EVALUATION OF STOCHASTIC SIGNALS FOR FAST EMISSION MEASUREMENTS IN TIME DOMAIN
EMC' 2003

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Abstract. According to the standards, emission measurements are carried out in the frequency domain using a test receiver. In this paper the set-up and procedures of a measuring system in the time domain is presented. The advantage of this system is, that measurements can be done approximately 10 to 100 times faster. The emphasis in this paper is set on a special procedure to measure stochastic signals.

Introduction

Emission measurements for the EMC check of a device must be carried out (according to the standard [4]) in the frequency domain with e.g. a test receiver. It is necessary to execute a frequency sweep and to measure the emission at each frequency. This method has the disadvantage that the measurement lasts, depending on the selection of the parameters, for a quite a long time (typically 10 to 30 min). Since a long measurement always implies high costs, it is profitable to look up for possibilities to shorten the measurements without a loss of quality.

In particular, the measurement in the time domain provides a good possibility to save time. Instead of measuring in the frequency domain with a test receiver, several single shots are recorded with an oscilloscope. From these data a comparable spectrum can be calculated by using the discrete Fourier transform (DFT) and several correction procedures. In this paper the time domain measuring system FEMIT (Fast Emission Measurement In Time Domain) is described.

Measurement set-up

When measuring in the frequency domain, the signal is recorded directly with the test receiver, which executes a frequency sweep.

The central device for FEMIT is a digital oscilloscope. If the noise level has to be lower than approximately 10 dB below the limits (CISPR 16 [4], etc.), it is necessary to use a preamplifier. To make sure, that the sampling theorem is kept, an appropriate anti-aliasing low-pass should be connected in series to the oscilloscope.

Time consumption and accuracy

The time consumption of one FEMIT measurement is, depending on the parameters, 10 - 100 times lower than the one of a test receiver measurement; one measurement takes ≈ 5 - 20 s. The error is typically < 1 dB for narrow-band signals and < 1 - 3 dB for broad-band signals.

Typical applications

Typical applications for FEMIT are quick previews, repeated emission checks and the measurement of short or rare phenomena (e.g. switching impulse, flashover). The height scan and the check of the direction of highest emission can be performed fast. Furthermore, the emission of different modes of operation of a device can be measured separately.

Basic procedure of evaluation

The basic FEMIT procedure consists of a DFT, a smoothing procedure and a correction. The correction takes all frequency characteristics (antenna factor, low-pass, etc.) into account, so that narrow-band signals are measured correctly. This basic procedure was already described in detail [1].

Procedure for one pulse

Pulses with a repetition frequency less than the bandwidth of the test receiver have to be measured by a special procedure. The procedure was explained in detail in [2]. First, the trigger of the oscilloscope is set to a relatively high level in order to record a pulse. The spectrum is calculated by applying the basic procedure and is corrected *for all frequencies according to the correction value given by the correction curve* (Fig. 1) at the repetition frequency f_{rep} of the pulse.

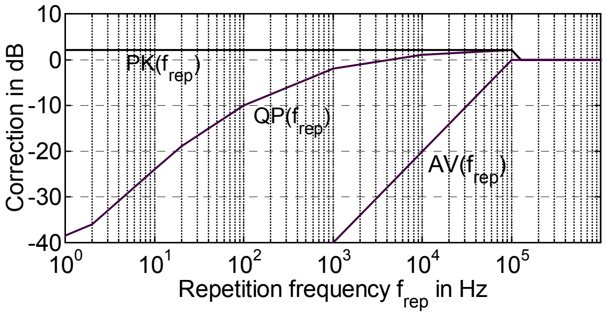

Fig. 1: Correction curves for peak PK(f_{rep}), quasi-peak QP(f_{rep}) and average detector AV(f_{rep}). Capture time 10 µs, 120 kHz band-pass

Formula (1) describes this correction by the example of the quasi-peak detector as

$$u' = u + \mathrm{QP}\left(f_{\mathrm{rep}}\right). \tag{1}$$

Here, u is the level (at any measurement frequency) after the DFT, u' is the level after the correction. $\mathrm{QP}(f_{\mathrm{rep}})$ represents the correction value according the correction function (Fig. 1).

