ELETTRONICA MONTI

C-1611 USER'S MANUAL

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List of Acronyms

- ADC: analog to digital convertion
- AVG: average
- EMI: electromagnetic interference
- FFT: fast Fourier transform
- IUD: intermittent, unsteady and drifting narrowband disturbances
- LP: low pass
- Pk: peak
- PRF: pulse repetition frequency
- QPk: quasi peak
- RBW: resolution bandwidth
- RMS: RMS-AVG in Test Menu.

1

Basic Safety Instructions

The manufacturers of C-1611 make all efforts to keep the safety standards up to date and to offer customers the highest safety. The product and the auxiliary equipment are designed, built and tested in accordance with the safety standards that apply in each case. To maintain this condition and to ensure safe operation, please observe all instructions and warnings provided in this manual.

It is user's responsibility to use the product in a proper manner. This product is designed for use solely in industrial and laboratory environments. It must not be used in any way that may cause personal injury or property damage. The user is responsible if the product is used for any purpose other than its designated purpose. The manufacturer shall assume no responsibility for an improper use of the product.

The product must be used for its designated purpose and in accordance with its performance limits (see data sheet, documentation, the following safety instructions). Using the product requires technical and theoretical skills. Specialised and trained staff should handle the product.

Observing the safety instructions may help prevent personal injury or damage.

An incorrect placement of batteries causes permanent damage to the product.

The product may be opened only by authorised personnel.

If the information regarding batteries and rechargeable batteries is not observed, users may be exposed to the risk of explosions, fire and/or serious personal injury.

- Batteries must not be taken apart or crushed.
- Batteries must not be exposed to heat or fire.
- Batteries must not be short-circuited.
- Batteries must not be exposed to any mechanical shocks.
- In case of broken batteries, avoid the fluid come into contact with the skin or eyes.
- Batteries must be recycled and kept separate from residual waste. Observe the national regulations regarding waste disposal and recycling.

The product must be disposed observing the national regulations regarding waste disposal and recycling. Particular attention must be paid to batteries.

2
General Information

The C-1611 EMI receiver tester is a signal generator designed to test EMI receivers' performance and their compliance with civilian standards. It specifically generates signals in accordance with CISPR 16-1-1 requirements to test a receiver's quasi-peak, average and rms-average pulse response as well as the response to "intermittent, unsteady and drifting narrowband disturbances". These tests can be performed in a quick and simple way with no need for any further equipment other than the C-1611.

All pulse rate frequencies (PRFs) as indicated in the CISPR 16-1-1 standard, are available and can quickly be accessed with a simple touch on the display. Isolated impulses are also available. Thus, the entire pulse repetition range can easily be checked. Moreover, the C-1611 shows the theoretical weighting (as defined in CISPR 16-1-1); the user has all theoretical values ready at hand for immediate comparisons without the need to look up elsewhere.

To test a receiver's response to "intermittent, unsteady and drifting narrowband disturbances" (IUD) normally two generators and a modulator are required. Instead, with the C-1611 this test can be done in a few seconds using only this device as everything that is needed is built-in and the generated waveform is specifically designed for the purpose.

Besides pulse generation, the C-1611 also includes the generation of two fixed sine-wave tones, one in-band and one out-of-band, in order to check the real instantaneous dynamic range. By activating a tone in addition to pulses, the user can see whether the receiver is really capable of simultaneously handling signals of very different amplitude. In practice, the user can verify that the EMI measurement at a certain frequency, or over a certain span, is not affected by other signals out of the span of interest.

The C-1611 has two built-in attenuators: (i) a 6 dB attenuator that works on all signals and helps checking overload / linearity of the receiver, and (ii) a 20 dB attenuator that works only on the continuous wave signals and allows checking the influence of a single tone signal on the pulse reading.

Two additional accessories are provided with the kit: (i) a 20 dB external attenuator helps resolving potential overload phenomena of a receiver and (ii) a 10 MHz low-pass filter behaving as a preselector helps checking whether the input band is sufficiently limited in the receiver.

2.1 *Kit composition*

- 10 MHz LP Filter (∼ 13.5 MHz Imp. Band)
- 20 dB External attenuator
- BNC Male plug to BNC Male Plug RF Cable 50 Ω (1 m)
- Rugged Hermetic case
- 4 alkaline batteries (Non-rechargeable model)
- 1 rechargeable Li-Polymer 9V-battery plus one spare battery (Rechargeable model)
- B Micro USB / A Male USB Cable (Rechargeable model)

