effective.

2. The plant has experienced a high incidence of contact failure, where contacts close mechanically but not electrically.

3. The packaging design is unsatisfactory. Service checking and changeout of modules is difficult and time consuming, and the package is not dust tight (the probable cause of the contact problem mentioned in 2).

4. The plant is perhaps 1/10 the size of an equivalent installation using vital relays.

5. The power drain was over 5 times that of an equivalent vital relay plant.

6. The reactions of the signal people involved were mixed. The maintainer liked it. The responsible signal engineer was ambivalent. A Signal Engineer who had formerly been responsible for this installation stated that if it was his responsibility, this plant would have been replaced long ago.

It is not possible within the scope of this study to completely review the circuit design of this plant. There is the possibility that more of the features of European technology could have been applied resulting in an interlocking plant which would be superior to that which was built. In the subject case, the relay manufacturer supplied only the relays. The circuit design was the responsibility of railroad personnel who had little previous experience with this kind of circuit design. This question has not been answered. Ways in which the relays are assembled into modules and the choice of connectors and timers used leave much to be desired. A very large percentage of the trouble which has been experienced with this plant can be directly attributed to the poor package design. There is reason to believe that maintenance at this plant would be close to if not better than a conventional plant, had a superior packaging design been developed, and an adequate supply of spare modules been provided.

In summary, it appears that this type of relay has not had a completely fair trial.

19.3 ALTERNATIVE 1-

A GRADE CROSSING WARNING SYSTEM USING EUROPEAN TYPE SIGNAL RELAYS

This system uses a modification of the conventional circuit shown in Figure 28. The relays used are European signal relays which have silver to silver front contacts, but also have an armature structure which prevents closure of any back contact unless all front contacts are open.

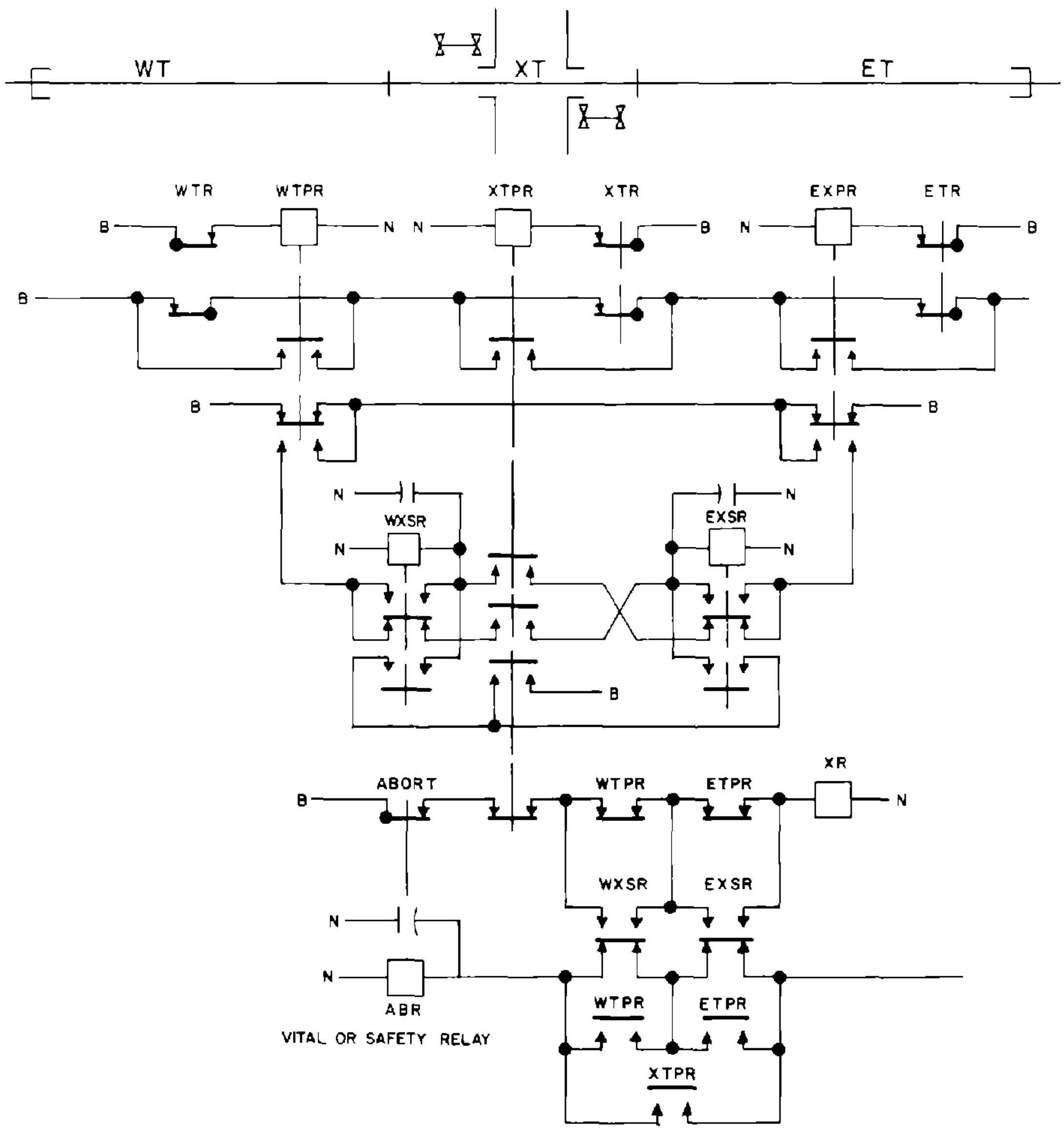


FIGURE 28. DETECTION AND DIRECTIONAL CIRCUITRY-ALTERNATIVE 1.

In this alternative, the track relays used are separate, and can be vital relay, or the European equivalent. A line relay or a relay driven by any Audio Overlay equipment which may be used can be substituted. In signal territory, where signal circuits would be carried through these track relays, use of vital relays is mandatory.

This alternative provides an abort circuit to insure that the relays perform as intended. Should this circuit be broken, a relay with non-welding contacts is dropped, causing activation of the grade crossing warning system. This relay must be slow release to avoid dropout during switching.

Figure 28 shows the basic circuit, and Figures 29 to 32 show this as it would be arranged for modularization to facilitate assembly and maintenance. Note that the type of relay used in this circuit is not of the plug-in type, hence complete modular construction is especially needed.

Operation - Train Detection (Refer to Figure 32)

Step 1 An eastward train approaching the crossing enters the WT track circuit. Track WTR drops away. Track repeater relay WTPR drops away due to open front contact in WTR relay. Abort relay circuit opens at second open front contact in WTR relay. Abort circuit is re-closed at back contact of WTPR to indicate that WTPR has dropped away, thereby complying with the circuit which caused the function to occur. Should any front contact fail to open, then no back contact can close in the WTPR. This system of back contact compliance checking is common to all track circuit repeaters. The circuit controlling XR is opened at WTPR front contact. XR drops away to start the warning system operating.

Step 2 The train enters the XT track circuit and passes over the crossing. Track relay XTR and track repeater relay XTPR drop away as described in Step 1. Positive energy (B) is taken across an ETPR front contact, WTPR back contact, WXSR back contact and XTPR back contact to EXSR coil to pick up EXSR and establish direction. The EXSR relay is then stuck up by B through closed back contact of XTPR and EXSR front contact to EXSR coil. The abort circuit is opened at EXSR back contact but re-closed by an XTPR back contact in parallel. The XR circuit is also opened at XTPR front contact.

