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A Pre-Scan Method to Accelerate Near-Field Scan Immunity Tests

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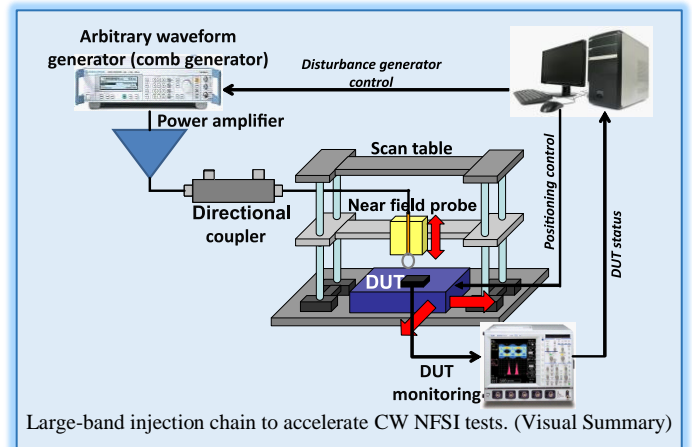
Abstract— Near Field Scan Immunity (NFSI) is a powerful measurement method to diagnose susceptibility issues at printed circuit board (PCB) and integrated circuits (IC) levels. However, one limitation of this approach is the excessive measurement time required to build the susceptibility maps, which reveals the sensitive pins or traces of the device under test. This letter presents a pre-scan method based on a large-band injection in order to determine rapidly the more relevant scanning positions, the frequency range of interests and an estimation of the susceptibility level on each scanning position. The pre-scan provides the configuration parameters of the full NFSI scan in order to keep an acceptable test duration.

Index Terms— Near Field Scan Immunity, Pre-scan, Time optimization.

I. INTRODUCTION

Near-Field Scan Immunity (NFSI) [1] is a powerful measurement tools to detect and diagnose failures related to electromagnetic (EM) disturbance coupling on printed circuit board (PCB) [2] [3] or integrated circuit (IC) [4]. Recent studies have shown how the results of this method can be processed to estimate the radiated susceptibility to continuous wave (CW) disturbances [5] [6]. However, the method is limited by an excessive measurement time, which could be prohibitive in an industrial environment. The measurement time depends on the surface to scan, the frequency range and resolution to analyze and the device under test (DUT). An approach to reduce the scan duration is a prior identification of scan positions and frequencies of interests, that is to say where the DUT exhibits susceptibility maxima. Once this fast initial test has been done, the NFSI in CW mode can be configured to focus only on these points and frequencies of interest and capture a more precise susceptibility map.

In this letter, a pre-scan method based on a large-band disturbance dedicated to the acceleration of NFSI in CW mode is presented and discussed. An arbitrary waveform generator (AWG) producing a large-band multifrequency comb signal is the central element of the pre-scan method, since it is able to produce a disturbance composed of several in-phase harmonics with equal amplitude. This type of source has already been used to accelerate radiated susceptibility test [7], but is combined with NFSI test for the first time in this study. After a discussion of the NFSI duration issue, the letter describes the large-band injection chain used during the pre-scan and provides some recommendations. Conditions to ensure that the vulnerable points that



appear on the NFSI map in CW mode are also detected during the pre-scan are discussed in Section IV. Then, the case study used to illustrate the pre-scan method is presented. Finally, the pre-scan is applied on the case study to evaluate the reduction of NFSI test provided by the pre-scan method.

II. THE NFSI MEASUREMENT TIME ISSUE

The measurement of the NFSI map to CW disturbances is a long process which requires a large number of iterations. It consists in repeating, for different positions of the near-field (NF) injection probe above the device under test (DUT), the search of the susceptibility threshold of the DUT for the different test frequencies. The maximal number of iterations N to build the NFSI map is given by (1), where N_P is the number of positions taken by the probe, N_f the number of test frequencies and N_e the number of tested excitation amplitudes, which are incremented from a minimal to a maximal power level.

