EMC MEASUREMENT SYSTEMS AND NOISE SUPPRESSION METHODS FOR LED LAMPS AND RF LIGHTING CONTROLS

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Abstract: The role of light-emitting diode lamps and radio frequency lighting controls is to reduce the energy consumption. The increase of lighting network complexity determines the increase of EMC noise emission. Being familiar with measurement systems is important for making correct measurement and for understanding the results of the measurement. Correct interpretation of measurement results is the first step in choosing the best suppression method. The suppression method depends on the common mode and the differential mode of noise type and on the frequency of signal noise.

Keywords: Light-emitting diode, Electromagnetic compatibility, Receiver detectors, Antennas, Conducted noise, Radiated noise, Common differential mode filter, Radiated power

1. Introduction

Energy consumption of lighting represents around 30% of total energy consumption. In a world where pollution becomes one of the most important problems, the reduction of energy consumption is equivalent to the reduction of environment pollution [1]. This way the energy management is followed by lighting industry too. Higher efficiency became the guide; this is the reason why the lighting industry is in a process of continuous transformation. Together with Light-Emitting Diode (LED) lamps the lighting control system is calling to reach a reduction of energy consumption more than 50% [2].

With the increase of lighting network complexity, increases the amount of electronic devices, which deserve these networks. With the increase of electronic complexity the electromagnetic noise emissions are increasing as well, [3].

To reduce these emissions below the limits required by standards, it is important to use measurement systems with correct settings, and proper suppression methods.

2. EMC measurement system requirements

In the Electro-Magnetic Compatibility (EMC) field it is crucial that the measurement system and the measurement receiver have the right settings. If the right settings are not used there it is possible that some frequencies of noise emission might not be detected. The correct measurement results give the possibilities to use right solutions for noise suppression. Detectors used during the measurements are required by standards. In EMC field typically three detectors are used: Pk (Peak), QP (Quasi Peak) and Av (Average). When there is not required any type of detectors then Root Mean Square (RMS) detector could be used. The measurement results give a lot of information about the measured noise signal [4].

Peak detector

The peak detector detects the peak value of the signals. If the receiver stays on a single frequency the peak detector will measure the envelope of the signal. This kind of detector is used typically for frequencies higher than 1 GHz. The advantage of this detector is the speed. It could be used for pre-compliance measurements.

Average detector

The average detector measures the average value of the signal. In case of a continuous signal the average signal will have the same value as the peak signal. In case of a pulsed or modulated signal the average measurement result will be lower than the peak measurement (*Fig. 1*).
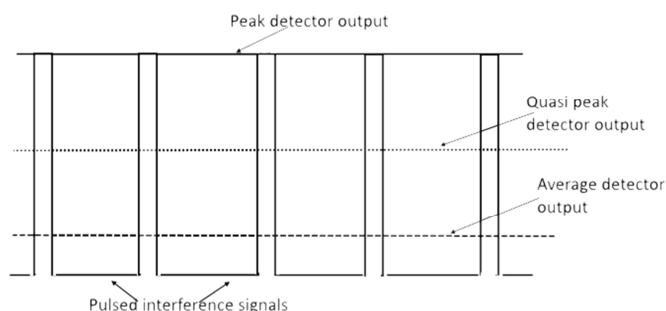

Fig 1. Detectors response for pulse interference

The average detector measurement is required by International Special Committee on Radio Interference (CISPR) standards for conducted emissions.

The effect of this is to penalize continuous emissions with respect to pulsed interference, which registers a lower level on an average detector.

Quasi-peak

The quasi-peak detector is a peak detector with weighted charge and discharge times, which is correct for the subjective human response to pulse-type interference. Interference at low Pulse Repetition Frequencies (PRFs) is said to be subjectively less annoying on radio reception than that at high PRFs. Therefore, the quasi-peak response de-emphasizes the peak response at low PRFs, or to put it another way, pulse-type emissions will be treated more leniently by a quasi-peak measurement than by a peak measurement [5].

RMS detector

The RMS detector uses a square-law detector and a low pass filter followed by a square root function. The low pass filter functions perform the mean operation associated with the RMS function, and it should have a sufficiently long time constant to smooth the output variations of the squaring detector that would otherwise arise from the modulation of the signal.

Measurement time

The quasi-peak and the average detectors require a long time for measurement. This time depends on the time constants of each detector. The typical method is to step the receiver at a step size of around half of its measurement bandwidth.

