# Comb Generator Coaxial Output Charactaristics and System Check with RefRad and Antenna Coupler


H. HAIDER[1], AUSTRIA, M. DEALESSI[2], ITALY
G. KOLB[1], AUSTRIA, X.TRANS [2], ITALY

[1] ARC Seibersdorf research GmbH, e-mail: harald.haider@arcs.ac.at

[1] TESEO SpA, e-mail: mdealessi@teseo.net



**Abstract.** Starting with a brief overview about theoretical background of the coherence of time- and frequency domain of signals the measurement problematic in detecting the coaxial output signal of a comb generator (RefRad 3000) is described in detail. This shows which parameters have to be considered to avoid invalid results due to unfit measurement settings. Further a novel procedure using a comb generator and an individual antenna coupler is shown which enables a fast, simple and highly repeatable possibility to check the function of RF-antenna receiving systems. All kind of faults affecting the amplitude level at any frequency within the operating range of the checked equipment will be found like problems with the antenna (broken tip-soldering, loose connected radiation elements), connectors, cables, receiving instrument and evaluation software. Such routine checks are an important QM-requirement (e.g. ISO/IEC 17025) to assure measurement quality of typical EMC-labs or all types of environmental EMF measurements. Consequently possible limitations of this system-check are considered.


## I: Introduction:

Imagine you are an operator of an EMC-testlab and during the annual recalibration procedure of your measurement antennas for radiation- and emission testing for your customers a problem on one of these antennas were found. Caused by a few not perfect conducted, loose radiation elements the AF is bad at the corresponding frequencies. That means, the antenna does neither radiate the expected fields for immunity testing at that frequencies nor detect emissions of the DUT in a correct way. However the most essential question in that situation would be how long this problem is existing? Does the antenna problem occur on the transport of the antenna to the institute performing the calibration or happen it any time before in your lab? If you have no possibility to check this, all past measurements performed with that antenna are doubtful and strictly they have to be repeated including all administrative and monetary consequences. Similar situations can occur in every lab or testing institute. To reduce this problematic, regular function checks in addition to (annual) calibrations of measurement systems are required in the range of ISO/IEC 17025 [1] to assure reliability of performed tests and measurements.

## II: Coherence of Time-Domain and Frequency-Domain

The mathematical instrument of the Fourier-Transformation was derived from the problem to split a signal from the time domain in the corresponding harmonics in the frequency domain. A solution for that transformation is given in formula 1 for signals with the periodicity T(t) [2].

$$f_{(t)} = \frac{a_0}{2} + \sum_{n=1}^{\infty} (a_n \cos n\omega t + b_n \sin n\omega t) = A_0 + \sum_{n=1}^{\infty} A_n \cos (n\omega t + \varphi_n) \quad \text{with} \quad \omega = \frac{2\pi}{T} \qquad (1)$$

Formula 1.

Without discussing this formula in detail, it can be seen, that a periodic time-function f(t) can be transformed to the frequency domain consisting yielding a discrete line spectrum with the amplitude coefficients $A_i$ and the spaced by $n\omega t$ along the frequency axis.

A simple sinus signal in the time domain would be transformed to only one single line in the frequency domain whereas a continuous sequence of indefinite short and high pulses (Dirac pulses) in the time domain with the periodicity of T would represented in the frequency domain by a indefinite number of spectral lines with a spacing of 1/T in the frequency domain. Such a signal represents the perfect model of a comb generator. In praxis of course the pulses are not indefinite short and also their amplitude is limited. For a mathematical model of the output signal of a comb generator a continuous, T-periodical sequence of short pulses with a length of $\tau$ for the pulses could be considered. In Figure 1 the corresponding spectrum of such a time signal is given. The spacing of the spectral lines is determined by the periodicity of the time signal with 1/T, whereas the amplitude corresponds with a (cosω)/ω- function. The first minimum of this amplitude envelope is given by the frequency corresponding to 1/τ. This means that for real comb generator devices the periodicity of the time signal determines the beginning of the spectrum (first line) and the length of the pulses is essential for the first minimum in the spectrum. Typically the amplitude of the spectral lines has to be much larger than the noise floor of frequency selective measurement instruments like receivers or spectrum analysers. This fact is limiting the upper frequency range of the comb generator.

