COMB GENERATOR MEASUREMENT TECHNIQUES

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ABSTRACT - Over the past 15 years, comb generators became an indispensable test instrument for EMC labs. Its easy operation led to a wide variety of application like intercomparison measurements of EMC test houses, cable loss measurements and radiated emission system check. The popularity of comb generators should not hide the fact that only the proper measurement know-how can avoid erroneous results. High pulse energy, broadband spectrum and limited frequency accuracy have to be considered when setting the measurement parameters on the EMI-receiver or spectrum analyzer. Good measurement practice is presented by example of cable loss calibration and system check for quality assurance in an EMC lab. The advantage of using an antenna coupler for the system check compared to the monopole antenna is a better repeatability and therefore a more reliable detection of defects (like a broken antenna or cable) in the receive path.

I. INTRODUCTION

Comb generators are widely used in EMC labs for measurements and validations. Typical applications are cable loss calibration, site attenuation measurement, chamber factor measurement, investigation of the influence of EUT tables and regular system checks as quality measure. Without the knowledge of the signal and proper measurement technique erroneous measurements might result. This paper describes the working principle of a comb generator, thus leading to a better understanding of the proper measurement technique.

II. APPLICATION OF COMB GENERATORS

There are numerous conducted and radiated measurements where comb generators have established as indispensable test instrument over the past 15 years:

- laboratory intercomparison measurements
- test site correlation measurements (same type)
- correlation of alternative test methods
- “pseudo” EUTs
- normalized site attenuation measurements
- chamber factor measurements
- investigation of table and mast influence
- cable loss calibrations
- system checks for test labs

Nearly all laboratory intercomparisons are conducted by using a comb generator as reference source: a) with a short monopole transmit antenna or b) built into an EUT where its output signal couples onto the internal wiring harness of the device (“pseudo” EUT). The stable, well defined emissions make it in addition to its easy, battery powered operation to an ideal device that can be operated by any laboratory. Due to it’s autonomous operation no instrument drivers for the test software are required.

Site correlation tests have been performed between 3 m and 10 m open area test sites and free space test sites. Also correlations between GTEM cells and “classical” emission test sites have been performed, e.g. [1]. These results were fed in the international standardization groups. Actual site correlations are performed in the automotive sector.

When the normalized site attenuation (NSA) or the chamber factor [2] is measured with a battery powered comb generator the test results are often much more repeatable than using a signal generator or network analyzer [3], [4]. Reason for this performance improvement is the absence of a coaxial transmit-cable. This transmit-cable influences the standing waves (modes) in the chamber depending on its routing and the quality of the chamber. The worse the chamber performance the more influence has a transmit cable.

Investigations on the influence of setup tables and antenna masts in radiated emission testing are a rather new requirement (respectively still in standardization process) [5]. Generating the field without the need of a metallic feed cable and instrument driver in the test software has its convenience.

It happens sometimes that the EMC measurement results are not as expected. If there is no signal measured or the field strength is much lower than expected the test engineer can investigate the problem by performing a system checkout.

III. TIME AND FREQUENCY DOMAIN

The operating principle of a comb generator in the frequency range of up to 3 GHz is a pulse generator. The pulse width and the repetition rate determine the spectrum in frequency domain (see Figure 1). Comb generators in the range up to 40 GHz use the harmonics generation principle. A step recovery diode or non linear transmission line generates harmonics from a strong CW signal. The low efficiency of this process limits the amplitude and applicability for EMC labs.

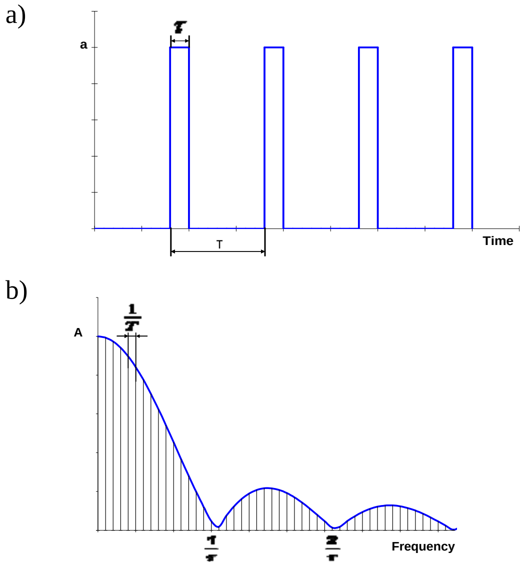

Figure 1: Mathematical model of the signal output of a comb generator a) in time domain and b) in frequency domain

