JITTER MEASUREMENT IN PDH/SDH-BASED TELECOMMUNICATION NETWORKS: OPTIMISATION AND PERFORMANCE ASSESSMENT OF A DIGITAL SIGNAL PROCESSING METHOD

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Abstract – *The paper deals with jitter measurement in PDH/SDH-based telecommunication networks. The attention is mostly paid to the accuracy assured by any PDH/SDH analyser compliant the ITU-T recommendations, which seems to be unsatisfying for both designers and manufacturers. Trying to give an answer to this problem, a digital signal-processing method was already proposed by the authors; it avoids the use of a timing recovery circuitry, which strongly degrades the aforementioned accuracy.*
The method is here optimised with the aim both of further enhancing the accuracy on jitter estimates and testing, in an automatic way, jitter performance of network elements operating at the PDH bit rate of 140 Mbit/s and the SDH bit rate of 155 Mbit/s. In particular, an innovative procedure for automatically recovering the binary information conveyed by the jittered signal under analysis and a proper strategy for carrying out instantaneous jitter measurements at uniform time intervals are developed.
After a brief outline of the old version of the method, the proposed modifications are described in detail. Then, the performance of the optimised method is assessed through many laboratory tests on emulated signals, the results of which are given and discussed. At the end, the outcomes of real automatic tests, conducted on PDH/SDH-based equipment produced by Marconi Sud S.p.A., are also presented.

Keywords – Jitter measurement, PDH networks, SDH networks, ITU-T recommendations, Digital communication system quality assessment.

1. INTRODUCTION

Timing jitter, or more commonly jitter, is defined by the ITU-T, the standardization sector of the International Telecommunication Union, as “short-term variations of the significant instants of a digital signal from their ideal position in time”. For the purposes of this definition, a *significant instant* is any convenient, easily identifiable point on the signal, such as the rising or falling edge of a pulse [1].

Jitter is the most crucial impairment in digital networks. With special regard to networks based on plesiochronous (PDH) or synchronous (SDH) digital hierarchies, jitter can severely degrade communications signals with negative impacts on several services such as data traffic, voice traffic, voiceband encoded data as well as video [2],[3]. Therefore, a careful policy of testing jitter performance of network elements, to be carried out both in design and production phase, is vital to escape from these hazards.

At this concern, ITU-T Recommendations O.171 and O.172 [4],[5] are mandated both to fix measurements needed to test jitter performance of PDH/SDH-based equipment and specify instruments capable of carrying out these measurements. However, as pointed out by several important factories such as *Marconi Sud S.p.A.*, the aforementioned recommendations do not seem to sufficiently satisfy both system designers and production managers. In particular, they are complaining that the measuring accuracy specified for test instrumentation does not give sufficient warranty about the correct working of functional tests on PDH/SDH-based equipment [6].

Trying to overcome this problem, a suitable measurement method was already proposed by the authors in [6]. The novelty of this method is that it is no longer based on timing recovery circuitry, which strongly degrades the accuracy of test instruments compliant the ITU-T recommendations [4],[5]. Specifically, the jittered data signal is first acquired and digitised by a suitable data acquisition system. Then, a digital signal-processing algorithm is applied to the acquired record. It sequentially allows:

a) the estimation of the actual bit rate by means of a windowed FFT and a successive interpolation of its results;
b) the recovery of the binary information according both to the code characterising the acquired data signal and the estimated bit rate;
c) the reconstruction of a jitter-free, reference data signal conveying the same binary information and characterised by linear rising edges; specifically, the slope of each rising edge is chosen to be equal to the

