Use of FFT-based measuring instruments for EMI compliance measurements

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Abstract* — *FFT-based measuring instruments can be used for EMI compliance measurements in accordance with Amendment 1 to 3rd Edition of CISPR 16-1-1 if this standard is referenced in the product standard. The use is motivated by reducing the scan time by several orders of magnitude. A part of this time saving can be used for applying longer measurement times in order to reliably detect narrowband intermittent signals or isolated pulses. For precise and reproducible measurements the use of preselection filters is highly recommended.

Key words: EMI receiver, FFT-based measuring instrument, EMI compliance measurement, CISPR 16-1-1.

I. Introduction

Conventional EMI receivers are measuring the signal within the resolution bandwidth in a given measurement time, which results in a long scan time for the entire frequency range. FFT-based measuring instrument are **measuring spectral segments much wider than the measurement bandwidth during the measurement time by parallel calculation at several frequencies.** It offers the following advantages:

- Scan time can be significantly reduced by several orders of magnitude without degradation of accuracy.
- Allows application of longer measurement times, e.g. for measuring intermittent signals.
- Makes enhanced measurement functions like IF analysis, spectrogram and persistence mode applicable.

With the publication of Amendment 1 to 3rd Edition of CISPR 16-1-1 [1] in June 2010 FFT-based measuring instruments were introduced for EMI compliance measurements. However, publication in the basic standard does not mean that FFT-based measuring instruments can be used immediately. Their use is only possible for emission measurement on sound and television broadcast receivers and associated equipment (CISPR 13:2006), lighting equipment (CISPR 15:2013) and for multimedia equipment (CISPR 32:2012). A detailed explanation about their applicability is given in section ***III How a basic standard comes into force***.

Care must be taken when selecting the measurement time using an FFT-based measuring instrument for measuring broadband disturbance and intermittent signals. Furthermore, the use of preselection filters is highly recommended for maximum dynamic range and to avoid overload. This is particular true for quasi-peak measurements of weak pulsed signals in the presence of high amplitude carriers. Guidance is given in section ***IV Timing and Dynamic Range Considerations using FFT-based Measuring Instruments.***

II. Concept of CISPR 16-1-1

Currently CISPR 16-1-1 uses a "black box approach" to define specifications for measuring apparatus. This means that all stated specifications in CISPR 16-1-1 must be met by the measuring apparatus, independent of the selected implementation or technology, in order to be considered suitable for measurements in accordance with CISPR standards.

To reflect this approach, a new definition of the term **"measuring receiver"** has been added in Amendment 1:2010-06 to CISPR 16-1-1:2010-01 [1], it says:

> *"instrument, such as a tunable voltmeter, an EMI receiver, a spectrum analyzer or an **FFT-based measuring instrument**, with or without preselection, that meets the relevant parts of this standard".*

As a consequence an FFT-based measuring instrument that meets the requirements of CISPR 16-1-1:2010 and its Amendment 1:2010 can be used for EMI compliance measurements. Generally, this comprises the parameters input impedance, detectors, bandwidth, overload factor, VSWR, absolute sine-wave voltage accuracy, response to pulses, overall selectivity, intermodulation effects, receiver noise, and screening.

In addition to the above general requirement the FFT-based measuring instrument shall sample and evaluate the signal continuously during the measurement time. This is essential for capturing impulsive disturbance and intermittent signals. It disqualifies the use of digital storage oscilloscopes for EMI compliance measurements due to the existence of blind times.

III. How a Basic Standard comes into Force

Basic standards come into force with dated or undated normative references in product standards:

- If the reference is undated, the **latest** edition of the standard shall apply.
- If the reference is dated, the **specific** edition of the basic standard shall apply.

CISPR 13:2006 (Ed. 4.2) has undated references to basic standard CISPR 16-1, whereas all other CISPR product standards for emission measurements have dated references, see Table I.