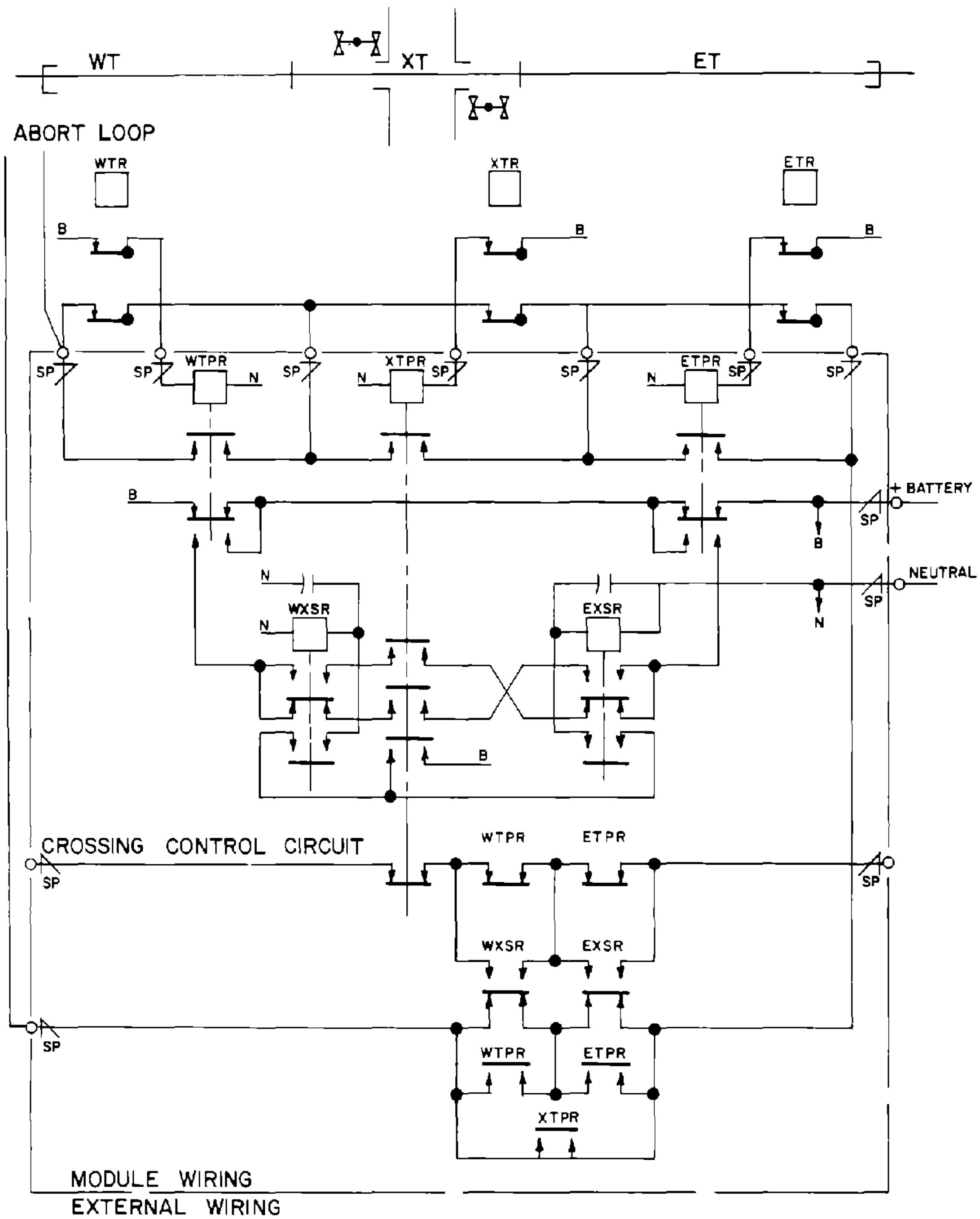
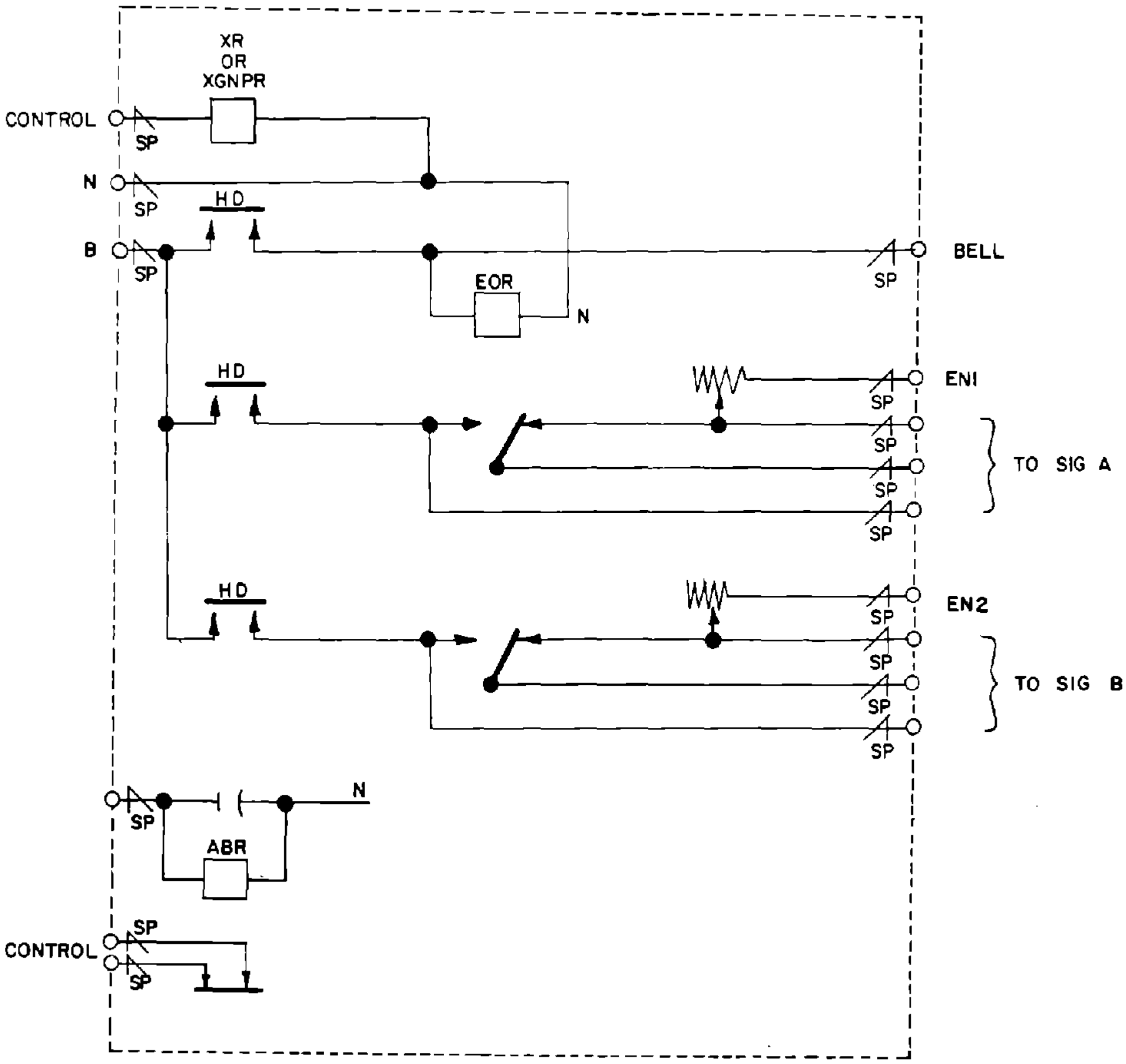


FIGURE 29. TRAIN DETECTION MODULE-ALTERNATIVE 1.



SP = SECONDARY TRANSIENT PROTECTION

FIGURE 30. FLASHING LIGHT CONTROL MODULE-ALTERNATIVE 1.

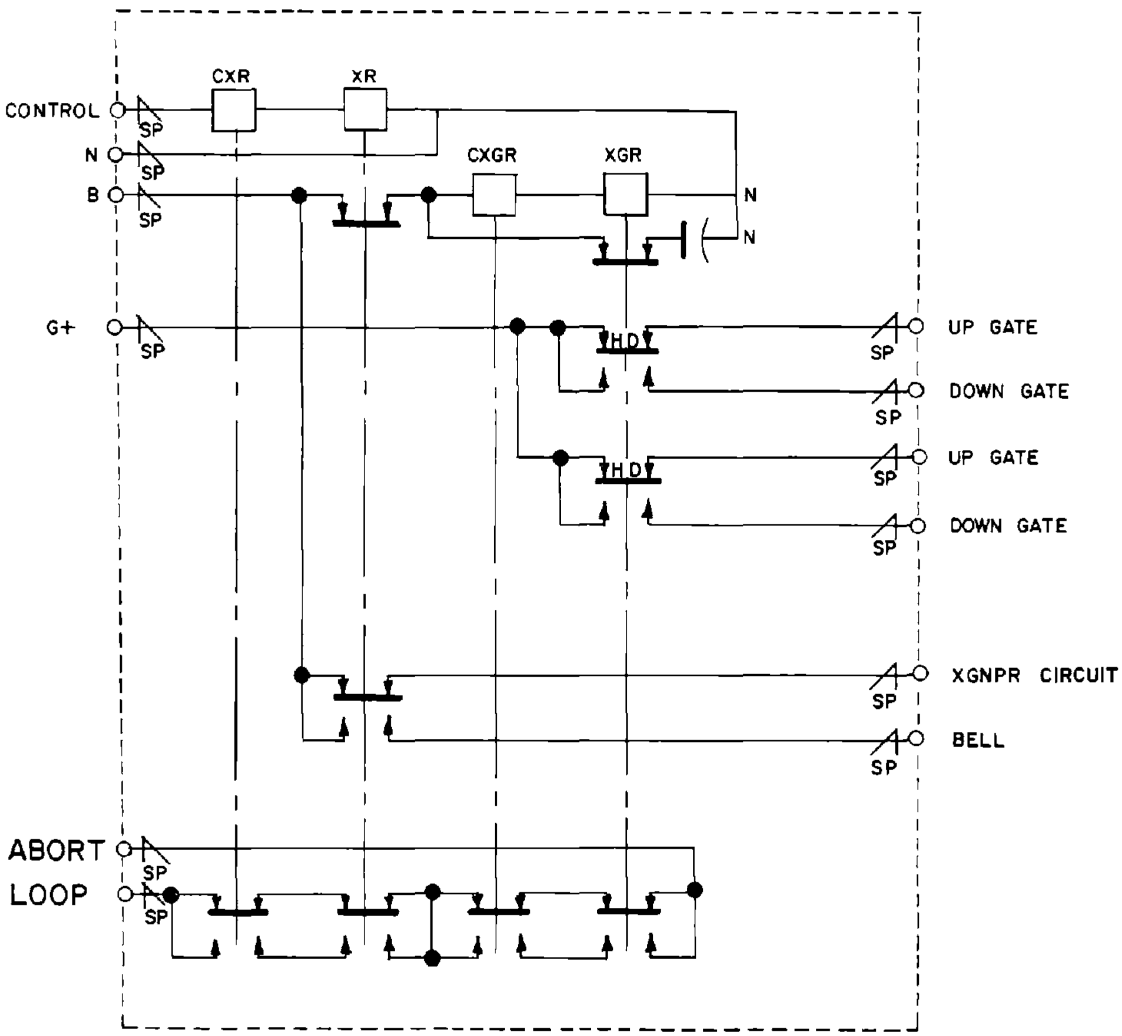


FIGURE 31. GATE CONTROL MODULE-ALTERNATIVE 1.

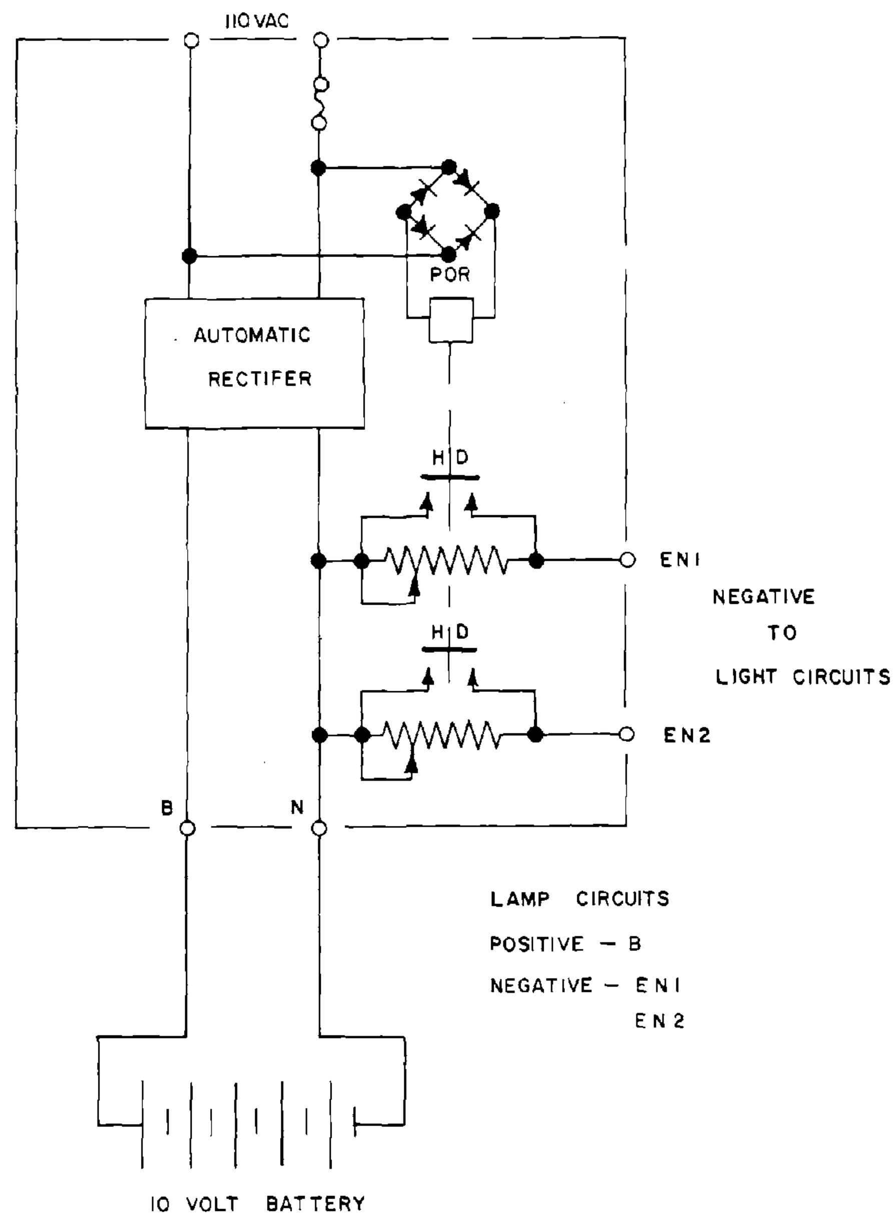


FIGURE 32. POWER SUPPLY MODUEL-ALTERNATIVE 1.