The energy of the pulses (determined by pulse width, amplitude and repetition rate) is related to the amplitude of the spectrum that can be measured with a spectrum analyzer. High frequencies (>1 GHz) and high output signal (> -20 dBm/line) require narrow pulses (< 0.5 ns) with a high amplitude (> 50V).

IV. FREQUENCY SELECTIVE MEASUREMENT OF THE PULSED SIGNAL

To understand the measurement principle the comb spectrum as seen on a spectrum analyzer display (frequency range 40 – 50 MHz, RBW 100 kHz) is presented in Figure 2. The comb spectrum (solid trace) contains the relevant information in the amplitude of the peaks; the noise floor between the peaks is not of practical interest. Therefore it's efficient to measure only the peak values at the comb frequencies (or any integer multiple) and connect them (dotted line). All comb generator measurements described and all results shown in this article use this principle.

Two types of measurement instruments are suitable for recording the comb spectrum frequency selectively: EMI receivers and spectrum analyzers. As there are differences in the way how to obtain good results the two measurement principles are described in an example: frequency range to be measured is 30 MHz to 1 GHz, comb spectrum: 1 MHz.

The EMI receiver is set to start frequency 30 MHz, stop frequency 1 GHz and step size 1 MHz. The resolution bandwidth (RBW) must be set large enough to account for frequency offsets of the comb generator. Then the sweep can be started and the measurement result is ready. This measurement could be done without any measurement software due to the built in capabilities of modern EMI receivers.

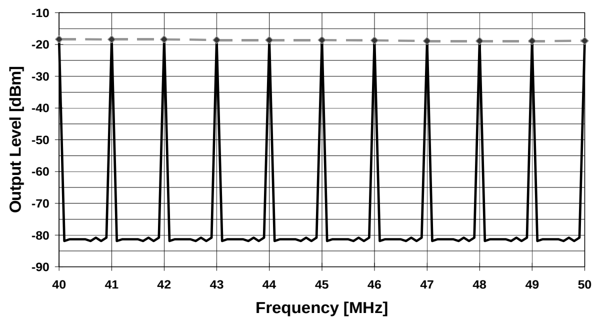

Figure 2: Schematic drawing of the measured spectral lines (solid) and the corresponding envelope (dotted) in the frequency domain

To measure with a spectrum analyzer a control software is required: First the span and the RBW are set; then for all frequencies of interest (30, 31, 32, … 1000 MHz) the centre frequency must be set accordingly, the sweep is taken and the marker value at the maximum of the curve is recorded.

The bandwidth of each spectral line is in the range of a few hundred Hz and determined by the phase noise of the crystal oscillator. The RBW at the receiver and at the spectrum analyzer must be chosen large enough to measure the whole spectral energy of each comb line and smaller than the pulse repetition frequency (e.g. 1 MHz). When setting the RBW within the proper interval, any change in the RBW is nearly invariant to the measured pulse peak amplitude. This is a great advantage compared to noise generators, where the measured amplitude also depends on the accuracy of the selected measurement bandwidth.

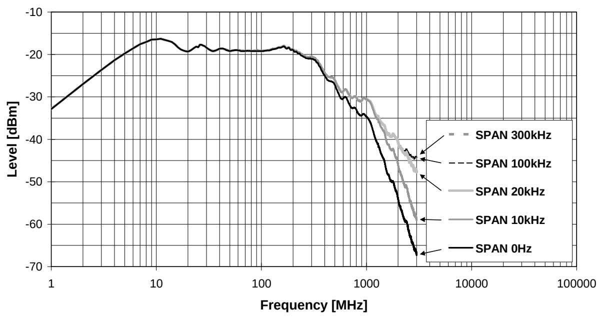

Figure 3: Influence of different span-settings to the envelope of the coaxial output (RBW = 10 kHz)

Another phenomenon that can lead to incorrect measurements is the frequency accuracy of the comb generator. Assuming the 1 MHz crystal oscillator frequency has an accuracy of 50 ppm, the 3000th harmonics (at 3 GHz) might have an offset of 150 kHz (see Figure 3). To avoid erroneous results when using an EMI receiver the RBW must be set larger than the offset (e.g. 200 kHz). When a spectrum analyzer is used either the span or the RBW must be set to account for the offset: Zero-Span and RBW of 200 kHz would give the same result as Span 200 kHz and RBW of 1 kHz. When measuring low level signals (e.g. NSA in 10 m distance) the second setting is the only possibility because the noise floor is reduced due to the lower RBW.

