Load Dump Pulses According to Various Test Requirements: One Phenomenon – Two Methods of Generation – A Comparison

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Abstract: Although the new European Directive 2004/104/EC as well as a First Draft of a European Standard drawn by CENELEG technical committee 210, working group 8 do not specify any immunity testing against high-energy Load Dump pulses this kind of tests is widely known in both international standards (e.g. ISO 7637-2:2004, SAE J1113 etc.) as well as in most specifications of car manufacturers world wide. Some test requirements still consider the Load Dump test as a transient immunity test while others rather see it as a phenomenon being related to battery voltage simulation. Tendencies show that the Load Dump test is separated from electrical fast transients and microsecond pulses and joined with battery voltage phenomenon like cranking, short interruptions etc. This could be considered as one of the reasons that some test requirements ask to simulate the Load Dump pulse by means of a programmable dc amplifier while others prefer the pulse generation being based on an energy storage capacitor that is discharged into a passive pulse forming network.

This paper will introduce the physical background of the Load Dump pulse and show measuring results of the real phenomenon found in a vehicle. Based on this the two methods of generating Load Dump pulses will be explained followed by a comparison of the waveforms achieved under different load conditions. Finally, an overview will be given about the method being applicable as per the various standards and requirements.

The Origin of the Load Dump Pulse

Looking at the description of the phenomenon Load Dump we find the following physical background in ISO 7637-2:2004:

Test Pulses 5a and 5b

This test is a simulation of a load dump transient, occurring in the event of a discharged battery being disconnected while the alternator is generating charging current and with other loads remaining on the alternator circuit at this moment. The amplitude of the pulse depends on the alternator speed and on the level of the alternator field excitation at the moment the battery is disconnected. The pulse duration depends essentially on the time constant of the field excitation circuit and on the pulse amplitude.

Possible reasons for the disconnection of the battery as described above are:
- cable corrosion
- poor or loose connection
- intentional disconnection with the engine running

The following general considerations of the dynamic behaviour of an alternator during load dump apply:

a) The internal resistance of an alternator, in the case of load dump, is mainly a function of alternator rotational speed and excitation current.
b) The internal resistance Ri of the load dump test pulse generator shall be obtained from the following relationship:

$$Ri = \frac{10 \times U\mathit{nom} \times N\mathit{act}}{0.8 \times I\mathit{rat} \times 12{,}000 \text{ min}^{-1}}$$

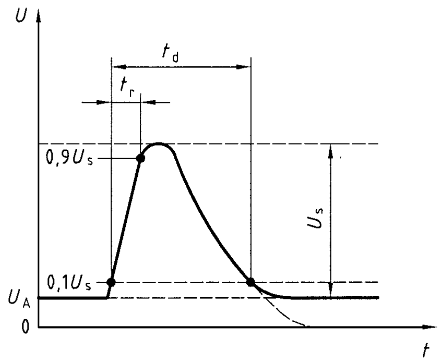
where

U*nom*	is the specified voltage of the alternator
I*rat*	is the specified current at an alternator speed of 6,000min^{-1} (as given in ISO 8854)
N*act*	is the actual alternator speed, in reciprocal minutes

c) The pulse is determined by the peak voltage Us, the calmpe voltage Us*, the internal resistor Ri and the pulse duration td. In all cases, small values of Us are correlated with small values of Ri and td while high values of Us correlate with high values of Ri and td.

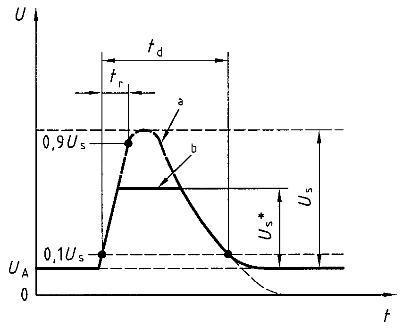
Definition of the Load Dump test pulses as per ISO 7637

The test pulses 5a and 5b are specified as follows:



Parameter	12 V system	24 V system
U_s	65 V to 87 V	123 V to 174 V
R_i	0,5 Ω to 4 Ω	1 Ω to 8 Ω
t_d	40 ms to 400 ms	100 ms to 350 ms
t_r	$\left(10\ {}^{0}_{-5}\right)$ ms	

Figure 1 : Definition of the Load Dump test pulse 5a



[a] Unsuppressed.
[b] Suppressed.