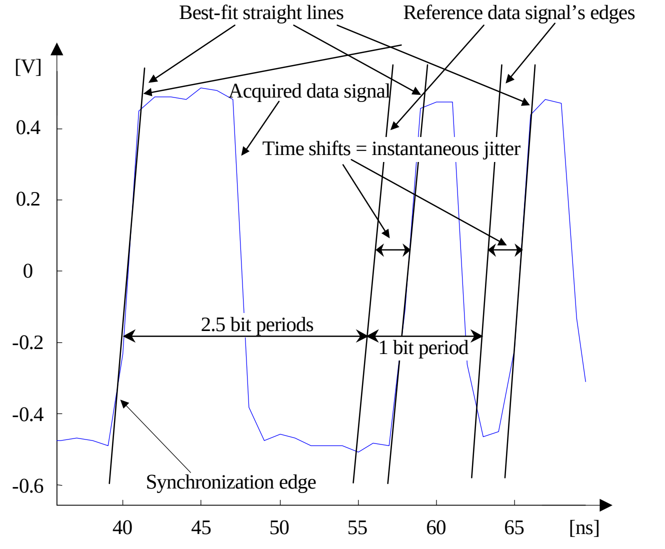

Fig.1 - Instantaneous jitter measurement: the non-uniform sampling of the jitter, due both to the analysed sequence and adopted code, is also highlighted.

mean slope of the corresponding edge of the acquired data signal (Fig.1);

d) the evaluation of the time shift between each rising edge of the reference data signal and the related one of the acquired signal (instantaneous jitter measurement) in order to achieve a discrete time-domain evolution of the occurred jitter; the reference data signal turns to be synchronized with the first, rising edge of the data signal under test (Fig.1);

e) the calculation of the main parameters of the jitter such as peak-to-peak amplitude and fundamental frequency.

Besides granting a better measuring accuracy than that characterising test instruments compliant the ITU-T recommendations, the method is adequately insensitive to the degree of distortion of the edges of the acquired signal. However, some drawbacks are still present. In particular, the procedure for recovering the binary information at the step b) is not completely automatic; user action is still needed to inspect the data signal under test thus greatly increasing the measurement time. Then, time shift measurements executed at the step d) are not equally spaced in time because the time interval elapsing between two consecutive rising edges is not constant, as in the case of timing clocks [7]. Its value varies along the signal with not only the bit rate but also according to the test sequence as well as adopted code. In other words, the results of instantaneous jitter measurements can be seen as samples of a hypothetical continuous jitter function taken at non-uniform time intervals. Consequently, to calculate the main parameters of the jitter at the step e), a suitable interpolation for restoring a uniform sampling has to be executed on measurement results; this is the major cause of accuracy degradation of the method.

In this paper the method is optimised with the aim of (i) reducing the uncertainty on jitter estimates, and (ii) testing, in an automatic way, tributary units, produced by *Marconi Sud S.p.A.* and working both at the PDH bit rate of 139264 kbit/s (140 Mbit/s) and the SDH bit rate of 155520 kbit/s (155 Mbit/s); both bit rates are characterised by CMI (Coded Mark Inversion) code [8]. In particular, a suitable procedure is implemented for automatically recovering the binary information from the analysed signal, and a new strategy is set up for carrying out instantaneous jitter measurements at uniform time intervals.

2. THE OPTIMISED METHOD

As stated above, the optimisation of the measurement method, already presented in [6], mainly concerns:

(i) the reduction of the measurement time, by developing a suitable procedure for automatically recovering the binary information conveyed by the CMI codified data signal, and

(ii) the improvement of the overall accuracy, by setting up a new strategy that allows instantaneous jitter measurements equally spaced in time (namely at each bit period).

The procedure, which (i) refers to, optimises the aforementioned step b) of the proposed method, while the measurement strategy, cited in (ii), turns out to be the innovative core of the step d); the other steps are practically left unchanged. These are the reasons why details related only to the modified steps, b) and d), of the method are