Figure 4 shows the coaxial output power vs. frequency of different commercially available comb generators. While the power of each spectral line is rather low, the sum of all emissions can easily exceed the +10 dBm as shown in Figure 5. The allowed maximum input power of a spectrum analyzer is the whole power present at the input connector and NOT only the signal measured. Therefore the broadband comb spectrum can easily overload the input of a spectrum analyzer.

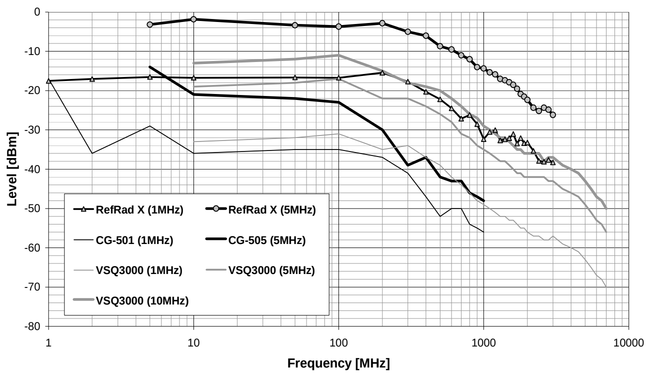

Figure 4: Coaxial output power of different comb generators. The values in brackets indicate the spectral line spacing.

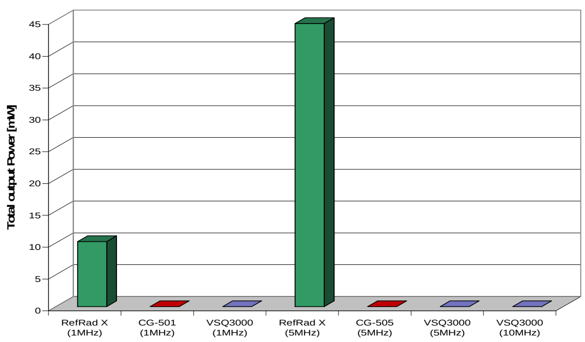

Figure 5: Total output power of different comb generators in the frequency range 1 MHz to 1 GHz. The values in brackets indicate the spectral line spacing.

To avoid erroneous measurements resulting from receiver input overload the test engineer must assure a certain attenuation of the comb signal. For coaxial measurements a 20 dB or even 30 dB attenuator is appropriate for the currently commercially available comb generators. When making radiated measurements the attenuation is given by the antennas and the propagation losses. Therefore protective attenuators can be omitted in this case.

V. CONDUCTED MEASUREMENTS EXAMPLE: CABLE LOSS CALIBRATION

Cable loss calibrations are a standard application of comb generators. Of course all kinds of attenuation measurements can be done according to this principle (e.g. attenuators, directional couplers). Due to their battery powered operation, comb generators are convenient for measuring the cable loss of fixed installed cables. There is no need for a long auxiliary cable and no need to carry a large remote controlled and mains powered signal generator to the opposite cable end.

Two measurements are required: First the comb generator is connected via the protective attenuator (!) to the receiver (or spectrum analyzer) and the signal P_{Direct} is recorded. Second the cable to be calibrated is connected to the receiver and the comb generator via the protective attenuator (!) is connected to the other cable end. Now P_{Cable} can be recorded. Finally the cable loss A_{Cable} is calculated according to (1).

$$A_{Cable} = P_{Direct} - P_{Cable} \qquad (1)$$

To improve the measurement accuracy the input attenuator of the receiver or spectrum analyzer should be at least 10 dB or an external 10 dB precision attenuator might be used at the input for all measurements. Also the test equipment (including comb generator) should be warmed up and the batteries of the comb generator charged to keep it running beyond the warm-up time and the measurement itself.

