DSLR Camera Immunity to Electromagnetic Fields – Experiment Description

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Abstract: - Currently, the issues of electromagnetic compatibility have become important due to the increasing number of electronic devices that share common space. An important part of this field is the area of electromagnetic susceptibility that studies how a tested device can withstand the interferences caused by other devices in its neighbourhood. As it is generally known that CCD sensors of photo cameras can also be affected by external electrical field as they use their own electrical field in order to transport the electrons generated in their structure, the authors of this paper decided to process a test of electromagnetic susceptibility on a DSLR photo camera Nikon D40. The configuration of the test as well as the obtained results are described within this paper.

Key-Words: - Electromagnetic susceptibility, Electromagnetic compatibility, Photo camera, Semianechoic chamber

1 Introduction

In 1968, H. M. Schilke, one of the founders of the field of science related to the electromagnetic compatibility, claimed: "The system itself may be perfectly reliable, but practically worthless in operation unless it is not electromagnetically compatible at the same time." [1]. Since that time, the constructers had to face many problems raising at the field of mutual electromagnetic compatibility of devices that had to be in a concurrent operation. For example, as described in [2], in 1984 the NATO airplane "Tornado" crashed in Germany after its circuits interfered with a powerful transmitter in Holkirchen. In 1982, the British cruiser Sheffield was sunk by Argentine aircraft in the Falklands War, partly because its defense system abetting the enemy rockets was switched. Due to its electromagnetic incompatibility, it interfered with radio communication, crucial for the cruiser's crew. According to [3], there were several accidents reported in the Czech Republic, for example a pileup of mining equipment failures in Náchod that was caused by an incompatible mining machine with a power of 3.4 MW.

The above mentioned examples demonstrate how the field of electromagnetic compatibility is important. Because this paper focuses mainly to the electromagnetic susceptibility, it is worth describing how the electromagnetic susceptibility is included in the field of electromagnetic compatibility. It can simply be said that the electromagnetic compatibility is divided into two groups that studies the interaction between the devices. These groups are as follows:

- Electromagnetic interference – describes how the tested device disturbs other devices. It is focused on measurement of the disturbing electromagnetic fields or currents emitted to the connected cables. It identifies the source of disturbances, describes the disturbing signals and focuses on elimination of the disturbances.
- Electromagnetic susceptibility – describes how the operation of the device can be affected by external disturbing signals, either spread by electromagnetic field, capacitive or inductive coupling or directly over the conducting line. It is focused on measurement of the device's ability to resist

the disturbances, describes the consequences of the interferences, identifies the locations at which the disturbances penetrate the device and focuses on elimination of the consequences.

In this paper a test of the susceptibility of the camera Nikon D40 is described. The measurement was processed according to the requirements of the standard EN 61000-4-3. It is obvious that it is only a part of a complex set of tests that must be performed in order to check the electromagnetic susceptibility of the device. However, complex testing of the camera would exceed the framework of one paper. The most common susceptibility tests and standards are enlisted in the subchapter below.

The theoretical background of the experiment is provided in chapter 2. The description of the experiment is provided in chapter 3, including the brief description of the instruments used in the laboratory. In chapter 4 the experiment progress and the obtained results are provided and in chapter 5 there is a brief conclusion.

2 Theoretical background

This chapter provides a brief theoretical background concerning the description of basic European standards, principle of a CCD operation and principles of shielding of the energy of the electromagnetic waves.

2.1 Basic European standards for susceptibility tests

The set of standards for electromagnetic susceptibility has developed into a complex system that covers almost all possible situations that can occur during the operation of the tested device. The system of standards is created as follows: there are basic (root) standards to define basic requirements on all devices tested for the electromagnetic susceptibility. On their basis more complex groups of standards are created, defining the requirements for certain groups of devices (for example computers, lighting devices, etc.). If the device cannot be assigned to any group, the tests are run according to the root standards. A shortened list of the basic standards is provided in the Table I.

2.2 Principle of CCD sensor operation

The motivation for processing of the test was triggered by the statement published in [9], where the authors claimed that the “CCD sensors are susceptible to modest electromagnetic environments”. This announcement can be considered as expectable, when studying the principle of the CCD sensor operation.

According to [7], the technology of charged-couple devices was developed in 1969 in the Bell laboratories, but it was expected to serve for other purposes than for digital picture scanning. The visualisation of an individual CCD sense element is provided in Fig. 1. Generally it can be said, that the elements respond to incident photons by absorbing much of their energy in the form of an electrical charge. This charge is linearly proportional to the light flux incident on a sensor pixel. [8] On the CCD sensor the sense elements are organized in a matrix and the obtained pieces of charge are sequentially moved to the amplifier (charge to voltage converter) and, sub sequentially, to the A/D converter. This process is stimulated by electrodes producing electrical field that attract the charger through the mass of the sensor. More information on this topic can be found in [7]. The principle of processing of the charges can be compared to a bucket brigade, as depicted in Fig. 2.