Superposition of several pulses

The so far described procedure calculates the correct spectrum when the signal contains (apart from the narrow-band signals) *one pulse with the repetition frequency* f_{rep}. Often, several pulses with different repetition frequencies are present in the signal. In [3] a procedure to measure and calculate the spectra of *two pulses* was presented. The interesting case of the quasi-peak-detector (due to its non-linearity) can be described by

$$u_{\mathrm{S}} = \max\left(u'_1,\, u'_2\right) + a \cdot \mathrm{e}^{-\frac{\left|u'_1 - u'_2\right|}{b}}, \tag{2}$$

where u'_1 and u'_2 represent *the separately attenuated spectra* of the two pulses (according to (1)). Therefore, at each frequency a correction term Δ_{s} depending on the difference between the two spectra $\Delta' = |u'_1 - u'_2|$ is added to the higher of the two spectra (see Fig. 2).

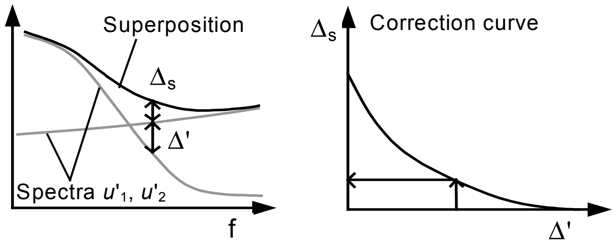

Fig. 2: Superposition of the separately attenuated spectra

Pulses of irregular period

So far, the considered pulses are regular pulses. One characteristic of a stochastic signal is the irregularity of the period. In a first step the difference between a pulse of regular and irregular period with the same number of pulses per second is determined.

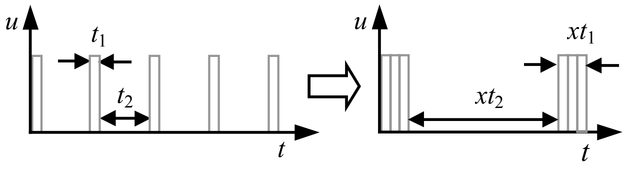

Fig. 3: Introduction of compression factor *x*

Here, the strongest effect is present, when the pulses are compressed to packages with long distances. Fig. 3 illustrates this by introducing a compression factor x.

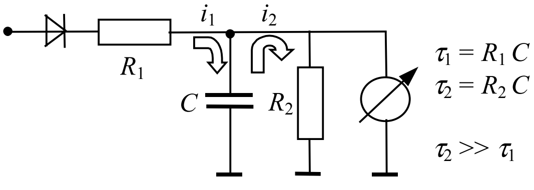

Fig. 4: Quasi-peak-detector

As the peak detector does not react on these changes, only the behaviour of the quasi-peak detector has to be evaluated. The schematic of this detector is shown in Fig. 4. To get a simple analytical solution, a rectangular input pulse is regarded (see Fig. 5).

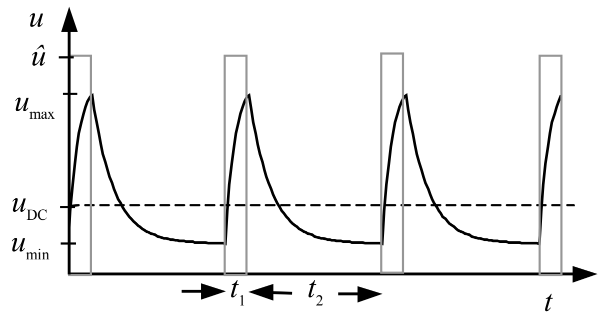

Fig. 5: Charging and discharging of the capacitor of the quasi-peak-detector

As τ_2 is much greater than τ_1 [4], the steady state can be described by simple exponential charge- and discharge-functions. Here, the time constants are $\tau_1 = R_1\, C$ respectively $\tau_2 = R_2\, C$. As the voltage is additionally filtered by a mechanical time constant, the final result equals the DC-part of the signal. The DC-part of the output signal can be described as (for space-saving reasons only the final result):

$$u_{\mathrm{DC}} = \hat{u}\; \frac{\tau_2}{\tau_1}\, \frac{(1-e^{-\frac{t_1}{\tau_1}})\,(1-e^{-\frac{t_2}{\tau_2}})}{1-e^{-\frac{t_1}{\tau_1}}\; e^{-\frac{t_2}{\tau_2}}}\,. \tag{3}$$

The irregularity can be described (worst case) by a compression as indicated in Fig. 3. Here, the pulses are combined to longer pulses with a corresponding longer period (same number of pulses/s). The now resulting DC-value can be derived by replacing $t_1 \leftrightarrow x\, t_1$ and $t_2 \leftrightarrow x\, t_2$ in (3). Fig. 6 shows the obtained attenuation of the quasi-peak-result normalized on the result of a regular pulse ($x = 1$) depending on the compression factor x and with the number of pulses/s as parameter.