Antennas for radiated field

An antenna is needed to couple the noise-radiated field to the measuring receiver. In case of far field the magnetic and electric field components are linearly polarized and perpendicular on each other. The electric and magnetic fields are related by the impedance of free space

$$Z_0 = 377\,\Omega\,.\tag{1}$$

To convert the measured voltage at the instrument terminals into the actual field strength at the antenna it is needed to add the antenna factor and cable attenuation. The antenna factor is an important parameter, and each broadband antenna has its antenna factor (in dB/m, for E-field antennas) versus frequency. Cable attenuation is a function of frequency.

Polarization

In the far field the electric and magnetic fields are orthogonal. Each field may be vertically or horizontally polarized, or in any direction in between. The polarization depends on the nature of the emitter. An antenna will show a maximum response when its plane of polarization aligns with that of the radiated noise field. During the measurement the used type of antenna depends on the measured frequency range.

The loop antenna measures (9 kHz - 30 MHz) the magnetic field strength. The measurement of magnetic field has a better repeatability in the near field than the measurement of electric field, which is easily perturbed by nearby objects.

The loop is a coil of wire, which produces a voltage at its terminals proportional to frequency, according to Faraday's law.

The biconical antenna (20 MHz - 200 MHz) (see *Fig. 2*) is a broad-bandwidth antenna and has a high input power.
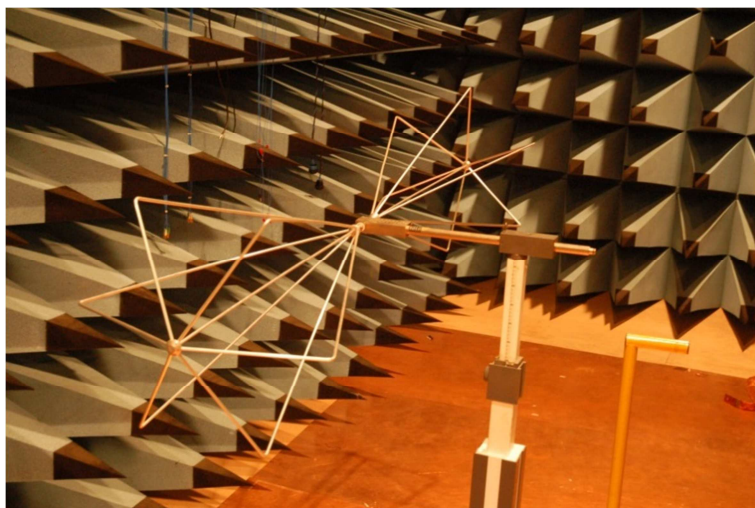

Fig. 2. Biconical antenna in the EMC lab of Stuttgart University

The biconilog antenna 26 MHz - 3 GHz) is a hybrid antenna and has an ultra-broadband frequency range, which can be used for emission and immunity testing.

The advantages of horn antenna (1 GHz - 18 GHz) are the moderate directivity, low Standing Wave Ratio (SWR) and broad bandwidth.

3. The switching power supply

Typically the switching frequencies of switching power supply used in controller and electronic ballast have a switching frequency around of 60 kHz. The harmonics of the supply can be emitted by differential; common mode conducted and radiated mechanisms. Switching waveform asymmetry normally ensures that the harmonics are presented both by odd and even components. Another cause of broadband noise can be

due to reverse recovery switching of the input rectifier diodes. If the fundamental frequency is stable the spectrum of narrowband emissions is produced and can reach frequencies over the 30 MHz when the waveform transition times are fast.

In the *Fig. 3* a typical direct-off-line switching supply is presented with the major emission paths marked, where 1 is the differential mode current conducted through DC link; 2 is the *H*-field radiation from high *di/dt* loop and *i* is the current; 3 is the common mode capacitive coupling of *E*-field radiation from high *dv/dt* node to earth, where *v* is the voltage [6].
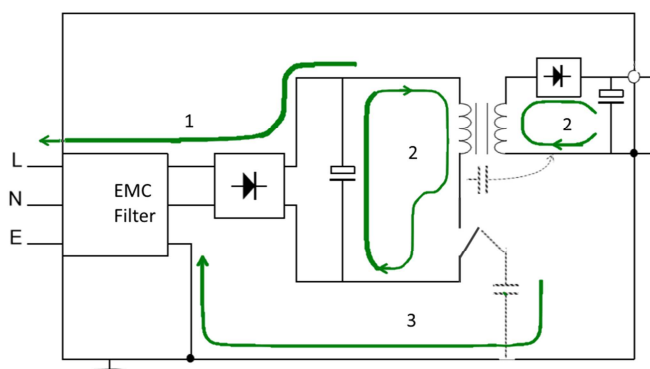

Fig 3. Switching supply emission paths

The magnetic radiation from a loop, which has a high *di/dt* can be reduced by minimizing the loop area or by reducing *di/dt* ratio.

