Application Note

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Testing the Radio Performance of TETRA Terminals and Base Stations

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Introduction

A TETRA network is only as good as the performance of the radio equipment which is used on it. This article outlines the reasons for testing TETRA radio equipment and the challenging new types of measurements which are specified to ensure adequate performance. Conformance testing only proves the design of the equipment by testing one sample, manufacturing testing proves the quality of each individual mobile or base station in the factory, whilst testing in service identifies equipment which no longer meets requirements. Throughout the different stages in the lifecycle of TETRA equipment, interoperability remains an issue which needs to be tested to ensure different manufacturers' equipment will work together.

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The Impact of TETRA Equipment Performance

Network integrity depends on correct performance of the radio equipment which is used on the network. TETRA radio equipment has performance requirements from conventional analog radio equipment, and requires new test methods.

It may seem like stating the obvious, but TETRA is a RADIO network and behind the radio (air) interface there is a complex infrastructure of switching and management functions which may dwarf the radio equipment in terms of cost and complexity. However, the infrastructure is largely tested by software and validation exercises to prove the design and once this is done, the performance of the infrastructure should be predictable and repeatable.

The radio interface is the weak link in the network, the link which is most likely to fail or perform sub-optimally. Radio performance depends on the manufacturing quality of the electronic hardware of each individual mobile and base station and is also susceptible to drifting due to component ageing, thermal cycling, harsh conditions and rough handling.

One of the most critical radio performance parameters is power level accuracy. Efficient use of radio spectrum depends on re-use of frequencies in cells; typically cell sizes are reduced as network roll-out progresses and use density increases. Control of cell size depends on both mobiles and base stations using the correct power level. Inadequate power restricts the reach of a transmitter and excessive power can cause interference in a distant cell re-using the frequency, as well as shortening battery life in a mobile.

Receiver sensitivity is also important for cell sizing. Radio receivers need to be able to receive low level signals in order for mobiles to work at the edge of a coverage area. They also need to work under the multi-path fading conditions typically experienced in urban environments, mountainous areas and moving vehicles. Power accuracy and adequate sensitivity are important for obtaining coverage within the intended range of operation. When inadequate, the equipment may still operate but provide a reduced quality of service.

The other principal network integrity requirement is to ensure that when a radio system is in use it does not interfere with other legitimate users of the spectrum, and similarly cannot be interfered with by other spectrum users. Poor radio performance degrades network performance, often to the detriment not only of the use of the poorly performing equipment, but also affecting other TETRA users or users of other radio systems. TETRA equipment is tested at the connection to the antenna and it is important not to overlook the integrity of the antenna installation itself.

Signalling messages between the mobile and base station are protected by channel coding and error detection schemes to compensate for a poor quality radio link. However, errors in transmission of signalling messages require re-transmission of the erroneous messages, which results in longer response times for the user and reduces the signalling opportunities for other users.

TETRA speech is partially unprotected and higher rate data (eg. video) is completely unprotected. Poor quality radio transmission and reception results in direct corruption of these services and poor radio quality may result in an inability to setup a call or to maintain communication between base station and mobile.

New radio performance requirements of TETRA

TETRA radio equipment will have to co-exist with analog radio equipment for many years and TETRA is highly specified in order to avoid interference to or from analogue and other radio equipment.

The signalling protocol for TETRA is considerably more complicated than that for analogue radio systems such as MPT 1327. However, leaving protocol aside, there are three fundamental radio aspects of the TETRA air interface which differentiate it from analogue radio.

TETRA is a Time Division Multiple Access System (TDMA), meaning that multiple users (up to four) are time-sharing the same radio frequency channel with transmissions interleaved in 14.2 ms timeslots. It is a digital system whereby all information transmitted is 1 s and 0 s and the quality of transmission and reception is judged by the success or failure in communicating binary data. It is also a controlled link system. Transmission power levels are variable, so that mobiles only transmit at their rated power output when necessary, thus reducing interference and conserving battery life.

