Signal Processing in Radiated EMI Measurements

WERNER SCHAEFER
Hewlett-Packard Company*

INTRODUCTION

During the course of a conducted or radiated EMI compliance measurement, different types of signals are detected, depending on the EUT. Often, the spectrum measured during a conducted test contains broadband emissions which are caused, for instance, by the brushes of the EUT's electric motor.

A determination of the frequency of this signal is rather complex because this information cannot be directly derived from the EMI receiver's display. Some further analysis is required to identify related spectral components and to calculate the actual emission frequency. Furthermore, the interception of broadband signals, especially those with low repetition rates, is complicated because the EMI receiver has to either dwell at the tuned frequency for a certain time or sweep across a band at an adequate sweep rate. In either case, prior knowledge of the characteristics of the signal to be measured is necessary to select the appropriate receiver settings. A solution to these specific problems is provided by so-called "trace-based" software packages, which record complete measurement traces of **swept** receivers and compare these data against one or more limit lines.

Usually, the EMI receiver sweep time and the number of sweeps per frequency band are selectable to ensure the interception of broadband signals. By taking this approach, the actual frequency determination of signals in these traces is avoided. When amplitudes exceed the applied limit line, the receiver will be swept across this small frequency segment using a different detector.

Overall test times can be reduced significantly by using signal processing algorithms on data collected during EMI measurements.

The result is documented as a graph showing the measurement traces along with limit lines. No signal lists are provided containing the emission's frequency, amplitude or other attributes because this demands a frequency determination and might require manual interaction.

With radiated EMI measurements, the emissions are predominantly narrowband. Therefore, an algorithm can be applied to the measurement traces to discern actual signals in the spectrum. In this way, signal information can be separated from measured broadband noise, reducing the number of emissions that need to be maximized during compliance testing. To ensure the shortest test time possible, only the significant signals should be maximized. The ability to discern signals in traces usually leads to a "list-based" software product, which provides signal lists as a basis for storage, processing and presenting signal data. These lists also serve as the input information for the maximization and measurement procedures. In addition, these lists provide powerful data comparison capabilities, which can be used in many different ways. For instance, the discrimination between ambient and EUT signals on an OATS is simplified by comparing two lists, where one contains ambient signals only and the second one holds both ambient and EUT signals.

Comparing signal amplitudes against limit lines, and sorting the lists according to a specified attribute of emissions meeting a definable criterion contribute to a shorter overall test time. However, the list-based measurement approach introduces a new set of technical challenges which are mainly related to signal processing. In the following paragraphs the focus will be on radiated EMI measurements and the issues related to signal discernment in traces and data handling.

DISCERNMENT OF SIGNALS IN TRACES

Sweeping an EMI receiver over the spectrum of interest provides a definite advantage over a stepped receiver: the optimization of the probability of signal detection. The receiver has to be swept as fast as possible and multiple sweeps over the same frequency range have to be taken. This multi-sweep test strategy results in many measurement traces which require special data handling in the controlling software. It is not feasible to save all digital points because of the amount of memory needed. More important, a lot of trace points are only associated with the measurement system's noise floor or adjacent data points which are related to the same signal. Using such a set of data as the input of a maximization or measurement procedure would cause measurements at irrelevant frequency points and

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thus lengthen the test time considerably. Signal processing is necessary to discern signals in traces. This requires an algorithm capable of detecting signals by evaluating adjacent frequency points and assigning the appropriate amplitude and frequency to a discerned signal. This information, along with other signal attributes like antenna height and turntable angle at the time of measurement, can be stored in a list.

A key parameter used by the discernment algorithm is the peak excursion entry in the software interface (Figure 1). Other significant criteria related to signal processing are also part of this central interface to ensure ease of use and to provide protection against unwanted modifications of these values by non-qualified personnel. Limited access to these parameters is essential because a change has a dramatic impact on the measurement result. For instance, change of the peak excursion criterion from a lower to a higher value will usually result in a smaller number of signals discerned in the same trace. Furthermore, results of signal comparisons as well as list manipulation operations are impacted by the signal matching criteria shown in the interface in Figure 1.

