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PO Box 141

Bradford, PA 16701

(814) 362-6811

TRAIN CHIEF REMOTE CONTROL SYSTEM
THEORY OF OPERATION

Report Number 00128
Revision: Rev. A
Date: March 5, 1999

Written By: Rob Reese
Approved By:

Revision History

Revision	Release Date	Comments
A	5-MAR-99	Initial Release for FCC submittal (rlr).

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1 Introduction

The objective of this document is to discuss the Theory of Operation of the Train Chief Terminal and the Locomotive Controller. For reference please refer to the diagrams listed.

1.1 *General System Description*

The Train Chief Remote control system provides wireless remote control of Short Line Locomotives. The operator Transmitter is specifically designed for this type of application because of its ergonomic and rugged design. Therefore, it is well suited to railroad yard demands for ruggedness with reliability with ease of operation. The objective of the Train Chief Remote Control System is to bring the locomotive control panel to the operator. This is achieved with the ergonomic design of the operator transmitter and the programmed controller on the locomotive. These components work together to provide a wireless remote control link that allows the operator freedom to move around the locomotive while under his control.

1.2 *Wireless Media*

The media used to facilitate the wireless connectivity between Operator with Remote and the Controller on the Locomotive is radio in the UHF band, specifically, 450 MHz to 470 MHz. Within this band the FCC has allocated several channels for Railroad telemetry applications. Please refer to the appendix for further details.

2 Operator Transmitter

The function of the Remote Transmitter is to provide an ergonomic device fitted tot he operator and configured for the type of application, i.e. Grain Elevators, steel mill yards, etc. The operator follows a startup procedure to place the system in remote mode of operation. The transmitter then scans switches and control levers creats a command data packet sets up the radio module then transmitts the data via the UHF Radio Module to its assigned locomotive controller receiver.

The transmitter consists of several subassemblies; Front Panel Module, Toggle Switch Module, Operator Display Module, and Base Unit.

The operator Transmitter scans the control switches and levers, checks switch position and acts appropriately then formats the switch data into a communication command packet for transmission to the programmed controller. Once the packet is ready for transmission the appropriate radio modules control algorithms are activated to complete the actual transmission of the packet by the radio module.

and transmits the control data to the programmed controller on the locomotive. The programmed controller receives the incoming data packet decodes it checks its integrity and acts on the data as required per the operational requirements of the application.

2.1 *Power Source*

The power source for this unit is provided by a re-chargeable 12V NiCad battery pack. A pre-regulator consisting of DC-to-DC Converter conditions the battery pack voltage to 7.2 Volts. This is the nominal operating for the Radio Module.

2.2 *Font Panel Module with Electronic Stack*

The Electronic Stack Module consists of the Logic Module, Communication Interface Module, Radio Module, Front Panel Mounting Plate, and the Antenna. All modules are mounted and antenna is mounted on the Front Panel Mounting Plate and facilitates easy installation in the main unit.

2.2.1 Logic Card

The logic card performs several functions. It contains the CPU with the application program to read the switch data, configure the data into the appropriate format for transmission over the air. The logic module controls the switch interface and control lever modules and the communication module.

2.2.2 Communication Interface Card with Radio Module

The Communication Interface Card provides the appropriate signal-conditioning interface between the Radio Module and the Logic Module. The board has provisions for a microcontroller. This microcontroller will be utilized for additional diagnostics and power level control. The power level control will enable the low power selection to extend battery life when the operator is within sufficient range.

2.2.3 Transmitter Antenna Configurations – Standard and Optional.

2.2.3.1 Standard – ¼ Wave Whip Antenna

The standard antenna for the transmitter is a ¼ wave rubber duck antenna mounted on the front panel.

2.2.3.2 Optional – ¼ Wave Patch Antenna

An optional antenna configuration is a Planar Antenna or Patch antenna. This antenna provides a rugged and out-of-the way option for the operator. Additionally, the Patch antenna out performs the Whip because the Patch is "matched" to the unit. Therefore, the Patch yields better efficiency then the Whip providing the best Bit Error Rate.