Table 10 — Parameters for test pulse 5b

Parameter	12 V system	24 V system
U_s	65 V to 87 V	123 V to 174 V
U_s^*	As specified by customer	
t_d	Same as unsuppressed value	

Figure 2 : Definition of the Load Dump test pulse 5b

In Annex E of ISO 7637-2:2004 it is further specified that the used transient generator shall generate pulse with a double exponential decay.

Measurements of Real Load Dump pulses

The following measuring results show results taken on an alternator with different loads connected

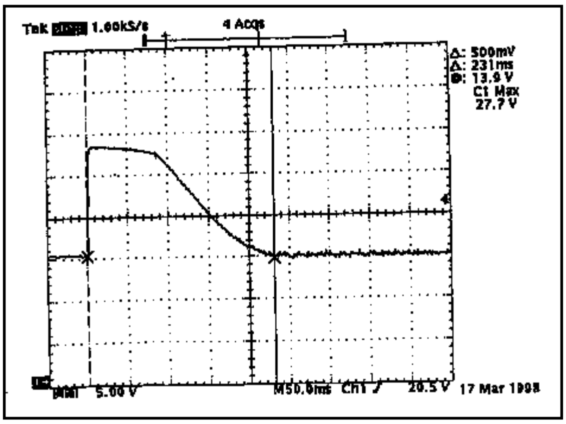


Figure 3 : Load Dump pulse measured under no load condition

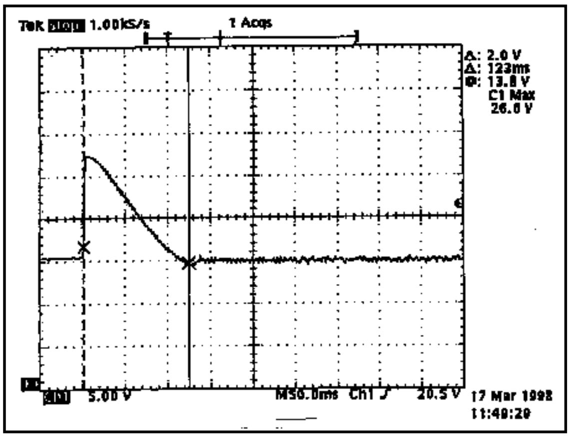


Figure 4 : Load Dump pulse measured with 4Ω load

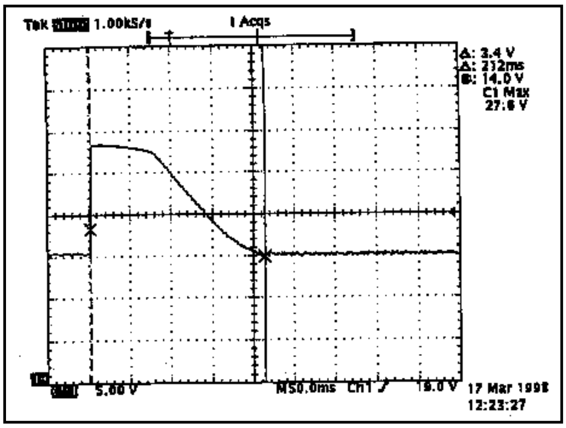


Figure 5 : Load Dump pulse measured with 0.5Ω load

The above figures (figures 3 to 5) show measuring results taken from real alternators equipped with a suppressor network in order to limit the amplitude of the pulse. What the waveforms show as well is that the pulse duration varies considerably depending on the load condition. While the pulses under no load condition and with a load of 4ohm are quite similar (figures 3 and 4) the pulse is much shorter when the alternator is loaded with 0.5ohm.

Another characteristic of the measured pulses is the fact that the pulse decay follows a double-exponential curve until it reaches the supply voltage (in our case the supply voltage is 12V).

Methods of Test Pulse Generation

Looking at commercially available test equipment for the generation of Load Dump pulses we can find two different methods how such pulses are generated.

Generators based on a LCR circuit

The first method is the classic way of generating transients using an energy storage capacitor that is discharged across a passive pulse-forming network. Figure 6 illustrates the basic circuitry.

The energy storage capacitor C_S is charged from a DC supply. When charged the switch S connects the energy storage capacitor to the pulse-forming network and the stored energy generates a transient pulse with a waveform defined by the components of the pulse-forming network L, R_i, R_1 and R_L.