Step 3 The train now enters the ET track circuit. The ETR and ETPR relays drop away as outlined in Step 1. The pickup circuit of EXSR is opened at the front contact of ETPR. EXSR is sustained only by the stick circuit described in Step 2.

Step 4 The rear end of the train leaves the WT track circuit. WTR and WTPR both pick up. EXSR stick circuit is paralleled as follows: B from WTPR front contact through ETPR back contact and EXSR front contact to EXSR coil. This circuit will sustain EXSR once the train leaves the XT track circuit. XR circuit remains open at XTPR front contact. Note: If train is short enough to occupy the XT track circuit exclusively, this step will occur before Step 3. That portion of Step 4 pertaining to the EXSR circuit will then occur as a part of Step 3.

Step 5 Rear end of train now leaves the XT track circuit. XT and XTPR relays both pick up. The EXSR relay is now sustained only as outlined in Step 4. XR relay picks up to stop the warning system due to positive energy from B through the abort relay front contact, the XTPR front, the WTPR front and the EXSR front contact to the XR relay coil. The abort circuit though opened at the XTPR back is re-closed at the ETPR back contact, since the EXSR back is also closed.

Step 6 The train leaves ET track circuit. ETR and ETPR both pick up. EXSR drops away due to open back contact in ETPR. XR relay remains picked up due to closed front contact in ETPR instead of front contact in EXSR. The abort circuit, though opened by ETPR picking up is re-closed by EXSR dropping away. Note: Should any track repeater fail to drop when its respective track relay drops away or should any directional stick relay fail to drop away when all 3 track repeaters are picked up, the abort circuit (abort loop) would open long enough for the capacitor on the abort relay to discharge and drop that relay. This is a carbon contact relay and will not stick in the energized position. The abort relay opens the XR circuit to start the warning system. Unless gates are used, the XR relay has no front contacts to weld shut and so cannot stick in the energized position. It has to drop away. In gate circuits both the XR and XGNPR are controlled through the abort relay.

Gate Operation

In the gate control module, there is a current checking relay, CXR. This relay is in series with the XR relay and its function is to open the abort circuit whenever the control of XR is opened. When XR drops away then the abort circuit is re-closed at an XR back contact. This type of back check is employed as well on the XGR, since both have working front contacts which could stick. As previously mentioned, both the XR and XGNPR circuits are energized by positive energy (B) taken through an abort relay front contact. This is because only the XGNPR has no front contacts and as such cannot stick up when de-energized. An abortive failure in the gate control would cause continuous operation of the flashing lights even though the gates might not go down.

Step 1 The XR circuit is de-energized as previously outlined. This causes the CXR relay to open the abort circuit. The XR relay also drops away. The abort circuit is re-connected at an XR back contact. The control of XGNR is opened, at an XR relay front contact. The XGNR relay drops away to start the flashing lights operating. The bell circuit is closed at an XR relay back contact to start the bell. The XCR circuit is opened at an XR relay front contact. XGR is sustained only by the charge on its parallel capacitor.

Step 2 The charge on the XGR capacitor is exhausted. The XGR drops. The CXGR drops. This opens the abort circuit at the CXGR front contact and recloses it at an XGR back contact. The hold clear magnets in both gates are de-energized when XGR front contacts in the up gate circuits are opened. The gate motors begin to drive down once the XGR back contacts energize the down gate circuits. Once the gates have descended 4degrees (from 90 to 86 degrees) the gate contacts in the XGNPR circuit also open. Contacts inside the gate mechanisms shut off the motors at 45 degrees and gravity drives the gates down to 0 degrees.

Step 3 The train having traversed the roadway and having left the XT track circuit, the XR relay and CXR relay again pick up. This causes the XGR and CXGR to pick up and re-energize the up gate circuits. The gates start to ascend. The bell stops ringing. The flashing lights continue to operate due to the open 86 to 93 degree contacts in the gate mechanism in series with the XGNPR relay.

Step 4 The gates reach 90 degrees and contacts inside the gate mechanisms open the motor circuits. The hold clear magnets remain energized to keep the gates vertical. The 86 to 90 degree gate contacts close thus restoring the circuit from B through XR relay front contact, the 86 to 90 degree gate contacts to the XGNPR relay coil. XGNPR picks up and shuts off the flashing lights.

Flashing Light Control

Control of XR or if gates are used, XGNPR is previously described. When this relay drops away no contacts are opened. Consequently no checking is required. The bell is energized if required here. The flashing relay is energized and 2 sets of series connected lights are turned on. The flasher contacts are connected to short out the lights which are off, thus avoiding the switching of an open circuit. The light circuits include a resistor with which to adjust the light voltages in order to compensate for line resistance.

Power Supply

Power for this circuit is obtained from a floating charged storage battery with an automatic rectifier. Unlike systems with a lighting transformer and transfer relay, this system uses the battery for lights at all times. When charging, there is an adjustable resistor in the circuit to each pair of lamps to compensate for the higher battery voltage which results. If the power fails, the power off relay shunts these resistors in order to maintain a constant supply voltage to the lamps.

19.4 ALTERNATIVE 2-

A SYSTEM HAVING MERCURY WETTED REED RELAYS

This system is built around the Mercury Wetted Reed Relay, a particularly reliable and long lived relay which has some very attractive characteristics. This circuit is similar to the conventional AAR circuit shown in Figure 20.

One of the limitations on the application of this relay is in the fact that a surge of sufficiently high amplitude can vaporize the mercury between the contacts and then weld the contacts. However, this would require a substantial amount of energy, and can be prevented by assembling the relays into modules which have secondary transient protection on all entering wires. A discussion with engineers of a leading manufacturer of this type of relay elicited the information that there had been no known cases of failure of one capsule to operate when another in the same relay had done so. However, to eliminate any possibility, the track relay is limited to a single capsule.

The mercury wetted reed relay is a design of relay available commercially from a number of manufacturers. It is currently listed in Mil-HDBK217A as having an MTBF of 5×10^{12} hours, and an MOBF of 1×10^{10} operations. Relays of this type with the sensitive type capsule require very small amounts of power, as low as 6 milliwatts in the metal tube configuration and 40 milliwatts in the printed circuit board mounted form. The contacts are coated with mercury. They are enclosed in a glass capsule. The contact configuration can be either from C (make after break) or from D (make before break). Contact ratings are 100 VA max, 500 volts max, or 2 amp. max. However, because of the mercury contact this relay has one of the highest surge handling capacities of any relay. It can handle short transients in excess of 10 times rated current without degradation. There is also a heavy duty capsule with a 250 volt ampere, 500 volt or 5 amp maximum rating. This requires approximately 3/4 of a watt to operate in the 3 capsule form.

Another limitation in applying this relay is the time for draining the excess mercury from the contacts when the relay is placed in service. This takes 90 seconds, one operating cycle, or a rap on a hard surface, whichever occurs first. The relay is position sensitive in service, but this is no different than is the case for many vital relays.

The mercury wetted reed relay is not a vital relay. Therefore, this circuit would need to be modified if it is to be used in signal territory where signal circuits are involved. Vital relays would have to be used for track relays. This could be done either by direct substitution, or, if the modules are factory assembled units, by repeating the track circuits into the modules. Refer to Figure 14.

In this circuit relays WTR, XTR, and ETR are single capsule mercury wetted reed relays which serve directly as track relays. Relays WXSR, EXSR, and ETPR are two capsule relays operated from the control battery. Relays WSXR and EXSR are both required to be slow release. This is provided by the installation of a capacitor across each coil. Relay ETPR is a repeater for relay ETR and is used to avoid the latter having a second capsule, both because of power limitation and the possibility of one capsule operating and the other failing to do so.