Because of the high voltage variation, *dv/dt*, the switching transistor will be coupled through a parasitic capacitive path to ground and will create a common mode interference current. The solution is to minimize *dv/dt*, and minimize coupling capacitance or provide a different route for the capacitive currents. The *dv/dt* could be reduced by a snubber and by keeping a low transformer leakage inductance and *di/dt*. The snubber suppresses voltage transients.

Differential mode interference is caused by the voltage across the finite impedance of the input buffer capacitor with high *di/dt* due to the switched power. It is the dominant interference source for the lower switching harmonics. Choosing a capacitor with low Equivalent Series Inductance (ESL) and Equivalent Series Resistance (ESR) will reduce this emission.

At the output of switching supply switching spikes appears which could disturb the proper functionality of the electronic ballast and controller [7].

Differential and common mode current

The differential-mode noise signal appears on two lines of a closed loop, and flow in opposite directions. This kind of interference essentially appears in series with the desired signal. The solution to suppress this noise signal is to use an inductor in series with the line and a shunt capacitor across the lines.

A common-mode noise signal appears on the two signal lines simultaneously in the same direction and phase. The signal on each line returns through a common ground (*Fig. 4*). If the length of the signal lines is comparable with quarter-wave of signal, it will work as a monopole antenna. The radiation of the monopole antenna could be simulated well [8].

A common-mode choke on the signal line produces an equal and an opposite magnetic field, which cancel each another. This way the common mode noise is reduced. A capacitor between each line to ground is also used.
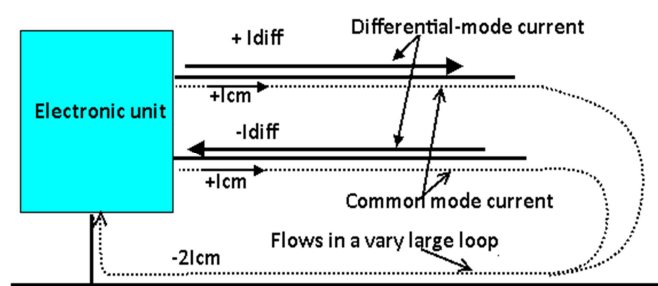

Fig 4. Common and differential mode noise signal propagation

4. High frequency noise emission on power supply cable

Typically the frequency range where ferrites could be used is between 5 - 500 MHz. The easiest method to know if a noise signal is common mode or differential mode is to use a proper ferrite. If the signal will not be suppressed by ferrite that means this signal is a differential one.

In *Fig. 5* a measurement results of LED lamps with Radio Frequency (RF) controller is presented [9]. This measurement setting does not contain ferrite, and the noise signals are above the limit. The frequency of noise signals is between 55 - 100 MHz. In this frequency range the ferrites could be used with good results. Using of a proper ferrite reduced the level of noise signal with 15 dB.

The capacitor used for noise suppressing has to be a ceramic or a tantalum capacitor. In the next *Table I* the typical capacitors used for different noise frequency suppression are presented.

Table I

Capacitors used for different noise frequency suppression

10 pF	100 pF	1 nF	10 nF	100 nF	1 µF
1550 MHz	460 MHz	160 MHz	55 MHz	22 MHz	10 MHz