Once the CCD sensor operates with electrical charges and transports these charges by means of electrical field, it can be expected that this device will be affectable by external electrical fields.

Table I. Basic standards for electromagnetic susceptibility tests [1] (shortened)

Standard code	Description
EN 61000-4-1	List of the susceptibility tests
EN 61000-4-2	Electrostatic discharge
EN 61000-4-3	Radiated electromagnetic field
EN 61000-4-4	Fast transients and/or set of pulses
EN 61000-4-5	Surge pulse
EN 61000-4-6	Interferences induced by the high frequency fields, conducted by wires
EN 61000-4-7	Harmonic and interharmonic frequencies in power supply mains – general
EN 61000-4-8	Magnetic field of the power supply mains
EN 61000-4-9	Magnetic field pulses
EN 61000-4-10	Damped oscillations of the magnetic field
EN 61000-4-11	Short-time decreases in supply voltage, short voltage drops and slow voltage changes
EN 61000-4-12	Oscillating waves
EN 61000-4-14	Voltage ripples

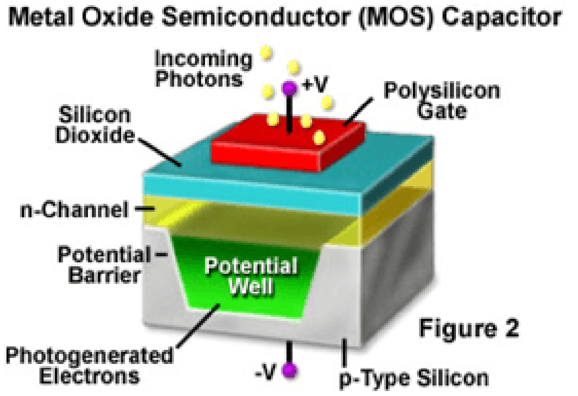

Fig. 1 Visualisation of an individual CCD sense element [8]

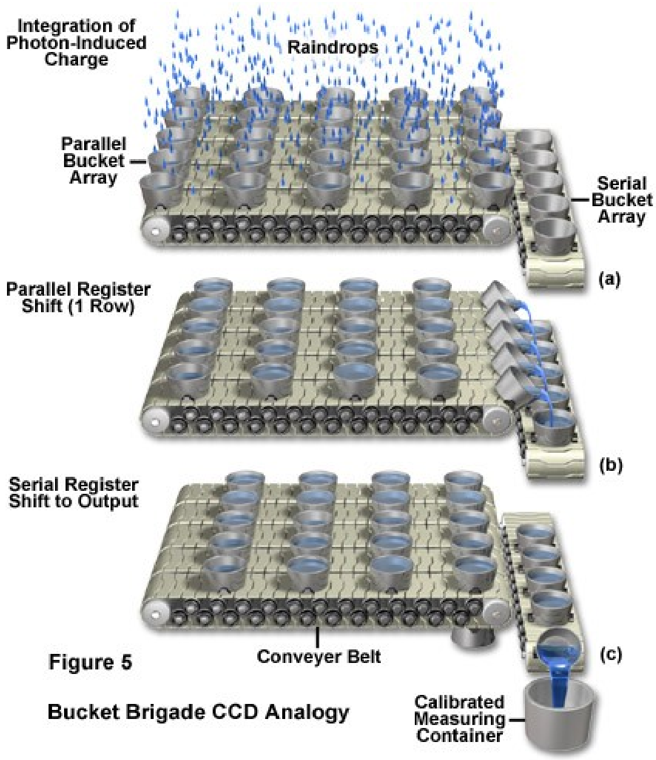

Fig. 2 Principle of the sequential processing of the sensed charges on the CCD matrix [8]

2.3 Protection against the effects of the external electromagnetic field

In order to prevent the intrusion of the external electromagnetic field into the device, a cover made of conductive materials is usually employed, causing electromagnetic shielding of the internal parts of the device. The mechanism of shielding is based on three main phenomena that apply simultaneously, as described in the text below.

The shielding effectiveness effectiveness is a parameter of a material that describes how the material eliminates the power of electromagnetic field radiated by a source that is placed behind this material. Its basic definition is as follows:

$$SE = 10 \cdot log \frac{P_1}{P_2} \; [dB] \qquad (1)$$

Where:
P1 – Power generated by the source of the interference [W],
P2 – Power being spread behind the shielding material [W].

In fact, there are three different mechanisms that contribute to the ability of the material to shield the electromagnetic field. A short description of all of them is provided below in this text. Generally, these contributions can be described as follows:

$$SE_{dB} = R_{dB} + A_{dB} + M_{dB} \qquad (2)$$

Where:
R – Attenuation on the interface with different impedances,
A – Attenuation caused by the absorption of the materiel (heat loss),
M – Attenuation caused by multiplied reflections.