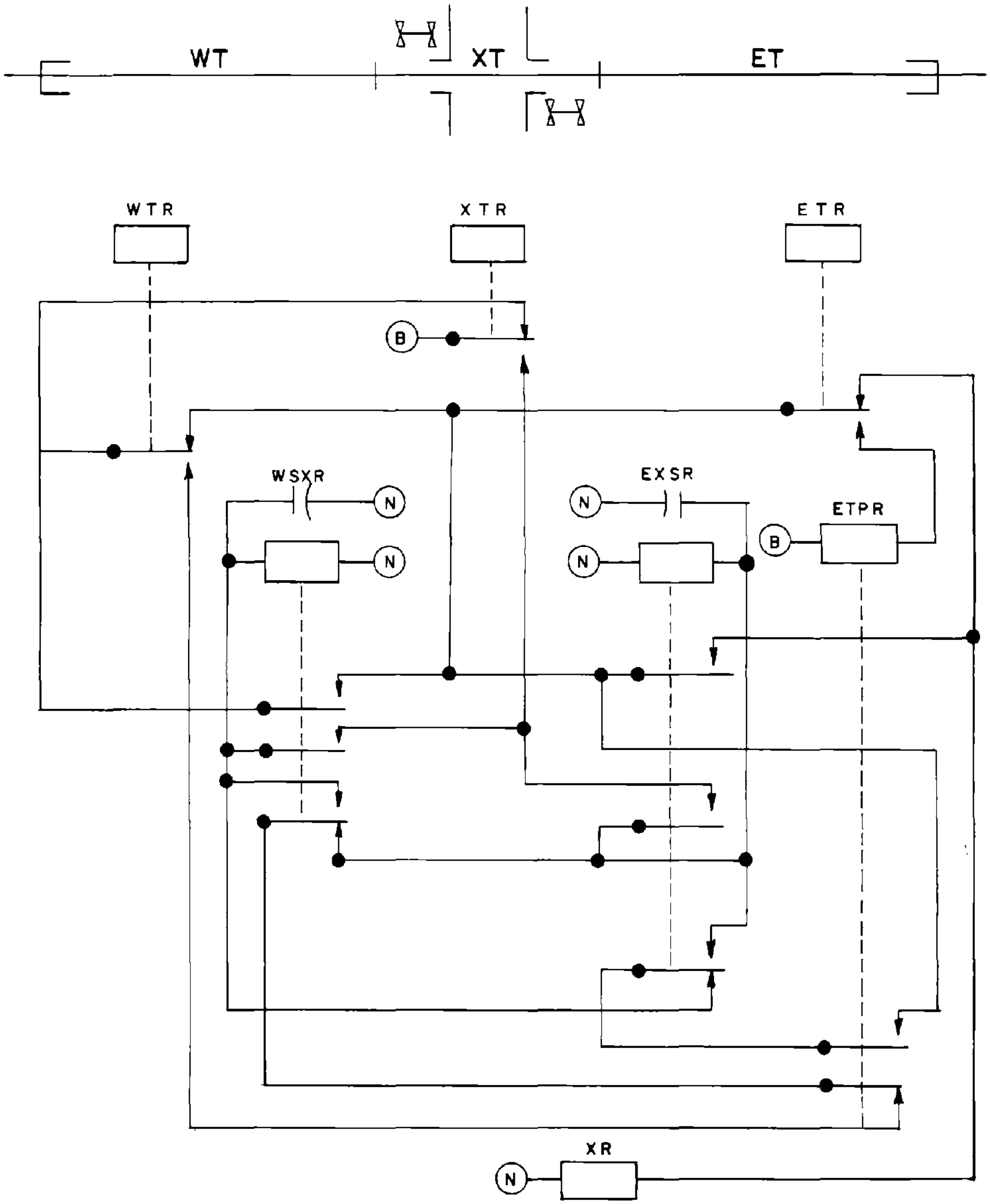


FIGURE 33. BASIC CIRCUIT-ALTERNATIVE 2

The functional operation of this circuit will be described. Refer to Figure 33 for this circuit. A train will be assumed to travel from west to east. At rest, relays WTR, XTR, ETR and XR are all up while WSXR, ESXR, and ETPR are all down.

Step 1 An eastbound train enters track circuit WT. Relay WTR drops. This drops relay XR, initiating the warning system. A circuit is completed from Battery through XTR front to WTR back to ETPR back to WSXR back to the coil of EXSR, pulling in that relay.

Step 2 The train enters the island circuit XT, dropping out XTR. Relay EXSR is held up over XTR back to EXSR front. Note that this contact is closed to the other front contact. This is a peculiarity of this type of relay.

Step 3 The train enters track circuit ET, dropping ETR. Note that ETPR does not pull in at this time because XTR is out.

Step 4 Train clears WT, picking up WTR.

Step 5 The train clears the crossing and the XT track circuit. Relay XTR picks up. A circuit is completed from Battery to XTR front to WTR front to ETR back to coil of ETPR, pulling it in. This further completes the same circuit from WTR front through ETPR front to EXSR front to the coil of EXSR to hold that relay up. Another circuit is completed through XTR front and WTR front to EXSR front to XR, energizing that relay and shutting off the warning.

Step 6 The train clears ET and relay ETR picks up. Relay ETPR drops as does relay EXSR, restoring conditions to the rest state.

A short train, one shorter than the XT or island track circuit could operate in the same manner. Relay EXSR could be held up by XTR back until XT is cleared, and then by the stick circuit through ETPR, as before. The slow release on EXSR would prevent dropout during transfer of other contacts.

The circuits for a train detection module and a Flashing Light control module are shown in Figures 34 and 35. The gate module and power supply would be substantially as in Figures 31 and 32 and need not be repeated.

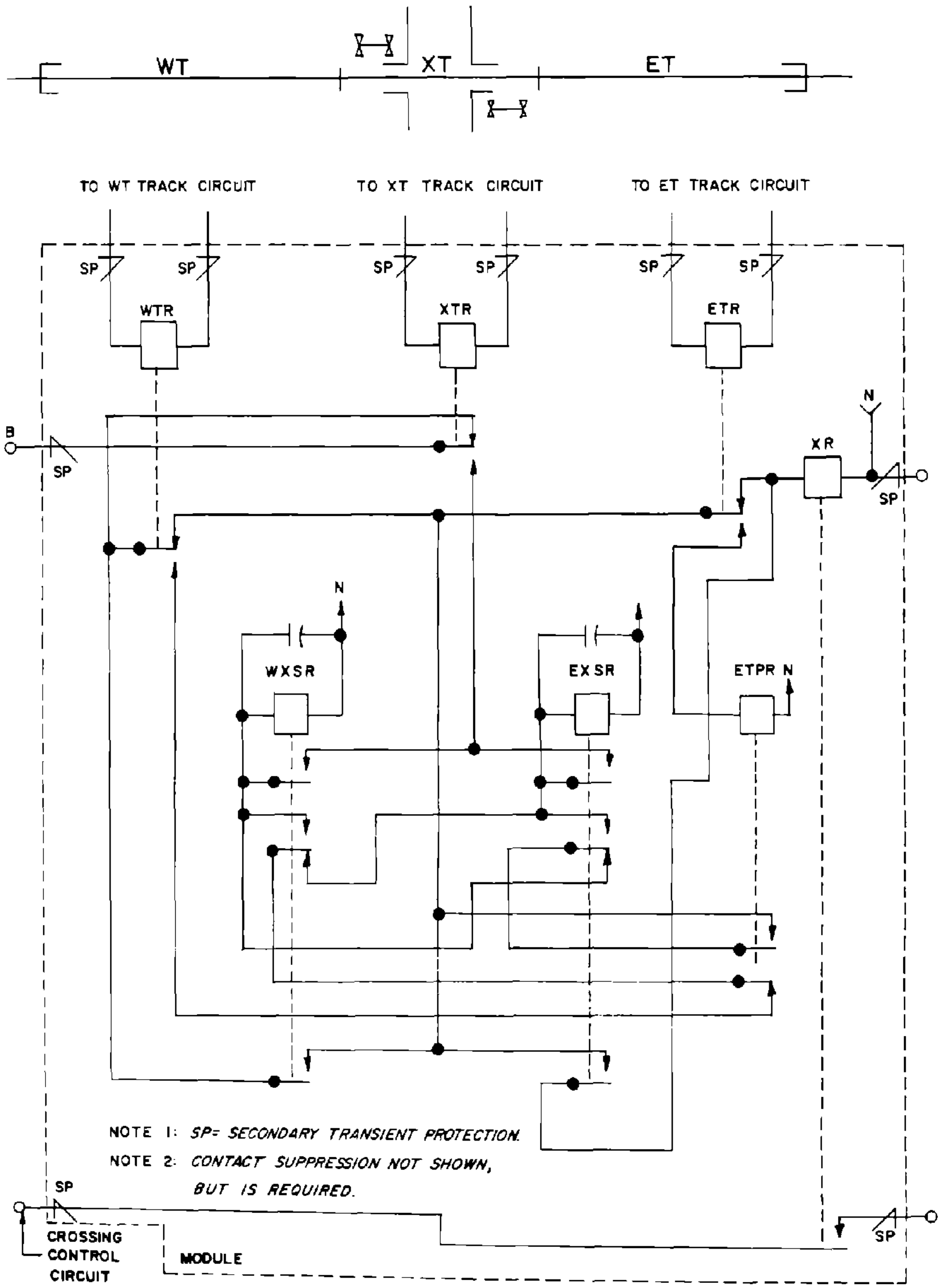


FIGURE 34. TRAIN DETECTION MODULE-ALTERNATIVE 2.

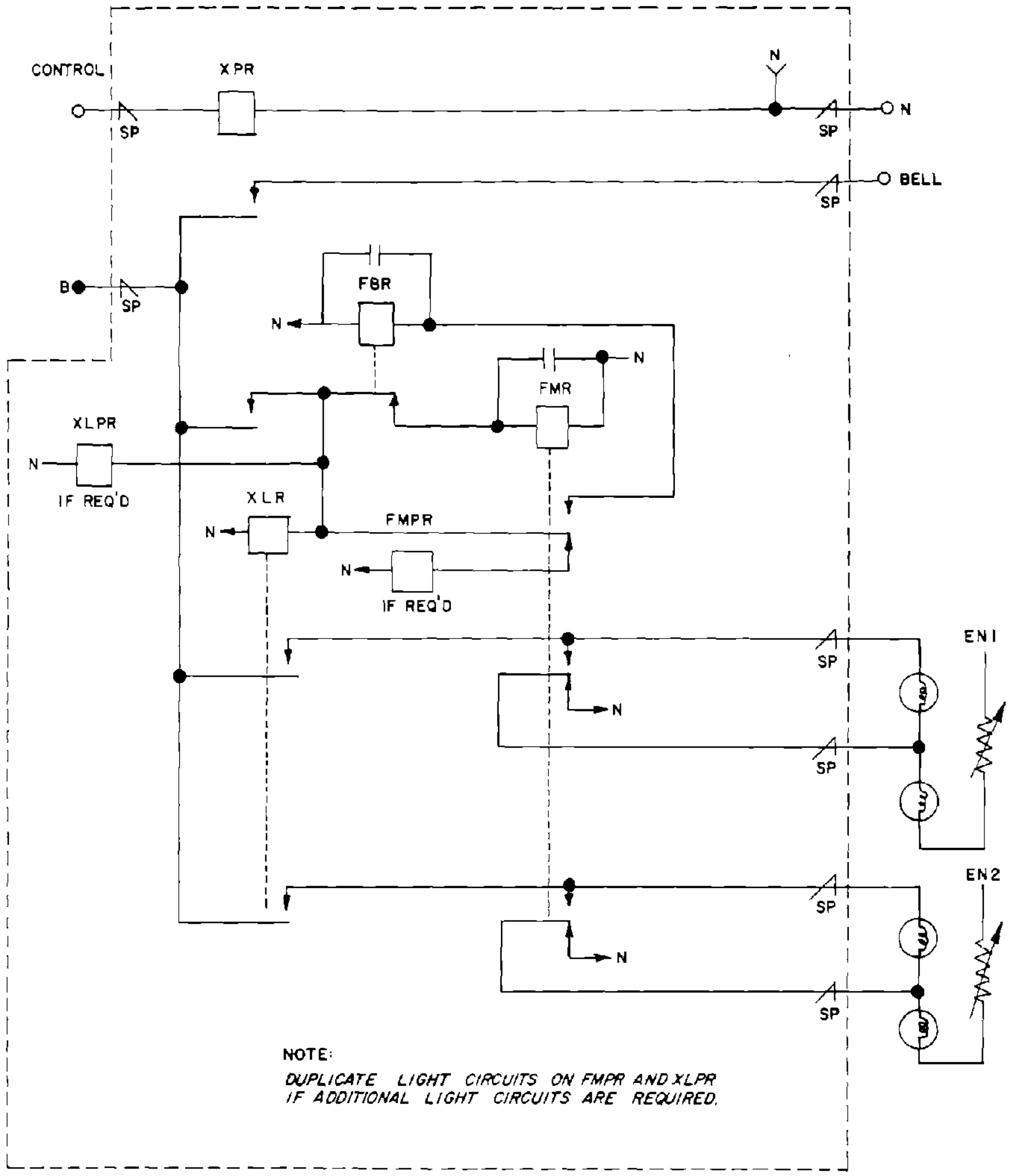


FIGURE 35. FLASHING LIGHT CONTROL MODULE-ALTERNATIVE 2.