In *Fig. 6* the noise emission on power supply cable of a LED lamp and an RF controller is presented.
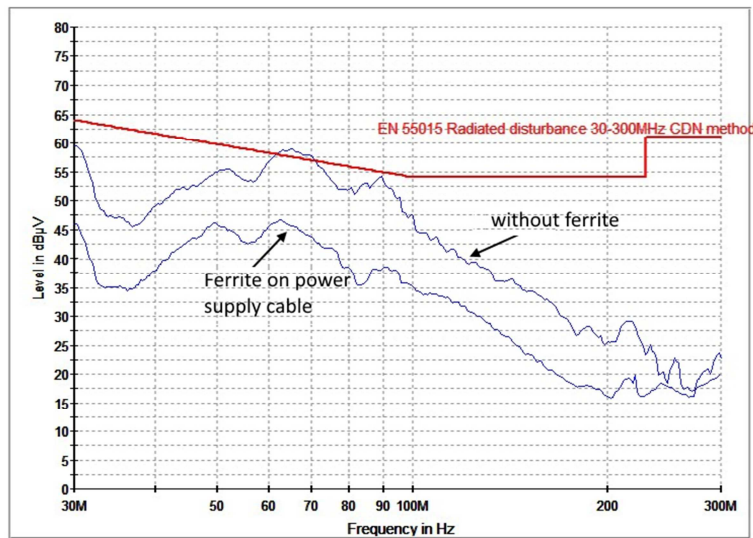
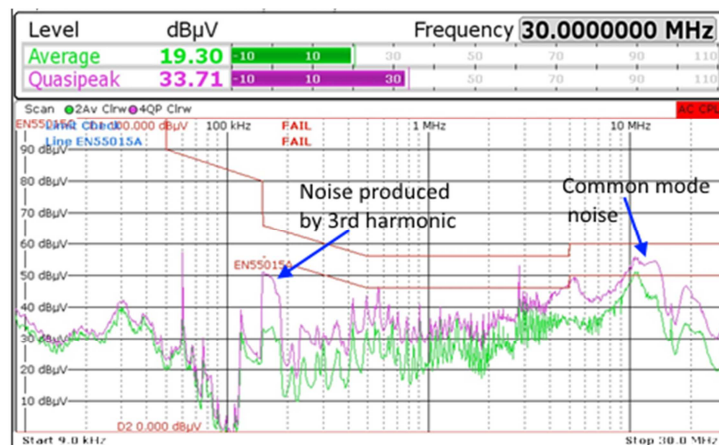*Fig 5*. Suppression of noise emission in 55-100MHz frequency band

Fig. 6. Noise emission on power supply cable

Around of 150 kHz the LED drivers have high noise emission which are a differential mode noise.

This noise type could be suppressed with the help of 25 µH inductors. In *Fig. 7* a failed measurement results are presented, where the noise were produced by the 3rd harmonic. Between measured signal and the limits have to be minimum 6 dB margin.
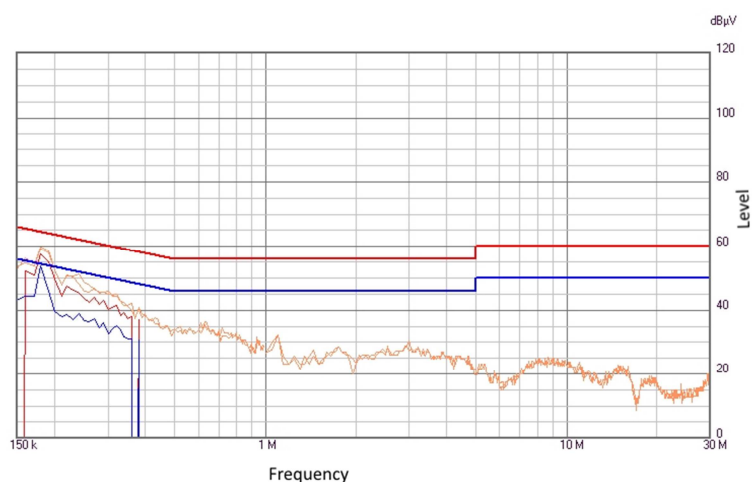
Fig. 7. Noises produced by 3rd harmonic

If an inductors is used on power supply cables, this noise type is reduced with more than 15 dB, *Fig. 8*.
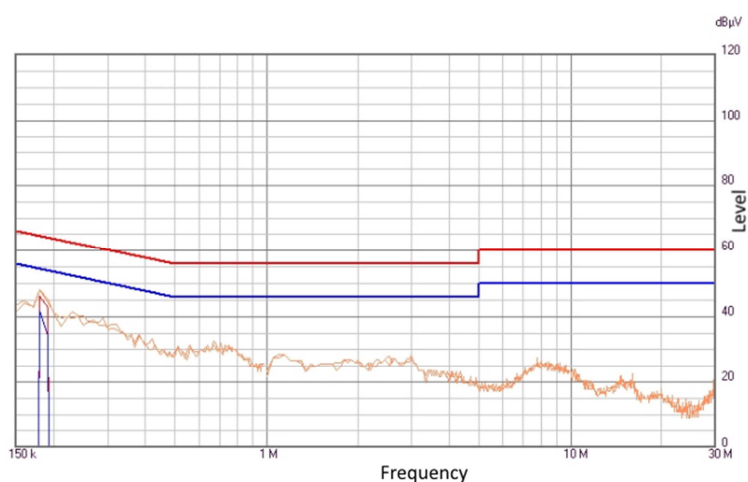

