Fast Magnetic Emission Tests for Continuous Measurements around an Equipment Under Test

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***Abstract*—For the assessment of radiated electromagnetic interference (EMI) emission of an equipment under test (EUT) traditionally a limited amount of positions around the EUT are chosen. This is due to the long measurement time per position of the EMI test receiver, although the introduction of time domain electromagnetic interference (TDEMI) analyzers already created serious reduction in measurement time. The limited amount of measurement positions around an EUT means however that the maximum interference can be missed at certain positions around the EUT, creating an underestimation of the maximum emission. With the use of a low cost baseband digitizer this paper realizes a continuous positional measurement around an EUT. This measurement presents the maximum emission of the interference by considering every position around the EUT.**

I. Introduction

Analyzing electromagnetic interference (EMI) is traditionally based on the spectral components of the interference. This is because time domain analysis was insufficiently accurate due to limitations of hardware, such as the limited analog to digital converter (ADC), sampling rate, memory or dynamic range [1]. The use of a super-heterodyne EMI test receiver is the default choice by analyzing each frequency individually while sweeping through the spectrum. As is done for radiated emission measurements of magnetic fields, according to standards (NRE01) [2]. These measurements are performed between 30 Hz and 100 kHz, with a bandwidth of 10 Hz and frequency steps of 5 Hz. A bandwidth of 10 Hz results in a minimum dwell time of 100 ms for every measurement. Measuring every frequency for at least the dwell time, at every position around a large equipment under test (EUT), for example equipment in an aircraft due to the development towards more electric aircraft (MEA), results in extremely long measurement times of days or even weeks. Furthermore, time domain information is lost. Time domain information became important due to the transition towards variable sources and loads. Switched-mode power supplies (SMPSs) are one of the main examples that require a new approach to test, especially with power efficiency as a high priority in mind, as the operation and power load is changing over time. This results in interference changing relatively slowly over time. This effect is known, and standards require measurement of the maximum emission, but do not give guidance for those slowly varying signals. This variation over time can also be seen in the power line communication channel which changes in a cyclo-stationary manner [3]. To notice the effect of the time domain variation these receivers have to measure every frequency bin for a certain amount of time. Two parallel detectors showing the peak and average value, a trick based on the MIL-STD 461C broadband-narrowband selection, can be used. A description of analyzing time variant disturbances can be found in [4], where a simulation model is developed to mimic these types of detectors. The measurement time per frequency, the dwell time, is dependent on the time variation of the interference at that specific frequency. Because of the long measurement time some standards only specify certain measurement positions around an EMI. This is introduced to reduce the total testing time of the EMI, but using a discrete number of measurement points around the EMI can possibly mean that the maximum interference is missed, and the radiated emission is underestimated. Performing a continuous measurement around an EMI is not feasible with the conventional techniques, as one has to move around the EMI for every frequency. To reduce the long measurement times, time-domain electromagnetic interference (TDEMI) analyzers became very popular, but remain expensive. This is due to the fact these TDEMI analyzers originally focused on the higher frequency domains, i.e. above 30 MHz, and therefore make use of an intermediate frequency, a heterodyne receiver. Advantages, as in [5], [6], and challenges, as in [7], [8], of TDEMI analyzers have been discussed previously. As we are interested in the magnitude of the emissions in the low frequency range a low cost baseband digitizer can easily do the measurements, much better and much faster. This gives rise to a number of possibilities when considering the portability due to the price and small size of such a baseband digitizer:

- Assessing a sub-systems EMI generation in the engineering phase can be beneficial to reduce troubleshooting at later stages
- Using a digitizer to go over the equipment and get real time results to detect major interfering sources
- Having a big EMI which can be measured using a laptop and a small digitizer
- Measure all frequencies, within a given range due to the sampling, together in parallel for a single measurement time, instead of individual measurement times for every frequency
- Performing peak and average detection via post processing with a single measurement
- Doing quick continuous measurements around an EMI