Figure 1 - Air Interface - TDMA illustrated

Each TETRA carrier is spaced at 25 kHz intervals and supports 4 users. The terminals can be operated either in simplex mode or duplex mode (allowing simultaneous communication in both directions). In a typical 400 MHz system there would be 10 MHz difference between the transmit and receive frequencies (45 MHz for 800 MHz systems).

On the physical air interface each call is allocated one of four time slots on a particular downlink carrier frequency for MS reception, and the corresponding time slot on the corresponding uplink carrier frequency for MS transmission. Each time slot contains traffic in two fields and a number of bits that aid the terminal in synchronising to the air interface signal. A TETRA call typically uses just one time slot on the up and down links, separated by a time equivalent of two slots, enabling the MS to avoid transmitting and receiving simultaneously.

At the base station the signals for four separate calls are assembled into one TDMA frame and these are organised into a structure of multi-frames and hyper-frames. Terminals use the timing information from the received signal to judge when they should transmit to the base station in their allotted time slot. TETRA timeslots are of duration 14.2 ms, in which a TETRA mobile is required to transmit at the correct power level for 12.8 ms. Guard periods are defined before and after the transmission period during which the mobile increases and decreases its powers in a controlled manner, known as ramp up and ramp down.

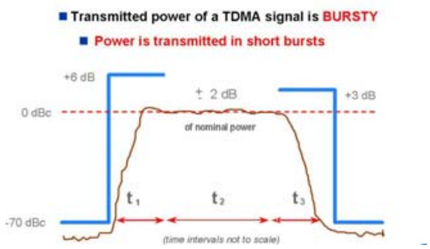

Figure 2 - TETRA Power Profile Mask

When a discontinuous TETRA device switches on it has to ramp its signal up in a controlled way. Ramping too fast will cause the signal spectrum to spread and if too slow, information in the useful part maybe lost. The ramp up and ramp down periods are defined by a power-time mask, which the power vs. time behaviour of the mobile (the power mobile) must not exceed. The mask defined for TETRA only ensures that the ramp up does not start too early, that the ramp down does not finish too late and that the power does not overshoot excessively during the ramp up period.

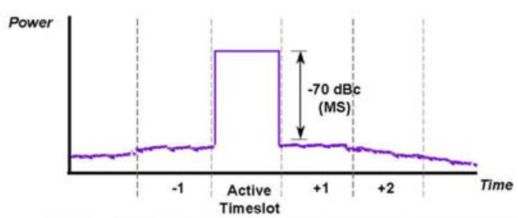

Figure 3 - Performance Requirements of a TDMA Systems

The bursted nature of TETRA makes power a difficult parameter to measure. In addition the modulation results in a non-constant envelope. In practice it is necessary for manufacturers to ensure that power ramp up and ramp down conforms to their own requirements in order that other TETRA specifications are not violated. If the ramping is not controlled adequately, the equipment will fail another TETRA test, which measures adjacent channel power due to switching transients. If ramp up or ramp down are too slow, the beginning or end of the burst will suffer low amplitude which will be revealed as excessive vector error in the TETRA modulation accuracy test.

Since the radio frequency channel is time-shared with other users, it is essential to avoid interference between users, which requires that each mobile correctly times its transmissions, and sufficiently attenuates its power during the timeslots in which other users are transmitting.

Digital radio transmission and reception is concerned with the reliable transfer of binary data, regardless of whether this is signalling, voice or data. Modulators, mixers and power amplifiers will introduce distortion into the transmitted signal, as for analogue equipment.

Whereas for analogue equipment distortion could be measured directly using e.g. a 1 kHz tone, digital radio systems such as TETRA require a more complicated measurement of modulation accuracy, known as Vector Accuracy. The criterion for successful digital transmission is that distortion of the modulated signal remains within acceptable limits such that the binary data in the signal can be correctly recovered.

