Signal Detection with EMI Receivers

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Abstract - Certain EMI receiver settings, such as dwell time or sweep time, receiver display mode and IF detection are very important when trying to capture and analyze emissions from EUTs (equipment under test). In the case of broadband signals, special attention and operator skill is required to select the appropriate values for these instrument settings. The receiver state can directly influence the probability of broadband signal intercept, and thus can determine if this type of signal is detected or not. Furthermore, the type of EMI receiver used (i.e., stepped or swept) must also be considered to prevent erroneous measurement results when measuring broadband signals. This paper addresses issues related to measurement procedures, frequency and receiver display resolution, and receiver detection modes, and explains their impact on signal detection.

Introduction

Today, both swept and stepped EMI receivers are used to make radiated and conducted EMI measurements. Even though their early designs were different, the modern hardware architecture of both types is similar in many ways. The first EMI receivers were manually-tuned instruments with analog meters for indicators. Later, receivers that could be automatically tuned to different frequencies and provided a numeric readout of the measured emission amplitude and tuning frequency became commercially available. More than 10 years ago, scanning EMI receivers were introduced. Since this receiver type was initially based on the spectrum analyzer concept, it was always continuously swept over the frequency range of interest, and provided a graphical representation of the measured spectrum. Scanning EMI receivers combine the advantages of spectrum analyzers with unique EMI receiver characteristics in a single instrument.

Since each approach offers distinct advantages, most EMC laboratories use spectrum analyzers and EMI receivers to accomplish their measurement tasks. However, there are still concerns within the EMC community about the measurement capability of scanning receivers, their compliance with the specifications called out in the various standards in particular CISPR (International Special Committee on Radio Interference) Publication 16 Part 1 and their general suitability for EMI compliance measurements. Proper signal detection with an EMI receiver is dependent on various parameters. Some are related to the characteristics of the signals to be measured, others to the receiver's hardware specifications and chosen instrument settings. The chosen measurement procedure also affects signal detection.

This paper focuses on practical issues related to both receiver types in the context of signal detection and briefly discusses relevant EMI receiver specifications.

Measurement Procedures and Test Time

Broadband signals cover a frequency spectrum wider than the receiver IF bandwidth. The detection and measurement of broadband (e.g., impulsive) signals with low repetition rates can be rather difficult, especially if their presence is not known before the beginning of the measurement. For a finite probability of intercept, the total test time must be longer than the period of any signal in the spectrum. Otherwise, signals may be missed simply because they were not present during the measurement. Even if a signal occurs during the measurement, it will not be detected if the receiver is tuned to a different frequency. This means that a fixed-tuned receiver must dwell at each frequency in the spectrum of interest for a time equal to

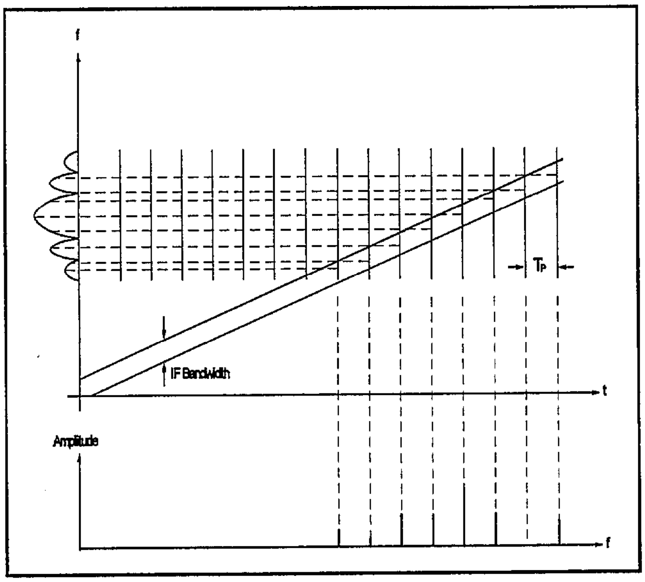

Figure 1: Pulse Detection (Single Slow Sweep)

