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Comparison of coupling networks for EFT Pulses Injection

***Abstract**. The paper compares behaviour of different types of coupling/decoupling networks for immunity testing against electric fast transient (Burst) from the point of view of their pulse transfer as well as their directivity. Aim of the paper is to show the possibility of using also electromagnetic clamp instead of capacitive clamp, which is less robust, in case of in-situ testing or special testing. The influence of overvoltage protection elements for auxiliary equipment decoupling upon the resulting test severity level is evaluated.*

***Streszczenie.** W artykule porównano właściwości różnych rodzajów sieci sprzęgających/odsprzęgających do badań odporności na szybkie elektryczne stany przejściowe (Burst) pod kątem przenoszenia impulsów oraz kierunkowości. Celem pracy jest wykazanie możliwości wykorzystania również cęgów elektromagnetycznych zamiast klamry pojemnościowej, która jest mniej wytrzymała w przypadku testów in-situ lub specjalnych. Oceniono wpływ elementów ograniczających przepięcia na odsprzęganie wyposażenia pomocniczego dla danego poziomu narażeń. (**Porównanie sieci sprzęgających do wstrzykiwania impulsów EFT**).*

Keywords: electric fast transients (EFT) testing; capacitive clamp; electromagnetic clamp (EM clamp).
Słowa kluczowe: badanie odporności na szybkie elektryczne stany przejściowe (EFT); klamra pojemnościowa; cęgi elektromagnetyczne.

Introduction

Pulse disturbance generated by transient phenomena during switching processes within power distribution network has significant capability to disrupt the function of electronic devices; specially devices with digital circuits. Thus a test of immunity against this disturbance - electric fast transients/burst (EFT) pulses belongs to basic electromagnetic compatibility tests [1], [2]. According to relevant standards the representative parameters of testing pulses were established as: high amplitude continuously rising from ±250 V to ±4 kV, very short rise time (5 ns), short pulse duration (50 ns) and high repetitive frequency (units of kHz). During this test the disturbing pulses are applied in to AC/DC power mains, data, signal, control and communications cables, if their operating lengths are more than 3 m. The standard EFT test waveform is shown in Fig. 1.

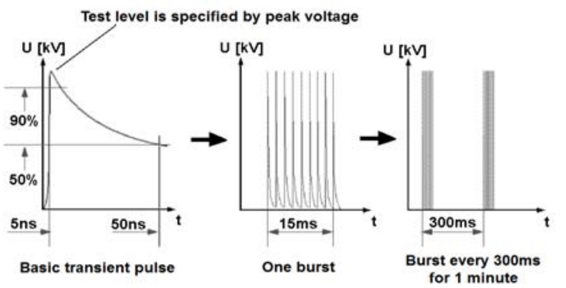

Fig.1. Standard EFT test waveform

Our aim has been to compare the behaviour of capacitive and EM clamps used for EFT testing. The main task was to find the condition under which their behaviours are comparable. Then one could perform both tests using the same coupling network only changing disturbing sources. It would be highly advantageous especially when the tests are performed outside a test laboratory, because it is not necessary to transfer more CDNs (Coupling/Decoupling Network).

Coupling methods

Special coupling/decoupling networks (CDN) are obviously used for burst pulses coupling to standard AC/DC supply cables. The coupling of EFT pulses is realized via 33 nF capacitor. Design of CDN is specified in the standard [3]. The problem is that the test cable should be necessary to interrupt and connect via the CDN. Another problem is that the CDN coupling is suitable only for simple power cables (2 or 3 wires cable).

In case of other cable interfaces the corresponding standard [3] prescribes to use special capacitive clamp and also its construction. Our capacitance clamp was precisely designed according to the standard requirements. Tested cable is placed between the two metallic plates of the capacitive clamp, to which the test pulses are fed. The disturbing pulses are distributed to both ends of the cable installed in the clamp by this arrangement. Neither interruption nor connection needs to be made to the cable under test. The advantage is that the capacitive clamp is also suitable for complicated types (multi-wire) of cabling. A typical capacitive clamp test arrangement is shown in Fig. 2.

