

AN ACCURATE SELF-SYNCHRONISING TECHNIQUE FOR MEASURING TRANSMITTER PHASE AND FREQUENCY ERROR IN DIGITALLY ENCODED CELLULAR SYSTEMS

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Abstract: Modulation quality in most of digitally encoded cellular systems is examined by measuring the phase error and the frequency error of the transmitted signal. Phase error is an indication of how accurately the individual bits modulate the radio-frequency carrier; frequency error is the difference between the specified carrier frequency and the actual carrier frequency.

The paper proposes a new technique for phase and frequency error measurement. The technique is based on a suitable digital signal-processing algorithm, capable also of gaining burst synchronisation on TDMA signals; downconversion and digitisation of the incoming signal are preliminary executed. Exploiting the instantaneous frequency trace related to the analysed burst and performing a nice interpolation of sampled data, the technique assures reliable demodulation along with low uncertainty.

Paying attention to GSM cellular system, the fundamental stages of the digital signal-processing algorithm are first described in detail. Then, the metrological characterisation of the proposed technique is carried out by means of experiments on GSM signals with known characteristics; the obtained results are finally compared to those obtainable by similar techniques already available in literature.

Keywords: Phase error, Frequency error, RF transmitter measurements

1 INTRODUCTION

The modulation quality of a radio-frequency (RF) carrier will directly affect the ability of a receiver to decode the transmitted information correctly. Many of the digitally encoded cellular systems, including the Global System for Mobile Communications (GSM) and North American Digital Cellular (NADC), use modulation schemes that rely on accurately controlling the phase of the carrier to encode the binary sequence being transmitted. Near-perfect modulation would be ideal but requires complex and expensive transmitter design. A balance must be struck between cost-effective design and the desire for low phase and frequency errors, frequently adopted as modulation quality indexes. In the GSM system, for example, the peak phase error must be less than 20°, the RMS phase error must be less than 5°, and the frequency error must be less than 90 Hz for a mobile [1].

Significant phase errors indicate problems in the baseband section of the transmitter (I/Q baseband generator, filters, and modulator). The output amplifier in the transmitter can also create distortion that causes unacceptably high phase error for multicarrier signals. In a real system, poor phase error reduces the ability of a receiver to correctly demodulate, especially with marginal signal conditions. This ultimately degrades sensitivity [2,3].

A stable frequency error indicates that a slightly wrong carrier frequency is being used. Unstable frequency errors can indicate short-term instability in the local oscillator, improper filtering, AM-PM conversion in the amplifier, or wrong modulation index if the transmitter is implemented using an analogue frequency modulator. In a real system, poor frequency error can cause several problems; as an example, the target receiver may be unable to gain lock and the transmitter may cause interference with other users [2,3].

Before the process of evaluating phase and frequency error can begin, a sampled record of the transmitter's phase trajectory during one TDMA (Time Domain Multiple Access) burst is captured. Understanding this process requires thinking of the phase trajectory as being relative to the phase of the carrier centre frequency. In the GSM system, streams of 1 bits will cause a phase increase of 90°

each, while 0 bits cause 90° phase decreases; specifically, the Gaussian premodulation filter stops the phase trajectory from meeting its 90° target points.

A number of techniques are available for obtaining this phase trajectory; some of them use analogue I/Q demodulators, other of them use high-speed sampling and digital-signal processing. To overcome accuracy and repeatability problems often associated with the analogue ones, digital-signal processing solutions are generally preferred [1]. They require a downconversion of the incoming GSM signal to a suitable intermediate frequency in order to allow the proper functioning of the data acquisition system mandated to its digitisation. The sampled data is then processed to extract the phase trajectory.

Once the phase trajectory has been obtained, a standard procedure is applied. In particular, a demodulated data pattern is first gained, and the reference phase trajectory is then mathematically derived. The phase error is determined by comparing the actual and reference trajectories. The mean gradient of the phase error signal is the frequency error. The short-term variation of this signal is defined as phase error and is expressed in terms of rms and peak [1÷4].