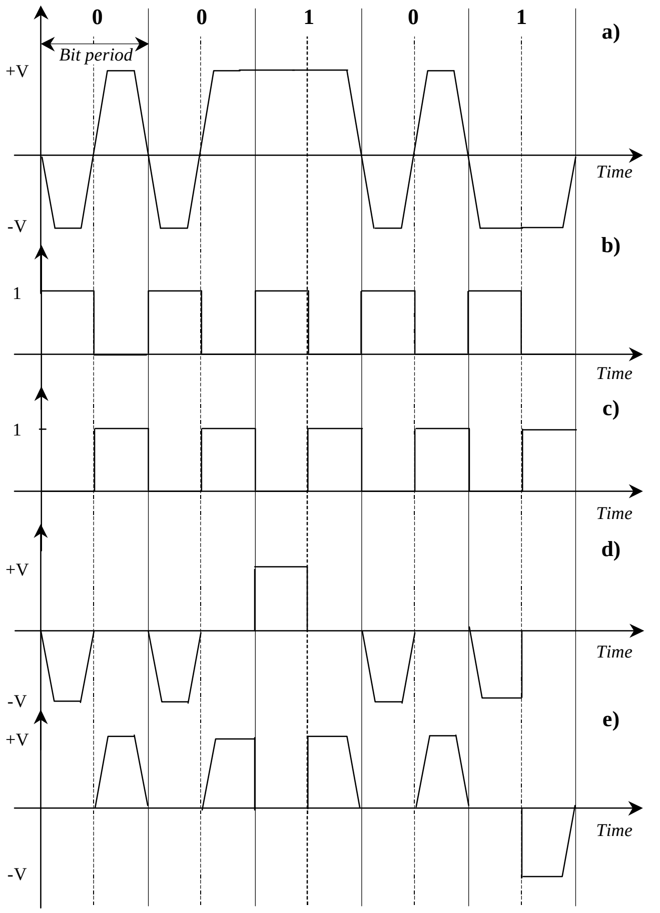

Fig.2 - (a) CMI coded data signal; (b) periodic signal s_1; (c) periodic signal s_2; (d) signal, r_1, resulting from the product between the data signal in (a) and s_1; (e) signal, r_2, resulting from the product between the data signal in (a) and s_2.

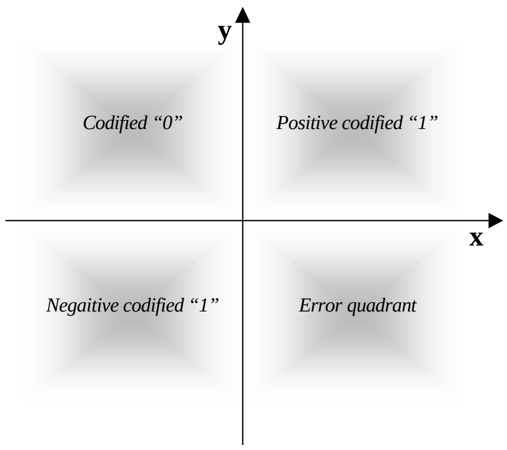

Fig.3 - Regions of decision used for recovering the binary information conveyed by the acquired data signal.

given in the following.

2.1 Automatic recovering of the binary information

With regard to (i), taking into account that any falling edge in a CMI codified data signal always denotes the beginning of a new bit period related either to a bit "0" or a negative codified "1", a preliminary synchronisation is carried out by pointing out the first falling edge in the acquired record. Starting from this edge, the data signal under test is multiplied by two periodical signals, s_1 and s_2, suitably constructed with a period equal to the estimated bit period (Figs.2a,b,c). Then, the mean value of the portion of each of the two resulting signals, respectively r_1 and r_2 (Figs.2d,e), contained in each bit period is calculated. The values obtained, x for the signal r_1 and y for the signal r_2, represent the coordinates of a point on the orthogonal Cartesian system depicted in Fig.3. At the end, the current bit is gained by simply finding out the quadrant the aforementioned point belongs to.

Besides being completely automatic, this procedure shows itself very insensitivity to the jitter affecting the data signal. As a matter of fact, the point of coordinates (x,y) associated to the current bit falls outside the right quadrant (for example, it might belong to the "error quadrant" in Fig.3) only in the presence of jitter levels that are very high (> 0.5 UIpp) with respect to those encountered in the practice for the considered bit rates [4],[5].

2.2 New strategy for instantaneous jitter measurements

As for the new measurement strategy, it allows instantaneous jitter measurements at each bit period. To this aim, it exploits the features of the CMI code [8], according to which the beginning of any bit period of an ideal, jitter-free data signal is always characterised by the presence of a rising or falling edge but when the current bit is "0" preceded by a negative or followed by a positive codified "1" (Fig.4).