Fig. 8. Suppression of noises produced by 3rd harmonic with inductors

The common mode noise from 10 MHz (*Fig. 6*) could be reduced with common-differential mode power supply filters. In this case a Schaffner FN2010-3-06 (*Fig. 9*) filter was used, which was placed near to LED driver and RF controller. The attenuation of filter in 10 MHz - 15 MHz frequency range is around of 52 dB. The parameters of the filter are presented in *Table II*.
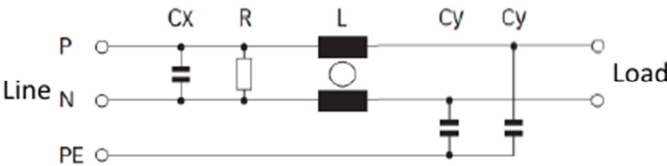
Fig 9. Common-differential mode power supply filters

Table II

Parameters of filter

Rated current	Leakage current [mA]	Inductance L[mH]	Capacitance Cx[µF]	Capacitance Cy[nF]	Resistance R[kΩ]
3	0.74	2.5	0.1	4.7	1000

The Cx capacitors are connected between line and neutral, to protect against differential mode interference. A failure of Cx capacitor does not create electric shock, but can create a fire risk. The Cy capacitors are designed to filter out common-mode noise, and are connected between line and chassis. A short circuit of this capacitor creates a risk of shock to the user.

In *Fig. 10* there is presented the measurement result of the same LED lamp and RF controller, which are presented in *Fig. 6* but with the Schaffner filter mentioned above. The filter was used at the input of LED lamp and RF controller, and filtered the conducted noise of the lamp and controller too. The result is the following:
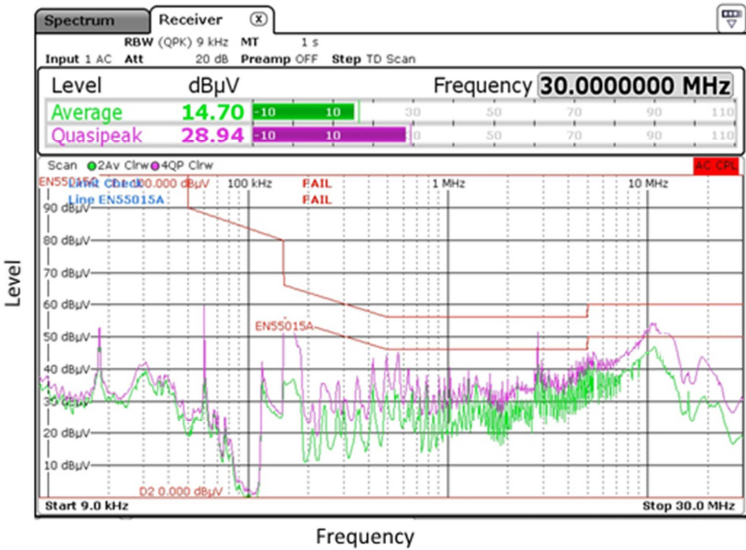

Fig. 10. Noise emission on power supply cable with filter

QP is reduced from 56 dBµV to 54 dBµV this is not a great noise suppression but in this case the emission limit is 60 dBµV, that means that the radiated noise margin is increased.

The important emission suppression is in case of A,V measurements, where the noise emission is reduced from 51 dBµV to 45 dBµV. With this noise reduction the LED lamp and the RF controller emissions are under limits.

5. Radiated power measurement

In case of RF controller it is important to know how much the maximum radiated power is, because in case of 868 MHz frequency, where the controller communicates the maximum radiated power can be 25 mW [10].