2.3.1 Attenuation on the interface with different impedances

The attenuation R_{dB} describes how much energy is reflected back from the shielding material. In case the shielding material creates a partition M between two different environments A and B, the attenuation caused by the reflection can be described as follows:

$$R = 20 \cdot log \left| \frac{Z_A + Z_M}{2 \cdot Z_M} \cdot \frac{Z_M + Z_B}{2 \cdot Z_B} \right| \; [dB] \qquad (3)$$

Where:
Z_A – impedance of the environment A [Ω],
Z_B – impedance of the environment B [Ω],
Z_M – impedance of the shielding material M [Ω].

2.3.2 Attenuation by the absorption

The attenuation due to absorption of the energy by the material can be described on the basis of the calculation of the intrusion depth δ:

$$A = 20 \cdot log \left| e^{\frac{t}{\delta}} \right| \; [dB] \tag{4}$$

$$\delta = \sqrt{\frac{2}{\omega\mu\sigma}} \tag{5}$$

Where:
t – material thickness [m],
δ – intrusion depth [m],
σ – material conductivity $[S \cdot m^{-1}]$,
μ - material permeability $[H \cdot m^{-1}]$,
ω – wave frequency $[rad \cdot s^{-1}]$.

2.3.3 Attenuation by multiple reflexes

The principle of attenuation caused by multiple reflexes is depicted in Fig. 1. It does not apply if (t >> δ), but if (t << δ), its value can be negative, decreasing the total shielding effect of the material. According to [5] it can be described by the following equation:

$$M = 20 \cdot log \left| 1 - \left(\frac{Z_O + Z_M}{Z_O + Z_M} \right)^2 \cdot e^{-\frac{2t}{\delta}} \cdot e^{-j\frac{2t}{\delta}} \right| \; [dB] \tag{6}$$

Where:
Z_0 – impedance of the surroundings of the material [Ω],
Z_M – impedance of the material [Ω],
t – material thickness [m],
δ – intrusion depth [m].

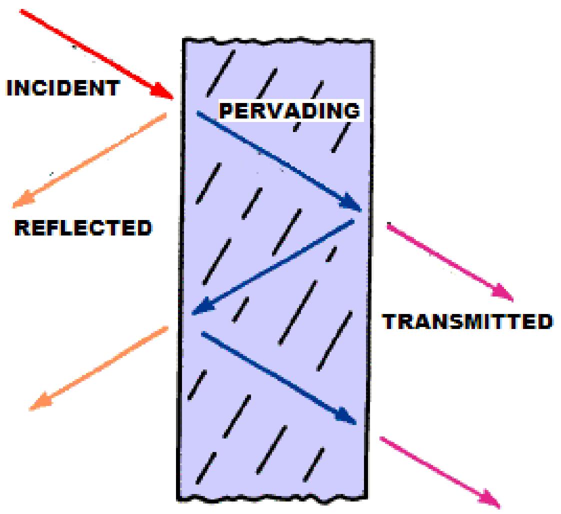

Fig. 3 Principle of attenuation caused by means of multiple reflections. Incident, reflected, pervading and transmitted waves are shown. [1]

3 Experiment Description

The experiment was run in the laboratory of the electromagnetic compatibility under the conditions and with the equipment described in this chapter.

3.1 Tested camera

As the equipment to be tested, an older DSLR Nikon D40 was chosen. The camera was frequently used for 7 years and suffered from minor wear. Nikon D40 is an entry-level single lens reflex camera that employs a sensitive CCD sensor with the resolution 3,008 x 2,000 pixels. The dimensions of the sensor are 23.7 x 15.5 mm and the basic sensitivity is ISO 200 and with the use of an internal amplifier, it can be increased up to ISO 3200. This is possible because on the area of the chip there is a low number of pixels. The pixels occupy larger area and thus the sensor reaches high sensitivity.

Fig. 4 Nikon D40 (subject to the test)

3.2 Equipment

The experiment was held in a shielded semi anechoic chamber Frankonia SAC 3 plus in which the camera and the transmitting antenna were placed. The signal was generated by Rohde & Schwarz SMF 100 A and amplified by a set of amplifiers Amplifier Research 150W1000 and 80S1G4. The signal was transmitted with the antenna Rohde&Schwarz HL046E. The frequencies and the modulation were set in accordance with the standard EN 61000-4-3. The power of the amplifiers was set by means of a feedback field probe ETS Lindgren HI-6005 that was located as close to the camera as possible. The instruments were driven by EMC 32 software. The camera was controlled remotely by means of the software Nikonkontrol 3k. The connection between the controlling computer and the camera was established by means of a shielded USB cable.

