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# TETRA factsheet

# Terrestrial Trunked Radio

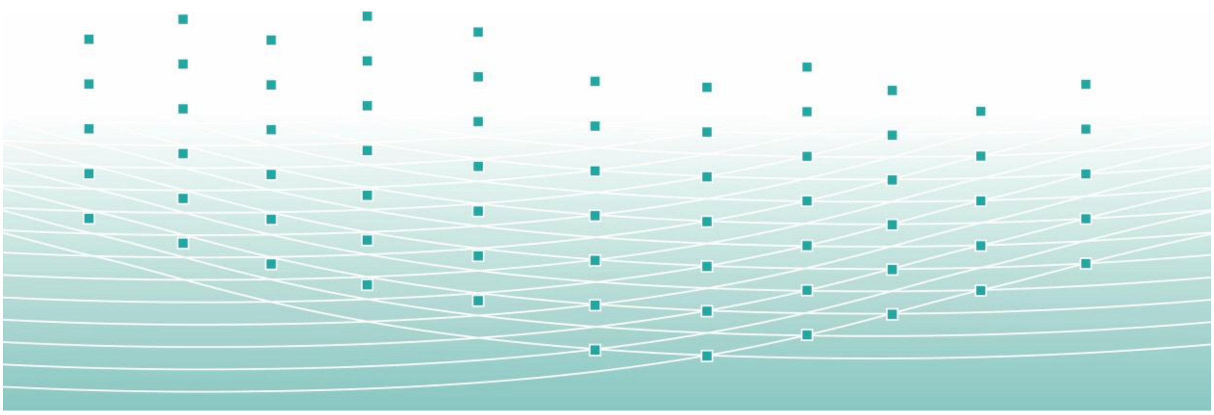
## Summary

TETRA is a digital, cellular trunked radio system for voice and data communications. Digital trunked radio systems are radio systems for private and public professional radio applications and for emergency radio applications. The TETRA standard was developed by the ETSI (European Telecommunications Standards Institute) and published in 1996. Since then it has been further developed. Today TETRA is one of the most important radio standards worldwide for secure and reliable voice and data communication.

TETRA works with the TDMA (Time Division Multiple Access) method. Four physical channels (time slots) are available on one radio channel. In its original configuration (Release 1) bit rates of up to 4 × 7.2 kbit/s are possible with TETRA, with π/4-DQPSK phase modulation on a radio channel with a 25 kHz bandwidth.

With Release 2 of TETRA (TETRA 2), from 2006 onwards extensive new functionalities were introduced into the standard, such as, for example, TEDS (TETRA Enhanced Data Service). TEDS is based on adaptive multi-carrier modulation with 8 sub-carriers per 25 kHz and on linear QAM modulation. With higher performing modulation and the bundling of up to 6 radio channels to form a transmission bandwidth of 150 kHz (a total of 48 sub-carriers), bit rates of up to 134 kbit/s are possible per time slot with TEDS - or if 4 time slots are occupied, in excess of 500 kbit/s is possible. TETRA 2 is therefore a WB (Wideband System).

TETRA 2 with TEDS uses the same TDMA structure as Release 1 and is completely backward-compatible.



# Contents

# 1 Introduction

TETRA is a digital, cellular trunked radio system for voice and data communications. Trunked digital radio systems are modern radio systems for private and public professional and safety radio applications (PMR/PAMR[1]). Unlike earlier conventional analogue fixed-channel systems (where each service and each user was permanently assigned a specific radio channel), with trunked radio systems the frequencies are assigned dynamically to the individual users. This means that the benefits of trunking can be exploited and spectrum efficiency can be increased. In addition, digital technology can help to substantially improve the quality and security of radio systems.

Trunked radio systems differ from public mobile radio systems such as UMTS or LTE primarily in terms of their faster call set-up, group calls, priority calls, end-to-end encryption and the possibility of direct calls from mobile station to mobile station without a connection via a base station (this is known as direct mode).