A new measurement technique for measuring transmitter phase and frequency errors in digitally encoded cellular systems is proposed. Once the incoming RF signal has been downconverted and digitised, a suitable digital signal-processing algorithm precisely locates the burst to be analysed thus granting a software, self-synchronising capability on the technique. Specifically, this goal is achieved in two sequential steps. During the first step, a rough localisation of the burst is achieved by comparing the time-domain envelope of the sampled signal to a fixed threshold; the second step provides a fine localisation by evaluating the maximum value of the mutual correlation between reference and measured phase trajectories.

Moreover, the aforementioned standard procedure has suitably been refined with the aim of assuring both reliable demodulation and low uncertainty. With regard to incoming RF signal demodulation, the instantaneous frequency trace is further evaluated [5]. The individual bits of the burst are then derived in a simpler and safer way by comparing the value of the instantaneous frequency trace to the carrier centre frequency at each bit period. To reduce measurement uncertainty, an interpolation scheme is adopted capable of providing an integer number of samples for each bit period regardless of the adopted sampling frequency. This condition allows the successive stages of the procedure to efficiently work and offer their best performance.

The fundamental stages of the measurement technique are first described in detail. Then, the attention is paid to its metrological characterisation with reference to GSM cellular system [6÷9]. To this aim, many tests on GSM signals with known characteristics are carried out; the obtained results are finally compared to those granted by instruments, already available on the market, which adopt a measurement approach similar to that proposed.

2 THE PROPOSED TECHNIQUE

A block diagram of the proposed technique is sketched in Fig. 1. A distinction has been drawn between the hardware required (a downconverter and a data acquisition system) and the digital signal-processing software with self-synchronising capability developed.

All fundamental stages of the technique appropriately work in any TDMA, digitally encoded cellular system. For the sake of clarity, a detailed description of the aforementioned stages is in the following given with references to GSM cellular system.

2.1 Downconversion and digitisation

Before being digitised, the incoming GSM signal is downconverted to a suitable intermediate frequency value according to the characteristics of the adopted data acquisition system. In particular, this frequency value along both with the maximum sampling frequency and memory depth of the data acquisition system have to satisfy two opposite needs. An entire GSM burst at least must be acquired for correctly measuring phase and frequency errors, and a number of samples at each bit period of the burst appropriate to the right functioning of the digital signal-processing algorithm have to be pursued.

As an example, Fig. 2 shows a bit period of a GSM burst downconverted at an intermediate frequency equal to 3.6 MHz, and acquired with a sampling rate equal to 50 MSamples/s.

2.2 Burst synchronisation

The GSM burst has to be located in a correct way along the sampled signal. This condition plays a crucial role in the reconstruction of the reference phase trajectory needed to carry out the requested measurements. In particular, the aforementioned task is fulfilled by taking two sequential steps referred to as "rough synchronisation" and "fine synchronisation".

2.2.1 Rough synchronisation

After being normalised, the sampled signal is compared to a threshold the value of which is fixed equal to the half of signal's absolute maximum. In particular, those two samples in correspondence of which the time-domain envelope of the signal respectively crosses the aforementioned threshold with positive slope and negative slope are pointed out. Thus, a portion of the signal (in the following referred to as time window), inside which the GSM burst is contained, is established (Fig. 3a).

2.2.2 Fine synchronisation

The main goal of this stage is the correct location both of the beginning ("front synchronisation") and the end ("tail synchronisation") of the burst.

Both "front synchronisation" and "tail synchronisation" perform the same digital signal-processing procedure in an iterative way; the only difference is the time window on which they work, and the way of changing its characteristics at each iteration. Specifically, as for "front synchronisation", the length of the time window is always the same and equal to that established in the "rough synchronisation" stage; in addition, this window slides (one sample at each iteration) from the original position in both directions along signal's samples (Fig. 3a). With regard to "tail synchronisation", the start point of the time window is that identified by the previous "front synchronisation", and its end point moves forward and backward thus changing the extent of the time window (one sample longer or shorter) at each iteration (Fig. 3b).

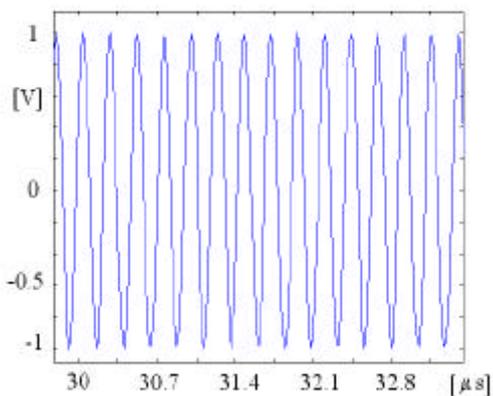


Figure 2. Portion of a GSM burst.

