Schnelle EMV-Emissionsmessung im Zeitbereich

Dipl.-Ing. Christoph Keller

Hauptberichter: Prof. Dr.-Ing. Dr. h. c. K. Feser
Mitberichter: Prof. Dr.-Ing. B. Yang
Tag der mündlichen Prüfung: 29.04.2004

Unter Elektromagnetischer Verträglichkeit (EMV) versteht man die störungsfreie Koexistenz von Sendern und Empfängern elektromagnetischer Energie [Schwab, 1990]. Die Begriffe Sender und Empfänger gehen in diesem Zusammenhang weit über die konventionelle Definition aus dem Bereich der Kommunikationstechnik hinaus und bezeichnen alle – auch unbeabsichtigte – Sender und Empfänger elektromagnetischer Signale. Zur Sicherstellung der EMV werden vom Gesetzgeber Störfestigkeitsprüfungen und Emissionsmessungen vorgeschrieben.

Emissionsmessungen müssen, wie in den Normen festgelegt, im Frequenzbereich beispielsweise mit Hilfe eines Messempfängers durchgeführt werden. Diese Messmethode weist jedoch zwei Nachteile auf:

- Aufgrund der Funktionsweise des Messempfängers dauert eine Emissionsmessung relativ lange. Der Zeitbedarf für eine Einzelmessung liegt je nach Wahl der Parameter im Bereich von einigen Minuten bis zu Stunden.
- Da der Messempfänger vergleichsweise viel kostet, ist es für Entwicklungslabore oder -abteilungen nicht rentabel, ein solches Gerät für entwicklungsbegleitende Emissionsmessungen zu kaufen.

Um diese Nachteile zu überwinden, wurde die Emissionsmessung im Zeitbereich entwickelt. Hierbei werden mit einem Digitaloszilloskop einige kurze Ausschnitte aus dem Messsignal aufgezeichnet und daraus mit Hilfe verschiedener Algorithmen ein zum Messempfänger vergleichbares Spektrum berechnet. Mit dieser Messmethode reduziert sich die Messzeit einer Einzelmessung auf einige Sekunden. Außerdem kann dieses Messsystem aufgrund der Tatsache, dass Digitaloszilloskope in den meisten Entwicklungslaboren schon vorhanden sind, mit nur geringen Kosten in Betrieb genommen werden. Im Falle einer Neuanschaffung eines Digitaloszilloskops kann dieses im Gegensatz zu einem Messempfänger auch anderweitig als universelles Messgerät verwendet werden.

In der vorliegenden Arbeit wird das Emissions-Messsystem im Zeitbereich FEMIT (Fast Emission Measurement in Time Domain) beschrieben. Ziel dieser Arbeit ist die Nachbildung des Messempfängers, um diesen ergänzen oder sogar ersetzen zu können. Dazu werden in der Arbeit einerseits die Funktionsweise des Messempfängers analysiert und andererseits alle erforderlichen systemtheoretischen Grundlagen für die Berechnung eines Spektrums betrachtet.

Da die Algorithmen des Messsystems grundlegend auf der Unterscheidung von schmal- und breitbandigen Signalen basieren, werden die zu diesem Themenkomplex gehörigen Phänomene diskutiert und insbesondere der Übergang von Schmal- zu Breitbandigkeit untersucht. Die Analyse des Messsignals ist entsprechend unterteilt in zwei Grundalgorithmen, auf denen alle Messungen beruhen: den Grundalgorithmus für Schmalbandsignale und denjenigen für Breitbandsignale. Für beide Algorithmen wird die optimale Wahl der Messparameter, der Messzeit und der Abtastfrequenz beschrieben. Auf diese Weise wird sichergestellt, dass vorgeschriebene Randbedingungen, wie beispielsweise eine ausreichende Auflösung, eingehalten werden.

