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Role of the Pulse Repetition Rate when Assessing Electromagnetic Immunity of Electronic Devices

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Abstract
Considering the shortcomings of the existing test methods, this paper provides a new procedure for validating the requirements on the repetition rate of repeating electromagnetic pulses when assessing the electromagnetic immunity of electronic devices. The pulse repetition rate should not be chosen arbitrarily, but should be consistent with the properties of the device under test. Two examples of a 60 W electrical power unit and a "Panasonic" video camera are presented to validate the conclusion in the paper.

Keywords Disruptions in electronic devices · Electromagnetic pulse (EMP) · Immunity · Key parameters of electromagnetic disturbances

1 Introduction

When testing electronic devices for their immunity to high-power electromagnetic pulses (EMP), researchers try to use a maximum number of EMP sources available for immunity tests. But the characteristics of test pulses, such as amplitude, waveform and pulse repetition rate are limited. Some common reasons for choosing certain concrete values of the mentioned characteristics are listed below:

- when carrying out tests the researcher must vary the amplitude and the repetition rate of test pulses in the greatest ranges;
- the frequency spectrum of test pulses has to be chosen taking into account the resonant properties of conductive elements (power supply lines, communication wires, conductive paths of printed circuit boards, etc.) of the devices under test (DUT);
- the repetition rate of test pulses has to correspond to certain frequencies characterizing the internal processes in DUT, for example, the frame frequency in the television observation system.

However, this approach does not guarantee that the test will detect all threats from EMP. Also, it can't ensure that we can obtain the data for the reliable forecast of the behavior of DUT in situations which weren't reproduced during tests.

In contrast, the new approach to choosing characteristics of test pulses offered in this article is able to preliminarily analyze the main mechanisms and regularities of the impact of repeating EMPs on DUT and identify key parameters characterizing the effectiveness of such influence. Carrying out this analysis gives the chance for a reasonable forecast about the behavior of the tested device in the difficult electromagnetic environment. To illustrate this new methodical approach, the procedure for validating the requirements on the repetition rate of test pulses is given below.

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2 Mechanisms of the Failures of Electronic Devices under Influence of High- Power EMP

In [8–12], the three effects, which can lead to failures of electronic devices exposed to high-power EMP, are: irreversible failure of some elements, transition of active elements into the saturation mode, and incorrect transfer of data between digital devices. The three effects can occur practically in any electronic device, and for this reason we may call them as the universal ones. There is also a set of effects whose appearance depends on the features of the objects subjected to the influence of high-power EMP. Therefore, we may call such effects as the specific ones.

Electric disturbances induced in conductive elements are the immediate cause of failures of the electronic devices exposed to high-power electromagnetic pulses. So-called key parameters of these disturbances can be used to assess the possibility of the failures. The amplitude and energy of the pulsed disturbances arising in the critical circuits of electronic devices are most often used as the key parameters [2, 5]. When estimating the immunity of the equipment to the repeating pulse disturbance, the repetition rate of this disturbance is the key parameter also [6].

It is noteworthy that now the amplitude and the energy of the aforementioned key parameters are widely used for the prognosis of possible effects in the electronic devices under influence of high-power electromagnetic pulses. As for the repetition rate, the literature so far hasn't given any way about determining its optimal value in tests of electronic devices. Therefore, we would like to offer one of such ways.

Suppose we need to test some device and to reveal (or to exclude) a possibility of failures of this device due to effects such as transition of the active elements into the saturation mode, and the triggering of non-nominal action of operating mechanisms during the test. Conditions for the occurrence of such failures consist in simultaneous realization of the following requirements [3]:

$$U_{\text{in}} > U_{\text{crit}} \quad (1)$$

$$W_{\text{in}} > W_{\text{crit}} \quad (2)$$

$$f > 1/\Delta T \quad (3)$$

Here, U_{crit}, W_{crit}, ΔT – respectively, are the minimum value of voltage U_{in}, at which transition of the active elements into the saturation mode (or the triggering of non-nominal action of operating mechanisms) begins; the minimum value of energy W_{in}, providing steady transition of the elements into this mode (or the triggering of non-nominal action of operating mechanisms); and the time of return of the elements from the saturation mode (or the time of return of the operating mechanism to an initial state) after stopping of a current (relaxation time).