Whenever the presence of an edge identifies the beginning of a new bit period, an instantaneous jitter measurement is executed by evaluating the time shift between the nominal occurrence of the bit period, according to the estimated bit rate, and the time instant in which the best fit straight line of the considered edge equals the mean value of the signal itself (Fig.4). This mean value is generally very close to zero.

When the edge is not available, a linear interpolation between the two values of the instantaneous jitter obtained at the previous and successive bit period is performed. Moreover, it can be demonstrated that no more than two consecutive instantaneous jitter measurements are missed whatever the binary stream analysed. Specifically, the worst case occurs in the presence of the bit sequence "101", being the first "1" negative codified.

Being the results of instantaneous jitter measurements equally spaced in time, an interpolation algorithm aiming at restoring a uniform sampling of the jitter for the calculation of its main parameters is no longer necessary. A measuring accuracy better than before is thus granted.

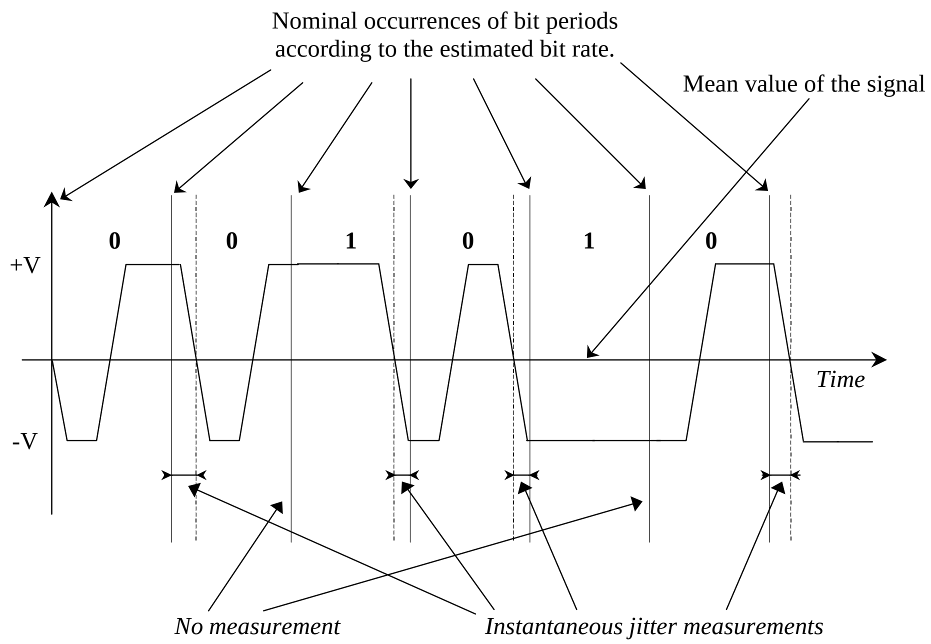

Fig.4 - The proposed new strategy for instantaneous jitter measurements.

3. PERFORMANCE ASSESSMENT

Many laboratory tests have been conducted on emulated data signals, characterized by a CMI code and affected by known jitter, in order to assess the performance of the optimised method. At this concern, the possibility of producing such reference signals through the generation section of currently available PDH/SDH analysers has

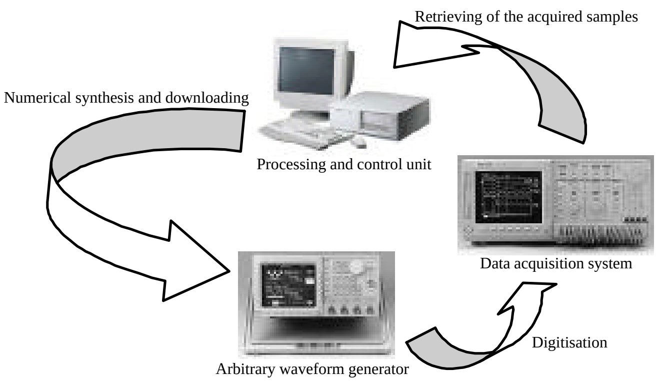

Fig.5 - The adopted measurement station for assessing the performance of the optimised method.

been discarded because of their unsatisfying generation accuracy specifications, already experienced in [6]. As a consequence, a suitable measurement station has been set up (Fig.5). It consists of a processing and control unit (namely, a personal computer), an arbitrary waveform generator (Tektronix AWG2020[TM], 12-bit vertical resolution, 250 MHz maximum generation frequency), and a data acquisition system (LeCroy LC 574A[TM], 8-bit vertical resolution, 1 GHz bandwidth, 4 GS/s maximum sample rate). They all are interconnected by means of an IEEE-488 interface bus.