Messsignale bestehen nicht nur aus schmal- oder breitbandigen Signalen, sondern aus beliebigen Kombinationen derselben. Das Messprinzip bei FEMIT besteht aus separaten Messungen von charakteristischen Ausschnitten des Messsignals. Die ununterbrochene Messung des Signals und die Berechnung des Spektrums, welche insbesondere bei komplexen Signalen die Ermittlung des Spektrums vereinfachen würde, ist hinsichtlich Rechengeschwindigkeit und Speicherbedarf mit handelsüblicher Hardware nicht realisierbar.

Mit Hilfe der Grundalgorithmen werden aus Ausschnitten die entsprechenden Teilspektren ermittelt. Das Gesamtspektrum wird durch Überlagerung dieser Teilspektren gewonnen. Die Berechnung der Überlagerungen wird für alle prinzipiell möglichen Kombinationen sowie für jeden der drei gängigen Detektoren des Messempfängers, dem Spitzenwert-, Quasi-Spitzenwert- und Mittelwertdetektor, hergeleitet. Für sämtliche Kombinationen werden Vergleichsmessungen zwischen FEMIT und dem Messempfänger vorgestellt, die an unterschiedlichsten Prüflingen durchgeführt worden sind.

Ein praktischer Teil rundet die vorgestellte Theorie ab und geht auf die für den Anwender interessanten Aspekte ein. Hier wird die erforderliche Hard- und Software beschrieben. Sowohl die Genauigkeit des Messsystems als auch dessen Grenzen, wie beispielsweise das Rauschen, werden ausführlich diskutiert. Des Weiteren werden die möglichen Anwendungen beschrieben und die erreichbare Reduktion der Messzeit analysiert, die in der Größenordnung von Faktor 10 bis 100 liegt.

▪ Fast Emission Measurement in Time Domain

Dipl.-Ing. Christoph Keller

The Electromagnetic Compatibility (EMC) defines the extent to which a piece of hardware will tolerate electrical interference from other equipment, and to which extent it will interfere with other equipment. There are strict legal EMC requirements for the sale of any electrical or electronic hardware. To ensure that the electromagnetic emission of a device does not exceed the limits defined in standards, emission measurements are required.

These emission measurements for the EMC check of a device must be carried out according to the standards in the frequency domain with a measuring receiver for example. It is necessary to execute a frequency sweep and to measure the emission at each frequency. This method has the disadvantage that the measurement takes quite a long time (from several minutes up to one or more hours) depending on the selection of the parameters. Since a time consuming measurement is a cause for high costs, it is profitable to look for possibilities to shorten the time of measurement without the loss of quality.

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

Principle of the fast emission measurement in time domain

With the current state of the art in technology, it is not possible to record the time domain signal in the required frequency ranges continuously and to reproduce the measuring receiver by digital filters because of the computing time and memory limitations. Moreover, in order to become an interesting alternative to the measuring receiver the measuring system should not be expensive.

As a result, only single, comparatively short measurements can be recorded. In spite of this fact, it is important to record those clippings of the time signal which contain the characteristic parts thereof to be able to calculate the spectrum correctly.

To be able to calculate the spectrum despite this fact correctly, it is a matter of recording those clippings of the time signal which contain the characteristic parts of the signal. The required spectrum is calculated from the corresponding spectra of these time signals by several superposition algorithms.

Narrowband and broadband differentiation

The signal types occurring during an emission measurement can be divided into narrowband and broadband signals. Belonging to the narrowband signals are sinusoidal oscillations of a discrete frequency and periodic pulses with a repetition frequency larger than the system bandwidth. Periodic pulses with a lower repetition frequency and non-periodic pulses are to be classified as broadband signals.

A distinct differentiation of the two signal types mentioned is necessary in FEMIT, as these have to be dealt with using different algorithms. The reason for this is that the linearity applicable to narrowband signals is no longer valid for broadband signals because the detectors of the measuring receiver attenuate broadband signals non-linearly.

Basic algorithm for narrowband signals

To measure a narrowband signal a measurement is recorded with the oscilloscope and converted to a spectrum using the DFT. A correction of the leakage and picket fence effect is made by using window functions such as the hamming and flat top window. These measures are necessary for the correct reproduction of narrowband peaks which are located between frequency points of the DFT.

