Realtime measuring equipment optimized for faster detection of critical EMI signals

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***Abstract* -** The developement of military and commercial products and the growing complexity of electronic devices has lead to a significant increase of EMC conformance testing. Due to pressure from market the product design cycle times continue to decrease. Companies are spending more money on multiple iterations of product EMI compliance testing at EMC test laboratories. Many companies pay for a product to be repeatedly tested at an EMC test laboratory, but it often makes more financial sense for companies to invest in their own test solutions. Such equipment is e.g. a high-end signal and spectrum analyzers or test receiver being upgraded to a realtime analyzer that provides the functionality on top of traditional signal and spectrum analyzer functions.

The core of the real-time analysis is the digital back-end. The critical point behind real-time analysis is to run data acquisition and data processing in parallel. To achieve this, the digital back-ends are equipped with a chain of powerful ASICs and FPGAs in combination with a large memory for captured data. This combination allows the instruments to process the data in several stages in a pipeline architecture. The last stage of the pipeline is the CPU, which reads the pre-processed data, applies the necessary scaling information and displays the results on the screen.

Different real-time display modes run in parallel on the real-time analyzer. This means that all available real-time results can be displayed in multiple diagrams at a time and a frequency mask trigger (FMT) can be used in addition to capture very rare events. This flexibility is a time saving, reliable and accurate testing method to reduce device design cycles without compromises to oversee sporadic or non-stable signals in gapless recording by realtime analyzers.

Keywords* - *EMI, real-time, FFT-windowing , overlap, filter requirements, spectrum analyzer, test receiver

I. REALIZATION TECHNIQUE OF REAL-TIME MEASURING TEST EQUIPMENT

The measurement speed available in today's spectrum analyzers or receivers is the result of an evolutionary process. Traditional spectrum analyzers measure frequency spectra by mixing the input signal to a fixed intermediate frequency (IF) using a swept local oscillator. The signal was down-converted in several mixing stages, and finally it passed the analog resolution filter, which determined the frequency. The measurement time was dependent on the settling time of the resolution filter and the time the first local oscillator needed to return from its end frequency to its starting point, the so-called re-trace time.

With increasing computing power following spectrum analyzer and test receiver generations were equipped with FFT filters for narrow bandwidths. Multiple narrowband FFTs were concatenated to a trace representing the selected frequency span. As the computing time for the FFTs was small compared to the settling time for narrow RBW filters, the FFT method provided a great speed advantage over the traditional sweep method.

The newest generation of test equipment makes excessive use of the FFT method for narrow resolution bandwidths. In addition, it introduces complex digital RBW filters for swept measurements. These complex digital filters can be swept by orders of magnitudes faster than their analog counterparts.

The solution comes with today's wideband, high resolution analog to digital converters (ADCs). The 16 bit or 18 bit ADCs allow capturing wide frequency ranges (e.g. 40 MHz up to 512 MHz) in a single shot with sufficient dynamic range without having to move the local oscillator (LO). Combining these wideband ADCs with fast FFT algorithms implemented in dedicated hardware (e.g. FPGA) is the basis for the design of a real-time spectrum analyzer.

The important keys to a real-time spectrum analyzer are:

▪ Parallel sampling and FFT calculation: The data acquisition continues while the FFTs are performed.

▪ Fast processing of FFT algorithms: The computation speed must be high enough to avoid that “stacks” of unprocessed data are being built up. Slow FFT computation will result in an overflow of the capture memory and a subsequent data loss (= a new blind time).

This gap in data acquisition, the so-called "blind time", has decreased with each new spectrum analyzer or test receiver generation.

CAPTURE AND ANALYZE

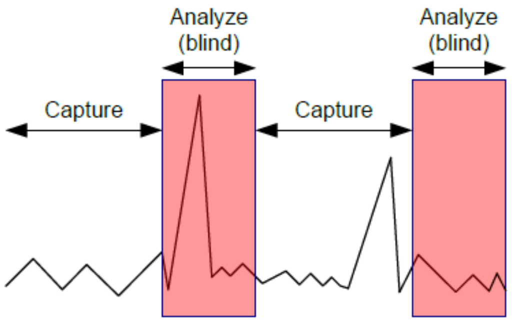


Figure 1-1: Sequential capture and analysis as used in e.g. FFT analyzers

Handling FFT results of short events (short compared to the FFT capture time) is a challenge, which must be handled properly by a real-time spectrum analyzer to minimize level errors.