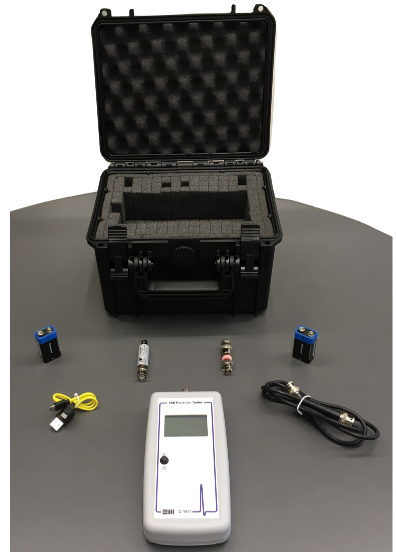

Figure 2.1: Kit rechargeable model

2.2 *Specifications*

Continuous Wave Signal Specifications				
Signal 1	Level	100 dBμV ±1 dB		
	Frequency	29.4912 MHz (<50 ppm)		
Signal 2	Level	100 dBμV ±1 dB		
	Frequency	32 MHz (<50 ppm)		
Pulse Specifications		**Band A**	**Band B**	**Band B+**
Frequency		9 kHz - 150 kHz	150 kHz - 30 MHz	150 kHz - 50 MHz
Spectral density		140 dBμV/MHz ±1 dB@150 kHz	107 dBμV/MHz ±1 dB@ 30MHz	102 dBμV/MHz ±1 dB@ 30MHz
Spectrum flatness		within 2 dB	within 2 dB	within 2 dB
Peak Voltage		3.1±0.2 V	17.8±0.9 V	15.5±0.8 V
Width		2.55±0.12 μs	11.5±0.6 ns	6.8±0.4 ns
Pulse Repetition Frequency (PRF)		standard PRFs for CISPR 16-1-1 quasi-peak and rms-average bench-tests isolated impulse capability		
Polarity		selectable +/-		
PRF Accuracy		better than 1 %		
IUD Specifications			**Band B**	**Band C**
Frequency			29.4912 MHz (<50ppm)	32 MHz (<50ppm)
Time Accuracy			better than 0.5 %	better than 0.5 %
General				
Dimensions (W x L x H)		93 x 70 x 32 mm		
Weight		<200 g (without batteries)		
Case Dimensions (W x L x H)		258 x 243 x 167.5 mm		

Table 2.1: C-1611 Specifications

2.3 *Front and rear panel*

Figure 2.2: C-1611 front and rear panel

Legend front panel from top to bottom:

- BNC Output
- Touch screen display: to show the instrument status and to select available functions
- Power / Return button: to switch the C-1611 On and Off and to return to the previous display

Legend rear panel from top to bottom:

- Battery case with four alkaline AA-batteries

3
Operating Instructions

3.1 *Setup*

Connect the C-1611 to the EMI receiver under test using the provided BNC Cable. Then, turn the C-1611 on by pressing the Power / Return button. The display will show the main menu and the release version.

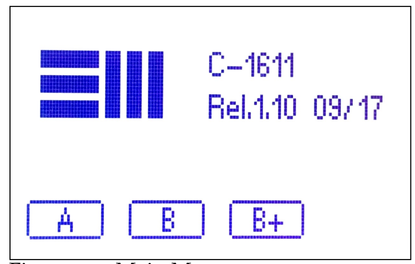

Figure 3.1: Main Menu

3.2 *Navigation*

To navigate the menu and select specific functions press directly (anywhere) on the display. The Power / Return button can be used to return to the previous display.

In the main menu, by pressing the Power / Return button, you enter the help mode (Fig. 3.2) where QPk and RMS-AVG CISPR 16-1-1 prescriptions are reported for Band A and B. To navigate through the different help pages, press directly on the display. To exit the help mode and go back to the main menu press the Power / Return button.

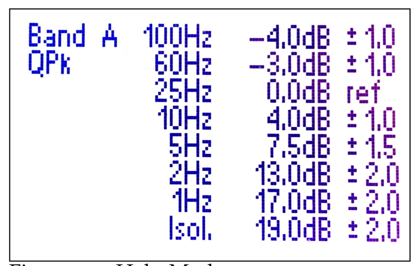

Figure 3.2: Help Mode

In the main menu choose which band (Band A, B or extended B (B+)) to test (Fig. 3.1). Band B+ can be selected also for some tests in Band C.

Figure 3.3: Test Menu

Once the band is selected choose the test method: "quasi-peak weighting (QP)", "rms-average weighting (RMS)" or "intermittent, unsteady drifting narrowband disturbances (IUD)" (Fig. 3.3). IUD is only available for Band B and Band B+ (Band C).

Selecting QP or RMS opens the signal menu (Fig. 3.4). From here, choose the type of signal to generate by entering the pulse menu (PUL) or continuous wave menu (CW). From the signal menu it is also possible to enter the attenuator menu (ATT).

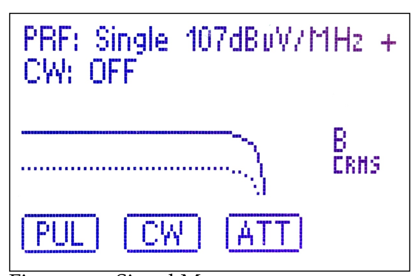

Figure 3.4: Signal Menu

When entering the pulse signal menu (PUL), the C1611 starts generating impulses as indicated on the display. The different test methods have different default settings so to promptly generate the reference signal in accordance to CISPR 16-1-1 requirements. For example, the default setting in Band-B QPk-weighting is the generation of a pulse signal with spectral density 107 dBμV/MHz and PRF 100 Hz, positive polarity. The pulse repetition frequency can be decreased (PRF-) and increased (PRF+), the polarity can be inverted (POL) or the generation of impulses can be switched off (OFF).

When the pulse signal is switched off (either by pressing OFF or by pressing PRF- repeatedly) by pressing SNG the C-1611 generates a single impulse.

The display shows the generated signal numerically and graphically, the polarity (+ or -), and reports the selected band. It also shows basic CISPR 16-1-1 weighting prescriptions. In QP mode, theoretical Pk and QPk delta readings in dB are shown. The displayed figures represent the logarithmic difference between (i) the expected Pk and QPk reading when dealing with a pulse having a certain PRF and (ii) the reference QPk reading dealing with a pulse having the reference PRF. In RMS mode selected in the test menu, theoretical C-RMS delta readings are shown. The displayed figures represent the logarithmic difference between (i) the expected C-RMS reading when dealing with a pulse having a certain PRF and (ii) the reference C-RMS reading given a pulse with the reference PRF. In case pulses with the reference PRF are generated, 0.0 is shown as QP or C-RMS delta reading.