3.3 Arrangement of the experiment

The tested camera was placed on a wooden table located on a rotatable surface. Its rotation was controlled by means of the EMC 32 software. Close to the camera the feedback field probe was placed, being connected to the instruments in the rack by means of an optical cable. In the distance of 3 m, the transmitting antenna was placed. The measurement was run in both antenna polarizations – the vertical and the horizontal one. The camera was connected by a shielded USB cable to a computer placed outside of the semi anechoic chamber. The cable was threaded through a waveguide in the penetration panel. Inside the chamber, non-radiating halogen lamps were used to ensure enough light for taking the photos. For each polarization of the antenna, the camera was exposed to the electromagnetic field produced by the transmitting antenna, the intensity of which was defined and controlled by the feedback probe.

According to the possibilities of the laboratory equipment, in order to reach higher field intensities than 10 V/m in the whole frequency range, the distance between the tested camera and the transmitting antenna had to be reduced proportionally to the demand of the increase in the field intensity.

Table II. Description of the elements depicted in Fig. 5

Element	Description
1.A	Computer running EMC 32 controlling software
1.B	Laptop running Nikonkontrol 3k, a software for communication with the tested camera
2	Signal generator Rohde & Schwarz SMA 100 A
3.A	Path switches Rohde & Schwarz OSP 130
3.B	Path switches Rohde & Schwarz OSP 150
4.A	Power amplifier Amplifier Research 150W1000
4.B	Power amplifier Amplifier Research 80S1G4
5	Antenna Rohde & Schwarz HL 046
6	Electrical field isotropic probe ETS Lindgren HI 6105
7	Converter from optical connection to USB ETS Lindgren HI 6113
8	Semianechoic chamber Frankonia SAC 3 plus
F	Tested digital camera Nikon D40

A diagram describing the whole arrangement of the experiment is depicted in Fig. 5. A description to the Figure is provided in Table II. In Fig. 6 a typical configuration for susceptibility tests according to [11] and [12] is described.

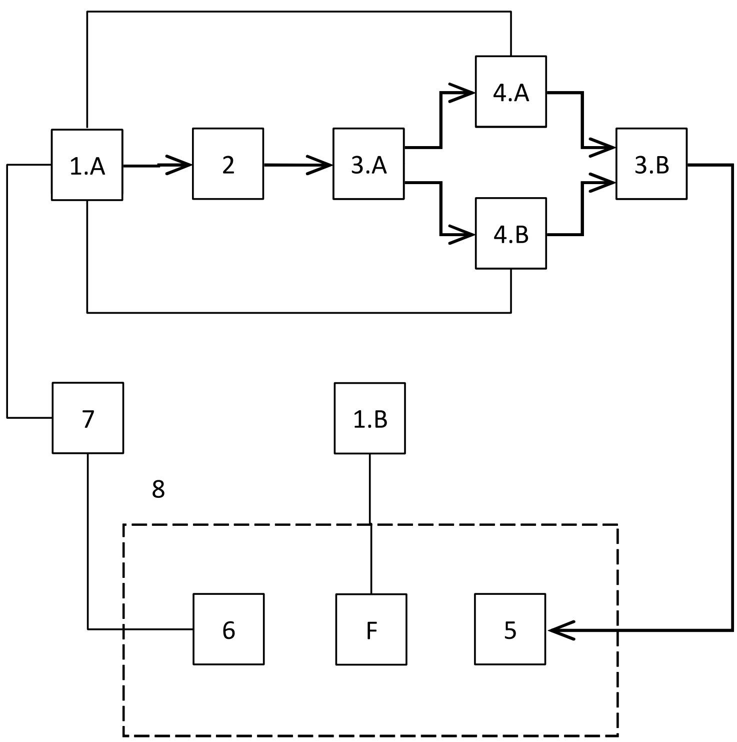

Fig. 5 Arrangement of the experiment described in this paper [10]