TABLE I
DATED REFERENCES TO CISPR 16-1-1

Product Standard	Reference to CISPR 16-1-1	Stability Date
CISPR 11:2010 (Ed. 5.1) — product standard for industrial, scientific and medical equipment (ISM)	CISPR 16-1-1:2006 and its Amendments 1:2006 and 2:2007	2014
CISPR 12:2009 (Ed. 6.1) — product standard for vehicles, boats and internal combustion engines (protection of off-board receivers)	CISPR 16-1-1:2006	2014
CISPR 13:2009 (Ed. 5.0) — product standard for sound and television broadcast receivers and associated equipment	CISPR 16-1-1:2006 and its Amendments 1:2006 and 2:2007	2014
CISPR 14-1:2011 (Ed. 5.2) — product standard for household appliances and electric tools	CISPR 16-1-1:2003	2014
CISPR 15:2013 (Ed. 8.0) — product standard for electrical lighting and similar equipment	CISPR 16-1-1:2010 and **its Amendment 1:2010**	2015
CISPR 22:2008 (Ed. 6.0) — product standard for information technology equipment (ITE)	CISPR 16-1-1:2006 and its Amendments 1:2006 and 2:2007	2017
CISPR 25:2008 (Ed. 3.0) — product standard for vehicles, boats and internal combustion engines (protection of on-board receivers)	CISPR 16-1-1:2006 and its Amendments 1:2006 and 2:2007	2014
CISPR 32:2012 (Ed. 1.0) — product standard for multimedia equipment	CISPR 16-1-1:2010 and **its Amendment 1:2010**	2015
IEC 61000-6-3:2010 (Ed. 2.1) — generic standard for residential, commercial and light-industrial environments	CISPR 16-1-1:2010	2014
IEC 61000-6-4:2010 (Ed. 2.1) — generic standard for industrial environments	CISPR 16-1-1:2010	2014

Therefore, the users of CISPR 13:2006 (Ed. 4.2), CISPR 15:2013 (Ed. 8.0) and CISPR 32:2012 (Ed. 1.0) can immediately employ an FFT-based measuring instrument for EMI compliance measurements if the instrument meets the requirements of CISPR 16-1-1:2010 and its Amendment 1:2010 (Ed. 3.1). For most of the other standards it may be possible to update the references in 2014. CISPR 22 will not be amended any further and will be replaced by CISPR 32 in 2017. For this reason, **pure FFT-based measuring instruments will still not be suitable for compliance measurements for long time.**

To overcome this acceptance problem it is recommended to use a measuring receiver, which combines the conventional EMI receiver functions with the FFT-based time-domain scan function in one device. With such instruments the time consuming preview measurements can be made using the fast time-domain scan followed by full compliant receiver measurements after data reduction and emission maximization, see Figure 1.

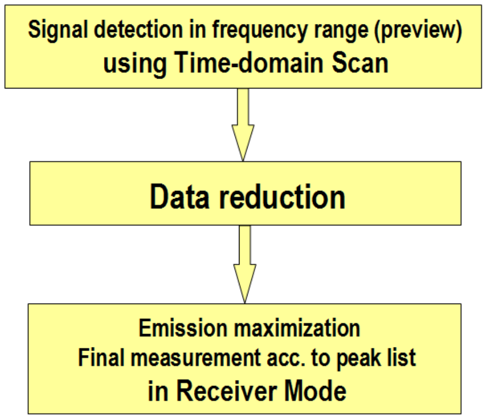

Fig. 1 EMI compliance measurements using Time-domain Scan if the product standard does not refer to CISPR 16-1-1:2010 ant its Amendment 1:2010

IV. TIMING AND DYNAMIC RANGE CONSIDERATIONS USING FFT-BASED MEASURING INSTRUMENTS

Two different types of FFT-based measuring instruments are available:

- Instruments that digitize the input signal with an analog to digital converter (ADC) in the baseband.
- Instruments that digitize the signal with an ADC at the output of the wideband IF filter.

Baseband systems are limited by the currently available ADCs, e.g. for a 1 GHz measuring receiver an ADC is necessary with 2 GS/s sampling rate to meet the Nyquist criterion and high resolution, e.g. 16-bit for an FFT-bandwidth of 30 MHz to meet the CISPR 16-1-1 overload requirements for quasi-peak detection. Such ADCs are simply not available today.

A good compromise is to combine both types in one instrument, e.g. baseband system up to 30 MHz and with FFT applied to the wideband IF signal above 30 MHz. This combination offers the following advantages:

- High dynamic range by limited bandwidth and applicability of high resolution ADC, e.g. 16-bit.
- Frequency range not limited by the Nyquist criterion.
- Conducted and radiated emission measurements up to 30 MHz in real-time with all CISPR detectors
- Above 30 MHz the frequency range of interest is subdivided into several segments of up to 30 MHz, which are measured sequentially.
- Long maximum dwell time by low sampling rate, e.g. up to 100 s
- Use of preselection filters for precise measurements of weak disturbance signals in the presence of high amplitude carriers.