The algorithm that discerns the signals processes traces by using two Boolean variables, Positive Slope Found (PSF) and Negative Slope Found (NSF), and a variable Peak Value to store the maximum trace amplitude based on the state of PSF. Both NSF and PSF are set to false before the actual trace processing starts. The point at the far left represents the start frequency of the trace, and initially serves as a reference point for the determination of a rise in the trace as defined by the peak excursion criterion. The algorithm processes the data points from the start frequency toward the stop frequency, checking simultaneously for an amplitude lower than the initial reference point and the first rise in the trace (Figure 2).

If an amplitude is found which is lower than the current reference point, the lower amplitude becomes the new reference value. When an amplitude meets or exceeds the peak excursion criterion relative to the current reference point, PSF is set to true. From this point on, the amplitudes of all following trace points are stored in the Peak Value variable until a fall in the trace is detected according to the peak excursion criterion. The storage procedure of trace amplitudes in the Peak Value variable utilizes a maximum hold function to retain the maximum value found during the analysis. Whenever data is stored in the variable (PSF=True, NSF=False), the reference for the detection of a fall in the trace is set to the currently processed point. If a fall is detected, NSF is set to true. The maximum amplitude retained in the Peak Value variable is associated with a frequency in the trace data array. This frequency and amplitude will be reported as a discerned signal and stored in a list. Now, both PSF and NSF are set to false and the processing starts over again from the current data point.

The trace shown in Figure 2 is processed by the algorithm in the following way: the first data point is used as the reference and is retained since new lower values are found before the first rise in the trace as defined by the peak excursion criterion. At this point PSF is set to true and data storage of amplitudes in the Peak Value variable occurs as long as increasing amplitudes are encountered. The amplitude of the first maximum, D_1, will be retained; the following data points are discarded because their amplitudes are lower than the value at D_1. No storage into Peak Value takes place until data point D_3 is processed and higher amplitudes are detected. The drop between point D_1 and D_2 does not meet or exceed the peak excursion criterion and thus is ignored. The maximum amplitude at data point D_4