[8,9], the individual bits of the burst are recovered by comparing the value of the instantaneous frequency trace to that of the carrier centre frequency at each bit period, as depicted in the same Fig. 4. The obtained bit stream is then used to synthesise a reference phase trajectory (i.e. the trajectory an ideal modulator would provide under theoretically ideal conditions) by means of a 0.3 GMSK

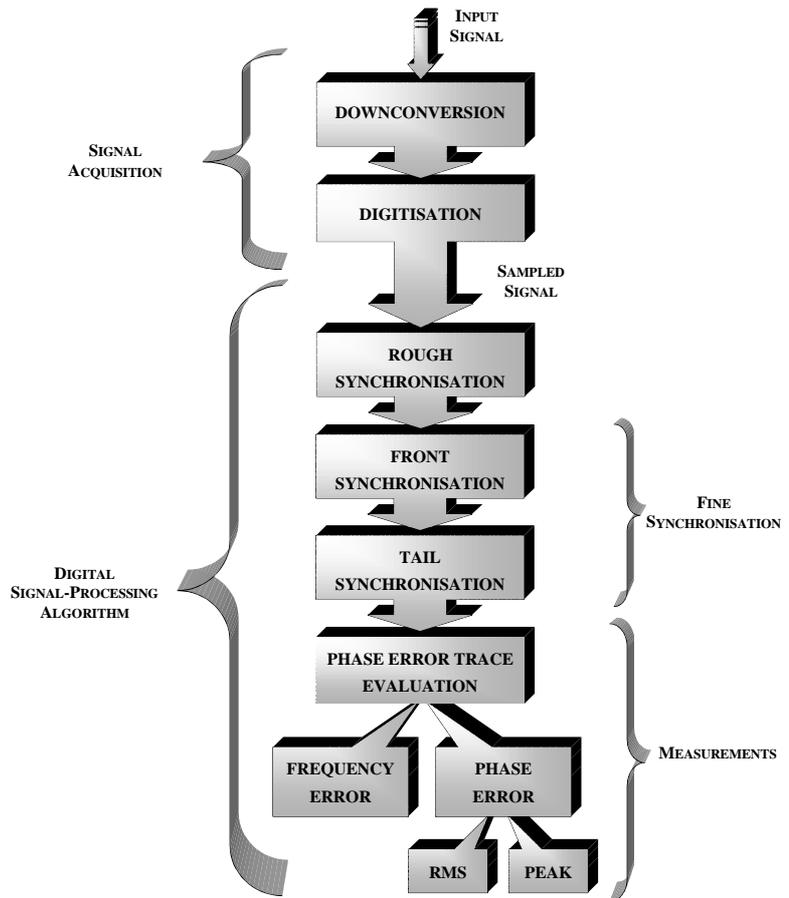


Figure 1. Fundamental stages related to the proposed measurement technique. Signal acquisition section and digital signal-processing algorithm are highlighted.

The digital signal-processing procedure executed both by the "front synchronisation" and "tail synchronisation" is depicted in Fig. 4. The input signal is first resampled by means of a suitable interpolation algorithm in order that the ratio between the bit period and the new sampling interval is an integer number. This operation shows itself essential for the successive comparison between the actual phase trajectory and the reference one, which intrinsically satisfies the aforementioned condition. In the considered example, the new sampling rate is equal to 49.84 MSamples/s.