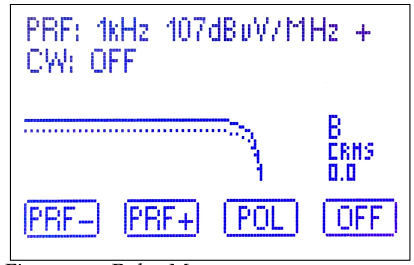

Figure 3.5: Pulse Menu

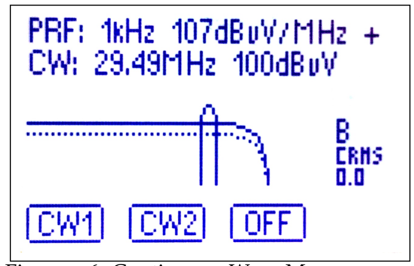

Figure 3.6: Continuous Wave Menu

In the continuous wave menu (CW), choose between two continuous wave signals: CW1 of amplitude 100 dBμV and frequency 29.4912 MHz or CW2 of amplitude 100 dBμV and frequency 32.00 MHz. The two signals are exclusive, they cannot be activated both at the same time. By pressing OFF in the continuous wave menu, the continuous wave signal is switched off. The selected signal is indicated on the display numerically and graphically. The pulse signal and continuous wave signal can be generated simultaneously.

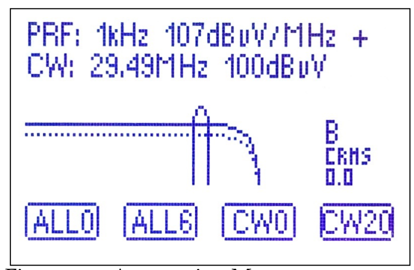

Figure 3.7: Attenuation Menu

From the attenuation menu (ATT) attenuate all signals (pulse and continuous wave) by 6 dB by choosing ALL6. ALL0 turns the attenuation off. Additionally, when the continuous wave signal is activated, you can choose to attenuate only the continuous wave signal by 20 dB (CW20). CW0 turns the attenuation of the continuous wave signal off. The resulting signal amplitude is reported on the display.

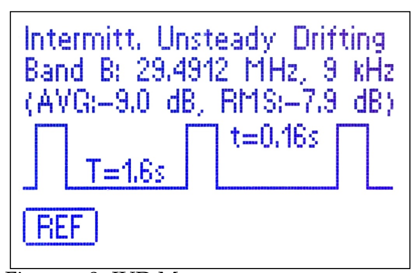

Figure 3.8: IUD Menu

From the test menu, in case Band B or B+ (C) was selected, press IUD to enter IUD menu. Once in the IUD menu, the C-1611 generates the intermittent single-tone signal at 29.4912 MHz for Band B and at 32 MHz for Band B+ (Band C). The display shows the On-Off period, marked as T, and the time the tone is on, marked as t. Further, it shows the selected band, the RBW that should be used in accordance with CISPR 16-1-1, the frequency of the intermittent single tone and the theoretical deltas between AVG and RMS and reference reading. In this menu press REF to start generating the reference continuous, single-tone signal at 29.4912 MHz for Band B and at 32 MHz for Band B+ (Band C). Press IUD to go back to the IUD menu.

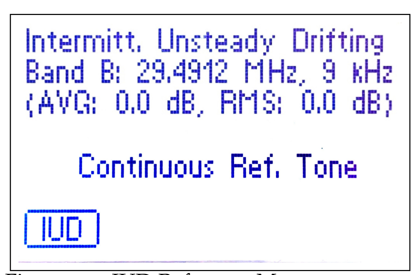

Figure 3.9: IUD Reference Menu

4
Theoretical Background

These introductory pages treat the main basic concepts that may help the user to better understand the theory behind tests to evaluate EMI receivers and thus to take fully advantage of the C-1611 tester.

4.1 Complying with standards is challenging

Since decades, CISPR 16-1-1 standard defines the requirements for EMI receivers in the civilian contexts, in order to benchmark these instruments in different setups and environments. For example, EMI receivers must use specific detectors (*e.g.*, peak, quasi-peak, average, RMS) and resolution bandwidths (RBW, *e.g.*, 200 Hz, 9 kHz, 120 kHz, 1 MHz), as defined in [CIS10]. To be able to comply with all requirements of CISPR 16-1-1, EMI receivers need to have a high dynamic range. For example, the prescriptions on the pulse response of the QPk detector for an isolated impulse (see Tab. 2 in [CIS10]) are particularly challenging.

4.1.1 Dynamic range

The dynamic range defines the capability of a receiver to correctly and simultaneously measure concurrent signals with (very) different amplitudes. Specifically, the dynamic range is defined as the logarithmic difference (or the linear ratio) between the maximum and the minimum signal level that a receiver can measure in one shot. This parameter is also called instantaneous dynamic range [Tsu01]. The minimum level is the lowest input signal level a receiver can detect. Signals with a lower level fall below the noise floor of the receiver and therefore cannot be detected. Instead, the maximum level is the highest input signal level a receiver can handle without compressing the signal. Signals with a higher level are distorted by one or more components in the receiving path of the receiver.

Since the dynamic range is limited by the noise floor of the instrument, it depends on the type of detector used and on the RBW value. Indeed, the use of different detector types leads to different noise floors. In standard conditions, the noise displayed with a peak detector is roughly 4 to 5 dB higher than with a QPk detector (depending on the band), about 12 dB higher than with an RMS detector and approximately 13 dB higher than with an AVG detector [RJM01]. This is due to the different nature of the detectors. While the peak detector captures the maximum value of the input signal, the QPk detector gives a weighted peak value of the input signal, the RMS detector measures the quadratic mean of the signal, and the AVG detector determines the signal average value.