Potential users of trunked radio systems include closed user groups such as transport services (taxi, Swiss Railways SBB, transport companies, etc.), airports, energy companies and emergency services (police, fire service, ambulance, the army, civil protection, the border agency, etc.). All these user groups have either their own private trunked radio system or use the services of a trunked radio operator.

As early as the first half of the 'eighties, initial attempts were being made to seek appropriate solutions for *digital* PMR systems. This step was essential in order to increase spectrum efficiency, improve technical reliability and facilitate call encryption. It was at this time that the first proprietary digital PMR systems appeared, including ASTRO and iDEN (both by Motorola), EDACS (Ericsson), SR 440 (Bosch/Ascom) and Tetrapol (Matra Communication/EADS).

However, the establishment of a uniform standard for digital PMR systems began only when manufacturers, administrations and user groups decided within ETSI in 1989 to draw up such a standard, designated TETRA. The standard was published in 1996. Since then, TETRA has become one of the most comprehensive standards ever developed by ETSI.

With Release 2 of TETRA (TETRA 2), from 2006 onward a number of important new functionalities were introduced into the standard, such as, for example, TEDS (TETRA Enhanced Data Service). With higher performing types of modulation and the bundling of up to 6 radio channels to form a transmission channel with a bandwidth of 150 kHz, bit rates of up to 134 kbit/s are possible per time slot with TEDS; if 4 time slots are occupied, this may even exceed 500 kbit/s. TETRA has therefore changed from an NB (Narrowband) system to a WB (Wideband) system. The first TEDS-capable networks went into operation at the end of 2013.

As with most mobile radio systems, TETRA also uses the frequency-division duplex technique (except in the case of Direct Mode). The uplink and downlink are handled on two different frequencies, which are separated by the duplex spacing. The size of this duplex spacing depends on the frequency band in which the system is operated. TETRA terminals (like most PMR systems) generally work in half-duplex mode, i.e. transmission and reception cannot take place at the same time. In order to transmit, a button must be pressed (Push-to-Talk).

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[1] The market for professional and private mobile radio is termed PMR (Private Mobile Radio) or PAMR (Public Access Mobile Radio). In the case of PMR, the radio system is operated by the user; in the case of PAMR the trunked radio services are obtained from an independent network operator. PAMR operators generally also provide access to the fixed network.

# 2 Technology

## 2.1 TETRA Release 1 (TETRA 1)

TETRA uses the TDMA (Time Division Multiple Access) channel access method, with four physical channels (time slots) or user connections on a single 25 kHz radio channel. If necessary for greater transmission capacity, an individual user can also occupy several (up to four) time slots.

The method is shown in the following illustration. The thick solid line shows the extent of the user's transmit power on time slot 1.

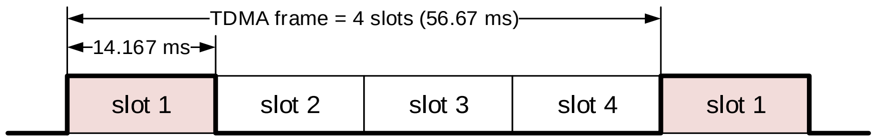


**Figure 1: TETRA’s TDMA structure**

The transmit power of the mobile equipment are continuously regulated by commands from the base station to the minimum which the base station needs to detect the data from the mobile equipment (power control). By means of power control, interference can be minimised and the battery life of the mobile equipment increased. In TETRA, the transmit power of the base station is not regulated.

The modulation method used is π/4-DQPSK (Differential Quaternary Phase Shift Keying). By means of a modulation filter the undesirable out-of-band emissions are suppressed. As a result, moderate amplitude fluctuations are created in the modulation signal. This requires a liner power amplifier which tends to be less efficient.

In principle, TETRA can be used on all frequencies below 1 GHz. In practice, however, only the typical frequencies authorised for PMR in the 160 and 400 MHz band are used.