Similarly, digital systems such as TETRA measure receiver performance not with a 1 kHz SINAD test, but using a digital signal for measurement of Bit Error Rate (BER) or Message Erasure Rate (MER). Again, the criterion for successful reception is that the binary data in the signal can be correctly recovered. TETRA systems transmit bits at a particular rate and it is essential that mobiles remain synchronized in frequency and timing to the base station to ensure correct alignment.

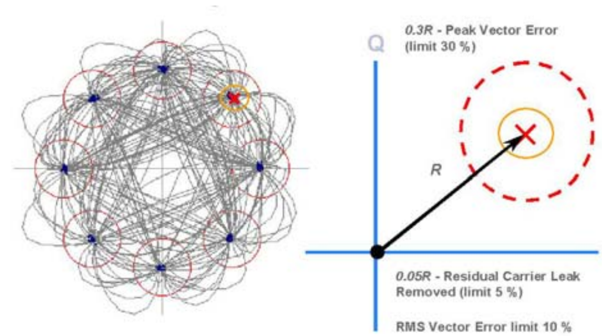

Figure 4 - Vector Accuracy

TETRA uses a modulation scheme known as phase offset Differential Quaternary Phase Shift Keying (pi/4 DQPSK), to transmit two bits of binary data in modulation symbol. The signal from a TETRA transmitter, after filtering in the receiver, is shown in the IQ diagram (Fig. 4), assuming there are no propagation defects. The distance from the centre (origin) is representative of amplitude and the angle from the right hand horizontal axis is representative of phase.

After filtering, the signal shows 8 bright spots, referred to as decision points, where the information content of the signal is determined. The information is contained in the relative phase shift between symbol points, not in the actual vector position at the symbol time. The fact that the decision points are bright spots indicates that there is no inter-symbol interference. There are 8 rather than 4 decision points because the modulation use a 45 degree rotation (phase offset) between transmitted symbols. This prevents the phase trajectory passing through the origin of the diagram, which ensures that the signal amplitude does not fall to zero at any time during data transmission.

Vector accuracy is defined as a circle about the symbol point in which the phase and amplitude of the carrier has to be. It is measured after any carrier frequency error and any carrier leak in the IQ modulator are mathematically removed. Two values are specified, peak and RMS. Vector errors are due to the accumulations of a number of factors in the design of the TETRA device. These include digital to analogue converter errors, IQ modulator inaccuracies amplifier distortion and phase noise on the local oscillator.

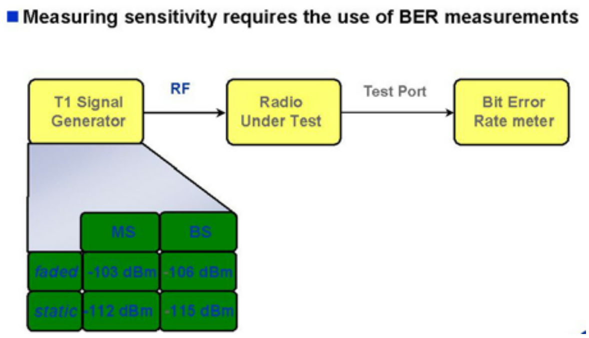

Figure 5 - Measure Rx Sensitivity

Sensitivity tests require an RF signal to be applied to the radio under test and the BER or MER measured. The BER/MER can be measured externally by an error rate meter, internally by the radio itself, or by requesting the radio to loop back the demodulated signal onto its transmitter and for a signal analyser or radio test set to recover the data and measure the BER.

The RF signal supplied needs to contain a pseudo random binary data sequence (PRBS) framed with timing and control information such that a TETRA receiver can synchronize to the signal and make sense of its data content. TETRA defines several such signals as 'test signal T1' and a specialized signal generator is required for this.

TETRA specifies measurements to be made under both static and dynamic (faded) conditions. The specifications for a base station are more stringent than those for a mobile subscriber terminal. Faded conditions simulate the effects of a mobile moving through a complex set of reflected signals from the same base station which interfere with each other. The signal received is constantly changing in amplitude and phase because of the sum of the different received signal paths varying with position.