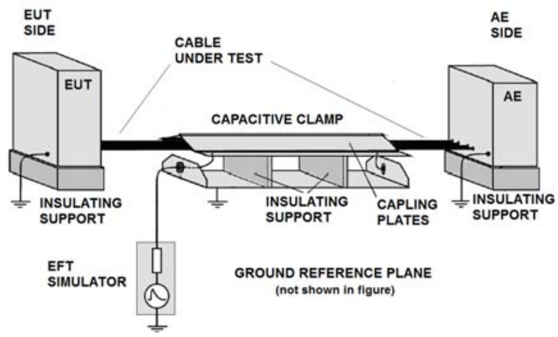

Fig.2. Test workplace arrangement with capacitive clamp

One of alternative to capacitive clamp is usage of an electromagnetic (EM) clamp. The EM clamp Lüthi EM101 is used primarily for the injection of disturbing continuous radio frequency (RF) signal according to the standard EN 61000-4-6 and its frequency range is up to 1 GHz [4]. The EM clamp manufacturer Lüthi declares that EM clamp can be used in EFT pulses mode operation for voltage level up to ±4 kV [5]. Both immunity tests at the signal cable interface of EUT have to be performed and their test configurations are very similar. Their principal advantage is that the testing is absolutely non-invasive - no direct connection needs to be made to the cable under test.

Principle of EM Clamp

The EM clamp is an RF current injection clamp that subjects the cable under test to both capacitive and inductive coupling of disturbing signal in the frequency range from 150 kHz to 1000 MHz. The simplified equivalent circuit of capacitance coupling is shown in Fig. 3.

The capacitive coupling originates between a semicircular metallic plate glued at the bottom halved rings and insulated by a dielectric cover and a cable under test. The output voltage at the EUT side and the auxiliary equipment (AE) side is proportional to the coupling capacitance and the time derivative of input voltage (1). The voltages at both sides are approximately the same and they have the same polarity.

$$U_{EUT} \approx U_{AE} \approx C \cdot \frac{dU}{dt} \quad (1)$$

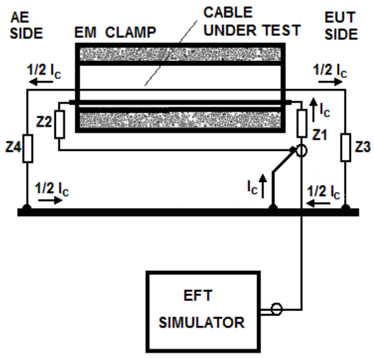

Fig.3. Simplified equivalent clrcuit of the capacltive coupling [4]

The inductive coupling appears between the semicircular metallic plate glued at the bottom halved rings and insulated by a dielectric cover and the cable under test inside ferrite rings. The simplified equivalent circuit of inductive coupling is shown in Fig. 4.

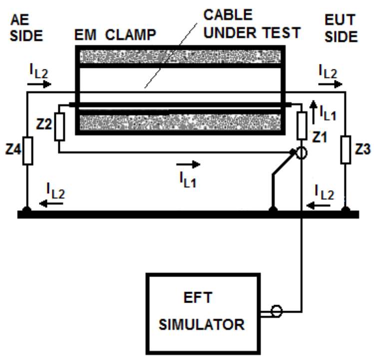

Fig.4. Simplified equivalent clrcuit of the inductive coupling [4]

The output voltage at the EUT side and the AE side is proportional to the coupling mutual inductance and the time derivative of current flowing along metallic plate (2). The ratio of voltages at both sides is approximately equal to the ratio of terminating impedances but the voltages have reverse polarity.

$$U_{EUT} \approx -U_{AE} \approx M \cdot \frac{dI}{dt} \quad (2)$$

The optimal design of the clamp is arranged that capacitive and inductive coupling paths is reinforced at the EUT end and compensated at the opposite AE end. This fact gives to EM clamp about 10 - 15 dB of directivity in frequency range above 10 MHz [6]. It is an important property because at the opposite site of cable end, where the AE is connected, the continuous disturbing signal or the test EFT pulses with hazardous amplitudes are undesired. Modelling of the capacitive clamps properties was published in several articles [7], [8] and [9]. Modelling of the EM clamps properties was presented in articles [6], [10], [11]. We decided to use the comparing measurements of both clamps.