The TETRA specifications cover three completely different areas of application, i.e.:

- Voice plus Data (V+D)
- Pack Data Optimised (PDO)
- Direct Mode Operation (DMO)

One standard was developed for each of these three applications. However, these are all based on the same physical radio platform (modulation, channel spacing, channel access procedure, etc.).

### 2.1.1 TETRA V+D

The V+D (Voice plus Data) specification is the most important TETRA standard [1] and offers a broad palette of carrier services, teleservices and supplementary services for voice and data communication.

TETRA's voice coder/decoder (Codec) is based on the CELP technique (Code-Excited Linear Predictive). The codec bit rate is 4.6 kbit/s. Although this bit rate is only about one third of that of the GSM codec, the speech quality is expected to be almost equivalent [3]. The speech quality (MOS) of GSM is 4 and that of TETRA is 3.6. MOS (Mean Opinion Score) is a subjective assessment technique for the comprehensibility of speech and extends from 1 (poor) to 5 (good).

TETRA's bit rates with π/4-DQPSK modulation with n occupied time slots n (n = 1, 2, 3 or 4) for different codings are:

- n × 7.2 kbit/s (unprotected, BER = 2.5%)

- n × 4.8 kbit/s (slightly protected, BER = 0.4%)
- n × 2.4 kbit/s (highly protected, BER = 0.01%)

The indicated BERs (bit error rates) apply to the dynamic receiver sensitivity of TETRA in a specific environment.

If 4 time slots are occupied for one connection, the maximum bit rates are then 28.8 kbit/s, 19.2 kbit/s and 9.6 kbit/s. A typical TETRA bit rate achieved in practice under real conditions, is 16 kbit/s per radio channel (25 kHz). Where applicable this capacity is distributed among several users in one cell.

TETRA uses various mechanisms for transmitting data securely. An initial security measure is encryption on the air interface. Each user negotiates the respective communication key individually with the base station. In addition, there is end-to-end encryption which also encrypts the data between the base station and the control centre.

The V+D standard has been massively extended over the course of time (see section 0).

### 2.1.2 TETRA PDO

Equipment which complies with the PDO (Packet Data Optimised) specification only supported packet-switched data services. Since the V+D standard (see section 0) is more comprehensive, has been continuously extended and also supports packet-switched data services for important voice transmission, the PDO standard has become obsolete. PDO has not been further developed by the ETSI since 1998 (standstill).

### 2.1.3 TETRA DMO

TETRA DMO (Direct Mode Operation) enables a direct connection from one mobile station to another mobile station, without the involvement of a base station (walkie-talkie). Thus for instance simple communication options are still available in areas with no coverage or in emergencies during which high traffic volumes are to be expected at certain times. This mode can also be used if users are outside the covered area.

With DMO, simplex operation only is possible. The mobile stations taking part in a call operate on the same frequency. With DMO up to two independent simplex connections can be maintained at the same time on one carrier.

Two other interesting equipment functions of DMO are the DMO repeater and DMO gateway:

- **DMO repeater:** If DMO mobile stations are too far away from each other to make contact directly, they can communicate with each other via a DMO repeater. The DMO repeater is a specially equipped mobile station which is located between the DMO users and interconnects them. This enables the range of DMO mode to be extended. This can also take place outside the coverage area of a base station.

- **DMO gateway:** A suitably equipped mobile station can be operated as a DMO gateway. A DMO gateway is used in order to connect DMO users who are outside the base station coverage area to the base station. For example, via a DMO gateway a rescue team in the depths of a large building and communicating with each other in DMO mode can remain in contact with network subscribers and the control centre. In this case, typically, a special mobile station in a vehicle which is in the vicinity of the building concerned acts as a DMO gateway and is connected to the base station.

## 2.2 TETRA Release 2 (TETRA 2)

Since the UMTS and LTE public mobile radio systems (the main competitors to PMR systems) are rapidly evolving and enable ever higher data rates, TETRA has also had to catch up, in order to meet the rising expectations of PMR customers. At the end of 2005, the ETSI published Release 2 of TETRA (TETRA 2) with, among other things, the following two major new functionalities:

- Range Extension
- TETRA Enhanced Data Service (TEDS)

The two functionalities are described below in greater detail.

