CHAPTER

1 KAVACH – An Overview

1.0 Introduction

KAVACH is an indigenously developed Automatic Train Protection (ATP) System meant to provide protection to the trains against Signal Passing at Danger (SPAD), excessive speed and collisions. KAVACH provides continuous update of Movement Authority (distance up to which the train is permitted to travel without danger). Hence during unsafe situations when brake application is necessitated, and the Crew has either failed to do so, or is not in position to do so, automatic brake application shall take place. KAVACH has additional features to display information like speed, location, distance to signal ahead, Signal aspects etc. in Locomotive cab and generation of Auto and Manual SOS messages (Distress messages) from Locomotive as well as from the Station unit in case of emergency situation. The communication between Stationary KAVACH and Loco KAVACH units shall be Safety Integrity Level 4 (SIL 4) certified as per the CENELEC standards for railways. Communication between two or more Loco KAVACH systems, Non-Signalling based additional collision protection (i.e. Head-on, Rear-end & Side Collisions) and Manual SoS are non-SIL based (i.e. not failsafe).

Spot or Intermittent update type system affects Line Capacity adversely due to inherent limitation of design. Continuous Update type of system like KAVACH is Line Capacity friendly by design. Continuous Update type European system has been using commercially off-the shelf mobile communication such as GSM-R for long. KAVACH uses innovative radio communication system designed by RDSO to achieve continuous communication between the Train and Track-side systems.The radio communication system operates in UHF band.

Safety Integrity Level (SIL): The concept of Safety Integrity Level (SIL) is a direct result of the IEC 61508 standard, which is not specific to railways. For the railway industry, CENELEC (European Committee for Electrotechnical Standardization) has developed the standards EN 50126 (The Specification and Demonstration of

Reliability, Availability, Maintainability and Safety (RAMS)), EN 50128 (Communication, signalling and processing systems - Software for railway control and protection systems), and EN 50129 (Communication, signalling and processing systems - Safety related electronic systems for signalling) which have been derived from the IEC 61508 standard to meet the specific requirements for the design, development, and assessment of safety-related electronic systems used in the railway industry.

SILs are assigned based on the level of risk associated with a particular system. The risk is determined by the likelihood and severity of a hazardous event occurring. The likelihood is calculated based on the probability of a component or system failure, while the severity is assessed based on the potential consequences of a hazardous event.

There are four Safety Integrity Levels, labelled from SIL 1 to SIL 4: The latter has the highest level of safety integrity and SIL 1 the lowest. The costs increase significantly to reach higher levels of SIL, however the cost of not implementing the appropriate SIL far exceeds the cost of the overall implementation.

The standard associates Safety Integrity Levels with numerical probabilities of hazardous failures for systems that operate continuously like Kavach (Table 1.1)

Table 1.1 SIL for Continuous Demand Mode

Safety Integrity Level	Probability of dangerous failure per hour (Continuous demand mode of operation)
SIL 1	$\geq 10^{-6}$ to $< 10^{-5}$
SIL 2	$\geq 10^{-7}$ to $< 10^{-6}$
SIL 3	$\geq 10^{-8}$ to $< 10^{-7}$
SIL 4	$\geq 10^{-9}$ to $< 10^{-8}$

As the SIL level increases, the Dangerous Failure Rate must decrease accordingly. Therefore, higher SIL levels require a higher level of reliability and safety, and more rigorous design and testing procedures.

1.1 KAVACH Features

1. Prevention of Signal Passing at Danger (SPAD)
2. Cab-Signaling, Loop Line Speed Control
3. Prevention of Over speed: Section Speed, Train Speed, Permanent Speed Restriction (PSR)
4. Protection of Roll back and Reverse movements
5. Prevention of Side-collision in block section
6. Prevention of Head-on & Rear end collisions
7. LC Gate Automatic Warning

8. Save Our Souls (SOS) Messages
9. Computation of Train Length
10. Shunt Limits Validation
11. Centralized live monitoring of Train movements in Networking Monitoting System (NMS).

1.2 System and Sub Systems

The brief overview of functioning of KAVACH is as given below:

- The trackside sub-system of KAVACH consists of Radio Frequency Identification (RFID) tags fitted on track in station section and block section for giving Trackside information to Loco KAVACH unit installed in the locomotive. Portions of track including berthing tracks, point and block sections are assigned unique IDs called Track Identification Number (TIN).
- The system also consists of Stationary KAVACH unit installed at Station with radio tower to communicate with locomotives in the jurisdiction of Stationary KAVACH which commence on approach of its first Signal. Stationary KAVACH is interfaced with station interlocking to acquire real-time dynamic information related with signalling such as various signal aspects. Route information of all the signals monitored by a specific stationary KAVACH unit is configured on the basis of KAVACH Control Table (excluding shunt signals and overlaps). Stationary KAVACH unit gets real-time information regarding Locations, Speed etc of various trains in its jurisdiction through UHF Radio Communication.
- Separate *Stationary KAVACH unit* is provided at Mid–Section interlocked Level Crossing Gate and Intermediate Block Signalling (IBS) locations if they do not come within the coverage of station radio tower.
- Remote Interface Unit (RIU) shall be used where remote signalling functions are required to be fetched to a nearby Stationary KAVACH unit for example from end cabins/ distributed interlockings or LC gate/IB coming within the radio coverage of station tower.
- The *onboard Loco KAVACH*unit installed in the locomotive determines the location of train by reading pre-programmed *RFID Tag data* with the help of *RFID reader.*
- By using the cryptographic technique malicious attacks will be eliminated. Only Authenticated Systems communicate *with each other* to ensure the safety of the system.
- Key Management System (KMS) is developed to check for authentication and distribution of secret keys.

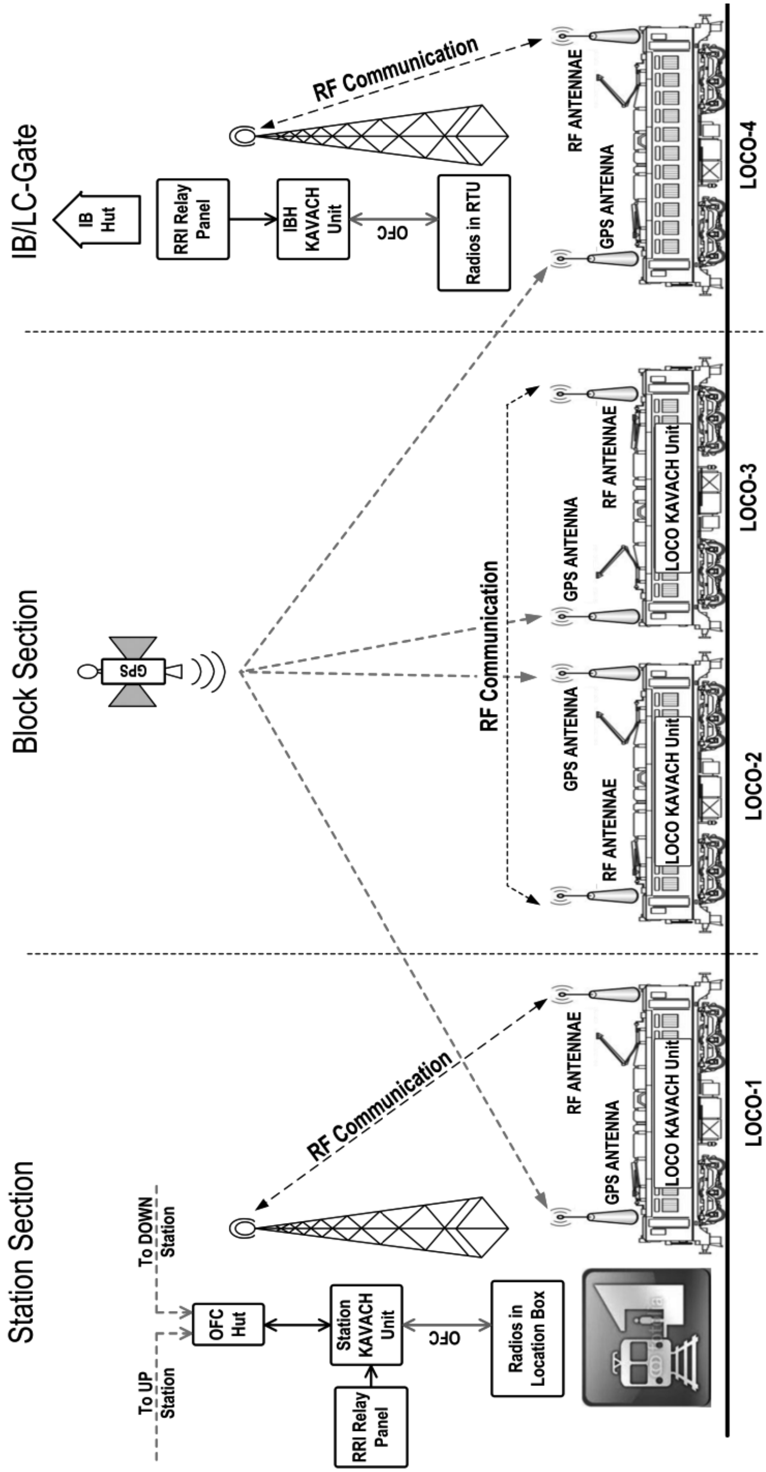


Fig. 1.1 KAVACH Automatic Train Protection

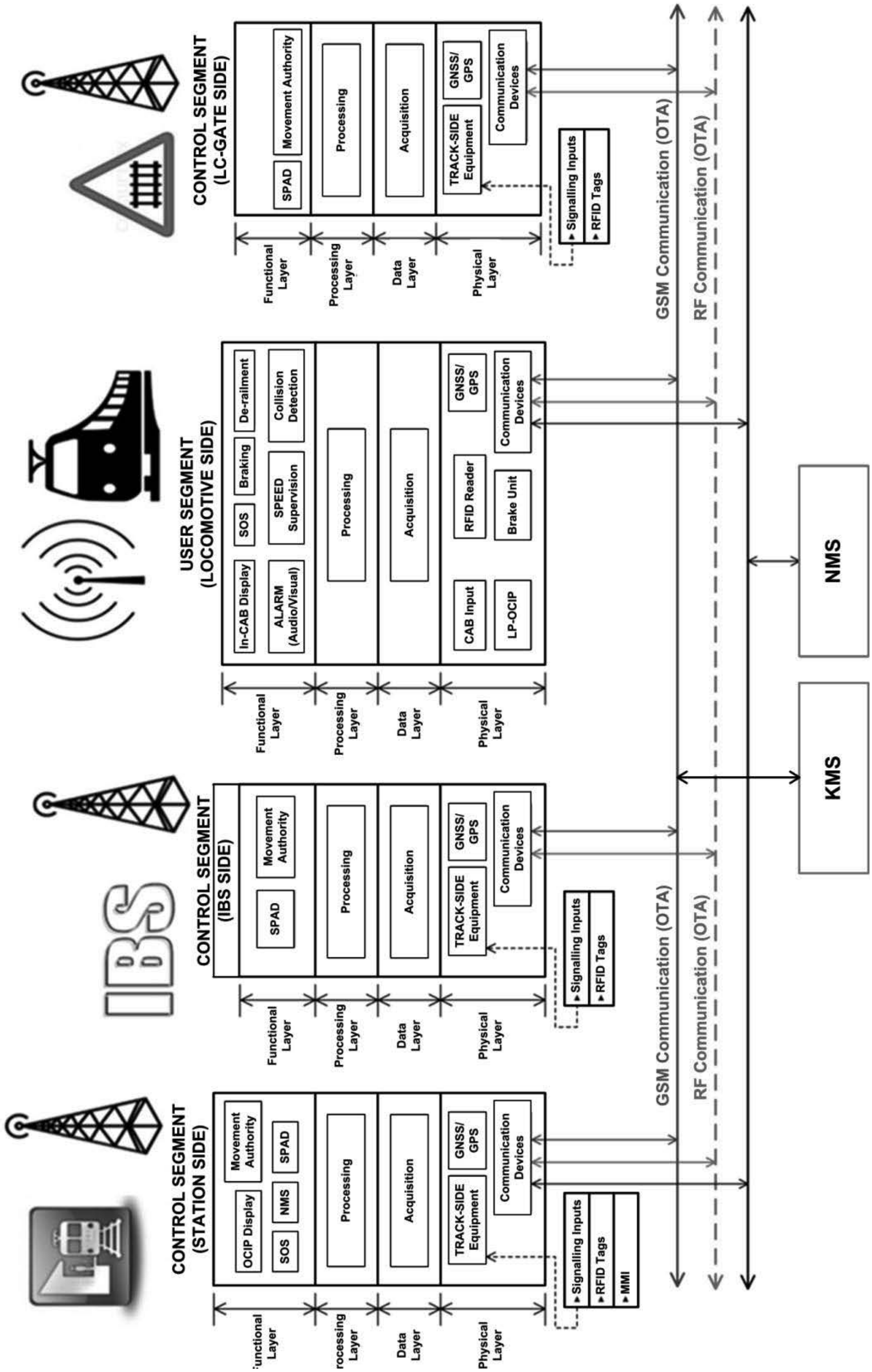


Fig. 1.2 KAVACHProcess flow

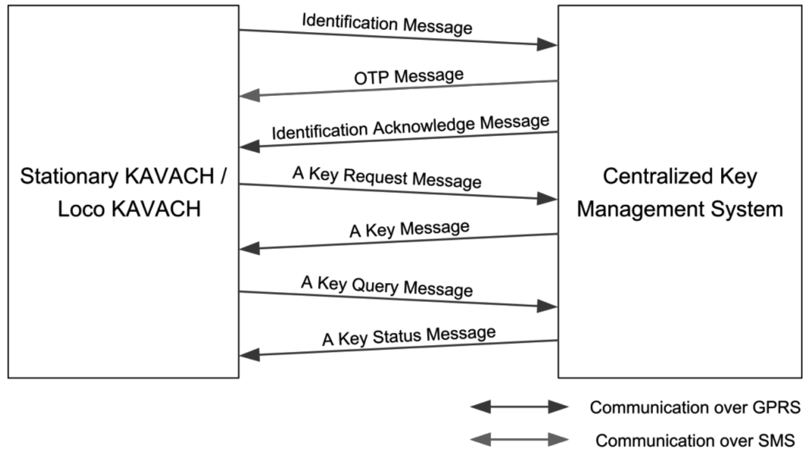


Fig. 1.3 Process flow for authentication keys transmission

- Loco KAVACH unit sets its absolute location (Approaching signal distance from the train position) and Track Identification Number (TIN) as undefined (zero) before determining the direction.
- The direction of movement of train shall be determined, when Loco/Train has passed two RFID tags sequentially with Absolute location.