Two parameters must be selected for the time domain measurement: sampling frequency and measuring time (length of a clipping). The sampling frequency should correspond to at least the twofold, better the fourfold maximum desired frequency, in order to avoid aliasing errors. The measuring time influences the frequency resolution of the spectrum. Based on the requirement that the frequency resolution of FEMIT must be equal to or better than the one of the measuring receiver, the optimum measurement time can be calculated. This time also depends on the selected window function. For measurements in band C and D, for example, 10 µs is selected.

Basic algorithm for broadband signals

For broadband spectra the non-linear attenuation of the detectors must be taken into consideration, i.e., the peak-detector, the quasi-peak-detector and the average-detector. The attenuations are a function of the repetition frequency of the pulse that generates the broadband spectrum and are shown in the pulse response curves. To simulate this effect in FEMIT, the pulse response curves of a time domain measurement have to be investigated. From the difference of the pulse response curves results a correction curve for FEMIT. This curve depends on the detector chosen, the repetition frequency of the pulse, the system bandwidth and the measuring time.

To measure a broadband spectrum the pulse is recorded and converted into a spectrum. This spectrum is corrected for all frequencies by the correction factor shown in the correction curve.

Superposition of narrowband spectra

Often, the amplitude of a narrowband signal is not stable, e.g. due to a poor stabilized or weak power supply. If the period of the fluctuation is larger than the measuring time, the result of FEMIT depends on the phase of the modulation signal. For peak- and quasi-peak-measurements the maximum possible result corresponds to the result of the measuring receiver. The result of the average detector approaches the average result of the FEMIT measurements.

The more single measurements are used to determine the spectrum, the more the calculated result approaches the result of the measuring receiver. Statistical considerations show that the superposition of three to five spectra results in satisfactory accuracy.

Superposition of narrowband and broadband spectra

If the signal consists of a narrowband and a broadband part the superposition of the two corresponding spectra has to be determined. The level of the resulting spectrum is always higher than the highest level of the single spectra, due to the effect of constructive interference. For each detector, an equation for the calculation of the superposition as a function of the two single levels is given.

Superposition of broadband spectra

A signal can be composed of different broadband signals. For analysing this type of spectrum, one sample impulse of each pulse train has to be recorded. The single spectra are calculated and corrected according to their pulse repetition frequency as described in the basic algorithm. From these spectra the superposition is calculated. The algorithm for the superposition depends on the detector.

Measurement procedures

As the number of measurements and the way of calculating the spectrum depends on the signal and on the demanded accuracy of the result, several measurement procedures are defined in FEMIT. The quickest procedure is applicable to stable narrowband signals and consists of just one measurement. Here, no superposition is necessary. The most extensive procedure is based on several measurements and is used for stochastic signals, such as brush discharge of a motor.

Superposition of stochastic signals

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 lower ones, and different repetition frequencies mean different attenuations due to the correction curves, the pulses of signals have to be devided into groups of similar amplitudes. It is useful to define approximately five amplitude ranges, respectively, five trigger levels. For each range the average pulse repetition frequency is determined. Then, for each range the spectrum of a measurement of this range is attenuated according to the corresponding correction value. Now, the superposition of these spectra is calculated as described in the previous paragraph.

Signal detection

Signal detection must be carried out in order to determine the correct measuring procedure. There are two possibilities: the signal can be analysed “manually” or automatically. With “manual” recognition the user her/himself must analyze how the signal is composed and select the corresponding procedure. An easier way, however, is provided by automatic signal recognition. The automatic detection is based on counting the trigger events for several trigger levels. From these data the composition of the signal can be analysed. However, it is often faster to select the procedure manually, since, especially for repeated measurements of the same device, the right procedure has already been established.

Frequency response correction

A frequency response correction must always be made as a final processing procedure. Frequency-dependent factors such as the antenna factor curve, cable attenuation, anti-aliasing low-pass filter etc. are considered here. The frequency response correction curve can be measured as well as calculated, if all transfer functions are available. In the first case a sinusoidal signal for various frequencies is first fed to the measuring receiver as a reference measurement, and then to FEMIT. The difference in the measuring results then corresponds to the frequency response correction curve.