Therefore, most FFT-based measuring instruments combining the parallel calculation at N frequencies and a stepped scan. For this purpose the frequency range of interest is subdivided into several segments that are measured sequentially, see Fig. 2.

The scan time T_{scan} is calculated as:

$$T_{scan} = T_m N_{seg} \quad (1)$$

where

T_m is the measurement time for each segment, and
N_{seg} is the number of segments

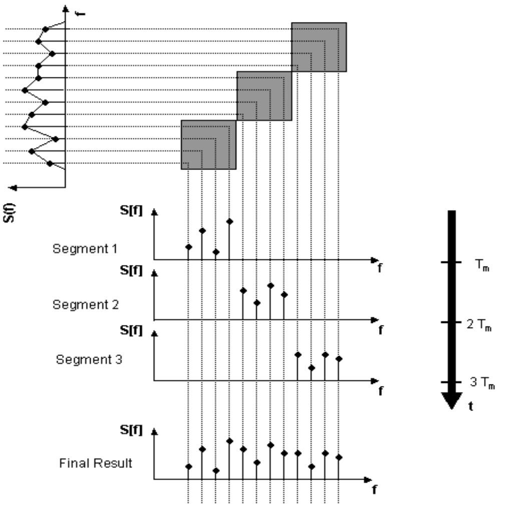

Fig. 2 FFT scan in sequence, Source: CISPR 16-2-3 [2]

The measurement time T_m is to be selected longer than the pulse repetition interval for a correct measurement of a broadband spectrum. If the measurement time is to short it can result in enormous measurement result errors. In a worst case the FFT-based measuring instrument may not capture the disturbance signal at all. This is in particular fatal if the segment size has a large width, e.g. 30 MHz or more.

Therefore, a timing analysis of the EUT disturbance characteristic has to be performed to determine the pulse repetition interval, e.g. using the *Zero Span* mode of a spectrum analyser or by connecting an oscilloscope to the IF output of a measuring receiver. If the pulse repetition interval cannot be identified, multiple scans with various measurement times using a "maximum hold" function are necessary to determine the spectrum envelope. For low repetition impulsive signals, several (e.g. 20 to 50) scans will be necessary to fill up the spectrum envelope of the broadband component. The correct measurement time can also be determined by increasing it until the difference between maximum hold and clear/write displays is below e.g. 2 dB.

Generally the FFT-based measuring instrument must be equipped with preselection filters for providing a sufficient dynamic range for quasi-peak measurements of pulse signals with a low pulse repetition frequency (PRF) and particular to **protect the input circuit of the instrument from overload or damage when measuring weak disturbance signals in the presence of high amplitude signals** or strong broadband signals with a bandwidth that is much wider than the instrument's measurement bandwidth, see Fig. 3.

A preselection filter of this type should provide at least 30 dB of attenuation at the frequency of the strong signal. A number of such filters are required to cover the frequency range 9 kHz to 6 GHz.

The dynamic range is limited on the bottom line by the displayed noise level at the requested resolution bandwidth, e.g. 120 kHz in CISPR band 30 MHz to 1000 MHz. The upper limit is the 1 dB compression point of the first mixer. This maximum dynamic range can be used to measure a continuous-wave (CW) signal (narrowband signal) only. If a high level broadband signal is measured, there will be very high levels of distortion products due to nonlinearities of the mixer.

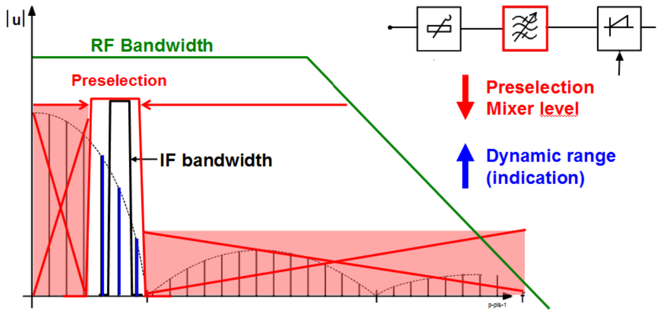

Fig. 3 Principle of preselection

As a consequence, the maximum intermodulation-free input level (maximum indication range) is reduced by the bandwidth factor. See Fig. 4