2.3 *Toggle Switch Panel Module*

The Switch Interface Card acts as the Switch Coordinator for the unit. All operator control switches and levers are routed through this card. Toggle switches with PCB pin terminals plug directly into the card via on-board pin sockets. The board provides provisions for five toggle switch locations. These toggles switches plug directly into the switch matrix. The switch matrix consists of seven scan lines and 4-read lines. This results in a maximum switch processing capability of 28 switches. However, in this application a maximum of 18 switches can be utilized in one configuration.

2.4 *Control Lever Switch Module*

The Control Lever Switch module includes a 32-position rotary switch with spring-return-to-center. The switch provides actual 16 positions with double redundancy. From the center-spring-return position is an idle position. At center when the operator moves the switch forward the first position is a brake release or coast function then next 8 forward positions are throttle advance steps.

The PCB on the mechanical rotary switch is the electronic interface between the rotary switch and the logic module. The PCB conditions the contact closures then formats the switch position into the appropriate format for the SPI interface.

2.5 LED Display Module

The LED Display module provides the user with Transmitter operating status and battery condition. The four LED's indicate transmitter status as listed in the Owner's manual. The four LED are mounted directly on the PCB. Each LED is driven with a P-channel FET. The LED control signals come from the Switch Interface card. The Tilt sensor is mounted on this card and connected directly to the J2 for routing to the Switch interface card. The Panel Meter used to display battery voltage is plugged directly into the PCB pin sockets. This eliminates discrete wiring thereby improving assembly efficiently and system reliability.

3 CONTROLLER

3.1 Locomotive Antenna System

The locomotive antenna system consists of an antenna cable (91-03-0-018) from electronics cabinet to the locomotive cab roof. At the bulkhead connector mounted in the cab roof or on a bracket a ½ wave whip antenna is mounted.

3.2 Communications Card

The Communications Card contains the Radio Module and Communication Interface Card and support circuitry. Additionally, LED indicators provide diagnostic aid and status.

3.2.1 Communications Interface Card with Radio Module

This is the same configuration as the transmitter. Control signals from the Processor card setup the configuration for receive only mode. The recovered analog data is conditioned by a data slicer on the Communications Interface Card to provide the data stream in a TTL format to the Processor Card.

3.3 Processor Card

The Processor Card provides the main control functions for the Controller. The Microprocessor contains the application code to control and monitor relays, update the status indicators, read on board DIP switches to determine system configuration. Additionally, the MCU controls the Radio Module and receives serial data packets from the Radio Module. These data packets contain the command data from the Operator remote which the MCU by the application code controls the appropriate relay(s).

4 Data Communications

4.1 *Introduction*

This section will define the Data Communications Protocol used to facilitate the wireless connection between the Transmitter and Controller. The primary objective of the Data Communication Protocol is operator safety. This is achieved through the implementation of data link controls in each command data packet which include a unique address, Parity bits for error detection, and appropriate packet rates for man-machine responsiveness.

The discussion will present the Data Communication Protocol in the following layers; Physical Layer consisting of the RF Channel and Radio Module, Data Link Control Layer is responsible for "packetizing" and retrieving the Command data for the transmitter and controller respectively.

4.2 *Physical Layer:*

4.2.1 Medium – Radio Frequency UHF Band

The system uses as its medium of wireless connection the Radio UHF Band, specifically 450 to 470 MHz. This particular band is utilized primarily because the FCC has allocated this portion for Industrial applications of which this system is an appropriate candidate. Additionally, since this system has a specific application in Locomotive Railroad the FCC has allocated 12 frequencies for usage by radio frequency equipment for remote control and telemetry. These frequencies are listed in the Appendix. The FCC Coordinator assigns these frequencies for licensed users.

Another advantage of the 450 MHz UHF Band is it is out of the band of typical industrial noise, and therefore, provides a good communication channel.