The circuit used in this alternative is a straight forward adaptation of a standard AAR circuit. The power requirements of mercury wetted road relays are low enough that two relays could be connected in series for a track relay, thus making redundant circuitry possible. However, this relay has an established reliability which is so much better than conventional practice that redundancy is not warranted.

19.5 COMPARISON OF ALTERNATIVES

The comparison of alternative approaches with each other and with present practice is shown in Figure 36. The cost, power requirements, and reliability are compared.

The first demand is that any new approach be safe. While the comparison is made on the basis of straight reliability, and MTBF and MOBF estimates made, the circuit designs follow conventional signal practice. It is therefore reasonable to assume that the same small percentage of all failures will be unsafe, and a comparison based on the MTBF and MOBF will be valid.

On this basis, Alternative 1 uses components which have comparatively similar failure rates as conventional practice, but because of more contacts, the overall system failure rate is lower, although not by a very large amount. However, the reliability of Alternative 2 is very much better, over 3 orders magnitude (1000 times) in hours and over 2 orders (100 times) in operations, clearly a much superior reliability.

In power required during idling (when the system is at rest between trains), Alternative 1 requires approximately 4 times the power of present practice while Alternative 2 requires only 20% more. This 20% premium is significant, but it is not unreasonable. The 400% required for the circuit in Alternative 1 is a serious drawback.

A comparison of cost shows that both alternatives are less costly than conventional assemblies. The cost basis used is the cost of relays and wiring only for the equivalent functions. This includes track relays, logic, the flasher, etc. but not the power transfer relay or the batteries, etc. Alternative 2 is 62.5% of present practice, while Alternative 2 is only 25% of present practice in the single track without gates version. Note that the total cost being discussed here is a little over 10% of the total cost of installation of a grade crossing warning system.

The ratio of volume is a measure of the amount of cabinet space needed. Both alternatives show a greatly reduced spare requirement, with Alternative 2 the best. If

RELIABILITY	Alternative 1 European Signal Relays	Alternative 2 Mercury Wetted Reed Relays	Present Practice
Relay Only			
MTBF	3.9×10^{7} hr.	5×10^{12} hr.	2.6×10^{7}
MOBF	20×10^{6} opr.	1×10^{10} opr.	20×10^{6}
System (1 Track, No Gates)			
MTBF	1.1×10^{6} hr.	2.9×10^{11} hr	1.5×10^{6} hr.
MOBF	0.8×10^{6} opr.	5.8×10^{8} opr.	1.2×10^{6} opr.
Power Drain (idling)			
1 Track, No Gates	.4 amp	.12 amp	.1 amp
Estimated Cost (equivalent function)			
1 Track, No Gates	$1500	$600	$2400
2 Tracks with Gates	$2400	$850	$3700
Approximate percent of Vol. of modules, 1 track, no gates	20%	15%	100%

FIGURE 36 COMPARISON OF ALTERNATIVES

batteries are put in a separate well, either alternative would fit into a very small cabinet. This simplifies placement, and reduces problems with vandalism.

In conclusion, Alternative 2 is the most attractive provided the limitations on the relay as described in connection with the detailed description of that alternative are acceptable.

20. CONCLUSIONS AND RECOMMENDATIONS (NON-VITAL RELAYS)

20.1 CONCLUSIONS

The results of this study show that assemblies using circuits similar to present practice with components other than vital relays can be employed to produce fail-safe grade crossing warning systems with reliability equivalent to or higher than that of existing assemblies. These assemblies are much lower in cost and much smaller than present assemblies.

20.2 RECOMMENDATIONS

In light of the results of this study, it is recommended that the necessary steps be taken to advance both alternative designs to field installations and tests.

It will be necessary to waive the standard 3000 volt insulation resistance test to obtain acceptance of these designs, but this will be similar to what has already been done for solid state equipment.

APPENDIX A

SYSTEM COMPONENTS

A.1 INTRODUCTION

In this appendix will be found a listing and description of the hardware components of a grade crossing warning system. This material is supplemental to that in the body of the report. Motion sensing devices are not treated further, as they are fully discussed in the previous sections.

A.2 LOGIC COMPONENTS

Regardless of the system of train detection used, one or more track relays are used to control all of what comprises the crossing control circuits. These track relays detect train occupancy of each circuit and activate the logic system which follows. This may consist of one or more of the following:

1. Direction Detection

Directional stick relays are vital circuits relays so circuited that after the rear wheels of the train pass off the roadway, one of two directional stick relays corresponding to the train direction will be picked up and will shunt the crossing control circuits around the track relay for the departing approach zone, thus causing the protection to stop operating.

Once the opposing (Departing) approach zone is no longer occupied, both the directional stick relays drop away to permit direction detection of the next train. There are several schemes for operating these relays. In most, the relay for the particular direction involved picks up when the approach circuit is occupied and opens the pickup circuit of the opposing directional stick relay. The relay which is then picked up remains up by a circuit through one of its front contacts. This stick circuit (from which this scheme derives its name) is maintained through the back contacts of the opposing approach occupancy detection relay, be it a track relay or line relay, and in some schemes the island circuit track relay.

In another scheme, the directional stick relays are not inter-circuited and are arranged so that they both pick up on occupancy of the island circuit, and each sticks on occupancy of the opposing approach zone.

This situation could result in no advance protection at all should both approach zone relays (track or line) fail to pick up after the passage of a train. The circuit does possess a very desirable characteristic in that at stations or switching areas a train need only occupy the island circuit and then back off in order to clear the protection during switching moves or when making station stops. If this feature is necessary or if "timeouts" or "whenouts" are used at side track switches, the added hazard of this type of circuit is dealt with by breaking the signal controls in both directions through the back contacts of both directional stick relays or in the absence of block signals by timing out the directional detection circuits after a period of time longer than the maximum use of such a cutout feature. Great care must be taken in application of this type of circuit since it does not offer following train protection in the event of a track circuit failure.

The so called interlocking relay was the first successful attempt at detecting train direction. It is totally mechanical and is accomplished by use of a mechanical interlock between two relay armatures, each with its own coil and contacts, mounted in a common enclosure. The relay armature which drops out first, to start the protection operating, causes the interlock to place a stop in the path of the other armature which prevents it from dropping away completely. The two coils are used in place of either track or line relays corresponding to the two approach zones of the crossing. Special contacts in the interlocking relay do not open with their particular armature on the stop (dropped halfway out). The front and back regular contacts on the other hand operate normally. It will be seen that this system permits any type of protection to be controlled with a minimum of equipment. Interlocking relays connected directly to the track cause anxiety among block signal designers since their front contacts on the second side to drop do not open as far as a conventional relay. In addition, the interlock, being mechanical tends to give trouble as the unit ages. None the less, there is many an interlock relay still in use, many of which are well over the usual 20-year life expectancy of a vital relay. The device is, however, not favored for new installations.

2. Speed Detection

Circuits which detect train speed utilize the "speed multiplied by time = distance" concept. If maximum train speed requires a much longer approach zone than minimum speed, then the train is run over a timing track circuit of known length. If a timing relay completes its cycle before the train reaches the maximum speed approach zone, a stick relay picked up by the timer in combination with the timing track relay cuts the first approach zone track relay out of the control circuit for that zone. If several different speeds are encountered each additional speed has a timer and a starting point with its own track circuit, and stick relay. The timers are either thermal or motor driven. In both cases it is necessary to check the timer as being ready to operate and at the beginning point of its cycle. This is sometimes accomplished by breaking block signal control circuits through a checking contact in the timer mechanism. In the absence of this scheme or if it is not feasible for any reason, a timer checking stick relay is used. This relay picks up when the timing track is occupied if the timer is in its start position and the timer stick relay is dropped out. The timer check stick relay then sticks up over a back contact of the timing track relay and a front contact of the timer stick relay and permits the timer to start operating. In still another scheme the timer checking stick relay is eliminated by breaking the circuit output control through the checking contact to insure that the timer drops back to its starting point once the timer stick relay picks up. It must be pointed out that this is less than full checking since each timer start is checked by the previous operation and an occasional long ring due to a defective timer may go unnoticed. The advantage of this circuit is that it utilizes the full cycle time of a thermal timer. A recent improvement on this scheme is a system which uses one short timing circuit and a standard slow release vital relay so arranged that warning time becomes a function of the charge in a capacitor in the crossing control circuit. The faster the train the less charging time while the train is on the timing circuit. A train at maximum authorized speed produces zero charging time and subsequently utilizes the total approach zone of the crossing. If train speed is relatively constant, then this system will approximate constant warning time. Under such circumstance this system is useful since it is less expensive and much simpler than the one described previously.

3. Cutouts

These are devices and/or circuits which cause crossing protection to cease operation once a train has stopped or prevent it from starting as conditions require. They may be of one of the following types:

A. Timeouts

Automatic operation uses equipment similar to that used with speed detection except the secondary (slow speed) starting point is usually eliminated in favor of an island circuit of some kind at the crossing. The timer is adjusted so as to permit the slowest train to reach the crossing before the time has expired. Therefore, it is assumed that the train has stopped if the time runs out. When the train departs the circuit is automatically reset for the next train. These are usually used around yards and passenger stations.

Semi-automatic operation is a system in which the timeout is manually initiated, usually with a push button at trackside or in an agency station, after which it functions to stop operation of the warning devices when a time limit has run out. In this case the time is to afford protection for trains at speed should the timeout be operated erroneously. No further manual operation of the controls is necessary to reset the circuit once the train leaves.

The manual timeout is similar to the semiautomatic timeout except it is not self-restoring in back of a train. It usually involves a plunger switch, a toggle or a plug box as an initiating control, which must be manually restored to the normal position to return the protection to normal mode. This scheme has the advantage of enabling the operator to re-start the protection before the train continues, thus avoiding a stop at the crossing to allow the usual 25 to 30 seconds advance warning time. Its failing is human in that train crews do not like to use manual timeout equipment for fear they will be held responsible if the warning system fails to operate properly for the next train. With this in mind, all timeout circuits should also set block signals approaching the crossing at stop if possible.