Take-Home Messages:

- The proposed pre-scan method aims at accelerate NFSI test in CW mode.
- It consists in determining the scanning positions, the frequency ranges of interest and an estimation of susceptibility level in order to limit the number of iterations of the CW NFSI test.
- The method relies on the injection of a comb signal (e.g. produced by an arbitrary waveform generator) to explore rapidly the susceptibility at each scanning position.

$$N = N_p N_f N_e \quad (1)$$

For example, let consider a scan surface covering a 40×20 surface of a PCB. With a scan step of 2 mm, 200 scanning positions are required. Let suppose also that the immunity test done over 20 frequency points (e.g. 10 points per decade over two frequency decades), and 20 excitation points (e.g. from 20 to 40 dBm with a 1 dB step). The maximum number of iterations to acquire the NFSI maps at each frequency reaches 80000. The test duration is mainly dominated by the dwell time of the disturbance, the configuration of the test instruments and acquisition of measurement results. If the duration of an iteration is assumed to be 3 s, the total duration of the test reaches 66 h, i.e. 3 days. This excessive duration is a serious drawback for immunity diagnosis in an industrial context.

The main strategy to reduce the test duration consists in limiting the number of iterations N . A first approach may be an increase of the scan, frequency and amplitude steps in order to reduce N_p , N_f and N_e , but this strategy may lead to a missing of critical frequencies or points on the DUT. Another approach consists in performing an initial pre-scan in order to identify the points and the frequency of interests rapidly. Experience shows that failures appear only on some positions of the injection probe because of the localized injection, so that it is preferable to identify this interest points before a precise search of susceptibility level on these points. Testing several frequencies simultaneously is an interesting idea to reduce N_f . This strategy requires a source able to generate several harmonics spread over a sufficiently large frequency range, but separated by a gap enough small to not miss critical frequencies. A comb generator is adequate for this purpose. If we consider the previous example, if we suppose that all the frequencies are tested simultaneously with only one excitation point, the number of iterations will be limited to 200. After 10 minutes, the pre-scan will identify all the positions where the DUT shows vulnerability. The NFSI test will focus only on these points.

III. LARGE-BAND INJECTION CHAIN

The proposed large-band injection chain for the pre-scan test is described in the visual summary (in page 1). The central element of the NFSI pre-scan test bench is the comb generator, which produces a multifrequency signal made of several in-phase harmonics with identical amplitude covering a large frequency range. One convenient approach to produce such a signal consists in using an arbitrary waveform generator (AWG). In this study, the model Anritsu AWG710B is used. It is characterized by a sampling rate of 4.2 GS/s, a 3-dB bandwidth of 1.1 GHz and a memory length of 64.8 million of points. Fig. 1 shows an example of a comb signal produced by the AWG, covering the range 10 to 1000 MHz, repeated every 100 ns. The envelop of the spectrum is almost flat. The maximum output power is limited to 13 dBm so the generator must be followed by a RF power amplifier for conventional susceptibility tests. In this study, the RF power amplifier TESEQ-1G-070 is used. It covers the range 10 to 1000 MHz and delivers maximal average and peak power equal to 49 and 52 dBm. An important requirement is to ensure that the average power, and, more importantly, the peak power of the amplifier does not exceed its limit. An adjustable attenuator may be required to limit the risk of overloading of the power amplifier. In order to facilitate the extraction of the excitation delivered by the AWG and the power amplifier, the amplitude of each harmonics is supposed identical and equal to P_{harmono} . From the Parseval's identity, the average and peak powers of the

delivered signal can be computed according to (2) and (3), where P_i is the average power of each harmonic and M the number of harmonics forming the signal.

$$P_{\text{avg}}(\text{dBm}) = 10 \log(\sum_{i=1}^M P_i) = P_{\text{harmono}} + 10 \log(M) \quad (2)$$

$$P_{\text{peak}}(\text{dBm}) = P_{\text{harmono}} + 20 \log(M) + 3 \quad (3)$$

This equation shows that the limiting factor of the power amplifier is not related to the maximum average power, but the maximum peak power, as explained in [7]. Increasing M results in a saturation for a lower level of average power, so that M should be limited in practice to keep an acceptable crest factor. A possible strategy is to cover one frequency decade and limits M between 10 and 20 harmonics. The excitation delivered to the injection probe is measured through a bidirectional coupler and a powermeter. As the power of all the harmonics is supposed identical, the coupling factor of the coupler can be compensated and the average and peak powers can be measured.