4.2.2 Radio Module:

The radio module used in the Train Chief wireless data link is the Wood & Douglas UHF Synthesized Transceiver SX450C. The transceiver provides a maximum power output of 500mW and is designed to meet European standards ETS 300 220, ETS300 086 and ETS300 339.
The SX450 is controlled by a small microcontroller (PIC) which interfaces between the user and the transceiver. A parallel or serial interface is provided for the user to select the operating frequency. For the Train Chief application the frequency channel is selected via the serial mode and thereby provides additional security preventing the user from changing to an unauthorized frequency channel. Further details on the SX450 Radio Module are provided in the appendix.

4.2.3 Radio Module Control Signals

The control signals for the Radio Module are shown in Figure 3 of this document. The top timing diagram shows the control signals utilized by the Transmitter with the lower diagram showing those signals used by the Receiver at the Locomotive.

4.2.4 Communication Data Protocol

The Communication Protocol will define the Transmission Mode, Control Procedure, and Recovery Procedure.

The radio module will accept serial TTL data directly at its DMOD pin at a specified frequency response of 9Hz to 3KHz. The communication interface card provides the buffering between Radio Module and Logic module. The data to be transmitted originates at the Logic Module. The control signals are shown in figure 3. The table below lists the parameters of the Physical Layer.

Table 1 Physical Layer Characteristics

Characteristic	Description
Transmission Type	Asynchronous
Transmission Mode	Digital – FSK (Frequency Shift Keying)
Channel Spacing	12.5KHz
Data Rate	2400 bps
Data Stream Format	Asynchronous serial NRZ-C (1-Start, 8-Data, 2-Stop)
Acquisition	Data stream processing qualified by Squelch Input. Preamble provides stabilization time and Start of Packet indicator.
Preamble	Provides stabilization at the receiver analog audio data.
Synch	A unique bit sequence to qualify the start of the packet.

4.2.5 Spectrum Efficiency

Regarding the "Bandwidth Efficiency Requirement" of the CFR 47, paragraph 90.209. The data rate specified above of 2400 bps is the typical data rate to be utilized in the majority of applications for this product. If an application were to require a higher data rate the deviation would be adjusted accordingly to maintain the occupied bandwidth as specified in the paragraph 90.209. For example, if the data rate were to increase to 9600 bps the deviation would be reduced from 1.2KHz to 800Hz. This adjustment would be accomplished per the Radio module's manufacturer's test procedure, SX450 OVERALL TEST PROCEDURE.

4.3 Data Link Control Layer

4.3.1 Introduction

The Data Link Control layer defines the control mechanisms and Packet structures used at the link layer. This will include Packet rates and operational modes, addressing and packet error detection methods, and packet control mechanisms. Please refer to Figure 2 Train Chief Command Packet Structure v3.2.

4.3.2 Packet Frames for Active and Maintain Modes

To achieve maximum battery life for the Transmitter, "Transmit On" time must be kept to a minimum. One way to reduce transmit on time is to reduce transmit data packet length. However, the application may have particular information and parity requirements to insure reliable control. Thus, packet length or size is not always the "end-all" method to reduce transmitter on time. Another method is to very the packet duty cycle or Transmit Duty Cycle by changing the packet frame rate based on the operator's mode of operation. In a typical control scenario the operator will use basically two modes of operation. The primary operation mode, active mode, is used for machine positioning. This mode will require a packet frame rate with sufficient response to provide machine control responsiveness. The secondary mode, travel or maintain, is for machine re-location. To activate this mode the transmitter must determine the operator is in a constant operational condition as in re-locating the machine or moving a load. Once in the Maintain mode the frame rate is reduced to provide sufficient command data refresh to the controller. The controller requires the refresh data packet from the transmitter to validate the present relay output configuration. Since frame rates determine when the controller will shutdown functions or mainline (safety) outputs it must have a signal to indicate the rate is going to change to accommodate the transmitter operational mode by adjusting the appropriate timeout values. The "Packet Repetition Rate Mode" bit in the Packet Function register of the Command Packet facilitates this signal indicator to the controller. When packet refresh rates have not reset mainline and function relay timeouts the controller will command functional relay outputs and maintain the mainline relay output.

4.3.3 Active Mode – Primary Operational Mode (DEFAULT) PRRM = 0.

This is the primary communication mode for operator machine control. The frame period is established per application to provide sufficient operator machine control response while achieving maximum battery life.