B. When-outs

A when-out is a cutout which is initiated when something else happens. It could be merely a switch or button control or it could involve hand thrown switches within a crossing approach zone and occasionally the indication of a block or interlocking signal or a movable bridge. In the event that a crossing approach zone extended into and beyond an interlocking, means would have to be provided to cut out the crossing if a route were lined which did not involve use of the crossing. When-outs have the disadvantage of possibly being operated in front of a train approaching at speed. For this reason they are usually applied in conjunction with some form of safety device or procedure to insure full warning time under all conditions.

4. Display Controls

Display controls are circuits and hardware which actually make the warning system do whatever the detection and logic components require.

A Flasher Relay is either a vital circuits relay with special heavy duty contacts and an electronic pulse generator to provide 35 to 55 operations per minute or a magnetic mechanical multivibrator operating contacts alternately at the same rate. A recent development is a solid state flasher unit which has no contacts to maintain. It, however, is limited in scope since units of one manufacture cannot flash AC energy, and need a power transfer relay of 4 instead of 2 contacts.

Gate Sequence Relays are used when gates and flashing lights are used together. It is necessary that the lights start flashing about 3 seconds before the gates begin to descend. This is accomplished by a slow release vital circuits relay. The delayed operation is obtained by placing a large copper slug on the coil. This, in combination with the coil's characteristic resistance and current carrying capability produce a failsafe 3 or more second delay before the gate motor control is allowed to drop out. It is also desirable to use a"break and shunt constant"arrangement in the control of this relay to assure maximum dropaway delay time. Similarly it is necessary that the flashers continue to flash after the train has passed until the gates are up. This is accomplished by providing a relay which repeats all gates in the clear position and controls the lights and flashing relay. If bells are used, and they cut out once the gates are down, this is accomplished by contacts in each gate in parallel, or sometimes by a contact in one gate only.

The gate motor control relay has heavy duty vital contacts front and back if for up and down drive gates, front contacts only if gravity down gates are used. If power down gates are used, the relay contacts have to be able to handle the locked armature current of each gate should any gates be obstructed while being driven down. This current, though not injurious to the gate motor, is hard on relay contacts. Usually no more than one gate is driven from each set of contacts.

The Crossing Control Relay used with flashing lights alone or with the gate repeater relay must have heavy duty back contacts to handle the current of the light circuits, and bells if used. In addition, this relay must start the flasher relay.

A preemption relay (traffic relay) is a relay which controls the grade crossing phase of associated traffic light protection at an intersection near the track.

A.3 SOURCES OF ELECTRIC POWER

Electric power must be provided at all grade crossings having automatically operated active warning systems. This power can be obtained by purchase, by generation, or from primary batteries.

1. Purchased Power

Power may be purchased at each crossing. This involves a power service usually with a meter and separate billing and minimum charges per crossing by the power company. This minor disadvantage is amplified by lack of multiple feeds should local commercial power fail. Advantages include minimum maintenance of railroad owned equipment and no long power transmission line.

Power may be purchased at one or more points along a line and then distributed by a railroad owned transmission line. This is normal practice on electrified railroad lines, but is not usual unless there is a substantial demand for power. A large number of crossings on a line with high train density tends to make this approach economical. A block signal system using AC track circuits tends to need both more power and more reliable power, since the inverters needed for standby operation draw heavy current from the batteries. This approach tends to have greater service reliability than purchase of power at each crossing.

2. Railroad Generated Power

The use of continuously operated generating facilities is usually limited to railroads operated by electric traction. An auxiliary generator in a substation or power house provides power to the signal system, including grade crossing protection and often also to stations and other track-side buildings. If DC propulsion is used, the signal auxiliary may be fed by the same transmission line which feeds the sub stations for the traction system.

Standby Generators are sometimes used at interlocking and C.T.C. control points, and remote locations where loss of power is critical and the size of the load precludes adequate battery capacity to bridge maximum commercial power outages. These are usually engine driven alternators which can feed a transmission line to charge track, signal and crossing batteries should commercial power be out.

3. Primary Battery Systems

At locations where no commercial or railroad generated power is available, primary batteries must be used. Primary battery use is avoided wherever possible because this type of battery requires careful maintenance by skilled maintainers if a long life is to be realized. They require frequent checking during early life and again as they approach exhaustion. And of course they must be completely rebuilt when exhausted, a job which is dirty and time consuming. They are also very sensitive to contamination. A small brass nut the size of a pea accidentally dropped into a cell will cause it to become exhausted in a very few days.

Primary batteries do have advantages. They are uniquely matched to the needs of a DC track circuit. They are, when properly maintained, very reliable and relatively long lived. A battery of 500 ampere-hour cells will provide power to a crossing having the usual 8 flashing lights but no gates for 6 to 8 months. This can be extended to about 14 months if the primary-secondary battery combination system described below is used.

It is no longer general practice to rely entirely on primary batteries. A second (standby) source of power is usually required. Using a primary battery to charge a secondary (storage) battery through a charging control device not only is accepted as meetng the two source requirement but it also greatly lengthens the life of the primary battery by eliminating the sharply higher current drain which occurs when the crossing warning system is activated. This peak load is now carried by the storage battery.

Primary cells must be supplying at least a certain minimum current to a load at all times. If this is not done, the cell is subject to very rapid chemical decomposition. The minimum current drain is preferrably obtained by proper circuit design, but a dummy load can be used if necessary.

A.4 STANDBY POWER

Applicable government regulations require virtually every active grade crossing warning system to have a second power source to keep the system in operation when the primary (usually commercial) power source fails. The few exceptions to this are to be found on electrified railroads, where the trains also stop if power goes off, and on a few minor crossings, especially on industrial railroads.

Storage batteries are the almost universal choice for this second power source. However, a few systems based on a primary battery are used. Several types of storage battery are used. Several configurations of charging equipment can be used. These will be described herein. A power transfer relay is also required.

In addition to the batteries and charging equipment, at those locations where AC track circuits are used, some form of inverter is required to obtain the proper frequency AC for the track circuits.

1. Storage Batteries

There are several types of secondary or Storage batteries used in railway signal service, which includes active grade crossing systems.

The Lead-Acid battery is a battery having excellent high current capacity but has somewhat limited life. It is essentially the same type of battery as is used in an automobile, but differs in ways which improve its life in railway service.

Nickel-Iron batteries (the Edison or Alkaline cell) is a particularly rugged battery, but has a limited current surge capability. It is also relatively expensive. However, if fluid levels are maintained it has an extremely long life. Batteries 50 years old are still in service.

The Nickel-Cadmium battery is a relative newcomer to railway signal service. It effectively combines the surge current capacity of the lead-acid cell with the long life of the Nickel-Iron cell. This cell has the best overall combination of characteristics, but is the most expensive.

2. Charging Equipment for Storage Batteries

A. The Single rate charger

This device is essentially a transformer and a rectifier with a means to manually adjust the charging rate. The maintainer keeps a log of specific gravity, and, taking such factors as temperature, frequency of power outage, train density, the season of the year, etc. into account, manually sets the charging rate. This adjustment is an art, but a good maintainer can keep a battery charged without having to add water more often than twice a year.

B. The two rate charger

This device is similar to the single rate charger except that it has a relay which increases the charging rate when the grade crossing warning system is activated. This two rate charge control relay is dropped out on system activation, increasing the charge rate until the normal floating voltage is again reached, whereupon the relay picks up and returns the charging rate to the normal lower one. This charging system is particularly useful where there are gates or other devices which draw heavy currents from the battery. Note that the flashing lights are usually supplied directly from the main power source and are therefore not a part of the battery load until a power outage occurs.

C. Other charging devices

There are a number of other battery chargers in use. These include various types of automatic regulators, variable rate devices, etc. All of these are designed to float the batteries in a charged state and to quickly restore them after activation of the crossing warning system.

3. The Automatic Rectifier-Primary Battery System

A form of standby power supply occasionally used combines a primary battery with a device called an Automatic Rectifier. This is a device designed to supply all current in excess of that required to maintain the primary battery in good condition so long as the AC power source is available. In the event of a power outage, the primary battery carries the entire load. Again, the flashing lights are powered directly from the AC line, being transferred to the battery only during an AC power failure. A storage battery is not usually used with this system, which is a way of extending the life of the primary battery by a factor of as much as 3 times.

4. Inverters

An inverter is a device which converts DC power from battery into AC for use in track currents, etc. This device should be distinguished from the oscillators which generate the higher frequency AC used for audio overlay and motion sensing devices. AC track circuits typically operate at from 25 Hz to 100 Hz, while the audio overlay and motion sensor devices use frequencies of from about 200 Hz to above 10,000 Hz. There are several types of inverters in general use. These include:

A. The Vibrator Inverter

This is a device which uses an electromechanical vibrating device which switches the DC input to generate the required frequency AC. The device is relatively troublesome, and draws substantial power even when supplying a minimal output.

B. The Electronic Inverter

This is a solid state device which is essentially an oscillator which generates AC of the desired frequency. It is reliable and draws little power when not supplying a load, but being a solid state device, it has a much poorer than average resistance to damage from transients, including lightning.

C. The Motor-Alternator

This is a small DC motor driving an Alternator. The usual configuration has both devices on a common shaft in a common case. It is simpler and more rugged and reliable than the other devices, but being mechanical requires some routine maintenance.

5. Power Transfer Relay

A Power Transfer Relay is the device which transfers the light load from the lighting transformer to the battery should commercial power fail. If AC track circuits are used, it also transfers the track transformer to the inverter transformer or the motor alternator output and starts this device running. Power transfer relays are vital circuits relays although they do not always use silver to silver-impregnated-carbon contacts.

A.5 TRANSFORMERS AND RECTIFIERS

1. Transformers

A. Lightning Transformers

This device comes in a variety of sizes with a variety of different primary and secondary taps, whose function is to allow for adjustment of signal light voltage to around 80% of rated voltage of the lamp used, to provide maximum bulb life. Most crossing protection systems use ten volt lamps running at about eight volts.

B. Track Transformers

These are usually larger than lighting transformers and have a wider range of taps and frequently are equipped with trimmer windings. In some cases two secondary windings are used for two adjacent track circuits though this practice is not totally desirable. Many track transformers are equipped with a magnetic shunt which is used to adjust the output of the transformer. This also causes the transformer to be current limiting, a desirable characteristic during train shunt conditions.

C. Inverter Transformers

These are transformers especially designed to take the output of an inverter (which may not be a sinusoidal voltage) and supply the proper voltage to other devices requiring AC during standby operation. This may be an alternate function of the lighting transformer, since during standby conditions the lights are operated directly from the battery and the lighting transformer is not needed for other purposes.

2. Rectifiers

Rectifiers as used in railroad signal service are of many types. Bridge rectifiers are common, and practically all commercially available types have been used. However, solid state i.e. silicon diodes are not favored because of the difficulty of providing effective transient protection.