Each signal, numerically generated according to the masks specified by the ITU-T Recommendation G.703 [8], is downloaded into the internal memory of the arbitrary waveform generator by the processing and control unit. The analogue version of the signal, provided by the generator, is acquired by the data acquisition system (DAS). The stored samples are retrieved from the DAS by the processing and control unit and passed to a digital signal processing software implementing the proposed method.

It is worth noting that the adopted generator is not capable of providing data signals at the considered bit rates (140 Mbit/s and 155 Mbit/s) due to its limited maximum generation frequency. For this reason, signals at lower rates have been produced; moreover, the sample rate of the DAS has been regulated in such a way as to assure that the ratio between the new bit periods and the adopted sampling interval is as similar as possible to that achievable if signals

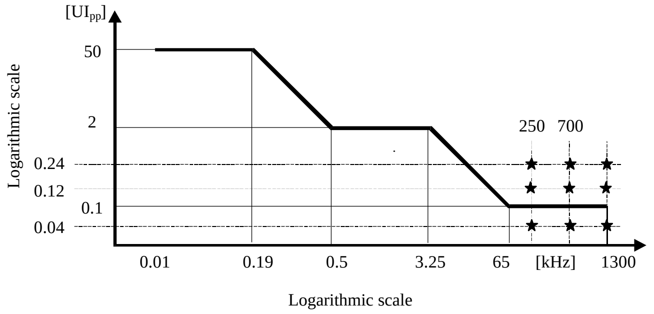

Fig.6 Amplitudes and frequencies (pointed out by the black stars) of the sinusoidal jitter affecting the reference signals; they are displayed against the jitter amplitude/jitter frequency characteristic fixed by the ITU-T Recommendation O.172 for STM-1e signals (SDH signals at 155 Mbit/s).

Tab.I Mean values (μ), differences between mean values and nominal ones (Δ), and experimental standard deviations (σ) of the measurement results, provided both by the optimised method and the old method and related to the peak-to-peak amplitudes of the jitter affecting the reference data signals.

	Optimised method			Old method		
f_i [kHz]	μ [UI_{pp}]	Δ [UI_{pp}]	σ [UI_{pp}]	μ [UI_{pp}]	Δ [UI_{pp}]	σ [UI_{pp}]
	A_1 = 0.24 UI_{pp}					
250	0.2286	-0.0114	0.0005	0.217	-0.023	0.004
700	0.2430	0.003	0.0006	0.245	0.005	0.005
1300	0.2412	0.0012	0.0007	0.244	0.004	0.005
	A_2 = 0.12 UI_{pp}					
250	0.1116	-0.0084	0.0004	0.108	-0.012	0.006
700	0.1241	0.0041	0.0004	0.129	0.009	0.006
1300	0.1240	0.004	0.0006	0.130	0.01	0.005
	A_3 = 0.04 UI_{pp}					
250	0.0426	0.0026	0.0004	0.053	0.013	0.009
700	0.0463	0.0063	0.0003	0.06	0.02	0.01
1300	0.0463	0.0063	0.0003	0.057	0.017	0.008

at the original bit rates were acquired at the maximum sample rate of the DAS (4 GS/s).