Measurement setup

The aim of this work is to compare the amplitudes of EFT pulses at both EUT and AE sides of clamp in case of the capacitive clamp prescribed by the standard and alternative EM clamp. We also performed measurements of internal CDN of EFT simulator EMTEST EFT 500N5. Measuring configuration complied with requirements of EN 61000-4-4 [3]. In CDN, single wire cable with insulation (type RG-CYH 1.0 mm) was placed to lap over the CDN edge approx. 10 cm. On both sides of cables we used 150 Ω/50 Ω adapters recommended by EN 61000-4-6 standard [4]. These adapters were loaded by 50 Ω coaxial loads. It was ensured by this connection, that the cable, to which we injected EFT pulses, was loaded by 150 Ω impedance with minimum parasitic properties. Commercial simulator EFT 500N5 was used to generate EFT pulses. Pulses have always positive polarity with amplitude of 1 kV. Output voltages were measured on terminated impedances by 1 GHz oscilloscope Tektronix DPO 4104 with additional high voltage probe HV 250 (2.5 kV, 300 MHz, dividing ratio 1:100). Measuring setup is schematically shown in Fig. 5.

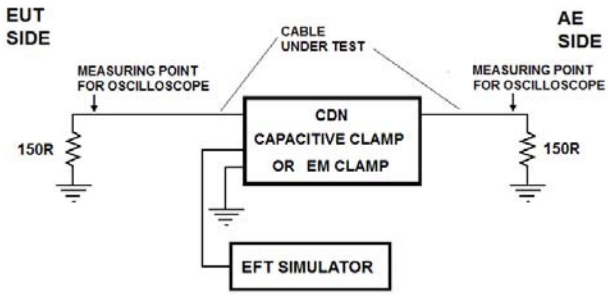

Fig.5. Measuring setup for different types of coupling networks

Later we appended the terminating impedances by bipolar transient-voltage-suppression diode (transil) BZW 06 5V8B. The aim was to find out, how the wave shape is changed at EUT side of CDN, if the opposite side is safeguarded by overvoltage protection to protect auxiliary elements against damage. Finally we put overvoltage protection elements at EUT side and we observed the deformation of pulses at the AE side. Measuring setup is schematically shown in Fig. 6.

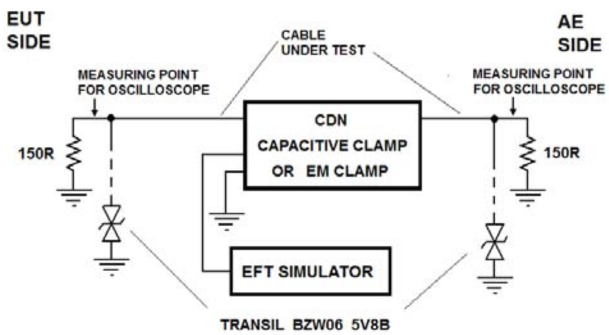

Fig.6. Measuring setup for different types of coupling networks with overvoltage protection

Results

First, we measured EFT pulses at the EUT and the AE site of the simulator internal CDN network. The pulse at the EUT side has a shape corresponding to the standard requirements. The measured pulse amplitude was about 750 V. The pulse at the AE side was fully suppressed by the decoupling part of CDN. It means that CDN has ideal directivity because the disturbing pulses had to have zero amplitude at the AE side. Measured pulses are shown in Fig. 7.

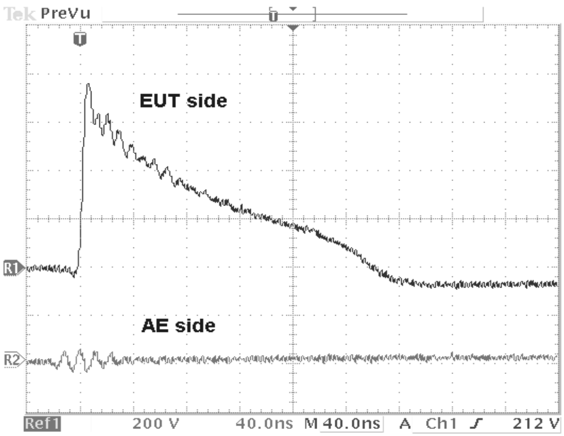

Fig.7. Output voltage of internal CDN of EFT simulator

During EFT immunity testing the parameters of disturbing pulses at EUT side of CDN are the most important, because they directly influence the test severity level. The particular pulses at the EUT side are presented in Fig. 8 for both studied CDNs – the capacitive clamp and the EM clamp. As it is visible in the figure, the amplitudes of pulses are approximately the same in both cases – 420 V, resp. 432 V. But in case of EM clamp the pulse duration is significantly longer (cca. 40 ns) in comparison to 15 ns of capacitive clamp. It is caused by inductive coupling dominating in this type of CDN.

