LOW COST BELL AND LIGHT PROTECTION SYSTEM FOR UNPROTECTED RAILWAY LEVEL CROSSINGS

by

J.A.K.S. Jayasinghe and G.G.D. Nishantha

Abstract

The design and implementation of a low cost bell and light protection system for a railway level crossing is described. This is directly targeted to cater for the unprotected level crossings in Sri Lanka. The design is entirely hardware oriented. It detects the presence of a train on the rail track to activate a set of red lights and a bell to warn the road users. To enhance the reliability of the system, the electrical continuity of the rail track is also monitored.

1.0 Introduction

The railway system is indispensable for the transportation requirements of Sri Lanka. The railway network spreads all over the island forming nearly seven hundred level crossings across highways and subways. As a developing country, Sri Lanka is not financially strong enough to provide protections for all of those level crossings against accidents. An automated bell and light protection system for a single level crossing costs nearly one million rupees (see appendix A). The high cost has limited the use of such automated protection systems only at level crossings across major highways, leaving a large number of unprotected level crossings. These unprotected crossings are unsafe for road users and many fatal accidents have occurred. As an intermediate solution, a few years ago a manually-operated bamboo gate system was introduced by the rail authorities. However, the manually-operated bamboo gate system has been discarded due to the heavy cost of labour, thus leaving many level crossings unsafe for road users.

1.1 An overview of the Conventional System.

An overview of the existing bell and light protection system is presented to simplify the presentation of the new design and for comparison. The conventional bell and light protection system uses two electrically isolated rail track segments, each around 1000m in length at either side of the crossing, as shown in Fig. 1. Each segment is powered with a DC source at the far end to energize a sensing relay connected to the track at the near end. In the absence of a train on a certain segment, the relay is always kept energized. When a train is present on a particular track segment, the corresponding relay is de-energized as the axles of the train shunt the relay current. The fact that whether a relay is energized (ON) or de-energized (OFF) determines the absence or presence of a train on any segment. In case of any track fault (discontinuity) also the relay is de-energized. This creates a fail-safe system as any track fault is detected as a train on the track condition. The system detects the presence of a train on the track or track fault and activates a set of red lights and a bell. When the train approaches a particular track segment at the far end, the bell and the red lights are activated and when the train leaves that segment at the near end, the bell and the red lights are deactivated.

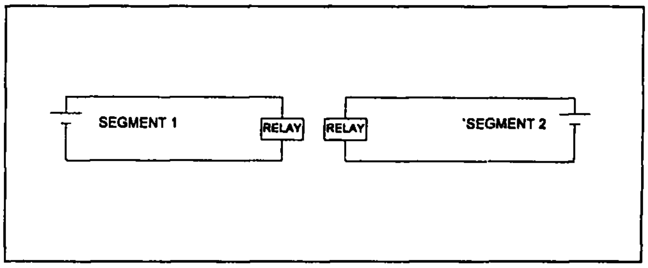

Figure 1: Track Arrangement of the Existing System

Eng. (Dr.) J. A. K. S. Jayasinghe, BSc Eng, MEE, PhD, MIEEE Head / Department of Electronic & Telecommunication Engineering, University of Moratuwa, Moratuwa.

G. G. D. Nishantha, BSc Eng.

APPENDIX [A]

Cost analysis for the existing system

(All the cost figures presented here are according to the information obtained from **SLR**)

Material	Quantity	Price (Rs.)	Foreign/Local
Relay JRK	02	110,000	foreign
Batteries 6V (Alkaline)	02	120,000	foreign
Batteries 12V (Pb acid)	01	5,500	local
Rectifier Bridges(230V/6V)	02	50,000	foreign
Rectifier Bridge (230V/12V)	01	38,000	foreign
Steel Cabinets	04	40,000	local
Terminal Boxes	04	14,000	local
Lightning Arresters.	02	6,000	foreign
Bond Wires	50 kg	3,000	local
Bond Pins	1000	8,750	local
Cable 10*1.5	500 m	142,500	local
Cable 2*2.5	2000 m	162,000	local
Nylon Insulation	25	6,000	local
Variable Resistors	02	1,700	local
Flashing Unit	01	3,000	local
Signal Unit	04	60,000	foreign
Warning Bell	02	56,000	foreign
Warning Boards/Fence/Rails		10,000	local
Electrical Connection		5,000	local
3" GI pipes	04	14,000	local
Others		10,000	foreign/local
material cost : FOREIGN		440,000	foreign
material cost : LOCAL		425,000	local
Cost of labour +Supervision		10,000	local
Total cost		875,000	

Cost analysis for the designed bell and Light System.