The noise floor is also proportional to the bandwidth which enters the system: the narrower the bandwidth, the lower the noise. Specifically, every time the input bandwidth becomes ten times narrower, the noise floor

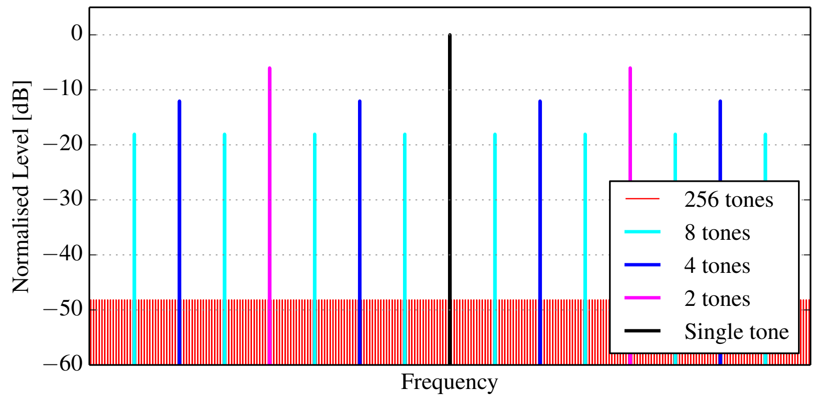

Figure 4.1: Non-compressing level of multiple-tone signals normalised to a single-tone signal (full scale). The represented signals are made of either a single tone, two tones, four tones, eight tones or 256 tones.

decreases by 10 dB [Wil92].

The maximum measurable signal level depends on the energy that a receiver is able to handle, and it is thus dictated by the signal type and amplitude, and may depend on the receiver's RBW. When a single sinusoidal signal enters the system, the input energy is fully concentrated in a single frequency component. For example, suppose that the circuitry of an EMI receiver, with a band-pass filter of 30 MHz, starts compressing at a level of 107 dBμV (namely 0 dBm). Such a receiver is capable of correctly measuring a single sinusoidal signal of maximum 107 dBμV.

4.1.2 Wide-band signals and pulses

In multiple-tone signals the signal energy is spread over the different frequency components. Further, the crests of the tones may sum up in phase. Hence, to guarantee that a receiver does not compress the signal, the maximum amplitude of the single tones should be lower to make sure that their peak amplitude does not exceed the maximum measurable level. More specifically, for a multiple-tone signal made of many sinusoidal components of equal amplitude, the maximum amplitude of the single components decreases by 6 dB for every doubling in the number of sinusoidal components (see Fig. 4.1). The hypothetical EMI receiver of the previous example would be able to correctly measure two sinusoidal signals of 101 dBμV each.

The worst case scenario is when the input energy spreads over the whole input bandwidth, namely with a pulse signal [RH97, Sch16]. As mentioned before, the maximum measurable level must be reduced in order to avoid compression phenomena. By reducing the input bandwidth through a filter, the energy can be limited before the signal arrives to the first compression sensitive component: the narrower the bandwidth, the lower the energy and thus the higher the maximum measurable level [MPM16b]. Obviously, in case of a pulse signal, this level depends on the RBW. For example, suppose we want to measure a pulse signal using again our EMI receiver with a band-pass filter of 30 MHz and which starts compressing at 107 dBμV. The spectral density, normalised to 1 MHz, should not exceed 77.5 dBμV/MHz ($= 107$ dBμV $- 20\lg(30\text{ MHz}/1\text{ MHz})$), otherwise the pulse signal would be compressed. If the RBW of the receiver is set to 100 kHz, the reading will be 77.5 dBμV $- 20\lg(1\text{ MHz}/100\text{ kHz}) = 57.5$ dBμV. By using instead a RBW of 9 kHz (RBW value required for Band B, see Tab. 6 in [CIS10]), the reading will be 36.6 dBμV. Thus, the maximum level that for a sinusoidal signal was 107 dBμV, for an impulse is merely 36.6 dBμV, seen with a 9 kHz RBW. This corresponds to a drastic dynamic reduction of 107 dBμV $-$ 36.6 dBμV $\approx$ 70 dB (see also the lab test in [MPM16a]). On the other hand, if we reduce the input bandwidth to 10 MHz, the maximum spectral density will increase to 87 dBμV/MHz, which means a reading of 46.1 dBμV with a RBW of 9 kHz. We have gained 10 dB in dynamic range.

An EMI receiver must always be capable of correctly working with all types of signals, first of all impulses. In EMI measurements there is no *a-priori* knowledge about the nature of the interference under investigation. This means that the receiver must be able to deal with very high and very low level signals at the same time. Thus, a high dynamic range is essential.

4.1.3 *Overload*

The lack of dynamic range in EMI measurements is a very critical aspect because it can easily pass unnoticed [MPM17b]. The reading of a high energy signal (such as an impulse) may be far below the maximum reading (instrument's Ref-Level) while the band is entirely occupied by the impulse. Thus, the user may erroneously think to still have a lot of dynamic range available while instead, the instrument may have already started compressing. In such conditions, for any change in the input there will no longer be a correspondent change in the output. Further, because the the receiver's front-end components no longer work in their linear range, they may cause harmonic distortions and generate spurious responses. Thus, overload conditions lead to erroneous, usually underestimated, measurement results [Sch04].

By using the C-1611 tester, the user can easily check whether the EMI receiver has a sufficient dynamic range to work in its linear range.

4.2 *Measurement uncertainty*

Today, EMI receivers can take advantage of Fast Fourier Transform (FFT) processing and thus benefit from the extremely short measurement time, compared to that obtained with traditional (super-) heterodyne technology, and of the complete digitalisation of the signal processing.

Before applying FFT algorithms, a necessary stage in the processing of the signal in FFT receivers is *windowing* [Har78]. Basically, signal samples are multiplied by the coefficients of a certain window function. This serves to reduce the effect of discontinuities at endpoints of input data. In this process, amplitudes of time samples are smoothly down-scaled the more they are away from the middle of the window. This means that a signal that falls close by the ends of the window is underestimated (erroneous estimation) or even completely missed (erroneous detection) [Har78].