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the signal period, and a scanning receiver must sweep at a rate of less than one IF bandwidth per the signal period. **Figure 1** (top graph) shows how a scanning receiver intercepts an impulsive signal when a slow, single sweep and peak detection is used. The impulse envelope is depicted on the vertical frequency axis and the occurances of the impulse are indicated by vertical frequency lines spaced along the time axis. The impulse of the period T_P is detected only half way through the receiver sweep. The measured amplitude at the detection instant is determined by the envelope of the pulse spectrum as traced out by the IF bandwidth and represents the impulse response of the receiver to the input signal. The bottom graph of **Figure 1** represents the scanning receiver's display showing responses only at the detection instances. Since a broadband signal is being measured, that the pulse repetition frequency (PRF) **cannot** be determined directly from the display by measuring the frequency difference between two responses with marker functions. The receiver's IF bandwidth is much wider than the PRF; thus the displayed responses are individual input pulses separated by the pulse period and the frequency may be calculated from the sweep time of the receiver. The correct interpretation of the measurement result is difficult without prior knowledge of the presence of a broadband signal. After a single sweep, it is not obvious that the displayed responses are due to an impulse and not caused by individual sinusoidal signals or some type of modulation. However, a narrower measurement span and longer sweep time will lead to more intercepted pulses; hence the well-recognized sin(x)/x envelope shape will be traced out and the impulsive signal will be easily identified. In **Figure 2** (top graph) another approach is used to intercept an impulse with a scanning receiver: instead of one slow sweep, multiple fast scans are taken. The sweep time for each individual scan, including the re-trace time and processing time, is selected such that the overall measurement time is identical to the measurement time for one sweep. The display of the scanning receiver, **Figure 2** (bottom graph), now shows multiple responses intercepted during **different** sweeps. A display max-hold function is applied to retain the results of multiple sweeps. In case the max-hold function is not used, responses are displayed at different locations on screen after each individual sweep. This causes an effect of "moving" responses on the display. When such a response is observed, the presence of a broadband (impulsive) signal can be concluded. Then a slow single sweep with narrower span and longer sweep time can be employed to analyze the signal further.

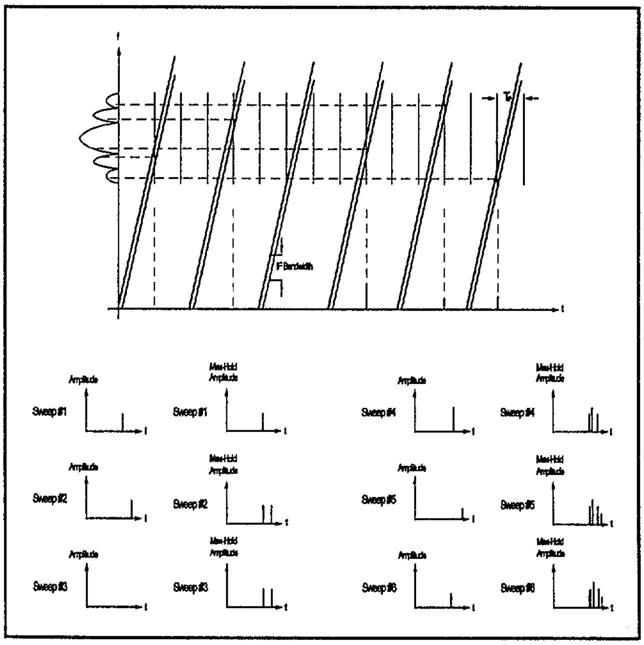

Figure 2: Pulse Detection (Multiple Fast Sweeps)