TETRA 2 uses the same TDMA channel access method as Release 1 and is completely backward-compatible.

### 2.2.1 Range Extension

The range of TETRA 1 is limited to 58 km due to the TDMA structure. By modifying the uplink and downlink time slots and the guard intervals between the time slots, with TETRA AGA (Air-Ground-Air) it has been possible to increase the range to 83 km. With AGA, users in aircraft can communicate with each other via a base station on the ground. This option is of particular interest to emergency services. AGA supports TETRA 1's V+D services 1, but not TEDS.

### 2.2.2 TETRA Enhanced Data Service (TEDS)

Whereas with the first TETRA systems voice communication was in the foreground, today more data-based applications are increasingly being used. With TETRA Enhanced Data service (TEDS), the most important innovation of TETRA 2, in addition to $\pi/8$-D8PSK phase modulation, a robust multi-carrier technology with QAM-modulated sub-carriers was introduced.

With the TEDS multi-carrier modulation, 8 sub-carriers per radio channel are introduced with a 2.7 kHz frequency spacing. The symbol rate for the QAM symbols on these sub-carriers is 2.4 ksymbols/s. In its principle, the multi-carrier technology strongly resembles the OFDM method, which is used, for example, with LTE or with digital broadcasting. In contrast with OFDM, with multi-carrier technology the symbols in the baseband are filtered and thus the unwanted out-of-band emissions are greatly reduced. Multi-carrier technology is advantageous in the event of difficult propagation conditions with many reflections.

The individual sub-carriers can be modulated as follows:

- 4-QAM (for coverage at the cell edge)
- 16-QAM (for moderate bit rates)
- 64-QAM (for high bit rates in the case of good signal quality)

With multi-carrier technology using QAM modulation, very large amplitude fluctuations occur. These are somewhat greater than with TETRA 1's phase modulation. Therefore, with TEDS, either very linear and complex power amplifiers must be used or the transmit power must be reduced. In the latter case the maximum cell radius for TETRA 2 is reduced.

In addition, with TEDS two, four or six 25 kHz radio channels can be bundled, so channel bandwidths of 50 kHz, 100 kHz or 150 kHz can be made available for a single connection.

With TEDS, 34 QAM symbols are transmitted per time slot (14.17 ms) and per sub-carrier on the downlink; with the largest channel bandwidth of 150 kHz (48 sub-carriers, the figure is therefore 1632 QAM symbols per time slot. The channel bit rates (not to confused with the usable bit rate) with TEDS are given in the following table:

**Table 1: TEDS channel bit rates on the downlink [kbit/s]**

| modulation type | channel bandwidth | | | |
|---|---|---|---|---|
| | 25 kHz (8 subcarrier) | 50 kHz (16 subcarrier) | 100 kHz (32 subcarrier) | 150 kHz (48 subcarrier) |
| 4-QAM (2 bits/symbol) | 38.4 | 76.8 | 153.6 | 230.4 |
| 16-QAM (4 bits/symbol) | 76.8 | 153.6 | 307.2 | 460.8 |
| 64-QAM (6 bits/symbol) | 115.2 | 230.4 | 460.8 | 691.2 |

After deduction of the overheads of the physical layer (header, synchronisation and pilot symbols), the redundancy of the channel coding and the headers of the lower protocol layers (MAC, LLC), the following maximum usable bit rates are possible with TEDS with 4 time slots for the transmission of IP packets:

**Table 2: Maximum TEDS bit rates with occupancy of four time slots on the downlink [kbit/s]**

| modulation type and coding rate | channel bandwidth | | | |
|---|---|---|---|---|
| | 25 kHz | 50 kHz | 100 kHz | 150 kHz |
| π/4-DQPSK (r = 2/3) | 15 | | | |
| π/8-D8PSK (r = 2/3) | 24 | | | |
| 4-QAM (r = 1/2) | 10 | 26 | 55 | 86 |
| 16-QAM (r = 1/2) | 20 | 51 | 110 | 173 |
| 64-QAM (r = 1/2) | 30 | 77 | 164 | 259 |
| 64-QAM (r = 2/3) | 40 | 103 | 219 | 345 |
| 64-QAM (uncoded) | 60 | 154 | 329 | 518 |

On the uplink the corresponding bit rates are some 10% lower.