The reference data signals have always been affected by sinusoidal jitter. Different peak-to-peak amplitudes (A_i, i = 1,..,3) as well as frequencies (f_i, i = 1,..,3) of the jitter have been considered; the black stars in Fig.6 point them out. Moreover, the same figure displays the mask accounting for the minimum requirements, in terms of jitter amplitude/jitter frequency characteristic, fixed by the ITU-T Recommendation O.172 [5] for any jitter test set when analysing STM-1e signals (SDH signals at 155 Mbit/s). The aforementioned amplitude and frequency values have been chosen on the basis of:

- the characteristics of the jitter that can be experienced in the network elements operating at the considered bit rates [3], [6]; it has been so possible to emulate measurement conditions as similar to actual ones as possible, and
- the aforementioned minimum requirements in order to show that the optimised method works in agreement with the ITU-T Recommendation O.172 [5] in terms of measurement capabilities.

For a given reference data signal, about one hundred

Tab.II Mean values (μ), differences between mean values and nominal ones (Δ), and experimental standard deviations (σ) of the measurement results, provided both by the optimised method and the old method and related to the frequencies of the jitter affecting the reference data signals.

	Optimised method			Old method		
A_i [UI_{pp}]	μ [kHz]	Δ [kHz]	σ [kHz]	μ [kHz]	Δ [kHz]	σ [kHz]
	f_1 = 250 kHz					
0.24	245	-5	1	243	-7	2
0.12	245	-5	1	243	-7	2
0.04	245	-5	1	241	-9	3
	f_2 = 700 kHz					
0.24	701	1	1	705	5	2
0.12	701	1	1	706	6	2
0.04	701	1	2	705	5	3
	f_3 = 1300 kHz					
0.24	1299	-1	1	1296	-4	2
0.12	1298	-2	1	1295	-5	2
0.04	1296	-4	2	1290	-10	3

tests have been carried out in an automatic way. In each test, it has always been considered an observation interval of about 320 μs of the signal under analysis, always acquired at a sample rate of 50 MS/s. Moreover, each test has furnished both the peak-to-peak amplitude and the frequency of the jitter affecting the analysed signal. Specifically, with regard to the peak-to-peak amplitude, the estimator defined in [9] has been applied to the instantaneous jitter estimates; as for the frequency, the weighted average algorithm presented in [10] has been applied to the results of the Fast Fourier Transform of the same estimates, previously windowed with the Hanning function. A statistical analysis has then been conducted with the aim of evaluating the mean value (μ) of the measurement results, the difference (Δ) between the obtained mean value and the originally imposed one, and the experimental standard deviation (σ).

The obtained results are collected in Table I and Table II along with those provided by the old version of the method; the performance enhancement assured by the proposed optimisations, in terms both of Δ and σ, can clearly be noted.

4. EXPERIMENTAL TESTS

The optimised method has been used for automatically testing jitter performance of some network elements produced by *Marconi Sud S.p.A.*. For the sake of brevity, only the results of output jitter measurements executed on typical cross-connect equipment, in two different operative conditions, are described in the following.

With regard to the first operative condition, the equipment has been configured in such a way as to provide a STM-1e signal conveying VC-12 traffic (i.e. 63 PDH channels at 2 Mbit/s) [11]. This traffic has been generated by making (i) an MP 1570A™ Anritsu PDH/SDH analyser provide a jitter-free, 2 Mbit/s PDH data stream at the input channel of the first tributary unit of the equipment, and (ii) the data stream at the output of this tributary unit pass through the other 62 tributary units. The synchronisation signal at 2.048 MHz has been provided by a HP 3324A™ waveform synthetiser, which, in turn, has been synchronised with a GPS 10 MHz clock. The jitter affecting the STM-1e signal has been measured. To this aim, the signal itself has been both monitored by another MP 1570A™ Anritsu PDH/SDH analyser and acquired by the adopted DAS.