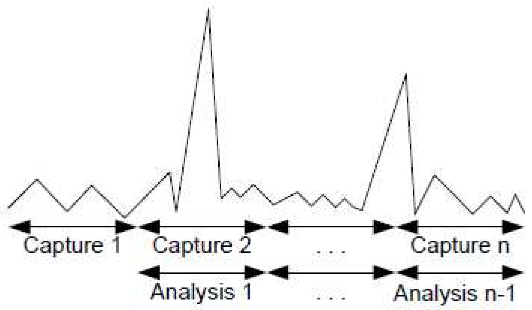


Figure 1-2: Parallel capture and analysis - no blind time

To show the critical situation, let's assume that the capture time frames for two subsequent FFTs do not overlap.

FRAMES OVERLAPPING

The energy of a short pulse, which hits the border of the two capture time frames as shown in Fig. 2-1, will be distributed among the results of both neighboring FFTs. As a result, each of the FFT results exhibits a lower power level compared to the true power of the time domain pulse.

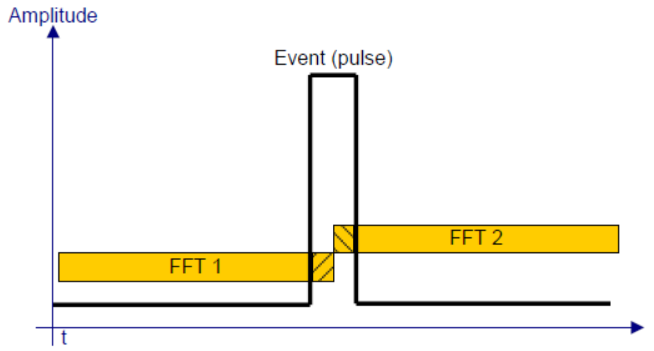


Figure 2-1: Pulse captured by two consecutive FFT time frames without overlapping

Real-time analyzers utilize a technique called FFT overlapping to avoid this situation. Overlapping “reuses” samples that were already used to calculate the preceding FFT result. Fig. 2-2 shows a pulse signal that is captured by several overlapping FFT time frames.

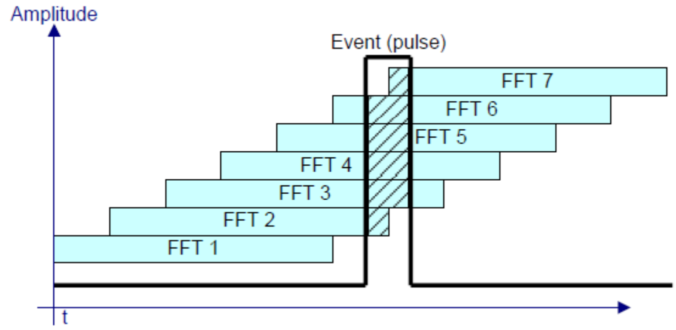


Figure 2-2: Pulse captured with several consecutive overlapping FFT time frames

In the example (Figure 2-3) there are several FFTs that capture the entire pulse and not only fractions of it. The overlap factor describes the ratio of reused samples to the total number of samples. In the case of high-end test equipment, an overlap factor of at least 80% is used. Overlapping depends on many factors, especially the FFT length and operating mode (High Resolution or Multi Domain), but is at least 50%, unless window lengths are below 1024 bins. Assuming an FFT length of 1024 bins and a bandwidth of 160 MHz, an overlapping of 2/3, i.e. 684 samples are reused.

Finally, a more detailed view on FFT techniques reveals another issue that requires an adequate overlapping ratio. An FFT analyzer usually applies a non-rectangular windowing function to the captured data before calculating the FFT. From Fig. 2-3 it becomes evident that pulses shorter than the window length can be significantly attenuated if they are located near the window edges. Sufficient overlapping ensures that short pulses that could be attenuated if they occur at the edges of a window are also correctly measured at the center of the window in subsequent FFTs.