The disturbing pulses should have significantly lower amplitude at the AE side, ideally zero. A connection of sensitive AE to EUT signal inputs could be then considerably simplified. Generally such devices are necessary for regular EUT functioning, but their immunity against EFT pulses uses to be limited very often.

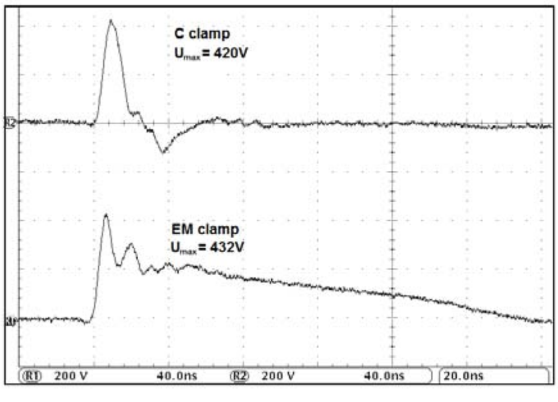

Fig.8. Output voltage of capacitive clamp and EM clamp at the EUT side of CDN

If the output pulses level of capacitive clamp was measured, we observed the decrease of peak level to 362 V. It is 14 % less than the same level at EUT side. Due to major effect of capacitive coupling the pulses at both sides have the same polarity.

Situation in case of the EM clamp is different. Polarity revolution can be observed due to the inductive coupling, which dominates over the capacitive one. The amplitude is only 30 % lower , this is approximately 3 dB decrease. This represents much lower directivity than is listed in [5] and [6] by continuous harmonic disturbance.

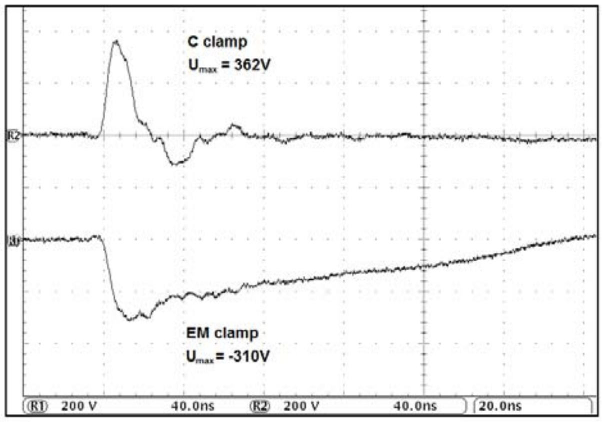

Fig.9. Output voltage of capacitive clamp and EM clamp at the AE side of CDN

It results from the measurements that sensitive AE connected to the AE side of CDN requires additional guarding by overvoltage protection circuit. Overvoltage protection can be either external or integral part of AE. It is important, that after connection of overvoltage protection at the AE side, the EFT pulses at EUT side applied to EUT cable interfaces can change just minimally (mainly in amplitude). Substantial amplitude change could negatively affect the test severity. The following experiment was dedicated to this analysis.

We appended the overvoltage protection of bipolar transil of type BZW06 5V8B to the terminating impedance on AE side. Then we measured the time waveshape at the EUT side terminating impedance by oscilloscope for both types of signal cabling CDN. In case of the internal CDN EFT simulator using, there was negligible impact on the amplitude and the shape of the pulses at EUT side. Obtained results for capacitive clamp and EM clamp are showed in Fig. 10.

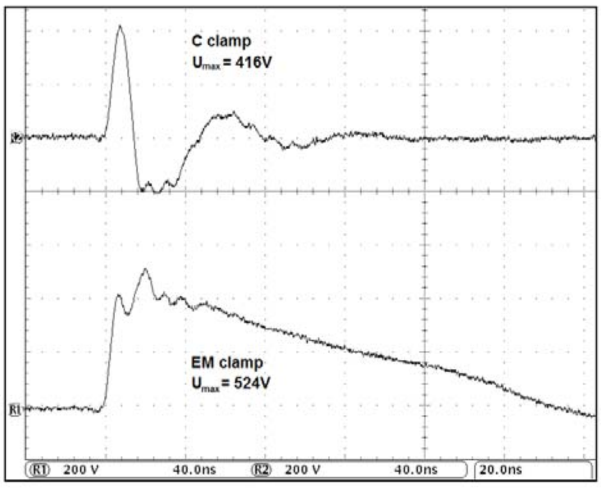

Fig.10. Output voltage of capacitive clamp and EM clamp at EUT side with overvoltage protection at AE side