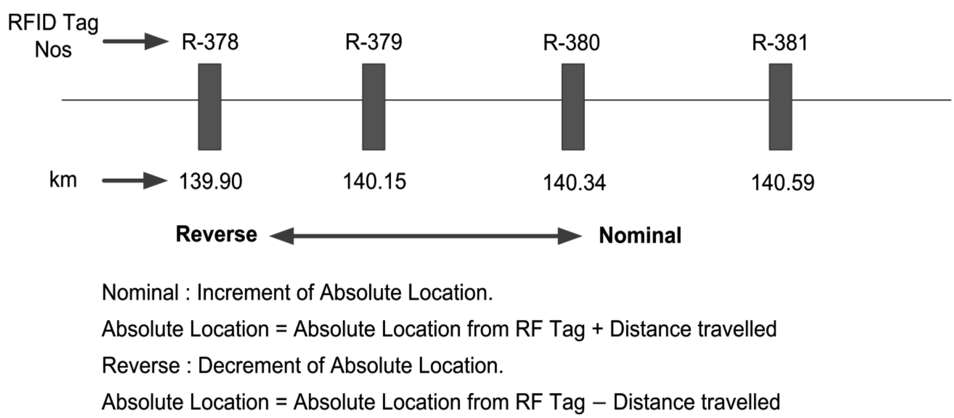


Fig. 1.4 RFID Normal and Reverse direction

- Loco KAVACH unit calculates the location of the train between two RFID tags dynamically based on the distance travelled from last RFID tag through speed sensing arrangement provided on Locomotive.
- On passing through the RFID Tag, Loco KAVACH unit transmits the location and direction of the train to the Stationary KAVACH unit through UHF radio antenna provided in locomotive.

- The Stationary KAVACH unit shall use the direction of movement of Loco/Train, to find approaching signal of the Loco/ Train.
- Stationary KAVACH unit shall then calculate the movement authority based on the signal aspect or/and track circuit status or/and route locking status, point position and the status of the berthing track circuit.
- Stationary KAVACH unit shall then transmit the Movement Authority to the Loco KAVACH in its jurisdiction in station area.

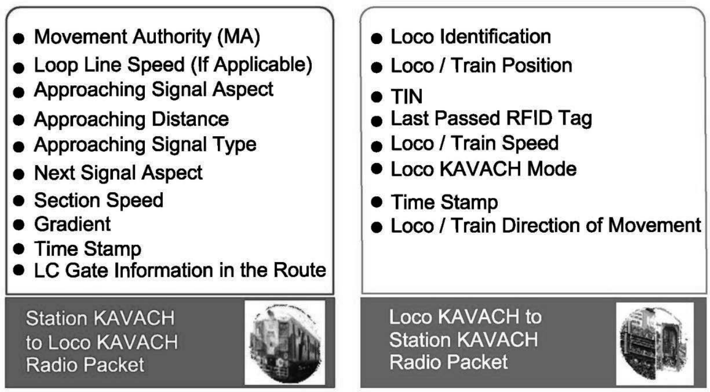


Fig. 1.5 Radio packet between Loco and Stationary KAVACH

- The length of the movement authority is decided based on the signal aspect of the approaching Stop Signal.
- The Loco unit shall make speed profile/ brake curve for different situations based on movement authority, speed restriction and other information as received from Trackside sub-system.
- The Loco KAVACH unit shall display the train speed, the permitted speed, the target distance and the target speed to the loco pilot through a *Driver Machine Interface (DMI)*.
- If a signal on approach is Red (Danger), the Stationary KAVACH unit shall transmit this information to the Loco KAVACH and reduce the movement authority to zero.
- If loco pilot fails to stop the train, automatic application of brakes shall take place, thus preventing *Signal Passing at Danger (SPAD).*
- In case of any conflict between signal aspect, point position, berthing track section, signal aspect sequence and TIN, the Stationary KAVACH unit shall transmit most restrictive aspect of that signal and shall reduce the movement authority accordingly. In this way train collisions are prevented in the station section.
- In case of block section if two trains are detected by Stationary KAVACH to be moving towards each other on same TIN, the SoS command would be generated by Stationary KAVACH for both the trains.

- On reception of such Loco specific SoS from Stationary KAVACH Unit, the Trains would be stopped through automatic application of brakes. There is also provision for broadcasting SoS message from Loco KAVACH to other Loco KAVACH in case of emergencies.
- Communication technique used for transfer of information between Stationary and Locomotive units in station area is *Full Duplex UHF Radio Communication* through *Multiple Access Time Division Multiple Access (TDMA)/ Frequency Division Multiple (FDMA) Access scheme.* A specific frequency pair is allotted to a station for communication between Stationary KAVACH and Loco under its jurisdiction.
- Loco KAVACH units can also communicate with other Loco KAVACH units in block section, in station area and in emergency situations (SoS, head-on, rear-end collisions) using a fixed frequency (f0) in its designated time slot.
- For centralized monitoring of KAVACH equipped Trains and Stations within the network, Network Monitoring System (NMS) with a central server in divisional office shall be provided over OFC Network. Transmission of exceptional fault/critical messages from Stationary KAVACH as well as Loco KAVACH to NMS is done through respective GSM interfaces available to them. Trouble shooting of error events, off line simulation, real time monitoring of KAVACH loco etc. are done through NMS.
- In the KAVACH System Radio Communication shall use cryptographic techniques to transfer messages between Loco KAVACH and Stationary KAVACH units. For secured communication, Authentication keys are received by Stationary KAVACH and Loco KAVACH using Global system for Mobile Communications (GSM)/General Packet Radio Service (GPRS) communication through a Key Management System (KMS). Real Time Clocks (RTC) of all the KAVACH systems are synchronized with Global Positioning system (GPS)/Global Navigation Satellite System (GNSS).

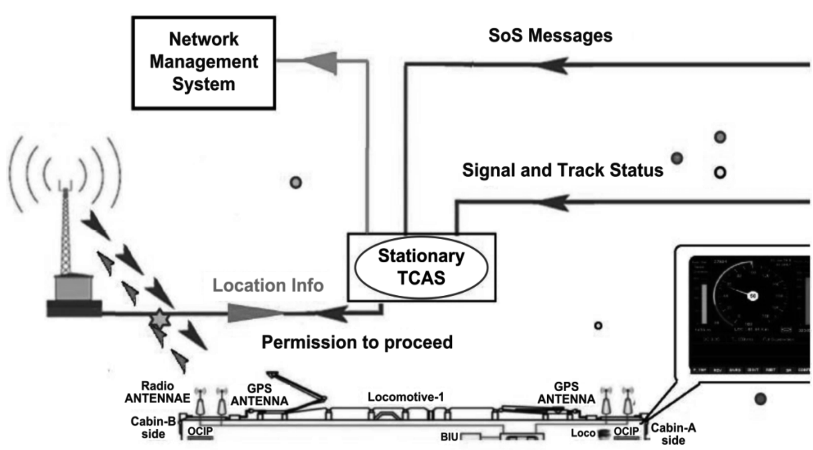


Fig. 1.6 KAVACH Functioning Schematic

1.3 KAVACH Requirement and Implementation

Requirement	Mechanism in KAVACH
Direction of trains	Comparing Absolute location of two RFID tags passed by train.
Location of Trains	Distance traversed beyond a RFID tag on Track Sleeper (Rail-road Tie) through speed sensing arrangement (Tachometer)
Extraction of dynamic Signalling Information by stationary KAVACH of station/ IB/ LC gate vital computer.	Interfacing to station interlocking (PI/RRI/EI)
Transfer of Signalling related information from Station KAVACH to Train	Radio Communication between Stationary unit & Train units through dynamic TDMA on a specific frequency pair in station area. Stationary units are allocated timeslots according to Topography and their size. Mobile units i.e. trains are assigned slots dynamically. This provides efficient utilization of channels.
Loco to Loco message broadcast	In block section, in station area and in emergency situations (SoS, head-on, rear-end collisions) using a fixed frequency (f0) in its designated time slot.
Prevention of over speed and SPAD	By reducing the movement authority based on the aspect of approaching signal.
Prevention of collisions between two trains	Through conflict between signal aspect, point position, berthing track section, signal aspect sequence and TIN in station area and through TIN conflict in block section.
Centralized monitoring of KAVACH equipped trains and stations	Through Network Monitoring System (NMS)
Security of radio communication between Stationary KAVACH and Loco KAVACH	Using GSM/GPRS communication techniques through a Key Management System (KMS)
Real Time Clock (RTC) synchronization	Through Global Positioning system (GPS)/ Global Navigation Satellite System (GNSS).

1.4 Data Flow between KAVACH Sub Systems

Information received by Stationary KAVACH unit from Loco KAVACH unit

- Direction of train movement
- Location of train
- Emergency messages

Information received by Stationary KAVACH unit from interlocking

- Approaching Signal aspect (ECRs)
- Berthing track circuit status (TPRs)
- Point status (NWKRs/RWKRs)
- Status of block instrument - Line Closed condition

1.5 Data sent by Stationary KAVACH to Loco KAVACH

- Aspect of the approaching signal on route.
- Approaching signal distance from the train position (absolute location).
- Approaching signal identity.
- Next signal aspect and its distance in the territory of same stationary KAVACH unit, if signal on approach is OFF.
- Movement authority (the distance for which the train is authorized to travel).
- Static Speed Profile.
- Temporary Speed Restrictions

1.6 Determination of Direction

- The direction of movement of train shall be determined through RFID Tags.
- There shall be three types of direction of movements, one for train such as forward or reverse, second for traffic such as UP or DN and the other for movement of direction such as Nominal or Reverse.
- The direction shall be derived when Loco/Train has passed two RFID tags with Absolute location (except Adjustment tag).
- If Absolute location value is incrementing, it shall be treated as Nominal direction. If Absolute location is decrementing, it shall be treated as Reverse direction.
- The direction of movement of train and TIN shall be used for determining whether two trains are approaching or one following the other or going away from each other.
- The Stationary KAVACH unit shall use the direction of movement of Loco/Train, to find approaching signal of the Loco/Train.

1.7 New Train Formation

A train shall be considered as a new formed train by Loco KAVACH unit under one or more of the following conditions:

- When Loco KAVACH unit has been switched on or restarted
- When Loco KAVACH unit has come out of Non-Leading/Shunt mode/System failure mode/Isolation mode.
- When driving cab/desk is changed except when Loco KAVACH is in Shunt mode.

1.8 Train Length Assisgnment

- Every stationary KAVACH unit shall monitor the status of track section identified for measurement of train length. (Only applicable to Station KAVACH units).
- Based on the time of occupation and clear status of these track sections, communicated by Stationary KAVACH unit, Loco KAVACH unit shall calculate its train length.
- Two track circuit (say AT & BT in sequence in the traffic direction of train movement) at the entry to block section shall be identified at each station for train length measurement. The track circuits identified shall be such that all the trains entering into a block section pass over these track circuits.
- The status of these track circuits shall be taken as input to stationary unit.
- Stationary unit shall communicate the time offset from frame cycle reference for 'BT occupied' and 'AT cleared' to concerned Loco unit, which shall be used by Loco unit for precise location for train length calculation.
- In case of overlapping territories, the train length measurement information shall be passed on by taking over station.

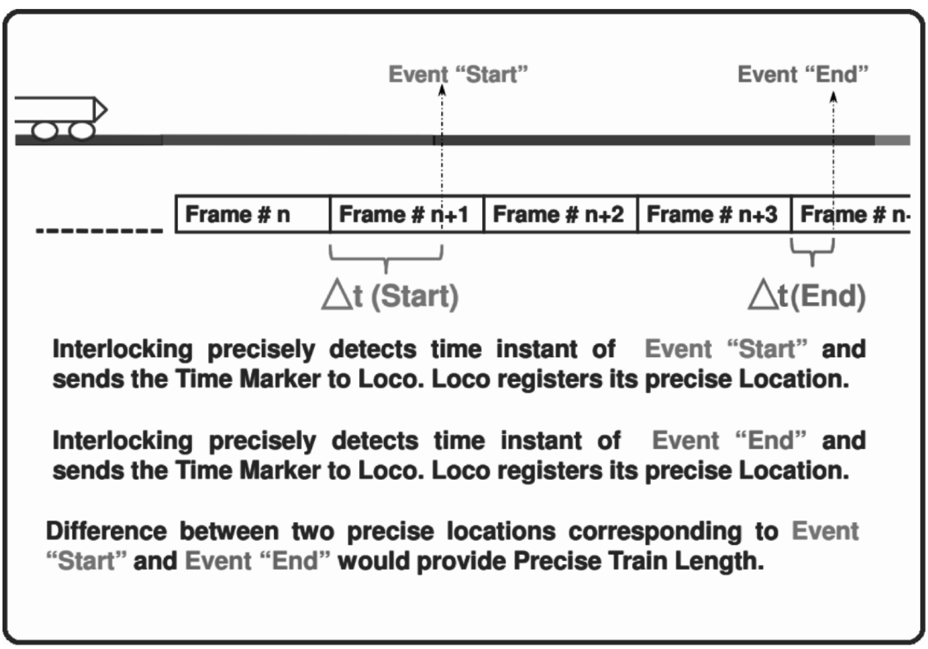


Fig. 1.7 Train length Measurement

1.9 Train Location

- The Loco KAVACH unit shall determine the location of the train with the help of RFID tag data and Speed sensor output.

- Loco KAVACH unit shall transmit the location of the train to the Stationary KAVACH unit every 2 seconds in Full Supervision mode.

1.10 Visual and Audio Warnings on the DMI

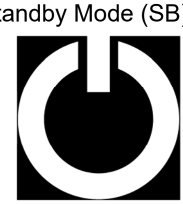
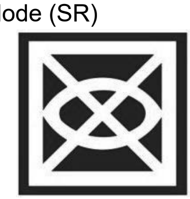
- As long as the current speed is less than or equal to permitted speed indicated on DMI, in Full Supervision mode, the Loco KAVACH Unit shall neither generate warning for brake application nor apply the brakes.
- Visual and audio warnings about expected brake intervention by Loco KAVACH unit shall be given to the Loco pilot to enable the loco pilot to react and avoid intervention.

1.11 Supervision of Movement Authorities and Speed Limits

- The Loco KAVACH unit shall supervise the end of movement authority, if this information is available onboard.
- A train shall be supervised to its static and dynamic train speed profiles.
- If the train speed exceeds the permitted speed by 2 kmph (configurable), warning for over-speed would be generated.
- If the train exceeds the permitted speed by 5 kmph (configurable), the Loco KAVACH unit shall execute a brake intervention along with warning until the actual speed is not more than permitted speed.