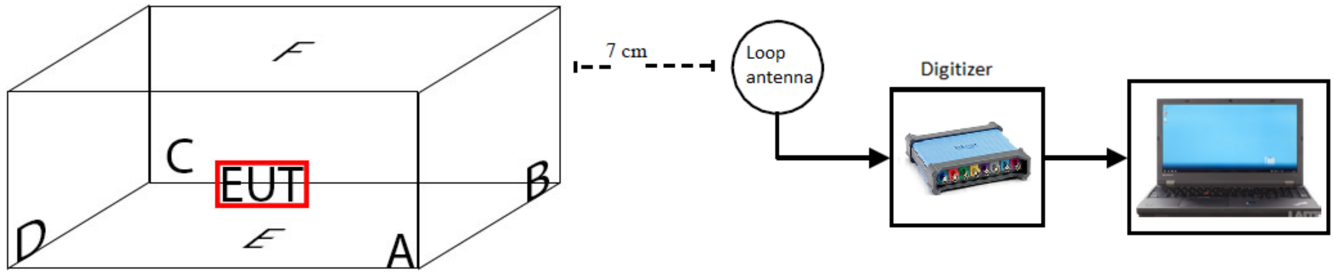

Fig. 1: Measurement setup with specifications of positions around the EMI

In this paper a comparison between existing measurement techniques and the time-efficient low cost and easy to use baseband digitizers for magnetic emission tests at low frequencies is mentioned. For this research the measurements in the horizontal plane of the EMI have been performed in one continuous measurement, measuring all sides of the EMI. In this way, no maximum interference in the horizontal plane will be missed.

II. Theoretical Background

A continuous measurement allows for exploration of the radiated emission at any possible position around an EMI in one measurement. In the following subsections, the concept is further explained and the necessity is elaborated on.

A. Large Equipment Under Test

For some large EMI specific guidelines should be followed for a measurement campaign. An example of such a guideline is the FGW/TR 9, 2014 [9], [10]. In this guideline the definition of the measuring positions around a wind turbine is defined. For this example at least four measuring positions are defined with regard to the feasibility of the measurement due to the long measurement times inherent to the conventional measurement techniques.

An example of such specifications of the positions around an EMI and the measurement setup proposed in this paper can be seen in Fig. 1. When considering a time variant interference repeating every 5 seconds, the conventional technique, following the NRE01 standard using an EMI test receiver and measuring every frequency for 5 seconds, would take around 45 minutes per position, while the proposed measurement technique would only take 5 seconds [5]. The conventional measurements have to be performed at six sides around an EMI, to assess a subsystems EMI generation, increasing the total measurement time to 4.5 hours, while the proposed technique can easily do it within minutes, due to the short measurement times, per position, of mere seconds. Changes in setup are required for both measurement techniques, which in itself can add up to a few minutes. When considering a large system, where every side would need 10 measurement points, giving a total of 60 measurement positions, the measurement time would even go towards 45 hours when using the conventional technique, while the proposed technique can do the same much faster. This new proposed technique allows for quick measures to be taken if necessary. This measurement technique could still miss some important emission positions, due to the limited amount of measurement positions.

As an improvement a multichannel oscilloscope can be utilized to acquire multiple measurements simultaneously. Even though more measurement positions could be taken with this proposed technique, due to the faster measuring and simultaneous measurements, this would still leave room for uncertainty with regard to some interfering peaks. The multichannel property also creates the possibility for measuring all three polarizations at the same time.

B. Time, Frequency and Space

By using a heterodyne EMI test receiver to analyze the frequency domain, most time domain information is lost. This is visualized in Fig. 2. In the figure the clear distinction between frequency and time is shown. The use of a low cost digitizer in conjunction with a computer gives rise to a trade-off between the time domain and the frequency domain. With the use of a short time fast Fourier transform (STFFT) in combination with increasingly better hardware the limit is pushed more and more in both the time and frequency domain.

Apart from these two domains we also have to consider the spatial domain. When assuming the previously mentioned discrete measurement only small spatial information is obtained. By using the proposed continuous time (and thus positional) measurements, in the horizontal plane, the limit is pushed further into the direction of a full description of the emission. These two possibilities are visualized in Fig. 2 by the dashed lines. More information can be obtained if a full spatial measurement is done by going around the EMI in a full sphere. All these techniques together push more to a more accurate emission assessment of an EMI.