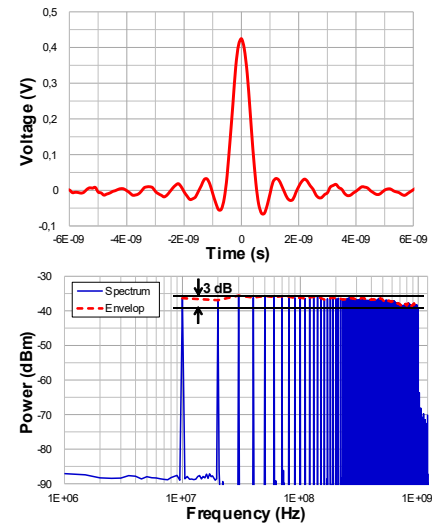


Fig. 1. Time-domain profile (top) and spectrum (bottom) of the large-band signal generated by the AWG and the RF power amplifier

IV. CONDITIONS TO CORRELATE CW AND LARGE-BAND NFSI MAPS

The use of a pre-scan based on a large-band injection to identify the interesting scanning positions during the final CW NFSI requires an existing link between the CW and large-band NFSI maps. This is a mandatory condition to ensure that a vulnerable point observed during the CW test at a given frequency is not missed during the large-band injection test. The purpose of this part is not to correlate the susceptibility levels measured in CW and large-band injections, as it remains a complex problem that goes beyond the scope of the paper, but rather determining the conditions that guarantee that no vulnerable points will not be missed during the final scan in CW mode.

Determining multifrequency susceptibility consists in finding the response of the device under test (DUT) to the superposition of several harmonic disturbances applied simultaneously. The main issue is that the actual combination of each applied harmonic is not straightforward due to the non-linear response of the DUT. The failure threshold to multifrequency disturbance is not necessarily the sum of the different contribution of the different harmonics and a complex process must be developed to extract the interactions between the harmonic contributions.

The correlation between CW and large-band susceptibility levels is obvious if the failure results from the linear superposition of the contribution of each injected harmonic to the failure generation. In this case, the disturbance superposition principle is verified. To illustrate it, let consider a multifrequency disturbance composed of M harmonics with frequencies f_k and amplitudes E_k , $k \in [1; M]$. S_k is the susceptibility threshold of the DUT to CW disturbance at a frequency f_k . The disturbance superposition principle is verified if (4) is met when the failure arises, where I is the interference coefficient. The impact of each harmonic is weighted by the CW susceptibility threshold in order to account for the susceptibility of the DUT at frequency f_k .

$$I = \sum_{k=1}^M \frac{E_k}{S_k} = 1 \quad (4)$$

If (4) is verified and if a vulnerable point is detected when a multifrequency signal covering a frequency range is injected, this point will also be detected on this frequency range during CW injection. There is no risk of missing a vulnerable point. Moreover, an interesting property can be observed if the amplitudes of the M harmonics are identical and equal to E_0 , as in the case of the signal produced by the comb generator. If (4) is verified, E_0 is given by (5). If the number of harmonics M over a frequency range becomes large enough, E_0 tends to a constant equal to the harmonic mean of the CW susceptibility over the frequency range. This property can be used to estimate a first order of the CW susceptibility level over the tested frequency range. It provides an additional approach to reduce the term N_e in (1) and thus the scanning time.

$$E_0 = \left(\sum_{k=1}^M \frac{1}{S_k} \right)^{-1} \quad (5)$$

The disturbance superposition is not verified if a failure arises for I different of 1. If a failure arises for I less than 1, it suggests that synergetic interactions exist between the different harmonics, which intensify the impact of each harmonic. (5) is not verified and the order of the CW susceptibility level cannot be estimated. However, there is no risk of missing a vulnerable point during the pre-scan. Conversely, if a failure arises for I larger than 1, the effect of each harmonic inhibits each other, leading to a risk of missing a point during the pre-scan. To avoid such situation, the nature of the interaction between the injected harmonics should be evaluated to test the application of the disturbance superposition principle. A first approach consists in evaluating I with (4) when a failure is detected during the pre-scan, but it supposes to have already measured the CW susceptibility of the DUT. Another approach consists in repeating the large-band injection over a frequency range with different numbers of injected harmonics M . If the disturbance superposition principle is verified, the failure will arise for a nearly constant harmonic amplitude level E_0 as suggested by (5). In contrary, if E_0 decreases when M is increased, this is the signature of a

synergetic interaction. If E_0 increases with M , inhibited interactions exist and a specific attention may be paid to these particular points to ensure that they will not be neglected during the final NFSI in CW mode.