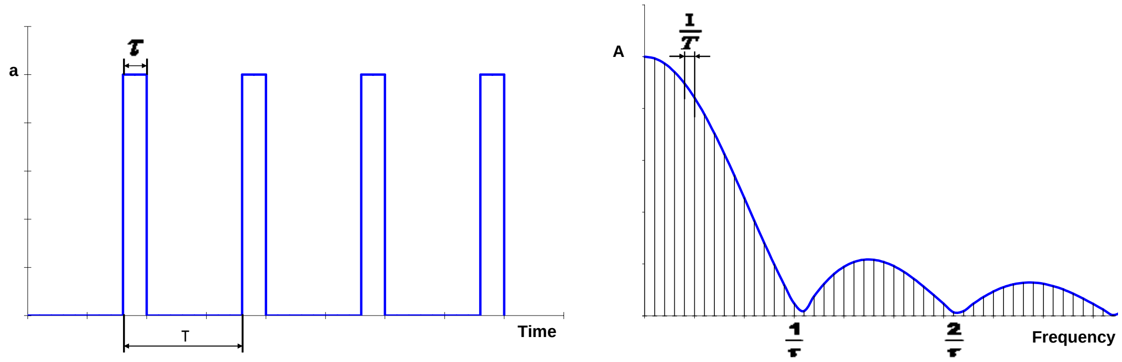


Figure 1: Mathematical model of the signal output of a comb generator in time domain and in frequency domain

### III: Coaxial Signal Output and Measurement Problematic of Comb Generator Signals

In Figure 2 a real time domain signal of the RefRad 3000 from Seibersdorf is given. It can be seen that each microsecond one pulse with amplitude of about 22 Volts is generated. The generation of the pulses is triggered by a 1MHz crystal and formed with the help of an electrical network to extremely short pulses of approximately 250 picoseconds.

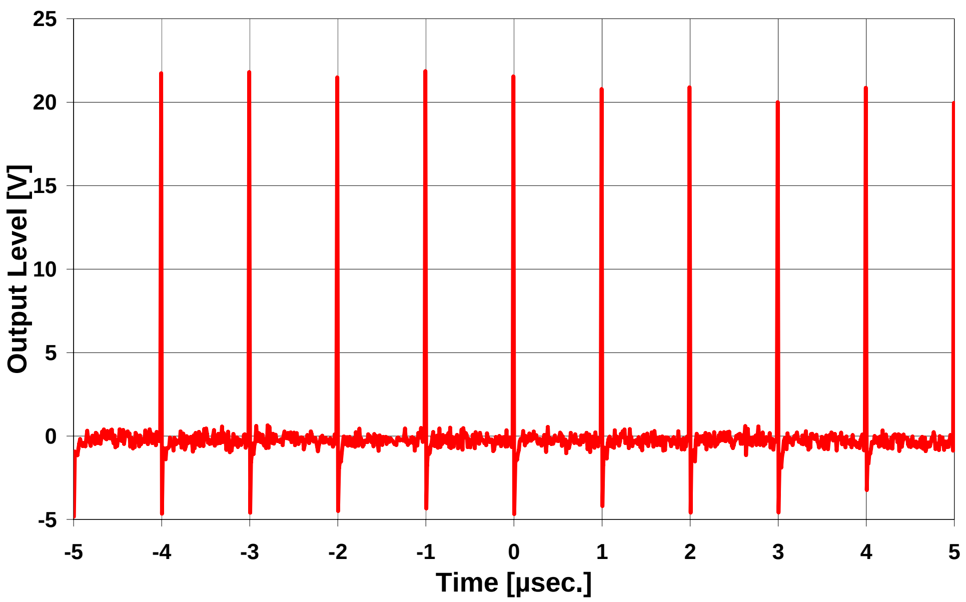


Figure 2: Coaxial output of RefRad 3000 in the time domain

To measure such signals in time domain, it has to be considered that the system bandwidth of the oscilloscope and the probe head are big enough. Typically at least 1,5 GHz or higher is necessary else the performance of the measurement equipment is limiting the minimum detectable pulse width.

More than the time domain signal, the frequency response measured with the help of spectrum analysers or receivers is interesting. Especially for these measurements a few things have to be considered to avoid wrong results or even to ruin the measurement equipment especially if it is directly connected to the coaxial output of the comb generator.

In Figure 3 it is zoomed in a small frequency range of the coaxial output spectrum of the RefRad 3000. The blue curve shows the 1MHz spaced spectral lines where each line has a bandwidth of about 250Hz. The red line is an upper envelope which is typically used to indicate the output level in frequency domain. The coaxial output spectrum of RefRad 3000 up to 3 GHz is given in Figure 4. Please consider that the coaxial output measurements were performed with an additional 20dB attenuator. For the figures this is corrected.