Thus, to assess the possibility of the effects mentioned above, it is necessary to subject the device to the influence of electromagnetic pulses with repetition rate exceeding $f_{\text{crit}} = 1/\Delta T$. In this respect, if the simulator used isn't capable of providing such pulse repetition rate, the objective of the test won't be achieved. It follows from this that before carrying out tests it is necessary to define value of the f_{crit} parameter for DUT. Another reason for the influence of the pulse repetition rate is considered in [7, 13]. In the following part, some examples of determining this parameter for two devices are provided.

3 Choice of the Pulse Repetition Rate When Assessing the Noise Immunity of the 60 W Electrical Power Unit

To find a relaxation time of ΔT for the chosen electrical power unit, it is convenient to use a periodic signal generated during the operation of this block. Such signals, for example, the signal of the clock frequency (CLK), are applied in many devices. A periodical alteration of logical level of the CLK signal is an indication that the device is operating normally. On the contrary, the lack of the alteration of logical level of the CLK signal for a long time is an indication of the transition of this device into the saturation mode.

The scheme of the electrical power unit under test is shown in Fig. 1. The essence of the experiment is that DUT is subjected to the influence of repeating EMP and at the same time the CLK signal is registered and the electromagnetic field near the device is measured.

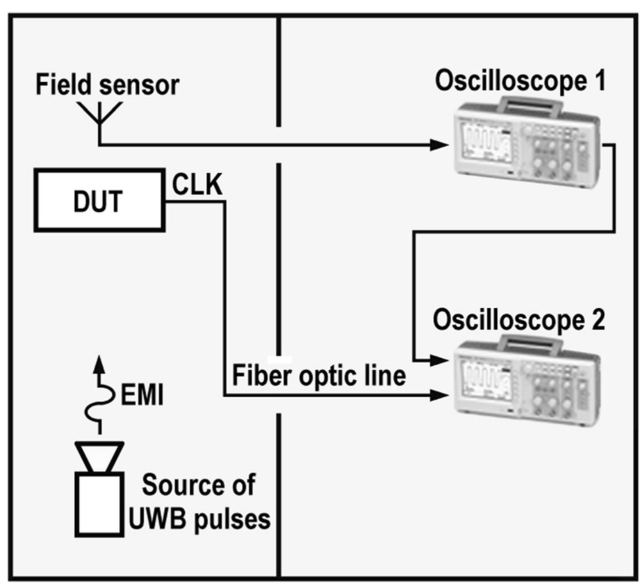


Fig. 1 Scheme of the electrical power unit under test

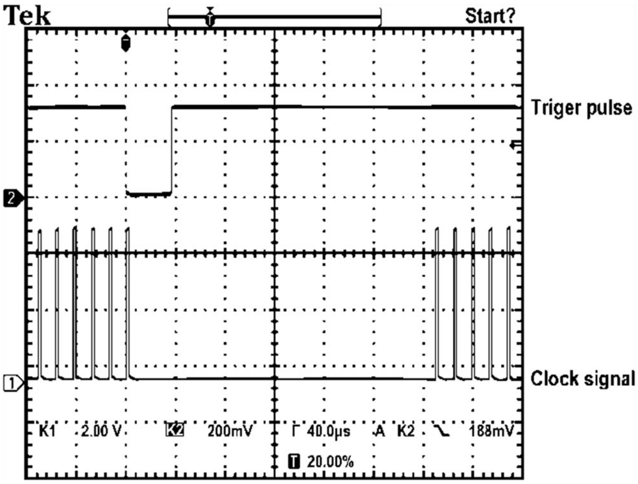


Fig. 2 Oscillogram of the trigger pulse and the CLK signal

Oscilloscope 1 is needed to register the exact moment of electromagnetic pulse (the exact moment when DUT is excited). Oscilloscope 2 not only displays the Trigger pulse which indicates the beginning of the electromagnetic impact but also allows us to observe the CLK signals. It is noteworthy that the trigger pulse duration (40 μs) is much longer than the EMP duration (<1 ns). This pulse is used for synchronization. As for the periodic CLK signal, concerned with the functioning of the device, the management signal of the power key of the electrical power unit was chosen. Frequency of this signal is equal to 70 kHz. To prevent the disturbances caused by interferences in the communication link, the fiber-optic link was used. The measuring equipment was located in a screened room. The EMP source with an effective potential of radiation of $E \times R = 200$ kV and a pulse repetition rate of 0.25 kHz was used. The distance between the source and DUT varied from 3 to 9 m.