Tpd = Packet Duration
Taf = Active Frame (TRAIN CHIEF Taf = 200mSec)

4.3.4 Maintain Mode – Secondary Mode PRRM = 1

The transmitter switches to Maintain mode when the operator has held the control switches in the same position for 6-seconds. The transmitter has determined command data is constant and has switched to maintain mode, indicated by PRRM = 1.

Once the controller is in the Maintain Mode it will maintain relay outputs as long as it receives a VALID command packet in the expected maintain frame period. If a VALID packet is NOT received, relay functions will be commanded off while maintaining the Main-Line relay (E-Stop or Address).

When the transmitter detects a change in operator switch position the transmitter will immediately switch to active mode and clear the PRRM bit (PRRM=0). Upon reception of the new command data the controller will act on the new data and switch frame rate modes and timeouts.

Tmf = Maintain Frame (TRAIN CHIEF Tmf=3.0-Sec)
Tmabf = Maintain mode Active Burst frame (Four Active Mode packets)
Tmid = Maintain Idle Duration

As shown in Figure 2 the Maintain Mode Frame consists of a Burst of four command packets at the active frame rate. This technique provides command data packet redundancy to insure the command data gets through the RF channel to provide the command refresh at the controller to maintain relay conditions.

By extending the frame rate in maintain mode, effective transmitter "on Time" is greatly reduced, thereby, improving transmitter battery life while providing reliable operator machine control.

4.3.5 Data Link Security, Control, and Status

The direction of the communication link is at this time is simplex - transmitter to controller. This is a Point-to-Point link with each command packet secured by an 8-bit address and CRC-16 parity check.

4.3.5.1 Packet Addressing

The Start-Of-Header byte also acts as an Address byte to secure the command data packet for the intended destination.

Start-Of-Header(SOH)/Address

7	6	5	4	3	2	1	0
ADDR.7	ADDR.6	ADDR.5	ADDR.4	ADDR.3	ADDR.2	ADDR.1	ADDR.0

Bits 0..3: ADDR0-ADDR3: Represents a 4-bit binary address providing 16 different application address.

Bits 4..7: ADDR4-ADDR7: Complement of ADDR0-ADDR3 and provides a "header" check to determine the start of packet.

4.3.5.2 Packet Parity for Data Integrity

To insure command data integrity a CRC-16 parity check is computed on each byte within the packet.

PARITY (CRC-HI)

7	6	5	4	3	2	1	0
CRC.7	CRC.6	CRC.5	CRC.4	CRC.3	CRC.2	CRC.1	CRC.0

Bits 0..7: CRC-16 computation result, high byte

PARITY (CRC-LO)

7	6	5	4	3	2	1	0
CRC.7	CRC.6	CRC.5	CRC.4	CRC.3	CRC.2	CRC.1	CRC.0

Bits 0..7: CRC-16 computation result, low byte

4.3.6 Packet Control Mechanisms

Packet Definition (type)

7	6	5	4	3	2	1	0
PF1	PF0	AB1	AB0	LB3	LB2	LB1	LB0

Bits 0..3: **LB0-LB3**: Lever byte length.

Bits 4..5: **AB0-AB1**: AUX byte length.

Bits 7..6: **PF0-PF1**: Packet Format Bits

Bit 7	Bit 6	
0	0	Train Chief Packet Format
0	1	TBD (Mod Hand Held)
1	0	TBD (Belly Box)
1	1	TBD (Wide Band)

PACKET FUNCTION (control)

7	6	5	4	3	2	1	0
PRRM	0	0	REQ	CNTR.3	CNTR.2	CNTR.1	CNTR.0

Bits 0..3: CNTR = Packet Sequence Counter.
Transmitter increments counter after each packet is sent to enable the controller to determine if packets have been missed. The objective of this function is to develop link performance statistics for future applications. One possible application is to establish a threshold when to switch packet rate modes in a two-way link. If the channel has interference it may improve the link reliability by increasing the packet rate.