Description	Cost (Rs)	Foreign/Local
Overall design cost		
:Track feeder circuit modules-2nos .		local
:Detection circuit modules -2nos.		local
:Decision circuit module -1no		local
:Bell circuit module - 1no		local
:Two horn speakers -2nos		local
	75,000	
Electrical connection	5,000	local
Cost of installation work carried out by RC&DC and SLR at site.		
-Track bonding		local
-Electrical wiring		local
-Terminal boxes		local
-Light head posts		local
-Steel cabinet		local
-labour		local
	150,000	
Total cost	230,000	

The overall system is designed using relay logic arrangements. Resistor capacitor arrangements are used to obtain the required timing delays. A battery back up system is also used to cope with power failures. Although this system is simple, due to the very high cost of sensing relays, batteries, power cables, etc., the overall cost of the system is almost 1Million rupees. (see Appendix A.)

The high cost has created an overwhelming need to replace the existing system with a locally developed protection system at an affordable cost. The design presented in this paper is as a result of research carried out at the department of Electronic and Telecommunication Engineering, University of Moratuwa in collaboration with Road Construction and Development Company (RC&DC).

2.0 Features of the New System.

This paper presents a novel design of an automated bell and light protection system at a very low cost utilizing the existing infrastructure. The key features of the design are

- Use of rail track segments powered from the near end of the crossing avoiding unnecessary cabling costs.
- Ability to detect both train ON/OFF the track condition (train shunt) and track continuity GOOD/BAD condition (track fault) separately.
- Replacement of the costly sensing relays used in conventional systems by semiconductor devices.

2.1 Principle of Operation

The system detects the presence of the train on either side of the level crossing and activates a warning bell and a red light as in the existing system. The detection of the train on the track condition is based on the condition that the rail track is short-circuited through the wheels and axle of the train. As shown in Fig. 2, two electrically isolated rail track segments on either side of the level crossing are used to detect any train approaching or leaving the level crossing.

A track segment longer than 1000m is recommended to provide a sufficient preparation delay for the road users [1]. The system is designed such that it detects not only the presence of a train (train shunt) but also the track continuity (track fault) to give a better guidance to the road users than the guidance provided by the existing system.

Each rail track segment is powered from the near end and the remote end of each track segment is terminated with a passive rectifier diode as depicted in Fig. 2. The near end of the rail track is powered by a bipolar pulsing signal. The presence of a train on the track is detected by the complete signal shunt caused by the wheels and axles of the train. The continuity of the rail track is detected by the clipping of negative half of the pulsing signal caused by the termination diode. The continuity of the rail track is essential to detect the presence of a train on the track. The states of both track segments are detected using the above technique and the activating signals for bell and lights are decided. The bell and light states for all possible track and train conditions are as listed in Table 1.

Table 1

Bell and Light States

Train On Track	Track Condition	Red	Green	Bell
YES	GOOD	ON	OFF	ON
YES	BAD	ON	OFF	ON
NO	GOOD	OFF	ON	OFF
NO	BAD	BLINK	BLINK	OFF

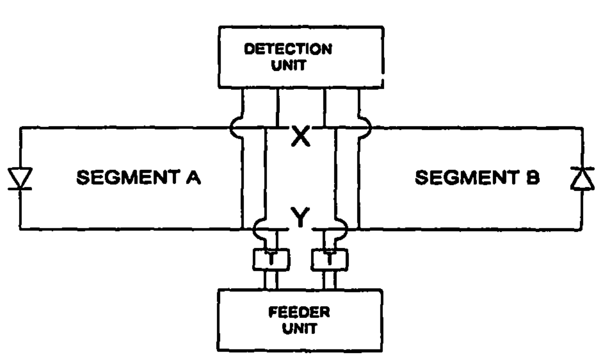

Figure 2: Basic Connections to the Rail Track

The sequence of operation of the bell and light depends on the direction of the train arrival as well. As soon as the front end of the train reaches the far end of the rail track the bell and red light are activated and when the back end of the train passes the crossing the bell and red light are deactivated.

3.0 Design and Implementation

The system is designed entirely with hardware components to make it more reliable, fail safe and cheap. The most important part of the design is the method of sensing the train on the track condition and fail track continuity. Several methods were tried out and only the best design proven in the field is presented in this paper. A detailed block diagram of the design is shown in Fig. 3. Functions of each block are explained in the next sub-sections.

3.1 The Rail Track

The rail track can be modeled as a lumped parallel resistance Rp and a lumped series resistance Rs as illustrated in Fig 4. Rp represents the leakage resistance and it ranges from 5 Ω - 200 Ω under water logged condition to fully dry ground conditions. The rail track resistance, resistance of bond wires and resistance contributed by other connecting wires contributes to Rs. The value of Rs has to be less than 1 Ω to be accepted as a good track connection.