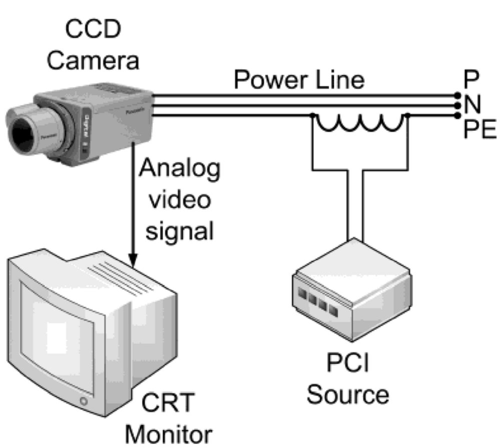


Fig. 3 The video camera test diagram

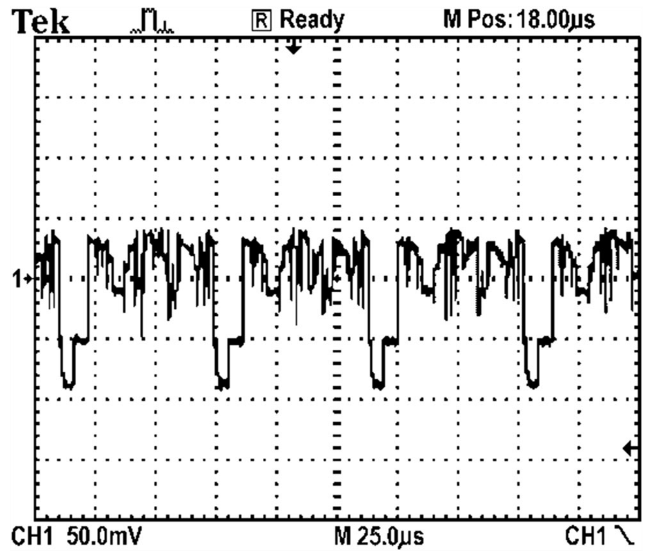


Fig. 4 The oscillogram of the video pulses entering to the monitor without test influences

During the experiment it was established that the impact of electromagnetic pulses on DUT is the result of the transition of the power key into the saturation mode and the loss of the CLK signal. The corresponding oscillogram is shown in Fig. 2. The moment of the beginning of electromagnetic impact on DUT corresponds to the moment of change of the trigger signal from "1" to "0". It is easy to see that the signal disappears at the beginning of the influence. The CLK signal restores not just after the influence, but significantly later. The restoring time (the relaxation time) is about 250 μs.

Using the measurement results of a relaxation time (ΔT), we could draw a conclusion that the pulse repetition rate during test has to be not less than 4 kHz. Only in this case will the experiment allow us to

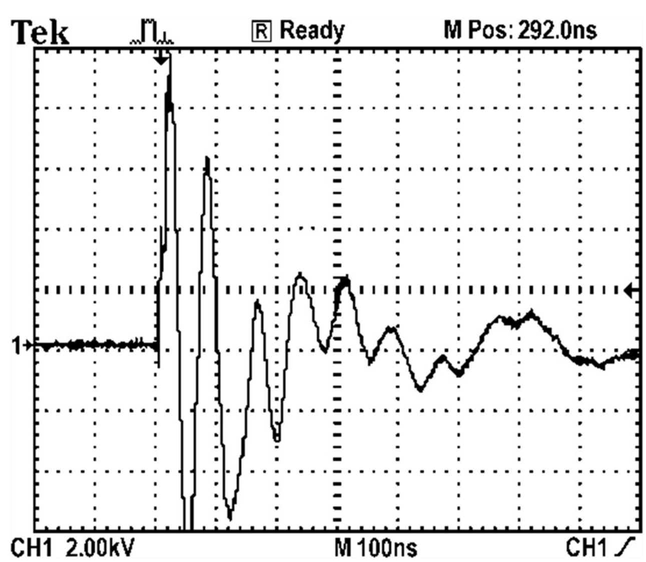


Fig. 5 A form of the pulses generated by GVP - 30 kV - 1 kHz

estimate the possibility of the stopping of the normal functioning of the device as the result of the transition of active elements into the saturation mode. It follows from this that the possibility of the above-mentioned stopping of normal functioning of the electrical power unit in the difficult electromagnetic environment can't be revealed by applying a EMP source with a pulse repetition rate of 0.25 kHz. To get reliable data about the noise immunity of the power unit it is necessary to use a source capable of providing essentially higher repetition rate of test pulses.

4 Choice of the Pulse Repetition Rate When Assessing the Noise Immunity of the "Panasonic" Video Camera

The impact of electromagnetic pulses on video systems was considered in [1, 4]. Unlike the previous test in which we tried to identify the role of the repetition rate of the test pulses, the video-camera in this test was subjected to pulses injected into a rupture of the PE wire of the power supply cable (Fig. 3). During the test the quality of the video image on the monitor was checked.