1.12 Operational Modes in Loco KAVACH

The KAVACH loco equipment shall be capable of supervising the following operational Modes:

S.No.	Modes	Responsibilities
1	Standby Mode (SB) 	1. This Mode is default mode. At Power-On or If No CAB is selected KAVACH comes into this Mode. 2. In This Mode Train is Supervised for Standstill. Any movement if detected it applies EB. 3. If any CAB is occupied, Based on New train Status It performs Brake system health test. 4. On test success it Suggests SR or Shunt Mode to Loco Pilot. 5. Radio Transmission is Active if it is in KAVACH Area
2	Staff Responsible Mode (SR) 	1. In KAVACH territory Transmits Radio packet. 2. Supervises Loco Ceiling Speed 3. It Supervise Roll away & Reverse Movement protection

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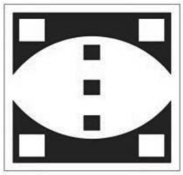
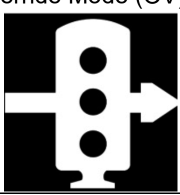
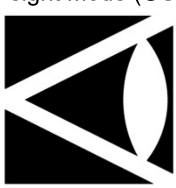
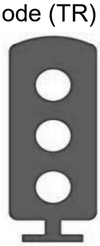
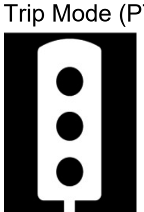
S.No.	Modes	Responsibilities
3	Limited Supervision Mode (LS) 	1. In KAVACH territory Transmits Radio packet. 2. Supervises Loco Ceiling Speed 3. If Track Data is Valid & Traffic Direction is Known It Supervises Section Speed (PSR), TSR (future use) & Collision Targets 4. It Performs Brake system health test 5. It obeys General SoS from Station if Loco is within 3km Radius 6. It Supervise Roll away & Reverse Movement protection. 7. If Radio communication is good supervises MA & Turnouts
4	Full Supervision Mode (FS) 	In this mode in addition LS mode 1. It Supervises MA, Turnout speeds received from Linked station 2. It performs Train Length Measurement 3. It Obeys Loco specific SoS from Linked Station
5	Override Mode (OV) 	1. Supervises OV Mode Speed 2. If MA is extended or after override timeout (Default: 240s), Section Speed is known & Traffic direction Known it will go to Full Supervision Mode 3. It Obeys SoS from Stationary KAVACH 4. Radio Transmission is Active if it is in KAVACH Area. 5. It can be entered only When MA
6	On-sight Mode (OS) 	1. It Obeys SoS from Stationary KAVACH 2. It Supervises On-sight Mode Speed (Configurable) 3. Radio Transmission is Active if it is in KAVACH Area
7	Trip Mode (TR) 	1. It enters in to this mode if (MA + 30m is crossed) or (Signal foot tag crossed after MA 2. Loco Pilot has to Acknowledge by pressing PTRIP soft key on DMI. Then it releases EB. 3. Stationary KAVACH shall send SoS to the Loco KAVACH unit until the trip mode is acknowledged. 4. Radio Transmission is Active if it is in KAVACH Area.
8	Post Trip Mode (PT) 	1. Supervises PT Mode Speed 2. If valid MA is received, Section Speed is known & Traffic direction Known it will go to Full Supervision Mode 3. It Obeys SoS from Stationary KAVACH 4. Radio Transmission is Active if it is in KAVACH Area

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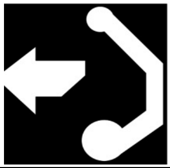
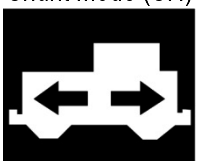
S.No.	Modes	Responsibilities
9	Reverse Mode (RM) 	1. Supervises Reverse Mode Speed (Configurable), Distance (configurable) and Timeout (configurable) 2. It Obeys SoS from Stationary KAVACH 3. Radio Transmission is Active if it is in KAVACH Area
10	Shunt Mode (SH) 	1. Supervises Shunt Mode Speed (Configurable) 2. KAVACH doesn't do Brakes test if Loco pilot Changes AB.(After exiting Shunt mode It performs) 3. It Obeys SoS from Stationary KAVACH 4. Radio Transmission is Active if it is in KAVACH Area
11	System Failure Mode (SF) 	It Applies EB Continuously. Radio Transmission is Active if it is in KAVACH Area
12	Isolation Mode (IS)	It Bypasses Brakes. Loco KAVACH Unit shall transmit an Loco-to-Stationary Radio Packet at a periodicity of not less than 02 minute on encountering a KAVACH territory tag (which excludes LC Gate Tag) in one of the randomly selected access timeslots merely to indicate the onboard mode to NMS through Stationary KAVACH Unit

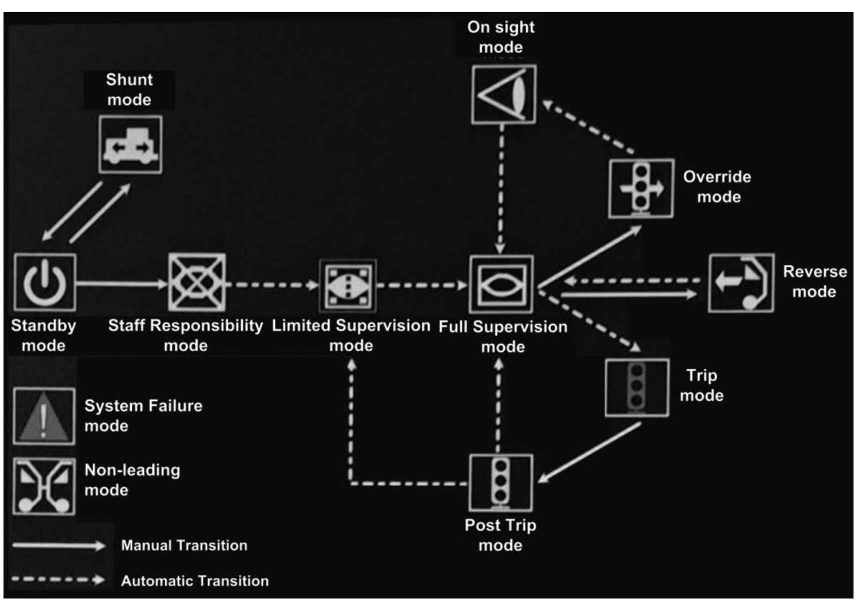


Fig. 1.8 Operational Modes flow chart

1.13 Static Speed Profile (SSP)

The Static Speed Profile (SSP) is a description of the fixed speed restrictions for a part of track sent from trackside to train. The SSP addresses the maximum permitted speed at any location. The static speed profile is a parameter that gives; the maximum permitted speed, that can be reached on the track based on physical characteristics of the track (curves, restriction to pass a point). The SSP is one of the data that allow the train to manage the supervision (Full Supervision, On Sight); for this the train will have to know the SSP throughout the Movement Authority.

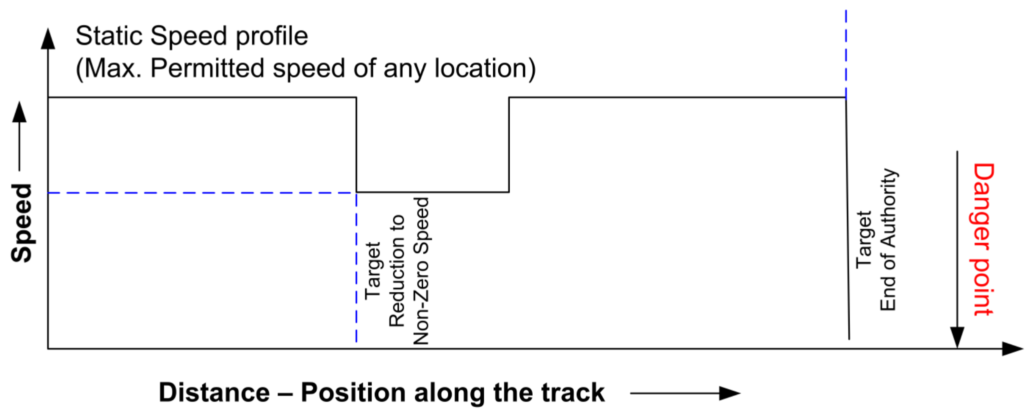


Fig. 1.9 Static Speed Profile (Distance-Speed graph) of a train

1.14 Dynamic Speed Profile (DSP)

Dynamic Speed Profile is the speed-distance curve which a train shall follow without violating the static train speed profile till the end of movement authority**.** This curve depends on the braking characteristics of the train and the train length. The dynamic speed profile considers the possible acceleration or deceleration curve of the movement of the train.

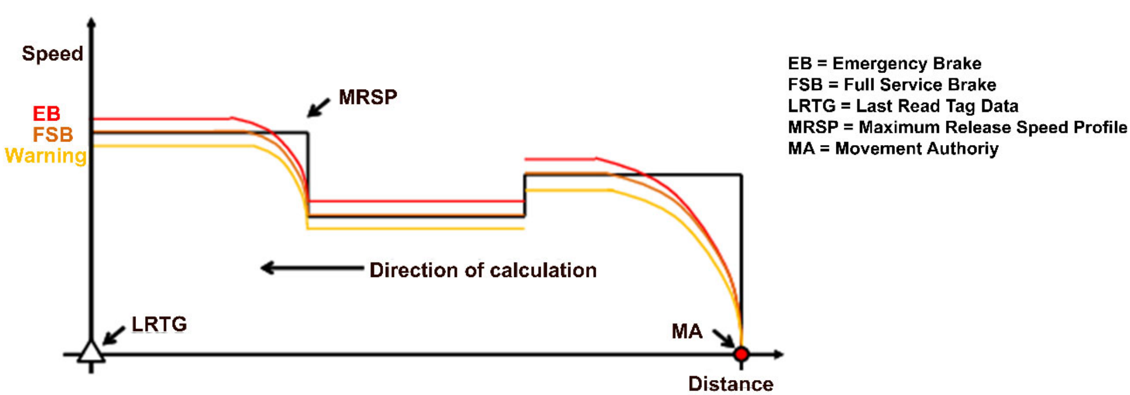


Fig. 1.10 Dynamic Speed Profile (Distance- Speed graph) of a train

1.15 Movement Authority

- Movement Authority (MA) is the distance upto which the train is permitted to travel without danger.
- The length of the movement authority is decided based on the signal aspect of the approaching Stop Signal.
- Aspect control chart is used to define the length of Movement of authority.
- In case of permissive signals, where the inputs for signal indications are available, the ECR shall be used for the purpose of displaying signal aspect. However, movement authority shall be decided based on the signal aspect of the approaching Stop Signal.
- In case of permissive signals, where the inputs for signal indications are not available, the signal aspect and movement authority shall be derived based on the signal aspect of approaching stop signal.
- The Movement Authority for the last signal of stationary KAVACH shall be the physical distance between the last signal of stationary KAVACH and the foot of next approaching Stop Signal. The Movement Authority shall be specified in meters. This movement Authority shall be used for train entering the block section.
- Stationary KAVACH unit shall calculate the movement authority based on the signal aspect or/and track circuit status or/and route locking status, point position, status of the berthing track circuit and status of the block instrument line closed condition. Stationary KAVACH unit then shall transmit the Movement Authority to the Loco KAVACH in its jurisdiction. The Movement Authority transmitted shall be the distance of End of Authority from actual Absolute Position of the train.
- For adapting KAVACH to an Auto section, it is necessary to communicate the signal aspects or/ and Track occupancy status to Stationary KAVACH, which then determines movement authority and communicates the same to the Loco KAVACH on radio.
- In the case of single line working, KAVACH shall extend Movement Authority after ensuring the establishment of direction of traffic and all stop signals (if available) against the established direction shall be at ON.

1.16 Sub Systems of KAVACH

The KAVACH (Indian Railway Train Protection System) broadly comprises of following components:

1.16.1 Track side Sub-systems

The Trackside subsystem shall be composed of

(i) RFID tag
(ii) Stationary KAVACH Unit
(iii) Tower and Antennae

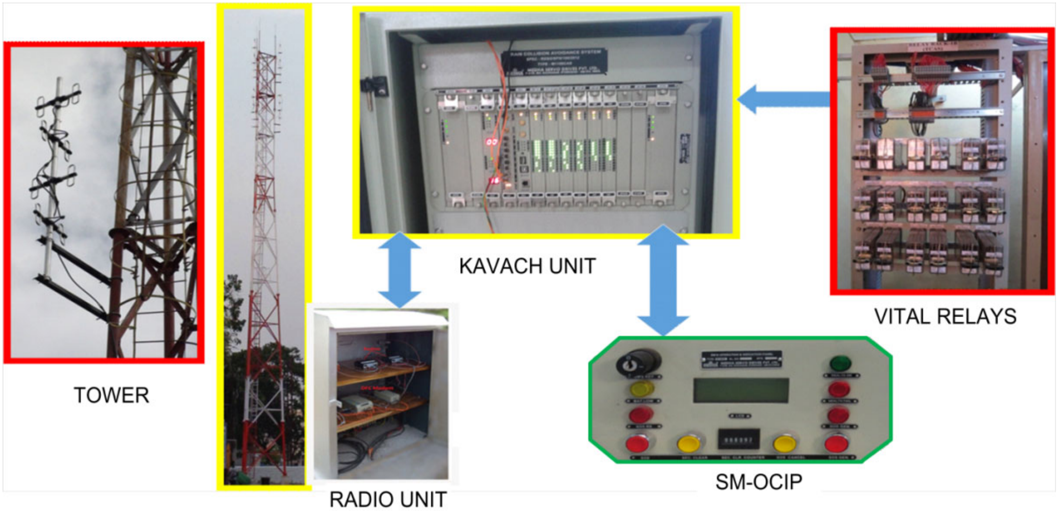


Fig. 1.11 Station KAVACH

1.16.2 On-Board Sub-Systems

The On-board subsystem shall be comprised

- Loco KAVACH Vital Computer
- RFID Reader
- Loco KAVACH Radio Unit with antennas and other communications
- Driver Machine Interface(DMI)
- Brake Interface Unit (BIU), where required

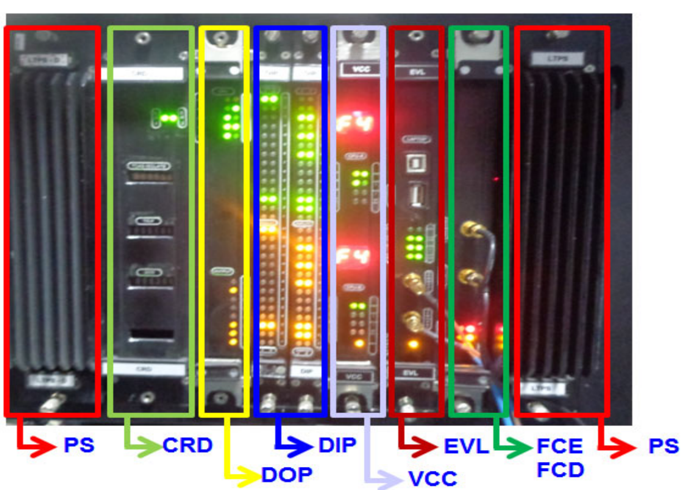


Fig. 1.12 A Loco Vital Computer

RFID Tag Reader

Loco Radio Modem

Driver Machine Interface (DMI)

Brake Interface Unit (BIU)

Fig. 1.12 B Loco KAVACH

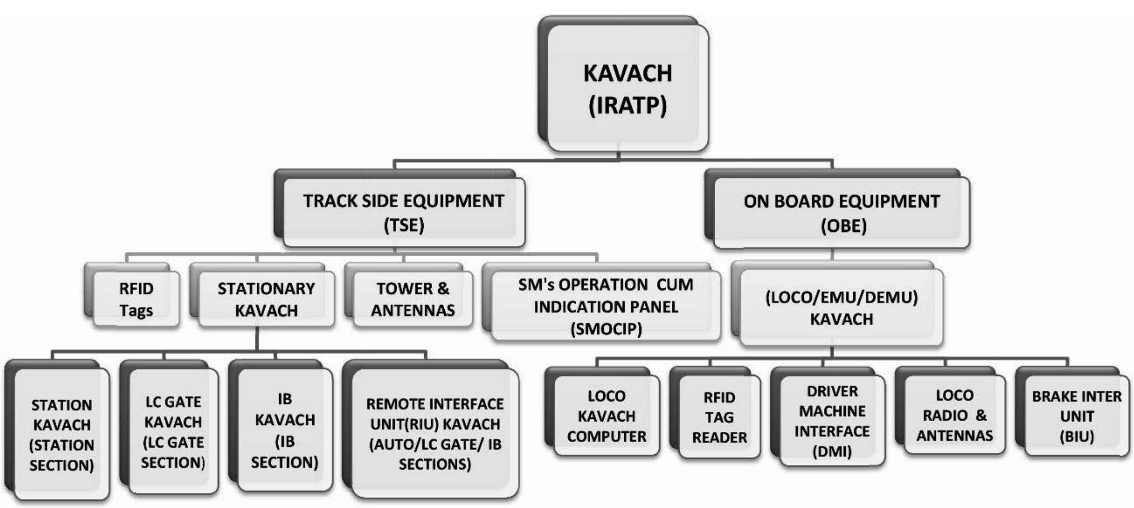


Fig. 1.13 Flow chart of KAVACH Sub-systems

1.17 Track Sides Sub-system

1.17.1 RFID Tag

RFID Tags provide location specific static information to Locomotive. Apart from acting as Location references these provide immediate information such as crossing the signal etc. to Loco Unit.

