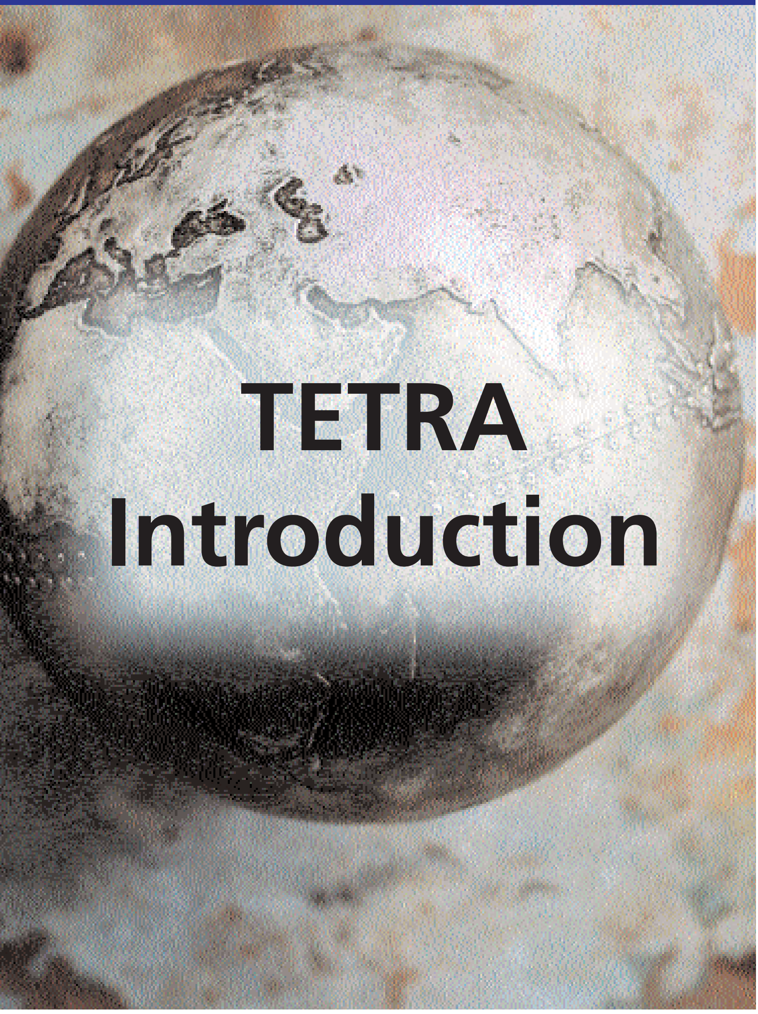
TETRA Introduction

Pocket Guide



ACTERNA

TETRA Introduction

Wireless Networks Division

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1. Overview

To put it very briefly, TETRA is a wireless communication standard for Professional Mobile Radio (PMR) and Private Access Mobile Radio (PAMR) applications. It is a digital format, i.e. speech is transmitted as binary data, which makes it far more difficult to monitor or eavesdrop.

The acronym TETRA stands for **TE**rrestrial **T**runked **RA**dio. Initially it stood for Trans-European Trunked RAdio, but the creators of TETRA within the European Telecommunications Standards Institute (ETSI) decided to give it a far more global scope.

Apart from ETSI, where TETRA is defined, there is another organization to promote the TETRA standard, the TETRA MoU – a non-profit organization with its secretary based at Simoco International, UK.

Further details of the MoU can be obtained from:

TETRA MoU Administration
c/o Simoco International
Tel. +44 1223 876200
Fax +44 1223 879200
www.tetramou.com

This pocket guide gives an overview of TETRA, both from the applications point of view as well as from the technology side.

2. The Market

PMR
Professional Mobile Radio (PMR) user groups own their network of terminals and base stations. The PMR system may be restricted to a specific area, e.g. factory area or town. Users have their own channels – another PMR system uses a different set of frequency channels.

User applications include emergency services (fire brigade, police, ambulance).

PAMR
A Private Access Mobile Radio (PAMR) network operator offers trunked system services to many different organizations. The operator administers a "trunk" of channels which are made available individually for the period of a call (individual or group call). This way, the frequency resources are shared much more efficiently. The PMR user groups mentioned above could share their networks thus becoming PAMR users.

Typical examples of PAMR users include maintenance fleets, courier and delivery services, as well as construction and taxi companies.

