Train radio system for Norwegian State Railways

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1 Introduction

SCANET is the train radio system for Norwegian State Railways. The radio system is developed by Ascom Radiocom in cooperation with Norwegian State Railways. The installation of the system started in 1993 and all the main lines will be covered by the end of 1996. The main purpose of the train radio is to permit radio communications between the engine driver and the train dispatcher (see Figure 1) and other subscribers involved in railway operations. The main parts of the system are the Mobile Station located in the engine, Base Stations along the railway lines, and the Central Traffic Control. The system is connected to the internal railway telephone network and acts like a normal telephone. The Automatic Train Control (ATC) is connected to the train radio. ATC is based on information received from ‘passive beacons’ located between the rails. One of the main purposes is to determine the train position. The position data is transferred via the train radio into the fixed network and ends up at the train dispatcher. The train radio will contribute to a safer and more efficient train transportation.

2 System description

2.1 General

The SCANET train radio is a system for supporting train transfer in Norway. The main purposes are voice communication between the engine driver and the Central Traffic Control and data communication (see Figure 1). But it is also possible to communicate on three other radio networks in the Norwegian State Railways.

The train radio system operates in the UHF frequency band, 457.600 – 458.475 MHz (up-link) and 467.600 – 468.475 MHz (down-link), all the networks included. Frequency Division Duplex (FDD) is used to separate the two transmission directions with a duplex spacing of 10 MHz. Frequency Division Multiplex (FDM) is used with a channel spacing of 25 kHz giving 34 full duplex channels for all the radio services. The total number of channels for the train radio communication is 12 duplex channels and the modulation type is PM for voice and FM for data. The power output for the Base Station and the Mobile Station is 10 W.

All main railway lines in Norway are divided into different radio areas identified by a specific number. Each area is connected to a Central Traffic Control and there are several Base Stations within one area. Each area is allocated a group of 4 channels. The Base Station operates like a repeater station between the Central Traffic Control and the Mobile Station. Messages are transmitted in both directions simultaneously. All areas are supervised and monitored by the Dispatch Centre. Speech and data signals are transmitted simultaneously using speech compression and time division multiplexing. There is only one speech connection at the same time in one area. There is also a connection to the internal railway telephone system.

A call from a train to the train dispatcher is shown on a screen in the Central Traffic Control. The screen indicates the train number and position. The train dispatcher chooses whom to answer first. A call from a train will also be indicated if the train dispatcher is talking to another train. The train number and position is continuously indicated on the screen at the Central Traffic Control.

As we can see from Figure 2, the Mobile Station is the centre of the complete communication network. All communications are carried out to and via the Mobile Station. The radio station is divided into two radio transceivers and one scanner. Train Radio Communication (TRC) and Operation Radio (OPR) are connected to one transceiver, and Station Radio (STR) and Internal Radio (IR) are connected to the other transceiver. The scanner automatically updates the best TRC Base Stations (or OPR base stations).

The importance of man-machine interface in the system is taken into account for the entire system. The users have been involved during the whole project period to form the best user interface.

2.2 Network construction

The radio system can communicate on four networks (see Figure 2):

- TRC network (Train Radio Communication) – central traffic control and engine drivers
- OPR network (Operation Radio) – construction and maintenance services
- STR network (Station Radio) – railway station and shunting personnel
- IR network (Internal Radio) – personnel on board the train.

The TRC network is a duplex transmission of speech and data between the Mobile Station in the engine and the Central Traffic Control. Speech and data signals are transmitted simultaneously using time division multiplexing. The data are coming from the TRC system itself and the Automatic Train Control (ATC). The engine driver also has direct access to the railway telephone network via a PABX (Private Automatic Branch Exchange) connection at the Central Traffic Control.

The OPR network is a speech service radio network using semiduplex transmission. It is used for maintenance service along the railway line. The network consists of handheld radios which can communicate with base stations or other handheld radios. The transmission between the TRC Mobile Station and an OPR base station is duplex. If trouble occurs in the TRC network, the OPR network can be used by the engine drivers as a stand-by system. It is also connected to the PABX.

The STR network is located in the station and shunting area and the system operates on semiduplex transmission to the handheld radio and on duplex to the base station.

Communication within the train is possible in the IR network. The handheld radios are mainly used by the train guards on a moving train. The transmission between two handhelds is simplex and semiduplex with Push-To-Talk (PTT) to the Mobile Station and the TRC Base Station. The handheld can also have direct access to the railway telephone network. It requires two channels, so that two crossing trains do not disturb each other.

2.3 Central Traffic Control

The Central Traffic Control consists of one control cabinet and several operator consoles. The control cabinet contains the Front Ends and the Dispatch Centre (see Figure 3).

The Dispatch Centre consists of a central processor and base band switching arrangements. The switch executes the interconnection of speech and data signals from the dispatcher consoles to the Front Ends and the assigned area. It is possible to connect 8 operator consoles and 8 Front Ends to the Dispatch Centre. One operator console can handle up to 6 Front Ends. Several computers (for service purposes) and a printer can also be connected.

The Front End is the interface between the Dispatch Centre and the area lines.