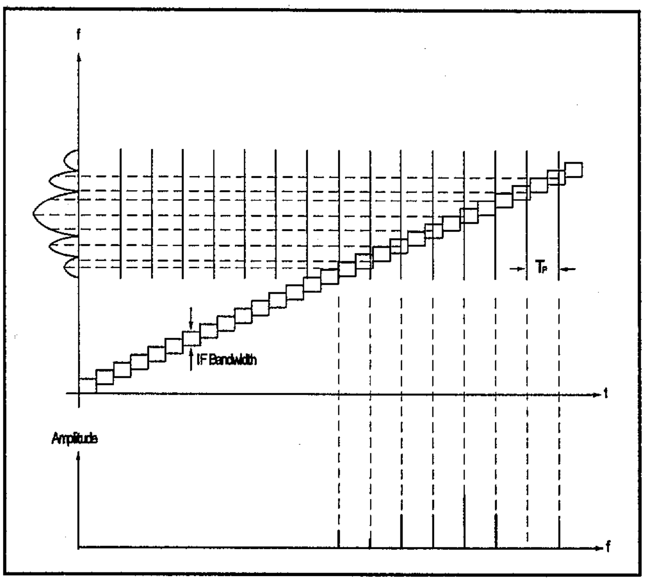

Figure 3: Pulse Detection (Stepped Measurement)

The way a fixed-tuned receiver intercepts an impulsive signal is depicted in **Figure 3** (top graph): the receiver is tuned across the frequency range of interest in discrete frequency steps. This step size needs to be about half of the used IF bandwidth to avoid missing signals in between measurement frequencies. A graphical display of such a receiver, **Figure 3** (bottom graph), shows the same result as achieved with a scanning receiver when using a slow single sweep. However, it usually takes more time to achieve the same result with a the stepped receiver because of step rate limitations. When the presence of a broadband signal is known, a greater frequency step size can be chosen and measurement times for scanning and stepping receivers will be on the same order of magnitude.

A scanning receiver provides the capability to use multiple fast scans for detection of broadband signals as well as a single slow sweep to measure these signals. The stepped receiver, however, does not offer the capability to quickly scan over wide frequency ranges; thus "moving" response effects cannot be detected and the presence of impulsive signals determined.

Frequency and Receiver Display Resolution

Frequency resolution is the ability of an EMI receiver to separate two input sinusoidal signals into distinct responses on the display. Since the input signal to the receiver is fixed and the LO swept, the products from the mixer are also swept. If a mixing product sweeps past the IF, the bandpass filter's frequency response is traced out on the receiver display. The narrowest filter in the IF chain determines the overall receiver bandwidth. Unless two signals are far enough apart, the traces they cause will merge and look like only one response. Narrower filter bandwidths help in resolving closely-spaced signals. However, commercial EMI regulations call out fixed bandwidths for certain frequency ranges, so the use of a narrower bandwidth for improved frequency resolution is not an option.

In general, two sinusoids of equal amplitude can be resolved if their frequency separation is greater than the 6 dB bandwidth of the EMI receiver's IF filter. Actually, the signals can be closer together before their traces merge completely, but the 6 dB bandwidth is a useful number for the resolution of equal-amplitude signals. When measuring sinusoids with different amplitudes, the smaller signal can be lost under the skirt of the response traced out by the larger. The frequency resolution in this case is determined by the selectivity of the IF filter, which is defined in CISPR 16 Part 1 by masks for each bandwidth that specify filter insertion loss versus frequency offset from center frequency.

Frequency resolution of an EMI receiver is strictly related to the characteristics of the IF filter. Since the bandwidth and selectivity are specified for commercial measurements, the frequency resolution is similar for all receiver types.

In the case of fixed-tuned receivers, a suitable frequency step size must be chosen. As previously indicated, a fixed-tuned receiver is stepped in discrete frequency steps over the spectrum of interest. The frequency steps must be chosen small enough to avoid missing signals that are present between the receiver tuning frequencies. A step size about half the IF bandwidth is required.