V. DEVICE UNDER TEST SUSCEPTIBILITY

In this paper, the proposed approach is tested on a small board with a bandgap reference (LT1798 of Linear Technology) is tested. This integrated circuit (IC) delivers a 2.5 V reference voltage from a 5 V power supply. When it is submitted to EM disturbances, a negative offset is induced on the output and compromises the circuit operation. In this paper, the maximum allowable offset is set to 20 mV. In a first experiment, the conducted susceptibility of the bandgap reference is measured according to the standard IEC62132-4. The test is performed either with a CW or a comb excitation signal over the frequency range 10 MHz to 1 GHz. The maximum forward power is set to 33 dBm. The aim of this experiment is to compare the results obtained with CW and large-band disturbance, determine the nature of the interaction between the injected harmonics and test the application of the disturbance superposition principle for this particular DUT.

Fig. 2-left shows the measured susceptibility threshold of the DUT to CW disturbance. The circuit is not particularly susceptible below 100 MHz, but exhibits a marked vulnerability around 300 MHz. The large-band test is done in 9 different configurations: the signal covers either the full range (10-1000 MHz), 10-100 MHz and 100-1000 MHz, with three different frequency gaps between harmonics: 5, 10 or 20 MHz. Results are summarized in Fig. 2-middle. Failures are detected in every configuration, except when the disturbance covers only the range 10-100 MHz. The RF power amplifier saturates before the susceptibility threshold of the DUT were reached. Moreover, for each tested frequency range, the susceptibility level is nearly constant whatever the number of harmonics. The results prove that the failure mechanism in this IC depends only on the average power of the disturbance. As suggested in Section IV, this is the sign of application of the disturbance superposition principle. It is confirmed by the evaluation of the interference coefficient I (Fig. 2-right), which is equal to 1 whatever the frequency gap when the failure is detected. This result proves that a vulnerable point observed during large-band test over a frequency range will also be observed during the CW test. Moreover, as (5) is verified, the order of the CW susceptibility threshold can be estimated from the large-band injection results in order to reduce the scanning time during the NFSI in CW mode. The CW susceptibility threshold is necessarily comprised between the amplitude of each harmonic of the large-band disturbance P_{harmonic} and the average amplitude of the disturbance P_{avg} in case of the susceptibility threshold is constant over the frequency range.

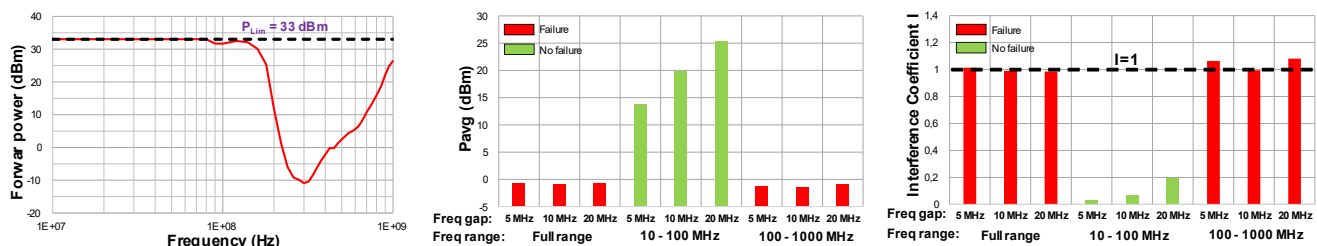


Fig. 2. Susceptibility threshold to CW injection of the bandgap reference (left). Susceptibility threshold to large-band injection of the bandgap reference (middle) and extraction of the interference coefficient (right) for the three frequency ranges and gaps

VI. NFSI PRE-SCAN

A NFSI in CW mode and a pre-scan have been performed on the previous bandgap reference, in order to evaluate the scan duration reduction provided by the pre-scan. The proposed approach can be applied on any near-field map results, without any restrictions about the type of used NF probes (E or H-field probe). In this paper, only the results of tangential magnetic field injection are presented for conciseness purpose, but similar results can be obtained for E or H-field injection made with other field directions. The NF probe is placed at 2 mm above the test board and scan a 14×10 mm area centered on the bandgap reference IC. The scan steps along X and Y axis are 2 and 1 mm respectively, leading to 88 probe positions.