Although PMR and PAMR may be very different from the perspective of channel ownership, the underlying protocol and RF interfaces can be the same. Also, user groups communicate with each other over the air interface; it is a radio-to-radio communication, possibly connected by a relay base station. There can be a conversation between two distinct users or there may be a group call, i.e. one person broadcasts to many others. In order to talk, the terminal user pushes a button to reach a whole group, or typically enters a three-digit number to access another user.

This is different than the cellular phone usage, where communication is always between two users, one of whom is often connected to the fixed line telephone network. People are used to dialing, for example, a ten-digit number and then waiting a couple of seconds before the call is routed through and the person at the other end has answered the call.

Typical features of PMR / PAMR systems include:

- Individual & group calls
- Fast call set-up
- Semi- and/or full duplex
- Support of calls into the PSTN
- Potentially Direct Mode Operation (DMO)
- Flat rates instead of per minute charges

Why a New Standard?

Users of current analog systems require new features, such as those listed below:

Features lacking in the past	Support by TETRA standard
Voice encryption (most current FM- or PM-modulated systems can be tapped)	Digital speech transmission Additional encryption supported
Data transmission at higher rates (e.g. MPT 1327 allows only 1.2 kbit/s)	7.2 kbit/s per channel (unprotected) 28.8 kbit/s with multislot operation (unprotected)
Late entry to group calls	Supported by TETRA standard
Possibility to operate without a base station	Direct Mode Operation (DMO)
Higher spectrum efficiency	Four channels per 25 kHz (TDMA)
Short data service	SDS
Other supplementary services	More than 20 supplementary services defined, such as Ambience Listening, Call Barring, Call Hold, Call Diversion

Many manufacturers, operators and user groups participated in the creation of the new standard, so it is anticipated that it reflects today's and tomorrow's needs. Phase 1, the basic standard, was completed in 1996. Since then, trial systems have been set up, followed by full network installations.

The TETRA standard is a living standard. While systems are deployed to the current standard, a range of new applications can be opened up simply by adding features to the specifications.

TETRA Applications

Most of the applications described below require short communication connection times. Companies want to be able to budget the costs of their radio communication, rather than having a little surprise every time they receive a new monthly mobile phone bill. Therefore trunked network operators offer flat connection rates depending on the required services.

Utility services not only have networks of electricity lines, gas pipelines and water pipes, but also their own set of frequencies. Radio communication is of vital importance to keep the services going and to achieve quick repair. Up until now, most calls were voice only, but it is not difficult to imagine how drawings and digital maps could vastly improve the performance of a service fleet with mobile data capability.

A whole range of new applications become feasible with PMR in **public transport**. In the first step, all drivers use their radio to be able to contact their base. The next step is to enable vehicles to report their respective positions, so that their location is known. This can then be used to calculate delays in scheduled departure times. If delays accumulate too much, additional vehicles can be requested and allocated automatically (by a central computer). "Next bus/train" information can be provided at bus stops, train platforms, and even on TV (TeleText) or on the Internet, so that the passenger starts his or her walk through the rain only when it is time to catch the next bus or train. And subway trains can have TETRA-enabled "Help" phones and video cameras to enhance security.

Many companies employ **service fleets** to install and repair equipment, which can range from washing machines to photo copiers. Technicians need to be accessed very quickly, especially in the case of maintenance contracts with fast response time. This can only be achieved if the technician is equipped with a radio terminal, preferably with data transfer and print capabilities, so that necessary information for the next visit (location, specifics of the defect device) can be made available. The technician could then send a report back which is used for archive purposes, as well as to bill the customer.

Police, ambulance and fire brigade need radio communications every day, not only in highly populated areas but also in the countryside. The beauty of systems like TETRA is that they can share services provided by a single network, and where network coverage is not achieved (e.g. during disaster relief in tunnels), direct mode terminals can communicate with each other without requiring a network.