3.2 Track Feeder unit

Fig. 5 illustrates the basic functional block diagram of the track feeder unit. Each track feeder unit excites the rail track with a bipolar pulsing signal. A four transistor switching circuit [2] is used to feed the rail track with the bipolar pulsed signal . Two such circuits are used to feed two rail track segments separately. A transformer isolation is used between the source and the track to improve the protection against lightning surges [3].

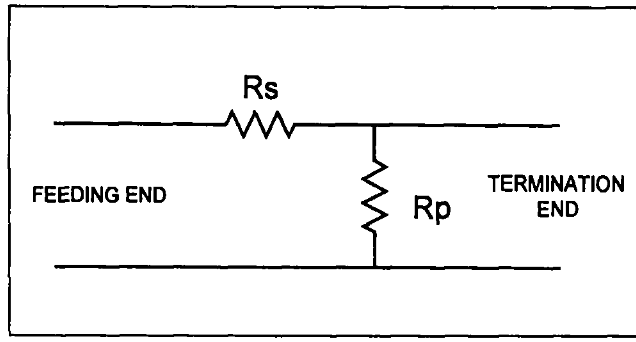

Figure 4: The Rail Track Model

The main considerations taken into account in designing the track feeder circuit are:

- *Large variation of track to track open loop resistance Rp.*

  The resistance of a typical track segment measured at the end terminals yields a value ranging from 5 Ω to 200 Ω in fully water logged to hot dry conditions respectively.