In a scanning EMI receiver, the signals to be measured remain in analog form throughout the processes of frequency translation, filtering, amplification and detection. In a traditional EMI receiver with an analog meter, the IF signal is then applied to the meter. Digital displays require some additional signal processing, as well as specialized display modes. Before the measurement data can be displayed it must be digitized. Therefore, the detected signal is applied to an A/D converter, which provides sufficient speed, resolution and linearity. Since both the amplitude and frequency axes of the display are digitized, the single data value taken for each point must provide a meaningful indication of the entire signal amplitude history for the cell between two display points.

Two display modes are of particular importance for EMI testing: *positive peak* and *sample*. In **Figure 4** the analog signal to be processed is shown at the top. The positive peak detector retains the maximum amplitude found in a cell and displays its value at the right digital point defining the cell. Since the worst-case emission amplitudes are displayed, this mode is very useful for compliance testing, because it allows coverage of wider frequency ranges and thus reduces test time. However, larger frequency errors are potentially introduced by selecting a wider cell width, which is defined as: *(number of horizontal display points -1) / frequency span.* If a single scan is defined to cover the frequency range from 30 MHZ to 1 GHz, and a receiver with 1001 display points is used for the measurement, the cell width is 970 kHz. This leads to a worst-case frequency error of 970 kHz when the true maximum amplitude of the analog signal happens to be at the beginning of the cell, but the positive peak detector displays it at the end of the cell. The frequency shift is usually of minor importance in a compliance test, but may not be tolerable in other applications. When the ultimate goal of the test is to minimize test time, positive peak detection should be used to obtain the highest emission amplitudes in a wide frequency spectrum. This ensures that no worst-case amplitude is missed.

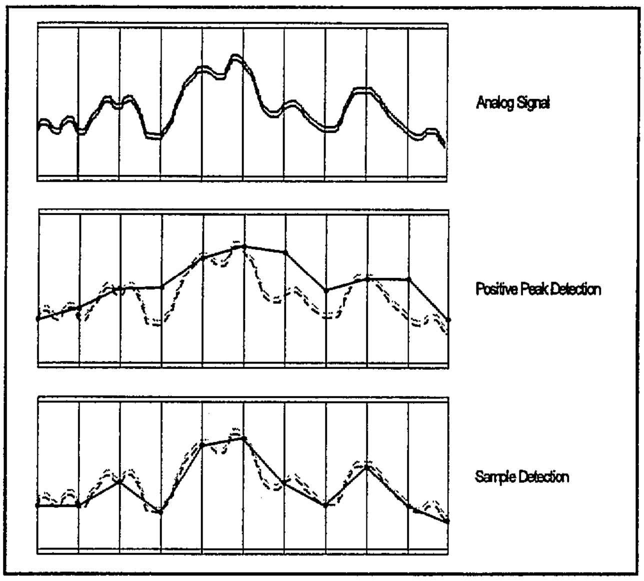

Figure 4: Receiver Display Detection Modes

The sample detector (bottom of **Figure 4**) avoids frequency inaccuracies, since it displays the cell values present at the display points. Therefore, this mode is very useful when signal characteristics are to be determined using a swept EMI receiver. The changes in signal amplitudes between consecutive sweeps, as well as the cell occupancy of signals, provide valuable information about the nature of the emissions. This information is effectively used in signal comparisons; e.g., automatic ambient discrimination. However, this detection mode should not be used when the frequency separation between display points exceeds 70% of the receiver IF bandwidth, since very narrow, high level signals within the cells will not be displayed. For practical purposes, the frequency spacing for the sample detector should be set to 25% or 30% of the resolution bandwidth.