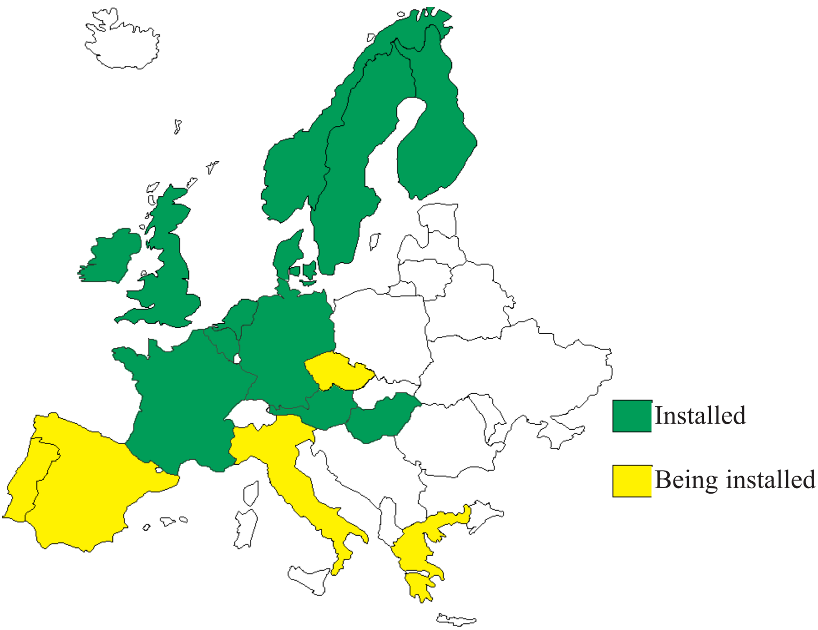
Other applications can be found for example in courier services, for construction sites, building security, taxis and even in the military.

TETRA Roll-Out

TETRA systems are in operation in a number of places such as Finland (Helsinkin Energi, VIRVE), Norway (Oslo airport) and the United Kingdom (Dolphin Telecoms). More networks are being installed, such as the public safety networks in Belgium (Astrid) and The Netherlands (C2000) as well as commercial systems like Dolphin in France and Germany.

PAMR operators are investing in the new digital technology to make trunked systems more attractive by new features, services and a wider range.

TETRA applications are not restricted to Europe – installations can be found in many other countries, e.g. in Australia, New Zealand, Hong Kong, Singapore, Israel, and new countries and networks are added to the list. The roll-out pace is increasing and new network installations are reported every month.



The TETRA/Tetrapol Race

TETRA manufacturers are competing with another system – Tetrapol, developed by the French company EADS/DSN (formerly Matra Nortel). While both systems provide the same basic services, the technology behind the services is quite different (Tetrapol is an FDMA system with a gross data rate of 8 kbit/s, with recommended channel spacing of 12.5 kHz). Both systems have their specific advantages shown below.

TETRA	**Tetrapol**
Better spectral efficiency (four channels in 25 kHz)	Fits very well in existing 12.5 kHz channel spacing scheme
	Permissible range between network and radio terminal may be higher, reducing BS costs
Scalable data rates up to 28.8 kbit/s	
Approved ETSI standard	Many existing deployments prove that the Tetrapol standard is a feasible solution
Multi-vendor system	

When selecting a standard, new operators are first tempted to compare initial deployment cost, but soon realize that the total cost of ownership needs to be taken into account. This requires a detailed study of the business case based upon user needs.

3. The Technology Behind TETRA

TETRA Sub-Standards: V+D, PDO, DMO

TETRA comes in three different modes:

- Voice + Data (V+D)
- Direct Mode Operation (DMO)
- Packet Data Optimized (PDO)

V+D

V+D is the standard most commonly referenced. It allows switching between speech and data transmission instantaneously; both can even be transmitted "at the same time" (in different time slots on the same channel). The radio protocol has been optimized to allow fast call set-up, both semi- and full duplex and high spectrum efficiency in a trunked mode environment, i.e. using base stations to relay information.

DMO

DMO supports voice and data transmission as well, but without a base station between radio terminals. The current or last terminal transmitting user data (e.g. voice) acts as a kind of base station. Full duplex radio is not supported in the DMO standard.

PDO

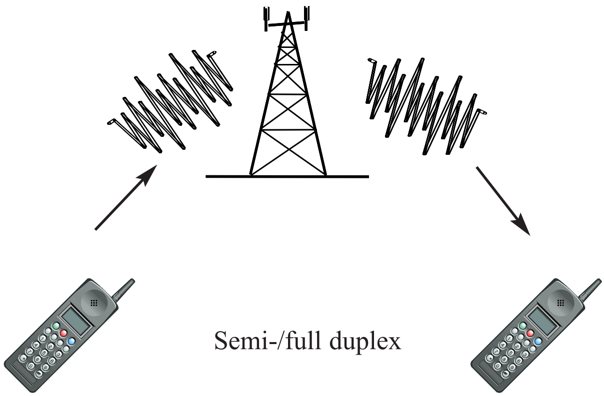
For applications requiring occasional data transmissions, the PDO standard has been created. This can be a highly efficient method for data-only transmissions to save costs. There are much higher data rate requirements foreseen in the future and to cater for these new demands, an ETSI project group (DAWS) has been set up to define a faster system built on the TETRA PDO core.