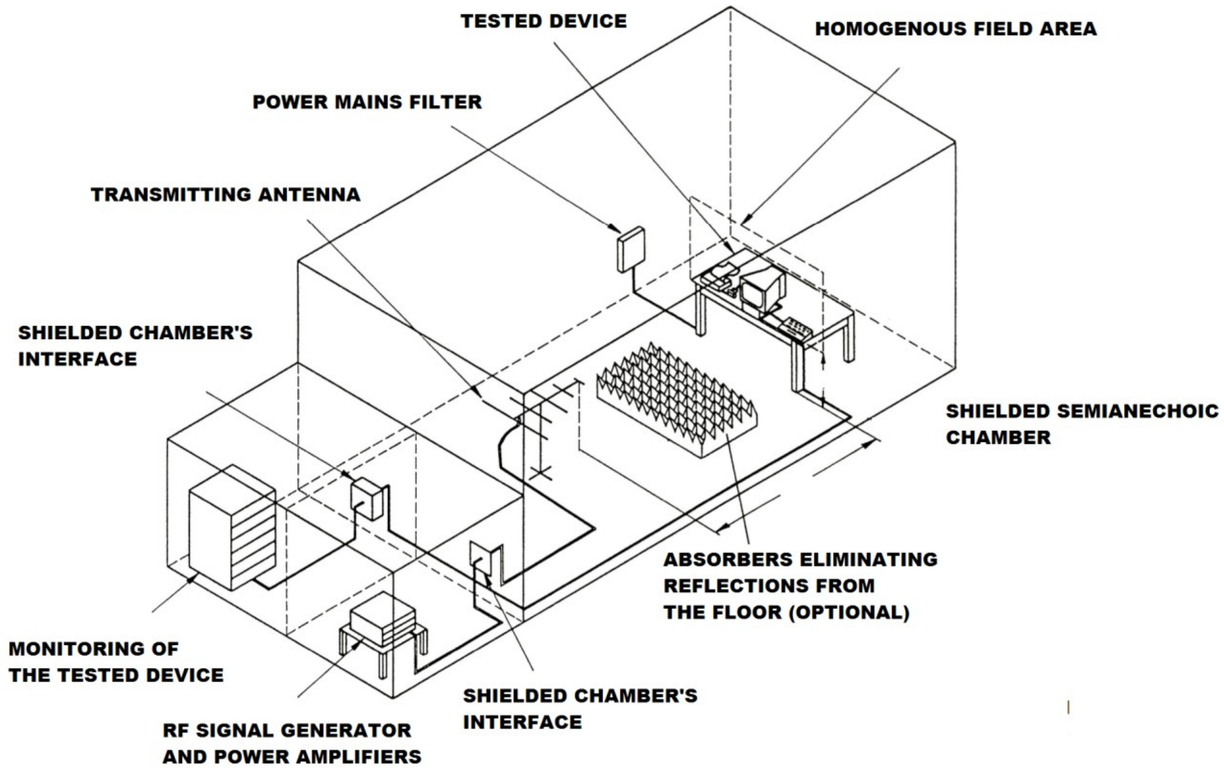

Fig. 6 Typical susceptibility test configuration according to [11] and [12]

3.4 Requirements of the Standard EN 61000-4-3

This standard requires processing of the measurements in the frequency range from 80 to 1,000 MHz. The amplitude of the testing signal is modulated with the frequency of 1 kHz. The depth of the modulation is 80 %.

According to the class of the tested device, the device should stay in operation up to the intensities defined in Table III. Usually, the levels up to 10 V/m are applied. The higher levels are not defined by means of the standard as it is expected that if needed, they are explicitly defined in the separated agreement between the producer and the consumer.

3.5 Experiment Conditions

The experiment conditions were chosen according to the requirement of EN 61000-4-3 for the first set of measurements. The intensity of the fields was set according to Table III Class 2 and Class 3.

In the second set of measurements, more challenging conditions were used:

- The modulation depth was increased to 100 %,
- The intensity of the electrical field was increased to 30 V/m or 50 V/m respectively by shortening the distance between the transmitting antenna and the tested camera.

Table III. Test intensities of the electromagnetic fields

Class	Intensity [V/m]	Description
1	1	Device is operated in the area with low interferences, the radio and TV transmitters are in the distance higher than 1 km.
2	3	Device is operated in the area with moderate interferences, the transmitters in its neighbourhood does not exceed the output power of 1 W.
3	10	Device is operated in the area with high interferences, close to powerful transmitters or scientific, medical or industrial appliances.
X	-	Device is operated under specific conditions, described by other documents.

3.6 Functional Criteria

When the electromagnetic susceptibility of any device is tested, it is important to classify the influence of the received electromagnetic field on the operation of the device. The unified set of functional criteria is therefore defined by EN 50082 in order to enable the evaluation of the test. The list of basic functional criteria according to EN 50082 is provided in Table IV.

Table IV. Functional criteria according to EN 50082

Criterion	Description
A	The operation of the tested device is not affected by the external electromagnetic field.
B	The operation of the tested device is affected by the external electromagnetic field, but once the external field is eliminated, the tested device will operate normally. The external electromagnetic field does not change data stored in the memory of the device as well as the device's parameters.
C	The operation of the tested device is affected by the external electromagnetic field, but once the external field is eliminated, the normal operation of the device is recovered either automatically or by means of the remote controlling system or by the operator according to the steps defined in the user's manual of the device.
D	The operation of the tested device is permanently affected, even when the external electromagnetic field was eliminated. The device is destroyed or damaged.