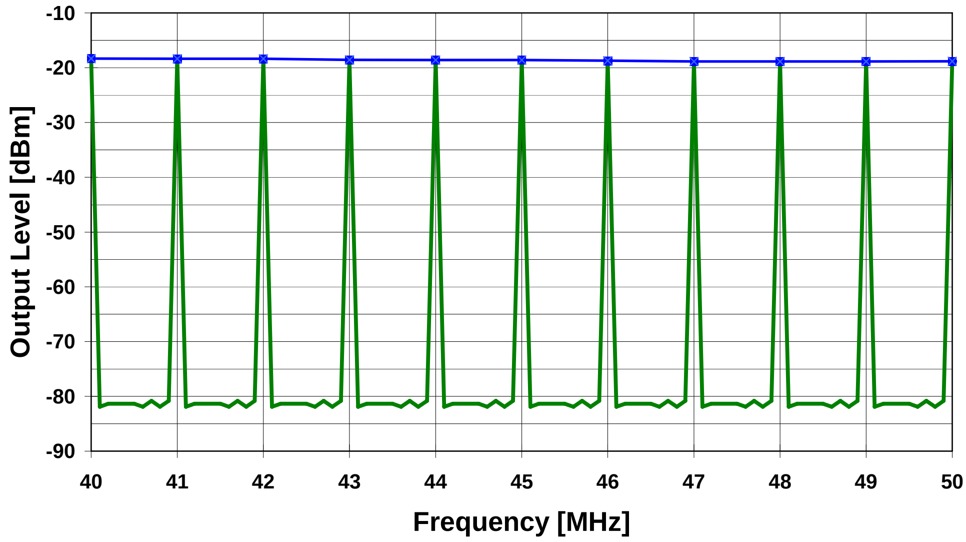


Figure 3: Schematic drawing of spectral lines and the corresponding envelope in the frequency domain

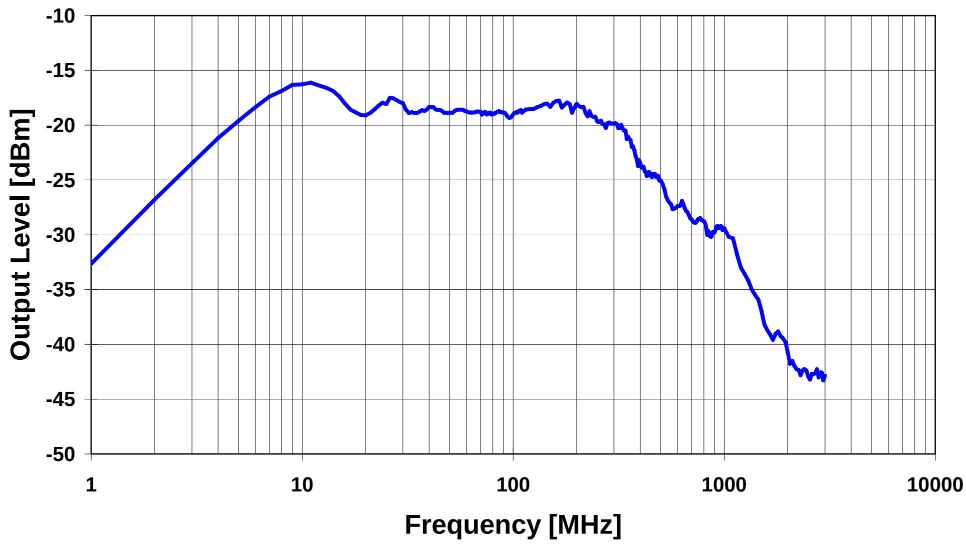


Figure 4: Typical coaxial output of RefRad 3000 in the frequency domain

Even if the power of each spectral line is very small (e.g. one line with -15dBm is representing a power of about 0.03mW), the total power of all spectral lines together is about 8,4dBm (6,9mW). This is the effective power on the input connector of any measurement device, if the RefRad 3000 is directly connected with the instrument. Depending on the maximum specified input power of the connected instrument, the wideband comb generator signal can lead to damage of spectrum analysers or other instruments. This danger could be avoided by general use of suitable attenuators (e.g. 20dB) if a comb generator is directly connected with the input of any other measurement instrument.

It is recommended that the measurements in frequency domain are performed with the frequency steps corresponding with the spectral line spacing (or with multiples of that to save time) so that only the relevant signal information is shown as upper envelope curve. For the RefRad 3000 this would be 1MHz (or multiples of 1MHz). The bandwidth of the spectral lines is extremely small (about 250Hz) so that the resolution bandwidth (RBW) of the receiver could be small also to achieve high dynamic range respectively a low noise floor level. The used RBW should have no influence on the measured amplitude (typical RBW is 10kHz or 100kHz) as long as it is smaller than the spectral line spacing. Variations are caused by the measurement uncertainty and a small offset occurs because of different noise parts at various RBW filter settings. Larger differences (about 0.4 dB) indicate a problem with the receiver. This could be a void calibration, improper other settings e.g. leading to mixer overflow at to low mixer level (often automatically set with the reference level) or even a defect of the receiver. For RBW settings above the spectral line spacing the receiver catches more than one frequency line at once for at each measurement point and the indicated power will be even higher (see Figure 5).