The actual phase trajectory (Fig. 5a) is evaluated by means of a typical I/Q demodulation scheme [2] tuned on the carrier centre frequency and preceded by a band-pass filter for reducing the effect of quantisation noise. Successively, the instantaneous frequency trace is evaluated [5]. Thus, exploiting the most significant features of the *minimum shift keying* (MSK) modulation technique

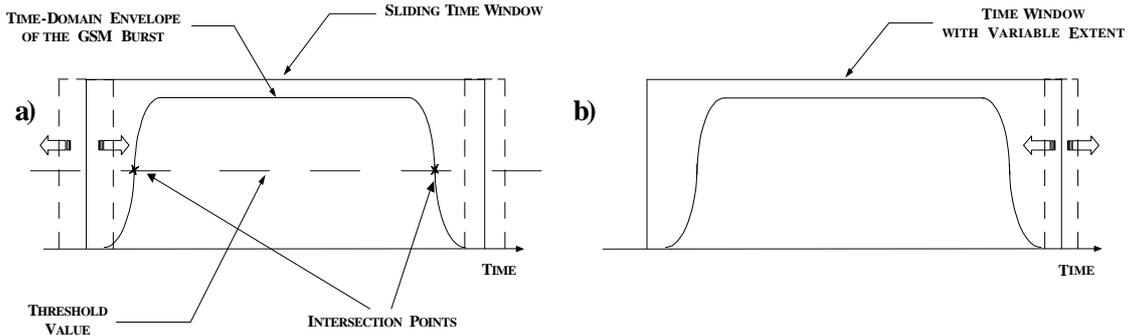


Figure 3. (a) Sliding time window for the “front synchronisation”; b) time window with variable extent for the “tail synchronisation”. The threshold adopted in the “rough synchronisation and its intersections with the time-domain envelope of the GSM burst are also highlighted in (a).