A. Full NFSI scan in CW mode

The full NFSI test with CW injections is performed initially on 28 frequency points spread between 10 and 1000 MHz. The susceptibility threshold is searched by increasing the forward power of the disturbance from 10 to 36 dBm by 2-dB step. The analysis of the NFSI maps shows that failures arise when the injection probe is placed above

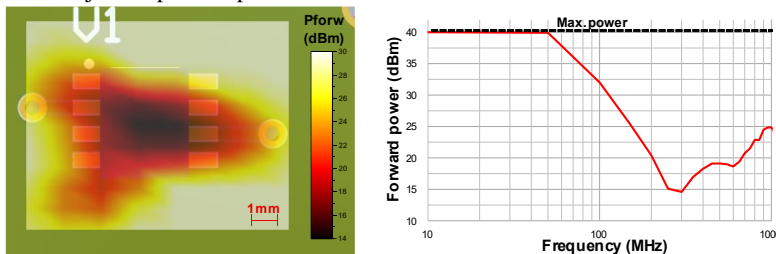


Fig. 3. Maximum susceptibility map of the bandgap reference in CW mode (left). Susceptibility threshold measured on the most sensitive point (right)

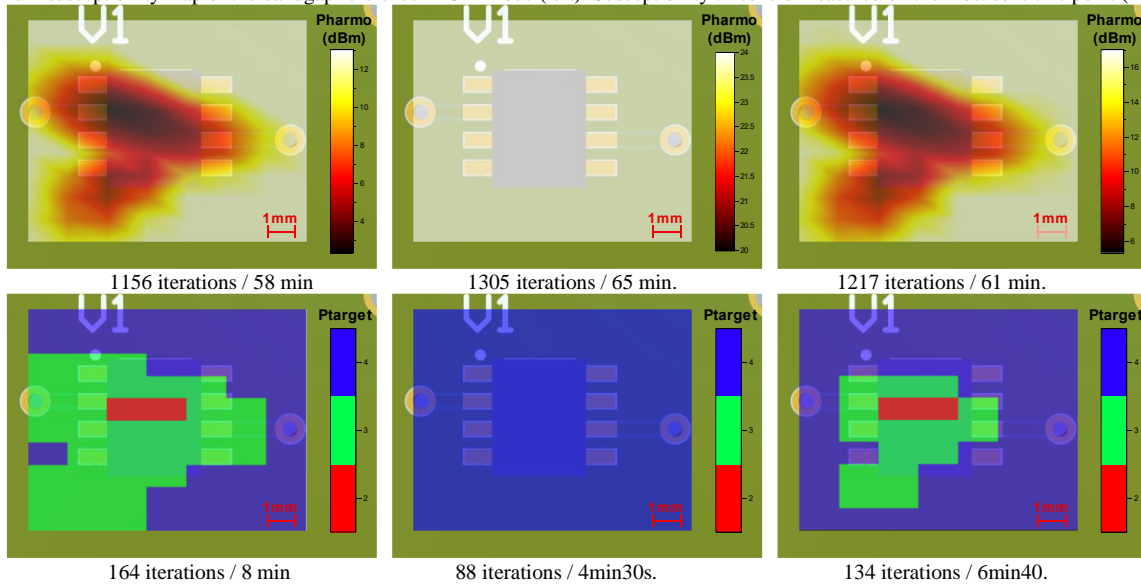


Fig. 4. Susceptibility map of the bandgap reference in large-band injection: precise search mode (top row) and rough search mode (bottom row). Full range (left), low-frequency range (middle), high-frequency range (right)

B. Pre-scan results

The pre-scan based on the large-band injection is performed. Tests have been done on three different frequency ranges:

- the full range from 10 to 1000 MHz with a frequency gap of 10 MHz. $M = 101$ harmonics, P_{harmonic} is limited to 13 dBm.
- the low frequency range from 10 to 100 MHz with a frequency gap of 10 MHz. $M = 10$ harmonics, P_{harmonic} is limited to 24 dBm.

the input, the output and the ground reference pins of the bandgap. It is illustrated in Fig. 3-left, which presents the minimal immunity map, which gives for each scan position the minimal amount of excitation to induce the failure whatever the frequency. The analysis of such a map, coupled with the possible extrapolation of the radiated susceptibility level as suggested by [8], could help designers to identify the actual risk level when the IC pins are exposed to EM disturbance, and determine the most adequate solution to correct his design (e.g. adding a filter close to a sensitive IC pin, burring a trace or placing the IC into a shielded enclosure).