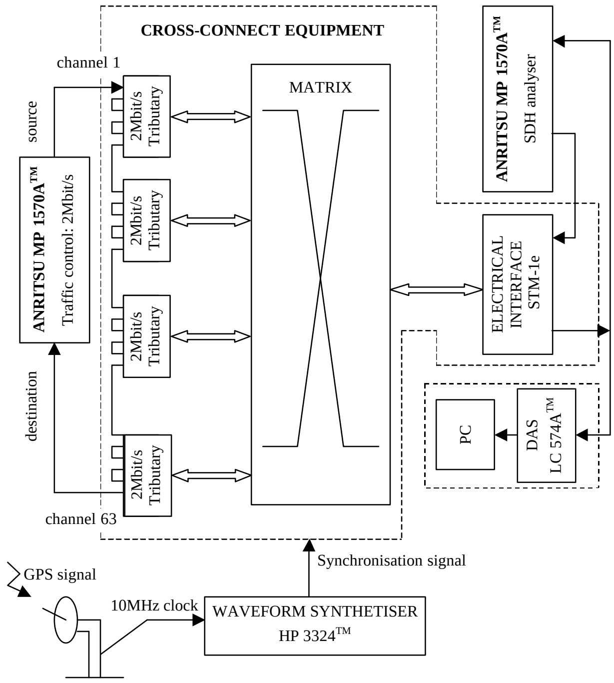

Fig.7 – The arranged measurement apparatus for jitter performance tests on the cross-connect equipment when a STM-1e signal equipped with a VC-12 traffic is delivered on the SDH line; the STM-1e signal is also routed both to the Anritsu SDH analyser and the adopted DAS.

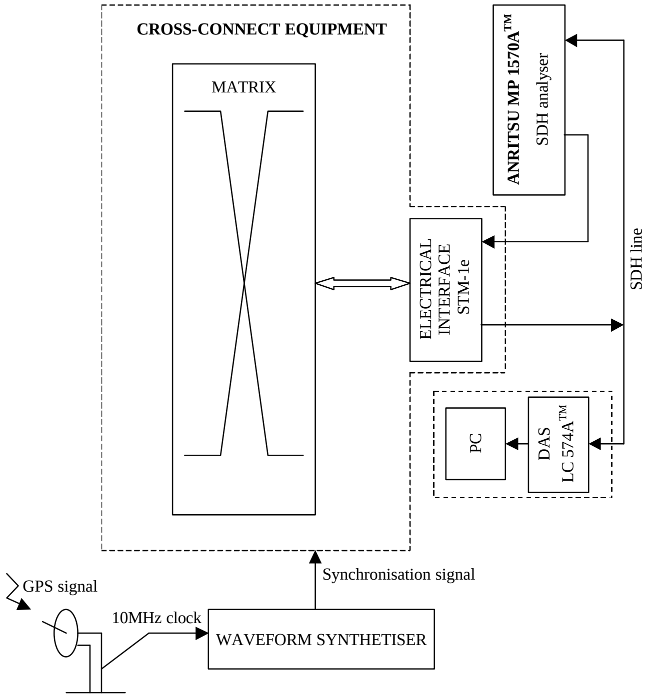

Fig.8 – The arranged measurement apparatus for jitter performance tests on the cross-connect equipment when a STM-1e signal equipped with a VC-4 traffic is delivered on the SDH line; the STM-1e signal is also routed both to the Anritsu SDH analyser and the adopted DAS.

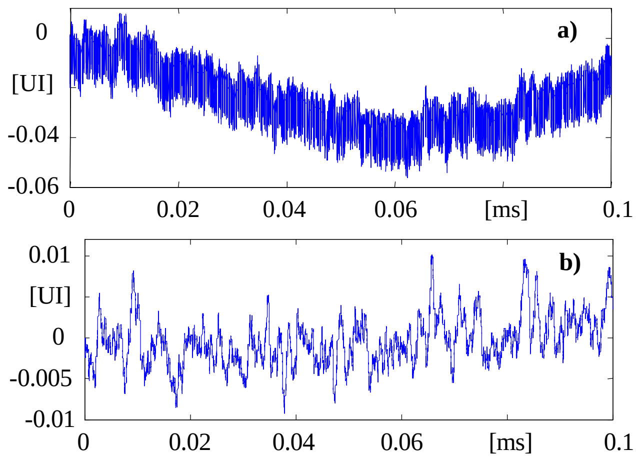

Fig.9 – Piece of a jitter waveform reconstructed during the tests in the first operative condition, in the absence (a) and presence (b) of filters.