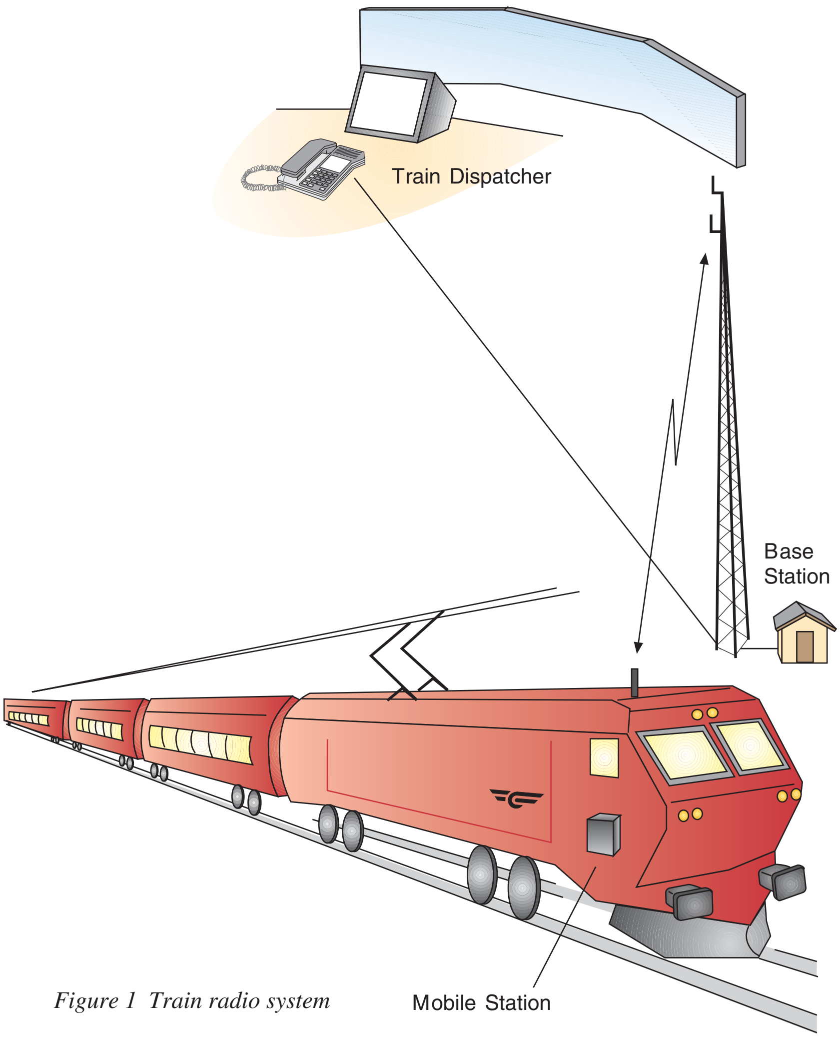

Figure 1 Train radio system

The Front Ends control all the Base Stations and provides synchronisation of speech and data transmission. One Front End can handle up to 30 Base Stations. Each Front End has an interface to the telephone network for speech calls between train subscribers and telephone subscribers. The access to the PABX is still working if the Dispatch Centre fails. Speech compression and expansion takes place in the Front End and in the Mobile Station.

The operator consoles are located at the operation desk at the Central Traffic Control and they are used by the train dispatchers (see Figure 4).

2.4 Base Station

The Base Stations are located approximately every 7 km along the railway line (see Figure 5). A four-wire line (area line) links the parallel connected Base Stations to the Front End in the Central Traffic Control (see Figure 2). For radio areas far away from the Central Traffic Control, the communication goes via fibre optics links on fixed 64 kbit/s or 2 Mbit/s channels. The connection to the four-wire line is done facing a high impedance (approximately 10 kOhm). Up to 30 Base Stations can be connected to one radio area (Front End). The Base Station consists of two parts, a radio part and a data part. The transmitter is continuously in operation and transmits a polling signal periodically which is used by the Mobile Station for a login procedure. It also continuously transmits an identification code specific to its own area. This means that a Base Station does not effect Mobile Stations outside its area.

The Base Station transmits speech signals in compressed form simultaneously in both directions together with slotted data using Time Division Multiplexing (TDM). To achieve synchronisation between speech and data blocks, all the Base Stations must be correspondingly delay adjusted in respect to the Base Station which has the longest communication link to the Dispatch Centre. The Base Station located nearest the Dispatch Centre will have maximum delay.

The data sent to the Base Station are not passed through transparently. They are decoded by modems in store and forward mode before retransmitting. The data is transmitted from the Dispatch Centre to the Base Station and from the Base Station to the Mobile Station and the other way round in two separate polling cycles.

Figure 6 indicates a typical Base Station installation.

2.5 Mobile Station

The Mobile Station is installed in the engine (see Figure 7) and the control unit is located at the control panel in the driver's cabin (see Figure 8). The Mobile Station has two independent transceiver sections and two antenna switch connections. The main transceiver operates in the TRC/OPR network and the second transceiver operates in the STR/IR network (see Figure 2). In addition, the receiver section operating in the TRC/OPR network is equipped with a scanner which carries out a procedure for selecting the correct Base Station within the area. The scanner continuously searches for the Base Station with the highest field strength level. Before the receiver is tuned to a new stronger channel, the signal level of the new channel must exceed a level threshold compared to the old one (hysteresis). The Mobile Station switches to the new channel automatically. The scanner has a minimum reference level and if the signal is above this level, the channel will not be changed, even if a stronger signal occurs. The system provides handover between the Base Stations. The handover to another Base Station during a speech connection is almost unnoticeable to the user.