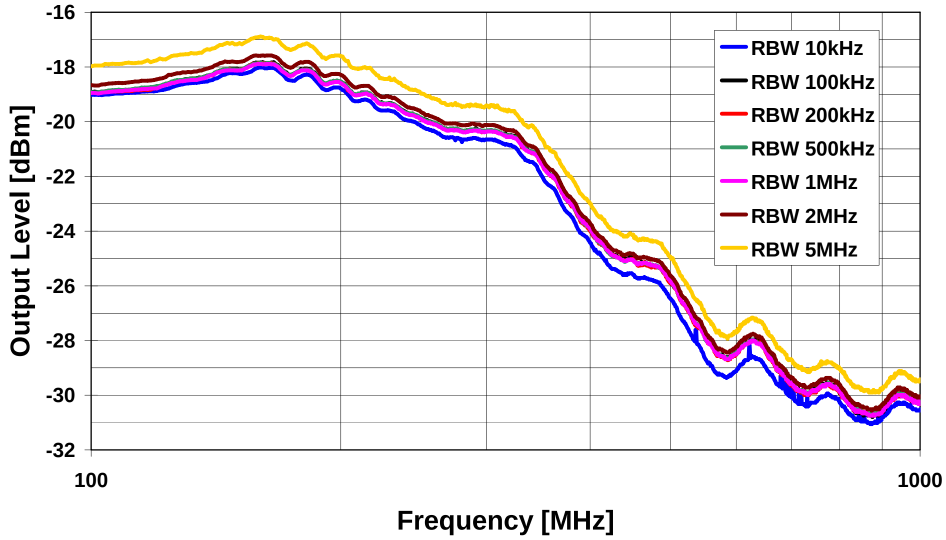


Figure 5: Influence of different RBW-settings to the envelope of the coaxial output

But there is another effect which can easily lead to wrong measurement results because the crystal generating the 1 MHz pulses has a small frequency offset in the range of parts per million (e.g. 50 ppm for RefRad 3000) caused by manufacturing uncertainty and temperature rise. For the first frequency lines this does not effect measurements in a remarkable way, but e.g. for the 3GHz spectral line this small offset have to be multiplied by 3000 times and reaches a few hundred kHz (e.g. ±150kHz based on 50 ppm uncertainty for the crystal). Also for the receiver a frequency offset has to be considered and the comb generator is usually not synchronized in any way with the receiver. Therefore especially at higher frequencies it could occur that the RBW-filter of the receiver does not (or only partly) overlap the comb generator spectral line at the measurement frequencies determined by the step size of the receiver. This problematic could be avoided by an additional span of the receiver around each measurement frequency or measurement point. In Figure 6 this effect is demonstrated. As long as the span of the receiver at each measurement frequency is big enough that the RBW-filter is totally overlapping the corresponding spectral line, no difference in the results can be found. With increased frequency the frequency offset also increases and only with a suitable chosen span an overlapping can be assured. If this is not the case, the RBW-frequency filter can not overlap the corresponding spectral line of the comb generator and the measurement result becomes to low.

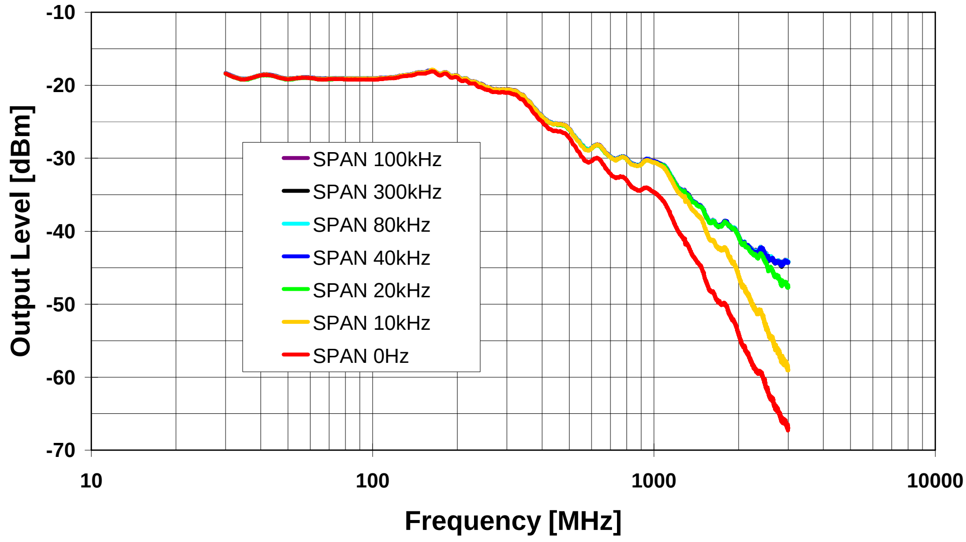


Figure 6: Influence of different span-settings to the envelope of the coaxial output

In connection to the coaxial output diagram of a comb generator some important technical specifications for the user can be derived. First of all there is of course the operating bandwidth starting with the first spectral line. The end of this bandwidth is typically not a fixed frequency in practise even if there is such a value given in the description of the comb generator (nominal operating bandwidth). In fact the minimum dynamic range which is necessary for the measurement application is limiting the end of the usable bandwidth. This could be below the nominal frequency value, however also above, because only the amplitude of the spectral lines is typically reduced with frequency (the spectrum of course does not end with that spectral line). The spectral line spacing determines the minimum frequency resolution of any investigations and should be fine enough to characterise the considered/measured equipment in the frequency domain. Last butt not least of course also the amplitude of the spectral lines is very important. This determines the dynamic range to perform measurements respectively the resulting field strength produced by connected antennas available at a certain distance. To enable repeatable measurements, especially the stability of the amplitude of the spectral lines considering temperature rise and battery voltage cycle over time is very important to whereas the curve/shape of the coaxial output envelope is not essential. Therefore it does not matter if this curve is not identical for different RefRads or if there are differences to the typical coaxial output curve, but it is essential that the individual curve of one device is very stabile. An example of one produced charge of RefRad 3000s is given in Figure 7. The spectral output of all of them is manually optimised and each one has to pass the minimum amplitude level curve.