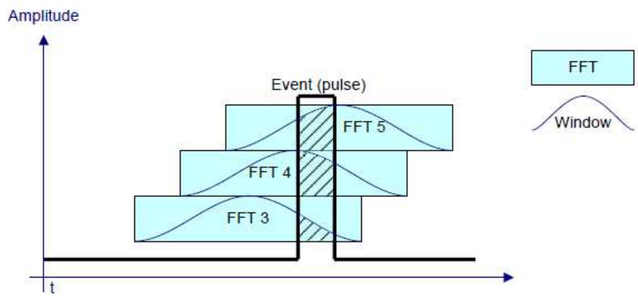


Figure 2-3: Overlapping compensates effects resulting from windowing function

With an overlap ratio of 50% or higher, level errors caused by the window function can be neglected.

Overlapping is directly derived from the maximum real-time bandwidth and the maximum number of FFTs the analyzer can calculate per second. So for a real-time spectrum analyzer comparison, it is important to keep an eye on the specified FFT update rates, i.e. the number of FFTs per second.

Within the real-time FPGAs, the resolution bandwidth (RBW) is tied to the FFT length and the span. With its fixed FFT length, the RBW cannot be set explicitly. Modern test equipment allow different FFT lengths for realtime setups. By selecting a certain Span/RBW ratio, the RBW can be changed for given span. Since the available span/RBW ratios vary with the selected window function, Table 1 gives an overview of the maximum ratios available, i.e. the span/RBW ratio that corresponds to a 16k FFT. Clearly, the FFT or window length scales down with the selected ratio.

Maximum span/RBW ratio (16k FFT)					
Blackman	Flattop	Gauss	Rectangle	Hamming	Kaiser
3200	1600	3200	6400	4000	3200

Table 1: Window functions corresponding to 16k FFT

II. DISPLAY OF REALTIME MEASUREMENT RESULTS

Wireless communication systems such as headsets or hands-free sets in a car use often frequency hoppers to be less disturbed by interference signals or applications in the same frequency range.

Also inside tactical communcation systems as well as radar applications frequency hopping technique ensures security against interception respectively reduction or suppression of unwanted interference.

For the analysis of frequency agile systems the signals should be displayed in realtime fast, accurate and gapless. This is the only way to analyze short and unwanted signals in detail.

III. PROBABILITY OF INTERCEPT

For above measurement tasks todays analyzers/ receivers are fitted with real-time bandwidths of 40, 80, 160, 320 or 512 MHz. Using e.g. a 512 MHz real-time bandwidth the FFT rate must be up to 1,1 million spectra per second. The analyzer detects signals correctly by level, which are present at least for only 0,91 µs (100-% Probability Of Intercept, POI) and catches also those signals with a duration of a few nanoseconds with reduced level accuracy. The human eye differs between 30 pictures per second only and modern test equipment offer diverse options for displaying these results and events with detailed resolution in frequency and time domain, offering more information available about the measured spectra.

The conventional display of real-time spectra calculates many thousands of traces with a detector to display the spectrum of maximum values. If there was an interferer or disturbance signal, it was captured and displayed although the event might have been existing for only nanoseconds.

Key parameter for real-time analysis		
FFT-length	1024 to 32k	1024 to 16k
Maximum real-time analyzer bandwidth	512 MHz	160 MHz
Maximum FFT-rate	1 171 875	585 938
POI	**0,91 µs**	**1,87 µs**
Resolution bandwidth (RBW) free configu-rable for Span/RBW	6,25 to 6400	6,35 to 3200

Table 2: Comparison of real-time parameters for modern test equipment of signal- and spectrum analyzer

IV. SPECTROGRAM FUNCTION

For a better resolution of the frequency domain the user can take benefit from a spectrogram display., which lines up all traces and spectra color coded. Signal levels and traces are linked in rows one after the other to form a histogram where the newest measurement is on top and the older ones are listed below. So frequency hoppers are caught and displayed gapless.

The device memory e.g. saves up to 100,000 spectra. With the sweep time of 200 µs the maximum spectrogram history depth is 20 seconds, whereas a sweep time of 30 ms allows the spectrogram to cover 3000 s, almost an hour. For continuous operation of the real-time analyzer, the history depth can be directly converted into a maximum display time by multiplying the depth of 100,000 frames with the selected sweep time.

See lower diagram of figure 4-1 where the hopping sequencies of a Bluetooth carrier and a WLAN signal can be seen and analyzed. The minimum resolution in realtime domain is 55 µs.