With active error protection under real propagation conditions, with a 50 kHz channel bandwidth, in practice TEDS achieves a typical bit rate of 80 kbit/s and with a channel bandwidth of 150 kHz it achieves a typical bit rate of 250 kbit/s. This capacity is distributed where applicable among several users in one cell.

TEDS is mainly used for transmission of IP packets across the air interface. By means of dynamic adaptation of the channel bandwidth and modulation to changing propagation conditions, a constant and reliable connection of mobile equipment with the control centre can be maintained via an intranet or the internet.

# 3 Services

In simple terms it can be said that TETRA can provide almost everything that has been possible to date with conventional PMR systems, plus a wide range of possibilities in relation to the increasingly important data communications.

In addition, TETRA's flexible system and interface structure offers even greater opportunities. To illustrate this, we have sub-divided the services into different groups: teleservices, carrier services (or data services) and supplementary services. Many of these services have not (yet) been implemented in the public mobile radio systems.

The list below is not exhaustive and merely contains a selection of services which can be provided by TETRA.

### 3.1 Teleservices

- **Individual Call:** This service corresponds to a call in a public mobile radio system (GSM, UMTS, LTE). One user calls another individual user and is connected with the latter.

- **Group Call:** One user calls a predefined group. Each member of the group can hear everything and can speak. The group call can be set up so that the individual members must acknowledge or not. A group can be modified dynamically, i.e. members can be added or removed.

- **Direct Mode:** In direct mode, two or more mobile stations communicate with each other, without involving a base station (walkie-talkie).

- **Broadcast Call:** This is a unidirectional point-to-multipoint call within a specified area. The area and the users are defined in advance. The individual users do not acknowledge the call and therefore the caller is unable to verify who has and who has not received the call.

- **Emergency Call:** An emergency call button sets up a high-priority call to a dispatcher or a predefined group of users.

- **Include Call:** During a call, this function makes it possible to ring one or more additional users and include them in the call.

- **Open Channel:** A group of users can converse with each other on a specific channel for a specific period. Within the group, all participants can hear each other and can speak at any time. In TETRA this service is not explicitly standardised. However, it can be installed with the aid of a broad range of extra services (e.g. Pre-emptive Priority Call and Call Retention) (see [4]).

### 3.2 Carrier services (data services)

- **Status Transmission:** very short, predefined messages can be transferred from the dispatcher to the mobile stations and vice versa or between mobile stations.

- **Short Data Service:** predefined messages can be sent to individual subscribers or to a group.

- **Circuit-switched data services (TETRA 1):**

| | | |
|---|---|---|
| - non-protected data transmission: | n x 7.2 kbit/s | (n = 1, 2, 3 or 4) |
| - protected data transmission: | n x 4.8 kbit/s | (n = 1, 2, 3 or 4) |
| - highly protected data transmission: | n x 2.4 kbit/s | (n = 1, 2, 3 or 4) |

  (n = number of occupied time slots per connection).

- **Packet-switched data services:**

  - **TCP/IP access**: this important data service allows the mobile stations to access the internet or servers which support the TCP/IP protocol. With TEDS (see section 2.2.2), in the 50 kHz channel bandwidth the typical data rate is 80 kbit/s.

### 3.3 Supplementary services

- **Discreet Listening:** an authorised person can monitor radio communications without the subscribers concerned being aware of this.