The BER/MER can be measured by requesting the TETRA radio to loop back the demodulated signal onto its transmitter and for a signal analyser or radio test to recover the data and measure the BER. This RF loopback test configuration is specified in EN 300 394-1 Annex D (ETSI) and TTR 001-8 TIPv4 Part 8 (TETRA MoU).

This test interface requires that a TETRA device recognizes a test mode where signals from a TETRA simulator are decoded by the device under test and then transmitted back to the simulator for analysis. In this way, basic receiver and transmitter tests can be performed without access to a proprietary interface. In addition, the test mode requires the device under test to use normal call setup procedures which gives the user confidence that the device will operate on a system.

This test method also avoids test personnel having any knowledge of the security aspects of a TETRA installation bypassing the normal security procedures in a way that is not a threat to the security of a network. As such, the RF Loopback method of testing the Rx is extremely useful for service and maintenance of TETRA radio equipment.

With analogue radio systems such as MPT 1327, manufacturers simply sell radio equipment as being of a particular power rating. Normally the radio equipment operates at this power rating whenever the transmitter is keyed, although there may be a manual switch to a lower power level. This causes radio transmissions to spread over a greater area than may be necessary, and requires large heavy battery packs to compensate for this inefficient operation.

TETRA radios have to conform to a defined power class. There are four defined classes of 30 W, 10 W, 3 W and 1 W, as well as four new intermediate 'L' classes that are 2.5 dB lower.

All TETRA radios have to implement power level control, such that the power can be varied in 5 dB steps down to 30 mW. A TETRA radio is expected to control its own power level in response to the strength of signal received from the base station, in conjunction with parameters broadcast by the base station (open loop power control). This requires that the mobile can accurately measure the strength of the signal received from the base station.

Radio systems define radio frequency channels in which radio equipment transmits and receives; in the case of TETRA these channels are 25 kHz wide. In real life, all radio transmitters produce a degree of interference outside of the allocated channel. A TDMA system such as TETRA also has the potential for interference due to the switching transients as it ramps up and down the power for each burst.

The DQPSK modulation and TETRA filter are designed, in theory, to avoid spectral spread into adjacent channels (unlike constant envelope schemes such as FM or GMSK). In practice, modulator and transmitter impairments result in a certain amount of power appearing in the adjacent channels. Transmitter non-linearity can cause an increase in adjacent channel power and TETRA permits occasional increases in ACP for the purposes of linearity correction.

Although a radio receiver is tuned in to a particular frequency channel, real life receivers do not provide infinite attenuation of signals at other frequencies, and may be susceptible to degradation in the presence of high level interfering signals in other channels.

In order to avoid problems between TETRA and analogue radio users, or indeed between TETRA users, the TETRA specifications include some very demanding requirements for transmitter and receiver performance. To measure this performance imposes demanding requirements on the test equipment.

The TETRA Adjacent Channel Power (ACP) specifications have proved to be particularly demanding, requiring close attention to transmitter linearity, modulation accuracy and the implementation of the TETRA filter. Power in the first adjacent channels (+/- 25 kHz) must not exceed - 60 dB w.r.t. the allocated channel. Power in the second and third adjacent channels (+/- 50 kHz and +/- 75 kHz) must not exceed - 70 dB (relaxed slightly for 1 W mobiles).

TETRA transmitters must also be protected against signals from other transmitters at different frequencies that can cause intermodulation problems. Base stations may be co-located and thus have a tighter specification than mobiles.

TETRA receivers must withstand the presence of other TETRA signals and analogue signals at much greater levels than the wanted TETRA signal in the frequency channel to which the receiver is tuned.

New Challenges of Testing TETRA equipment

The new testing methods may be unfamiliar to analogue radio users and the demanding TETRA specifications create challenging new requirements for test equipment.