A call can be set up as soon as the engine driver has completed the login procedure. The engine driver registers his area and train number. Within a particular area, the scanner selects any of the four available channels which provides the best link to a Base Station. If an area change takes place during a call, a warning tone is transmitted from the Mobile Station. The communication is then disconnected and the area change is carried out automatically. The area change is trigged by a 'passive beacon' located between the railway lines (see Figure 9). As soon as the area change has been completed, a

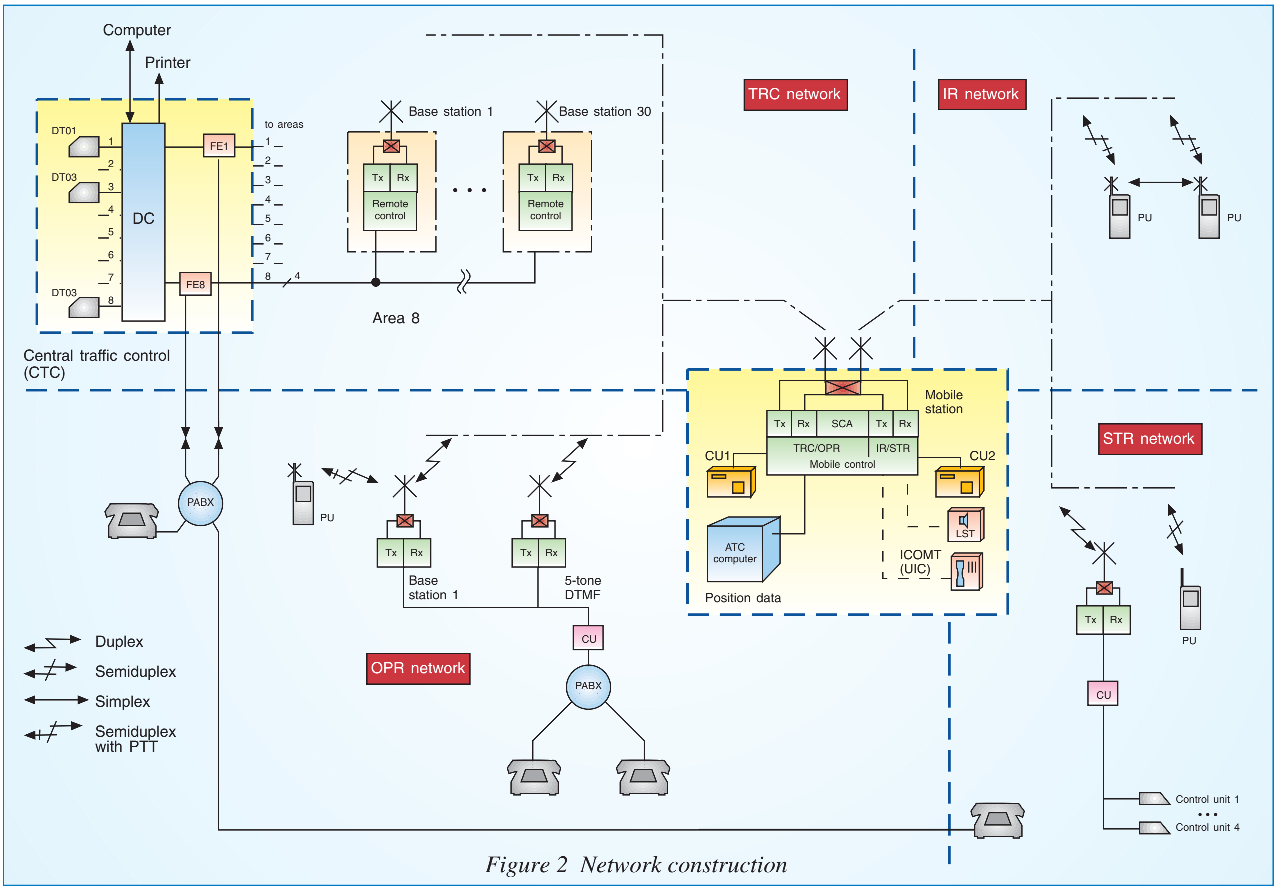

Figure 2 Network construction

Figure 3 Dispatch Centre (upper part) and four Front Ends (middle part)

Figure 4 The operator console located at the Central Traffic Control (beside the blue cup)