- **Ambience Listening:** This supplementary service allows the dispatcher to listen in unnoticed to a vehicle in unclear or dangerous situations. This service is important above all for the police or other emergency services.

- **Priority Call:** This supplementary service allows a user to allocate a priority to the call. The call is then processed before all other calls which have a lower priority. If no more network resources are available (e.g. all channels are busy), the necessary resources can be released by means of the so-called Pre-emptive Priority Call. The calls with the lowest priority are consequently aborted in this case.

- **Late Entry:** This supplementary service allows a user to connect at a later time to a group call, for example if he was engaged at the time of the call or if he had not yet switched his equipment on.

# 4 Summary and comparison with Tetrapol

The table below summarises the key technical data of the TETRA air interface:

**Table 3: Technical data of the TETRA air interface**

| | **TETRA 1** | | **TETRA 2 (TEDS)** | |
|---|---|---|---|---|
| access scheme | TDMA<br>4 physical channels/RF channel | | TDMA<br>4 physical channels/RF channel | |
| channel bandwidth (CBW) | 25 kHz | | 25 kHz, 50 kHz, 100 kHz, 150 kHz | |
| duplex separation | 10 MHz, 45 MHz | | 10 MHz, 45 MHz | |
| modulation class | phase modulation | | Multi-Carrier filter-bank based QAM | |
| modulation type | π/4-DQPSK | | 4-QAM, 16-QAM, 64-QAM | |
| peak-to-average power ratio (PAPR) | 3.2 dB | | up to 11 dB | |
| modulation rate | 36 kbit/s | | 2'400 symbols/s/subcarrier | |
| max. user bit rate (1 timeslot) | *high protected:* | 2.4 kbit/s | *4-QAM, r = 1/2, CBW = 50 kHz:* | 6.5 kbit/s |
| | *low protected:* | 4.8 kbit/s | *16-QAM, r = 1/2, CBW = 50 kHz:* | 12.8 kbit/s |
| | *no protected:* | 7.2 kbit/s | *64-QAM, r = 1/2, CBW = 50 kHz:* | 19.3 kbit/s |
| max. user bit rate (4 timeslots) | *high protected:* | 9.6 kbit/s | *4-QAM, r = 1/2, CBW = 150 kHz:* | 86 kbit/s |
| | *low protected:* | 19.2 kbit/s | *16-QAM, r = 1/2, CBW = 150 kHz:* | 173 kbit/s |
| | *no protected:* | 28.8 kbit/s | *64-QAM, uncoded, CBW = 150 kHz:* | 518 kbit/s |
| typical user bit rate (4 timeslots) | **16 kbit/s** | | *CBW = 50 kHz:* | **80 kbit/s** |
| | | | *CBW = 150 kHz:* | **250 kbit/s** |
| nominal transmit power user equipment | 0.56 - 30 W (typically 1 W) | | 0.18 - 30 W (typically 1 W) | |
| transmit power base station | 0.6 - 40 W (typically 25 W) | | 0.6 - 40 W (typically 10 W) | |
| cell range suburban (400 MHz) [2] | 5.2 km | | *64-QAM, r = 2/3, CBW = 50 kHz:* | 2.4 km |

For calculation of the cell radius in Table 3, the same transmit power as for TETRA 1 (1 W) was used for TEDS at the mobile station. With TEDS, however, it is possible that the transmit power may have to be reduced due to the large amplitude fluctuations of the signal, so that out-of-band emissions do not exceed the limit value.