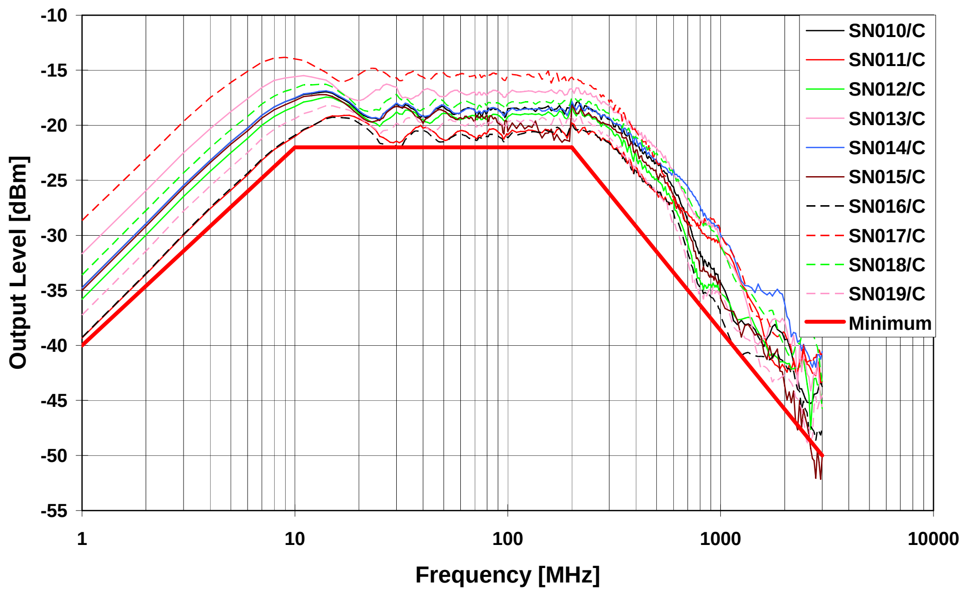


Figure 7: Coaxial output of one charge of RefRad 3000 and minimum level curve

### IV: System Check with RefRad 3000 and Antenna Coupler

With the use of a comb generator like the RefRad 3000 and a dedicated antenna coupler fast, simple and highly repeatable function checks of RF-antenna receiving systems are possible.

A well defined coaxial output signal is generated by the RefRad 3000 and emitted with a small, in the antenna coupler integrated dipole. The antenna coupler is accurate positioned in very close proximity to the receiving antenna. With a well checked setup a measurement is done once as a reference and it is repeated before each measurement campaign or whenever there are doubts on the measurement results. A comparison between the reference and the actual system measurement ensures the quality of the results (system check). Any defect in the antenna (e.g. broken soldering) in the receive cable (e.g. bad connector) in the spectrum analyser (e.g. broken input attenuator) or in the RefRad will be detected easily and fast and wrong measurement results are avoided. Especially the antenna coupler with its well balanced dipole type transmit antenna, its accurate positioning and its close proximity to the receiving antenna makes the discrimination of any defect much more reliable without any increase in measurement time. Also the system check becomes insensitive to the environment and can be done very precisely even with the EUT set up in the EMC test chamber. Such routine system checks improve the quality of EMC or EMF measurements and are a requirement according ISO 17025 [1].

Figure 8 is showing an antenna coupler fixed on the tip of a receiving antenna whereas Figure 9 presents measurement results of several system checks we performed in an anechoic chamber without ferrites using a CBL 6112A BiLog from Chase (frequency range 30MHz to 2GHz) as receiving antenna, a dedicated antenna coupler CU6112 from Seibersdorf, our RefRad 3000 and an ESI 7 from R&S as receiving instrument. For the reference measurement the antenna was horizontal polarized at a height of 1.8 m in the centre of the chamber.