4.2.1 *Time-domain error and scalloping loss*

The shape of the window (*e.g.*, the α-parameter in a Gaussian window) defines the 'width' of the window [Har78] and affects the measurement error due to the weighting of time samples of the signal. Further, it plays a crucial role in the *scalloping* loss, namely the loss in amplitude due to signal frequency components that fall half way between two bins in the frequency domain [Har78]. Practically, the shape of the window represents a trade-off to obtain acceptable scalloping losses and time-domain measurement errors.

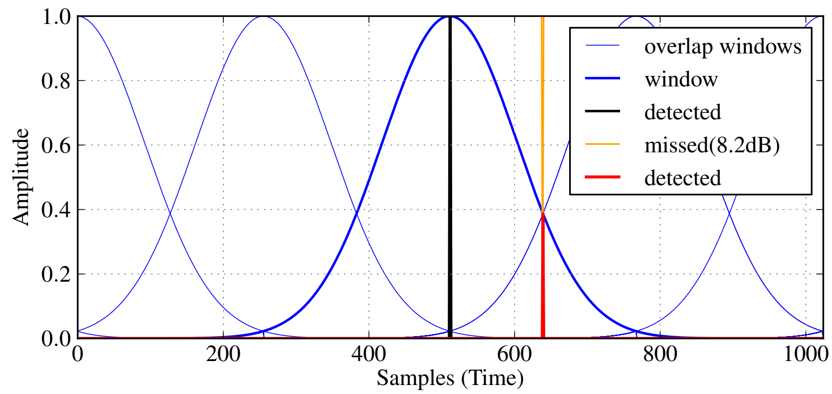

Figure 4.2: Overlapped Windowing: Gaussian windows ($\alpha = 5.5$) with an overlap of 75%. This makes the maximum time-domain measurement error 8.2 dB. An impulse (black) that falls in the middle of the window is estimated correctly. An impulse that falls between two consecutive windows is only partially estimated (red); 8.2 dB are lost (orange). Measurement units of both axes are neglected because absolute values are not relevant.

4.2.2 *Overlapping to reduce measurement uncertainties*

A common approach to solve the measurement error in the time domain, but not the scalloping loss, is performing several FFTs over overlapped intervals of samples. Fig. 4.2 shows the procedure in time domain. The more the overlapping is, the less the measurement error is, but the more FFTs are required to cover a certain number of points. The counterpart of overlapping with high factors, in order to reduce the measurement error, is the high computational load required to perform the many FFTs. In practice, either many parallel hardware modules (FPGAs) must simultaneously compute FFTs over overlapped intervals, or a single switched module must perform consecutive FFTs at a higher speed.

If we decrease the overlapping factor we get higher error values. For example, by using a Gaussian window with $\alpha = 6$ and an overlap of 75% we get a maximum measurement error of 9.8 dB. This represents a high value which does not comply with CISPR 16-1-1. With $\alpha = 2.5$, the theoretical scalloping loss would be 1.69 dB and, assuming a 75% overlap, the maximum time-domain measurement error would be 1.7 dB.

Statistical approaches in EMI measurements can compensate measurement errors. For example, instead of performing a single signal acquisition with a subsequent FFT processing using high overlapping factors (e.g., more than 75 %), it is possible to perform several signal acquisitions with subsequent FFT processing using reduced overlapping. Of course, to benefit from this method in terms of hardware resource reduction, the different signal acquisitions and processing are performed sequentially. In this way, the hardware can perform less demanding tasks, *i.e.*, FFTs with lower overlapping factors (e.g. 75 %), in consecutive steps.

Approaches that exploit repeated measurements work well with high PRF pulses but are not suitable in case of low PRF pulses or an isolated pulse. Practically, statistical approaches in EMI measurements require frequency components and amplitude levels to be stationary so to guarantee that repeated measurements of a certain set of frequencies produce the same results (assuming that the setting of the receiver does not change meanwhile) [BR06]. While this is true for example for continuous signals and for pulse signals that have a non-zero pulse repetition frequency (PRF), this is not true for an isolated impulse.

The C-1611 tester includes the generation of low-PRF pulses and isolated pulses, as prescribed in CISPR 16-1-1, to evaluate the actual measurement uncertainty of the receiver under test.

4.3 *Beyond standard compliance*

Tests described in today's standards cannot fully estimate the actual quality of the instruments for EMI measurements.

4.3.1 *Relative* vs. *absolute readings*

CISPR 16-1-1 requirements include an *absolute* calibration measurement that controls a correct relationship between peak and QPk readings (see Tab. 7 in [CIS10]). This calibration measurement has to be performed under specific conditions for each band. For example, in Band B the receiver must use a RBW of 9 kHz and the generated pulse must have a PRF of 100 Hz. All other CISPR 16-1-1 requirements are based on this reference measurement and are thus only *relative* measurements. For instance, Tab. 2 in [CIS10] prescribes the relative QPk pulse response of measuring receivers for different PRFs compared to the previously obtained reference value. Hence, the receiver is calibrated to measure peak values under certain conditions but not for other conditions where only relative QPk values are observed. As the QPk detector gives a weighted peak value of the envelope of the input signal, any underestimation of peak values is necessarily also reflected in the QPk measurement. Thus, it can happen that the relative values as prescribed in [CIS10] and [CIS16] may be correct, while the absolute reading is wrong, since the receiver is overloaded [MPM17b]. Paradoxically, the more a receiver is overloaded, the more it is able to satisfy the requirements of low PRFs and hence, the better it may seem to work. However, these relative measurements based on compressed absolute values are, of course, completely unreliable and such EMI receivers cannot be used to make accurate characterisations of EUTs. After all, limits for EUT's emissions refer to absolute values, independently of the detectors.

The C-1611 is an EMI receiver tester and should not be used to calibrate absolute readings, see Sect. 2.2 to see the level specifications of the C-1611. Still, it is a valid tool to test whether the aforementioned phenomena affect the tested EMI receiver.