The characteristics of the video signal on entering the monitor were measured simultaneously and then compared with the characteristics of this signal recorded without the test influences. The oscillogram of the video signal in the case without test influences is shown in Fig. 4.

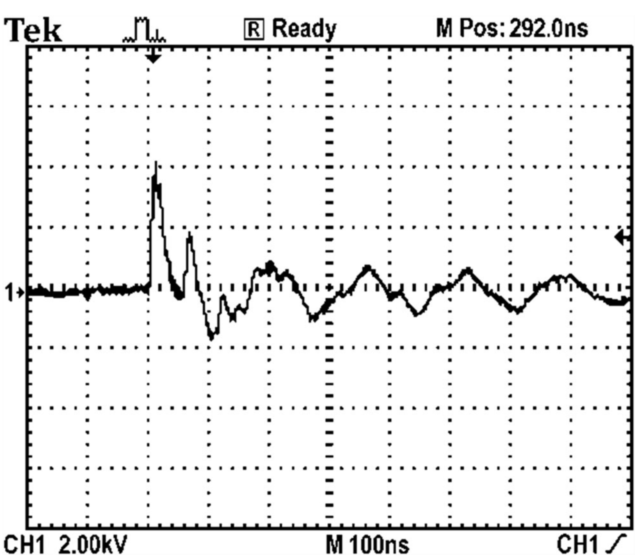
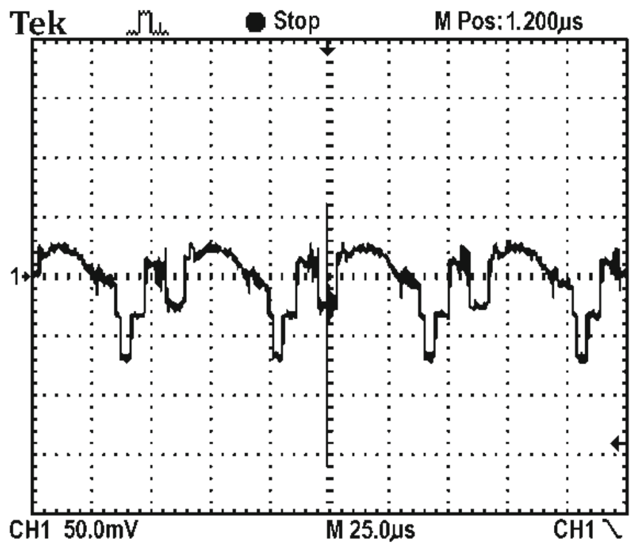


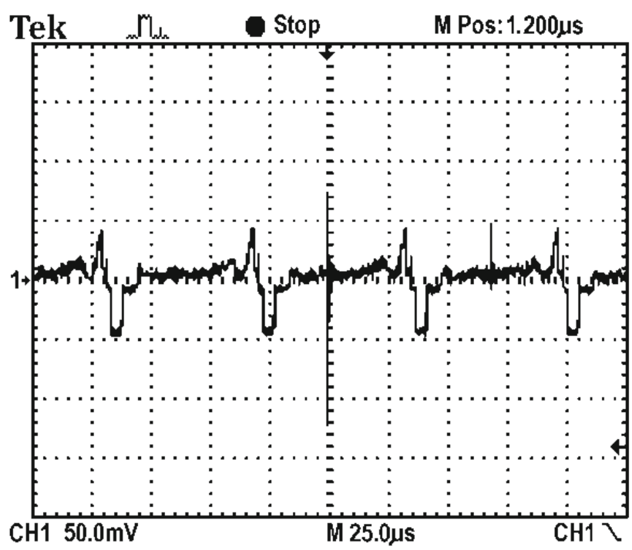
Fig. 6 A form of the pulses generated by GVP - 4 kV - 6 kHz. a) Initial stage of the monitor screen darkening. b) Final stage of the monitor screen darkening

In the first series of experiments, a generator-injector of test pulses GVP – 30 kV – 1 kHz was used. The form of the injected pulse is shown in Fig. 5. The repetition rate of test pulses was chosen to be 1 kHz, and their amplitude was increased gradually from 2.6 kV to 4.2 kV.