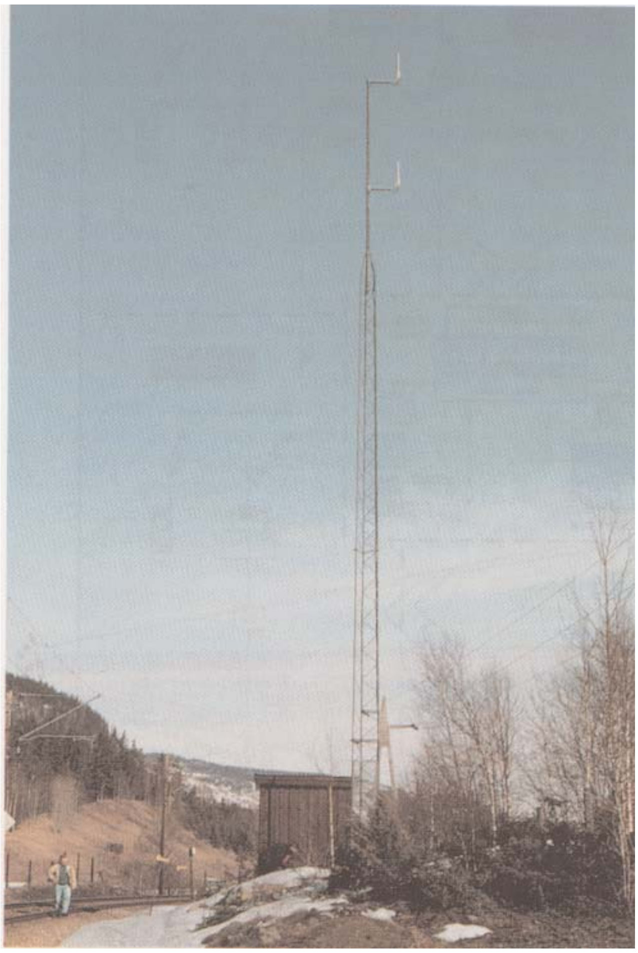

Figure 5 Typical Base Station

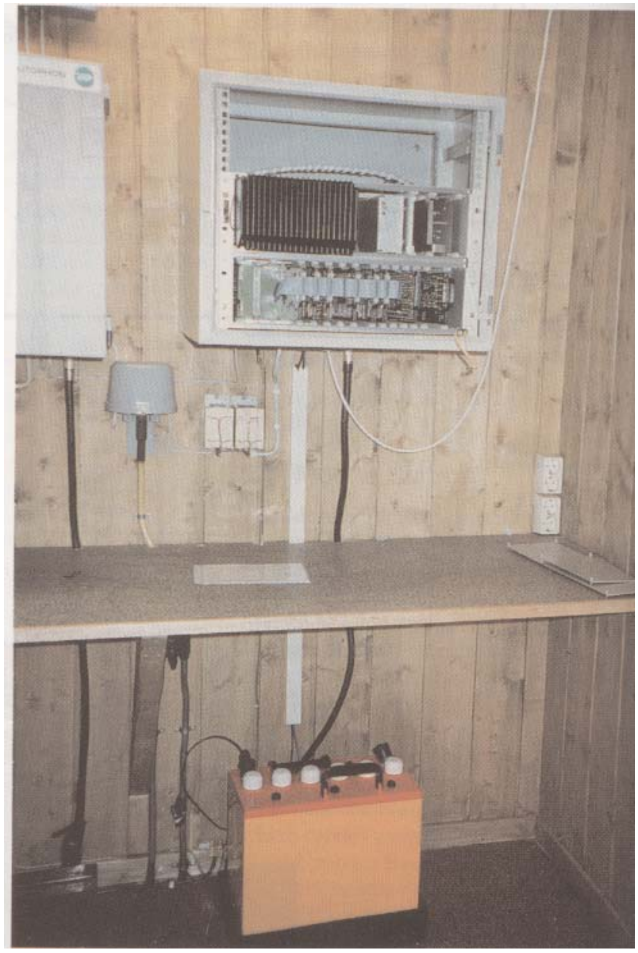

Figure 6 Typical Base Staton installation

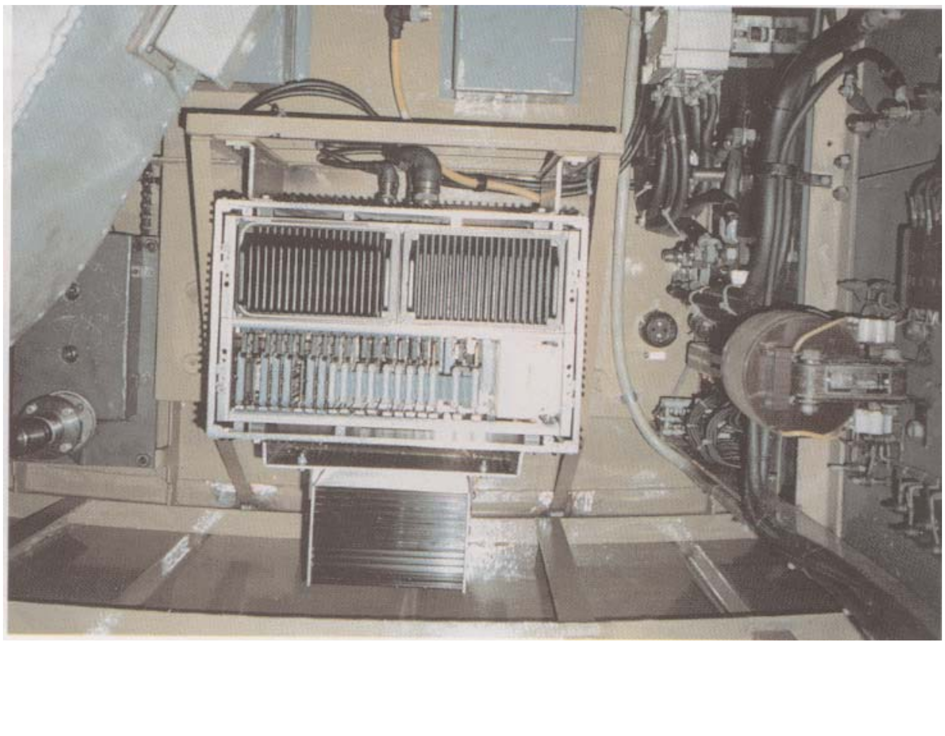

Figure 7 Mobile Station installed in a train engine

call can be set up again. In most cases, the changeover is carried out within the premises of a railway station. If the automatic changeover is not trigged, the engine driver has to enter the new area number manually after resetting the ATC because the ATC data has the highest priority.

The Mobile Station can be connected to the inter-communication system and the engine driver can use the internal loudspeakers in the train.

Figure 8 The Mobile Station control unit located in a train engine

3 Speech and data transmission

3.1 Speech compression and expansion

Speech compression is implemented to make the system able to have

- calls from other trains to the Central Traffic Control during a conversation
- ATC signalling number transmission during a conversation
- data from other engines during a conversation
- emergency calls.

Figure 9 Balise (information points) located between the rails

The system operates on a four-wire line. Speech and data are transmitted simultaneously thanks to speech compression. If no conversation is taking place on the lines, the data transmission capacity is 1200 bit/s. During a speech connection the capacity is reduced to 1200 bit/s in 260 ms per 1040 ms time slot, giving a total capacity of 300 bit/s. It is possible to upgrade the system with another four-wire line exclusively for data (1200 bit/s). The total data capacity is then 2400 bit/s.