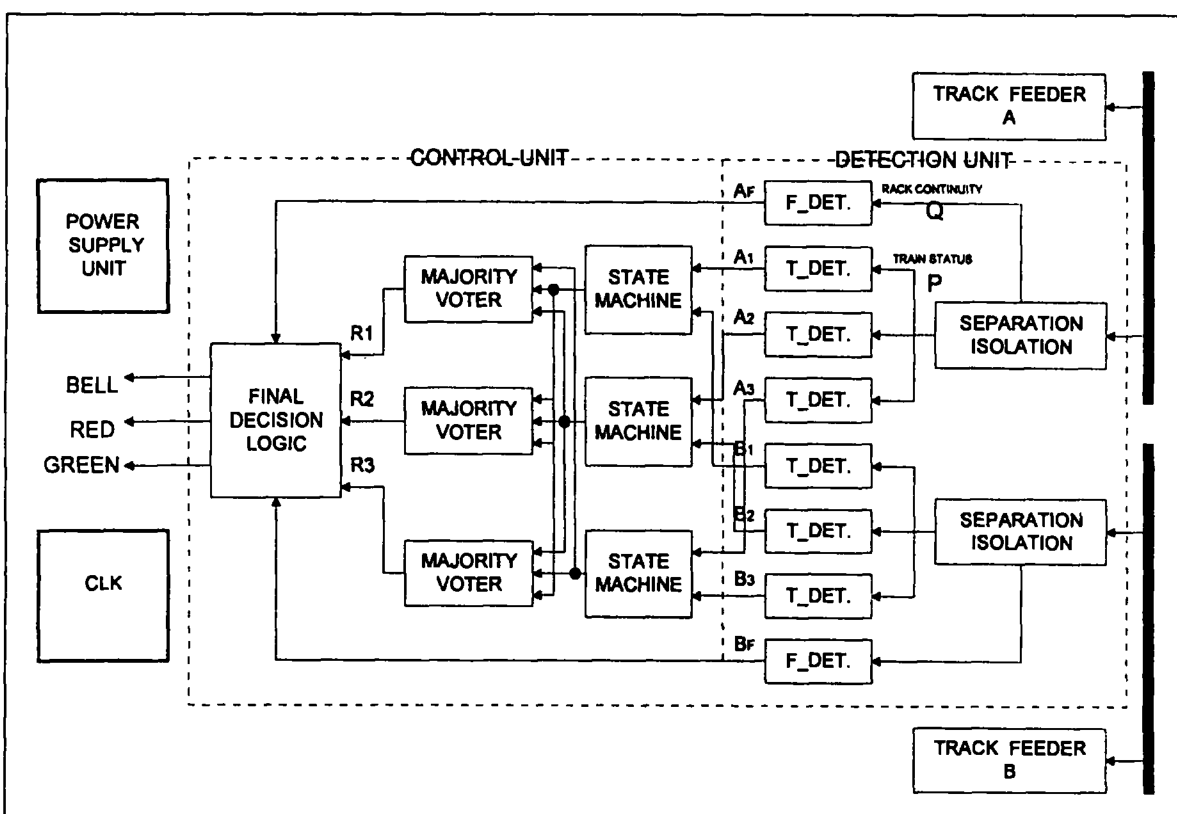

Figure 3: Detailed Block Diagram

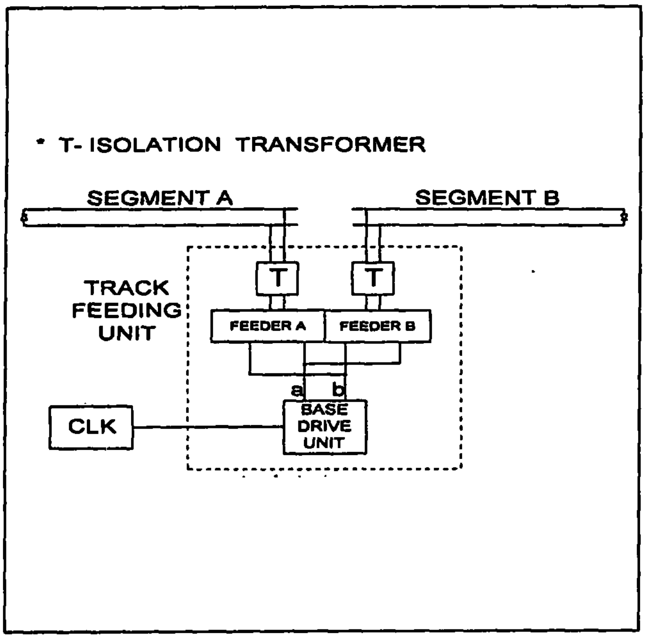

Figure 5: Basic Connections to the Rail Track

- *Minimization of excessive power dissipation.*

  Leakage of current through ground, especially, on rainy days is another issue. This becomes very critical in the absence of commercial power. A low frequency pulse signal with a small duty cycle was introduced as the track excitation signal to reduce the power dissipation due to leakage currents.

- *The excitation and detection point locations.*

  The point at which the signal is fed to the rail track is also a vital consideration. In conventional systems, power feeding is done at the remote end. This is a major problem in rural areas where commercial power is not available at the remote end. Then a high cabling cost has to be borne. This fact greatly influences the requirements for detection of track continuity. To overcome these problems, excitation and detection are carried out at the near end of the track using the bipolar signal with the terminating diode fixed at the far end of the rail track.

The schematic diagram of the 4 transistor arrangement of the track feeder unit and the waveforms corresponding to base drive and output signals are shown in Fig 6.a and Fig. 6.b respectively. Base drive signals for the two transistor switching circuits are generated in a single unit. On the positive and negative edges of the master clock two base drive waveforms are generated and applied to each pair of transistors in the transistor switching circuit.

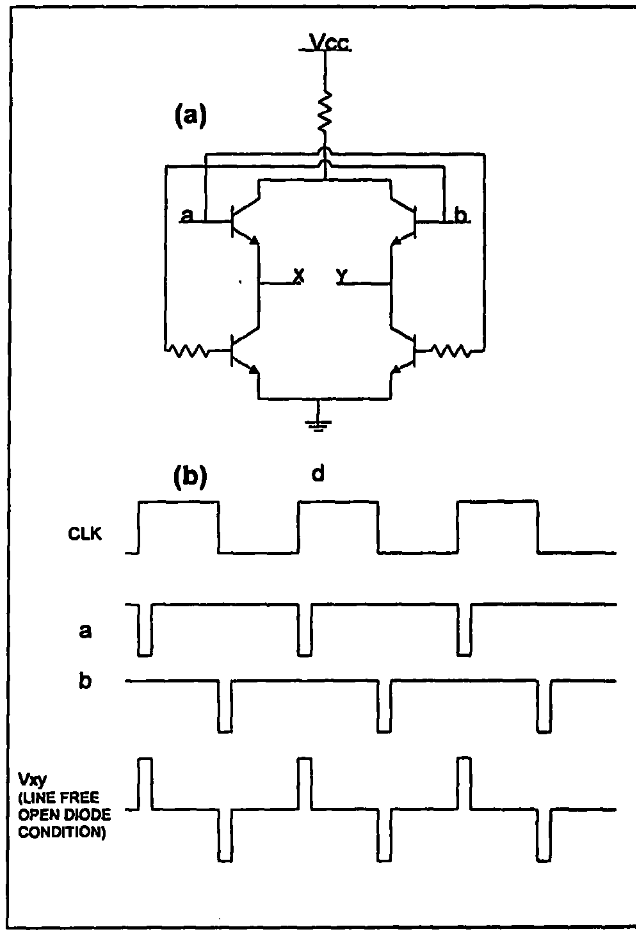

Figure 6:(a) Schematic Diagram of the Transistor Driver
(b) Base Drive Signals and the Output at XY

3.3 Detection Unit

The functionality and the design aspects of the detection unit are described in the following subsections.