RFID tags are fitted on track in station section, point zones, near Signals & in block section for giving Trackside information to Loco KAVACH unit.

The RFID tags shall be fitted on the sleepers between the rails as per guidelines given for Indian Railways.

Specification of RFID tag :

- Suitable for reliable working at train speed upto 200 KMPH (minimum).
- Frequency of operation: 865-867 MHz.
- Can be programmable with minimum 128 bits (including CRC) of user data.
- Shall be able to work even when submerged in water up to rail level.
- Under field operating conditions RFID reader antenna shall be able to read,
- RFID tag from a vertical distance of 700 mm from bottom of RFID reader antenna to top of the rail level.

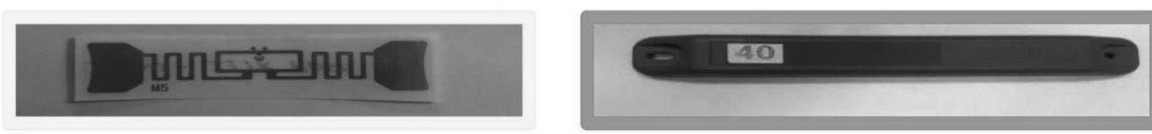


Fig. 1.14 RFID Tag fixed on sleeper

1.17.2 Stationary KAVACH Unit

Stationary KAVACH Unit shall be universally suitable for various types of signalling of Indian Railways with provision of colour light signalling. By default, it shall be suitable for interfacing with Panel Interlocking (PI), Route Relay Interlocking (RRI) and Electronic / Solid State Interlocking (SSI).

Normally Stationary KAVACH Unit shall be provided at Stations to cover all the trackside signals. It shall also be provided at Intermediate Block Locations (IBS) and midsection interlocked Level Crossing Gates where the radio signal coverage of station KAVACH tower is not adequate. This shall be interfaced with interlocking equipment to acquire real-time dynamic information related with signalling such as various signal aspects. It has database of static signalling related information such as location & details of RFID tags and Speed Restrictions. It gets real-time information regarding Locations, Speed etc of various trains in its jurisdiction through UHF Radio Communication.

On the basis of this information, it detects any emergency situation and can direct the command to Loco to take action to stop.

Stationary KAVACH Unit shall comprise of:

1. Station/ LC/ IB KAVACH Vital Computer
2. Stationary KAVACH Radio Unit
3. Remote Interface Unit (as per requirement)
4. Station Master Operation cum Indication Panel (SMOCIP)

1.17.2.1 Station/LC/IB KAVACH Vital Computer

The Vital Computer of Station/ LC/ IBS KAVACH Unit is a computer-based system that generates messages to be sent to the train on basis of information received from interlocking inputs and on basis of information exchanged with the Loco KAVACH units. Vital Computer architecture shall be minimum 2 out of 2. Station/ LC/ IBS Vital Computer shall have Real Time Clock synchronization facility with GNSS clock to synchronize with other KAVACH systems in hot standby manner. Station/LC/IBS Vital Computer shall have provision for the following:

- To interface with signalling inputs in fail-safe manner.
- Ethernet/ E1 port and two GSM interfaces for connectivity with Network Monitoring System (NMS) and Key Management System (KMS).
- To interface with OFC (E1 interface/ Dark Fibre) for connectivity with Remote Interface unit with minimum Four (six proposed).
- USB interface for downloading of log & other data for diagnostic purposes. To interface with Video Display Unit (VDU) to show real time display of Loco movements and signal aspects of the yard, (to be provided separately).

1.17.2.2 Stationary KAVACH Radio Unit

Radio communication network shall be used for the bi-directional exchange of messages between Loco KAVACH unit and StationaryKAVACH units.

Stationary KAVACH Radio Unit shall have two UHF full duplex Radio modems with separate cable and antennae in hot standby mode to communicate with Loco KAVACH unit.

1.17.2.3 Remote Interface Unit (RIU)

Remote Interface Unit (RIU) is a miniature version of Stationary KAVACH without radio communication unit, which captures (multiplexing) the relay information wired to it and exchanges the data with master Station KAVACH directly without any relay interfaces. Remote Interface Unit (RIU) shall be used where remote signalling functions are required to be fetched to a nearby Stationary KAVACH unit, for example from end cabin, distributed interlocking, a nearby LC Gate, Intermediate Block or Automatic Signalling section. RIU at such end cabins/ distributed interlockings or LC gate/ IB shall be installed if they are coming within the radio coverage of station tower. RIU is used to communicate remote signalling inputs to Stationary KAVACH over OFC media. In multiple RIUs scheme these are connected in a Ring network topology to increase the availability of the network. In a Ring network, each RIU is connected to two adjacent RIUs in primary and secondary. A single RIU shall be capable of communicating with two adjacent RIU units so that the operations are not affected in case of communication link failure on one side only. A single RIU shall be capable of handling at least 32 field inputs. RIU KAVACH unit shall consist of Vital Input modules with minimum Two-Out-Of-Two architecture.

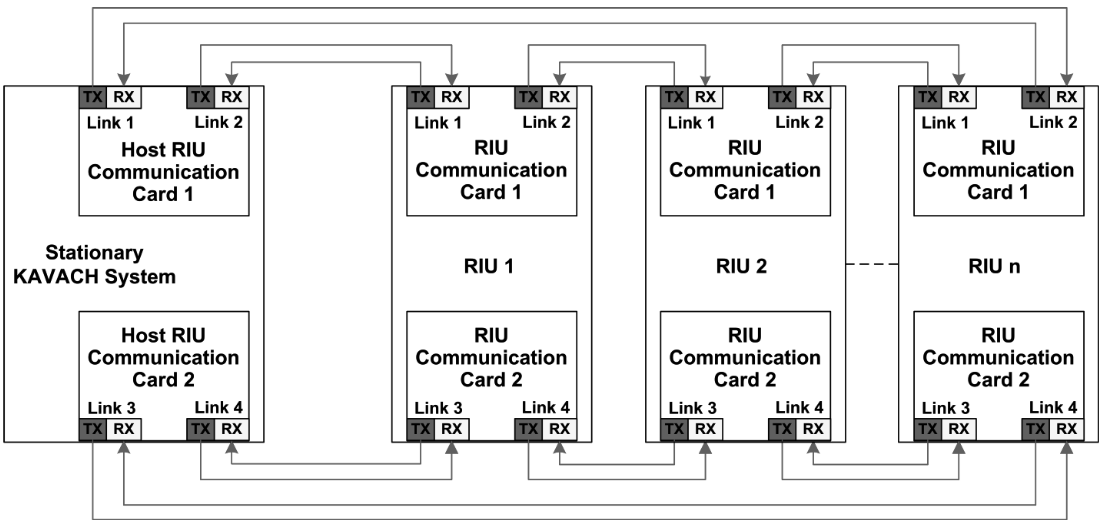


Fig. 1.15 Connectivity between Remote Interface Units (RIUs) and Stationary KAVACH

1.17.2.4 Station Master Operation Cum Indication Panel (SMOCIP)

Purpose of SMOCIP:

- Station Master can generate SOS to Loco KAVACH units in its jurisdiction.
- Cancellation of SOS generated by stationary KAVACH.
- Monitoring the health of Stationary KAVACH.
- SOS status display on LCD panel of SMOCIP.

Connectivity of SMOCIP:

- 12 Core signalling cable is used for SMOCIP in SM Room to Stationary KAVACH in Relay Room For button, counter & power supply
- 10 pair PIJF cable is used for SMOCIP in SM Room to Stationary KAVACH in Relay Room for communication between SMOCIP and Stationary KAVACH.

SMOCIP consists of following:

- LED Indications
- Switches
- LCD Panel
- Buzzer

- Digits counter which are updated on pressing of manual SOS switch Station Master's key.

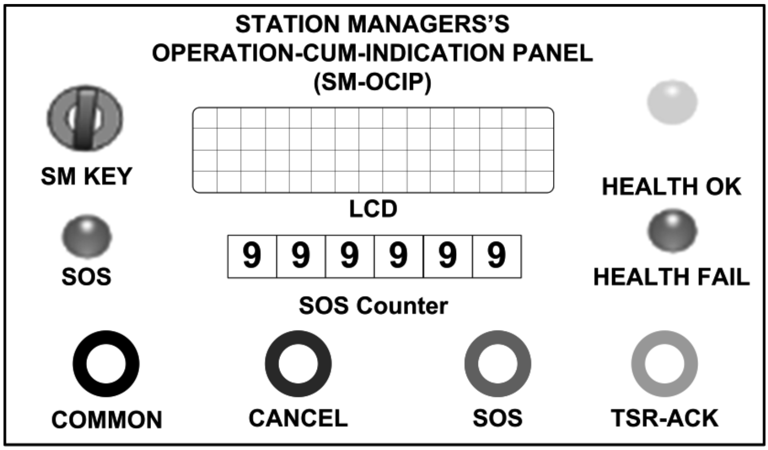


Fig. 1.16 Front Panel diagram of SMOCIP

It has the following LED Indications on the Console:

Sl. No.	LED Name	Colour	Description
1	HEALTH OK	GREEN	Indicates Stationary KAVACH Healthy
2	HEALTH FAIL	RED	Indicates Stationary KAVACH Un Healthy
3	SOS	RED	When SOS generated from Station

It has the following switches on the Console:

Sl. No.	LED Name	Colour	Description
1	COMMON	BLACK	Common switch to press along with SOS switch
2	CANCEL	BLUE	To cancel the SOS from station
3	SOS	RED	To generate SOS from Station

No functionality of switches is allowed without SM-KEY insertion into SM-OCIP.

Following indications/ buttons/ buzzers shall be given in the Station Master's OCIP:

(a) Station Masters Key
(b) LCD display (4 Line x 20 char)
(c) SoS indication
(d) Health indication
(e) Audio Buzzer
(f) Three Push Buttons (Common, Generation and Cancellation) to generate and cancel the SoS.
(g) Electromechanical non-resettable 6 digit counter for recording SoS operation.

1.17.3 Tower and Antenna

Self supported lattice towers of height 40meters are used to cater 4.5km range of radio coverage for Radio communication between Stationary KAVACH and Loco KAVACH.

The antennae for stationary communication system at station/ IBS/ midsection interlocked Gate unit shall be combination of vertically polarized omni and/ or directional antennae. The antenna cable & antenna shall be suitable to provide a minimum range of communication approximately 1.5 km on approach of first signal of the Stationary KAVACH unit (typically 4.5 kms in case of Double-Distant territory of Indian Railways).

1.18 On-board Sub-system (Loco KAVACH Unit)

The On-board subsystem shall be comprised of

(a) Loco KAVACH Vital Computer
(b) RFID readers consisting of two RFID Reader Antenna in hot standby
(c) Loco KAVACH Radio Unit consisting of two Radio Modems in hot standby with separate cables and antennae.
(d) Two Driver Machine Interface (DMI) for each locomotive or one DMI for each Driving motor coach of EMU/DMU/MEMU/DEMU etc.
(e) Brake Interface Unit (BIU).

1.18.1 Loco KAVACH Vital Computer

The Loco KAVACH vital computer is a system that supervises the movement of the train to which it belongs, on basis of information exchanged with Stationary KAVACH units and other Loco KAVACH units. Vital Computer architecture shall be minimum 2 out of 2. Loco KAVACH vital computer shall have Real Time Clock synchronization facility with GNSS clock to synchronize with other KAVACH systems in hot standby manner. Loco KAVACH vital computer shall have provision for the following:

- To interface with train interface unit & brake interface unit.
- Two Direction sensing type Speed Sensor interface for distance and speed measurement.
- To interface with RFID reader to read RFID tags fitted on the track.
- To interface with Driver Machine Interface (DMI) consisting of display arrangement & buttons/ switches for operation.
- Two GSM interfaces for connectivity with centralized Network monitoring System (NMS) and Key Management System (KMS). It shall be also to be operable with LTE where LTE is proved.
- USB interface for downloading of log &other data for diagnostic purposes.