4.3.2 *Evaluating EMI receiver hardware beyond modern processing techniques*

CISPR 16-1-1 standard was originally developed for traditional heterodyne EMI receivers and today, it only partially refers to the new technology. The standard does not prescribe tests specifically thought for FFT receivers and that check the validity of newly-introduced signal processing techniques [MPM17a].

Today, with the complete digitalisation of the signal processing, new methods have been implemented to improve the performance in the measurement of certain types of signals and in certain conditions. A/D approaches, known as scaled or multi-resolution ADCs [BR05], may be used to increase the range between maximum and minimum signals that a receiver can correctly measure separately. Repeated measurements can reduce uncertainty [KF07], for example introduced by the processing of the digitalised signal. Multi-sampling techniques [BR06] help reducing instrument distortions caused by non-linearities in the different components of the receiving path (amplifier, ADC and possibly filters). Subtraction of the receiver noise, which is measured in a first calibration measurement, can reduce the noise floor [Agi10].

Although such processing techniques can be successfully implemented, for example, to improve performances of spectrum analysers, they fall short of improving (or may even worsen) the measurement capabilities of EMI receivers [MPM17a]. They cannot be exploited to substitute well-performing hardware.

The C-1611 can be used to check the actual performance of EMI receivers. Chapter 5 provides specific tests to evaluate the actual instantaneous dynamic range of the receiver, to check the presence in the receiver's front-end of valuable hardware (*e.g.*, preselector), to expose the use of repeated measurement techniques and thus to confirm the receiver's capability to correctly detect sporadic wide band interferences (*i.e.*, isolated pulses).

5 Tests

The C-1611 tester can be used to evaluate the actual instantaneous dynamic range, the benefit of a hardware preselector, the capability to correctly measure sporadic wide-band signals, the weighting according to current standards, the correctness of absolute readings, the maximum measurement uncertainty that an EMI receiver may exhibit, and finally the receiver's response to intermittent, unsteady and drifting narrowband disturbances.

5.1 Dynamic range

The C-1611 tester offers two ways of evaluating the dynamic range of an EMI receiver. The less demanding test makes use of continuous single-tone signals; most spectrum analysers and EMI receivers pass this test. The other test makes use of pulses; this test challenges even high-quality, state-of-the-art receivers.

5.1.1 Dynamic range with continuous, single-tone signals

The dynamic range of the EMI receiver can be evaluated by using continuous, single-tone signals. Choose a band of interest, for example Band B, and generate the continuous, single-tone signal at 29.4912 MHz with the C-1611 (continuous wave menu: CW1). Then, set the EMI receiver to correctly read the signal level: tune the receiver to 29.4912 MHz; the specific RBW setting is not important but must be maintained throughout the test, set for example 9 kHz RBW. Change the receiver's internal input attenuator manually to make the CW1 signal level being the maximum measurable signal level, yet avoiding overload conditions. To do that, first set the receiver's internal attenuator to its maximum value (maximum attenuation) and ensure to have switched off all attenuators in the C-1611 (attenuation menu: ALL0 and CW0). Read the level at 29.4912 MHz on the receiver. Then, insert the C-1611's internal 6 dB attenuator (attenuation menu: ALL6). The reading must decrease by 6 dB as well. If this is the case, decrease the receiver's internal attenuator and repeat the procedure. If the reading decreased by less than 6 dB, it means that the receiver is compressing the signal. The last correctly-measured value represents the maximum measurable signal level. Set the receiver's internal attenuator to the minimum attenuation value that guarantees no compression.

The granularity of the EMI receiver's internal input attenuator affects the maximum measurable signal level. For example, if the internal attenuator can be adjusted with steps of 5 dB, in the worst-case scenario, the maximum measurable signal level is reduced by 5 dB from its optimal value.

In case the input level is too high and the receiver has an insufficient internal attenuator, use the provided 20 dB external attenuator to further reduce the input level.

To evaluate the minimum detectable signal, keep the single tone switched on and read the noise level at a frequency that is close to 29.4912 MHz, so to make the maximum and minimum readings as much comparable as possible, but distant enough from 29.4912 MHz, to avoid the noise reading being affected by the single-tone component (for example, with 9 kHz RBW, read the noise level at 29 MHz). This noise level reading represents the minimum measurable signal level to be used to estimate the instantaneous dynamic range. The dynamic range is defined as the (logarithmic) difference between the maximum and minimum measurable signal levels.

To expose the possible use of scaled (or multi-resolution) ADCs, switch the single tone off and evaluate again the noise floor. For receivers that use valuable front-end hardware, the noise level reading at a certain frequency (e.g. 29 MHz @ RBW=9 kHz) is not affected by the presence/absence of a continuous, single-tone signal at another frequency, distant enough not to fall in the RBW range.

If the noise floor changes in presence or absence of the single-tone signal, this means the receiver is making use of processing techniques that merely shift the working point of the receiver but that are unable to improve the instantaneous dynamic range. In this case, the limited dynamic range could be insufficient when dealing with pulses.