Bit 4: REQ = Request for Data from Down – Link.
REQ = 0, no request.
REQ = 1, transmitter data Request to controller.
This bit signals the controller to send the appropriate data (i.e. weigh scale data, system status, etc.) via the down-link.

Bits 5..6: not used, read/write as zero.

Bit 7: PRRM = Packet Repetition Rate Mode.
PRRM = 0, active rate.
PRRM = 1, maintain rate.

4.3.7 Application Layer – Transmitter Command Data

Below is the listing of the application command data bytes and definitions for the Train Chief Application.

Train Line Brake

7	6	5	4	3	2	1	0
0	0	0	0	TL3	TL2	TL1	TL0

Bits 0..3: 4-bit Step resolution provides 16 steps of Train Line Brake application.

Bits 4..7: Not used, read/write as zero.

Throttle / Brake

7	6	5	4	3	2	1	0
THR	BRK	0	0	TB3	TB2	TB1	TB0

Bits 0..3: 4-bit Step resolution provides 16 steps of Throttle advance or Brake apply step application defined by BRK and THR bits.

Bit 6: BRK. Indicates Throttle advance command with step position defined by bits 0..3.

Bit 7: THR. Indicates Brake Apply command with step position defined by bits 0..3.

Logical Function

These bits are logically determined based on dedicated switch functions and sequences and operational requirements that cannot be established with a simple Aux switch.

7	6	5	4	3	2	1	0
DM	BREL	TILT	0	F	N	R	ML

Bits 0: ML = MainLine (E-Stop) = 1: Normal Operation Mode. The ML bit is set when the Reset/Start button is activated and the E-Stop button is in its normal operation position.
ML = MainLine (E-Stop) = 0: Emergency Stop Active. The ML bit is cleared when the E-Stop button is push in or some other E-Stop condition has occurred, such as, Tilt or Alert time out.

Bit 1: R = Reverse

Bit 2: N = Neutral

Bit 3: F = Forward

Bit 4: Not Used, read/write as zero.

Bit 5: TILT: This bit is set when the Transmitter detects a valid Tilted condition – greater then 45-degrees and debounced. If Tilt is active for more than 2-seconds, Tilt timeout, the transmitter will go into Emergency Stop Mode. This bit is used by the Controller to initiate the Man Down Alarm Timer.

Bit 6: BREL = Brake Release.

Bit 7: DM = Deadman.

AUX 3 – AUX 1

Transmitter Control Switches are assigned specific bit positions in the stream to allow the controller the ability to map these bits to the desired relay outputs for a given application.

Designator Definition:
** = Switch Type
PB = Push Button
TS = Toggle Switch
# = number
**#.1 = towards operator
**#.2 = away from operator

AUX 3

7	6	5	4	3	2	1	0
5.3	5.2	5.1	5.0	4.3	4.2	4.1	4.0

	Switch Address	Designator	Optional
Bit 0:	4.0	PB2.1	TS6.2
Bit 1:	4.1	not used	TS6.1
Bit 2:	4.2	PB1.1	
Bit 3:	4.3	not used	
Bit 4:	5.0	PB4.1	TS7.2
Bit 5:	5.1	not used	TS7.1
Bit 6:	5.2	PB3.1	
Bit 7:	5.3	not used	

AUX 2

7	6	5	4	3	2	1	0
3.3	3.2	3.1	3.0	2.3	2.2	2.1	2.0

	Switch Address	Designator	Optional
Bit 0:	2.0	TS3.1	
Bit 1:	2.1	TS3.2	
Bit 2:	2.2	not used	
Bit 3:	2.3	not used	
Bit 4:	3.0	TILT	
Bit 5:	3.1	SLCT1	
Bit 6:	3.2	SLCT2	
Bit 7:	3.3	SLCT3	

AUX 1

7	6	5	4	3	2	1	0
1.3	1.2	1.1	1.0	0.3	0.2	0.1	0.0

	Switch Address	Designator	Optional
Bit 0:	0.0	TS4.1	
Bit 1:	0.1	TS4.2	
Bit 2:	0.2	TS1.1	
Bit 3:	0.3	TS1.2	
Bit 4:	1.0	TS5.1	
Bit 5:	1.1	TS5.2	
Bit 6:	1.2	TS2.1	
Bit 7:	1.3	TS2.2	