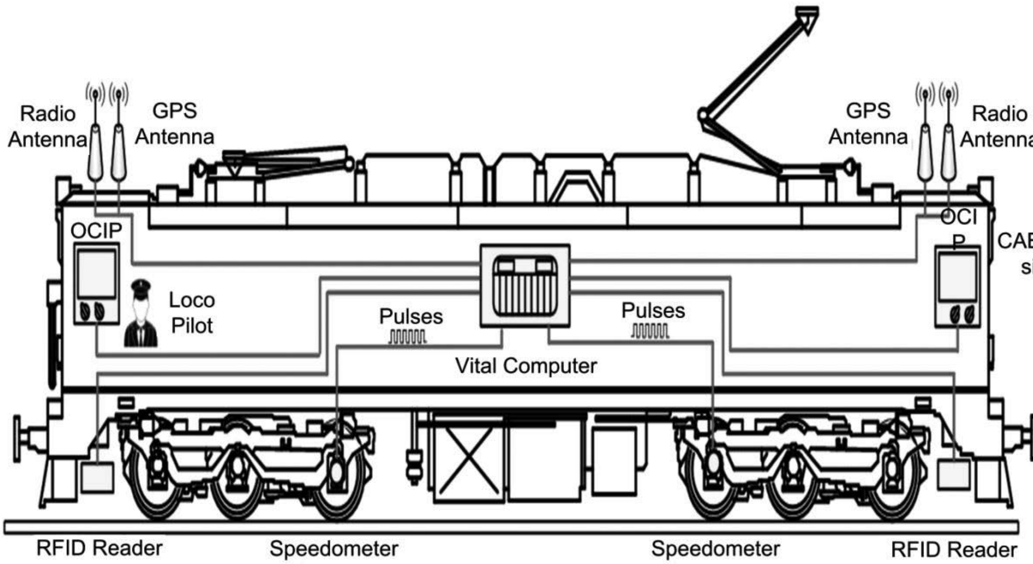


Fig. 1.17 A Electric Loco KAVACH

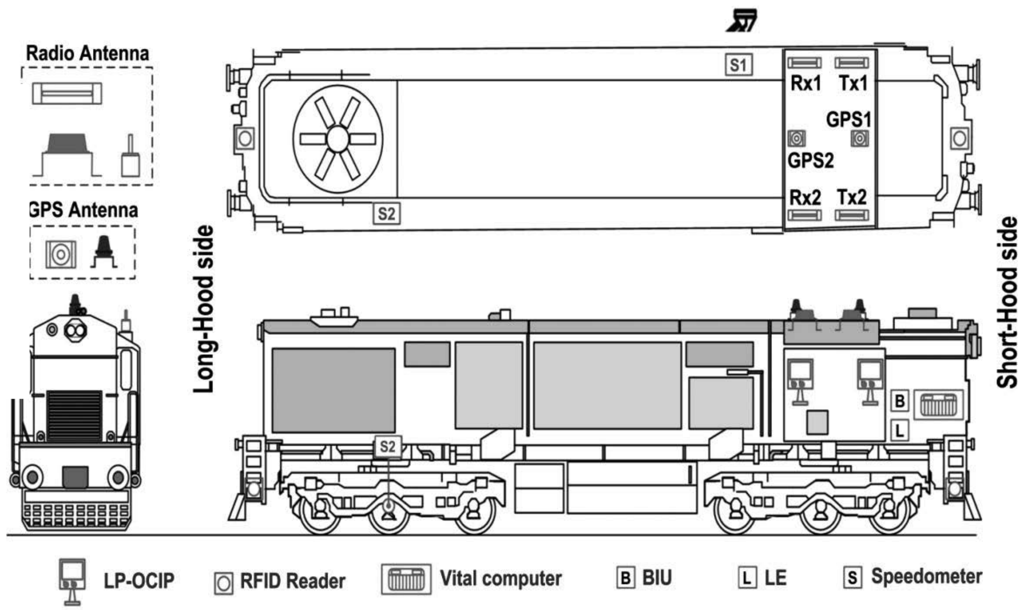


Fig. 1.17 B Diesel Loco KAVACH

1.18.2 RFID Reader

Each Loco KAVACH unit shall have two RFID readers for getting the information from RFID tags fitted on the trackside in hot standby manner.

1.18.3 Loco KAVACH Radio Unit

Loco KAVACH radio unit specifications shall be similar to stationary KAVACH radio unit. Loco KAVACH radio unit shall have two uhf full duplex radio modems with separate cable and antennae in hot standby mode to communicate with stationary KAVACH unit.

1.18.4 Loco Pilot Machine Interface (DMI)

Fig. 1.18 A DMI

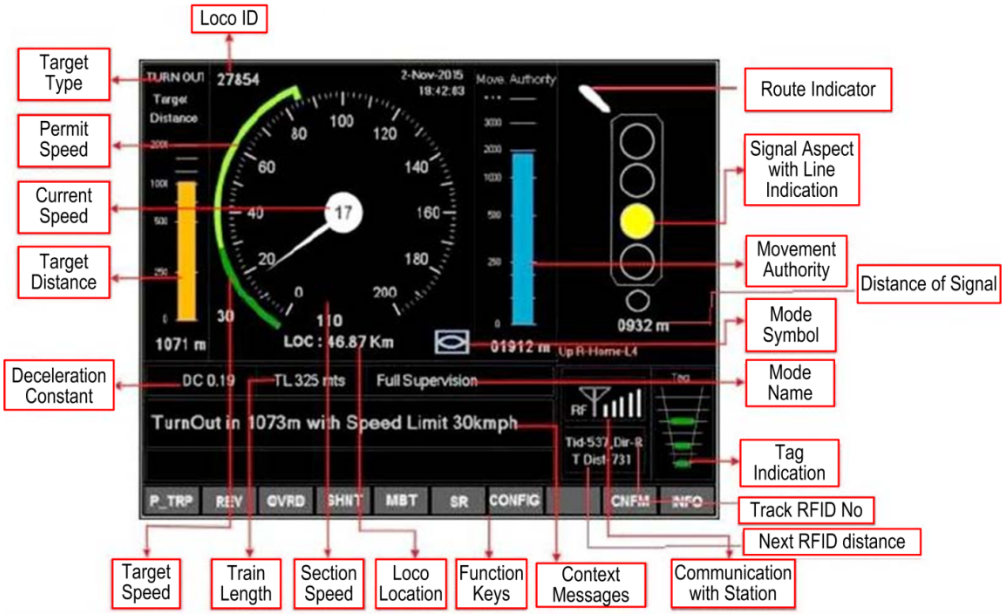


Fig. 1.18 B

Loco Pilot Machine Interface (DMI) is a general, operational, system, technical, functional, and performance requirements for Loco KAVACH Driver Machine Interface so that there is clear and consistent understanding between the Loco Pilot and the KAVACH system.

Most of the information displayed is in form of Analog Displays in form of Circular Gauges (Arcs) and bars keeping ergonomics and convenience of Loco Pilots. Digital values have also been additionally displayed. Audio prompts and warnings also are implemented.

Two LP-OCIPs (Operation cum Indication Panel) provided for Loco pilot and Asst. pilot interaction with KAVACH.

Loco Pilot's Operation-cum-indication panel (LP-OCIP/DMI) shall consist of suitable arrangements and buttons/ switches for display/ operation of following functions:

(a) Communication with Loco KAVACH.
(b) Train type selection by the loco pilot.
(c) SOS operation by the loco pilot.
(d) Signal aspect display.
(e) Train length display
(f) Train type display
(g) Display of all modes of loco operation
(h) Current speed

(i) Over speed
(j) Permitted speed
(k) Target speed (For entering into loop line)
(l) Movement Authority (MA)
(m) The function in DMI for displaying the context messages for Loco Pilot's attention

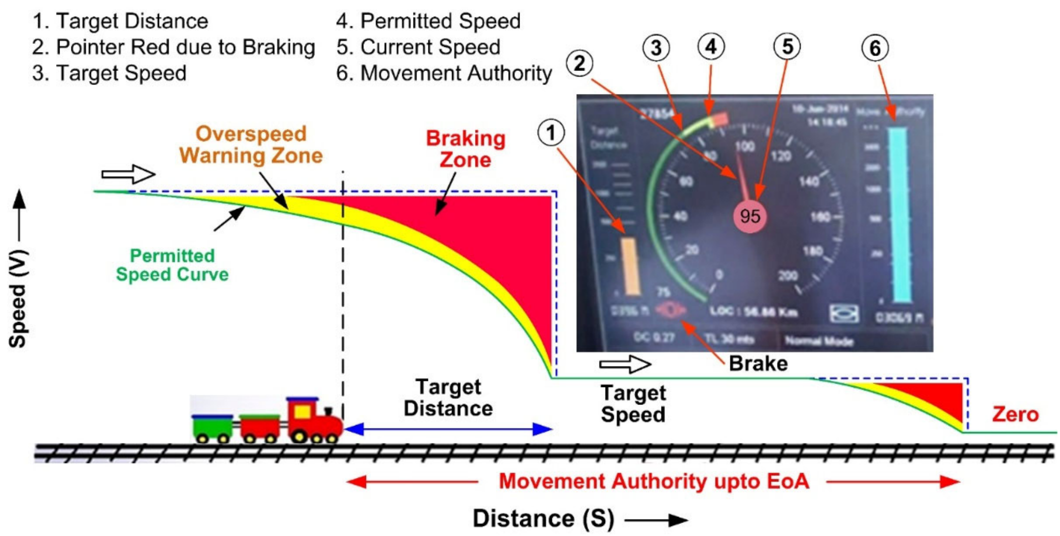


Fig. 1.19 A DMI with Movement Authority

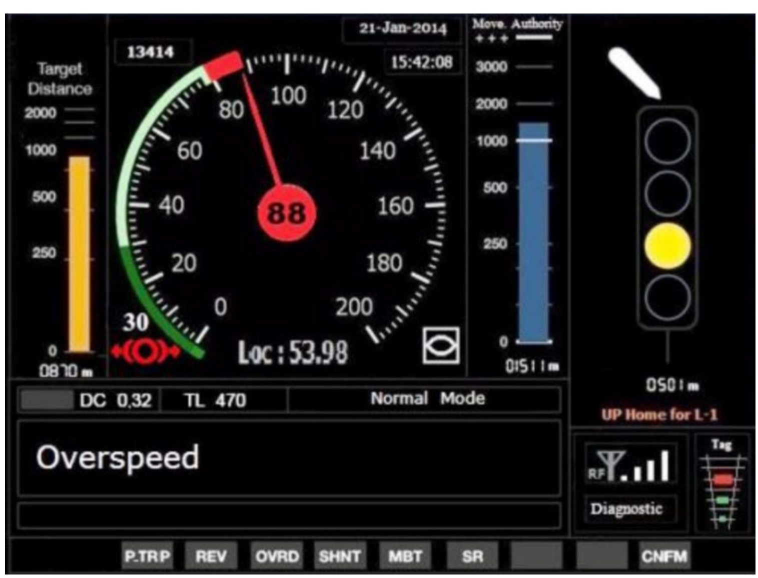


Fig. 1.19 B DMI Showing Over Speed

Braking Systems in Railway Vehicles

I. Introduction

The brakes are used on the coaches of railway trains to enable deceleration, control acceleration (downhill) or to keep them standing when parked. While the basic principle is similar from road vehicle, the usage and operational features are more complex because of the need to control multiple linked carriages and to be effective on vehicles left without a prime mover. In the control of any braking system the important factors that govern braking action in any vehicle are pressure, surface area in contact, amount of heat generation and braking material used. Keeping in view the safety of human life and physical resources the basic requirements of brake are:

The brake must be strong enough to stop the vehicle during an emergency with in shortest possible distance.

There should be no skidding during brake application and driver must have proper control over the vehicle during emergency.

Effectiveness of brakes should remain constant even on prolonged application or during descending on a down gradient

Brake must keep the vehicle in a stationary position even when the driver is not present.

The brake used in railway vehicles can be classified according to the method of their activation into following categories.

(a) Electrodynamic Brake

(b) Mechanical Brake

(c) Electromagnetic Brake

(d) Pneumatic Brake

(e) Compressedair Brake

(f) Vacuum Brake

(a) Electrodynamic Braking System: Braking system used is electric trains is electrodynamic braking that converts the motor into a braking generator dissipating the kinetic energy in the form of heat. Regenerative braking uses the generated electricity instead of dissipating it as heat, and is becoming more common due to its ability to save energy. Principle of the electrodynamic traction, dynamic braking and regenerative braking systems is shown in Figures below.

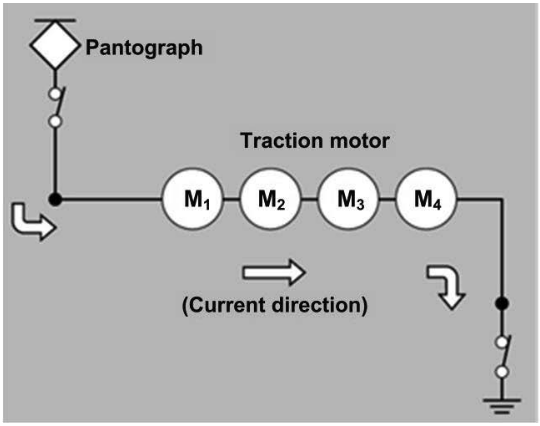


Fig. 1.20 Principle of electrodynamic traction

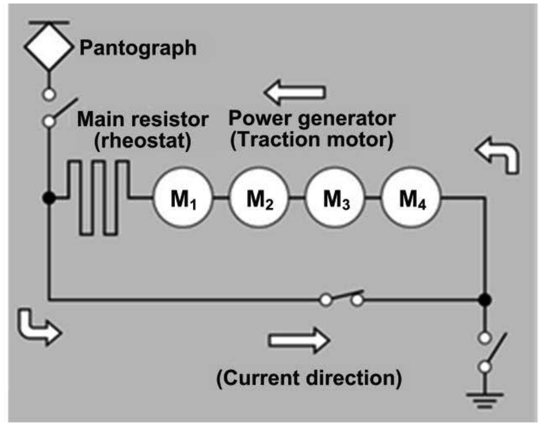


Fig. 1.21 Principle of dynamic braking

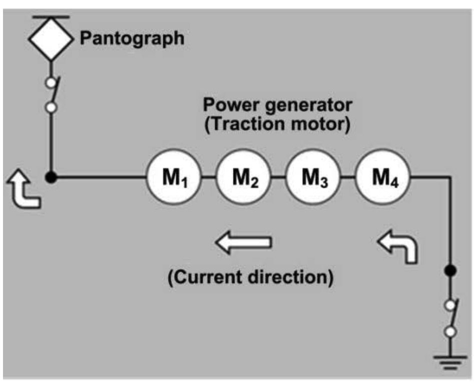


Fig. 1.22 Principle of regenerative braking

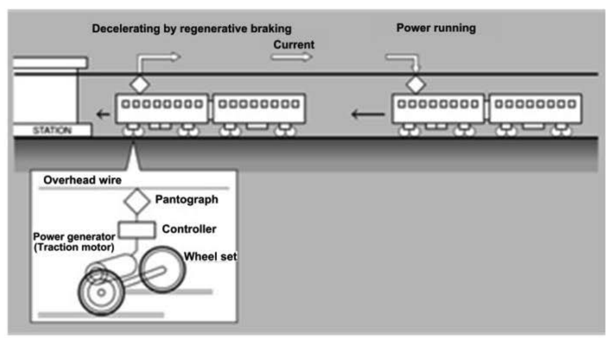


Fig. 1.23 Principle of recycled regenerated electric power

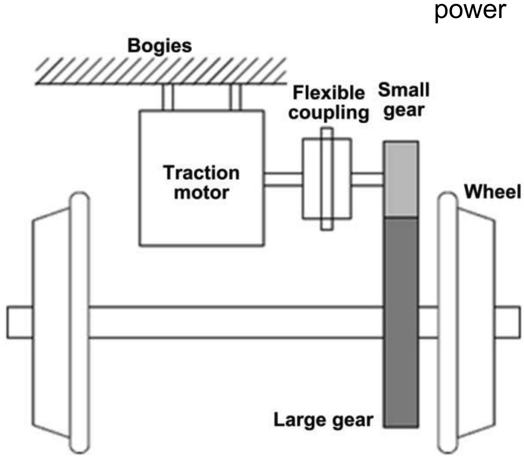


Fig. 1.24 Transmission of braking force from traction motors to wheels

The traction motor drives and accelerates the train, during braking and it acts as an electric generator instead, forming part of a circuit that consists of a rheostat, armatures and a field system. Electricity is consumed by the main resistor, which converts kinetic energy of the train into heat and acts as a brake. Regenerative braking uses the same type of circuit; however the electricity generated by braking is not consumed by rheostat. It is transmitted to the overhead wire.The flow of this electricity is controlled by a controller under the pantograph that opens and closes within fraction of time. Electrodynamic brake systems are economical to use because they do have friction elements, as in mechanical brake systems. The regenerative braking system is even more economical because the electricity regenerated from the trains kinetic energy is transmitted to the overheadwire, and becomes available to power other rolling stock.