C. Position

For the rotation in the horizontal plane a constant angular velocity is assumed. Following this assumption the relation between the time and angle around the EMI is written as:

$$\omega = \frac{\phi}{t}$$

Where ϕ is the angle. Using Eq. 1 together with the effective width of the antenna with respect to the circumference of the full rotation gives the amount of time a certain point in space is considered. This is written down mathematically as:

$$\tau_{position} = \frac{D * t_{total}}{2\pi r}$$

Where $\tau_{position}$ is the time a certain position is measured by the antenna, D is the diameter of the effective antenna aperturem t_{total} is the total measurement time of the entire rotation and r is the radius of the circle of rotation. To still notice a time varying interference this $\tau_{position}$ should be larger than the dwell time of the interference, such that every interference changing over time at a certain position. This means that a measurement can be done continuously without the interference changing too much due to the positional changes.

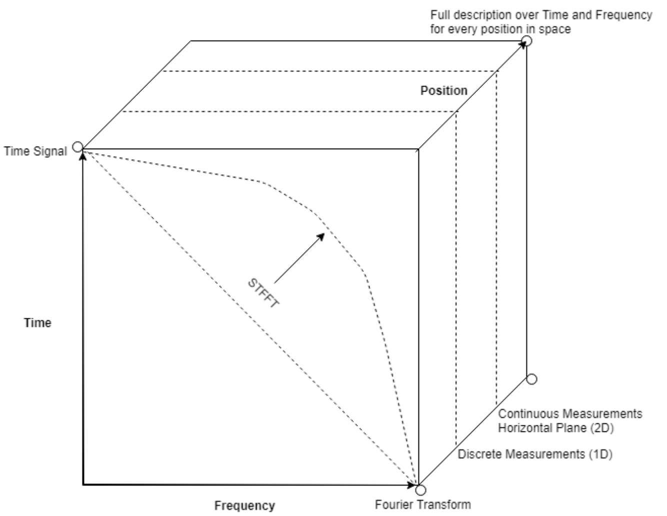

Fig. 2: Schematic overview of the certainty for emission tests with respect to time, frequency and space

III. Measurement Setup

In this section the measurement setup is described. It starts with a general description of the radiated emission measurements of magnetic fields used, derived from the standards (NRE01) [2], as previously described [3], [5]. After this a description of the continuous measurement in the horizontal plane of the EMI is given.

A. Discrete Measurements

A diagram of the general test setup can be seen in Fig. 1 where a low cost digitizer, a PicoScope, is used in conjunction with digital signal processing (DSP) via a computer. In this figure, the six positions around the EMI are also specified. In this setup the PicoScope acts as the TDEMI receiver by sampling and digitizing the incoming data. This is then transferred to the connected computer where the post processing is performed. The frequency plots are obtained by performing an STFFT after which post processing is used to mimic traditional EMI receiver for peak detection [2], [11]. The parameters and windows used are according to the standard and the aforementioned paper.

B. Continuous Measurements

In this paper an extra improvement is made by doing the four positions, in the horizontal plane, around the EMI in one continuous measurement. The positions are the corner points AB, BC, CD and DA as seen in Fig. 1. Apart from these four positions, all the other positions in between are also measured. A schematic of this setup for the horizontal plane is shown in Fig. 3. The antenna is rotated around the EMI, keeping the same, specified, 7 cm distance from the EMI, not taking into account the small distance variations at the corners.