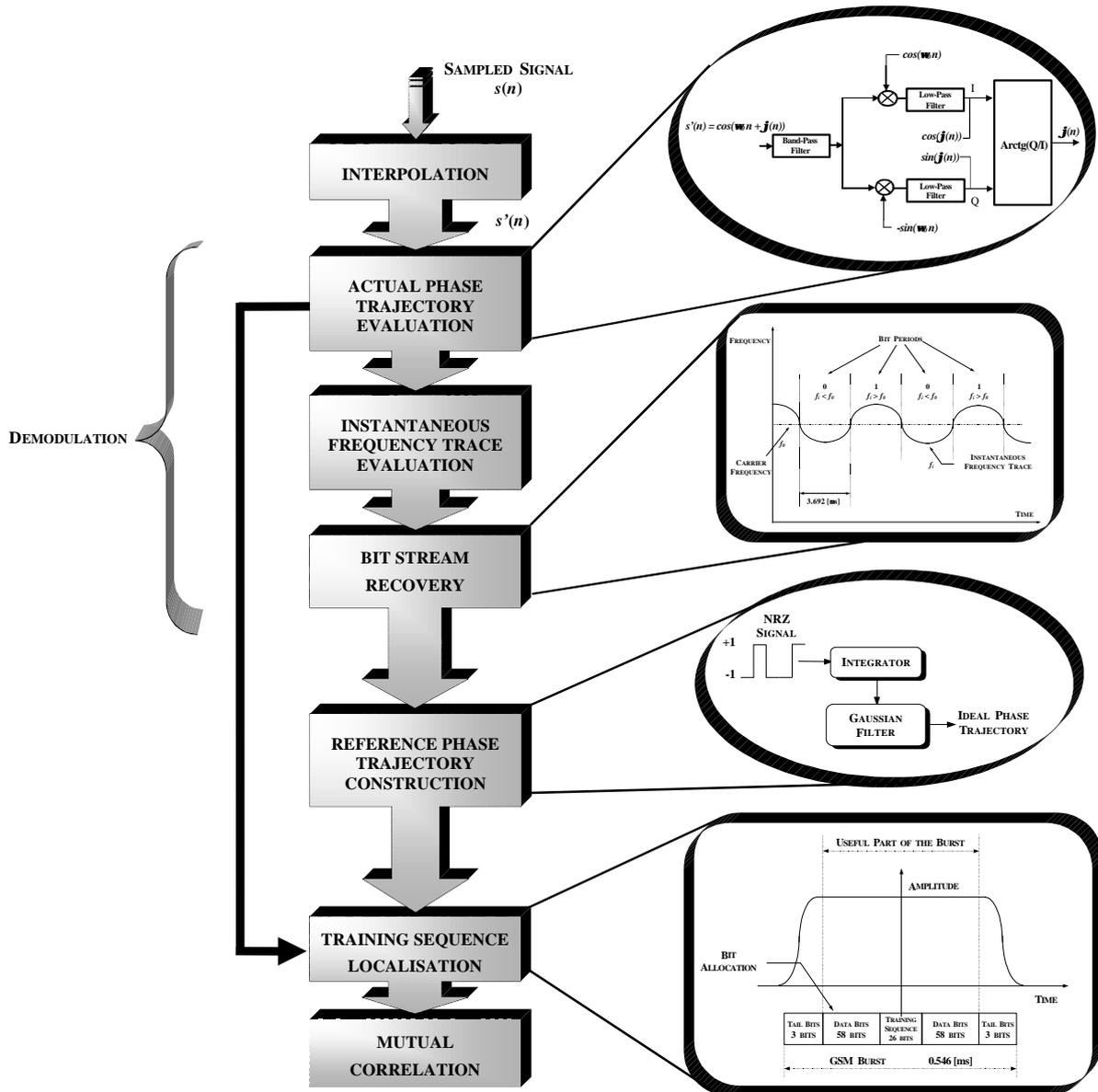


Figure 4. Fundamental stages related to “fine synchronisation” procedure. Details are depicted regarding actual phase trajectory evaluation, bit stream recovery, reference phase trajectory construction, and training sequence localisation.

modulation scheme (Fig. 4) [8,9]. Both in actual and reference phase trajectory, those parts related to the training sequence, a sequence of known bits characterising any GSM normal burst [6,8,9], are localised; the mutual correlation between them is finally evaluated.

It is worth highlighting that both “front synchronisation” and “tail synchronisation” give as outcome that time window on which the aforementioned correlation reaches its maximum. Furthermore, the number of iterations executed by both of them depends on (i) the characteristics of the analysed signal and (ii) the sampling frequency adopted. Anyway, a number of iterations equal to the number of samples covering half a bit period could be satisfying. With reference to the considered example, the “front synchronisation” executes 7 iterations; the “tail synchronisation”, on the other hand, 9 iterations.

2.3 Measurements

Subtracting the actual and reference phase trajectories produces a plot of phase error at each point across the burst (Fig. 5b); the imperfections in the measured modulation are thus highlighted. This phase error trace is characterised by slope and roughness. A best-fit straight-line is used to calculate the slope, and therefore, the frequency error (Fig. 5b). Then, the change of phase across the burst produced by the straight-line is subtracted from the phase error trace; the peak and rms values of the remaining trace give respectively peak phase error and rms phase error.

Concerning the example, no frequency error is met; as for peak and rms phase errors, they resulted equal to 4.3 degrees and 1.8 degrees, respectively.

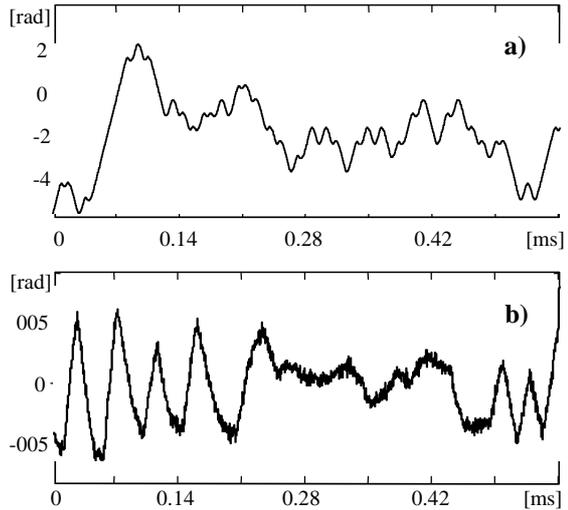


Figure 5. a) Actual phase trajectory of the GSM signal shown in Fig. 2; b) phase error trace and best-fit straight-line.

3 METROLOGICAL CHARACTERISATION

To assess the performance of the proposed technique, an automatic measurement station has properly been set up (Fig. 6). It consists of a control and processing unit, namely a personal computer, an arbitrary waveform generator (12-bit vertical resolution, 250 MHz maximum generation frequency), a spectrum analyser (9 kHz-2.2 GHz analogue bandwidth), and a digital scope (8-bit vertical resolution, 100 MHz analogue bandwidth, 100 MSamples/s maximum sample rate). They all are connected by means of IEEE-488 interface system.