3.3.1 Signal Separation and Isolation

The signal between the two rails of a track segment is taken back to the system at the point of excitation as an input for train detection. The front end of the detection unit isolates and separates the received signal from the rail track into two channels using an opto-isolator arrangement as shown in Fig.7.

The positive pulse of the sampled signal at XY carries the ***train on the track*** (train shunt) information whereas the negative pulse contains ***track continuity*** (track faulty) information. Thus ***train shunt*** information and ***track faulty*** information are directed to channel P and channel Q respectively.

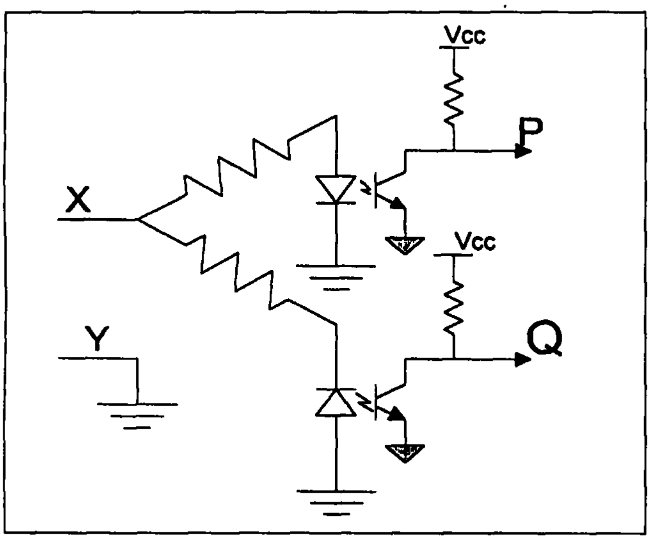

Figure 7: Schematic Diagram of the Signal Separator

3.3.2 Signal Detection

Fig. 8 illustrates the output of P and Q on different track conditions. The detection of train shunt and track fault are decided on the basis of whether P and Q channels are pulsing or not. The detection criteria is as follows.

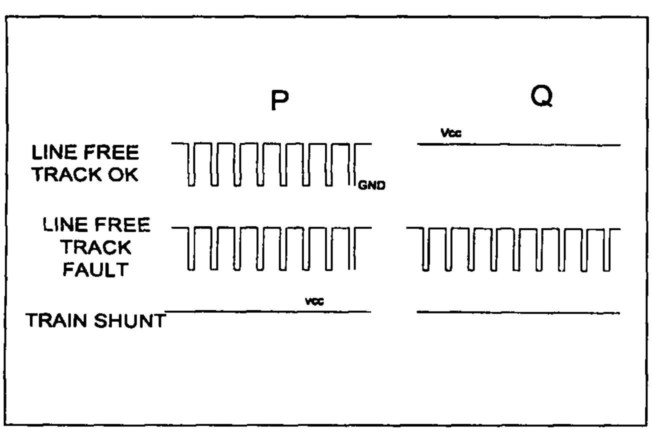

Figure 8: P, Q on Diffrent Track Conditors.

- If a signal high state is on P channel, a train shunt is assumed where as pulses on P channel indicates line free state.
- If Q channel gives a pulsing signal the rail track discontinuity (track fault) is understood whereas a signal high state on Q channel occurs when the track continuity is good.

From the signal behavior on P and Q channels, it is understood that a simple pulse detection circuit is sufficient to fulfill the detection requirements. But the technique would count any unauthorized pulses and would yield unfavorable results, especially in the context of fail safety. Hence, synchronous pulse detection technique is introduced.

Except for the working edge of the clock, the synchronous detection circuit configuration for both train shunt and track fault detection is a similar master slave arrangement as depicted in Fig 9.a and Fig.9.b.

Fig. 9.c illustrates the operation of synchronous detection for detection of train shunt using timing diagrams. The track fault detection is also performed using the same principle. The timing diagram is drawn for the worst case condition considering a small time delay between the clock edge and the resulting pulse on the P channel. This creates a possibility of having momentarily pulsed output at Q1 (see Fig.9.a even when P channel is pulsing on a line free condition. Hence there exists a possibility of misdetection of the train if only one flip-flop is used. The master slave operation is meant to address this problem and disturbances caused by any other unauthorized pulses. Fig. 10 illustrates the complete block diagram of the circuit used for train shunt detection (T-DET). The additional functional blocks are incorporated to gain further reliability and fail safety.