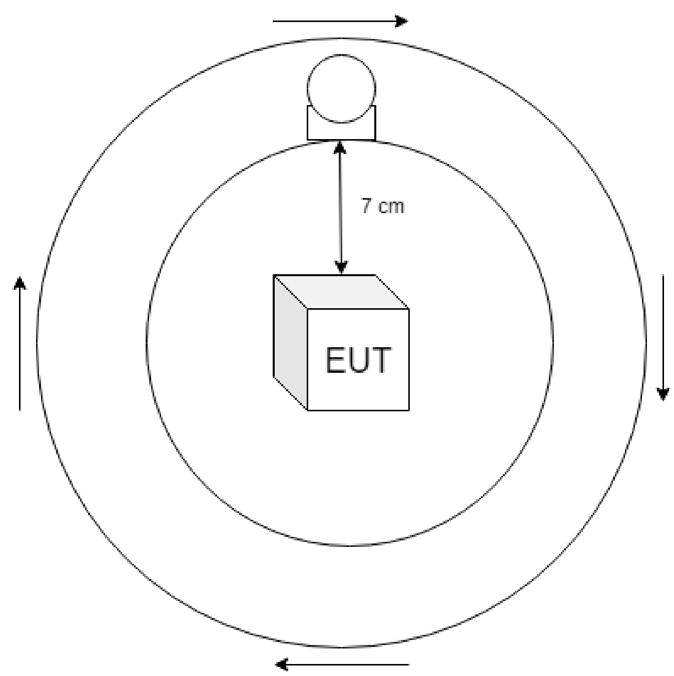

Fig. 3: Schematic overview of the test setup

IV. Results

This section shows the results found with the measurement setups mentioned in the previous section. It has the same subsections plus a comparison of the two measurements.

A. Discrete Measurements

For the discrete peak measurements four different positions around the EMI in the horizontal plane are chosen. These positions are chosen following the aforementioned description. The peak measurements, following the NRE01 standard, at the four different positions are plotted together and can be seen in Fig. 4. For this paper the problem arising with discrete measurements is stated and shown to exist. It is important to note that the EMI is considered a black box, for which it does not matter what the background noise is, since the difference with regards to positional changes are still apparent. In Fig. 4. two main distinctions can be seen between the group AB,BC and the group CD,DA. This example shows that by only choosing positions AB and BC big peaks of the interfering emission would have been missed by the measurements.