Simplex, Semi-Duplex, Full Duplex

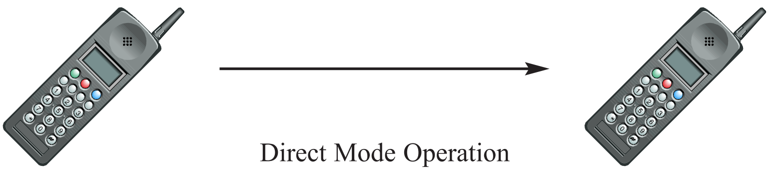
In trunked mode operation, there is always a base station and network to switch information between one or several users. Any type of communication can be:

- Full duplex (both users can speak and listen at the same time)
- Semi-duplex, where only one party can speak at a time, usually a Press-To-Talk button is used and the end of speech is announced by “Over”
- Simplex, which can be a broadcast message

In order to avoid interference, base station and mobile station use different frequencies with a fixed duplex offset, e.g. 10 MHz.



There is also a direct mode operation (DMO) being used when there is no base station available. In this case, only one party can speak at a time (simplex). Receive and transmit frequencies are identical (no duplex spacing).

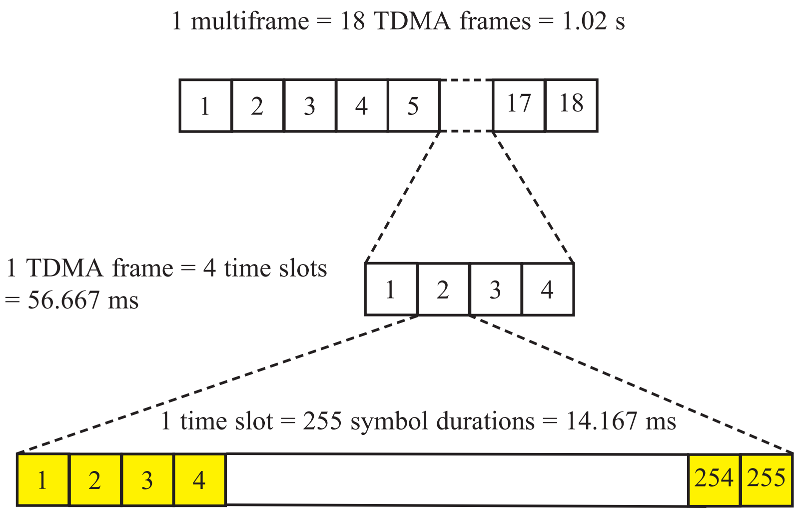


TDMA

TETRA is a TDMA standard. This means several users share one frequency, speech and data are transmitted in digital format and multiplexed into time slots. All of the four different TETRA time slots on one carrier bear different channels, so there can be as many as four different calls on one 25 kHz wide carrier frequency.

There are (at least) two advantages of this method:

- Several time slots can be used to transmit voice and data at the same time or time slots (channels) can be combined to transfer data at higher rates.
- The four channels are transmitted and received by the same equipment in the base station, which can reduce the infrastructure cost.

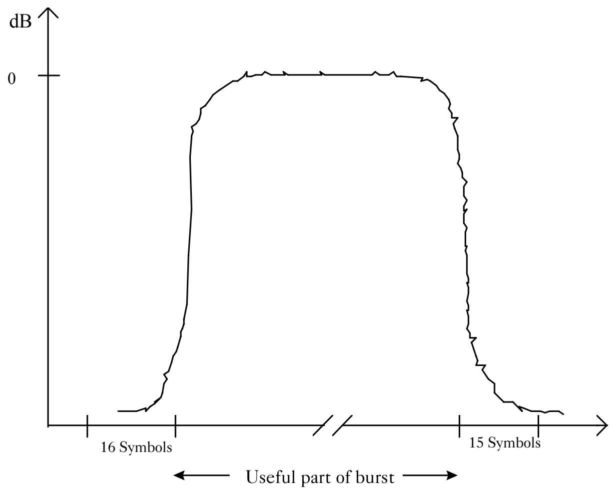


One time frame consists of four time slots. Data is compressed and sent in one of the available time slots.

On a traffic channel, every 18th frame is used to exchange additional control information between the radio terminal and the base station as shown below:

one multiframe	**= 18 frames**	**= 1.02 s**
one frame	**= 4 time slots**	**= 56.667 ms**
one time slot	**= 255 symbols**	**=14.167 ms**

Several radio terminals may use the same carrier. So that they do not interfere with each other's communication, each terminal is assigned its own time slot for the duration of the call. The terminal sends its data in a burst, i.e. the radio power is turned on for a short period and turned off again before another terminal transmits in the next time slot.



