Inconsistency in CISPR 16-1-1 performance tests for disturbance analysers

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***Abstract*—Civilian standards define the characteristics and performances of disturbance analysers and prescribe a range of tests that these instruments should pass. Unfortunately, two of these tests are *per definition* impossible to pass as they are prescribed today. In this paper we provide evidence of this inconsistency in current civilian standards and validate our claim with lab experiments. Further, we discuss possible solutions that range from simple modifications of the standard to the introduction of alternative IF detectors.**

***Index Terms*—Click, CISPR, discontinuous disturbance, IF output, 200-Hz background noise**

I. Introduction

Since decades, CISPR 16-1-1 defines the characteristics of instruments for the measurement of radio disturbance in the civilian context, in order to benchmark these instruments in different setups and environment [1]. CISPR distinguishes between continuous and discontinuous disturbances (the latter are also called 'clicks'). A disturbance whose quasi-peak (QP) amplitude is constantly above the "QP limit of continuous disturbance" ("QP limit" throughout the rest of this paper) is classified as continuous disturbance. Continuous disturbance can be broadband, produced by mechanical switches, commutators or semiconductor regulators, or it can be narrowband, produced by electronic control devices like microprocessors [2]. Clicks are broadband disturbances which are usually produced by switching operations in appliances. The maximum of their spectral characteristic is below 2 MHz and the disturbance they produce depends on the amplitude, the duration, the spacing and the repetition rate of clicks [2]. Clicks are supposed to be less disturbing than continuous disturbance. For this reason, CISPR 14-1 standard contains several relaxations on the limits for this kind of disturbance. Disturbances that do not fulfill the requirements of discontinuous disturbances are treated as continuous disturbances [2].

For the measurement of the amplitude of clicks a measuring receiver with a QP detector (in accordance with CISPR 16-1-1) should be used (see §C.2.2 in [2]). The QP detector gives a weighted peak value of the envelope of the input signal and makes that pulses with lower repetition rates exhibit lower levels than pulses with higher repetition rates (with equal amplitude and duration), see [3], [4] for details on the QP detector response. The duration and spacing of the clicks should be measured on the intermediate frequency (IF) output (see §C.3.2 in [2]). The IF output is the instantaneous, unweighted value of the tuned input signal.

In the past, the IF measurement was done manually with a storage oscilloscope. Nowadays, specialised instruments are used. These so-called disturbance analysers embed both the QP detector and the IF output [2], [5].

The characteristics and performances of disturbance analysers are defined in [1], §9. Specifically, the analyser must pass a range of tests, listed in [1], Table 17 and Table F.1. Unfortunately, two of these tests, as they are still described today in the standard, cannot be passed. In this paper, we provide evidence of this inconsistency in the current CISPR 16-1-1 standard and discuss possible approaches to let disturbance analysers pass these tests.

Specifically, the remainder of the paper is structured as follows. In Sect. II, we first report the precise definition of a click. Then in Sect. III, we discuss the existing inconsistency in detail, and in Sect. IV, we report on possible solutions. Finally, in Sect. V, we discuss on why disturbance analysers have passed the tests in these years, and we conclude the paper in Sect. VI.

II. Click Definition

To understand the inconsistency in the standard, it is important to first explain the nature of a click and explain how it should be evaluated.

According to CISPR standards [1], [2] a click is defined as follows:

- the QP level must exceed the QP limit;
- the duration must be not longer than 200 ms;
- the disturbance must be separated from a subsequent disturbance by at least 200 ms.

A click can contain a number of pulses. Still, its total duration, measured from the beginning of the first to the end of the last pulse, must be not longer than 200 ms (not considering exceptions). The durations are determined from the IF output that exceeds the QP limit.

The QP detector is used to evaluate if there is a click while the IF output is used to characterise this click. The QP detector is used because the effective annoyance of a disturbance is better represented by the QP value than by the IF output. Originally, the QP detector came about to characterise the annoyance of disturbances which interfered with radio broadcast reception [6]. The disturbances were mostly unintentionally generated man-made radio noises, *e.g.*, noise from power lines, switching transients or electric motor commutator sparking. The disturbances were impulsive and their annoyance increased with increasing repetition rate in a way that was found to be approximated by a quasi-peak detector circuit [6]. On the other hand, the QP reading cannot fully characterise a disturbance. For this reason, the IF output should be monitored when evaluating a click, as the IF output gives precise information about the amplitude and mainly the duration of a disturbance.

