On-Site Measurements of TETRA Standard Emission Disturbing Interference

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Abstract. In this paper a simple test-bed to evaluate the effect of an unmodulated disrupting signal on a TETRA π/4-DQPSK (Differential Quadrature Phase-Shift Keying) signal has been developed and implemented, such that the transmitted signal does not affect other communication system existing in the same area. An unmodulated disrupting signal, with increasing amplitude, has been overlapped on the transmitted data and the parameters of the received signal has been evaluated with an Agilent Vector Signal Analyzer model 89600. Based on the results obtained, several interesting conclusions have been highlighted at the end.

Keywords: Disturbing signal · Interferences · Phase modulation · Signal quality parameters · TeTRa

1 Introduction

TETRA is a Professional Mobile Radio (PMR) standard that offers a wide range of services, starting with security services and ending with space-based modes of work [1]. A great advantage of the system is the large coverage using a single frequency, without the need to implement complex radio frequency re-use schemes. Another major advantage is the possibility of providing services to several institutions on the same infrastructure. Mobile stations (MS) communicate via TETRA standard base stations. Also, MS can communicate between them without base stations in situations where the network is unavailable or base stations are stopped for various reasons. The major application of TETRA is group dial mode [2]. The structure of the network is shown in Fig. 1.

The most important interface specification is the ETSI TETRA air interface, which ensures interoperability between radio terminals and base stations that allows a basic communication mode commonly referred to as Trunked Mode Operation (TMO). Even though the TETRA system has been developed and standardized during the 90 s, there is still recent research that aims to develop the system and to find new applications for it. In [3, 4] the authors proposed a positioning method of tram vehicles by combining positioning data from satellite positioning system, the interconnection between the vehicles being performed using TETRA; the system benefits thus of reduced costs, high accuracy positioning preserving also the continuity, reliability and maintainability of

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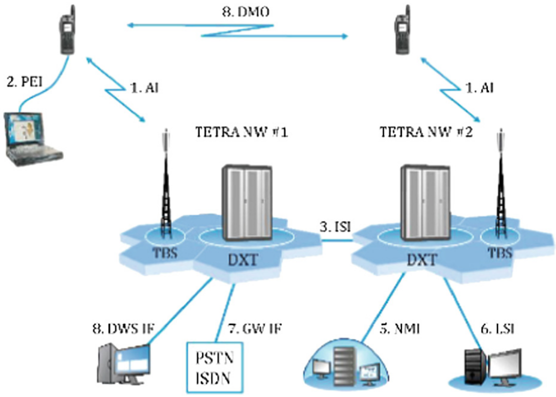

Fig. 1. Tetra network interfaces [3]

the TETRA system. In [5] is presented an innovative signalling compression method for the Mission-critical push-to-talk over LTE call service introduced in LTE release 16, with limited capacity of carrier aggregated broadband system and proposed an architecture that hosts compression proxies for the network and user without the changing the core network of LTE system. During the last couple of years patent applications have been also been made. In [6] the authors presented a system and a methodology developed for reducing the interference between two communication entities based on a determined geographical proximity of the two mobile stations, while in [7] an authentication method and the associated structure has been presented.

The remainder of the paper is organized as follows in the second chapter are described the signal quality parameters that are evaluated and the mathematical background that stands behind them. Chapter three presents the measurement setup, the location, the resources used, and the simulation algorithm, as well as the results obtained under different disrupting parameters, the way in which the modulation quality parameters are affected. In the final part some interesting results are highlighted.

2 Measurement and Evaluation of TETRA Signal Parameters

The data is transmitted digitally, by the Tetra base station, through a channel affected by noise, fading and other disturbances and, in order to evaluate their effect, a vector analyser is used at the receiver end. This represents each received symbol as a vector, compares it with a reference, and evaluates several parameters [8, 9] that reflect the quality of the received signal, as follows. The *Measured Error Vector*, EVM, denoted by [*n*] is the Euclidean distance between the measured point and the ideal reference point, given by

$$EVM[\mathrm{n}] = \sqrt{Ierr[\mathrm{n}]^2 + Qerr[\mathrm{n}]^2} \tag{1}$$

where *Ierr*[n] and *Qerr*[*n*] are the in phase and quadrature components of the error vector. The mean square value of EVM (*% EVM*) is determined as

$$\%EVM = \frac{\frac{1}{N}\sum_{k=1}^{(N-1)} \sqrt{Ierr[k]^2 + Qerr[k]^2}}{[peak\ reference\ vector]} \tag{2}$$

where *N* is the number of measured points considered for calculating EVM root mean square and the [*peak reference vector*] is the amplitude of the most important (highest power) point in the reference signal constellation. The *IQ Magnitude Error* is determined as the difference between the magnitudes of the measured signal and reference the one

$$IQ\ Magnitude\ Error = \sqrt{IMeas^2 + QMeas^2} - \sqrt{IRef^2 + QRef^2} \tag{3}$$