However electrodynamic brake systems occasionally malfunction because they have complex circuits. Therefore they cannot be used as emergency brakes. In an electrodynamic braking system, the braking force of the traction motor is transmitted to the wheels via gears.

(b) **Mechanical Braking System:** The basic braking devices used by mechanical braking systems are: wheel tread brakes, axle-mounted disc brakes, and wheel-mounted disc brakes. These brake mechanisms use a brake shoe that applies friction force to the disc. The applied pressure is adjusted to control the braking force. In wheel-tread brake, the brake shoe applies friction force to the wheel tread, creating a sliding effect. High-speed trains cannot use this type of brake, because doing so may damage the wheel tread. Therefore, they use axle- or wheel-mounted disc brakes. Axle-mounted disc brakes require sufficient space to accommodate therefore used in trailer bogies. Wheel-mounted disc brakes are used on motor bogies because it requires accommodating the traction motor only and having insufficient space for an axle-mounted brake. In both systems, compressed air or oil is applied to a brake cylinder that pushes the brake lining against the disc. Brake discs are dead weight that is useful only during braking, therefore operators can install lighter discs. Carbon/carbon-composite multi-discs and aluminium composite discs offer lighter weights and are widely used. The carbon/carbon-composite multi-disc has alternate sections of carbon-fiber rotors and stators. During braking, they rub against each other to create a frictional force that slows down the wheel or axle. The disc is lighter in weight than conventional materials and has good heat-resistant properties. Aluminium-composite brake discs may be made much lighter than today’s forged steel and cast-iron brake discs. Moreover their structure is common for both axle or wheel-mounted discs, achieving a much lighter disc without design.

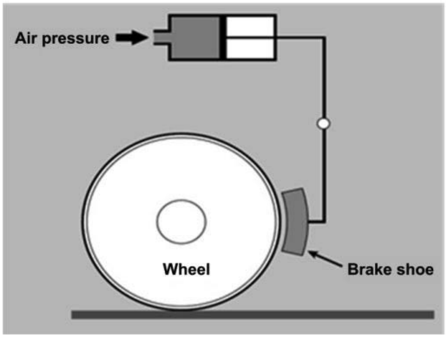


Fig. 1.25 Principle of wheel tread brakes

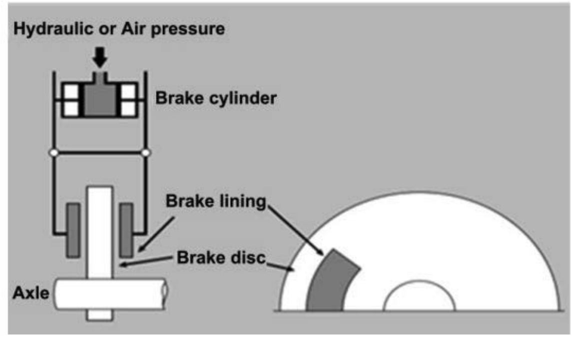


Fig. 1.26 Principle of axle-mounted disc brakes

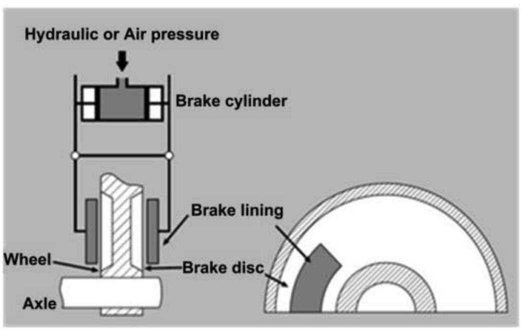


Fig. 1.27 Principle of wheel-mounted disc brakes

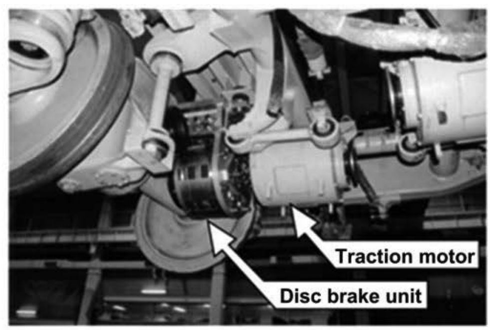


Fig. 1.28 Carbon/Carbon-composite multi-disc system

(c) **Electromagnetic Braking System:** Conventional train braking systems depend heavily on adhesion between the wheel tread and the rail. In the case high-speed trains, adhesion decreases as speeds increase, making it necessary for the train to reduce braking force to avoid wheel sliding. This result is longer braking distances. To overcome this problem, a electromagnetic brake system that does not depend on adhesion was developed. It produce a braking force by using magnetic repulsion obtained from eddy currents generated on the top surface of the rails. Earlier it was not used because of assumption that the eddy currents would heat small sections of the rail to such a degree that the rail would bend sideways. This is solved by development of a electromagnetic brake that uses eddy currents and frictional force. The electromagnetic brake on bogie is connected to batteries that create alternating north and south poles forming magnetic fields between the poles. The magnetic fields generate eddy currents in the top surface of the rails, creating a force acting in an opposite direction to the movement of the train, in other words, a braking force.

(d) Pneumatic Brake:

(i) Compressed Air Brake Systems

Automatic Air Brake System: An automatic air brake system is shown in Fig. Air compressors mounted every two to four coaches supply compressed air to the air brakes. The air, which is compressed to nearly 8 kg/sq.cm, is piped below coach floors to main air reservoirs. The air pressure is lowered to 5 kg/sq cm with pressure regulator and air is fed via the brake valve, brake pipes, and control valves to auxiliary air reservoirs. If the compressed air in the brake pipes and auxiliary air reservoirs of each coach is at 5 kg/sq cm, brakes are not activated. The activated brake valve cuts the flow of air from the pressure regulator and air pressure in the brake pipes falls. The fall in air pressure is detected by the control valves on each coach. The control valves then regulate the flow of compressed air from auxiliary air reservoirs to brake cylinders. The brake cylinders activate the basic braking mechanisms to slow down and stop the coach. The control valves regulate the flow of air from the auxiliary air reservoirs to the brake cylinders at a pressure that is proportional to pressure drop in the brake pipes.

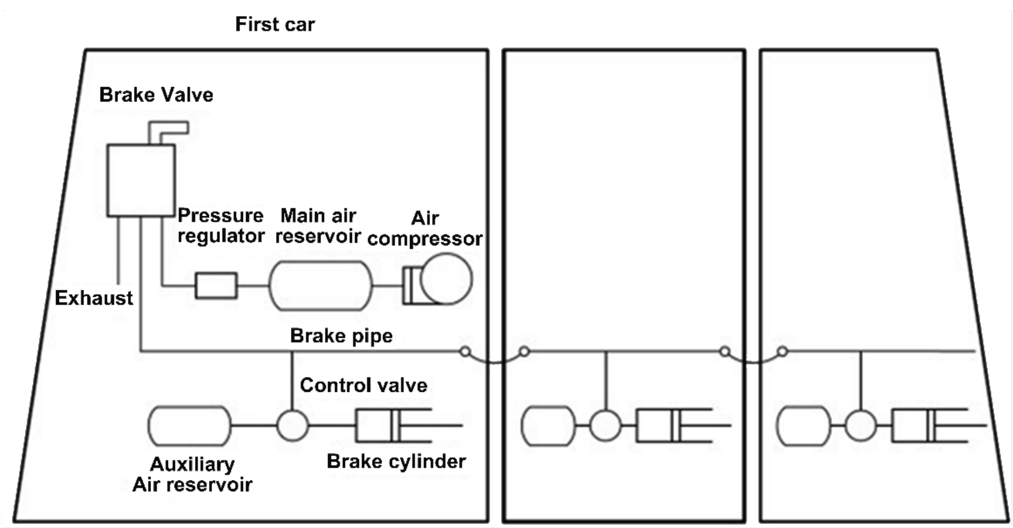


Fig. 1.29 Principle of automatic air brake system

(b) Straight Air Brake System: A straight air brake system is shown in Fig. 1.30. The straight air brake system does not have a control valve or auxiliary air reservoir in each coach as in automatic air brake system. Activation of brake valve forces compressed air from straight air pipe to brake cylinders, activating the basic braking mechanism. As the straight air pipes do not contain compressed air during normal running conditions, the brakes would fail if coaches became uncoupled. In order to avoid this, the straight air brake system may be used in conjunction with the automatic air brake system. It can also be avoided by using another pipe, called a main air reservoir pipe, from the first to the last coach. The air pressure in main air reservoir pipe acts like the compressed air in the brake pipes of the automatic air brake system. If compressed air in this main air reservoir pipe falls, or if it leaks from air pipes or from air hoses between coaches, etc., pressure drop is detected and brakes are applied automatically.

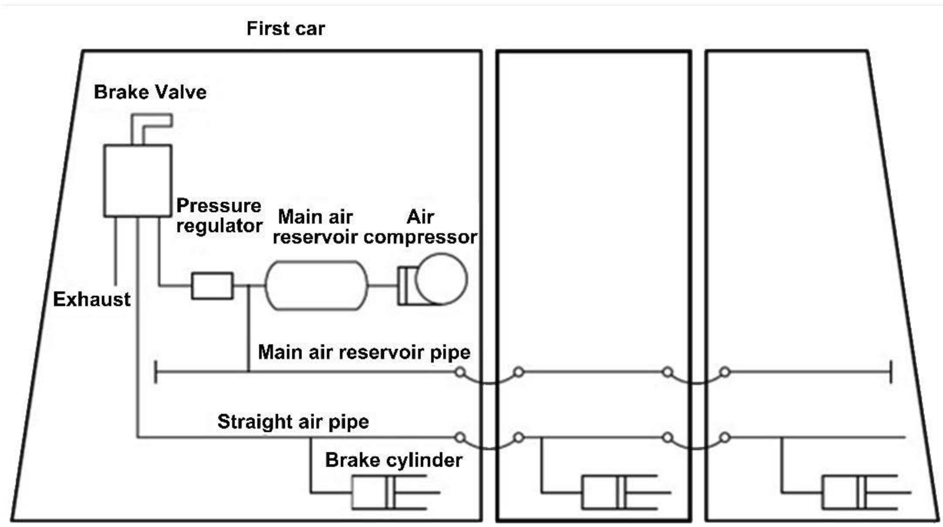


Fig. 1.30 Principle of straight air brake system

Air brake system may also be classified as follows:

Direct release air brake system

Graduated release air brake system

Direct release air brake system is most suitable for leveled track or constant gradient route. Due to this reason it is not suitable for Indian Railways. Graduated release air brake system is most suitable for Indian Railways. In graduated release air brake system the brake pressure is applied and released such that the magnitude of braking force is proportional to reduction in brake pipe pressure.

Graduated release air brake system can also be divided into two categories.

Single pipe graduated release air brake system

Twin pipe graduated release air brake system

(c) **Single Pipe Graduated Release Air Brake System:** Single Pipe Graduated Release Air Brake System is shown in Fig. 1.31. The operation is same as that of the twin pipe system except that the auxiliary reservoir is charged through the D.V. instead of feed pipe, since there is no feed pipe in single pipe system. As compared to single pipe graduated release air brake system, twin pipe graduated release air brake system is more suitable for passenger coaches.

(d) Twin Pipe Graduated Release Air Brake System: In twin pipe graduated release air brake system (Fig. 1.32), The Brake pipe is charged to 5 kg/cm^2 by the driver's brake valve. The auxiliary reservoir is charged by the feed pipe at 6 kg/cm^2 through check valve and choke. The brake cylinder is connected to the atmosphere through a hole in the D.V. when brakes are under fully released condition. To apply brakes, the driver moves automatic brake valve handle either insteps for a graduated application or in one stroke to the extreme position for emergency application. By this movement the brake pipe pressure is reduced and the pressure differenced is sensed by the D.V. against the reference pressure locked in the control reservoir. Air from the auxiliary reservoir enters the brake cylinder and the brakes are applied. At the time of release the air in the brake cylinder is vented progressively depending upon the increase in the brake pipe pressure. When the brake pipe pressure reaches 4.8kg/cm^2 the brake cylinder is completely exhausted and brakes are fully released.

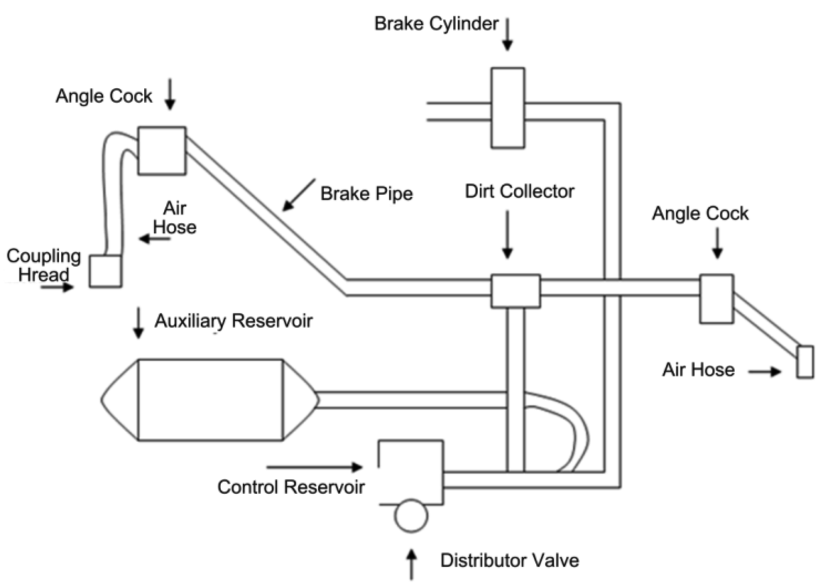


Fig. 1.31 Single pipe graduated release air brake system

II. Calculation of Train Stopping Distance

For trains to safely travel on a railway, trains must be provided with sufficient distance in which to stop. Allowing too long a distance reduces the capacity of the line and has an impact on rail infrastructure investment. Too short a distance and collisions would occur, because the train would not be able to stop with in the available distance and would therefore occupy a section of track that could be allocated to another train.

Consequently it is important that distance be adequate. Train braking distance is function of following factors

Train speed when the brakes are applied.