Bursts and Time Slots

A radio terminal transmits its data in so-called “bursts”. The transmitter emits RF power for a defined period of time (usually a time slot). The RF carrier is modulated with the bits that make up the call or control information. During a call, one burst is transmitted per TDMA frame.

Although a base station usually sends a continuous bit stream, this stream of data is also divided into time slots often called bursts (although the power remains on).

A burst can carry one or several logical channels, e.g. in the downlink (from base station to terminals). Most bursts consist of a long bit sequence for one channel and a shorter bit sequence to broadcast how and when this physical channel is used (see AACH on page 15).

Each time slot consists of a number of bits, grouped into bit fields with their respective meaning. The TETRA **base station** uses the following types of bursts:

- Normal (continuous or discontinuous) Downlink Burst **NDB**, used for most transmissions from the base station to the terminal
- Synchronization (continuous or discontinuous) downlink Burst **SB**, carrying a longer training sequence, used to support the terminal when it synchronizes to the base station

The TETRA **terminal** uses a different set of bursts:

- Control uplink Burst **CB**, a half-slot burst used by the terminal for initial network access
- Linearization uplink Burst **LB**, a burst sent only to allow the terminal to adjust its own transmitter
- Normal uplink Burst **NUB**, the burst type used in any other transmissions

Channel Structure

In TETRA, there are physical channels and logical channels. A physical channel is determined by its frequency and time slot number. Each physical channel may carry several different logical channels. One example is that every 18th frame is a control frame carrying a control channel, no matter which type of channel is allocated in the other frames.

Also, a traffic channel (TCH) carrying user data, may be interrupted by a Stealing Channel (i.e. stealing a traffic channel) for the purpose of transmitting control information.

The following control channels can be found in TETRA V+D:

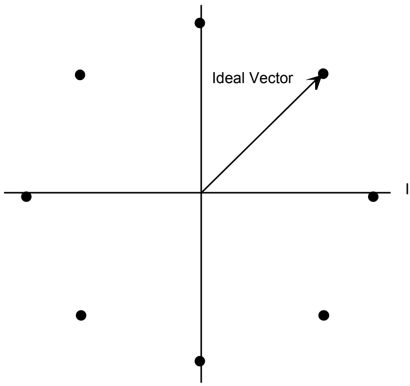
- Broadcast Control Channel (BCCH), consisting of two sub-channels:
  – Broadcast Synchronization Channel BSCH
  – Broadcast Network Channel BNCH
  Both channels are transmitted by the base station to allow the terminal to identify the network. The base station also defines basic access parameters.
- Linearization Channel (LCH), allowing the base station or the terminal to align its transmitter
- Signaling Channel (SCH), used to exchange control information between the base station and the terminal, e.g. when the terminal registers with the base station (location update) or when the call is set up
- Access Assign Channel (AACH), a channel transmitted by the base station in the middle of every normal burst to announce how the current physical channel is used and when it can be accessed by terminals
- The Stealing Channel (STCH), associated with a TCH. During an ongoing call, TCH transmissions can be replaced by a STCH when important protocol information shall be exchanged, e.g. for a hand-over to a different cell or frequency.

Higher Data Rates: Multislot Operation

The maximum user data throughput on a channel is 7.2 kbit/s. This may not be sufficient for future applications, e.g. for slow video transmission. A method to enhance the data rate is channel bundling. In this case data transmission spans two or more consecutive time slots, thereby reaching a maximum user data rate of 28.8 kbit/s. This is not fast compared with today's fixed line modems, but in the field of radio communications, it is a major improvement over today's technology. It is about 20 times faster than with MPT 1327 and three times faster than the basic GSM standard.

Modulation and Channel Coding

The modulation format of TETRA is π/4 DQPSK (differential quaternary phase-shift keying). This modulation method shifts the phase of the RF carrier in steps of ±π/4 or ±3π/4 depending on the data transmitted. With each phase change, one symbol containing two bits is transmitted. In a vector diagram of the modulation signal shown below, the ideal positions of the eight possible signal vector states lie on a circle.