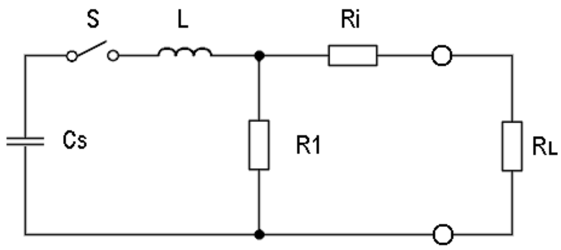


Figure 6: General circuit diagram of a classic transient generator

Generator based on a programmable DC amplifier

The second method of generating load dump pulses is based on a DC amplifier. The corresponding general circuit diagram is shown in figure 7.

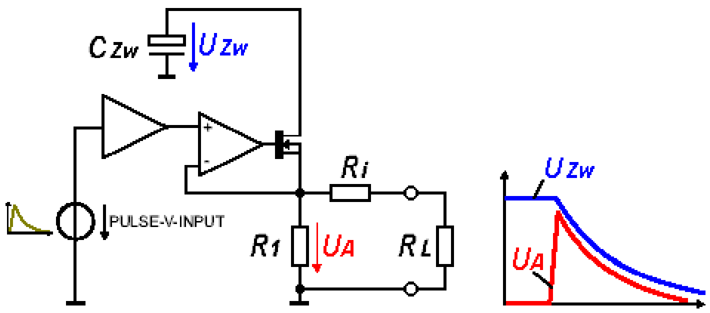


Figure 7: General circuit diagram on a DC amplifier based transient generator

As illustrated in figure 7 the output waveform follows waveform that is connected to the input of the amplifier and will remain unchanged as long as the stored energy of the energy storage capacitor C_{Zw} is sufficient. Hence the generated waveform is more or less independent from the connected load R_L.
Both methods are used in the standards and are considered to be a valid solution for pulse generation. ISO 7637-2:2004 and all manufacturer standards referring or related to this document require the use of a transient generator with an energy storage capacitor discharging across a passive pulse-forming network (as per Annex E of ISO 7637-2:2004). Other manufacturer standards, not making reference to ISO 7637-2:2004, use DC amplifier based load dump generators.
It is up to the user to determine which type of generator to be used for the different test application.

Overview about standard pulses vs. generation method used

The following table of standards (not complete) gives an overview about the type of load dump generators used:

Standard	follows ISO 7637-2:2004	doesn't follow ISO 7637-2:2004
Chrysler PF-10540	X	
Ford ES-XW7T-AC	X	
GMW 3097	X	
Renault 36.00.808/G, Pulse 5a	X	
Renault 36.00.808/G, Pulse 5b		X
Mitsubishi	X	
BMW GS 95002	X	
Fiat 9.90110	X	
Peugeot PSA B21 7110		X
VW TL 82066		X
DC 10615		X
Volvo		X

The following highlights some typical waveform and pulse specifications. As a first example we will introduce the load dump generation as per GMW 3097 (02.2004). The second example being shown is the Peugeot PSA B21 7110 (B) for the 42V supply system.

GMW 3097 (02.2004) referring to ISO 7637-2:2004

GMW 3097 (02.2004) refers to ISO 7637-2:2004 for the Load Dump test pulse 5b (suppressed load dump pulse and specify the following:

- Remove the suppression network and verify that the open circuit unsuppressed load dump voltage waveform meets the specifications of Table 20. (figure 8).
- Connect the suppression network and verify that the open circuit suppressed voltage waveform meets the specifications of Table 20. (figure 8)
- Connect the 2Ω load and verify that the suppressed loaded open circuit voltage waveform meets the specifications of Table 21. (figure 9)
- Replace the 2Ω load with the DUT and start the test.

Table 20: Open Circuit Load Dump Pulse Parameters Specifications

Parameter	Unsuppressed	Suppressed
Transient Amplitude	+100 V ±10 %, ($U_a + U_s$)	(+34 +0/-1) V, ($U_a + U_{s^*}$)
t_d	400 ms ± 30 %	400 ms ± 30 %
t_r	≤ 10 ms	≤ 10 ms

Figure 8: Specification of the open circuit Load Dump pulse as per GMW 3097 (02.2004)

Table 21: Two Ohm Loaded Load Dump Voltage Pulse Parameter Specifications

Parameter	Suppressed
$U_a + U_s^*$	(+34 +0/-1) V

Figure 9: Specification of the 2ohm loaded Load Dump pulse as per GMW 3097 (02.2004)

The following measurements illustrate how the pulses look like. Figure 10 shows the waveforms measured directly at the output of the generator while the waveforms shown in figure 11 are recorded at the end of 1.5m harness with no change to the generator setting.