No failures have been detected for a large number of scan positions: no failures observed on 27 scan positions for forward power less than 32 dBm, 59 points for forward power less than 25 dBm. Fig. 3-right shows the susceptibility level on most vulnerable point. The IC is susceptible only on the range 100 – 1000 MHz. The full scan required 31993 iterations, i.e. a scan duration of more than 27 h. The prior identification of frequency and scan positions where the DUT is not susceptible would have led a significant reduction of the scanning time.

- the high frequency range from 100 to 1000 MHz with a frequency gap of 20 MHz. $M = 45$ harmonics, P_{harmonic} is limited to 17 dBm.

The search of the susceptibility threshold is made according to two different modes:

- A precise search: the excitation power is increased from 10 to 36 dBm with a step of 2 dB. The maximum number of tested excitation amplitude per frequency and scan position is $N_e = 14$.
- A rough search: the DUT is tested with 3 different power levels

separated by 10 dB. For example, for the full range test, if the DUT withstands the maximum power level (13 dBm), the target level for the scan position is set to 4. If the DUT is susceptible for a power comprised between 3 and 13 dBm, the target level for the scan position is set to 3. Thus, excitation power is increased from 10 to 36 dBm with a step of 2 dB. the maximum number of tested excitation amplitudes per frequency and scan position is $N_e = 3$.

The first row of Fig. 4 presents the susceptibility map provided by the pre-scan in precise search mode for the three frequency ranges (from left to right full range, 10-100 MHz, 100-1000 MHz). The number of iterations and the test durations are also given. No failures are detected in the low frequency range. We can deduce that no failures should appear on this range in CW injection between 24 and 34 dBm. This result complies with tests done in CW mode. Moreover, it can guide the choice of the minimal power to apply during the NFSI test in CW mode on this frequency range. Maps obtained in the full and high frequency ranges are similar. The sensitive pins of the DUT are identified, so that the NFSI in CW can concentrate only on these pins. In the high frequency range, failures arise for a minimum power per harmonic of 3 dB, so the CW susceptibility level should be comprised between 5 and 21.5 dBm, as in the CW injection test.

The duration of pre-scan tests in precise search mode is about one hour, which is significantly less than the NFSI in CW mode. The second row of Fig. 4 shows the susceptibility map provided by the pre-scan in rough search mode for the three frequency ranges. The interest points of the susceptibility map are detected extremely rapidly since the duration of pre-scan does not exceed 8 minutes. Although the pre-scan on the full range seems beneficial, it may be more advantageous to separate the range in two subbands (10 – 100 and 100 – 1000 MHz) in order to determine more precisely the configuration of the NFSI test in CW mode (frequency of interest, minimum power for the search of susceptibility threshold. The total duration of pre-scan on the low and high frequency ranges reaches 11 minutes, but the test reveals that the IC is not susceptible on the range 10 – 100 MHz which can be omitted during the CW NFSI test. For example, if the results of pre-scan in rough search mode are used to configure the CW NFSI test and if only the points at target level 2 and 3 are kept, only 23 points on the 88 points forming the scan surface will be investigated during the CW NFSI test. If the power search starts at the minimum power related to the target level, CW NFSI requires only 3600 iterations, i.e. a test duration of about 3 h. It leads to a reduction of a factor 9 compared to the full CW NFSI scan. A more stringent selection of the interest scan positions revealed by the pre-scan would lead to a higher reduction of the scanning time.

VII. CONCLUSION

This letter has presented a pre-scan method based on a large-band injection produced by a comb generator in order to accelerate NFSI tests. With this method, the scanning positions and frequency ranges of interest are identified rapidly and a first estimation of the susceptibility level in CW injection can be established. The number of iterations required to determine completely the near-field susceptibility of a PCB or an IC can be reduced. In the example presented in this letter, the pre-scan duration is negligible compared to the full NFSI and it helps to optimize the parameter of a NFSI test in CW mode, leading to a reduction by a factor nine of the duration of the

NFSI test. The reduction depends on the DUT to scan and measurement configurations. In case of a large PCB, the duration of pre-scan may also become important. Advanced surface sampling methods and pre-scan could be used together to reduce more the number of scanning positions, such as the adaptative sampling method applied on near-field emission measurement in [9].

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