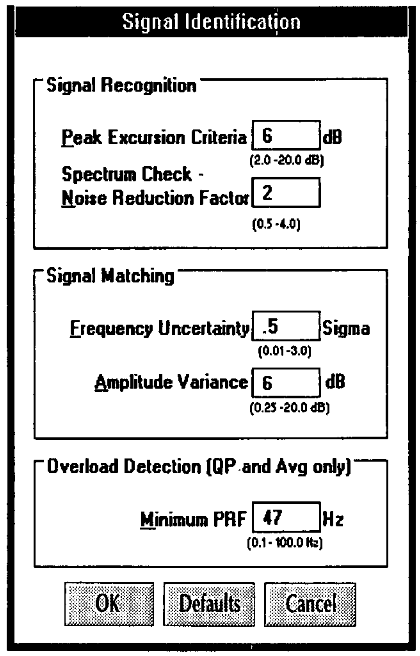

Figure 1. *Signal Identification Parameter Interface.*

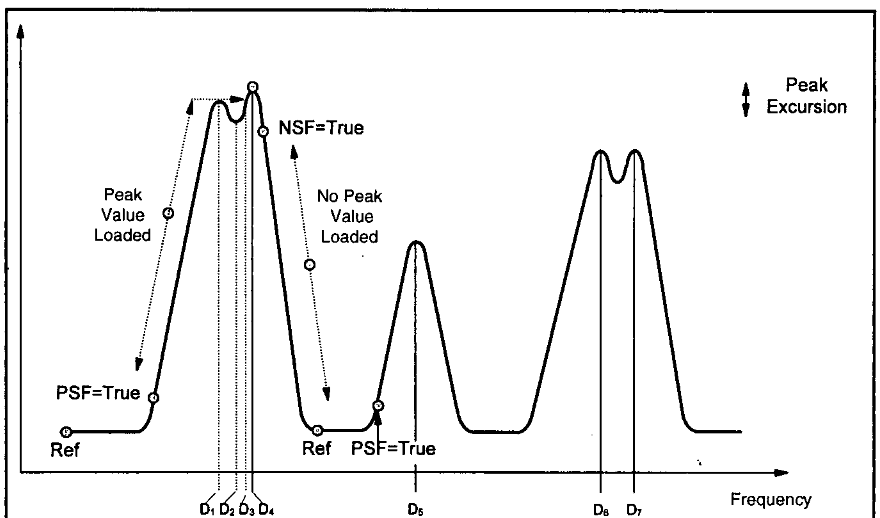

Figure 2. *Signal Discernment in Traces.*

is stored and the reference is moved to this trace element. Thereafter, only lower amplitudes are detected while processing adjacent points. When a fall is found which meets or exceeds the peak excursion criterion NSF is set to true. The amplitude D4 is related to its frequency in the trace array and saved in a list. PSF and NSF are set to false and the processing starts over. The reference is now moved along the trace as long as consecutively lower amplitudes are found.

The algorithm detects four signals in the example trace at data points D4, D5, D6 and D7. The impact of the peak excursion value, which is user definable, is obvious: a smaller value would have caused the discernment of an additional signal at point D1. A higher value will cause fewer signals to be discerned; for instance, the signal at point D6 might have been discarded. A careful selection of this value is necessary to ensure proper measurement results.

SIGNAL MATCHING PARAMETERS

It is often desirable to identify two signals as duplicate signals to avoid multiple storage in a list. Since no signal has a perfectly stable frequency and amplitude, a signal comparison cannot just include a check of their nominal frequency and amplitude values; frequency uncertainty, amplitude variations and signal characteristics have to be used during the comparison of two signals to identify them as "the same signal." Even if their nominal values differ from each other, the algorithm has to be able to identify them as duplicate signals. Furthermore, the EMI receiver has a limited frequency and amplitude accuracy, which contributes to the signal ambiguity and therefore demands a more sophisticated comparison algorithm.

For example, a signal might be found in the first trace at 150 MHz with an amplitude of 60 dBµV, and in the following trace at 150.5 MHz with a 59 dBµV signal level. In case duplicate signals are not desired, a determination has to be made if both signals have to be retained, if they truly are two different signals or if one signal has to be discarded. In the latter case, an additional decision is required to determine which of the two signals to retain. This process, also known as signal matching, involves two parameters, frequency uncertainty and amplitude variance, which can be specified by the user in a dedicated interface (Figure 1).

The application of the frequency uncertainty parameter is shown in Figure 3: three signals, A, B and C, were discerned in three different traces and have identical amplitudes. Their individual frequency uncertainties, indicated by the arrows, are different. In the first step of the matching process, possible duplicate signals are determined based on the nominal frequency and frequency uncertainty. Two signals are candidates if the nominal frequency of one signal lies within the uncertainty range of the reference signal. This does not mean that the frequency uncertainty of one signal has to be fully contained in the reference signal's range.

In the example, signal A is the reference for the comparison and signal C lies within A's uncertainty range; therefore A and C are candidates. The nominal frequency of signal B is not contained in signal A's frequency uncertainty. Signal B does not qualify as a candidate even though their uncertainty ranges overlap. For that reason, B will be retained because it is not considered a duplicate signal. In the next step, a decision is made on which candidate signal, A or C, to keep. The most accurate signal, C in this case, will be kept because it has a smaller frequency uncertainty associated with it. If two candidates have identical frequency uncertainties, the reference signal will be kept. It should be noted that the order of the comparison is very important because the results may differ. If signal B is chosen as a reference, neither signal A's nor C's nominal frequency lies within B's uncertainty range. Therefore, no candidates are identified and all three signals are retained. The signal-matching algorithm applies the frequency uncertainty criterion first, then uses the amplitude variation for further identification.