Hard- and software of FEMIT

The central device for FEMIT is a digital oscilloscope. The maximum sampling frequency should be 4 GS/s for measurements up to 1 GHz (band D). To avoid aliasing errors, a low-pass filter is needed. Depending on the level of the signal, it can be necessary to use a preamplifier with an amplification of 20 dB to 25 dB. The measuring data of the oscilloscope are transmitted via the GBIB bus to the PC where the spectrum is calculated by the program FEMIT. This program selects, depending on the frequency range, the correct parameters for the measurement and uses the described algorithms to determine the spectrum.

Accuracy of measurement

The accuracy comprises three aspects: the accuracy depending on the devices, the algorithms and the signal itself. The measuring errors of the devices are lower than 1 dB and are, therefore, negligible in terms of the total accuracy attained.

Using the DFT gives a mathematically perfect correlation between frequency and time domain representation. Thus, there is complete correspondence with stable narrowband signals. A regular pulse can also be correctly measured for all detectors. It is only when the superposition of several spectra is calculated that errors, caused by approximations in the algorithms, can occur up to approximately 1 dB.

The measuring signal itself influences the accuracy of the result. In principal there can be two causes for this:

- The signals are often not constant, but rather subjected to a certain degree of fluctuation. As the FEMIT system is only able to calculate the spectrum on the basis of a few random sample measurements, such fluctuations can lead to deviations from the measuring receiver measurement.

- With FEMIT two to three different pulses can be measured and calculated in addition to the narrowband part. Errors can occur if more pulses, all dominating the spectrum in various frequency ranges, are present.

In summary it can be established that, above all, the type of measuring signal itself is crucial for the accuracy of the result. The maximum deviations typically occurring in practice from the referenced measuring receiver measurement are lower than 1 dB to 2 dB for narrowband signals, lower than 2 dB to 4 dB for pulses and lower than 5 dB to 6 dB for stochastic signals.

Noise and signal-to-noise-ratio

The theoretically attainable maximum signal-to-noise ratio (SNR) is obtained from the bit width of the digital oscilloscope and the number of points used for the Fourier transform. For number of points used in FEMIT, this maximum SNR amounts, in theory, to appoximately 95 dB. In practice, the obtained SNR is lower due to various effects. For example, the dynamic range of the oscilloscope usually cannot be used completely and the noise factor of the preamplifier and the internal amplifiers of the oscilloscope reduce the SNR by adding additional noise. The typically obtained SNR is, depending on the parameters, in the range of 50 dB to 75 dB.

The minimum noise level of the spectrum is located at 15 dBµV to 25 dBµV. With a preamplifier this level decreases depending on the amplification.

Time reduction

The entire measuring process including calculation lasts 5 s to 40 s, depending on the desired accuracy and type of measuring signal. Compared with the measuring time of the measuring receiver, this system offers a time advantage by a factor of around 10 to 100!

The calculation of the spectrum takes just 1% to 3% of the total time. Over half of the total time currently needed is required for the transmission of data from the oscilloscope to the PC. With an integration of the software into the measuring device, which is technically possible, the measuring time would be significantly reduced.

Applications

A diverse range of applications is conceivable for the measuring system. It is particularly suitable for:

- Preliminary and overview measurements
- Measurements accompanying product development
- Determining the direction or area of the highest radiation
- Checking the effectiveness of interference suppression
- Measurement of transient phenomena (e.g. switching impulse)

Conclusion

With the FEMIT system EMC emission measurements can be carried out within several seconds, thus saving a considerable amount of time and expenses. The examination of all the important characteristics of the measuring system, such as accuracy, noise level and SNR, shows that FEMIT represents a worthwhile alternative for many applications. Especially, for smaller companies or development departments where it is not profitable to buy a measuring receiver. With an oscilloscope, which is usually already available, EMC emission measurements can be carried out with sufficient accuracy and sensitivity in approximately 1 % to 10 % of the time, in comparison to the use of a measuring receiver. The interest of the industry in the FEMIT system shows the potential of this measuring system and is an encouragement to present it to the standardization committees.