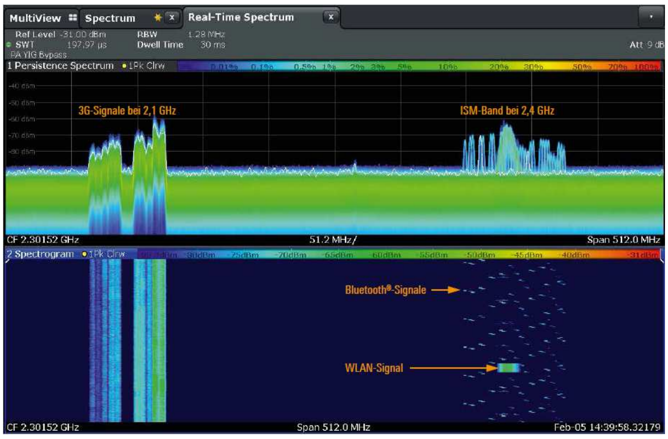
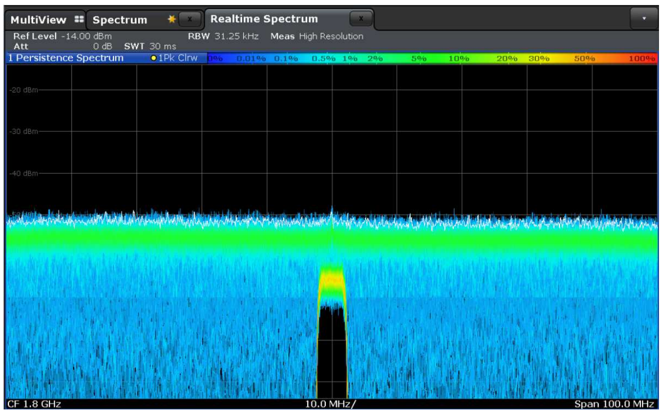


Figure 4-1: 3G-signals at 2,1 GHz and Bluetooth®- / WLAN-signals inside the 2,45 GHz ISM-Band can be analyzed simultaneously with a realtime bandwidth of 512 MHz

V. PERSISTENCE MODE

With a persistence-mode the analyzer writes all available traces on top of the other and codes the probability of appearance by color. More often appearing signal levels are colored red and more rare signal are colored in blue. If a signal doesn't occure longer it disappears after a while from persistence screen (Figure 4-1 upper diagram).

This display mode offers an overview of the dynamic of frequency agile systems. Frequency hops as naturally given in the ISM-band, where Bluetooth®- and WLAN-signals can collide and through this the data rates will be reduced, can be analyzed in detail to find better algorithms to avoid collisions. The persistence mode helps to detect ultrashort disturbances or spikes or even hidden signals which cannot be found by legacy spectrum analyzers. (See figure 5-1 and 5-2.)



Figue 5-1: Wideband noise covering a WCDMA signal

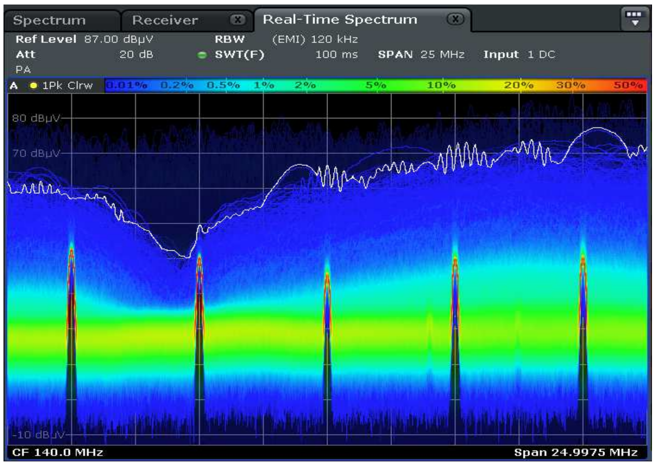


Figure 5-2: EMI broadband disturbance and a pulsed signal measured in persistence spectrum mode.

VI. FREQUENCY MASK TRIGGER (FMT)

When only one special signal is of interest, which probably has been detected in the spectrogram or persistence mode or just a signal where the frequency is known, the use of the frequency mask trigger becomes important. The user defines by points a mask in the frequency range and the analyzer compares these points with e.g. 1,1 Mio FFT spectra per second. If any signal hurts the mask the analyzer stops the real-time measurement and records it. Parameters of time for Pre-Trigger and Post-Trigger have to be set for the signal to be recorded. The continued analysis gives an overview how often distinctive signals appear and whether their behavior is similar all the time or not (Figure 6-1).