The radiated power is measured with the antenna measurement method. Emission has to be measured in vertical and horizontal polarization. The lamp has to be rotated with 360° to find the position where the radiated power has maximum value. The distance between the lamp and the antenna is 3 m. This is the minimum distance required for this measurement type. The measurement is done in an anechoic chamber, where the ambient noise does not disturb the measurement results. Another advantage of the anechoic chamber is the lack of wave reflections inside the chamber. The ferrite tiles and the HF foam absorbers from walls and floors absorb the incident waves. Typically an anechoic chamber could be used up to 18 GHz. In *Fig. 11* and *Fig. 12* two measurement results are presented where the radiated signal had maximum -20 dBm for horizontal and -40.8 dBm for vertical polarization at 865 MHz [11].
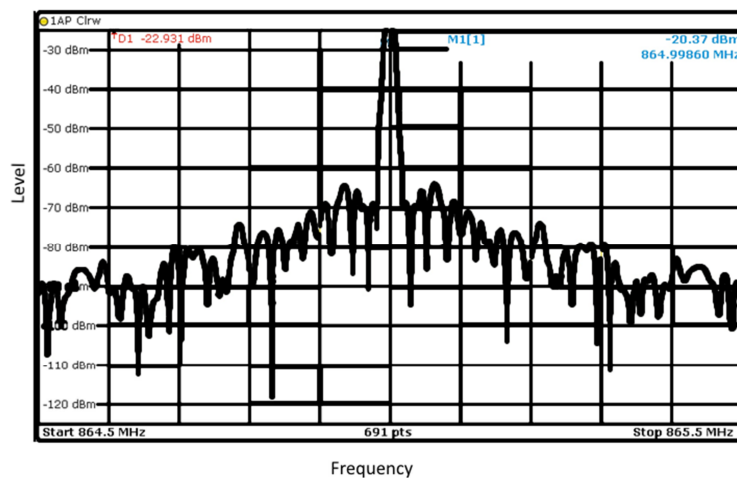

Fig 11. Power radiated horizontal polarization

From the figures it could be seen that the radiated power in horizontal polarization is higher with 20 dB than in vertical polarization. That means that the antenna of controller radiates in horizontal polarization. If the receiver antenna receives in vertical

instead of horizontal polarization then there is a 20 dB signal loss. This result is a plus reason for doing this type of measurement. In *Fig. 13* measurement results of radiated emission in 30 MHz - 6 GHz frequency band are presented. The main emission is on communication frequency.
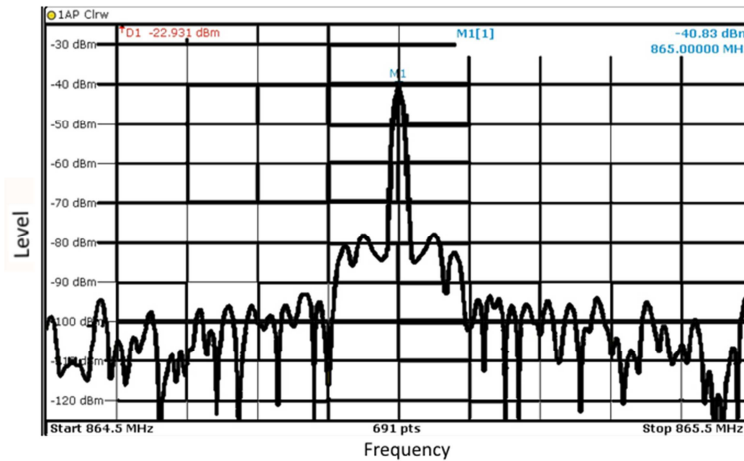

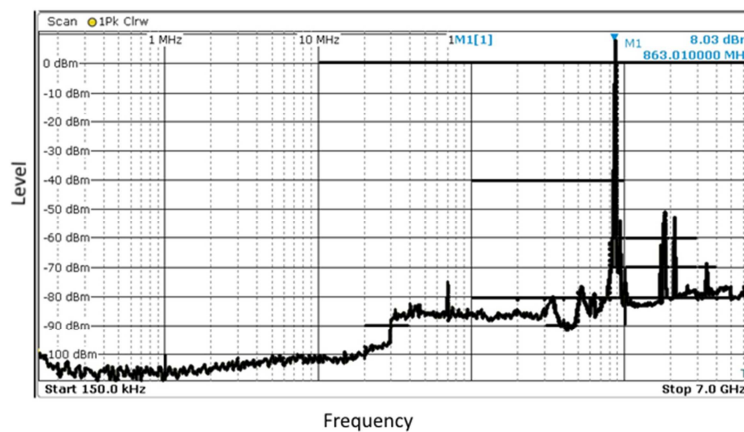*Fig 12*. Power radiated vertical polarization

Fig 13. Radiated emission of LED lamp and RF controller

6. Conclusion

The proper setting of EMC measurement system is important for correct measurement results. Incorrect settings could increase measurement time or some frequencies of noise signal emission might be missing from the measurement result. Understanding the used detectors it gives more information about the emitted noise

types. Different frequencies require different type of suppression methods. The main types of suppression methods are presented in this paper.

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