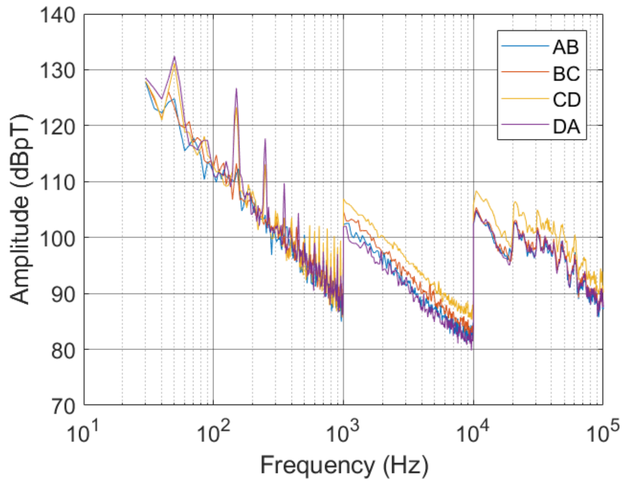

Fig. 4: Magnetic field emission at four different positions

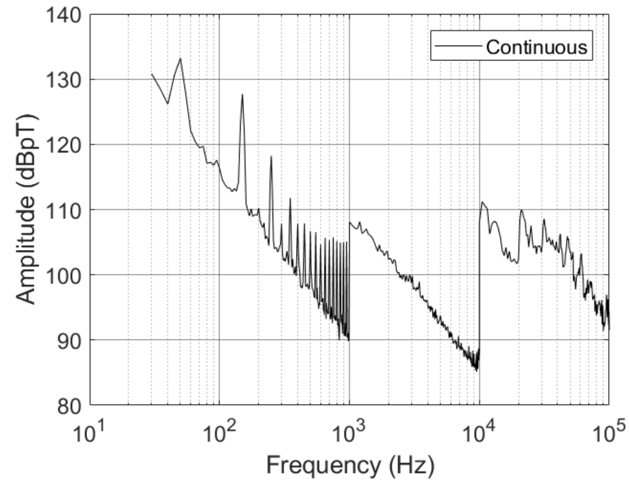

Fig. 6: Worst case magnetic field emission over all positions

B. Continuous Measurements

Instead of doing discrete measurements at a limited amount of positions this paper proposed to do a continuous measurement around the EMI. This is done to make sure no peaks of interference at a certain position are missed. A spectrogram of such a measurement is shown in Fig. 5. In this figure the time of the measurement can be converted into the position in the horizontal plane around the EMI. This is done by using Eq. 1. At a first glance two major dips of interference can be spotted at 2 distinct positions. It turns out that these dips are close to the previously mentioned positions AB and BC. By using this continuous measurement technique one is sure to find all the maximum interfering points, while discrete points only result in uncertainties. A peak detection is also performed for the entire continuous measurement via DSP and can be seen in Fig. 6. This peak detection measurement shows the worst case scenarios for the emission of the EMI with respect to all positions. It can be seen as a max hold function of the emission at all frequencies over all the positions.

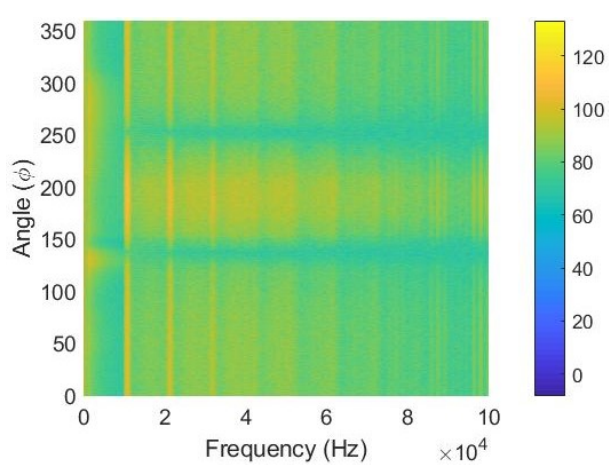

Fig. 5: Magnetic field emission over frequency and position in a circle around the EMI

C. Comparison

This worst case scenario of the emission with respect to all positions around the EMI in the horizontal plan can then be used to compare it to the discrete measurements. This comparison can be seen in Fig. 7. In this graph only a small difference can be seen between the actual worst case scenario and two chosen positions. For higher frequencies however a higher result can be seen meaning that these maximum emissions would have been underestimated if only the discrete measurements would have been used. Really big differences can be seen with respect to positions AB and BC of roughly 15 dB. If only these positions would have been chosen the actual emission of the EMI would have been highly underestimated.

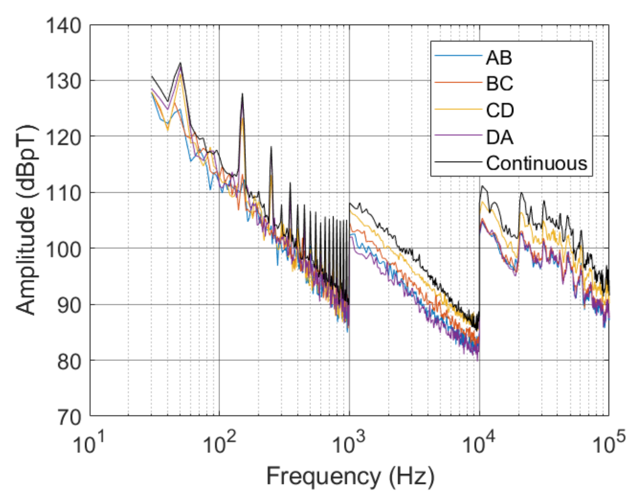

Fig. 7: Comparison of the magnetic field emission at four positions with the worst case scenario over all positions around the EMI

V. Conclusion

In this paper the importance of a continuous time domain measurement is described. The importance arises due to the possible underestimation of the emission of an EMI when using discrete measurements at a limited number of positions. Using the conventional techniques however, continuous positional measurements were not possible. It is shown that via this technique peaks of emission can be missed at certain positions. Peak measurements at different positions were compared to a continuous measurement, which is used as the worst case scenario for all positions. A spectrogram is also created to show the emissions with respect to frequency and position. With a sufficient low rotation speed with respect to the dwell time, the measurements can be considered continuous. From such a spectrogram peaks and dips of emission are clearly seen with respect to the spatial domain, which allows for quick measures to be taken if necessary.

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