Fig. 7 Configuration of the experiment inside the semi anechoic chamber; part of the transmitting antenna can be seen on the right side while the tested camera is put on the wooden table in the distance of 3 meters

Fig. 8 Configuration of the experiment inside the semi anechoic chamber; camera put on the wooden table with a feedback probe behind

4 Experiment Progress and Results

The experiment was held in two phases. In both of them, the frequency range and type of modulation were chosen according to the requirements of EN 61000-4-3 and the tested camera was rotated on a turntable controlled by the EMC32 software in order to find such mutual position of the transmitting antenna and the tested camera, in which the susceptibility of the camera reaches the worst results. The configuration of the experiment was always done according to the diagram depicted in Fig. 3. The photos from the semianechoic chamber can be found above.

4.1 Phase A

In the first phase, the intensity was set to 3 V/m and 10 V/m respectively, according to the values defined in Table III. In all positions and both, horizontal and vertical, polarizations of the transmitting antenna, the results of the experiment was evaluated according to the Table IV and the operation of the device was not affected. The result was, according to Table IV, classified by the grade A.

4.2 Phase II

On the basis of the results of the first phase of the experiment, more challenging conditions were set as described in the text above. The modulation depth of the transmitted signal was increased to 100 % and the intensity of the electrical field was increased to 30 V/m and 50 V/m respectively. Several

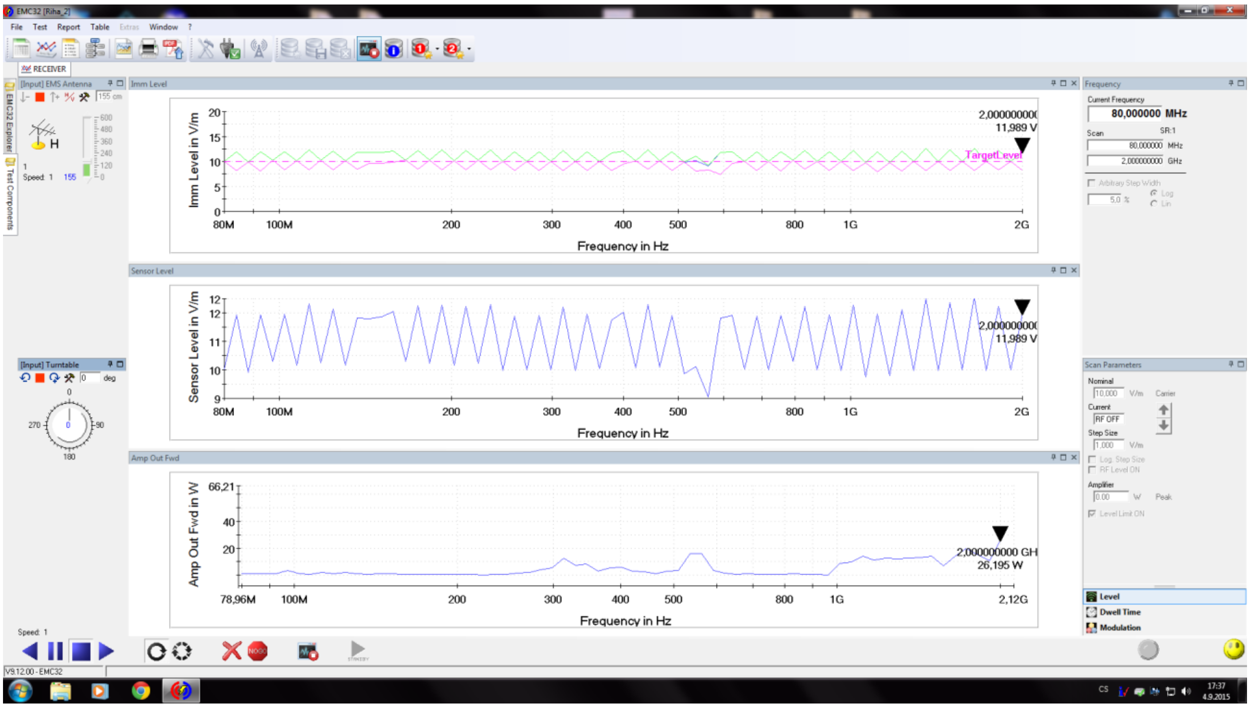

Fig. 9 Screenshot of the control software EMC 32. It gives information on the generator's frequency, output power of the amplifiers and measured intensity of the electrical field by the isotropic feedback probe.