5.1.2 *Dynamic range with pulses*

To challenge the dynamic range of the EMI receiver under test, use pulses to evaluate the maximum measurable signal level. Thus, switch on the pulses in the C-1611 (enter the pulse menu; signal menu: PUL). The PRF setting does not effect the evaluation of the maximum measurable signal; yet, high PRF values make the setting of the receiver easier. As described in Sect. 5.1.1, set the EMI receiver to correctly read the signal level. Thus, in the receiver, choose the peak detector and tune to a frequency in the band of interest, *e.g.*, 20 MHz for Band B. Set the RBW according to prescriptions in CISPR 16-1-1, *e.g.*, 9 kHz for Band B, and maintain this setting throughout the test. If the prescribed RBW value is not available in the receiver setting, chose a RBW value as close as possible to the prescribed value. Change the receiver's internal input attenuator manually to make the pulse level being the maximum measurable signal level, yet avoiding overload conditions. To do that, first set the receiver's internal attenuator to its maximum value (maximum attenuation) and ensure to have switched off all attenuators in the C-1611 (attenuation menu: ALL0 and CW0). Read the level on the receiver. Then, insert the C-1611's internal 6 dB attenuator (attenuation menu: ALL6). The reading must decrease by 6 dB as well. If this is the case, decrease the receiver's internal attenuator and repeat the procedure. If the reading decreased by less than 6 dB, it means that the receiver is compressing the signal. The last correctly-measured value represents the maximum measurable signal level. Set the receiver's internal attenuator to the minimum attenuation value that guarantees no compression.

The granularity of the EMI receiver's internal input attenuator affects the maximum measurable signal level. For example, if the internal attenuator can be adjusted with steps of 5 dB, in the worst-case scenario, the maximum measurable signal level is reduced by 5 dB from its optimal value.

In case the input level is too high and the receiver has an insufficient internal attenuator, use the provided 20 dB external attenuator to further reduce the input level.

To evaluate the minimum detectable signal, select the quasi-peak detector in the receiver, switch off the pulses in the C-1611 (pulse menu: OFF) and read the noise level. The dynamic range is defined as the (logarithmic) difference between the maximum and minimum measurable signal levels.

To expose the possible use of scaled (or multi-resolution) ADCs, switch a continuous single-tone signal on (it does not matter whether in or out of band, *e.g.*, continuous wave menu: CW1). Evaluate again the noise floor, making sure to measure at a frequency that is distant enough from the frequency of the switched-on single tone. For receivers that use valuable front-end hardware, the noise level reading at a certain frequency is not affected by the presence/absence of a continuous, single-tone signal at another frequency.

If the noise floor changes in presence or absence of the single-tone signal, this means the receiver is making use of processing techniques that merely shift the working point of the receiver but that are unable to improve the instantaneous dynamic range. In this case, the limited dynamic range could be insufficient to correctly weight pulses in presence of other coexisting signals and disturbances.

The evaluated difference between the maximum peak level and minimum quasi-peak level should be higher than the weighting prescribed in CISPR 16-1-1 for the isolated impulse, *i.e.*, reasonably higher than 25.1 dB for Band A and reasonably higher than 30.1 dB for Band B.

5.2 *Band B+ tests*

Pulses represent the most challenging signals to be measured correctly because their energy is spread over a very wide band. The wider the pulse spectrum is, the higher the energy entering the receiver is. The C-1611, in Band B mode, generates pulses that extend up to 30 MHz with a flatness of 2 dB and in Band B+ mode, it generates pulses that extend up to 50 MHz with a flatness of 2 dB. Thus, the same weighting tests of Band B can be extended in Band B+ mode, beyond actual CISPR 16-1-1 prescriptions, so to challenge the receiver's measurement capability.

The reading of a high energy signal may be far below the maximum reading (receiver's Ref-Level) while the band is entirely occupied by the impulse. In this case, the dynamic range may seem sufficient while instead, the instrument may have already started compressing. Check the theoretically expected absolute values.

Receivers, which do incorporate a valuable hardware preselector at the very front-end of the receiving path, limit the input energy to the sole band of interest.

5.3 Emulating a front-end preselector

When dealing with pulses, the receiver may exhibit an insufficient instantaneous dynamic range. To improve this figure, the input bandwidth of the receiver should be reduced so to limit the energy facing the first sensitive components in the receiving path (*i.e.*, pre-amplifier, mixer or ADC). Practically the receiver should make use of a valuable hardware preselector exhibiting a band sufficiently narrow.

It is possible to emulate a hardware preselector. The external 10 MHz LP filter, provided with the kit, should be placed between the receiver input and the C-1611 output. In case the receiver has no preselector or the preselector's band is too wide, the emulated preselection (external 10 MHz LP filter) increases the saturation point of the receiver. Practically, repeating the procedure described in Sect. 5.1.2 to estimate the maximum measurable pulse level, in presence of the external 10 MHz LP filter, the receiver may need a lower internal attenuator to guarantee no compression, improving therefore the effective dynamic range.

When emulating preselection, by inserting the provided 10 MHz LP filter between the receiver input and the C-1611 output, measurements must be performed at frequencies lower than 10 MHz.

It is possible to roughly estimate the band of the preselector, which may be built in the receiver, by measuring the saturation level improvement brought by inserting the external 10 MHz LP filter (having an impulse band of roughly 13.5 MHz).

$$B_{presel} = 13.5 \cdot 10^{\Delta_{dB}/20} \tag{5.1}$$

where B_{presel} is the approximated band in MHz of the receiver's preselector and Δ_{dB} is the increase in dB of the saturation level once having inserted the external 10 MHz LP filter. No improvements means that the receiver makes use of a hardware preselector with a band which is narrower than 10 MHz LP filter (narrower than $\sim$ 13.5 MHz impulse band).

5.4 Absolute readings

Although the C-1611 tester is not a calibrator, this instrument can be used to find out whether the EMI receiver is capable or not of correctly detecting a signal, without focusing on mere relative measurements such as QPk and RMS-AVG weighting.

The formula to calculate the expected theoretical Pk reading is

$$Pk_e = PSD - 20 \cdot Log\left(\frac{1e6}{RBW}\right) \tag{5.2}$$

where Pk_e is the expected theoretical Pk reading, PSD is the spectral density given in Sect. 2.2 for each band, RBW is the resolution bandwidth in Hz of the receiver. Pk_e is expressed in dBμV if the spectral density is given in dBμV/MHz. For example in Band B and with 9 kHz RBW, for a pulse with a spectral density of 107 dBμV/MHz, the expected peak reading should be 107 dBμV/MHz $- 20\lg(1\text{MHz}/9\text{kHz}) = 66.1$ dBμV.