Because of the speech compression, time slots are made available between the speech blocks. The data packets are inserted into these slots using TDM (Time Division Multiplexing). Speech compression and expansion is carried out in the Mobile Station and in the Front End. The free time slots are used to transmit data with a 1200 bit/s modem (see Figure 10). First the analogue speech is going through an analogue/digital converter. The speech compression is achieved by reading in the sampled data with a low data rate for a period of 1040 ms and writing it out at a faster data rate. All the frequency components in the base band are multiplied by 4/3. From Figure 11 we can see that the upper part of the base band is cut off by the radio link. The 1040 ms speech slot is therefore reduced to 780 ms giving a compression rate of 0.75.

Expansion uses a similar procedure in the reverse sense. The received sampled data is read at the high data rate for a period of 780 ms and written out at the low data rate for a period of 1040 ms.

3.2 Echo cancelling

Speech communication from the engine driver can take place from the Mobile Station, through the Base Station and the Front End ending at a subscriber telephone connected to the telephone exchange. The speech signal travels along a four-wire connection to the output of the telephone exchange where it is normally converted to a two-wire con-

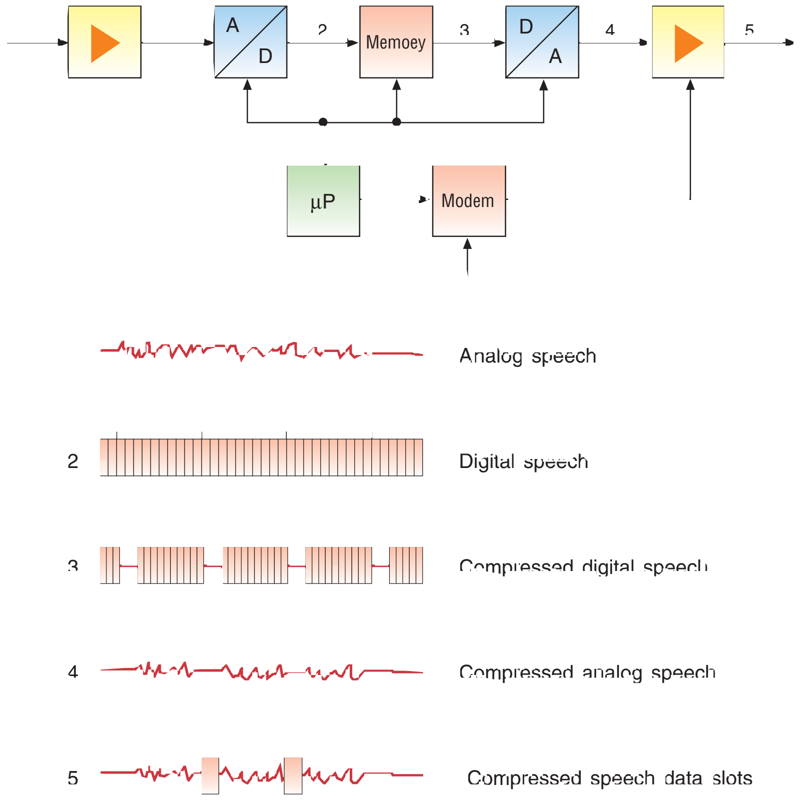

Figure 10 Speech compression

nection for a subscriber. The received signal is attenuated approx. 20 dB in the two-to-four line hybrid converter before it returns along the transmit path back to the engine driver. In the front end the signal is amplified in the order of 15 dB by the AGC (Automatic Gain Control). However, due to speech compression and expansion the signal is delayed by 260 ms, and will be heard as a loud echo in the order of 0.6 s by the engine driver, making it very difficult to hold a conversation. To solve this problem an echo cancelling in the digital signal processor software is introduced which attenuates the returned signal path depending on the magnitude of the signal received from the engine driver (see Figure 12). The echo cancelling is fully digital.

3.2 Synchronisation

Speech and data slots must be synchronised to all Base Stations in an area (Front End). The main goal of the synchronisation is to separate speech and data on the same channel. To achieve synchronisation between speech and data blocks, all the Base Stations must be correspondingly delay adjusted in respect to the Base Station with the longest physical distance from the Dispatch Centre. The delay adjustment is of course zero for this Base Station. The Base Station located nearest the Dispatch Centre will have the maximum delay adjustment. The Front Ends and the Base Stations are equipped with a timer. The Front End generates the master time and periodically sends synchronisation signals to all Base Stations, approximately every 2 minutes. The Base Stations transmit the synchronisation signals periodically over the radio link to the Mobile Station, approximately every 3 seconds (see Figure 13). The synchronisation over the radio link is only necessary during speech mode.

3.3 Polling procedures

The Front End transmits a poll datagram to the Base Station and the Base Station transmits a poll datagram to the Mobile Station. The datagram structure is given in Figure 14. If the Base Station or the Mobile Station has to transmit data to the Front End, they start after a delay of approximately 15 ms. The modems of the Base Station and the Mobile Station are switched on and they start with the modem synchronisation before the normal SCANET datagram. Approximately 15 ms after the received datagram the Front End and the Base Station send the next poll datagram. Between two poll datagrams there is a delay of approximately 100 ms (see Figure 14).

3.4 Data communication between the Front End and the Base Station

3.4.1 Physical characteristics (layer 1)

Transmission medium:	4 wires
Connection type:	Multipoint
Modem:	
- Modulation:	FSK
- Frequency assignment:	0: 2100 Hz 1: 1300 Hz
- Transmission rate:	1200 bit/s
Communication mode:	Synchronous, half duplex
Hardware interface:	V.24

3.4.2 Data link and the transport network protocol (layer 2–4)

The data link protocol is based on the HDLC protocol.