In Figure 4, the use of the amplitude variation is shown. The nominal frequencies of signals B and C are assumed to lie within the frequency uncertainty of reference signal A, and all three signals have the same frequency uncertainty but different amplitudes. The frequency uncertainty check indicates that all three signals are candidates. The amplitude variance specification is applied to determine which signals to discard. Since signal B's amplitude is within the amplitude variation range of reference signal A, they are identified as candidates. The matching algorithm retains the signal with the higher amplitude, in this case signal B.

If candidates have identical amplitudes, the reference signal will be kept. The amplitude of signal C is considerably lower and does not lie within the amplitude variation window. Therefore, signal C will be stored as a separate signal. In general, the most accurate signal with the lowest frequency uncertainty will be retained. If the candidate signals have identical amplitudes, the amplitude variation is used to determine the resultant signal. In this case the candidate with the highest amplitude will be used.

If multiple signals are contained within the uncertainty window of the reference signal, as shown in Figure 5, a determination of the candidate closest to the reference has to be made. Each distance between the reference and all other signals is calculated and the candidate with the shortest distance is retained. All other signals in the uncertainty window will be discarded and not used by the matching algorithm. In Figure 5, signal C and the reference will be kept

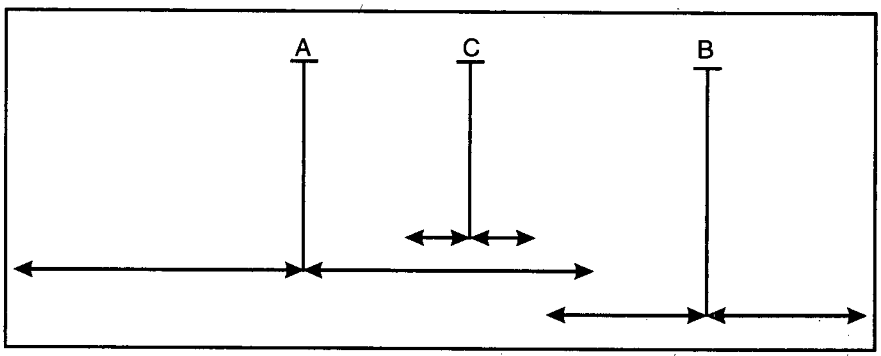

Figure 3. *Frequency Uncertainty Specification.*

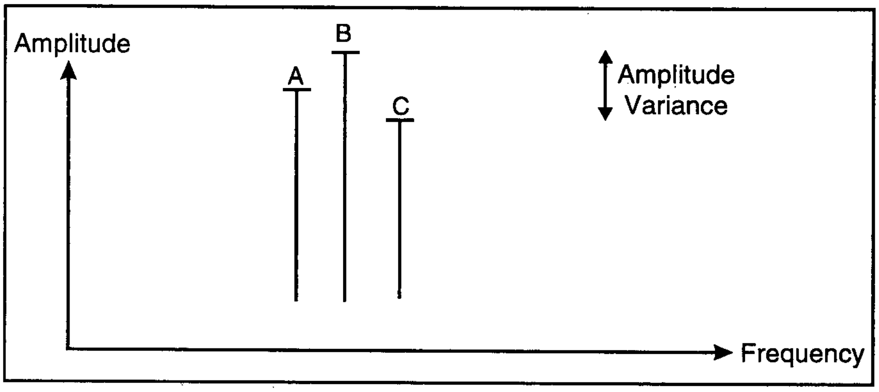

Figure 4. *Amplitude Variance Specification.*

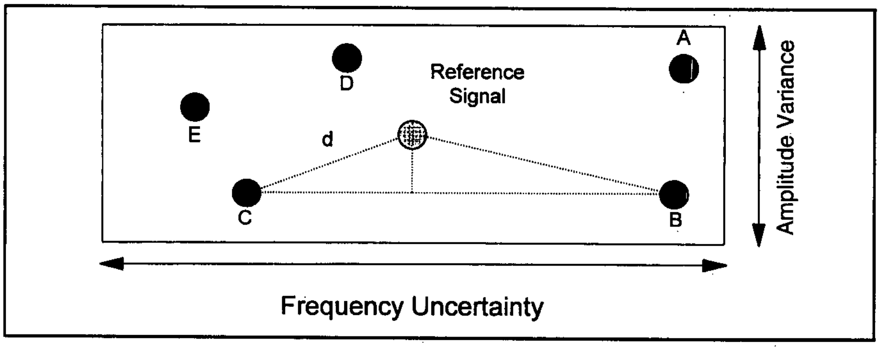

Figure 5. *Multiple Signal Matching.*

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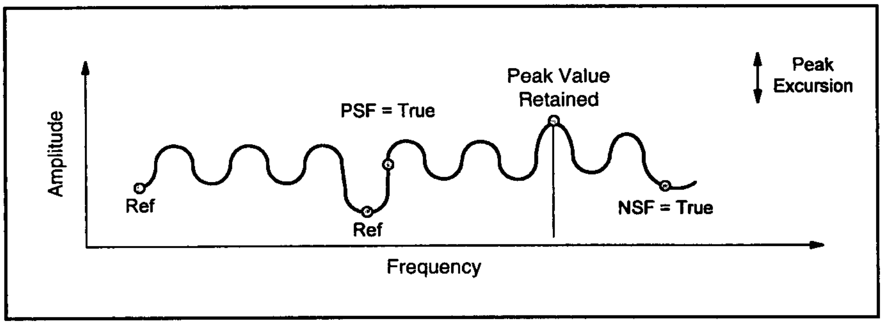

Figure 6. *Discernment of Modulated Signals.*

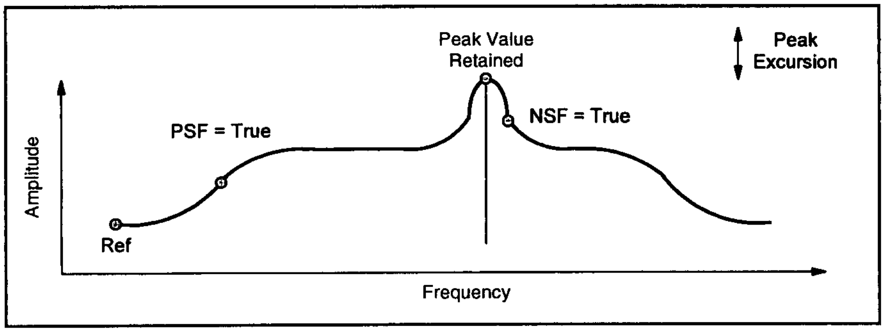

Figure 7. *Broadband Signal Discernment.*

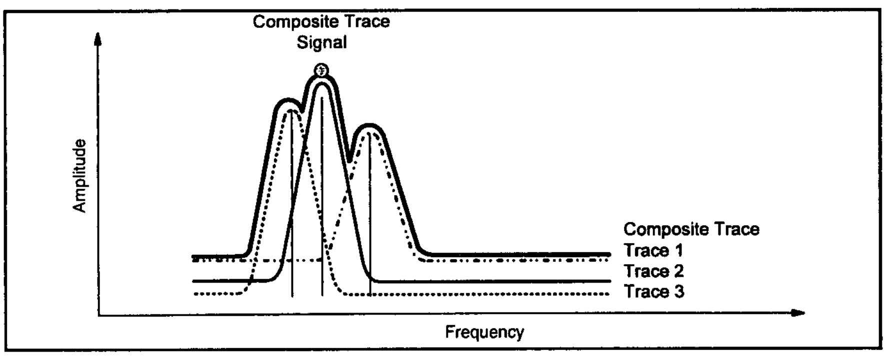

Figure 8. *Signal Identfication in Composite Trace.*

and the algorithms described above are applied to these two signals only.