Absolute readings are affected by tolerances specified in Sect. 2.2. Absolute reading errors in the order of the dB are acceptable.

Absolute Pk readings should not be affected by the change of PRF.

5.5 *QPk and RMS-AVG weighting*

Checking the correctness of the EMI receiver's weighting is very simple. First, choose the band of interest in the C-1611 tester (main menu) and the type of weighting you want to test (test menu) and set the EMI receiver consistently, *e.g.*, Band B, 9 kHz RBW and QPk detector. Enter the pulse mode (signal menu: PUL) in the C-1611 tester and automatically the pulses are generated at the reference PRF value in accordance with the current standard CISPR 16-1-1, *e.g.*, 100 Hz @ band-B QPk weighting test. Read the level at a frequency within the band of interest, *e.g.*, 25 MHz @ band-B test. This represents the QPk reference level. For example, in a band-B QPk weighting test, the Pk reading should be 6.6 dB higher than the QPk reading; ± 1.5 dB is the admitted tolerance. Once obtained the reference QPk value, QPk weighting with other PRFs should be checked (pulse menu: PRF- and PRF+). The (logarithmic) difference between the receiver's QPk readings with reference PRF and other PRFs should match the value indicated in the C-1611. The related tolerances can be looked up in the help menu. In QP mode, both Pk and QPk readings can be evaluated; in RMS mode, C-RMS readings can be evaluated.

The acquisition time of the EMI receiver (also called observation time or hold time) should be set to ensure capturing at least a pulse, *e.g.*, with a PRF=100 Hz the acquisition time should be more than 1/100=10 ms.

If the receiver works in overload conditions, it may still correctly weight the signal and may provide correct relative readings, while the absolute readings may be wrong. Check absolute readings as well.

Overload conditions may be avoided by using the provided 20 dB external attenuator to reduce the input level.

5.5.1 *Measurement uncertainty*

Measurement uncertainty manifests in unstable readings; Pk readings most exhibit such phenomena due to the nature of the detector. Practically in pulse tests, the peak reading changes among adjacent frequencies or changes over time.

The more pulses are observed within a given acquisition time, the less the measurement uncertainty is. Thus, to evaluate the maximum measurement uncertainty that the receiver may exhibit, perform the pulse test making sure the acquisition time of the receiver is smaller than twice the pulse repetition period (<2/PRF), and of course greater than a period (>1/PRF).

Pk readings should not be affected by the PRF.

5.5.2 *Single pulse*

The most challenging signal to be measured correctly is the single pulse (pulse menu signal: SNG). Since the pulse is one, no repeated measurements can help the receiver to better detect/estimate the signal.

The single pulse test is particularly helpful to estimate the quality of EMI receivers, with particular attention to its hardware; the single pulse test makes inefficient all post-processing techniques that may reduce the measurement uncertainty under special conditions.

When evaluating the receiver's weighting in case of a single pulse, the single pulse must be generated (pulse menu: SNG) within the acquisition time set in the receiver. This test is easier to perform with a long acquisition-time setting, *e.g.*, 10 s.

5.6 *Beyond the standards*

When the receiver's hardware cannot guarantee a sufficient dynamic range, the EMI receiver is not capable of correctly weighting the signal anymore. However processing techniques, such as multi-resolution ADC, can make do with the insufficient dynamic range and thus let the receiver pass weighting tests such as those described in Sect. 5.5 and prescribed in the current standard.

To further check whether the instantaneous dynamic range is sufficient or not, the weighting tests can be repeated in presence of the continuous, single-tone signal at 29.4912 MHz (continuous wave menu: CW1). QPk or RMS-AVG readings in Band A or B should not be affected by the presence of a single-tone signal with a frequency sufficiently distant from the tuned frequency, no matter if the signal is in or out of the band of interest (an out-of-band signal should definitively not affect the measurement; preselection should cut off signals out of interest).

5.7 IUD test

In intermittent, unsteady and drifting narrowband disturbances (IUD) tests, the C-1611 tester makes use of an intermittent single-tone signal, at 29.4912 MHz in Band B mode and at 32 MHz in Band B+ mode (Band C). The test is very simple.

First, choose the band of interest in the C-1611 tester (main menu) and the IUD test (test menu), and set the EMI receiver consistently, *e.g.*, Band B, 9 kHz RBW, AVG detector, tuned at 29.4912 MHz. Generate the single-tone signal (IUD menu: REF) and read on the receiver the reference value of AVG and/or RMS. Go back to the IUD menu (IUD reference menu: IUD) to generate the intermittent single-tone signal. The (logarithmic) difference between the receiver's AVG and RMS readings and reference AVG and RMS readings should match the values indicated in the C-1611.

During IUD test, the acquisition time of the receiver should be set greater than the On-Off period of the intermittent single-tone signal.

5.8 Available tests

Not all tests can be performed in all bands. The following table makes clear which tests are available in each band.

	Band A	Band B	Band B+	Band C
QPk and RMS-AVG weighting CISPR 16-1-1 compliant	✓	✓		
QPk and RMS-AVG weighting with out-of-band single tone	✓	✓		
QPk and RMS-AVG weighting with in-band single tone		✓	✓	
Measurement uncertainty	✓	✓	✓	✓
Absolute reading correctness	✓	✓	✓	✓
Preselection emulation		✓		
Dynamic range estimation		✓	✓	✓
IUD test		✓	✓	✓

Table 5.1: Available Tests

Most tests in Band C can be performed only at the very beginning of the frequency band.

Tests in Band B+ and in Band C can be performed in B+ mode.

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