Primary:	Front end
Secondary:	All base stations
Polling:	Cyclic with individual link address
Maximum frame length:	25 bytes (200 bit)
Maximum frame transmission time:	166.7 ms

3.5 The radio link between the Base Stations and the Mobile Stations

3.5.1 Physical characteristics (layer 1)

Transmission medium:	Radio link
Connection type:	Multipoint
Modem:	
- Modulation:	FSK
- Frequency assignment	1: 1200 Hz 0: 1800 Hz
- Transmission rate	1200 bit/s
Communication mode:	Synchronous, half duplex
Hardware Interface:	V.24

3.5.2 Data link and the transport network protocol (layer 2–4)

The data link protocol is based on the HDLC protocol.

Primary:	Base station
Secondary:	All mobile stations within the range of the base station
Polling:	Cyclic with individual link address. Periodic 'group poll' for logon request
Maximum frame length:	25 bytes (200 bit)
Maximum frame transmission time:	166.7 ms

4 TRC system and Automatic Train Control (ATC)

The Automatic Train Control is a system which automatically switches on the train brakes if the maximum allowed speed is exceeded, the train is moving too fast towards a stop signal ('red light') without proper brake action from the engine driver, or the train is passing a stop signal. The ATC gets all the data from information points along the railway line. The information points are 'passive beacons' (balise) located between the rails (see Figure 15). The balise is totally passive and it is only activated when a train is passing. The ATC radio carrier from the train antenna activates the balise. The balise consists of an antenna and electronic encapsulated in a glass fibre reinforced polyester construction (400 x 500 mm).

The ATC transmission part on the engine consists of a transmitter, receiver, antenna and surveillance. The purpose is to energise the balise and receive the codes. The antenna is located under the train engine and transmits a 27.115 MHz carrier. The carrier is amplitude modulated with a 50 kHz frequency clock signal balise synchronisation. The transmitter power is 10 – 15 W.

The signal from the balise to the engine operates on 4.5 MHz with 10 mW radiated power. Each balise is identified with a unique code word (1's and 0's) which is transmitted from the balise when a train is passing. The duration of one bit is 20 µs (50 kHz data rate). Amplitude Shift Keying (ASK) is used for the 4.5 MHz

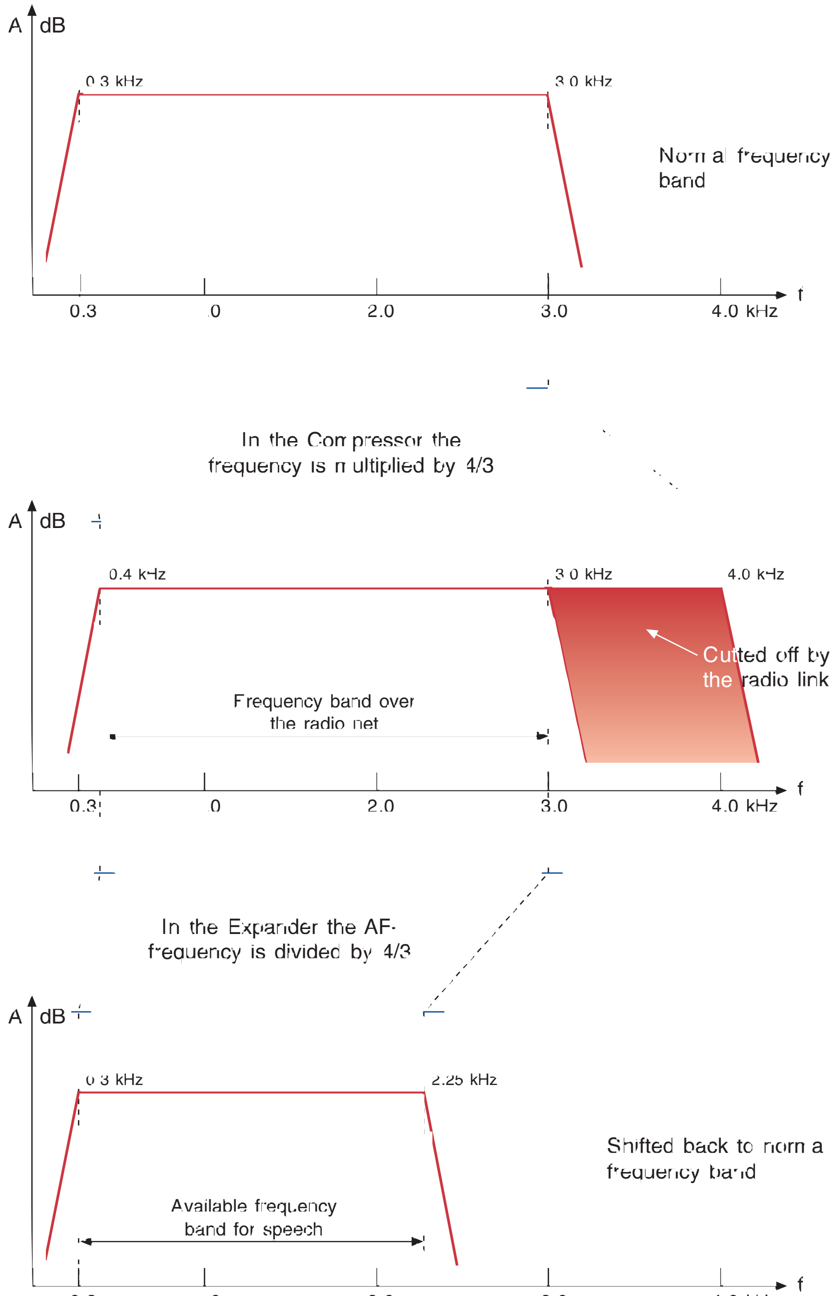

Figure 11 Frequency response after compression/expansion

carrier with '1' being carrier switched on and '0' carrier off.