Traditional power meters are not designed for measuring short bursts of power from TDMA systems. If a power reading is produced at all, it may not be reliable. A traditional frequency meter is likely to give an incorrect reading of the centre frequency of a TETRA modulated signal, even if this is non-bursty.

Conventional 1 kHz transmitter distortion and receiver SINAD measurements are not normally used for TETRA as there is no correlation between the audio signal and the modulated radio signal. TETRA is a digital system and audio signals are processed by a speech codec as well as being subject to channel coding.

Conventional swept frequency spectrum analyzers can be useful as a visual inspection of a TETRA signal to identify gross impairments but a spectrum analyzer alone is inadequate for TETRA signal analysis.

TETRA transmitter measurements are complicated. Most transmitter measurements require capture of a burst transmission with the measurement period time-aligned to the active period of the burst. Many measurements require much finer alignment such that the measurement is only made at the decision points of the modulation symbols. This applies even to average power measurement.

Further, most TETRA transmitter measurements must be filtered. A TETRA radio implements a TETRA (Root Nyquist) filter in both the transmitter and the receiver, such that the overall transmit-receive response is Nyquist filtered. For making valid TETRA transmitter measurements, the test equipment must emulate a TETRA receiver by Root Nyquist filtering the measured signals. The Nyquist filter restricts the spectral spread of the signal without introducing inter- symbol interference (ISI).

Measurement of Adjacent Channel Power and non-active power, where the radio under test is required to achieve 70 dB dynamic range or better, requires the test equipment to achieve at least 80 dB. The TETRA filter in the test equipment must be very precise, requiring a digital filter with a minimum length of 30 symbols.

The T1 signal generator for receiver testing must implement TETRA channel coding schemes and conform to the TETRA multiframe structure. The T2 signal generator for adjacent channel interference testing must produce less than -70 dB adjacent channel power.

The parameters above should be tested at the design validation stage to ensure that the receiver design is sound and can reject interfering signals according to specification.

All these tests are unlikely to be made on all production units but at some stage, either periodically or on a batch, manufacturers will need to carry out all these measurements. Here the test methodology may be simplified where otherwise it would be too time consuming and require specialist equipment, such as fading simulators and complex filtering.

Evaluating test solutions for TETRA

Different types of testing are required at different stages in the lifecycle of TETRA equipment, from R&D through conformance testing, manufacturing test and service testing.

Conformance testing establishes that a particular manufacturer's product meets the essential specifications of the standard aspects defined in ETSI EN 300 394-1 v2.3.1.

This covers all the RF performance aspects of the air interface such as power and modulation accuracy. The effect the equipment has on the RF environment is also regulated so it is necessary to measure for example, the power generated in an adjacent channel and the level of spurious signals emitted.

Although conformance tests are performed using fading simulators to produce dynamic receiver sensitivity tests, these require very long test times to obtain statistically valid results which means that manufacturing tests are normally performed using static signals.

For receiver measurements a specified test pattern is generated and the digital information recovered by the radio is analyzed. Other RF signals are added to assess the effect of interferers (co-channel, adjacent channels, blocking and intermodulation) on the received signal quality. Propagation simulators are added to test the effect of multi-path conditions on the receiver performance. Transmitter measurements are performed using a TETRA signal analyzer. The analyzer must be capable of capturing a complete TETRA burst and performing modulation and spectrum analysis with a specified TETRA filter as well as conventional spectrum analyzer measurements.

The most important requirements for TETRA manufacture testing are speed, accuracy and repeatability. In the early phases, it is likely that a large number of testing parameters on every radio manufactured will be carried out, but as the manufacturing process becomes more mature and typical performance can be characterized, this can be reduced. To ensure that each individual sample of the product meets the required specifications, manufacturing tests may be performed as a subset of the conformance tests, designed to ensure that the product continues to be correctly manufactured. This process will also reflect the manufacturer's own test strategy and the perceived areas of risk in the product.

The manufacturing process employed and the modularity of the product will determine the test strategy. For example if the product is functionally divided into an RF module and a signal processing module, much of the test can be carried out at module level.