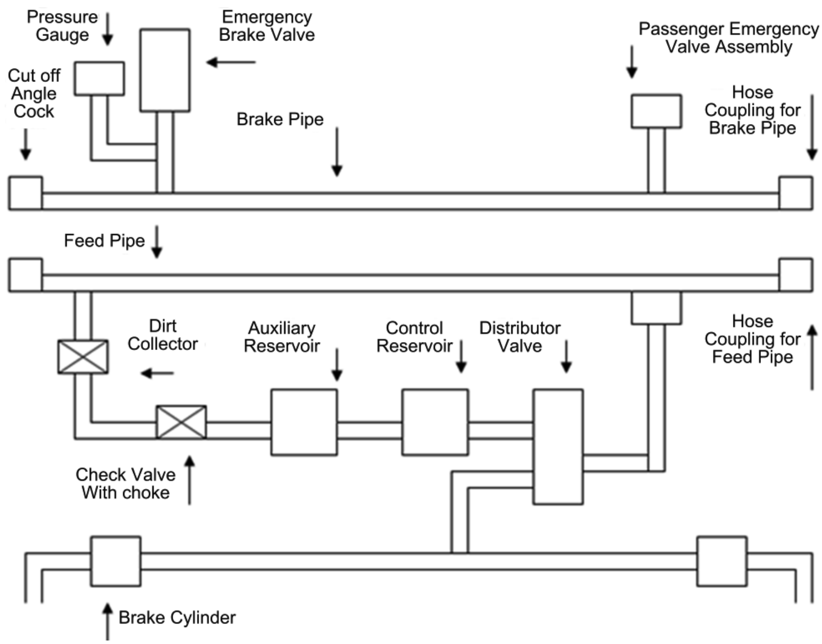


Fig. 1.32 Twin pipe graduated release air brake system

The available friction at wheel-rail surface which influences the retardation rate for complete brake application.

Time from when the brakes are applied by the train driver to when they are actually become effective i.e. brake delay time.

The magnitude of wear of brake pads and the pressure available in brake cylinders.

Track gradient when brakes are applied and mass distribution of track.

In order to stop the train it requires the work. The required work is the sum of change in the train's kinetic energy and the change in its potential energy due to change in the height due to the gradient of the track.

Mathematically it may be expressed as:

$$mas + \frac{mV^2}{2} + mg(h_2 - h_1) = 0 \qquad .....(1)$$

Where,

M = mass of train,

V = Speed at which the retardation begins

S = Stopping distance,

h_1 = Height at which the retardation begins,

h_2 = Height at which the train stops ($h_2 - h_1$)
a = Retardation provided by braking system,

The above equation suggests that mass has no direct effect on the train stopping distance. However mass distribution has influence on train stopping as train's centre of gravity varies with the mass distribution. In case off reight wagons where the mass varies from no load to full load the rear two levels of brake for ceused empty and loaded.This influences the design of the brake system. For calculating the braking distance calculations the lowest deceleration rate is used to calculate the deceleration rate for the complete train.

Eq. 1 may be written as

$$S = \frac{(-V^2)}{2(a - g \tan a)}, \text{for } a < 0 \qquad \ldots..(2)$$

α = Angle of slope, for small values of α, $\sin\alpha \approx \tan\alpha$

Assuming constant gradient track and considering brake delay time the stopping distance can be calculated using following expression.

$$S = \frac{(-V + bt_d)^2}{2(a + b)} - Vt_d - \frac{bt_d^2}{2} \qquad \ldots..(3)$$

b = Retardation provided by gravity; t_d = Brakedelaytime

1.19 Brake Interface Unit (BIU)

BIU shall apply normal, service & emergency brakes of locomotives respectively based on the type of brake command received from Loco KAVACH unit. In addition to these brakes, it shall also apply Loco brake, if Loco Brake command is generated by Loco KAVACH.

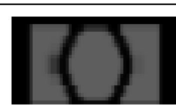
S.No.	Name of Brake	Symbol
1	Normal Brake	
2	Full Service Brake	
3	Emergency Brake	

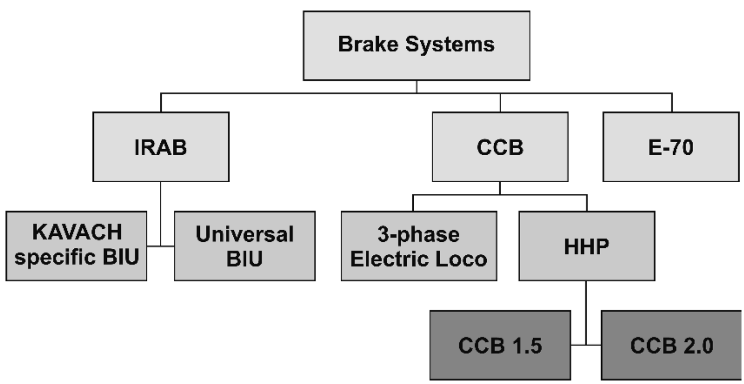
Fig. 1.20 NB, FSB & EB

1.19.1 BIU consists of Two Modules

1. **Electronic Module:** It consists of a Control Card having built-in air brake control logic. Control Card interfaces with Analog Input Module, Digital Input Module & Digital Output Module to monitor and control air brake application/ release.
2. **Pneumatic Panel:** It consists of different valves, pressure transducers and manual cocks-Interfaced with IRAB system & Electronic Module for brake control purpose.

1.19.2 BIU of Locomotives

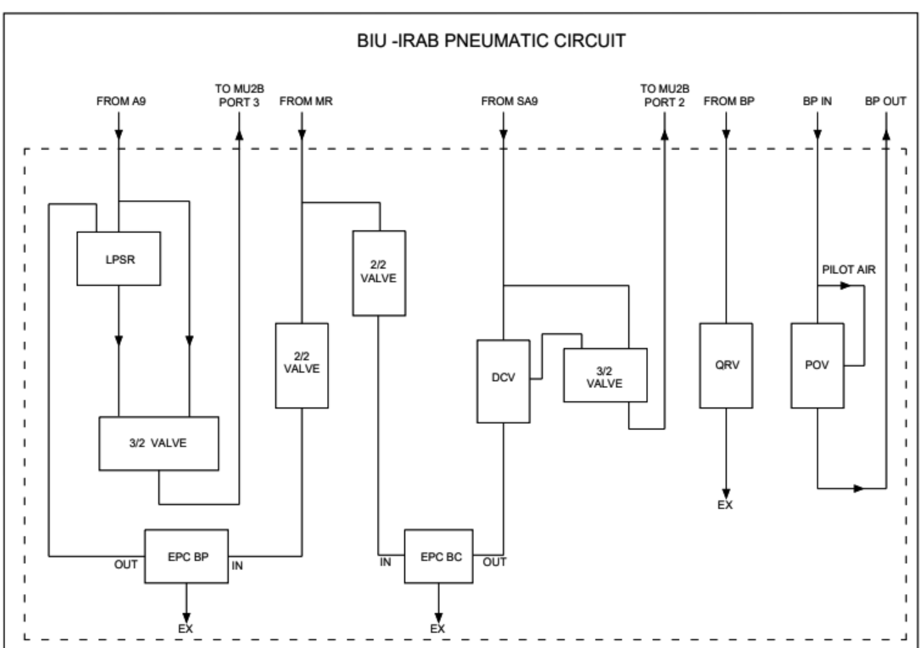
At present IR is using different types of Electric and Diesel Locomotives. In a broad way, three types of brake systems Viz. IRAB, CCB and E-70 brake systems are being used in these locomotives. Since the design of all these brake systems is different, the KAVACH-Specific BIUs are also different for each brake system. The classification of various BIUs specific to brake system is given below.



1.19.3 BIU for IRAB Brake System

1. To understand the working of Brake Interface Unit, the working of BIU for IRAB brake system is explained in this section.
2. In the locomotives to enable the application of brakes in the locomotive and formation, locomotive generates and maintains a pressure of around 10kgs/cm^2 in MR (Main reservoir) and this pressure is reduced by the pneumatic system and fed throughout the brake pipe (BP) and feed pipe (FP). The pressure in BP is maintained at 5.0 kg/cm^2 and FP is maintained at 6.0kg/cm^2. The purpose of FP is to enable quick release of brakes and hence there is no need to interface with KAVACH BIU. To apply the brake while working a train (Locomotive + Formation), Loco Pilot destroys pressure in brake pipe to the desired level and based on the reduction of pressure in Brake Pipe, brakes are applied in the train. The greater the reduction of Brake Pipe pressure, the stronger the application of brake i.e more Brake cylinder pressure . To ensure the complete release of brakes in the train, Loco Pilot again needs to maintain the B.P pressure at 5.0kg/cm^2 by keeping the handle in release position.

3. In IRAB brake system, there are two types of brakes provided for usage i.e. through A9 (train brake) and through SA9 (locomotive brake).
4. The A9 valve (Train Brake) is having four positions viz. Run/release, Initial, Full Service and Emergency. To create BP to 5.0kg/cm^2 loco pilot keeps the A9 handle in run position. This will ensure the complete release of brakes in the Train.
5. When Loco Pilot, places the A9 handle (of A9 valve) in Initial, Full service or Emergency position, BP reduces through the IRAB brake system to 4.5kg/cm^2 (0.5 kg/cm^2 reduction), 3.5kg/cm^2 (1.5 kg/cm^2 reduction) or 0kg/cm^2 (5.0 kg/cm^2 reduction) as the case may be to ensure application of brake in the formation. The mechanism of application of brake in the formation as a result of reduction in Brake pipe pressure is beyond the scope of present discussion. (This mechanism is part of IRAB brake system).
6. In addition to the above, during emergency position, the brake pipe pressure is vented to atmosphere by direct vent in the A9 vale to ensure quick reduction of brake pipe pressure so as to ensure fast application of brakes.
7. While working single locomotive i.e. as LE (light engine), the brake application in LE takes place through SA9 valve. This valve has two positions i.e. Release and Apply. In the release position, SA9 valve results in brake cylinder pressure of 0kg/cm^{2}and there is no application of brakes in the locomotive. When the SA9 handle is operated from Release to Apply (depending on the position of SA9 handle), the SA9 valve creates brake cylinder pressure upto 3.5kg/cm^2 which results in application of brake in the LE.



Working of IRAB Brake Interface Unit

Application of Train Brake through KAVACH BIU

From the above basics, if the KAVACH need to apply brake while working as Train (Locomotive + Formation), it has to perform the similar job of operating A9 handle to ensure application of Normal Brake/Full Service Brake(FSB)/Emergency Brake(EB) as the case may be.

The block diagram of BIU of IRAB brake system is shown above. For application of brake through A9 circuit, BIU of KAVACH is integrated into the A9 circuit of locomotive through LPSR(Low pressure Sensor), EPC-BP(Electric Pneumatic Controller for BP), 3/2 Valve and 2/2 valve. The EPC-BP, 3/2 Valve and 2/2 valve are electrically operated valves through KAVACH electronic module. Whenever the KAVACH system is working, it first operates 2/2 valve which is energized to open. The input for 2/2 valve is MR (Main Reservoir) pressure of locomotive which is maintained at 10kg/cm^2 and output is connected to EPC-BP. When the electrical supply cut off, then 2/2 valve isolates MR pressure from feeding EPC-BP. EPC-BP is a electrically controlled valve which will reduce the input pressure of MR to a desired level based on the electrical current given to controller. It takes current from 4-20mA and depending upon the extent of current out pressure will be created i.e. higher the input current higher will be the pressure output. When the current signal is withdrawn, it will exhaust the pressure in output pipe line through exhaust port (shown as Ex). The 3/2 valve is also an electrically operated valve which can route the two input i.e. one direct input from A9 (LP command) or output from LPSR to the output port. When electrical supply is given to 3/2 valve, the LPSR output pressure is routed to output or otherwise input from A9 is routed to output. During isolation of KAVACH, the 3/2 valve is de-energized and the LP commands are directly routed through its output and KAVACH brake commands through A9 are isolated.

During working of KAVACH, the 3/2 valve is energized such that the output of LPSR is given as input to the IRAB brake system. LPSR is a pneumatic valve which allows the lowest of the input pressures (Two different pressures) to its output port. 2/2 valve is also energized to provide input pressure to EPC-BP. When KAVACH is not intervening with brake system, the current signal to EPC is kept such that it always creates 5.5kg/cm^2. This will ensure that output of LSPR always corresponds to A9 valve output of LP (the maximum value of A9 is 5.0 kg/cm^2) since it is lowest as compared to output of EPC-BP and enables application of brakes by LP.

When KAVACH initiates braking, it provides appropriate current signal to EPC-BP such that it creates 4.5kg/cm^2, 3.5kg/cm^2 or 0kg/cm^2 as the case may be for Normal/FSB/Emergency brake application through KAVACH. In addition to the above, LPSR functionality also allows LP to apply any more restrictive brake than KAVACH as it always allows lowest of the pressures to its output.

In addition to the above, KAVACH while applying Emergency Brake, de-energizes QRV (Quick Release Valve) to vent out BP to atmosphere similar to the provision in

A9 handle. The normal condition of QRV is always energized except during emergency brake application through KAVACH.

Application of Loco Brake through KAVACH BIU

When KAVACH has to apply brake while working as LE (Light Engine), it has to perform the similar job of operating SA9 handle to ensure generation of brake cylinder pressure.

The block diagram of BIU of IRAB brake system is shown above. For application of brake through SA9 circuit, BIU of KAVACH is integrated into the SA9 circuit of locomotive through DCV(Double Check Valve), EPC-BC (Electric Pneumatic Controller for BC), 3/2 Valve and 2/2 valve. The EPC-BC, 3/2 Valve and 2/2 valve are electrically operated valves through KAVACH electronic module. Whenever the KAVACH system is working, it first operates 2/2 valve which is energized to open. The input for 2/2 valve is MR (Main Reservoir) pressure of locomotive which is maintained at 10kg/cm^2 and output is connected to EPC-BC. When the electrical supply cut off, then 2/2 valve isolates MR pressure from feeding EPC-BC. EPC-BC is an electrically controlled valve which will reduce the input pressure of MR to a desired level based on the electrical current given to controller. It takes current from 4-20mA and depending upon the extent of current, out pressure will be created i.e. higher the input current higher will be the pressure output. When the current signal is withdrawn, it will exhaust the pressure in output pipe line through exhaust port (shown as Ex). The 3/2 valve is also an electrically operated valve which can route the two input i.e. one direct input from SA9 (LP command) or output from DCV (Double Check Valve) to the output port. When it is electrical supply is given to 3/2 valve, the DCV output pressure is routed to output or otherwise input from SA9 is routed to output. During isolation of KAVACH, the 3/2 valve is de-energized and the LP commands are directly routed through its output and KAVACH brake command through SA9 circuit are isolated.

When KAVACH initiates, FSB/EB through SA9 circuit it creates EPC output pressure of 2.5kg/cm^2 or 3.5kg/cm^2 as the case may be routed through DCV (Double check valve) for application of brake through SA9. The double check valve output is always maximum of the two input pressures connected to it. In case LP applies higher brake through SA9 than KAVACH, then such higher pressure will be routed into SA9 circuit as output of Double Check Valve is maximum of two input pressures connected to it.