APPLICATIONS OF SIGNAL PROCESSING ALGORITHMS

Sample applications for the previously explained algorithms are now described. When signal discernment is used with a modulated signal, as shown in Figure 6, the algorithm might determine only one signal within many smaller responses, depending on the current value of the peak excursion criterion. First, the reference is chosen to be the first point in the trace. The algorithm processes adjacent trace points to the right and discards the first three "ripples" in the trace because no rise has been detected which meets or exceeds the peak excursion value. Then, an amplitude lower than the current reference value is found, and becomes the new reference point for the ongoing processing. A rise is detected on the positive slope next to the reference and PSF is set to true. The maximum amplitude found is retained until NSF is set to true. In this example all ripples are discarded and only the signal with the maximum amplitude is discerned. The advantage of this approach is the elimination of noise amplitudes, because only those signals rising above the measurement system's noise level will be detected. However, in processing a modulated signal, information on the modulation content might be lost. This example demonstrates the impact of the peak excursion criterion and the need to choose its value very carefully.

Figure 7 shows a spectrum envelope comprised of both narrowband and broadband signals. The signal discernment algorithm detects a positive slope caused by the broadband signal, then finds the maximum amplitude of the narrowband signal and eventually recognizes the negative slope caused by the narrowband signal contour. This results in the detection of the narrowband signal only. Even a very small peak excursion value would not lead to the discernment of the broadband signal. This means that the described algorithm is very well-suited for the determination of narrowband signals, but more elaborate processing techniques are required to capture broadband signals.

In Figure 8 a spectrum envelope called "composite trace" is shown. This software tool can be used to find the worst-case, or highest, amplitudes of emissions during a preliminary measurement. Tower and turntable movement might be included in this fast pre-scan test, which utilizes the speed advantages of a scanned EMI receiver. The receiver is swept several times over a predefined frequency range and individual traces (Traces 1-3) are stored in computer memory. A running "maximum hold" function is applied to retain the highest amplitude encountered during the measurement at each trace point. The signal discernment leads to different results if it is applied to one of the individual traces or the composite trace. The signal in each trace shown in Figure 8 will be detected by the algorithm; however, the algorithm would only discern the highest signal in the composite trace, assuming the responses to the left and right do not meet the peak excursion criterion. Therefore, signals in Traces 1 and 3 will not be saved to a list. This might cause different

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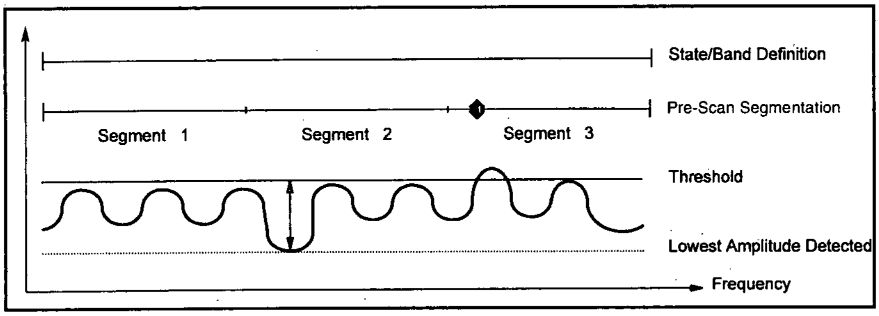

Figure 9. *Noise Reduction Factor for Spectrum Check.*

results when a sweep is taken interactively, because the discerned data is stored to a list and then compared to a second list that shows signals found in a composite trace covering the same frequency range.