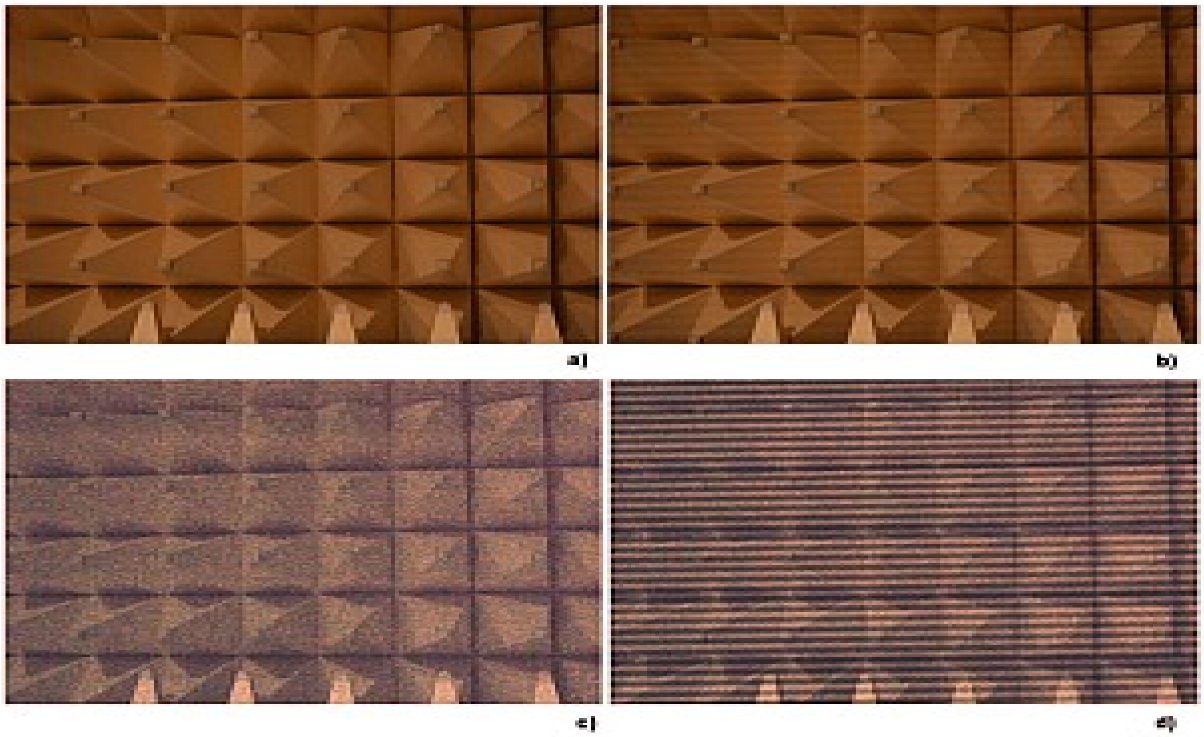

Fig. 10 Results of the experiment: a) reference picture taken under conditions described in Table V with no external field, b) picture taken under conditions according to Table V, c) reference picture taken under conditions described in Table VI with no external field, d) picture taken under conditions according to Table VI

malfunctions of the tested camera were detected. Most of them consisted in loss of the connection between the camera and the controlling laptop, which occurred always on the frequencies above 112 MHz. On the lower frequencies of the disruptive electromagnetic field, several changes in the colour and quality of the captured image were observed, as depicted in Fig. 4. Generally, it can be stated, that for the intensity of electromagnetic fields between 10 V/m and 50 V/m, the tested camera complied with the functional criterion B according to the list in the Table IV.

4.3 Effects of the disruptive electrical field to the quality of the captured image

The disruptive electrical field resulted in black lines occurring in the captured image. Slight changes in histograms of the obtained pictures were also observed. In order to achieve the highest visibility of these lines, the signal from the CCD sensor of the tested camera was amplified by means of the internal amplifier by setting high ISO sensitivity.

Different settings with ISO 800 and ISO 1600 were applied, as described in Table V and Table VI. The comparison of a picture captured in the area without intensive electromagnetic field and the picture captured in the area with intensive electromagnetic field is provided in Fig. 8. Figures 8 a) and 8c) show the reference images that were taken under the settings described in Table V or Table VI respectively, but with no generated electrical field. Figures 8 b) and 8d) refer to the pictures taken under the same conditions, but with the influence of the disruptive electrical field.

Table V. Conditions under which the pictures in Fig. 10a) and 10b) were captured

Field settings	Frequency of the disruptive field	82 MHz
	Modulation frequency	1 kHz
	Modulation depth	100 %
	Intensity of the disruptive field	30 V/m
Camera settings	ISO sensitivity	800
	Time of exposition	1/100 s
	Focal length	31 mm
	Aperture	F 8.0
Position	The camera is in the same height as the transmitting antenna, the transmitting antenna is in horizontal position, the angle between the transmitting antenna and the camera lens is 90°	

As stated above, the measurement instruments were controlled by means of the software EMC 32 that controls the generator, amplifiers and measure the real intensity of electrical field close to the tested device by means of the isotropic field probe. The screenshot of the user's interface while the test is in progress is depicted in Fig. 7. It gives information on the generator's frequency, output power of the amplifiers and measured intensity of the electrical field by the isotropic feedback probe.

In Fig. 11 the shift in the histogram observed at the field intensity of 50 V/m is depicted.