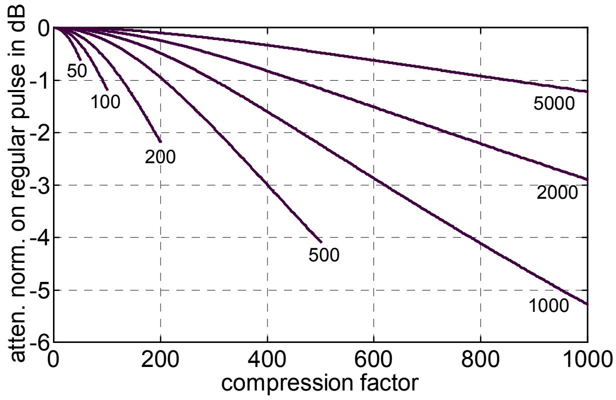

Fig. 6: Attenuation of the quasi-peak-result (normalized on a regular pulse) depending on the compression factor *x*. Parameter: number of pulses/s

Two conclusions can made: first, the result for irregular pulses is always *lower*. Second, for realistic compression factors and number of pulses/s the attenuation is very low (< 1-2 dB). Therefore, *irregular pulses can be regarded as regular pulses with the same number of pulses/s*. This effect was additionally proved by a Pspice-simulation (see Fig. 7) and test receiver measurements.

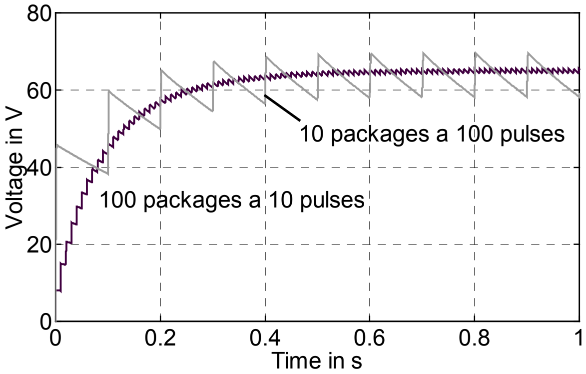

Fig. 7: Output voltage of the quasi-peak-detector for signals of 1000 pulses/s and different distribution (Pspice-simulation)

Classification of the statistically distributed pulses

Typically, a stochastic signal consists of pulses of different amplitudes. As the higher pulses in the signal usually have a lower repetition frequency than the low ones and different repetition frequencies mean different attenuations due to the correction curves (Fig. 1), the pulses of signal have to be devided into groups of similar amplitudes. It is useful to define approximately 5 amplitude ranges respectively 5 trigger levels u_{tr} (Fig. 8 left).

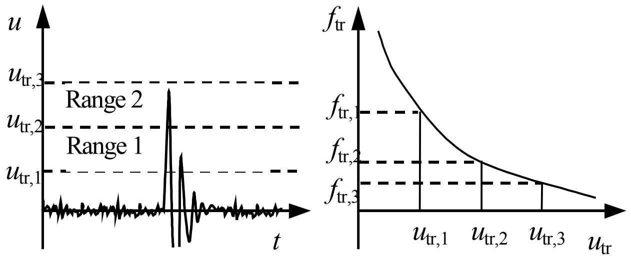

Fig. 8: Definition of the trigger-ranges and trigger-frequency over triggerlevel

All pulses are arranged into groups according to their maximum amplitude (Fig. 8 left: pulse of group "range 2"). In the next step the average number of pulses/s for the pulses of each range is determined. Therefore, the time $T_{tr,\mu,100}$ for e.g. 100 trigger events is measured for each trigger level μ (e.g. by using the "sequence mode" of the oscilloscope).

$$f_{tr,\mu} = \frac{1}{T_{tr,\mu}} = \frac{n}{T_{tr,\mu,n}} . \qquad (4)$$

$$f_{tr,\,range\mu} = f_{tr,\mu} - f_{tr,\mu+1} . \qquad (5)$$

By evaluating (4) the average repetition frequency $f_{tr,\mu}$ for trigger level μ can be determined. As in this value the pulses of higher ranges are also included, the repetition frequency $f_{tr,\mu+1}$ of the next higher trigger level has to be subtracted (5) to get the average number of pulses/s $f_{tr,range\mu}$ inside trigger range μ.