Despite the extreme level of the test influences, the camera maintained working capacity. It follows from this that the amplitude is not the single parameter of EMP that influences the noise immunity of electronic devices. For informative tests, it is necessary to reveal the role of other parameters,



a) Initial stage of the monitor screen darkening



b) Final stage of the monitor screen darkening

Fig. 7 Oscillograms of the video pulses arriving at the monitor in the process of injecting voltage pulses into the power supply cable at $U_{gen} = 4.2$ kV; $f_{rep} = 1.2$ kHz

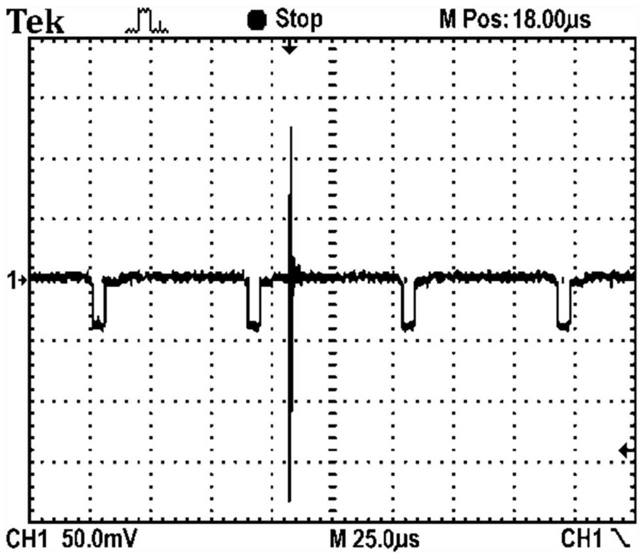


Fig. 8 The oscillogram of the video-pulses arriving at the monitor in the process of voltage pulses injecting in to the power supply cable at U_{gen} = 2.6 kV; f_{rep} = 1.6 kHz

including the repetition rate of EMP. With that aim the second series of experiments by means of GHV – 4 kV – 6 kHz was carried out. This generator forms voltage pulses, repeating with higher rate (until 6 kHz).

A form of the pulses injected into the cable by means of the generator is shown in Fig. 6. The following has been observed:

– at amplitude of test pulses of 4.2 kV and pulse repetition rate of 1.2 kHz, the monitor screen slowly (during 20–30 s) darkened;
– at the same amplitude and the pulse repetition rate of 1.5 kHz, the monitor lost image fully.

Oscillograms of the pulses arriving at the monitor in the process of injecting pulses with such parameters are shown in Fig. 7.

When injecting pulses with an amplitude of U_{gen} = 2.6 kV and a repetition frequency of f_{rep} = 1.6 kHz, the screen rapidly dimed (up to complete image loss). The oscillogram of the video pulses for this case is shown in Fig. 8.

The experiments have shown that the repetition rate of acting pulses significantly influences the functioning quality of the video camera. If this parameter is less than a certain value (in our case it is 1.6 kHz) the system will function normally, even under the influence of pulses with extremely high amplitudes. However, if the repetition rate of test pulses exceeds this threshold, the video camera stops normal function.

5 Conclusion

In this article we have discussed two effects which can occur under the influence of repeating EMP and lead to failures of electronic devices:

- the transition of active elements of the power supply unit into the saturation mode;
- the non-nominal action of the control system of a diaphragm in the "PANASONIC" video camera.

The experimental estimation of relaxation time of the power supply unit (that is, the time of return to an initial state) was carried out. It was established that the relaxation time considerably surpasses the duration of the influencing electromagnetic pulse and in our example is equal to about 250 μs. The knowledge of this parameter allows choosing correctly the repetition rate of test pulses when testing the immunity of electronic device to repeating EMP. For example, for testing the 60 W electrical power unit, the pulse repetition rate should be not less than 4 kHz.

Similar tests of the "PANASONIC" video camera have shown that the reliable data about the noise immunity of this video camera can be obtained only when using the EMP source capable of providing the repetition rate of test pulses not less than 1.6 kHz.

We suppose that estimating the relaxation time a priori is a very difficult task. To solve it, a very accurate and complete DUT model is needed. This is not always possible in practice. This is why we used an experiment. The generality of our approach is to use a periodic signal (CLK) to diagnose the device health and measure relaxation time. We have shown the possibility of application on two devices: a power supply unit and a video camera. The relaxation time is an individual characteristic of each device (or part of it) and should be determined experimentally.

As for the pulse repetition rate, then the maximum available one can be used. However, our work allows us to choose the frequency reasonable. In addition, our approach allows us to understand whether the available generators will be enough to completely block the operation of the DUT. Also, our estimates are useful when creating new generators for testing.

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