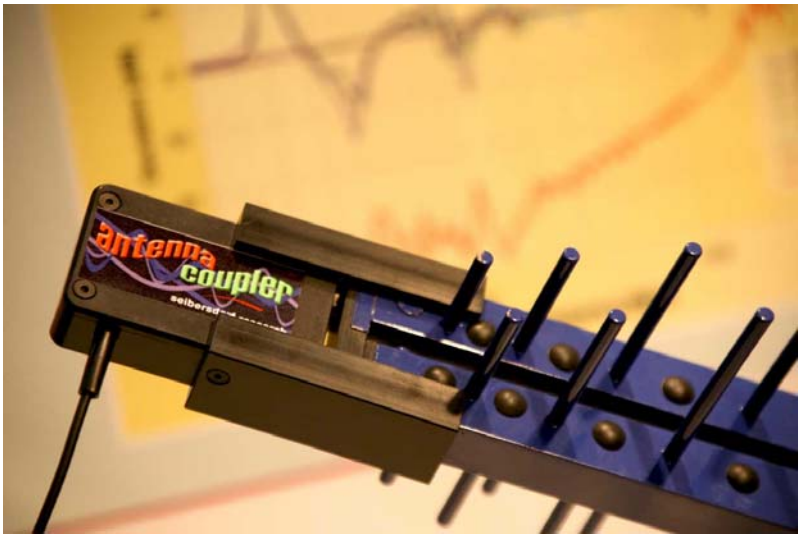


Figure 8: Antenna coupler fixed on the tip of an antenna

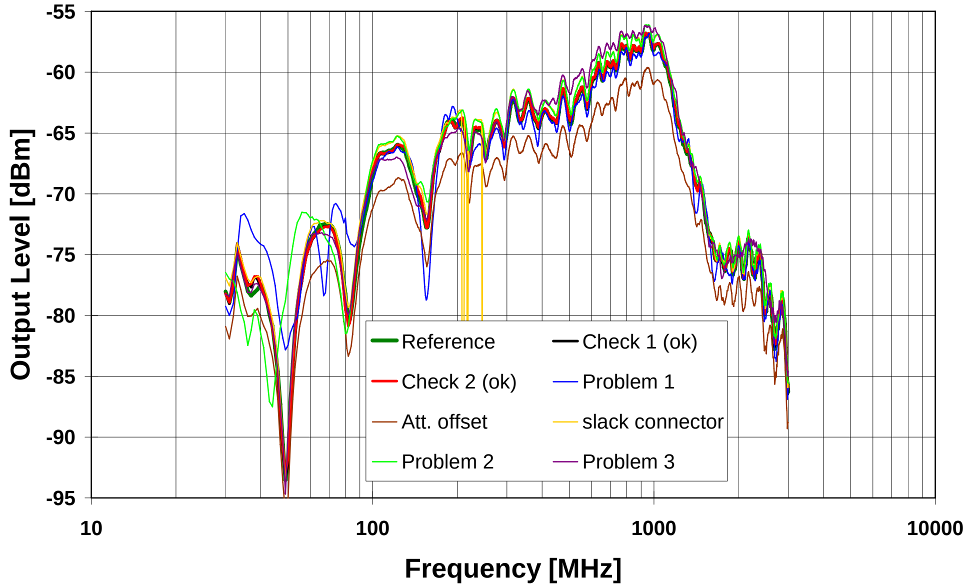


Figure 9: Receiver readings from System checks of a Bilog CBL 6112A

Caused by cable loss and frequency dependent coupling between the BiLog antenna and the coupler the measured signal level is much lower than the coaxial output and strongly frequency dependent. Here we present the direct readings from the receiver in [dBm] because it is easier to compare those values. Of course all results could also be expressed as fieldstrength e.g. in [dBµV/m]. This is recommended if the measurement evaluation is done automatically by software because for that case also the SW-routine and settings are part of the system check. To point out the results of a system check very clearly, the difference between the reference and the check-measurements could be calculated and presented like Figure 10. For the graphs showing a significant difference, we add an additional attenuator in the receiving path, produced a slack cable connection or we covered some elements of the receiving antenna with absorbing materials. Due to the frequency selective evaluation of occurred problems, it is possible for the engineer to narrow them very often.