Receiver Detection Modes

EMI receivers as well as spectrum analyzers convert the IF signal to a video signal using an envelope detector. These signals have a frequency range from zero (dc) to some upper frequency that is determined by the detection circuit elements. In its simplest form, an envelope detector consists of a diode followed by a parallel RC combination, as shown in **Figure 5** (top). The output of the IF chain is applied to the detector. The time constants of the detector are chosen such that the voltage across the capacitor equals the peak value of the IF signal at all times, which requires a fast charge and slow discharge time. In case the preceding resolution bandwidth of the receiver has only one spectral line in its passband, the IF signal is a steady sine wave with a constant peak amplitude. The output of the envelope detector will be a constant dc voltage without any variation for the detector to follow as depicted in **Figure 5** (top). However, there is usually more than one signal in the IF filter passband. In case of the two sine waves in the passband, as shown in **Figure 5** (bottom), their interaction will create a beat note, and the envelope of the IF signal varies according to the phase change between the two sine waves. The maximum rate at which the envelope of the IF signals can change is determined by the resolution bandwidth. Since IF filters of receivers are not rectangular, the charge time of the detector must be a fraction of the reciprocal of the IF bandwidth (e.g., one-tenth) to obtain the envelope of the IF signal.

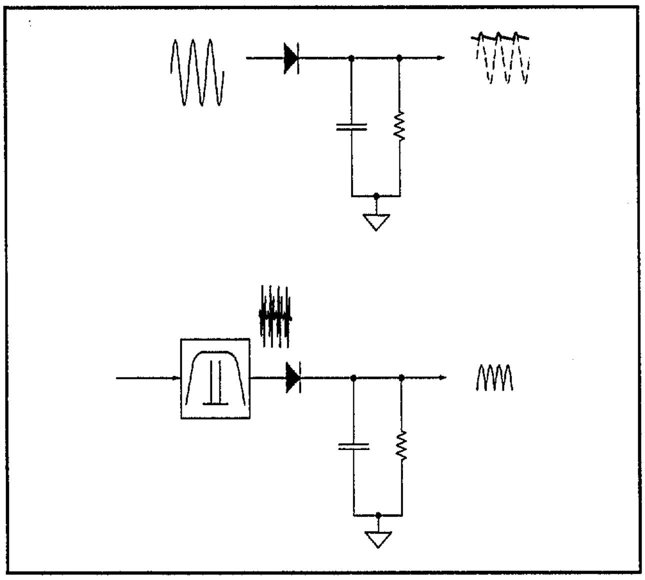
Figure 5: Envelope Detection

Most commercial compliance measurements require quasi-peak detection. This detector type is unique to EMI receivers or spectrum analyzers with EMI measurement capability. Originally, the quasi-peak detector was designed to obtain a receiver reading proportional to the annoyance effect of interference on broadcast radio listeners. The design of the detector circuit, which has various charge and discharge constants dependent on the frequency range, results in the weighting of broadband signals as a function of their repetition rate. Signals with a lower repetition rate cause less annoyance and thus get less emphasis. Emissions with a high repetition rate get more emphasis because they have a higher annoyance effect. As the repetition rate approaches that of a CW signal - i.e., 100% duty cycle - it has the maximum annoyance effect and thus gets no weighting applied to its amplitude level. The time constant of the meter movement following the detector has a smoothing effect on the output signal so that a steady amplitude reading can be obtained. It is important to recognize that the quasi-peak amplitude of a signal will always be lower or equal to the amplitude measured with the envelope detector.

International and US EMI regulations require the use of average detection, either in addition to quasi-peak detection in the case of conducted emissions measurements, or as the only detection mode for measurements above 1 GHz. Average detection was introduced to measure lower-level narrowband signals in the presence of broadband noise. In general, the interference potential of narrowband signals is higher than that of broadband signals.

When a narrowband signal is combined with an impulsive signal, a measurement with the quasi-peak detector can completely mask the lower-level narrowband signal because the detector responds predominantly to the peaks of the broadband signal. Average detection, on the other hand, is used to suppress broadband signals and is therefore well suited to recover the amplitudes of narrowband signals. It should be noted that the recovery of narrowband signals in the presence of broadband emissions is the primary purpose of the average detector. It is not used to determine the average value of a broadband pulse train. The average detector consists of a lowpass filter which is placed behind an envelope detector (described above). The average value of the peak-detected IF signal is obtained by feeding it into a narrow lowpass filter, which functions as an integrator. For this reason, the cutoff frequency of the lowpass filter must meet the following two criteria: first, it must be set to a value sufficiently narrower than the resolution bandwidth of the receiver to achieve any averaging; and second, it must be set to a value smaller than the lowest frequency component of the measured emission. For example, when a 9 kHz resolution bandwidth is used, the cutoff frequency of the lowpass filter may have to be set to 1 Hz to suppress any components of the envelope-detected fluctuations from 50 Hz power-line spikes. Furthermore, a linear amplitude scale must be used for correct average measurements.