In this way, KAVACH Interfaces its brake commands through BIU.

1.20 Working of BIU

KAVACH identifies the braking requirement.

KAVACH communicates braking signal(s) to BIU.

BIU communicates signals to existing brake system of locomotive

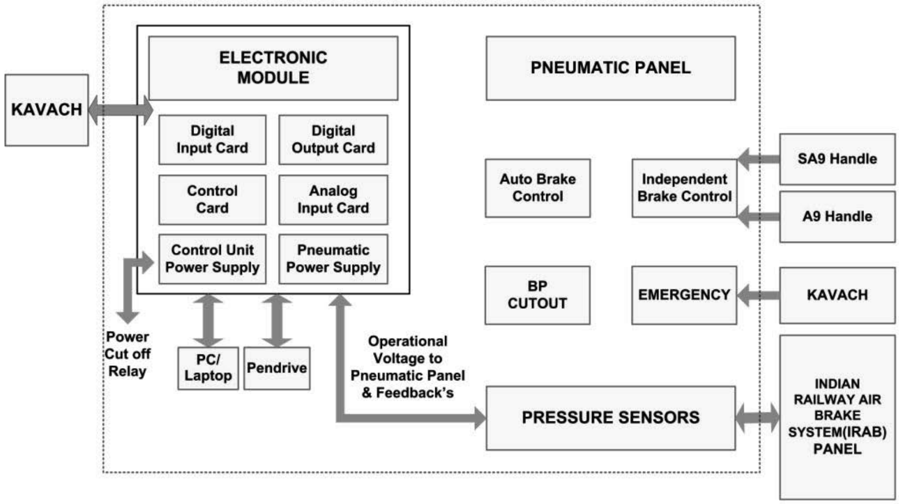


Fig.1.21 Loco Brake Interface

1.21 Block Diagram of Brake Interface Unit

BIU communicates signal for cutting off traction of locomotive.

BIU generates audio-visual indication for Loco Pilot.

BIU gives status of execution of braking command to KAVACH.

1. **Features of BIU:** BIU works parallel to Locomotive Brake System.

   Does not affect brake characteristics of locomotive/train.

   Can override the Loco Pilot Braking and Vice-Versa - Higher braking prevails.

   BIU initiated braking cannot be reduced by Loco Pilot.

   Manual and automatic isolation possible.

2. **Health Monitoring by BIU:** Periodical monitoring of pressures at short interval - Confirms required pressures are maintained.

   If feedback is not correctly received - Automatic Emergency Brake

   Analyzes brake application commands for correct execution – Brake Pressure (BP) drop or build up.

   Heart-beat monitoring of pneumatic valves- voltage and current once every 200ms - Any failure, message alert to LP through KAVACH display and automatic Emergency Brake.

   Power supply 'ON' health monitoring - Alert to LP through KAVACH display.

   Fail safety.

   Loss of electric power leads to Automatic Emergency Brake.

   Loss of communication between Loco KAVACH unit and BIU results in Automatic Emergency Brake.

   For any brake application Traction power is cut-off.

3. **Braking Logic:** The onboard equipment shall have provision for acquiring the braking characteristics through DMI as per the selections made by Loco Pilot at the start of mission or whenever there is change in train consist.

   The brake characteristics shall be such that in the event of perceived danger, the loco unit shall be able to stop train short of safe distance or control the speed to desired value before target. This distance should be possible to be configured during installation with nominal values as 300m for Rear end Collision prevention, stop immediately on detection of Head-on Collision prevention and short of Signal at Danger in case of SPAD prevention.

   By pressing Manual Brake Test (MBT) button by the Loco Pilot in stationary condition of the train, working of all brake valves of Brake Interface Unit (BIU) can be tested.

   The braking logic of the Loco unit shall be so intelligent that based on the (i) brake characteristics of the train, (ii) speed of the train and (iii) gradient of the location & the target, Loco unit shall decide which type(s) of brake and when to be applied to stop the train short of safe distance or control the speed to desired value before target without frequent repeated braking.

   Design of the Loco unit equipment shall be such that its brake interface unit can be isolated by the Loco Pilot as and when required.

   The isolation of brake interface shall be communicated to the Network Monitoring System (NMS) through GPRS/LTE-R.

   Traction cut off feature through KAVACH shall also be isolated under such events.

1.22 Connectivity of Stationary KAVACH Unit with Interlocking

Stationary KAVACH unit shall be capable of taking potential free inputs from interlocking through double cutting arrangement. It shall be capable of taking minimum 256 inputs. (The maximum number of field inputs are 2048). There shall be provision for expansion by providing additional Input cards or Multiple Field Input Units (FIUs). Each Vital Input Card/ FIU can accommodate 256 inputs. Based on the Field inputs required to be connected with each stationary KAVACH units. The requisite number of Vital Input cards/ FIUs shall be procured for each stationary KAVACH.

The break status of potential free contact shall indicate absence of input.

Signal aspect status, position of points, berthing track circuit status, status of track circuits nominated for computing train length and status of block instrument Line Closed condition shall be interfaced to Stationary KAVACH. IBS & Gate unit shall not require inputs for point position, track circuits nominated for computing train length & berthing track circuit status. Gate unit shall not require input for status of block instrument Line Closed condition

1.23 Fall Back Procedures

(a) Radio communication failures:A radio communication failure shall be deemed to have occurred when 30 seconds for Absolute Block Section and 10 seconds for Automatic Block Section have passed since the last packet received from Stationary KAVACH in communication mandatory zone.

If the last packet received from Stationary KAVACH unit is more than 6 seconds older, the signal aspect and signal description shall be made blank. However, the Loco KAVACH shall continue to function in Full Supervision mode and shall supervise the Movement Authority received in latest packet.

In the event of a Radio Communication failure longer than applicable time-out, the Loco KAVACH unit shall transit from Full Supervision mode to Limited Supervision Mode and if Loco Pilot does not acknowledge within stipulated time Loco KAVACH unit shall apply service brake. In addition, it shall send the message to Network Monitoring System (NMS) through GPRS/LTE-R.

Stationary KAVACH unit shall send the Fault message to NMS through Ethernet/ GPRS/LTE-R interface.

In the event of a failure of only one radio when other radio is providing radio communication in hot standby, the Loco KAVACH unit should log the fault. Loco KAVACH Unit shall also send the message to NMS through GPRS/LTE-R. Stationary KAVACH unit shall send the Fault message to NMS.

(b) RFID Reader failures: If both RFID readers fail, Loco KAVACH unit should stop radio communication and shall switch to System Failure mode. It shall send the message to Network Monitoring System (NMS) through GPRS/LTE-R.

In the event of any one RFID reader failure, Loco KAVACH unit should log the event. In addition, it shall send the message to NMS through GPRS/LTE-R.

(c) GPS/GNSS failure: Station/LC/IBS Vital Computer shall have Real Time Clock (RTC) synchronization facility with GPS/ GNSS clock to synchronize with other KAVACH systems in hot standby manner

Incremental difference between the CPU time and GPS time is to be cross checked. If the incremental difference between CPU and GPS time is not matching, the time reference shall change to other GPS. If the difference between two GPS is greater than the frame interval, message shall be sent to Network Monitoting System (NMS).

Diverse make of GPS are preferable to avoid common cause failures.

In the event of failure of both – GPS/GNSS and Real Time Clock (RTC), the Loco KAVACH unit shall stop radio communication and shall switch to System Failure mode. In addition, it shall send the message to NMS through GPRS/ LTE-R.

If the incremental difference is also not matching with second GPS or both systems are failed, then the system shall work on CPU time for 30 minutes, (default, Min: 10, Max: 60) until the situation is stabilized. If there is no stability after GPS time-out, the Loco shall transit out of Full Supervision Mode.

In the event of failure of both – GPS/ GNSS and RTC, Stationary KAVACH unit should stop radio communication and shall switch to System Failure mode. Fault message shall be communicated to NMS through Ethernet interface. In addition, it shall send the message to NMS either through Ethernet or GPRS/LTE-R.

(d) **Driver Machine Interface (DMI) communication failures:** In the event of Active Cab/ Desk DMI communication failure, Loco KAVACH unit shall switch to System failure mode. In addition, it shall send the message to Network Monitoring System (NMS) through GPRS/LTE-R.

In the event of Non-Active Cab/ Desk DMI communication failure, Loco KAVACH unit shall log the fault. In addition, it shall send the message to NMS through GPRS/LTE-R.

1.24 Protection Functions

(a) **Prevention of Signal Passing at Danger (SPAD):** Stationary KAVACH unit shall calculate the movement authority based on the signal Aspect or/and track circuit status, point position and the status of the berthing track circuit.

In case of any conflict between signal aspect, point position, berthing track section, signal aspect sequence and TIN, the Stationary KAVACH unit shall transmit most restrictive aspect of that signal and shall reduce the movement authority accordingly.

Stationary KAVACH unit shall check route information configured on the basis of the KAVACH Control Table of the stationary KAVACH Unit (excluding overlaps).

The off aspect and movement authority for LSS shall be transmitted by Station/ IBS unit only when LSS is off and it is ensured that the concerned Line Clear is available.

(b) **Unusual Stoppage in Block Section:** In case of unusual stopping of train in the block section, if Movement Authority is greater than 300m (configurable), Loco KAVACH unit shall transmit the 'Side Collision' message, after a delay of 15 seconds (configurable) of stoppage of the train unless acknowledged by the Loco Pilot.

(c) **Protection of Roll Back:** Loco KAVACH unit shall be capable of detecting Roll Back of the train through train interface. It shall apply brake and give audio/ visual warning if train has rolled back by more than 5 meters (configurable). KAVACH needs Direction sensing type speed sensor.

(d) **Prevention of Head on & Rear end Collisions in Block Section:** Loco KAVACH units either directly or through Stationary KAVACH unit, shall be capable of detecting head on collisions, rear end collisions of trains/locos on single line, multiple lines in all possible scenarios based on the track identification, speed of the trains, train location, train length, train direction movement (Nominal/ Reverse) etc.

In case of head on collision situation, Loco KAVACH units of both the trains shall automatically apply brakes immediately with warning either in Absolute or in Automatic Block Section.

In case of rear end collision situation, Loco unit of only rear train shall automatically apply brakes to bring it to stop short of stipulated distance (300m in block section, configurable) from the train ahead.

In Station sections, Stationary KAVACH shall prevent train collisions with the help of SPAD and TIN conflict.

In case two trains are detected by Stationary KAVACH to be moving towards each other on same TIN in adjacent block section, the SoS command would be generated by Stationary KAVACH for both the trains. On reception of such Loco specific SoS from Stationary KAVACH Unit, the Trains would be stopped through automatic application of brakes.

In case of Multiple locos, the rear end collision message shall be displayed with the details of approaching loco/train only

(e) **Manual SoS generation/ Cancellation:** Loco as well as Stationary KAVACH unit shall have provision of sending SoS message by pressing SoS and Common buttons together.

Loco as well as Stationary KAVACH unit shall have provision to cancel the Manual SoS message by pressing 'Common' and 'ACK/Cancel' buttons together.

When the SoS and Common buttons are pressed simultaneously in Loco or Stationary KAVACH units, the Loco KAVACH units of all the trains/ Locos within 3000m of Location of SoS originating source as well as self-train (if SoS is generated by Loco unit) and approaching towards Location of SoS originating source, shall apply brakes to bring the train/locomotive to standstill before reaching the originating Location of "SoS" message. After the train speed is reduced to zero kmph, train speed shall be supervised for 30kmph (configurable) till the train passes the originating Location of "SoS" message.

SoS sending as well as receiving KAVACH equipment shall log sending & receiving of SoS message. In addition, the information shall be sent to Network Monitoring System by Loco KAVACH through GPRS/LTE-R and StationaryKAVACH units either through Ethernet or GPRS/LTE-R.

(f) **Train trip:** When a Train in Full Supervision or Limited Supervision Mode passes a stop signal at ON or End of Authority + 30m, the emergency brake shall be triggered.

Operation of the train trip shall be indicated on the DMI.

The emergency brake shall be applied until the Train comes to halt.

When the Train is stationary, the loco pilot shall be required to acknowledge the train trip condition. This acknowledgement will release the emergency brake.

(g) **Auto whistling on approach of Level Crossing Gate:** Auto whistling feature on approach of level crossing gate is optional.

Loco KAVACH unit shall display the level crossing gate information (Gate ID) on DMI, when approach of LC Gate is detected through LC Gate Tags.

Loco KAVACH unit shall blow the Loco horn at LC gate, based on the information received from LC gate tag/ SSP

Loco KAVACH unit shall not blow the horn for LC gate, if movement authority is less than the LC gate distance from its current position.

Continuous whistling shall commence from a distance of 600m on approach of a LC Gate till the time that train reaches LC Gate. Whistling pattern shall be configurable.

1.25 Protection during Transient Conditions

(i) **Radio Communication failure:** If the communication timeout is longer than 6 seconds, the signal aspect and signal description shall be made blank. However, the Loco KAVACH shall continue to function in Full Supervision mode and shall supervise the Movement Authority received in latest packet.

If Radio Communication failure is longer than 30 seconds, the Loco KAVACH unit shall transit from Full Supervision mode to Limited Supervision mode and shall seek acknowledgement from Loco Pilot. If Loco Pilot does not acknowledge within stipulated time of 15 seconds (Configurable), Loco KAVACH unit shall apply service brake. In addition, it shall send the message to Network Monitoring System through GPRS/LTE-R. Stationary KAVACH unit shall send the Fault message to Network Monitoting System through Ethernet/ GPRS/LTE-R interface.

In the event of a failure of only one radio when other radio is providing radio communication in hot standby, the Loco KAVACH unit should log the fault. Loco KAVACH Unit shall also send the message to Network Monitoting System through GPRS/LTE-R. Stationary KAVACH unit shall send the Fault message to Network Monitoting System.

(ii) **Signal goes to danger on approach:** When a stop signal on approach is thrown back to danger, and the train in Full Supervision or Limited Supervision Mode passes the stop signal at ON or End of Authority + 30m, the emergency brake shall be applied until the Train comes to halt.

Operation of the train trip shall be indicated on the DMI.

When the Train is stationary, the loco pilot shall be required to acknowledge the train trip condition. This acknowledgement will release the emergency brake.

After the acknowledgement, the loco pilot shall be able to continue the movement in Post- Trip Mode.

Loco KAVACH unit shall supervise the train against a ceiling speed of Post Trip Mode (Default: 15 kmph) and shall exit the Post Trip Mode after crossing the next approaching signal at OFF.

(iii) **Signal, point or track circuit, failure:** As mentioned earlier, Stationary KAVACH unit is interfaced with station interlocking and calculates the movement authority based on the signal aspect or/and berthing track circuit status or/and route locking status or/and point position. Hence in case of any abrupt failure of signal aspect, point position or berthing track in the face of an approaching train, the movement authority is reduced accordingly and an automatic application of brakes is initiated.