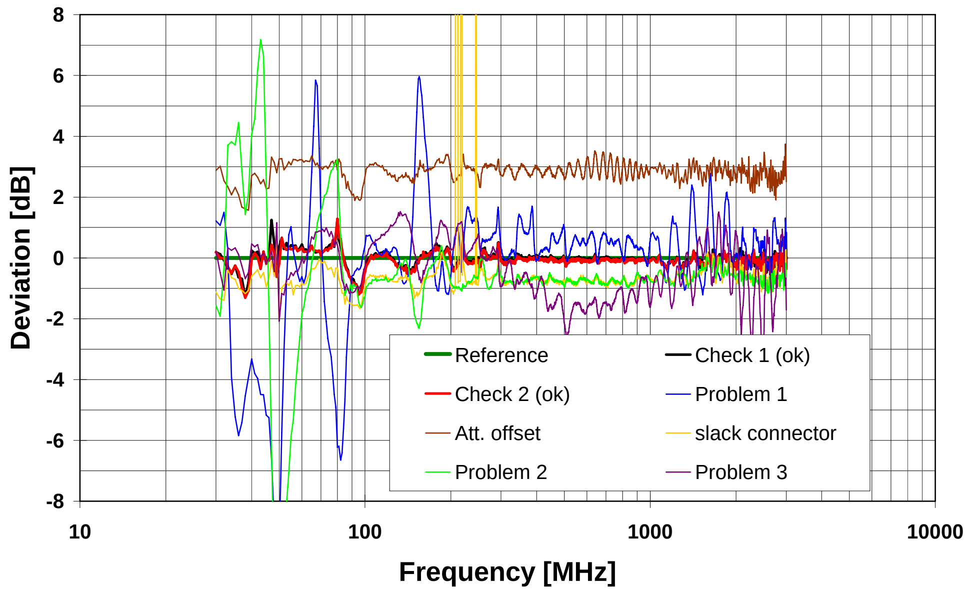


Figure 10: Results from System checks for a few check measurements

## V: Impact of different setups and positions in a chamber to the system check

In this chapter we will give some examples of check measurements to demonstrate also the limitations of a system check with RefRad and antenna coupler. Therefore we have a closer look about variations of the cables connected to the receiving antenna and the antenna coupler as well as the influence if we change the height and the position of the receiving antenna in the measurement chamber.

First we have look what will happen if the cable connected with the receiving antenna is changed from its loose hanging position ± 20 or 40cm to front and back. The height of the vertical mounted antenna was 1m. In that case no influence of the results can be observed (Figure 11).

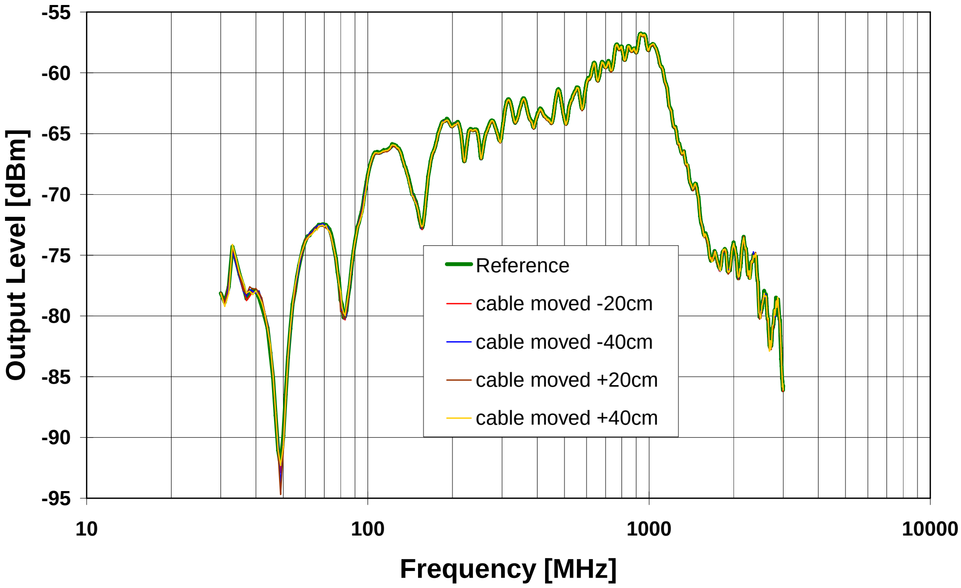


Figure 11: System check at variation of receiving antenna cable

Next we change the position of the RefRad which is originally placed under the tip of the receiving antenna on the floor. This time we move the RefRad (and the cable of the antenna coupler) up to 100cm away from the receiving antenna stand. This time we can see perceptible deviations especially at lower frequencies, were the performance of the anechoic chamber is relatively bad and at resonant lobs (e.g. at 48 MHz, 83 MHz and 170 MHz). For one check measurement we wrap the cable of the antenna coupler several times around the tip of the receiving antenna. There a lot of resonant effects can be seen. Of course this is not a realistic setup for a check measurement but it gives a 'worst case' estimation for an improper setup (Figure 12).