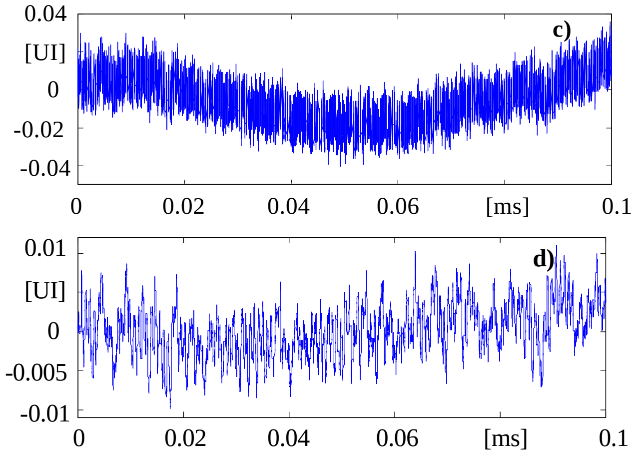

Fig.10 – Piece of a jitter waveform reconstructed during the tests in the second operative condition, in the absence (a) and presence (b) of filters.

In the second operative condition, the cross-connect equipment has acted like a regenerator ("loopback" configuration). A single Anritsu analyser has been adopted, which has provided a jitter-free STM-1e signal conveying VC-4 traffic (a single PDH channel at 140 Mbit/s) [11] at the input of the SDH side. After passing through the equipment, the signal has been delivered on the SDH line again, where it has been both monitored by the Anritsu analyser and acquired by the DAS.

Moreover, measurements have been performed both in the absence and presence of proper filters in order to establish the whole level of the jitter as well as its contribute in a typical frequency range (65-1300 kHz). For example, Fig.9a and Fig.10a show a piece of a jitter waveform, reconstructed without using filters and associated, respectively, to the first and the second operative condition, while Fig.9b and Fig.10b depict the related filtered versions.

For each operative condition 50 tests have been carried out. Table III gives the mean values (μ) and experimental standard deviations (σ) of the obtained results, along with the maximum and minimum values of the readings provided by the Anritsu analyser. From the analysis of this table, the following considerations can be drawn:

- the Anritsu analyser always exhibits the greatest variability of the measurement results;
- all measures are compatible, i.e. the mean value of the results provided by the proposed method is always inside the interval related to the readings of the Anritsu analyser.

Taking into account that *Marconi Sud S.p.A.* requires an output jitter level lower than 0.075 UI_{pp} for the considered equipment to pass the functional test, the better reliability of the proposed method with respect to other instruments compliant the ITU-T recommendations is clearly evident from the analysis of the aforementioned table.

Tab.III Results obtained during the experimental tests.

	Proposed method		Anritsu MP 1570A
Filters	μ [UI_{pp}]	σ [UI_{pp}]	Min-max of the readings [UI_{pp}]
	1st operative condition		
Off	0.060	0.004	0.052-0.078
On	0.020	0.002	0.005-0.025
	2nd operative condition		
Off	0.063	0.003	0.058-0.080
On	0.024	0.003	0.012-0.034

5. CONCLUSIONS

The paper has aimed both at optimising a digital-signal processing method, already proposed by the authors for jitter measurement in PDH/SDH-based networks, and assessing its performance, when it is used to test network elements operating with CMI codified signals at 140 Mbit/s and 155 Mbit/s.

Concerning the optimisations proposed, a new procedure, for extracting, in an automatic way, the data stream conveyed by the jittered signal under analysis, and an appropriate strategy, for a more reliable reconstruction of the jitter waveform, have been developed.

Many tests, conducted on data signals affected by known jitter, have demonstrated that the performance of the optimised method is surely better than that characterising the old version of the method. Specifically, the experimental standard deviation of the measurement results has always been both reduced of about one order of magnitude and, practically, independent of the level as well as frequency of the jitter. The reliability of the method has been confirmed also by the results of several output jitter measurements executed on typical cross-connect equipment.

The on-going activity is mainly oriented to (i) extend the applicability of the method to other digital hierarchies, characterised by different codes, and (ii) verifying its reliability and efficacy also in the presence of bursty jitter, which can strongly degrade the measuring accuracy of currently available instruments.

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