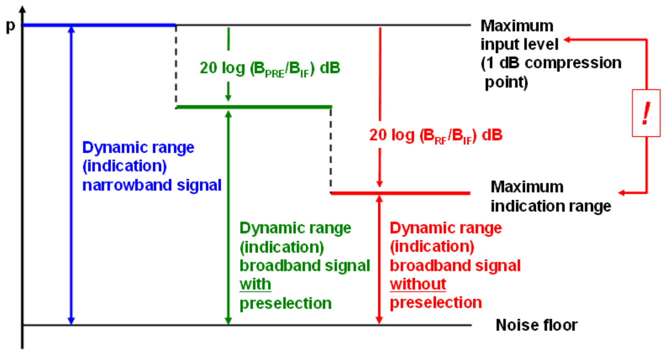

Fig. 4 Dynamic range and bandwidth factor

Example: The bandwidth factor without preselection $20*\log(B_{RF}/B_{IF})$ is about 26 dB using an IF filter bandwidth B_{IF} = 50 MHz and assuming that the bandwidth of the broadband signal is equal to the RF bandwidth of the FFT-based measuring instrument B_{RF} = 1 GHz. The bandwidth factor is about 6 dB using a preselection filter with a bandwidth B_{PRE} = 100 MHz, hence **the maximum indication range is 20 dB higher** than without preselection.

V. More Speed with Time-Domain Scan

The new generation of FFT-based measuring instruments for CISPR 16 compliant disturbance measurements can deliver measurement speed few thousand times faster than can be achieved in conventional, stepped frequency scan mode.

Frequency scans in the CISPR bands using the peak detector can be performed in just a few milliseconds and even with quasi-peak and average detector it takes just seconds which makes preview measurements with peak detector obsolete, see Fig. 5.

Frequency range	Weighting detector; measurement time; IF bandwidth; step width for stepped scan (SS) and Time Domain Scan (TD)	FFT-based measuring instrument	
		Stepped frequency scan	Time-domain Scan
CISPR Band B 150 kHz to 30 MHz	P; 10 ms; 9 kHz; SS: 4 kHz, TD: 2.25 kHz	82 s	0.11 s (745 x)
CISPR Band B 150 kHz to 30 MHz	QP, 1 s, 9 kHz SS: 4 kHz, TD: 2.25 kHz	approx. 3.8 h	2 s (6 940 x)
CISPR Bands C/D 30 to 1000 MHz	Pk, 10 ms, 120 kHz SS: 40 kHz, TD: 30 kHz	114 s	0.99 s (115 x)
CISPR Bands C/D 30 to 1000 MHz	Pk, 10 ms, 9 kHz SS: 4 kHz, TD: 2.25 kHz	3 693 s	1.08 s (3 420 x)
CISPR Bands C/D 30 to 1000 MHz	QP, 1 s, 120 kHz SS: 40 kHz, TD: 30 kHz	approx. 10 h	80 s (450 x)

Fig. 5 Scan time in CISPR Bands using time-domain scan versus stepped frequency scan with R&S ESR

The ultra-fast measurement speed is particular useful if the equipment under test can be operated only during a short period of time, e.g. a starter motor in cars. It is also essential for EUTs that get damaged when operated too long or that change their behavior during operation. A part of the time saving can also be used for applying longer measurement times in order to reliably detect narrowband intermittent signals or isolated pulses.

VI. CONCLUSIONS

FFT-based measuring instruments can be used for EMI compliance measurements in accordance with Amendment 1 to 3rd Edition of CISPR 16-1-1 if this standard is referenced in the product standard or if the reference is undated. Therefore, the users of CISPR 13:2006 (Ed. 4.2), CISPR 15:2013 and CISPR 32:2012 (Ed. 1.0) can immediately employ an FFT-based measuring instrument for EMI compliance measurements. The users of other standards can use the ultra-fast time-domain scan to speed up the time consuming preview measurements.

The use of FFT-based measuring instruments is motivated by reducing the scan time by several orders of magnitude and to get more insight due to the possibility for applying longer measurement times.

For precise and reproducible measurements the use of preselection filters is highly recommended.

REFERENCES

[1] Amendment 1:2010-06 to CISPR 16-1-1:2010-01 (Edition 3) Specification for radio disturbance and immunity measuring apparatus and methods – Part 1-1: Radio disturbance and immunity measuring apparatus – Measuring apparatus

[2] Amendment 1:2010-06 to CISPR 16-2-3:2010-04 (Edition 3) Specification for radio disturbance and immunity measuring apparatus and methods – Part 2-3: Methods of measurement of disturbances and immunity – Radiated disturbance measurements