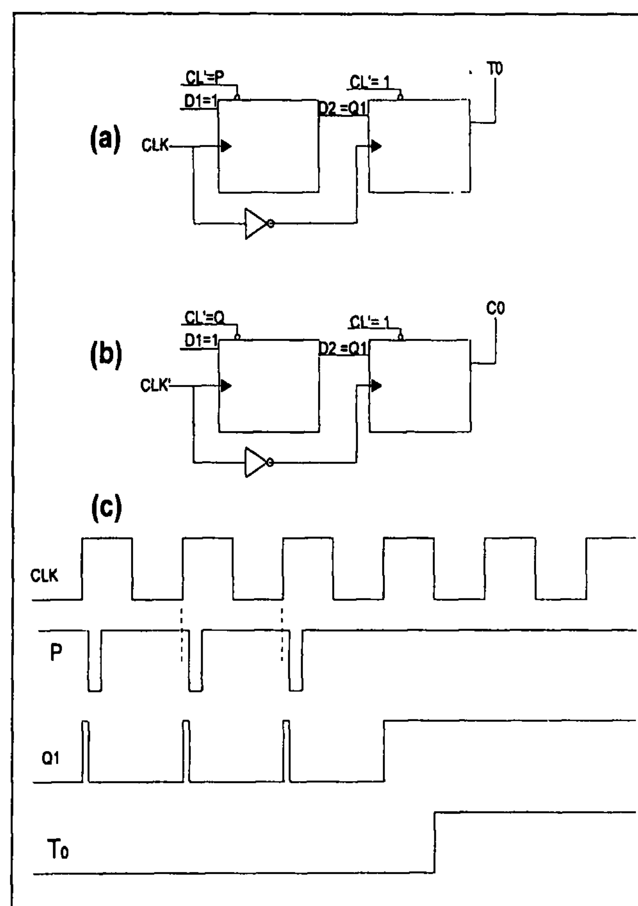

Figure 9: **(a) Schematic Diagram of Train Shunt Detection**
(b) Schematic Diagram of Track Fault Detection
(c) Timing Diagram for Train Shunt Detection

In the context of fail safety, any situation where P signal does not carry a pulse stream has to be critically analyzed. Lack of pulse activity may be caused due to the P signal becoming stuck at the signal ground or signal high state. Signal high state is always treated as a train shunt indication whereas signal ground state leads to a situation of train miss which is a major system failure. A pulse activity detection circuit, as depicted in Fig. 10, along with the synchronous detection circuit is used to rectify this problem. The absence of pulses on channel P is considered as the train shunt condition ensuring the fail safety of the system. Still the detected output is subjected to the effect of bouncing as the train bounces on the track. A debouncing circuit is incorporated at the end of the detection circuit to avoid the problem of bouncing [4] (see Fig. 10).

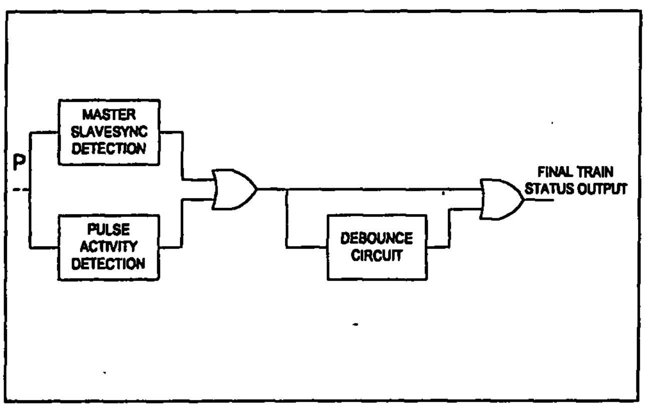

Figure 10: Schematic of the Detection Circuit

To enhance further reliability, three detection circuits (T-DET) are used in parallel for the train detection. Only one circuit (F-DET) is used for track fault detection. The complete detection circuit arrangement is illustrated in the detailed system block diagram in Fig 3.

3.3.3 The Control Unit

Three T-DET units operating in parallel detects the train status for a single track. A single F-DET unit detects the track continuity of a single track. The train status and track continuity of the other rail track is detected by another set of identical T-DET and F-DET units. The output of T-DET and F-DET units are fed to the finite state machine (FSM) in the control unit to detect the state of the system.

The state transition diagram of the FSM [4] is depicted in Fig. 11. The FSM identifies when the front end of the train reaches the far end of the track and further more it detects when the back end of the train leaves the level crossing. Three finite state machines operate independently with identical inputs and their outputs are applied to three majority voting circuits. Three finite state machines working with the majority voting circuits enhance the reliability of the system. Finally these outputs are combined with the outputs of the F_DET circuits to decide the bell and light states. Fig.12 illustrates the schematic diagram of the final logic arrangement. The red light and the bell are activated immediately when the front end of the train reaches the far end of a track and red light and bell are deactivated when the back end of the train leaves the level crossing. In case of a track failure, red and green lights are made to blink to indicate the faulty condition to the road users.