Table VI. Conditions under which the pictures in Fig. 10c) and 10d) were captured

Field settings	Frequency of the disruptive field	82 MHz
	Modulation frequency	1 kHz
	Modulation depth	100 %
	Intensity of the disruptive field	50 V/m
Camera settings	ISO sensitivity	1,600
	Time of exposition	1/640 s
	Focal length	31 mm
	Aperture	F 8.0
Position	The camera is in the same height as the transmitting antenna, the transmitting antenna is in horizontal position, the angle between the transmitting antenna and the camera lens is 90°	

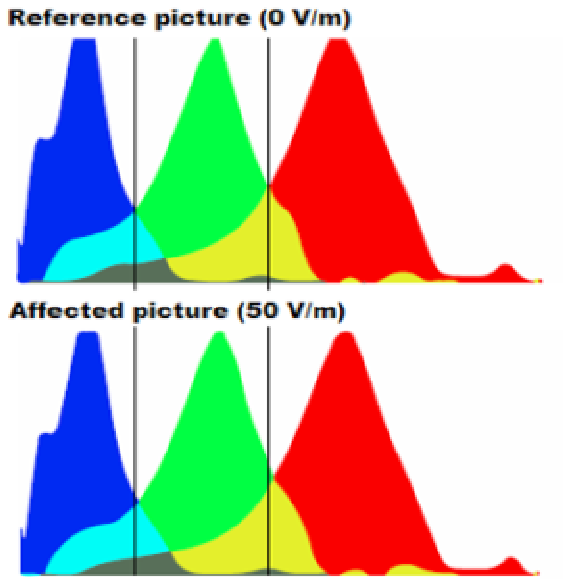

Fig. 11 Color shift between the figures 10c) and 10d) depicted by means of a histogram

4.4 Communication Failure

During the test with higher electrical field intensities (30 V/m and 50 V/m), several malfunctions of communication between the camera and the controlling computer have been observed. These malfunctions always resulted in losing of connection, causing the impossibility of taking pictures at disruptive field's frequencies higher than approximately 112 MHz. In order to resume the communication, the control software Nikonkontrol 3 k must have been restarted and the USB cable

Table VII. Complex evaluation of the test

Field intensity	Parameter	Camera rotation			
		0°		90°	
≤ 10 V/m	Amplitude modulation depth	80 %		80 %	
	Antenna to camera distance	3 m		3 m	
	Polarization	Horizontal	Vertical	Horizontal	Vertical
	Test result	A	A	A	A
30 V/m	Amplitude modulation depth	100 %		100 %	
	Antenna to camera distance	1 m		1 m	
	Polarization	Horizontal	Vertical	Horizontal	Vertical
	Test result	A	B	B	B
50 V/m	Amplitude modulation depth	100 %		100 %	
	Antenna to camera distance	1 m		1 m	
	Polarization	Horizontal	Vertical	Horizontal	Vertical
	Test result	B	B	B	B

reconnected. However, the proper operation of the camera was restored as soon as the disruptive field as eliminated without a need of any user's action. Therefore, according to the Table B, the performance of the camera was evaluated according to the criterion B.

4.5 Data Storage

An SD memory card with the capacity of 4 GB was installed in the camera. The data stored on this card were neither affected at any electrical field intensity nor any electrical field frequency.

4.6 Complex Evaluation

When evaluating the performance of the camera according to the set of criteria defined in Table IV, the results of all tests can be described by Table VII.

5 Conclusions

This paper describes the experiment that consists in testing of a digital camera Nikon D40 susceptibility to the disruptive electromagnetic field according to EN 61000-4-3.

According to the obtained results, the camera is fully operational without a malfunction within the external electromagnetic fields the intensity of which does not exceed 10 V/m. At higher intensities, the quality of the captured image is affected, which is documented by a comparison provided in Fig. 4. As it can be seen, the black lines emerging in the picture due to the effect of interfering electromagnetic fields are observable at a certain frequency of the field (82 MHz) and are not parallel to the edge of the picture. The authors of the paper assume that this effect is formed directly on the CCD chip of the camera, which is expected to be sensitive to disruptive electrical fields and which is scanned gradually within the period of the sensing, as depicted in Fig. 2. Within the framework of this assumption it can be stated, that what is actually observed, is directly the effect of the electrical field on the CCD sensor.

The susceptibility of the camera was tested up to the intensity of the electrical field of 50 V/m which is rather high value. Even thus the functionality of the camera complied with the functional criterion B according to EN 50082.

Further tests are planned to be performed inside a GTEM cell. The achieved results will be compared to the results presented in this paper.

The main advantage of the method used in this experiment is obvious. As the requirements of the given standard are fulfilled, the experiment can be repeated with different cameras and therefore their direct comparison is possible. The main drawback, however, also results from the fulfilment of the standards – complex and expensive equipment is required. This drawback seems to be partly eliminable when the above mentioned GTEM cell is used.

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