TETRA and Tetrapol are the two-best known systems for digital trunked radio in Europe and have a very different structure, despite the similarity of the names. TETRA was developed, as described above, by ETSI, the recognised European standardisation institute, in co-operation with the industry. Tetrapol, however, is a proprietary specification of the Matra Communication company (now EADS) and is neither a European nor an international standard. Tetrapol was designed in particular to meet the requirements of the emergency services and is very successful in this market segment. Some advantages and disadvantages of TETRA compared to Tetrapol are summarised in the following table:

**Table 4: Advantages and disadvantages of TETRA compared with Tetrapol**

| **Advantages** of TETRA compared with Tetrapol | **Disadvantages** of TETRA compared with Tetrapol |
|---|---|
| • TETRA's data rates are significantly higher than those of Tetrapol (with TEDS, 4 time slots and 50 kHz channel bandwidth by a factor of approximately 20).<br>• Voice and data can be transmitted simultaneously with TETRA.<br>• Duplex mode is possible with TETRA without an antenna splitter thanks to the TDMA channel access method and is therefore simple to implement.<br>• TETRA's spectrum efficiency is greater than that of Tetrapol (by a factor of 1.16 to 2.0 depending on the environment).<br>• TETRA is an acknowledged European standard, whereas Tetrapol has not been accepted as an ETSI standard.<br>• TETRA is an extremely flexible system and can be used for all PMR applications as well as for emergency radio and conventional PMR/PAMR.<br>• A less expensive antenna network is required in the base station, since TDMA (time slot method) means that 4 channels are available for each carrier frequency.<br>• With TETRA Release 2 (TEDS), with the multi-carrier method in a 150 kHz bandwidth, theoretical data rates in excess of 500 kbit/s and typical data rates of 250 kbit/s have become possible. TETRA is therefore a wideband system. | • The maximum cell radii of TETRA are approximately 30% smaller than those of Tetrapol (assuming the same peak transmit power). TETRA therefore needs around twice as many base stations as Tetrapol to cover a specific area.<br>• With TETRA, unwanted out-of-band emissions are greater than with Tetrapol. Frequency allocation is more difficult. If possible, whole frequency blocks must be allocated, rather than individual frequencies.<br>• With TETRA, simulcast is more difficult to implement and require terminals with powerful equalisers (MS Class E).<br>• Devices with TDMA channel access as with TETRA tend to have greater peak transmit power and may induce audible low-frequency interference in electro-acoustic equipment. |

## Abbreviations

| | |
|---|---|
| BER | Bit Error Rate |
| CBW | Channel Bandwidth |
| D8PSK | Differential 8 Phase Shift Keying |
| DL | Downlink |
| DMO | Direct Mode Operation |
| DQPSK | Differential Quaternary Phase Shift Keying |
| EIRP | Equivalent Isotropically Radiated Power |
| ETSI | European Telecommunications Standards Institute |
| FDD | Frequency Division Duplex |
| GSM | Global System for Mobile Communications |
| LLC | Logical Link Control |
| LTE | Long Term Evolution |
| MAC | Media Access Control |
| MOS | Mean Opinion Score |
| NB | Narrowband |
| OFCOM | Federal Office of Communications |
| OFDM | Orthogonal Frequency-Division Multiplexing |
| PAMR | Public Access Mobile Radio |
| PAPR | Peak-to-Average Power Ratio |
| PDO | Packet Data Optimised |
| PMR | Private Mobile Radio |
| QAM | Quadrature Amplitude Modulation |
| TDD | Time Division Duplex |
| TDMA | Time Division Multiple Access |
| TEDS | TETRA Enhanced Data Service |
| TETRA | Terrestrial Trunked Radio |
| UL | Uplink |
| UMTS | Universal Mobile Telecommunications System |
| V+D | Voice plus Data |
| WB | Wideband (400 - 500 kbit/s) |

## Literature

[1] ETSI TS 100 392-2: Terrestrial Trunked Radio (TETRA); Voice plus Data (V+D); Part 2: Air Interface (AI). (2013)

[2] ETSI TR 102 580: Terrestrial Trunked Radio (TETRA); Release 2; Designer's Guide; TETRA High-Speed Data (HSD); TETRA Enhanced Data Service (TEDS). (2007)

[3] Ketterling, Hans-Peter: Introduction to Digital Professional Mobile Radio, Boston. (2004)

[4] ETR 120: ETSI Technical Report; TETRA Voice plus Data (V + D); Open channel. (1994)