The settings of the receiver have to be made according to the considerations of the previous chapter. As example a measurement of a Rosenberger Utiflex cable (10 m length) installed in the EMC fully anechoic chamber using the RefRad X comb generator and a Rohde & Schwarz ESIB7 is given. The measurement traces and the results are shown in Figure 6. The settings of the instrument are given in Table 1

Table 1: Instrument settings of the ESIB7 for the cable loss measurement example.

Instrument Mode	EMI Receiver
Start	1 MHz
Stop	3 GHz
Step	1 MHz
Input Attenuator	20 dB
RBW	100 kHz

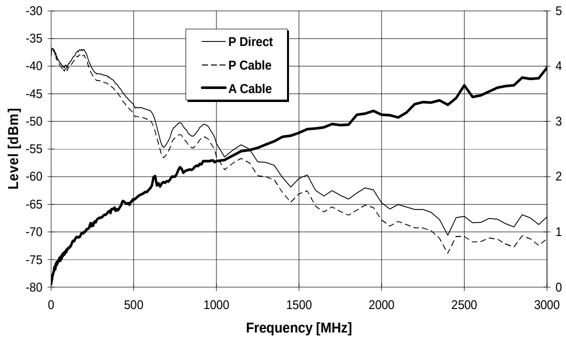

Figure 6: Measurement curves and result of cable loss measurement example.

VI. RADIATED MEASUREMENTS EXAMPLE: SYSTEM CHECKOUT

Regular system checkouts of radiated emission test setups are an essential quality assurance tool for accredited EMC test labs. It assures proper function of the equipment and correct application of the transducer factors. Defects in the system like a damaged antenna, a loose connector or a defective cable are detected within minutes. The reliability of test results and laboratory test quality are increased.

Before a system checkout can be performed, a reference measurement is required. The test setup is double checked and documented. The signal source can be a comb generator using: a) a monopole as transmit antenna (functional check) or b) an antenna coupler (system check). The difference between the reference and the check measurement is computed and if the deviations are below a threshold level the test setup is regarded as working properly. The level is set by the lab depending on its quality approach and the sensitivity of the test. If the level is exceeded an investigation is required to isolate the reason.

The functional check with a monopole directly connected to the comb generator is very easy but not always reliable; for EMC measurements the functional check is suitable only if the test site is empty and the positioning is done very precisely. Otherwise just a signal/no signal decision should be made.

By using an antenna coupler the reliability of the system check is improved. It consist of a very small balanced dipole antenna completely protected in a plastic housing which is mounted directly on the EMC receive antenna. The critical positioning is done via the shape of the housing with accuracy better than a few tenth of a millimeter. Due to the close proximity of transmit and receive antenna the system becomes insensitive to the environment which is a further advantage of the antenna coupler. The system check can be done very precisely even with the EUT set up in the EMC test chamber.

With the antenna coupler, problems caused by a defective receive antenna can be detected easily. In Figure 7, several contact problems of individual dipoles or on the large triangle elements are induced and the deviation to the proper working antenna is plotted. Additionally the most common problem to hybrid antennas – the broken connector in the tip of the antenna – is shown.

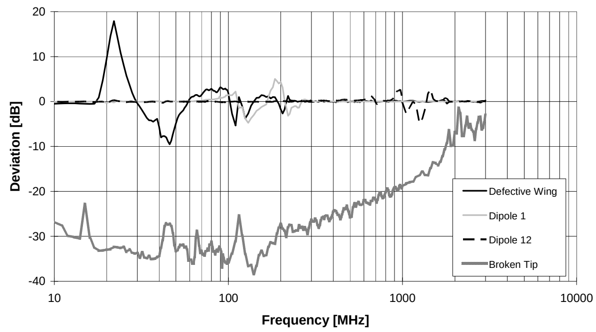

Figure 7: System check results with some intentionally caused “problems” on a hybrid antenna

VII. CONCLUSIONS

The comb generator is a powerful measurement tool for everyday laboratory use. Although its very easy operation adequate care must be taken for the pulses to avoid receiver overload and for setting the measurement parameters correctly.

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