Table 1. Determination of the attenuation/range. Example: parting-off grinder

μ	$u_{Tr,\mu}$	$T_{Tr,\mu,100}$	$T_{Tr,\mu}$	$f_{Tr,\mu}$	$f_{Tr,Range\,\mu}$	QP_{μ}
1	**10 mV**	150 ms	1,5 ms	670 Hz	420 Hz	**-5**
2	**30 mV**	400 ms	4 ms	250 Hz	150 Hz	**-8**
3	**50 mV**	1 s	10 ms	100 Hz	67 Hz	**-12**
4	**70 mV**	3 s	30 ms	33 Hz	23 Hz	**-19**
5	**90 mV**	10 s	100ms	10 Hz	10 Hz	**-24**

Now, for each group, the attenuation QP_{μ} according to Fig. 1 can be determined. Table 1 illustrates this procedure by the example of a parting-off grinder.

Evaluation of stochastic signals

After these preinvestigations, the final procedure for measuring stochastic signals can be described. First, for each range, 1-3 pulse samples are recorded and transfered into the frequency domain. To get the worst case, the maximum of the spectra of each group is calculated.

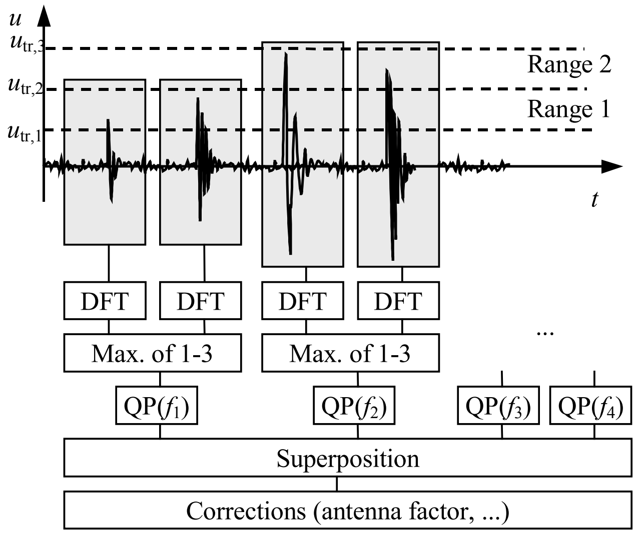

Fig. 9: Procedure for the measurem. of stoch. signals

Then, for each group the spectrum is attenuated according to the corresponding QP_{μ}. Now, the superposition of these spectra is calculated (see equation (2)) and in a last step the antenna factor is corrected.

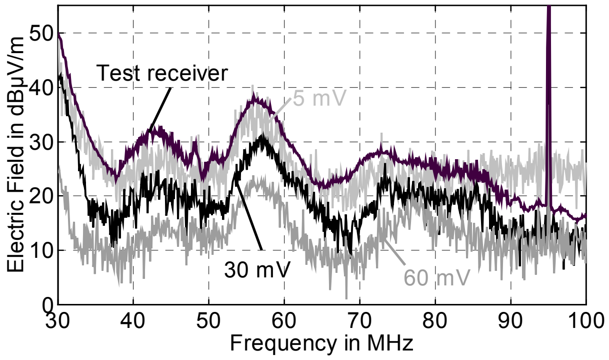

Fig. 10: Vacuum cleaner: corrected spectra for trigger levels 5, 30 and 60 mV and test receiver result

When the quasi-peak-corrected spectra (before the superposition) are regarded, the dominating pulse group can be found. Fig. 10 shows these spectra in comparison to the test receiver result by the example of a vacuum cleaner. In this example the dominating spectrum is the one of the pulses of the *lowest* range (trigger level 5 mV). This is surprising, but understandable, because these pulses have the highest repetition frequency and therefore the lowest attenuation.

Examples: Comparison FEMIT – test receiver

The following figures show the comparision of the FEMIT and test receiver result by the example of a electromagnetic bell (Fig. 11), a vacuum cleaner (Fig. 12) and a parting-off grinder (Fig. 13).