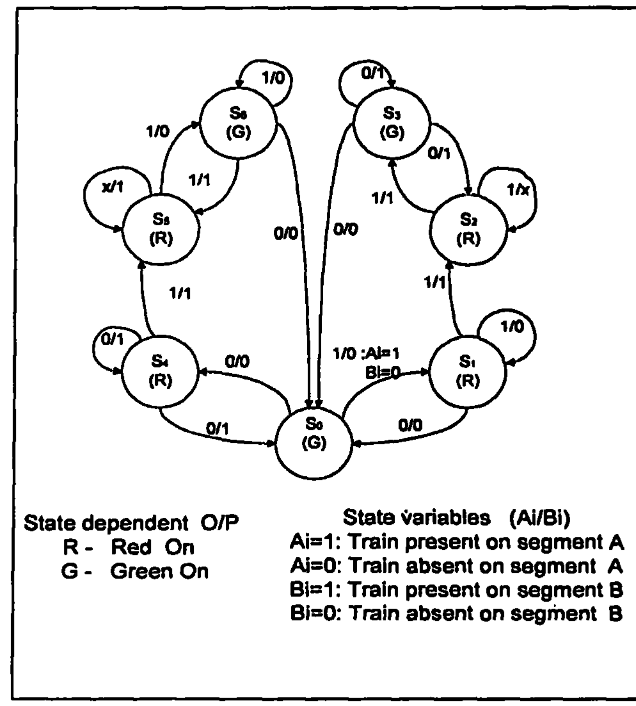

Figure 11: State Transition Diagram

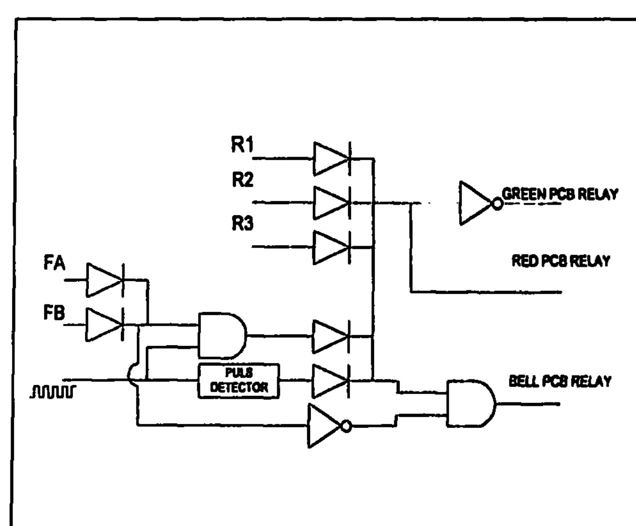

Figure 12: Schematic Diagram of Final Decision Logic

3.3.5 Power Supply Unit.

It consists of a 230V AC to 12V DC converter, battery charger with a battery and a power switchover unit. The battery powers the track feeder unit and the logic circuits directly. The bell and the lights are driven by battery power only in absence of commercial power.

3.3.6 Protection Against Lightning

The possibility of inducing high voltages on the rail track due to lightning surges is considerably high. This could cause permanent damage to the system circuitry. As protective measures, the following design strategies are used [3].

- Use of an opto-isolator in the detection unit to protect the system processing part as shown in Fig.7.
- Use of an isolation transformer to feed the track to cut off heavy lightning surges being passed in to the feeder circuitry as shown in Fig. 5.
- Use of Metal Oxide Varistor (MOVs) at strategic locations in the circuit as shown in Fig. 13.

4.0 Reliability and Fail Safety of the Design

The importance of reliability and fail safety expected from a system used with railways is very obvious. In all design steps, special attention has to be paid strictly on enhancing the fail safety of the system, while trying to obtain highly reliable system operation [1]. In the designed system, the inherent voltage drop across the clipping terminal diodes ensures that the track fault will be detected without leaving any possibility for missing the detection of the train under any abnormal conditions in the track. Therefore, the system will never run into an undefined state. As explained in Section 3, any kind of malfunctioning in the detection circuit would result in either the system identifying the fault as the train on the track condition or as a system fault, ensuring the reliability and the safety. The probability that the system would yield any hazardous indication to the road users is extremely low.