Representation of the modulation in the constellation (I/Q) display

TETRA uses error-tolerant modulation and coding formats. The information to be transmitted is coded, adding some redundant information in the CRC. This information can be used to identify reception errors and to reconstruct the correct bit stream with a highly sophisticated bit error correction algorithm. But if the correction function is operating at its limits (e.g. because transmitter and receiver are far from each other so that the signal quality is very low with many errors), speech quality could suddenly turn from good to bad. Therefore, correctly adjusted demodulators and modulators are necessary.

4. Basic Specifications

Frequency range:	Not fixed, preferred bands for European applications: 380 … 400 MHz for public safety systems 410 … 430 MHz for commercial applications 450 … 470 MHz 870 … 876/915 … 921 MHz
Duplex:	Frequency Division Duplex FDD
Duplex spacing:	Not fixed, but in Europe typically 10 MHz (downlink in the lower band usually)
Carrier spacing:	25 kHz
Channel multiplex:	TDMA: four time slots per frame (18 frames per multiframe)
Time slot length:	14.167 ms (frame length = 56.667 ms, multiframe length = 1.02 s)
RF transmit power:	MS: 15 … 45 dBm (0.03 … 30 W) in 5 dB steps (maximum power depending on mobile class)
	BS: 28 … 46 dBm (0.6 … 40 W), depending on BS power class
Gross bit rate:	36 kbit/s
Modulation:	π/4-DQPSK, roll-off factor $\alpha = 0.35$
Speech coding:	A-CELP (Algebraic Code-Excited Linear Predictive) Codec, 4.8 kbit/s
Data rate:	Up to 7.2 kbit/s per channel, 28.8 kbit/s with multiple slots

Glossary

BS	Base Station
CRC	Cyclic Redundancy Check
DMO	Direct Mode Operation: Mobile stations communicate directly with each other, without the need of a base station. More difficult to control (e.g. by a dispatcher), but the only way to communicate in areas where there is no base station available (e.g. in a tunnel).
ETSI	European Telecommunications Standards Institute
MCC	Mobile Country Code, standardized by an ITU specification
MNC	Mobile Network Code, to differentiate different networks in a country
MPT 1327	"MPT 1327 – A Signaling Standard For Trunked Private Land Mobile Radio Systems": First open trunking standard, prepared by the British Department of Trade and Industry
MS	Mobile Station: May be mobile phone, data terminal equipment, fax etc.; vehicle-mounted or hand-portable
PAMR	Private Access Mobile Radio
PDO	Packet Data Optimized: TETRA defines not only systems for direct voice and data communications, but also for packet data transmission.
PMR	Professional Mobile Radio
PSTN	Public Switched Telephone Network
PTT	Press To Talk: The button you press on simplex/semi-duplex mobile stations in order to transmit
$\pi/4$-DQPSK	$\pi/4$ Differential Quaternary Phase Shift Keying: A modulation format coding two bits of information into one symbol, hence the symbol rate is half the bit rate

SSI	Short Subscriber Identity: Part of MS identity number in TETRA, see TSI
SwMI	TETRA Switching and Management Infrastructure: Base station and network for TETRA
TCH	Traffic channel
TDMA	Time Division Multiple Access: Several physical channels are located on one frequency channel on a time-sharing basis. Each physical channel is defined by a fixed time slot (four time slots available in TETRA). The advantage of TDMA is that several channels are co-located on one carrier frequency, so less transmitters are required.
TETRA	TErrestrial Trunked RAdio: An open standard for PMR and PAMR applications, defined by ETSI
TMO	Trunked Mode Operation: Mobile stations communicate via a base station (in TETRA).
TSI	TETRA Subscriber Identity = MCC + MNC + SSI
V+D	Voice + Data: Part of the TETRA standard including a part of TMO and DMO, but not PDO

About the Authors

Achim Grolman holds a diploma in electrical engineering. He joined Acterna (formerly Wavetek Wandel Goltermann and TTC), Munich, Germany in 1987. He held various positions as a design and test software engineer as well as a project leader in the field of RF communications test systems, dealing with different standards such as MPT 1327, GSM, DECT, and TETRA. In 1997 he transferred to the Marketing Department to focus on market research, product definition and market introduction. His responsibilities include 3G systems.

Pavel Hasan graduated from the Czech Technical University in Prague with a degree in communications engineering. He was a member of the research staff at the Institute of Radio Engineering and Electronics, Academy of Sciences of the Czech Republic and a member of the academic staff at the Telecommunications Institute, University of Erlangen-Nuremberg. Recently he was a Technical Writer at Force Computers in Munich. He joined Acterna (formerly Wavetek Wandel Goltermann and TTC), Munich, Germany in June 2000.

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