The receiver in the engine receives the 4.5 MHz signal from the balise. It consist of an amplifier, a filter, a detector and an integrator. After each bit period, the integrator voltage is read to decide if the signal is logic '1' or '0'. The surveillance part continuously controls the transmitter level and modulation and it also tests the receiver. The antenna located under the engine consists of an inductive coil for transmitting. It is also a differentially coupled coil for receiving. One coil is for the 4.5 MHz signal and the other is for surveillance.

The train radio system is capable of sending data and the system can also handle data transfer during a conversation. The ATC produces a lot of data that could be

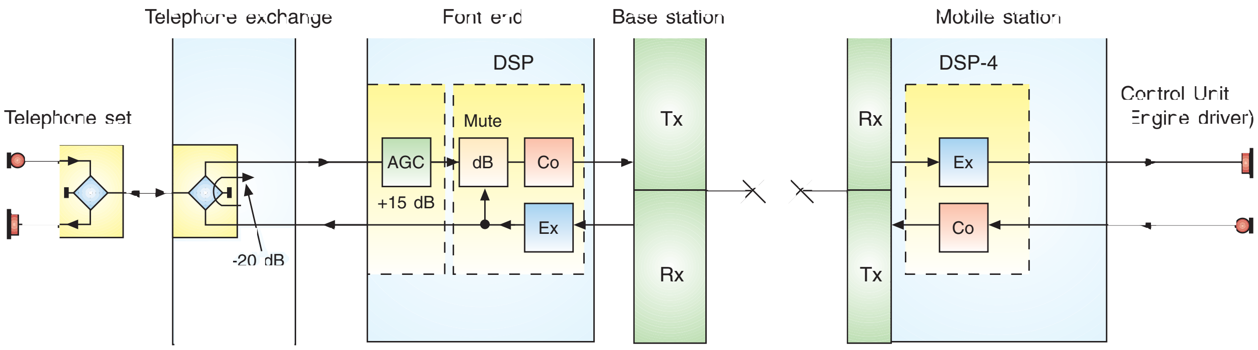

Figure 12 Digital echo cancelling

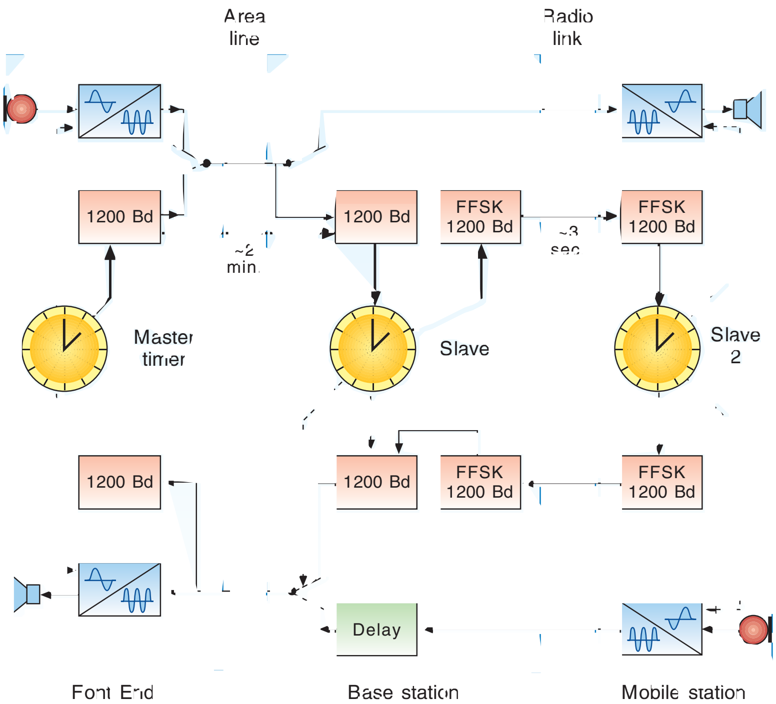

Figure 13 Synchronisation for speech compressor and expander

transferred over the train radio system, but presently only position and area data are transferred from the ATC to the Central Traffic Control.

The train radio system uses two types of balise:

- area change balise
- signal number balise (position balise).

The area change balise controls the change from one radio area to another.

The codes from the balise are sent via the on-board ATC computer to the Mobile Station and the code tells which radio area the train is entering. The Mobile Station gets the information from the ATC system and the radio area is changed automatically. The data are protected with a Hamming (8,4) code. The radio area number is always shown on the command unit display in the driver's cabin.

The signal number balise is located together with the main signal. The railway line is divided into blocks. The typical length of a block is a few kilometres depending on the traffic density and the speed of the train. A main signal (light signal) is always placed at the beginning and at the end of a block. For single track, only one train can be inside a block at the same time. The codes from the balise indicate the number of the next main signal (position of the train). The code used is a modified Hamming (16,11). Bit number 7 and 8 are interchanged to increase the safety. The signal number is sent from the Mobile Station to the Central Traffic Control via the Base Station (see Figure 15). The communication between the ATC and the Mobile Station takes place on a current loop RS232 connection. The interface card in the ATC repeats the latest balise information to the Mobile Station approximately every 4 second, but the Mobile Station does not pass any information to the train radio system before a change occurs. This is done to keep the data transfer in the system at a minimum. At the Dispatch Centre the Hamming code is decoded using a table decoder and presented as a decimal number (signal number) for the train dispatcher.

5 Future GSM train radio system

The UIC (Union Internationale des Chemins de Fer) is undertaking a project called EIRENE (European Integrated Railway Radio Enhanced Network) to define a new standard for a digital radio system for European railway organisations. UIC has decided that the new standard will be based upon the GSM digital cellular standard developed by ETSI. The

ETSI GSM standard will be enhanced to provide a number of features required by the railway organisations. The specification work is being carried out within the GSM phase 2+ standardisation programme. The additional specifications are particularly concerning the voice broadcast, group call and priority set-up services. The radio system is called EIRENE.