In practice, to measure clicks generated by an appliance under test, a disturbance analyser with embedded QP and IF outputs shall be used. If the IF output falls below the QP limit, a click evaluation should be performed. The QP amplitude should be measured 250 ms after the last falling edge in the IF output (see §9.2 in [1]). If the QP amplitude is above the QP limit, the duration of the click is determined as the time the IF output is above the QP limit. Additionally, if the IF output had already exceeded the QP limit during the 200 ms preceding the disturbance, the total duration of the disturbance is determined from the first time the IF output exceeded the QP limit, regardless if it fell below the QP limit in between the various disturbances.

III. Inconsistency in Current Civilian Standard

To be CISPR 16-1-1 compliant, disturbance analysers must pass a series of tests, listed in [1], Table 17 and Table F.1. These tests have been conceived to verify that the analyser is capable of correctly detecting discontinuous disturbances of different nature and features. Some tests check the temporal accuracy of the analyser; specifically the duration (test 1 in Table 17 and tests 1-6 in Table F.1) and separation (tests 6-8 in Table 17) of disturbances or a combination of the two (test 9 in Table 17). Other tests check the correct measurement of the disturbance amplitude (tests 4-5 in Table 17), the correct QP weighting (tests 10-12 in Table 17) and the correct handling of exceptions (tests 7-12 in Table F.1). Finally, tests 2 and 3 in Table 17 aim at guaranteeing that disturbance analysers are capable of correctly detecting short discontinuous disturbances even in presence of a background noise.

Specifically, tests 2 and 3 prescribe to correctly detect a click on top of a background noise consisting of 200 Hz CISPR pulses. The level of these CISPR pulses must be regulated such that their QP reading is 2.5 dB below the QP limit. However, according to [1], Fig. 1b, in Band B[1] the QP weighting with a pulse repetition frequency (PRF) of 200 Hz is approximately 1.9 dB below the reference level (at 100 Hz). Additionally, in Band B with a PRF of 100 Hz, the difference in readings between peak and QP should be 6.6 dB (see Tab. 7 in [1]). Therefore, with 200 Hz the difference in readings between peak and QP is $6.6-1.9 = 4.7$ dB. Thus, since the QP reading of the CISPR pulses should be 2.5 dB below the QP limit, the IF output will be $4.7 - 2.5 = 2.2$ dB above the QP limit. Fig. 1 shows the theoretical IF and QP readings of the 200-Hz-CISPR-pulse background noise as prescribed in test 2 of Table 17 in [1].

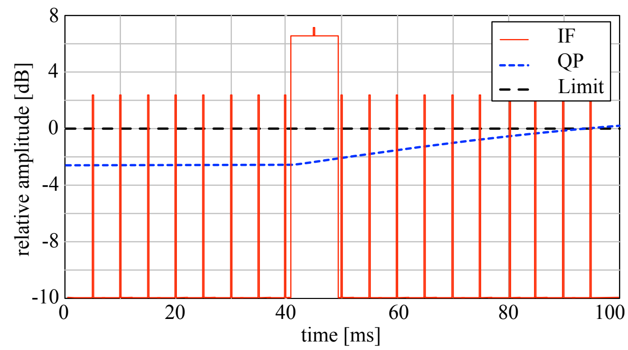

Fig. 1. Theoretical waveforms of test 2 as prescribed in [1], Table 17: a click of 9.5 ms with amplitude 6.5 dB above the reference level, on top of the CISPR background noise made of pulses with repetition frequency of 200 Hz, width of roughly 35 ns, and amplitude 2.2 dB above the reference level. When only the 200-Hz-CISPR-pulse background noise is present, the QP reading is 2.5 dB below the QP limit. As soon as the click is generated the QP reading starts increasing and exceeds the QP limit after roughly 50 ms.