Figure 1 System Block Diagram

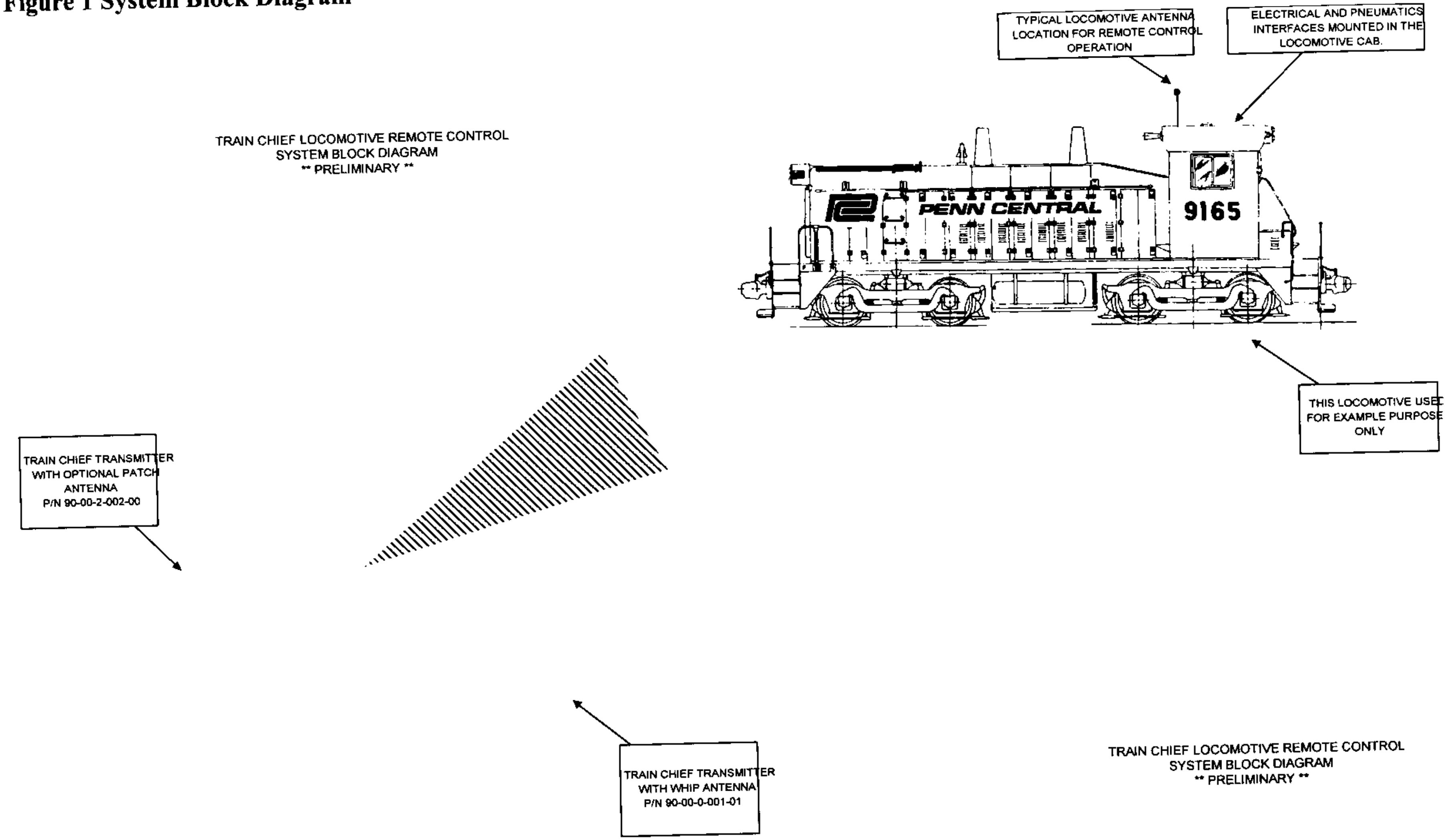
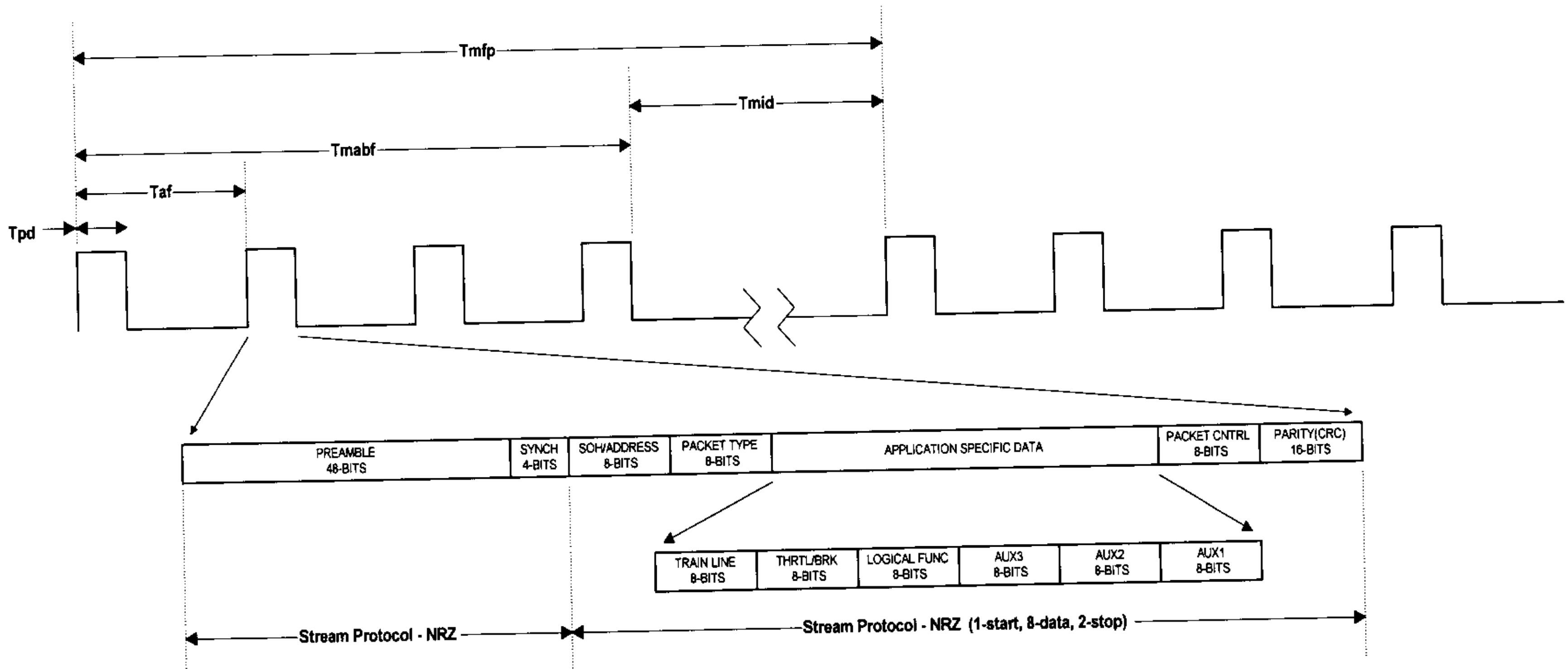


Figure 2 Train Chief Command Packet Structure v3.2



5 PROPOSED FREQUENCY CHANNEL PLAN FOR TRAIN CHIEF SYSTEMS.

6 SX450 UHF SYNTHESISED TRANSSCEIVER TECHNICAL MANUAL (1891 1067)

7 SX450C UHF SYNTHESISED TRANSCEIVER OPERATING INSTRUCTION (1892 1097)

8 SX450 FREQUENCY PROGRAMMING SOFTWARE OPERATING INSTRUCTIONS

9 SX450 OVERALL TEST PROCEDURE