The *Phase Error* represents the phase difference between the reference signal and the measured one and is determined as

$$Phase\ Error = \arctan\left(\frac{QMeas}{IMeas}\right) - \arctan\left(\frac{QRef}{IRef}\right) \tag{4}$$

The Frequency Error (*Freq Err*) is the difference between the frequency of the signal and the central frequency of the analyser, and shows the bearer frequency shift with respect to the local oscillator. The *IQ Offset* - represents an evaluator of the rotation of the constellation points due to channel effect and it is determined as.

$$IQ\ Offset = 20\log_{10}\left(\frac{signal}{offset}\right), \tag{5}$$

where *signal* and *offset represents* the ratio of the power from the central frequency to the average power of the signal.

The *Amplitude Droop* is a measure of the degree of change in the signal amplitude during a burst (temporal slot), measured in dB/symbol. The *IQ Gain Imbalance* compares the magnitudes of the in phase and quadrature components and is expressed in dB.

$$IQ\ gain\ imb = 20\log_{10}\left(\frac{Imag}{Qmag}\right) \tag{6}$$

Finally, the Quadrature Error (*Quad Err*) quantifies the deviation from orthogonality between the in phase and quadrature components, that usually indicates a problem on the transmitter side [6].

Maximal dynamic and static reference sensitivity levels for a BS receiver under normal and extreme conditions are stated in Table 1 [7].

Table 1. Maximum sensitivity levels for a base station receiver

Normal	−106 dBm	−115 dBm
Extreme	−100 dBm	−109 dBm

The limit values for phase modulation specifies the minimum reference interference ratio performances (*C*/*Ic* for co-channel, and *C*/*Ia* for adjacent channel), that depends on the channel type, modulation, channels state and receiver class. For π/4-DQPSK the reference interference ratios imposed by specifications are

- for co-channel interference, *C*/*Ic* = 19 dB for both mobile and base stations;
- for adjacent channel interference, below 700 MHz *C*/*Ia* = −40 dB for the mobile station and *C*/*Ia* = −45 dB for the base station while over 700 MHz *C*/*Ia* = −40 dB for both mobile and base stations.

3 Case Study

As more and more radiocommunication services emerges, radio interference becomes a phenomenon that increasingly affects the quality of TETRA services. These licenses include military, aeronautical, governmental and emergency services, which use the 380–385 MHz and 390–395 MHz bands. In addition to these, there are also many low-power, unlicensed radio transmissions from wireless microphones, Wi-Fi spots, video cameras, alarm systems, and more. Bucharest has over 2 million inhabitants, but, with the commuters, they can be twice as many, therefore, the discovery of the source of interference on a TETRA radio frequency is an important critical activity. In order to achieve this goal, several steps have to be performed.

In order to identify the disturbing signal, one has to see what are the signals that reach the device that might have problems, or behaves in an unusual manner. For example, a base station antenna is its first item checked. For digital transmissions, such as cellular ones, interferences manifests themselves by a decreased coverage, a blockage or a loss of conversions, or even a transfer rate lower than the usual one. That familiar cascade sound from the cellular phone or cellular station indicates a poor reception and a large bit error rate that can be caused by interference. A second interference indicator is the noise level that reflects into a larger bit error rate in the receiving channel. Other performance indicators, such as call set-up time, latency time, will suffer.

The measurements were performed in Bucharest and a Tetra base station was used for testing. The cell emission power was reduced to 10 W (40 dBm) in order to avoid disturbing other communications in the same area. Base Station Broadcasting Frequency was 394.587,5 MHz and the receiver frequency were 384.587,5 MHz. With the *Rohde & Schwarz SME 03* signal generator, a disturbance non-modulated signal with the power levels increasing from 3 mW (5 dBm) to 10 mW (10 dBm) and then 79 mW

(19 dBm) was generated successively on the base station's emission frequency (394.587,5 MHz). Evaluation of the received signal was made with the *Agilent Vector Signal Analyzer 89600*, tuned on the base station frequency (394.587,5 MHz). The distance between the generator antenna and the Tetra cell broadcast antenna was 30 m and the one between the signal generator's antenna and the receiving antenna of the Agilent analyser was 10 m. The block diagram of the test-bed setup is shown in Fig. 2.