To be CISPR 16-1-1 compliant, the spectrum of the generated 200 Hz CISPR pulses should essentially be constant up to the upper limit of the frequency band of the analyser. Namely, to be sufficiently uniform within the band of interest, i.e., 30 MHz (Band B), the variation of the spectrum amplitude should be smaller than or equal to 2 dB. This means that the width of a single pulse in the background noise should be approximatively 13 ns, considering the standard spectral bounds of a trapezoidal waveform with rise and fall time reasonably smaller than the width [7]. From the IF output of the receiver such an impulse is wider because of the effect of the resolution bandwidth (RBW) filter, which is prescribed to be 9 kHz for click measurements [1]. As the RBW value is defined as the 6-dB bandwidth, the impulse carried out by the IF output can be assumed to have an approximated duration of 35 μs. Thus, every $1/200$ Hz $= 5$ ms, there will be an impulse of width 35 μs and an amplitude that exceeds the QP limit by 2.2 dB, see Fig. 1.

When the clicks of tests 2 and 3 are activated on top of the 200-Hz-CISPR-pulse background noise, the QP amplitude will rise above the QP limit; see for example Fig. 1, where the theoretical waveforms of test 2 are depicted. Since after 250 ms the QP amplitude is still above the QP limit, a click evaluation must be performed. This means checking whether the IF output had already exceeded the QP limit during the 200 ms preceding the disturbance. As explained above and shown in Fig. 1, when only CISPR pulses are present, the IF output (red continuous line) exceeds the QP limit (black dashed line) every 5 ms. Thus, for every CISPR pulse preceding the test click, it should be checked whether there had been an additional disturbance that exceeded the QP limit within the preceding 200 ms. In this manner, "hopping back along the CISPR pulses", the total duration of the

[1]Discontinuous disturbances range from 150 kHz to 30 MHz and fall thus entirely in Band B.

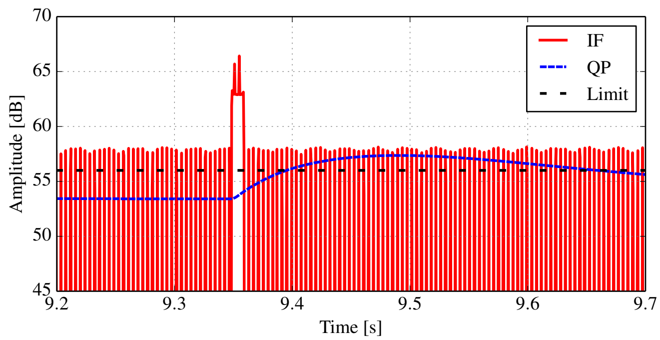

Fig. 2. Lab experiment with a modern click analyser with a digital IF detector with a time resolution of 500 μs. The experiment represents test 2 prescribed in [1], Table 17. The experiment's setup and results are directly comparable with theoretical curves depicted in Fig. 1. In presence of the test click, the click plus noise pulses should be considered as continuous disturbance.

disturbance should be considered from the beginning of the 200-Hz-CISPR-pulse background noise to the end of the actual test click. Consequently, the total duration of the disturbance exceeds the time limit for discontinuous disturbances and must be counted as continuous disturbance. Thus, it is *per definition* impossible to pass tests number 2 and 3 as the disturbance cannot be counted as a click, as the standard prescribes.

According to the actual standard, the same interference is classified differently depending on the presence/absence of other disturbances. Without the test click, the 200 Hz CISPR pulses would not be classified as disturbance at all, as their QP reading does not exceed the QP limit. Instead, in presence of the test click, the 200 Hz CISPR pulses would be classified as continuous disturbance.

To validate the theoretical values discussed in this section and thus prove the inconsistency in the current civilian standard, we performed a lab experiment with a modern click analyser having a pseudo digital IF detector with a time resolution of 500 μs, as prescribed in §C.3.2. of [2]. In practice, the pseudo digital IF is the peak value of the envelope of the IF output from the digital signal processing seen in 500 μs. The setup reproduces exactly the test 2 described in [1], Table 17. The results from our lab experiment are directly comparable with those shown in Fig. 1. Thus, with our experiment we could confirm the theoretically expected values.

In both Fig. 1 and Fig. 2, which report theoretically expected readings and actual lab measurements, pulses of the background noise appear as spikes on top of the test click in the IF reading, see Fig. 1 at 45 ms and Fig. 2 at roughly 9.35 s. The pulses of the background noise and the click sum up in phase. The number of spikes comes from the product of the pulse repetition frequency and the click duration, and it depends on where the click falls in time with respect to the noise pulses. As we can observe from both figures, these spikes do not influence at all the results of tests.