EMI Receiver Specifications

The hardware architecture of scanning and stepped EMI receivers is very similar. Both instruments are superheterodyne receivers and measure signal voltages frequency selectively. Most commercial EMI standards reference CISPR Publication 16 Part 1 as the standard specifying the instrumentation for EMI and EMS measurements. The definition of EMI receiver specifications is a very important part of this document. Its input impedance, detector characteristics and IF bandwidth shapes are called out. Also, the amplitude accuracy for measuring sine waves and pulses with varying repetition rates is specified. Additional requirements for spurious responses, image and IF rejection, intermodulation distortion and screening effectiveness complement the receiver specification section. The current version of CISPR 16 Part 1, dated 08-1993, calls out receiver specifications for the frequency range of 9 kHz to 1 GHz. However, an amendment is underway which extends this frequency range up to 18 GHz. If an instrument meets all these criteria, it can be used for compliance measurements. No specification in this document requires that a receiver must use a stepped or swept approach. Furthermore, no reference is made in regard to the indicator of measurement results: both numerical and graphical presentation of the test data is acceptable. In addition, no numbers are called out for the required dynamic range or actual sensitivity. These critical specifications are included in the amplitude accuracy specification for the measurement of pulses with varying repetition rates. Therefore, both scanning and stepped receivers are equally suitable for making EMI compliance measurements.

Summary

Accurate signal detection using an EMI receiver is dependent on many different parameters. Also, the receiver type has a significant impact on the measurement process and the associated test time, especially if broadband signals are present in the spectrum of interest. A scanning receiver allows signals to be displayed in the frequency and time domains, which greatly simplifies the identification and analysis of emissions. Complex tasks like the detection of broadband signals and their discrimination from narrowband emissions are conveniently achieved using a swept approach.

The frequency resolution of an EMI receiver is predominantly determined by its IF filters. If multiple signals are within the passband of the IF filter, the instrument cannot resolve those as separate signals. In this case, the superposition of the input signals determines the voltage at the filter output, which is further processed. The receiver display modes may also affect signal detection, because an additional frequency shift may be introduced by the selected mode or narrower frequency spans may have to be used to avoid missing signals.

The receiver's IF detectors directly determine the measured emission amplitudes. The peak detector retains the envelope of the IF signal and allows for fast scans over the full frequency ranges of broadband antennas or other transducers.

The quasi-peak detector introduces a weighting factor on broadband signals based on their repetition rate. The use of this detector requires long measurement times, since it's charge, discharge, and meter constants must be observed when selecting the receiver dwell time or scan rate setting. The average detector is used to recover the amplitudes of narrowband emissions within broadband signals. It's purpose is not to measure the average value of broadband signals but to strip them from narrowband signals in order to measure the amplitudes of the remaining signals.

Many of the discussed parameters are defined in CISPR 16 Part 1 as specifications of EMI receivers. For example, IF bandwidth filter shapes, detector characteristics and amplitude accuracy are important for signal detection. If instruments meet these requirements, the measurement results achieved with different types of receivers should be comparable. However, the selection of dwell time or scan rate, the test approach and receiver display mode are usually not specified and can introduce repeatability problems.

References

1. CISPR 16-1 (1993), *Part 1: Radio disturbance and immunity measuring apparatus.*

2. Siegfried Linkwitz, *Average Measurements using a Spectrum Analyzer*, EMC Test & Design, June 1991.