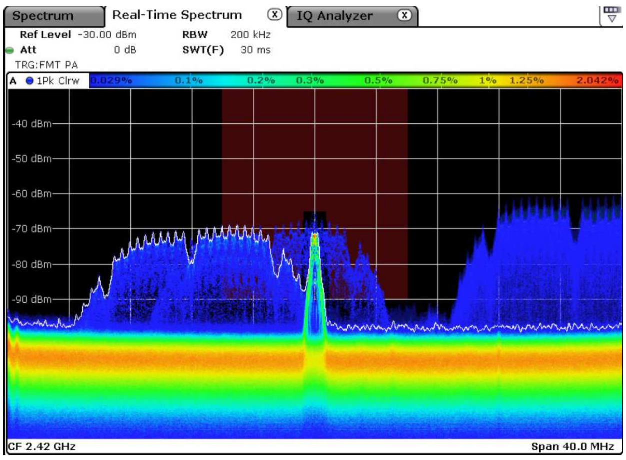


Figure 6-1: Frequency mask trigger

The recorded data (as by Multi-Standard-Realtime-Analysis - MSRT) can be exported to other applications like analogue modulation- or signal vector analysis. In order to get a reliable

FMT trigger with very short events, it is preferable to set the mask limit levels lower than the expected spectral power levels.

VII. MEASUREMENT EXAMPLES

A typical application for a persistence spectrum is the analysis of time varying signals. It is an especially powerful tool to give the user a first idea of a signal, before it can be analyzed in detail. Fast frequency hops can be clearly distinguished from amplitude drops with the persistence spectrum, whereas conventional analyzers may mislead the user. Opposite to the spectrogram display, the persistence spectrum offers a higher level resolution.

Fig. 7-1 shows two persistence spectra, one with a frequency agile DUT in the 2.4 GHz ISM band, and a second one in the 5 GHz band. At the moment this screenshot was taken, the signal was located on the right side of the spectrum. However, the persistence makes it clear that either the same or a different signal was located in the center part of the spectrum before

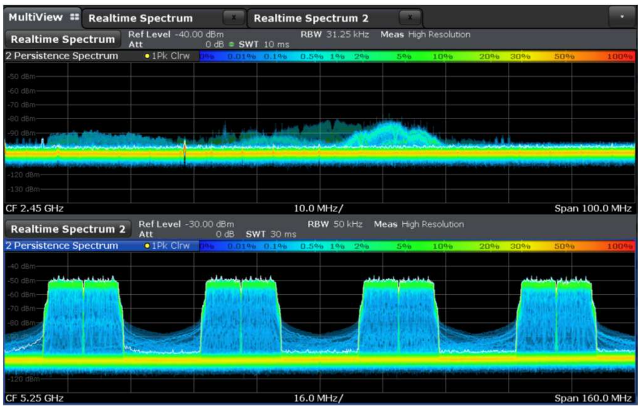


Fig. 7-1: Frequency agile DUT in the 2.4 GHz ISM band and 5 GHz band. Persistence shows signal longer than its duration

Stopping the continuous recording of figure 4-1, a post-processing and of the spectrum is possible by zoomimg in with a minimum time resolution of 20 ns. With the zoom e.g. the preamble of the WLAN-signal and details of modulation can be resolved easily (Figure 7-2).