Different approaches can be taken to make commercial radiated EMI compliance measurements. An EUT can be taken to an OATS and the spectrum of interest can be scanned. Since both ambient and EUT signals are captured during this measurement, an additional step has to be taken to identify the EUT emissions. Only the EUT emissions have to be processed further to find their highest amplitudes and to determine the amplitude using quasi-peak or average detection. If a semi-anechoic chamber is available, a preliminary signal list which contains only EUT frequencies can be quickly compiled. This list is then taken to the OATS and remeasured under conditions called out in the regulations. In both cases the frequency resolution and frequency accuracy are of key interest. If swept measurements are made over wide frequency spans, the signal resolution is low, which might cause signals to be buried under the response of a bigger nearby signal. The higher frequency uncertainty can cause difficulties in detecting the signals in the preliminary list when a search for these emissions is conducted on the OATS using a higher frequency resolution. The frequency accuracy and resolution (at a fixed IF bandwidth) of a swept EMI receiver is directly related to the selected frequency span: a smaller span provides better resolution and higher accuracy.

A frequency range to be measured, e.g., 30 MHz to 200 MHz, is called a band and can be broken up into multiple sub-ranges, called segments, which are measured individually with the swept receiver. This procedure achieves better accuracy and resolution but also increases the overall test time. When using high frequency accuracy and resolution, the fastest measurement time can be obtained by applying a function called spectrum check. This tool allows fast scans over the whole frequency band, ignoring any necessary segmentation, to detect locations of signal energy in the spectrum of interest. Only those segments which contain signals are measured with higher frequency resolution; the quiet segments will be omitted.

Figure 9 depicts the functionality of a spectrum check: the frequency band to cover must be divided, for example, into three segments, 1-3, to achieve a certain accuracy. A threshold is used during a spectrum check to determine a quiet zone in the spectrum. This threshold is determined by the peak excursion criterion and the noise reduction factor. The actual threshold value is calculated by multiplying the peak excursion value (e.g., 6 dB) with the noise reduction factor (e.g., 2). The result, 12 dB, is added to the lowest amplitude value found during the spectrum check measurement.

If the amplitude of a data point is equal to or greater than this threshold, the segment in which the point's frequency lies is marked for a high precision measurement. In Figure 9, only segment 3 is marked because no amplitudes exceeding the threshold are detected in the area of segments 1 and 2. The peak excursion criterion is used to calculate the threshold, because it defines a signal which will be discerned after the high precision measurement. The noise reduction factor determines how far above the noise floor a signal has to rise before it is considered for a high precision measurement. The spectrum check function is most valuable when many segments are necessary to ensure very high frequency accuracy. In this case, there is a high probability of finding quiet segments that do not need to be remeasured.

SUMMARY

List-based EMI software packages offer distinct advantages over trace-based products. Signal lists provide powerful comparison, selection, and sorting processes needed to complete many different tasks. For instance, discrimination between ambient signals and EUT emissions is greatly simplified by comparing two lists containing the appropriate information. Sorting signals in a list by turntable angle instead of frequency can considerably speed up an interactive maximization process. The discernment of signals in EMI receiver traces requires a powerful algorithm, which must be flexible enough to accommodate different measurement needs and test environments. Signal matching, a fundamental capability necessary for list comparisons, must take different attributes of signals into account when attempting to identify duplicate emissions. A software product can take over these tasks, but the suitable selection of key parameters used by these algorithms has to be made by the user.

WERNER SCHAEFER *received the degree of Dipl.-Ing. from the Technische Hochschule of Darmstadt in 1982 and an MBA from the Rendsburg University in 1991. His professional experience has been in the areas of microwave measurements, application software development and EMC measurements. Mr. Schaefer is an active member of both VDE and ANSI committees involved in the development of EMI standards, and is a NARTE-certified EMC engineer. He has published numerous papers on EMC and microwave topics in Europe and in the U.S. and has coauthored a book on microwave measurement techniques. (707)577-2817.*