A.6 SURGE PROTECTION

Surge protection problems in railway signaling are compounded by the nature of the railway itself. The proximity of the track to the ground, the length and conductivity of rails, the parallel signal line wiring, usually not transposed and the necessity to keep all but track connected signal wiring 1 megohm above ground all complicate providing transient protection. When electronic equipment is introduced, the problem worsens since this equipment is much more susceptible to transients. Surge protection is still further complicated by fault currents in parallel power transmission lines. These currents can be large enough to fuse the lightning arrestors now in use. There are two levels of surge protection.

Once the primary protection breaks down, the surge voltage is drawn down by the arrestor ground current. During the breakdown time of the primary arrestor, however, the surge voltage may reach several times the breakdown value. Since the rate of rise is so high, the more inductive the circuit is beyond the primary protection, the less effect the surge will have on equipment, so long as there is no insulation breakdown or arcing over. In situations using DC vital circuits relays only, the relay coil is the major inductance in the circuit and primary protection alone is adequate. However, in circuits utilizing solid state power supplies or control equipment, the initial surge voltage or equalizing current can puncture the semi conductor components and destroy the equipment. In such cases, secondary protection is installed.

1. Primary Protection

A. Bleeder Devices

The bleeder types have a relatively low resistance breakdowns and as such are not usable to ground on vital line circuits. In simple form, these are used to equalize surge voltage between elements of a circuit. Typical values for bleeder arrestors are:

50 to 300 volts breakdown
terminal to terminal resistance 1000 ohms minimum
working circuit voltage DC 0 to 12
working circuit voltage AC 0 to 25

Power line protectors of the bleeder type are made by series connecting up to five protector units in a common frame. Typical values for a bleeder type power line protector are:

up to 1000 bolts breakdown
terminal to terminal resistance 500 ohms minimum
working citcuit volts AC 115
not recommended for DC circuits

B. Air Gap Devices

The Air Gap type arrestors are intended for vital circuits and communication use. They utilize an open air gap to a carbon ground plate to start breakdown conductivity and a series of metal to metal points to sustain the arc. These arrestors can carry a very heavy surge current which melts back one of the points but except for high voltage power crosses or other sustained surges, no more than one point will be damaged per breakdown and then only if a particularly heavy surge is involved.

Typical values for a heavy duty air gap arrestor are:

700 to 1000 volts breakdown
terminal to terminal resistance 2 meg ohms minimum
50 to 260 volts on circuits limited to 4 amps short circuit
working circuit volts AC 0 to 175

Typical values for an air gap communication arrestor are:

400 to 700 volts breakdown
terminal to terminal resistance 2 meg ohms minimum
working circuit volts DC 0 to 30
working circuit volts AC 0 to 100

2. Secondary Protection

Even after the primary transient protector has done its job, the remaining transients are still large enough to damage solid state equipment. It is necessary to provide a second level of protection for these devices. Such devices are characterized by their ability to operate at high speed and the low voltage levels to which transients are limited. Single inductor-capacitor filters and zener diodes are used. However, special devices designed for this purpose are available, and are superior in most applications.

A.7 EQUIPMENT ENCLOSURES

1. Relay Cases

Relay cases are designed to accommodate the equipment to be housed with adequate room for inspection, maintenance, and minor changes. In addition, the enclosure must afford protection from the weather, insects, and vandalism. The design of the case usually is aimed at stopping vandals. Cases of wood, if of close grained hard pine or cypress and of a thickness of at least two inches, are able to stop most small caliber bullets and bird shot. Cases of metal are designed to afford at least this minimal protection, as unfortunately, railway signal installations make good targets. With this in mind, wiring and cable entries are protected by pipe from the case bottom to the ground. Cases are fitted with strong doors.

Relay cases are of 3 standard interior configurations and a large variety of sizes.

Most modern relay cases have doors front and back and are equipped with movable interior appointments. As they can be set up to utilize one or more of the following relay mounting schemes. If batteries are included in the relay case, a shelf or battery tray is usually provided to support them, although batteries may simply be set on the floor.

The first configuration uses shelves on which the equipment is placed. This system needs no fastenings to hold components in place, but the shelves get in the way of almost all work done in the case in the field. Fastening down the components becomes necessary in some cases where vibration is severe. Shelves also collect dirt, dust and are apt to collect junk as well. Shelf type relay cases are still the most common system.

The second configuration mounts equipment on brackets (usually an integral part of the equipment), securely fastened to the back of the relay case or to a backboard suspended away from the back. In the latter case, wiring is run behind the backboards and brought through holes at each circuit component. Unlike the shelf system, no provisions need be left to run wires vertically from one shelf level to another. Backboard construction also is more flexible in that terminations of outside wiring can be made conveniently on any point on the board rather than at one designated space where a backboard is provided for cable termination. Since most installations use underground cable in whole or in part, it is common practice to locate one or two of the bottom backboards forward of the others in order to increase the wire space behind and the access to the terminals in front.

In the third configuration relays are made to be plug mounted on special plug sockets including a secure locking device. The other devices are usually backboard mounted next to or below the relay plug mountings. In this configuration it is necessary to have access to both sides of the mounting rack which holds the plug sockets. Present practice requires cases with back and front doors. Adapter racks for shelf or backboard installation of plug mounted relays are also available, but their use is difficult because of the need for rear access. Relay cases equipped for plug-in relays are usually smaller for the same size installation since these relays are more compact.

Relay cases come in a variety of sizes. The smallest is intended for one relay and associated terminals while the largest may have as many as 5 doors on each side and contain more than 100 circuit devices. Such cases are not uncommon at complicated crossings usually involving several streets and more than one railroad.

Relay Cases are made of the following types of material:

A. Wood

Wood relay cases are the older technique. These were often built to order for each job in the signal shop, usually to company standards. Some railroads used simple wooden boxes set on or bolted to pieces of rail or concrete set in the ground. Other roads used the finest cypress and redwood for their relay enclosures and used paneled doors and steel banding in an effort to produce a long lasting case. Many of these survive today, even where economic necessity has precluded frequent painting. Disadvantages, however, are obvious: they include a need for frequent painting, danger of fire or termites and less resistance to vandals.

B. Cast Iron

The cast iron relay cases are nearly maintenance free since cast iron rusts very little. Disadvantages are the difficulty of repairing breakage, (cast iron is hard to weld or braze, and is very brittle), the difficulty in making interior alterations, and tremendous weight. Due to these disadvantages and the tremendous cost of casting, iron relay cases are seldom used today. However, many iron junction boxes and other underground enclosures are still made and used.

C. Fabricated Steel

Welded steel relay cases grew out of earlier riveted and bolted cases using cast iron tops, bottoms and doors with sheet steel sides and back. The steel case is the most rugged all-round relay case made today. It is also one of the cheapest to manufacture. If galvanized, it doesn't need paint and will last twenty years in most climates. Steel cases also adapt to peculiar installation configurations since fabrication of modifications can be done by welding. Interiors are insulated to prevent sweating and sudden interior temperature change.

D. Aluminum

Aluminum relay cases have been introduced during the past decade with an eye on maintenance cost reduction. In areas free from chemical pollution and salt, such cases need no paint. In areas of heavy DC ground current, such as on DC electrified railways, aluminum is susceptible to heavy electrolysis damage. Aluminum relay enclosures are more difficult to repair if damaged by collision, a common problem at grade crossings. In addition, aluminum cases are much more susceptible to vandalism and damage from gunfire.

E. Fiberglass

Fiberglass cases are another attempt at the universal relay case. This is probably the material of the future.

F. Concrete

Concrete has been used at one time or another for just about everything except rails on the railroad. Concrete relay cases were used during the first half of this century. These enclosures have a life expectancy without maintenance of about 50 years. These structures are very heavy and costly to build and, except for battery enclosures, are not in general use for new work.

2. Bungalows

Bungalows are larger than the largest relay and differ from them in that they are designed to permit maintainers to enter the unit. Each is equipped with one or more doors. Circuit components are hung from relay racks or shelves usually free-standing from the walls. Such enclosures are less common at crossing signal locations, being used only at the most complicated installations involving multiple tracks, railroads, streets and signal systems.

In most older installations using shelf or back-board mounted equipment, circuit devices were placed along walls in smaller bungalows and in larger ones on walls and freestanding racks. With the advent of plug mounted relays, the freestanding relay rack became a necessity since wall mounts precluded back access to the plug couplers. In more recent developments, aimed at reducing the overall size of the bungalow for a given number of relays, racks are mounted along but out from the walls and equipped with hinge mountings so each rack can be opened as a door to provide back access for wiring and inspection.

Bungalows are made of all the relay case materials in use today except wood and cast iron. Wooden bung-alows, usually called relay houses, have effectively disappeared from railway signaling in the United States.

3. Battery boxes or wells

These are of similar construction to relay cases except they nearly always open on top and are usually set in the ground instead of being mounted on a founda-tion above it.

The mounting arrangement for batteries is usually very simple,consisting of a wooden or plastic floor insert. In one now outmoded configuration primary cells are stacked one atop another in a wooden rack which is then lowered into a cast iron well about 10 feet deep. A suitable cover closed the top. This arrangement maintains a more nearly even temperature year round for the cells.

Most battery enclosures are made of cement with a steel or, in older installations, a wooden top. Some are of cast iron or fabricated sheet steel or fib-erglass. Aluminum is too chemically active with most common electrolytes for use in battery boxes. Bat-teries are sometimes put in wooden relay cases, al-though this practice is now considered undesirable.

3. Terminal Boxes

These could be small relay cases except they are usually too shallow to accommodate circuit components larger than lightning arrestors and protectors. Except for terminal boxes which are an integral part of the signal mast base and the light crossarm, these boxes are used to join two cables and provide for branch circuits and testing if necessary. Terminal boxes with surge protection is provided where open overhead wire goes to underground cable for any distance. The terminal box integral to a crossing signal base is intended as a means of resplicing the signal cable should the signal be knocked over by a train or auto. It is usual to bury five or more feet of signal cable to allow for base fracture. Should the signal be dragged, this slack is pulled up before the terminal wires pull out of the junction box.

Terminal boxes usually have blank interiors for mounting terminals according to the service demands of each particular job. Some specialized types include mounting pads for particular terminal configurations. Most metal terminal boxes contain tapped holes to mount one or more configurations of A.A.R. standard terminal blocks.

Terminal boxes are made similar to relay cases except concrete is never used as a material. Cast iron, cast aluminum and wood are the most common materials with wood no longer common on new installations.