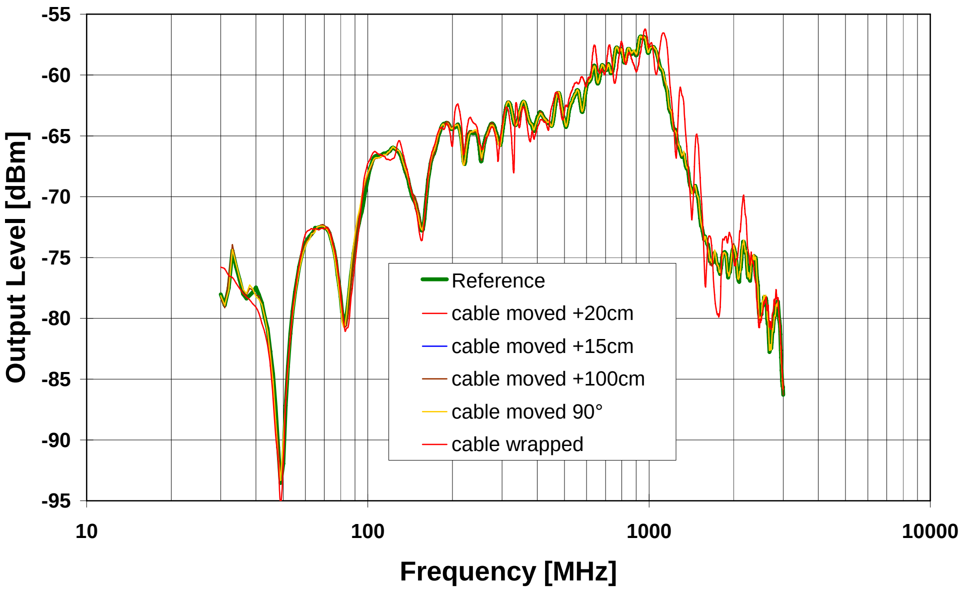


Figure 12: System check at variation of RefRad and antenna coupler cable

For the last demonstrations we varied the height of the receiving antenna and we also shifted the antenna stand from the centre of the chamber for about 3 meters very close to the backside wall. There we can find considerable differences in the check measurements for all setups, again primary at the lower frequencies (Figure 13).

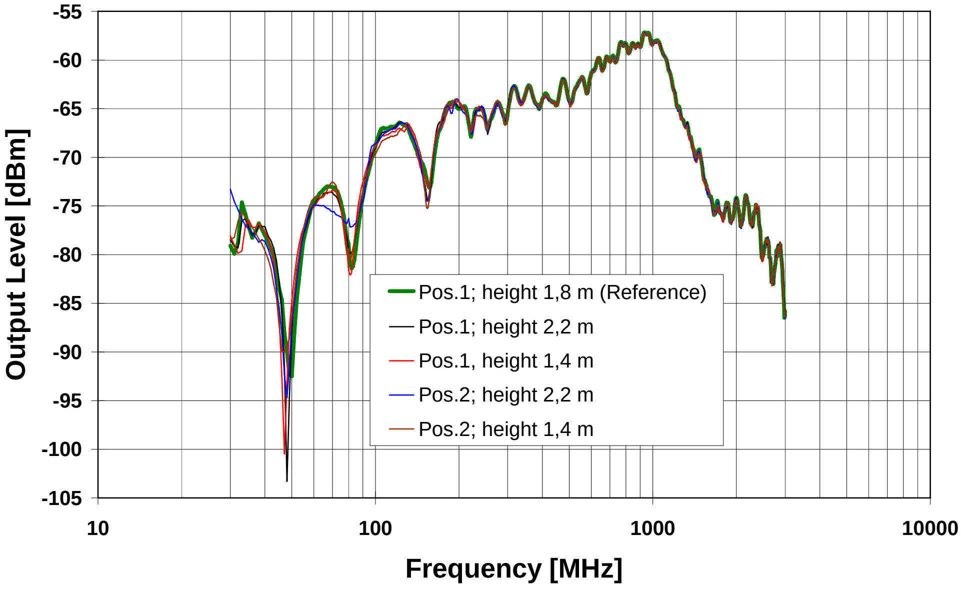


Figure 13: System check for different antenna heights and positions in the chamber

Resuming the impact of different setups and changed positions in a chamber it can be seen that small variations of the setup and positioning do not affect measurement results in a considerable way. If variations become major at resonant lobs between antenna coupler and receiving system noticeable discrepancies between the reference and the check measurements can occur. This problem is strengthened at frequencies where the environmental is reflecting, e.g. in our test chamber without ferrites up to 400 kHz. An easy way to avoid relevant setup-variations is to take pictures and make some written documentation during the reference measurement for easy repeatability.

## VI: Summary

Well developed comb generators like the RefRad 3000 provide the user by a permanent existing, discrete line spectrum over very large bandwidth with high stability over time and adequate coaxial output power. If some simple requirements for the measurement settings are considered such comb generators are best suited as reference sources for plenty applications in EMV. A novel one of these applications is the check of a RF-receiving system with a dedicated antenna coupler. Main advantages of such a system check are that it could be performed very easily and fast even if a DUT is installed at the measurement chamber, it is very reliable and because of close proximity of the transmitting coupler and the receiving antenna the check becomes insensitive to small setup variations, setup positioning and the environment. Furthermore if a defect is detected the frequency selective method enables the engineers in many cases to focus the problem easily. Therefore the system check is a suitable procedure to enlarge the system quality of EMC and EMF measurements and helps to fulfil the requirements of ISO 17025 were repeated function tests of the measurement systems are intended.

## References

[1] EN ISO/IEC 17025; "Allgemeine Anforderungen an die Kompetenz von Prüf- und Kalibrierlaboratorien. ", Ausgabe: 2005-08-01

[2] H. J. Dirschmid, "Mathematische Grundlagen der Elektrotechnik", Friedr. Vieweg & Sohn Verlagsgesellschaft, Braunschweig, 1986, ISBN 3-528-03034-8.