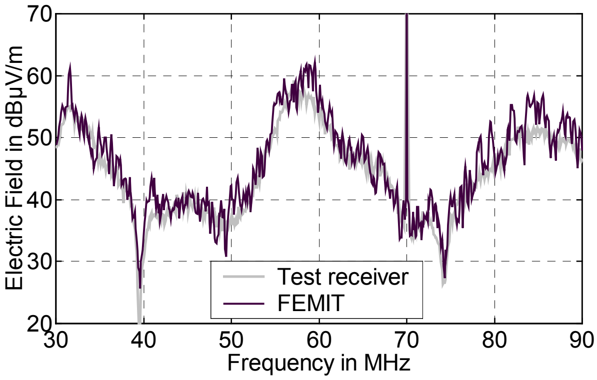

Fig. 11: **Comparision FEMIT- test receiver by the example of a bell,**

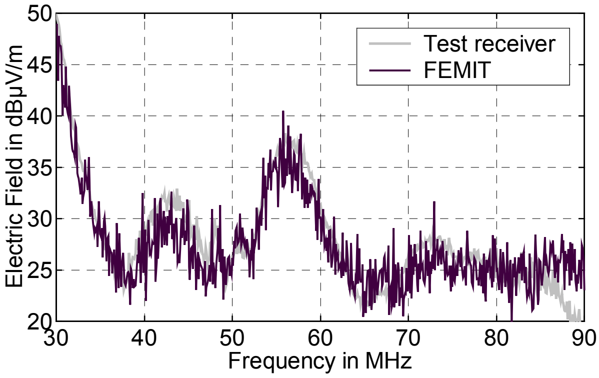

Fig. 12: ...a vacuum cleaner,

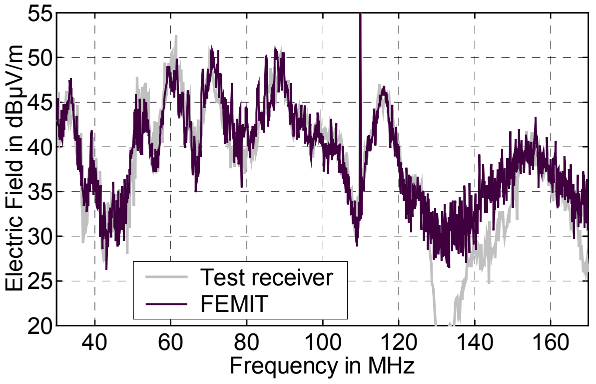

Fig. 13: **... and a parting-off grinder**

Errors and difficulties in measuring stoch. signals

When evaluating narrowband signals, the error of FEMIT (compared to the test receiver result) is < 1 dB, for regular pulses < 3 dB and for the here described stochastic signals < 5 dB. It has to be considered that these stochastic signals are generally difficult to measure. Fig. 14 illustrates this by the example of a test receiver measurement with the peak detector and different measurement times per step: 100 ms, 1 s and 5 s /step. The high differences between the results show the typical problem of the irregularity of stochastic signals.

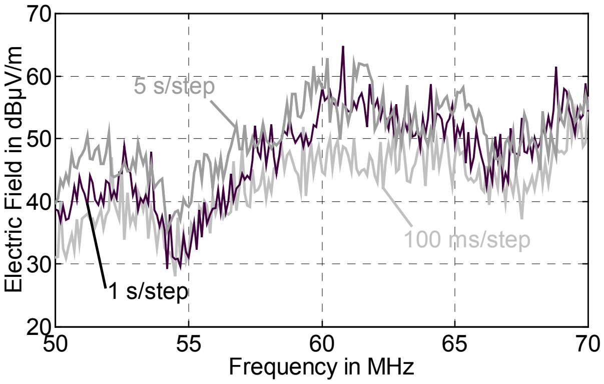

Fig. 14: **Test receiver measurements with peak-detector and different measurement times**

Other detectors

In this paper, the measurement procedure was described by the example of the quasi-peak-detector, which is (due to its non-linearity) the most difficult case. The simulation of the other detectors, such as average and peak-detector, can be done the same way with the following changes: the corresponding attenuations are given by Fig. 1 and the equations for the superposition are described in [3].

Conclusion

In this paper, the time domain emission measurement system FEMIT was described. FEMIT is an adequate measuring system especially for quick previews, repeated checks of the emission of an EUT and short phenomena.

The central result of the here presented aspect is:

- An advanced procedure allows the measurement of *stochastic signals* by calculating the *superposition of separately attenuated part-spectra.*

References

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[2] C. Keller, K. Feser, "A New Method of Emission Measurement", *2002 IEEE International Symposium On EMC*, Aug 19-23, Minneapolis, USA

[3] C. Keller, K. Feser, "Non-linear Superposition of Broadband Spectra for Fast Emission Measurements In Time Domain", *EMC 2003, Zurich*

[4] *International Electrotechnical Commission IEC*, "CISPR 16: Specifications for radio disturbance and immunity measuring apparatus and methods"