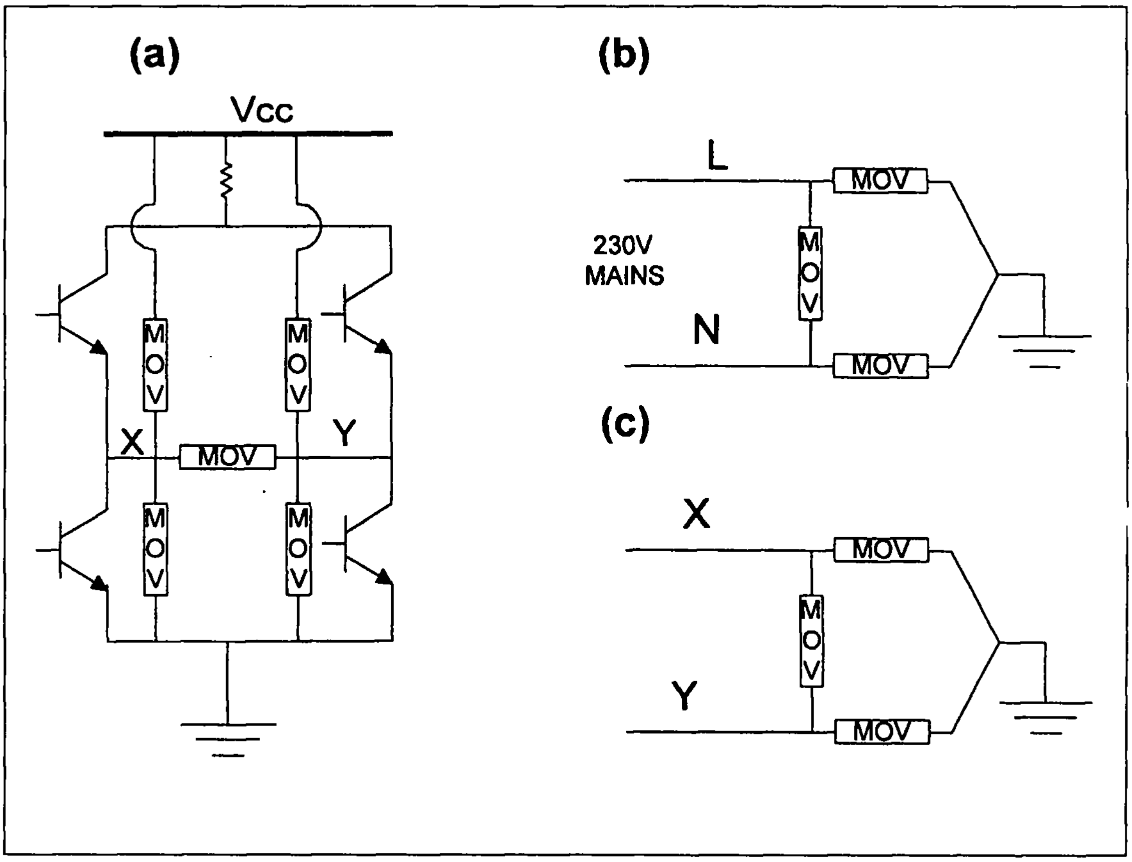

Figure 13: (a) Protection for the Feeder
(b) Protection for Mains
(c) Protection at Receiving Point

5.0 Comparison with the Existing Bell and Light Systems

The new system can be compared with the existing conventional system in several technical aspects.

- The detection principle in both systems is simply the shunting effect caused by the presence of a train. But the strategies are different. The costly sensing relay in the conventional system is replaced with low cost solid-state electronics in the new system.
- In case of conventional system, the rail track is powered at the remote end whereas both power feeding and detection are done at the home end in the new system. This reduces the cabling cost considerably and provides for easy maintenance.
- New system detects the track continuity failures and informs the road users by flashing red and green. In the conventional system, any track continuity failure is indicated by the red light as train on the track.

The overall cost of the conventional system is approximately 1 Million Rupees whereas the cost of the new system is approximately 150 Thousand Rupees. A detailed cost analysis is given in Appendix A. The huge discrepancy of cost figures is due to the elimination or reduction of high cost components.

The main cost reduction factors are follows:

- Two costly sensing relays used in the existing system is replaced with two cheap rectifier diodes.
- In the conventional system, a large cable cost is incurred to transmit power to the remote end. This cost is eliminated in the new system as power is fed at the near end. Furthermore, only one battery backup system and one charger unit is required in the new system. This reduces a considerable amount of money, as two batteries and two charger units are used in the conventional system.

6.0 Conclusion

The system described in this paper is a cost-effective design, for providing protection at unprotected level crossings. The system has been constructed and tested in the field. It has proven its fail safety in the field for a period of nearly 6 months.

References

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