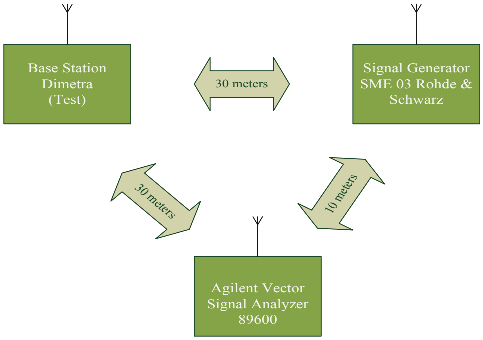

Fig. 2. Block diagram of the test bed

Case 1 Disturbing Signal Level 3 mW (5 dBm) - This level of the disturbing signal is still below the useful signal level, but, even though, the number of errors increase, and the Error Vector Magnitude value reaches the maximum admissible value of the standard (10% rms). The Freq Err and IQ Offset parameters do not change significantly with respect to the measurements without the disturbing signal. The results are presented in Fig. 3, which shows the six graphs that highlight the Tetra emission parameters, namely IQ Time Measurement, Spectrum, Error Vector Spectrum, Symbols/Errors, IQ Ref Spec, IQ MeasSpec, Vector Time Error and IQ Error.

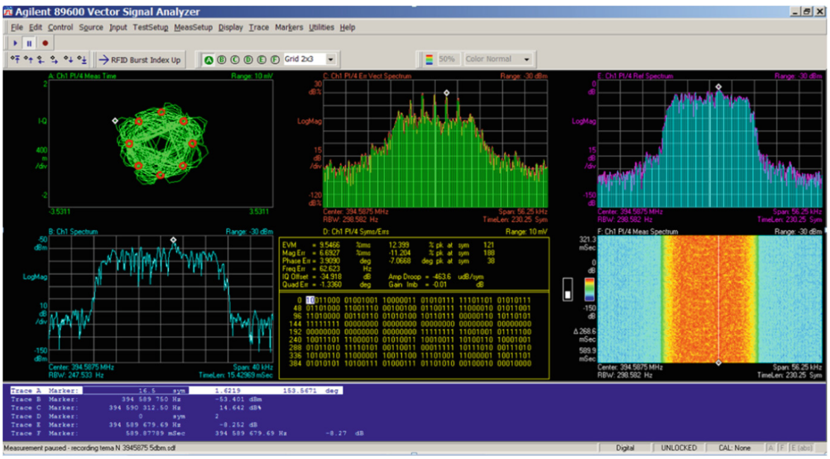

Fig. 3. Disturbed emission representation at 3 mW (5 dBm)

Case 2 Disturbing Signal Level 10 mW (10 dBm) - At this level of the disturbing signal (below the useful signal), the diameter of the constellation points decreases significantly, as shown in Fig. 4, thus the resistance of the π/4-DQPSK signal to noise reduces significantly, and so does the error probability.

An increase can be observed in all the Tetra transmission error parameters, except for the Freq Err and IQ Offset that did not change significantly. It can also be observed a sudden increase in the peak value of Phase Error, as well as the fact that some of the lines connecting the points of the constellation are passing through the centre of the imaginary circle on which these points are located increasing thus the dynamic range and making it even more sensitive to other noise, fading and other disturbances.

Case 3 Disturbing Signal Level 79 mW (19 dBm) - For this value of the disturbing signal is equal to the useful signal level, a significant increase of all the transmission error parameters, including Freq Err and IQ Offset, as it can be seen from Fig. 5. The constellation deteriorates importantly, the constellation points move and rotate from their original position, being barely distinguished (Table 2).