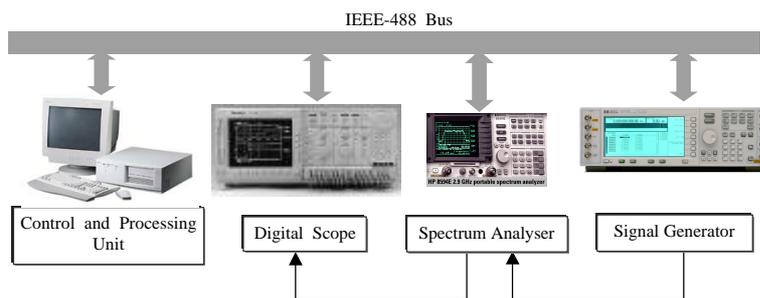


Figure 6. The adopted measurement station.

The arbitrary waveform generator provides as output GSM test signals with known characteristics. Specifically, these signals, numerically generated and transferred into the internal memory of the arbitrary waveform generator by the control and processing unit, are characterised by known frequency, and peak and rms phase errors; in addition, both tail and data bits in each GSM burst are established in a

random way. The generated signal is routed to the spectrum analyser acting like a downconverter. The signal coming out of its intermediate frequency output (3.6 MHz) is acquired by the digital scope at a sample rate equal to 50 MSamples/s. The stored samples are retrieved from the scope by the control and processing unit, and passed to the digital signal-processing software which implements the proposed algorithm. The measurement results are finally displayed.

For each considered value either of phase or frequency error, several GSM signals were analysed, each of which characterised by a different bit sequence. A statistical study was then conducted aiming at evaluating (i) the difference, to be used as a correction factor, between the mean value of measurement results and the nominal one, assumed as reference, and (ii) the measurement uncertainty according to the estimated standard deviation. Figs. 7 a,b show the uncertainty related

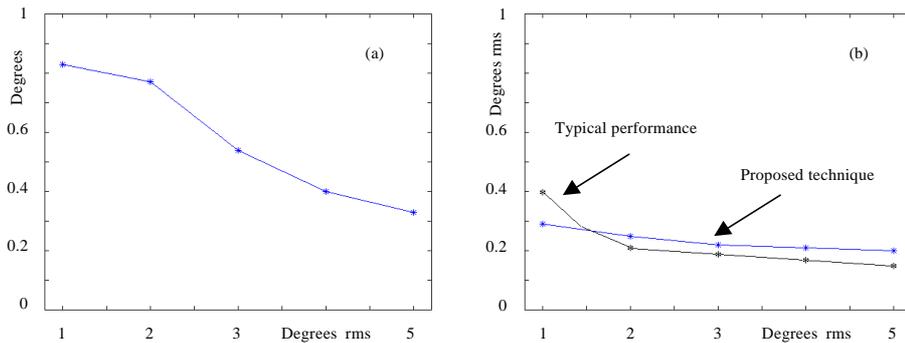


Figure 7. Measurement uncertainty related to (a) peak phase error and (b) rms phase error versus measured result.

respectively to peak and rms phase error measurement versus measured result. In particular, the measurement uncertainty related to rms phase error is compared to the typical performance given by Hewlett & Packard in [7]. With regard to frequency error measurement, the resulted uncertainty is equal to 3 Hz all over the investigated range (0÷100 Hz).

Finally, some tests were carried out with the aim of highlighting the benefit of a successful "fine synchronisation". In particular, it was experimented that a wrong localisation of the burst causes an increase of measurement uncertainty never lower than 20% of previously given values.

4 CONCLUSIONS

A new measurement technique for analysing transmitter modulation quality in TDMA, digitally encoded cellular systems has been presented. The technique is based on a digital signal-processing algorithm, which, after a preliminary downconversion and digitisation of the incoming RF signal, is capable of gaining burst synchronisation thus automatically measuring phase and frequency errors.

The metrological characterisation of the technique has been conducted with references to GSM cellular system; the resulted relative uncertainty is good enough (~4%) if compared to that granted by instruments adopting a similar measurement approach and already available on the market.

The on going activity is oriented to (i) optimise the choice of the measurement parameters of the data acquisition system (in terms of sampling rate and vertical resolution) for the technique to offer the lowest uncertainty, and (ii) assess the performance of the technique when utilised in other cellular systems.

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