A.8 POLES AND SIGNAL MASTS

1. Wooden Poles

Though some wooden crossing signal masts are still in use, wooden poles are generally limited to supporting power services and line wiring along the track. Yellow pine and cedar are the most common woods used for line poles. Pole line construciton for railway signal systems tends to use crossarms with open wire, though more modern practice uses cable, suspended from or containing a messenger. Except for temporary installations, poles are treated with preservative at least over that area usually placed in the ground. It is common to treat the whole pole. Pole spacing is usually limited to 125 feet in areas subject to ice and to 200 or so feet in areas not subject to ice.

2. Steel Poles

If aerial cable is to be lead into a small relay case of the type usually mounted on a foundation, some form of lead-in pole is usually provided. Though 2 to 3 inch pipe can be clamped to the side of the relay case, the more common practice is to use a case intended to be mounted between the foundation of a signal and its mast. This arrangement, known as a base-of-mast case is built to have sufficient strength to carry the side loading of cables attached to the mast. In addition the mast is equipped with a special wire inlet pinnacle and a strain clamp for a messenger to support cable or linedrop wires. This enables the wiring to enter the relay case directly instead of through elbows as with the side clamped arrangement while still preventing entrance of rain.

Steel poles are the most common masts for crossing signals in use today. Most are made of 4 inch pipe, 15 or more feet high, and are fitted with some form of base. The top of the mast is closed with a cone shaped pinnacle or a bell,if used. The entire warning assembly is bolted (clamped) to the mast and all wiring is installed inside the mast to afford maximum vandal and weather protection. If a clamp base is used, this may include a terminal box, enabling the wiring within the mast to be brought out for connection to the underground cable which leads to the relay case. If clamp bases are thought unsatisfactory due to crossing conditions or local practice, a cast iron sleeve base is substituted. This may be secured to the mast using sulfur or lead as a grouting compound. Sulfur, with lead as a weather seal is a common practice. The connection is similar, though stronger, than a lead joint in cast iron pipe.

A 5-inch pipe is used if gates are to be mounted, and if cantilever signals are used, the mast size and height are increased to carry the load of the cantilever. 8-inch pipe masts are not uncommon in such installations. In some cases, 2 or more masts are used to anchor a cantilever.

3. Aluminum Poles

Aluminum masts are rapidly being substituted for steel. The most common system follows steel mast practice. However, some installations using a spun aluminum mast and base similar to those used for street lighting and traffic signals are being made. Cast flanged bases applied by metal grouting are not used with aluminum masts.

Aluminum is very active chemically and as such has a severe corrosion problem in areas of local chemical atmospheric pollution. It is also subject to damage from electrolysis. This becomes a problem in areas of heavy DC ground currents such as around DC powered electric railways. The problem is made more insidious since electrolysis slowly attacks the joints in the structure and as such may continue out of sight of inspection until the structure nears failure.

D. Concrete Poles

Steel reinforcement concrete poles are used as line poles instead of wood in areas where wood pole life is short and replacement costs are high. The use of short cement poles for mounting relay cases is common on many roads.

A.9 FOUNDATIONS

1. Relay Case Foundations.

Cast iron foundations consisting of two flat cast plates each with an upright bolted in place are very common for mounting all sizes of relay cases too large to be pole mounted. One leg is buried under each end of the relay case with sufficient protrusion to allow adequate ground clearance. Depending on terrain and local practice, angle irons are sometimes bolted to the foundations and used to support a wooden or steel deck or platform for personnel working in the relay case. In soft ground under large heavily loaded cases, the foundations are crossbraced with iron rods running diagonally. The foundation castings have factory cast and drilled bosses for each of these features. This foundation technique is never used with base-of-mast cases because of the loading and side strain of the mast. Welded steel foundations are used in special applications, such as bedrock at or near the ground surface. These usually are of rail or special steel to minimize rusting.

Precast cement foundations of similar configuration to those of cast iron are in use. Some eliminate the flat plate in favor of a tapered upright with a wide foot. The crossbracing rods are usually eliminated. Anchor bolts are cast into the cement. Since many cases use essentially the same size mounting pads and two foundations are used per case, one under each end, there are very few different sizes of precast relay case foundations.

Cement foundations cast in place are used for relay cases of unusual dimensions or where ground conditions preclude the depth of a precast or iron foundation. Though many configurations are possible, a flat slab is most common. Anchor bolts are set in the cement to match the case mountings. Reinforcing rods are not generally used.

2. Crossing Signal Foundations

The foundations for crossing signal masts are almost always of concrete. Several types are in use. All crossing signal mast foundations must incorporate some provision for leading the signal cable into the bottom of the mast from a depth of about two feet. Since both road and track will be raised and the road may become gradually wider as time passes, designs used usually make provision to easily jack the foundation up or to the side as required.

Precast concrete foundations are limited to flashing light signals due to weight limitations. They are usually four feet high and about 36 inches square at the bottom. They taper to about 24 inches at the top for frost relief. On some railroads it is still the practice to use foundations with a hole from top to bottom to clear the mast, which is then secured to the top of the foundation by a clamp base and allowed to extend down inside the foundation for extra support. This practice has the disadvantage of leading to a bent mast or cracked base in the event of a collision with an auto.

Sectional precast foundations usually consist of two doughnut shaped collars with two or more notched pieces assembled in an X configuration between them. These are then secured top to bottom by long iron rods which also serve as the anchor bolts to secure the signal base to the top. The weakness of this design is the exposure of these rods to corrosion. The advantages of sectional precast foundations are flexibility and ease of handling. No pieces are too heavy to be put in place by a construction gang without use of a crane. If the signal is heavier than usual, or side loading is excessive, as with cantilever or when ground conditions are poort, additional center sections are added. This only requires a deeper hole and longer rods.

Concrete poured in place must be used for large foundations. A very long cantilever signal will require a foundation of substantial mass. These are also used if bedrock, underground power or water lines or other conditions make use of precast foundations impossible. A foundation for support of a gate is usually five feet square at the bottom and five feet high. It is usually set 4 1/2 feet in the ground. Cantilever foundations are usually six feet square and six to eight feet high. If double mast cantilevers are used, the foundation is even bigger and may need reinforcing.

Pancake foundations - a pancake foundation is a large flat cement slab usually round or octagonal in shape about 12 inches thick and containing a 2 foot downward protrusion at the center to anchor it to the ground. The slab is usually large enough to protect all protrusions on the signal itself from damage due to vehicle collision by acting as a curb around the signal. These foundations are commonly used if a crossing flasher or other mast mounted device must be set on top of the pavement, for example in the center of the road. This was once a common practice, though today it is limited to very special roadway configurations, and to temporary installations where deep excavation is impossible.

A.10 UNDERGROUND CONSTRUCTION TECHNIQUES

This is one of the most important aspects of design. It is also the one which frequently is given too little consideration. An installation which uses poor underground practice will become costly to maintain and possibly dangerously unreliable. The finding and rectification of such problems is both difficult and costly.

1. Ditching

Ditching Techniques, while seemingly simple, can be a contributing factor in keeping future maintenance costs low. Ditches should be at least one shovel width at the bottom and two or more feet below the lowest natural edge of the ditch or the bottom of the ties when under the track. In addition, ditches should be free of protruding stones, old track spikes, and sharp objects which frost or vibration may cause to cut or puncture signal wiring and cables. Wherever possible, ditches should be run perpendicular to the track when passing under the rails. Parallel ditches should be clear of the ends of the ties by a minimum of two feet except for the joiner between two risers at an insulated joint, both fed from the same lateral ditch. Care must be taken when digging under the track not to cause unnecessary disturbance to the track and subgrade. It is inadvisable to leave any ditch under the track open for any extended period. Ideally, such ditches should be dug out, wires installed, and the ditch refilled between trains. Under no circumstances should high speed trains operate over such ditching operations, as this will cause cave ins which will lead to a low spot in the track.

2. Use of Conduit, Duct Line and Outlets

A. Conduit

The use of heavy weight conduit from the relay case to signal locations or track circuit connections is not usual practice since masts at a crossing may have to be moved back as street width continues to encroach, or raised to correspond to new, higher, road surfaces. Conduit to a track connection is not often used since track connection outlets must be moved from time to time as rail is replaced, ties are moved or the track is raised. Increases in track elevation are the most common cause of the need to relocate track circuit outlets. Conduit is, however, used for runs under bridges and other structures where it is difficult or impossible to bury cable.

B. Ducts

At locations where a large number of wire runs are installed underground, it is considered good practice to run a duct line of steel, plastic or cement pipes (ducts) between manholes. In areas where duct is used, it is common to install a conduit from the nearest manhole to each relay case. Cables used are the same direct burial waterproof cable used elsewhere. However, splices are permitted in the manholes. Wiring from relay case to signals and track is usually buried directly. Should it be necessary to cable from a manhole to the track or a signal directly, it is usual to use direct burial technique with a sealed fitting installed in the manhole wall. Duct line especially iron duct must be protected from ice, by providing proper drainage.

C. Outlets

When underground wiring is brought to the surface to make connection to various ground mounted devices, such as switch circuit controllers, or to make connection to the rails, some form of riser or outlet is used. This device consists of a cast iron pipe with a flanged bottom and some form of connection box on top. Bootlegs or pot heads, as track connection outlets are called, are made with an insulated external cable clamp on top to connect the standard number 9 gauge underground track wire to a number 4 bronze wire rope bonding cable which makes the connection to the rail. In installing pot head outlets, it is usual to leave 10 to 12 feet of wire under each outlet, usually coiled and buried inside the bottom flange. Similar lengths of wire or cable are usually buried at each point where a wire or cable enters or leaves the ground. Such practice is invaluable when and if the outlet has to be moved.

3. Record Keeping

It is common practice to draw a sketch of the crossing location and outline in pencil the cable runs, whether direct burial, conduit, duct, etc., and dimensions of bends, distance from ditch to reference points for locating important turns and laterals and unusual variations of depth. Such a record sketch will ordinarily include date of installation, any in-service cables of other utilization disturbed during earth work and an honest estimate of their condition including possibility of damages during excavation. Such sketches are returned with the in-service mark up plans to the signal engineer who includes this data in his file on the crossing site.

4. Wire and Cable

The wire and cable used in railroad service is generally specially designed to meet the severe environment. Direct burial cable is protected against rodents by use of a metallic sheath, sometimes two layers, and sometimes by use of a poisonous layer under the outer sheath. Track connection wire has special extra tough insulation to resist the abrasion of the ballast. The wire used in relay cases is No. 16 or larger with an oil proof and rodent repellant insulation.

APPENDIX B
REPORT OF INVENTIONS

The objective of this study was application of conventional modern electronic technology to grade crossing warning control systems. Although the devices and components considered are therefore not novel, their application at grade crossings comprises a number of innovative or new system concepts. Principal among these are use of a set of universal control-circuit crossing control modules, suitable to a large percentage of crossings without custom engineering (Part II, p. 60); and application of European signal relays (Part III, p 133) and mercury-wetted reed relays (Part III, p. 142) to grade crossing circuits.

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