IV. Possible Solutions

As we have discussed in previous sections, the inconsistency arises because of (i) the nature of the 200-Hz-CISPR-pulse background noise, which cause a difference between QP and IF output of 4.7 dB and (ii) the definition of clicks, which requires to analyse both the QP and IF output with respect to the QP limit. In the following, we discuss five options: the first, although not feasible, is oriented to change the limit, the second and third are oriented to review the definition of the background noise so to reduce the difference between QP and IF output, and the last two are oriented to alternative IF detectors, which are perfectly capable of respecting all requirements of current standard and at the same time are precise enough to capture even the shortest prescribed clicks.

A. Changing the limits

If the IF output did not exceed the QP limit, the noise impulses would not be counted to the disturbance. At first sight, increasing the QP limit might seem a possibility. However, this is not a solution because the QP limit should be higher than the IF reading of the background noise but at the same time it should be lower than the QP reading of the test click, otherwise this click would not be counted. As can easily be seen in Fig. 2, such a value does not exist, being the maximum QP reading of the click below the IF reading of the background noise. An alternative could be to have two separate limits: the QP limit to be used for the QP evaluation and a new IF limit to be used for the IF output evaluation. However, this would mean further compromising the consistency of current tests. Indeed, to be able to pass tests 2 and 3 in [1], Table 17, the IF limit should be at least 2.2 dB above the QP limit. However, to be able to pass test 4 in [1], Table 17, the IF limit can be at maximum 1 dB above the QP limit. Thus, there exists no single value for a new IF limit that would make it possible to pass the CISPR tests. A dynamic limit (changing according to the test performed) is also not an option. In a real disturbance measurement the interferences are unknown and thus the limits cannot be changed on-the-go depending on the disturbance. Moreover, different disturbances can be concurrent and it may not be possible to discriminate them. After all, the CISPR tests are thought to challenge a receiver to correctly measure different kinds of disturbances.

B. Changing the background noise

The only valid alternative to change the standard is to redefine the background noise so to reduce the difference between QP and IF output. This can be achieved in two ways. Instead of using such an impulsive background noise, another noise model could be adopted. The background noise should be characterised by peaks with a repetition frequency and an amplitude such that the difference between QP and IF output remains within 2.5 dB, in order that the IF output remains below the QP limit.

A simpler alternative would be using the noise model described in recent CISPR editions but with a different PRF. The PRF of the CISPR-pulse background noise could be

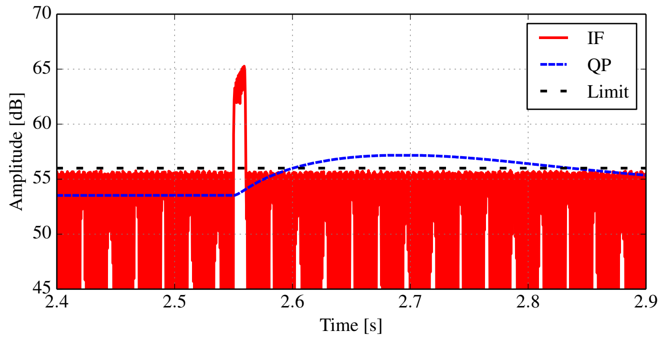

Fig. 3. Lab experiment with a modern click analyser with a digital IF detector with a time resolution of 500 μs. The experiment represents test 2 prescribed in [1], Table 17 but with a different background noise. The noise is made of CISPR pulses with a PRF of 1 kHz. The IF reading of the noise pulses remains below the QP limit and the test disturbance is correctly counted as a click.

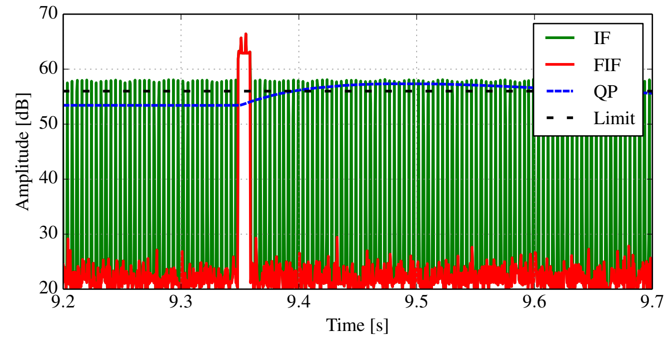

Fig. 4. Theoretical functioning of a frame-IF detector (FIF) which ignores the first 40 μs of each disturbance (after the IF output exceeds the QP limit of every disturbance). The figure represents test 2 prescribed in [1], Table 17. With the IF limiter the background noise is not detected and the test disturbance is correctly counted as a click.