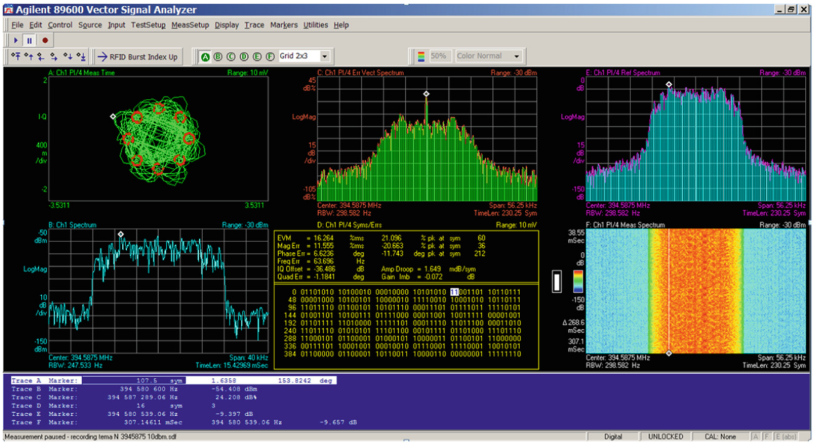

Fig. 4. Disturbed emission representation at 10 mW (10 dBm)

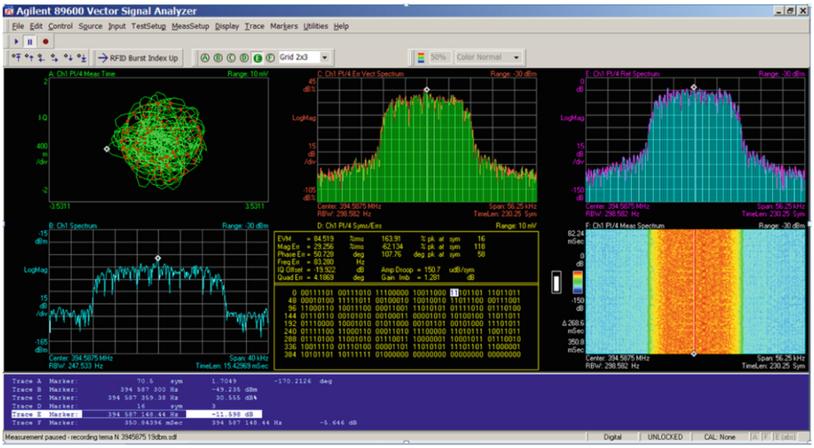

Fig. 5. Disturbed emission representation with 79 mW (19 dBm)

Table 2. Centralization of results from simulations

Disturbing signal level	EVM % rms	Mag err % rms	Phase error deg	Freq Error Hz	IQ Offset dB	Quad Err deg	Amp Droop mdB/sym	Gain Imb dB
undisturbed	1.4	0.9	0.62	64.1	−35.1	0.1	4.1	0.18
3 mW (5 dBm)	9.5	6.6	3.9	62.6	−34.9	−1.3	−463.6	−0.01
10 mW (10 dBm)	16.2	11	6.6	63.6	−36.4	−1.1	1.6	−0.07
79 mW (19 dBm unmodulated)	84.5	29	50.7	83.2	−19.9	4.1	150.7	1.28

4 Conclusions

All the measurements presented in this paper had been performed to highlight the changes in the modulation constellation accuracy and the overall quality parameters of the received signal when an unmodulated disrupting signal is affecting a standard TETRA communication system. The measurements were performed in real conditions in Bucharest and a Tetra base station had been used as receiver.

Based on those results, the following conclusions have been drawn, as follows:

1. The Agilent Vector Signal Analyzer 89600 analyser detects based on the Error Vector Spectrum graph low-level disrupting signals under the TETRA cell fingerprint in all cases.
2. In the case studied, at the value of 5 dBm of the disturbing signal, the Error Vector Magnitude reaches the maximum permissible value of the standard (10% rms).
3. When the disrupting signal equals to the level of the useful signal, a significant increase in all transmission error parameters has been observed, including the Freq Err and IQ Offset, that had not changed significantly so far. Also, the constellation deteriorates, the received signal points move from their initial position and can no longer be distinguished.
4. In comparison to other phase-modulated transmissions, the π/4-DQPSK (Differential Quadrature Phase-Shift Keying) proved to be more efficient, but also more sensitive to disturbing signals and less robust to variations in transmission channel parameters.
5. When the disrupting signal exceeds 10 mW, some of the lines connecting the constellation points are passing through the centre of the imaginary circle on which they are located, increasing thus the dynamic range and making it even more sensitive.
6. The error transmission parameters increase with the level of the disrupting signal, until it reaches the level of the useful signal, then the increase of the level of the disturbing signal no longer causes the increase of the errors.

According to the standard, the traffic can no longer be performed at a disturbing signal 19 dBm higher than the useful signal; no evidence has been made in this respect, but it has been found that at this level of disrupting signal, the errors are very high and the whole constellation deformed.

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