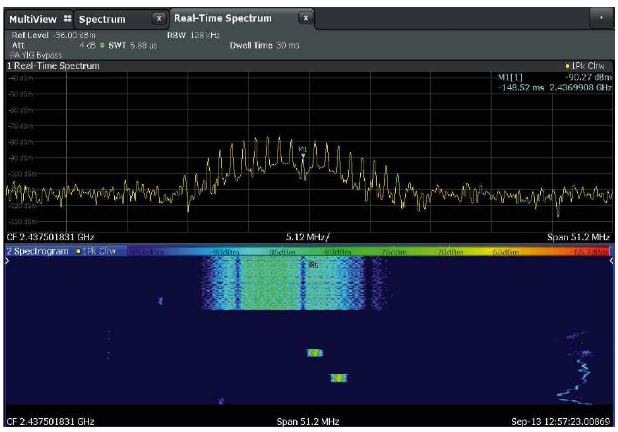


Figure 7-2: Zoomed WLAN-signal

Figure 7-3: BT signal

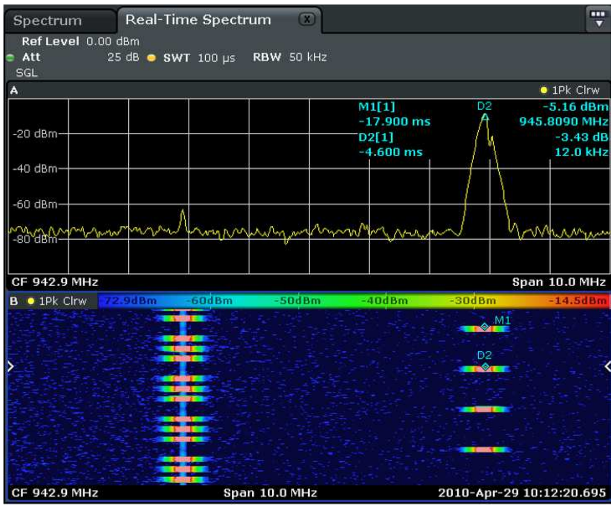


Figure 7-4: GSM signal

Power versus time application with spectrum analyzers

Typical real-time applications

- The time overview enables users to measure the duration of signals
- Waterfall of power versus time gives the possibility to look at pulse to pulse jitter

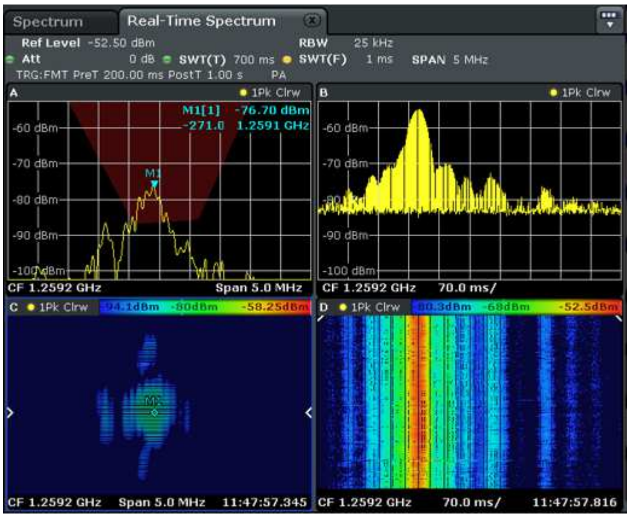


Figure 7-5: Airborne radar signal

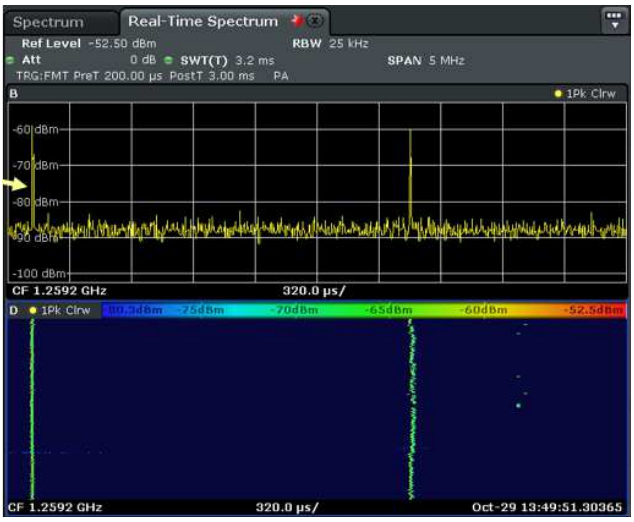


Figure 7-6: Airborne radar signal - jitter

VIII. CONCLUSION

Signal- and spectrum analyzers as well as test receivers of the newest generations can characterize frequency agile systems with large real-time bandwidts. So ultrashort disturbances and frequency hoppers can be detected and analyzed – a valuable feature and operating mode for developers of radar and communication applications. All RF-parameters of an application can be measured accurate and precisely.

EMI test procedures and design circles can be speeded up significantly by factors. Modern test equipment including real-time application give better interpretation of results and can prepare certification measurements.

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