In case of capacitive clamp the situation is relatively better. Pulse amplitude was lowered only negligibly (from 420 V to 416 V). The negative overshoot was increased. It achieved 50 % of the amplitude of primary positive pulse. But still the positive part of the pulse remained dominant. So, directivity properties of capacitive clamp ensures that placing of overvoltage protections at clamp AE side does not significantly influence the level of the pulses at EUT side.

In case of using EM clamp, the situation is more complicated. As consequence of connected transil's parallel impedance the current driven by EFT simulator will increase, which will impose rising of output EFT pulse amplitude at the EUT terminal. We observed the change from 432 V to 524 V, which is more than 20 % grow. Still it is not critical change, because obviously the severity classes differ by double ratio.

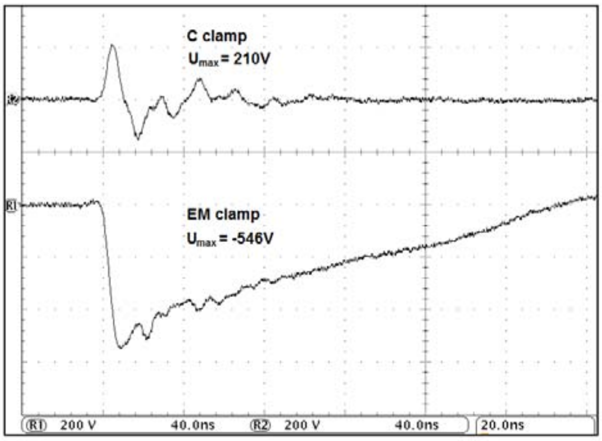

Fig.11. Output voltage of capacitive clamp and EM clamp at the AE side with overvoltage protection at the EUT side

EUTs often involve various internal overvoltage protection circuits, which reduce the influence of EFT pulses. It is advisable to know also reverse directive properties of both CDN types to estimate the behaviour of EFT pulses at the AE terminal of CDN. For this purpose we used the same overvoltage element but at terminating impedance at the EUT side and we measured the pulse shape at the AE side. The results are shown in Fig. 11.

In case of capacitive clamp the situation is as expected. The amplitude of primary positive pulse falls down from 362 V to 210 V, which represents 42 % decrease. This falling down simplifies the requirements on AE safeguarding.

In case of EM clamp the EFT pulses amplitude was significantly increased due to inductive coupling nature. The negative pulse amplitude raised up from -310 V to -546 V, which is 46 % grow. This is the largest pulse amplitude we measured during our experiments. Such level needs additional filtering precautions in many cases.

Conclusion

We compared the behaviour of different CDN types using application of EFT pulses to signal cables at EFT immunity testing. Our measured results show that the amplitude of transferred pulses of the capacitive clamp and the EM clamp is almost the same (Fig. 8), but substantially lower than in case of simulator's internal CDN with a coupling capacitor (Fig. 7). Moreover in cases of the EM clamp and the CDN with a coupling capacitor the pulse widths are much closer to nominal width of EFT pulse prescribed by standard (50 ns by 50 Ω load).

It was shown that the directional properties of both CDNs for signal cabling are different. In contrast to obvious capacitive clamp in case of EM clamp it comes to polarity reversion at the AE side of the CDN. Then using of overvoltage protection at one side of EM clamp can cause the amplitude increase at opposite CDN side. This means that using of protective elements at the AE side can increase the pulse amplitude at the EUT side. In nature this means moderate increase of the test severity level. Corrective adjusting of EFT generator output voltage level may compensate this difference.

This paper approved that the EM clamp can be fully used for realisation of immunity against EFT pulses tests according to EN 61000-4-4 standard despite of mentioned restrictions. The EM clamp may be advantageous in some cases specially by in-situ testing as coupling via the EM clamp is much less sensitive to position to the reference conductive plane, it is mechanically much more robust and shorter than capacitive clamp.

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