increased in order that the QP reading approaches the IF output and remains within the 2.5 dB difference. For example a 1-kHz-CISPR-pulse background noise would cause the IF output to be 0.4 dB below the limit. Indeed, the QP weighting of pulses with a PRF of 1 kHz is exactly 4.5 dB below the reference level (at 100 Hz) (see Fig. 1b in [1]). Additionally, in Band B with a PRF of 100 Hz, the difference in readings between peak and QP should be 6.6 dB (see Tab. 7 in [1]). Therefore, for a PRF of 1 kHz the difference in readings between peak and QP is $6.6 - 4.5 = 2.1$ dB. Thus, since the QP reading of the CISPR pulses should be 2.5 dB below the QP limit, the IF output will be $2.5 - 2.1 = 0.4$ dB below the QP limit. In this case, the IF reading of the noise would be below the QP limit and would thus not be counted during the click evaluation. In Fig. 3 we show the results of a lab experiment performed to validate the theoretical values. We used the same disturbance analyser we used to obtain results in Fig. 2. Thanks to the high PRF, the IF reading of the 1-kHz-CISPR-pulse background noise remained below the QP limit.

C. Changing the detectors

A different approach would be adapting current disturbance analysers so to avoid that pulse background noise can influence the analysis of disturbances.

A first solution would be introducing a new detecting rule for the IF output, which imposes a minimum disturbance duration of roughly 40 μs.[2] We show the theoretical functioning of this "frame-IF detector" (FIF) in Fig. 4, again using the setup of test 2 in [1], Table 17. Specifically, the disturbance analyser should ignore the first 40 μs of each disturbance, *i.e.*, the first 40 μs after the IF output exceeds the QP limit. In this way, the 200-Hz-CISPR-pulse background noise would not be detected. The missing 40 μs of the disturbances are hidden because of the much higher value of the prescribed time resolution (500 μs). Additionally, the shortest click prescribed by current standard, *i.e.*, 110 μs, remains well detectable since a large portion of the disturbance would still be measured. However, this approach requires much higher performance from the detector's side, which should be able to sample the signal at least every 10 μs instead of the prescribed 500 μs. Thus, it would mean a more than fifty times higher load.

A second solution would be applying a low-pass (LP) filter to the IF detector. We call "quasi-IF detector" a single pole LP filter which smooths the instantaneous IF output with a time constant long enough to avoid counting as disturbance the 200-Hz-CISPR-pulse background noise but short enough to capture short discontinuous disturbances. We define this time constant as $\tau = 1/(2\pi B_{3dB})$, where B_{3dB} is the half power band of the LP filter. We implemented such a quasi-IF detector in our disturbance analyser where we set $\tau = 28$ μs. With this setting, the disturbance analyser does not count as disturbance the 200-Hz-CISPR-pulse background noise because their quasi-IF reading remains 0.5 dB below the QP limit.[3] Fig. 5 shows the result of a lab experiment using as setup test 2 of Table 17 in [1] (results are directly comparable with measurements in Fig. 1, Fig. 2 and Fig. 3) when using a digital disturbance analyser with the aforedescribed quasi-IF detector. Despite the LP filter, the disturbance analyser is still capable of correctly detecting the shortest click prescribed by current standard, *i.e.*, 110 μs. Fig. 6 shows the result of a lab experiment using as setup test 1 of Table 17 in [1], which prescribes a click with a duration of 110 μs. The disturbance analyser with the quasi-IF detector was able to correctly detect this very short click. In fact, the quasi-IF detector brings an underestimation of the click of roughly 1.5 dB (see the difference between the results obtained with the IF detector and with the quasi-IF detector shown in Fig. 6). However, this figure is negligible as in this setup there is a 34-dB margin between IF output (90 dB) and QP limit (56 dB).

[2] This value comes from the impulse response of the RBW filter. As mentioned in Sect. III, the impulse carried out by the IF output is roughly 35 μs.