The Quality Control strategy of the manufacturer will also influence the level of test carried out directly on the production line. Often three levels of test are involved, with all samples going through the minimal production test. A smaller proportion, maybe 2%, are subjected to a higher level of testing, whilst 0.01% of samples are subjected to a subset of the Type Approval test at the manufacturer's own premises.

Installation and maintenance tests are performed to ensure that the installation satisfies the users' needs and continues to do so throughout its life. The level of testing may reflect the users' perception of the value of testing (e.g. it is much more important in safety critical applications) and the manufacturer's recommendations.

Interoperability between different manufacturers' terminals and base stations is tested by a combination of IOP tests on real infrastructure and terminal tests on a Radio Test Set. Interoperability is important for radio test equipment because functional tests such as registration and call placement are used to operate the terminal's transmitter and receiver so that RF tests can be performed - the test equipment has to work with all manufacturers' TETRA terminals.

Design repeatability may be a factor in the early stages of TETRA manufacture with special testing required to ensure that a particular performance goal is achieved. This may influence the test equipment used in production such that laboratory results can be replicated.

Most transmitter measurements will be made using a modulation analyzer. Difficult measurements such as ACP and non-active power require high dynamic range and an accurate implementation of the TETRA Root Nyquist filter. For statistically valid results, TETRA specifies 200 repetitions of each measurement. Since these measurements are computationally intensive, fast measurement processing is needed to achieve short test times.

Service testing may be performed by personnel with little knowledge of the technical details of TETRA. It is important that equipment for service testing is quick and easy to use without requiring specialist knowledge. The purpose of this phase of testing is to ensure that the equipment performs as intended when installed and continues to do so throughout its life. Equipment for this purpose is usually portable, being capable of both field and workshop operation. Typically a system simulator in the form of a Radio Test Set is used.

It is also important that it is possible to test a TETRA radio in its normal operational mode or a similar manner, so that service testing operators do not need knowledge of special manufacturer specific test modes. ETSI EN 300 394-1 Annex D specifies an RF Loopback mechanism for TETRA radios, ensuring that receiver Bit Error Rate (BER) can be measured with one simple RF connection in the same manner as for GSM mobile phones. This eliminates the need for separate manufacturer specific test connectors and test modes, and makes testing faster.

The RF loopback specification also enables the test equipment to obtain the radio's TETRA Equipment Identity (TEI) or hardware serial number, its power class and receiver class, so that automated testing can be performed.

CHINA Beijing
Tel: [+86] (10) 6467 2716
Fax: [+86] (10) 6467 2821

CHINA Shanghai
Tel: [+86] (21) 6282 8001
Fax: [+86] (21) 62828 8002

FINLAND
Tel: [+358] (9) 2709 5541
Fax: [+358] (9) 804 2441

FRANCE
Tel: [+33] 1 60 79 96 00
Fax: [+33] 1 60 77 69 22

GERMANY
Tel: [+49] 8131 2926-0
Fax: [+49] 8131 2926-130

HONG KONG
Tel: [+852] 2832 7988
Fax: [+852] 2834 5364

INDIA
Tel: [+91] 80 5115 4501
Fax: [+91] 80 5115 4502

KOREA
Tel: [+82] (2) 3424 2719
Fax: [+82] (2) 3424 8620

SCANDINAVIA
Tel: [+45] 9614 0045
Fax: [+45] 9614 0047

SPAIN
Tel: [+34] (91) 640 11 34
Fax: [+34] (91) 640 06 40

UK Burnham
Tel: [+44] (0) 1628 604455
Fax: [+44] (0) 1628 662017

UK Stevenage
Tel: [+44] (0) 1438 742200
Fax: [+44] (0) 1438 727601
Freephone: 0800 282388

USA
Tel: [+1] (316) 522 4981
Fax: [+1] (316) 522 1360
Toll Free: 800 835 2352

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www.aeroflex.com

info-test@aeroflex.com

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