The fundamental requirements of the system are that it should

- operate in the 900 MHz frequency band
- be a digital system based on GSM capable of operation with train speeds faster than 500 km/h
- be an open standard enabling competition between manufacturers
- give a broad user base to provide economies of scale.

The special railway requirements are that it should enable

- broadcast calls (for emergency broadcasts over tens of kilometres of the railway line)
- group calls (for local teams and for driver-to-driver group calls over wide areas)
- priority and pre-emption (to ensure operational calls are granted network resources in preference to less important administrative calls)
- fast call set-up (about 1 second for emergency calls)
- GPRS (General Packet Radio Service)
- interpretation of pre-defined short messages
- shunting radio
- multiple driver communication.

A common European frequency allocation is required. The exact up- and down-link frequency band will be decided by CEPT in the near future.

The first test of the system will take place in Germany in 1995. The test is only on standard GSM but with respect to existing services for railway applications. Important test items are the speed requirements and data transfer. Based on this time schedule, the first prototype EIRENE will probably be available in 1997.

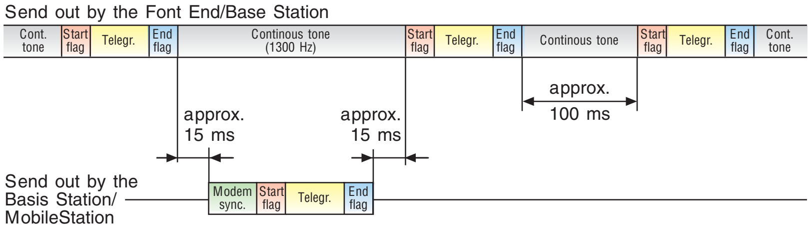

Figure 14 The poll datagrams and the answer of one base station / mobile station

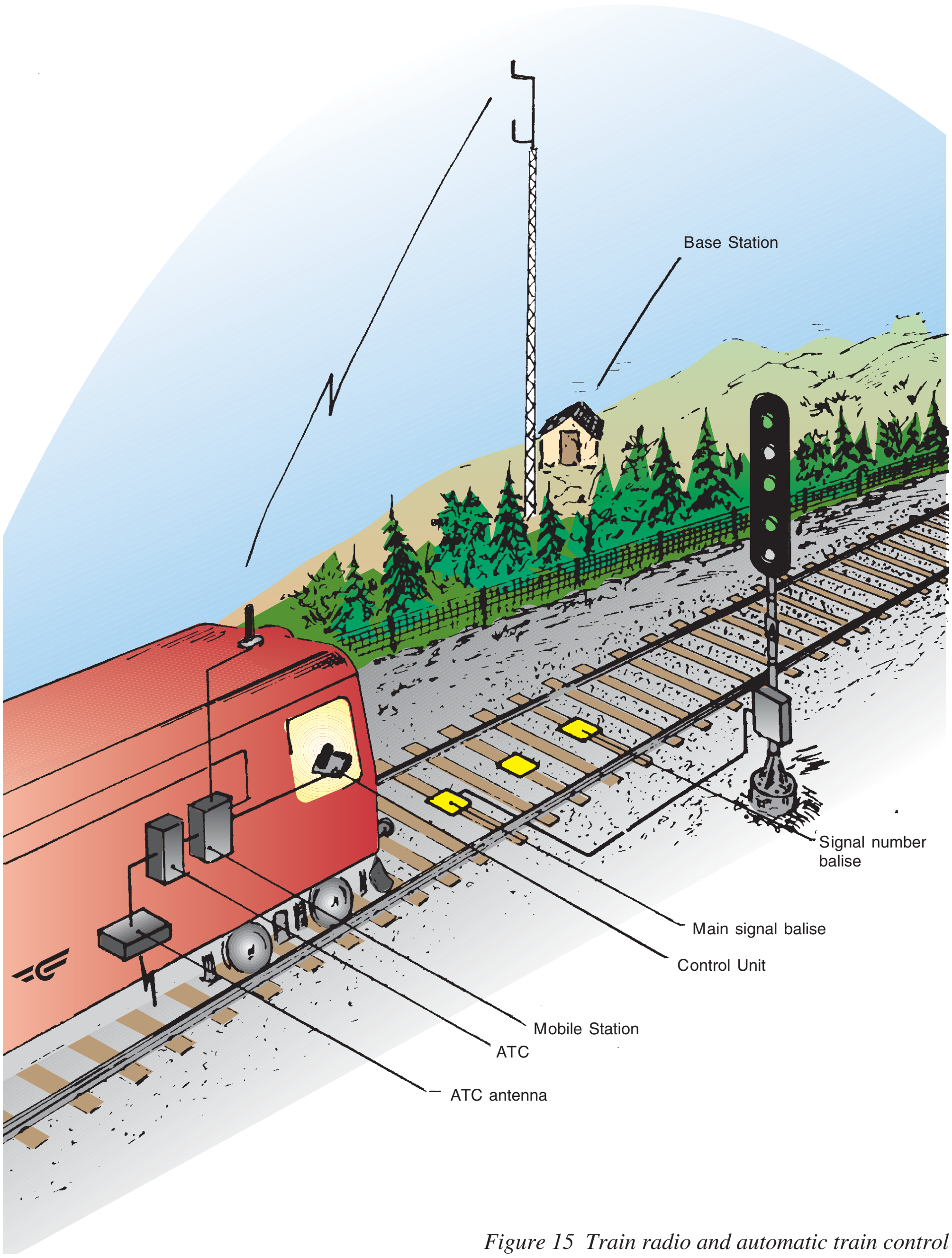

Figure 15 Train radio and automatic train control