[3] We opted for $\tau = 28$ μs to obtain a margin figure similar to that obtained with the 1-kHz-CISPR-pulse background noise (solution previously discussed).

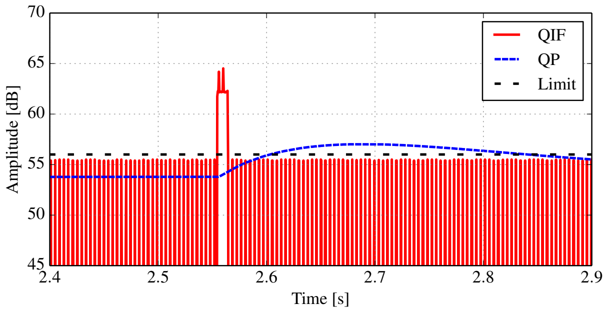

Fig. 5. Lab experiment with a modern click analyser with a quasi-IF detector with a time resolution of 500 μs and a time constant of 28 μs. The experiment represents test 2 prescribed in [1], Table 17. Noise pulses do not influence the analysis of disturbances and the test disturbance is correctly counted as a click.

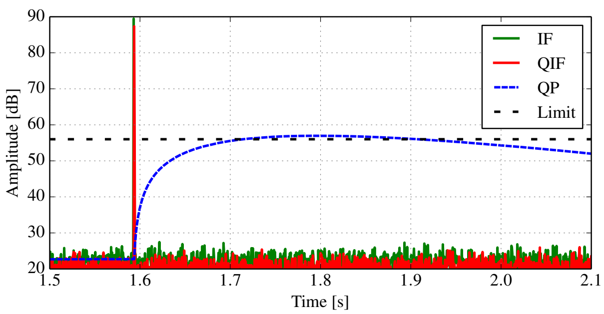

Fig. 6. Lab experiment with a modern click analyser with a quasi-IF detector (QIF) with a time constant of 28 μs and an IF detector (IF) both with a time resolution of 500 μs. The experiment represents test 1 prescribed in [1], Table 17. The 110 μs-long click is correctly detected. The click is underestimated by the quasi-IF detector by roughly 1.5 dB (difference between QIF and IF).

V. Discussion

Despite the inconsistency present in the standard, which we have described in Sect. III, disturbance analysers were still able to pass the required tests. This was probably due to the evolution that the standard's text has experienced over the last decades. Previous editions of the standard (for example CISPR 16-1 [8]) mentioned a generic background noise. This background noise was not further defined. In successive CISPR 16-1-1 editions it was possible to either use a generic background noise or the 200-Hz-CISPR-pulse background noise. Instead today, the 200-Hz-CISPR-pulse background noise is mandatory. While with the 200-Hz CISPR pulses the QP weighting with respect to the instantaneous value is well defined, the QP weighting of generic noise is not uniquely quantified and thus, the QP output may be less than 2.5 dB below the instantaneous value.[4] In this case, the IF output would not exceed the QP limit and the problem would not arise.

The standard's text mentions the 200-Hz-CISPR-pulse background noise since more than twenty years and modern disturbance analysers are still able to pass the required tests. Probably, designers of these instruments have long implemented dedicated solutions to overcome the inconsistency in the current standard. However, because possible solutions such as those described in Sect. IV make CISPR tests 2 and 3 possible to pass but let disturbance analysers behave very differently, we believe that a shared solution should be clearly indicated in the standard.

[4]The level of the background noise should be adjusted such that its QP reading is 2.5 dB below the QP limit. If the IF output is less than 2.5 dB above the QP reading, then it remains below the QP limit.

VI. Conclusion

Today's civilian standard presents an inconsistency in prescriptions for disturbance analysers. The background noise prescribed in tests 2 and 3 does not represent a disturbance if it is analysed alone whereas it falls into continuous disturbances if it coexists with another discontinuous disturbance (click). Such an inconsistency lets disturbance analysers fail two of the prescribed tests. In this paper, we have proposed four solutions, two of which require a simple adaptation of the standard, one which involves a smoothed down intermediate frequency output and one which adopts a frame-IF detector that cuts out the first short part of disturbances. Probably, already today designers of disturbance analysers adopt similar solutions to overcome the inconsistency in the standard. We believe that a shared solution, well documented in the next standard editions, is necessary in order to harmonise the behavior of disturbance analysers.

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