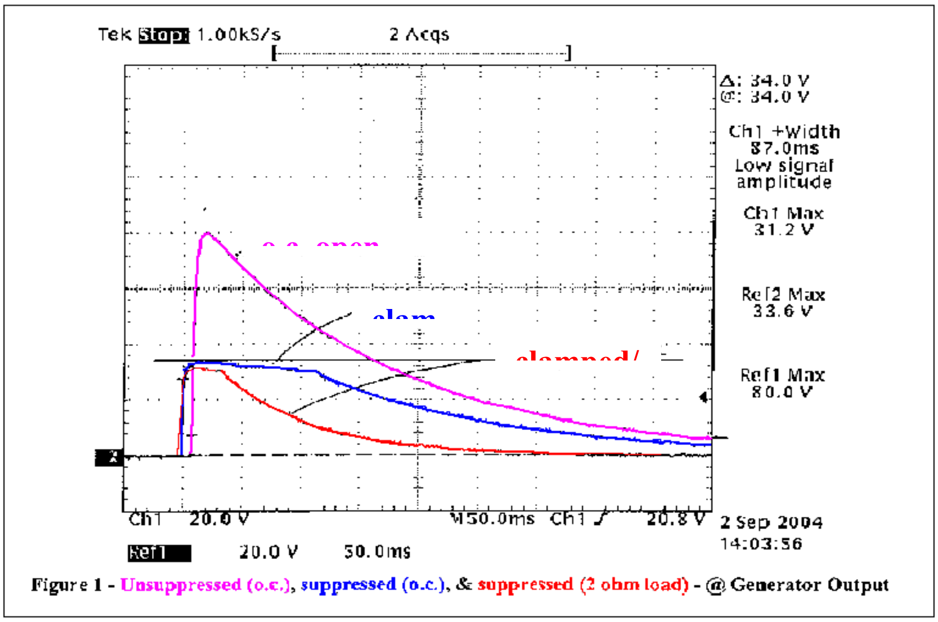


Figure 10: Measurements according to GMW 3097 (02.2004) requirements taken from the generator output

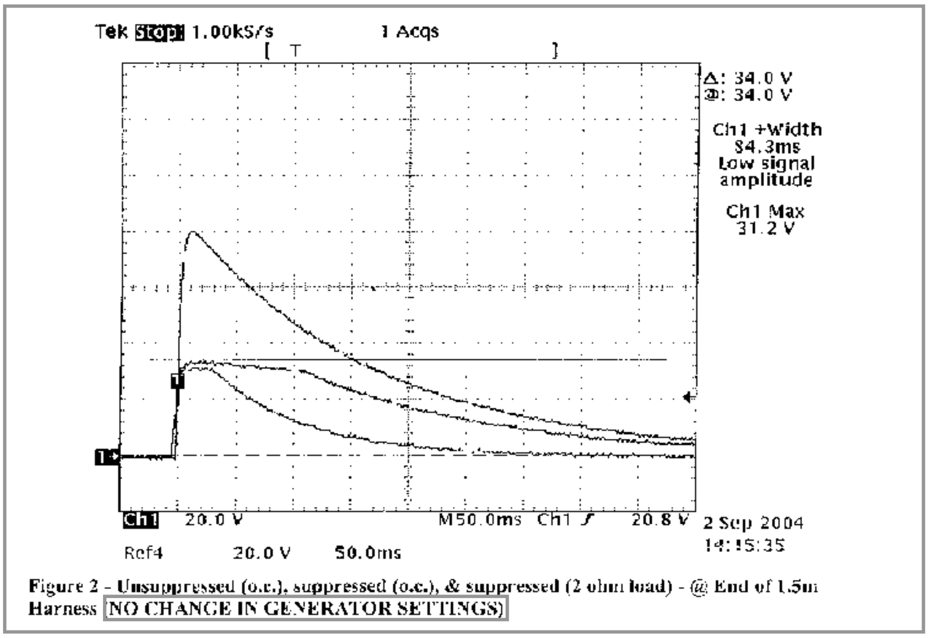


Figure 11: Measurements according to GMW 3097 (02.2004) requirements taken from the end of a 1.5m harness

When comparing the waveforms of figures 10 and 11 we recognise that the related waveforms are almost equal despite of the fact that a harness is connected. But what we can clearly determine from these measurements is the difference between open circuit and loaded condition due to the fact that the pulse generation is based on an energy storage capacitor being discharged across a passive pulse-forming network.

Peugeot PSA B21 7110(B) for 42V supply systems

Figure 12 gives the specification of test pulse 5b as per the above standard (Impulsion 5b).

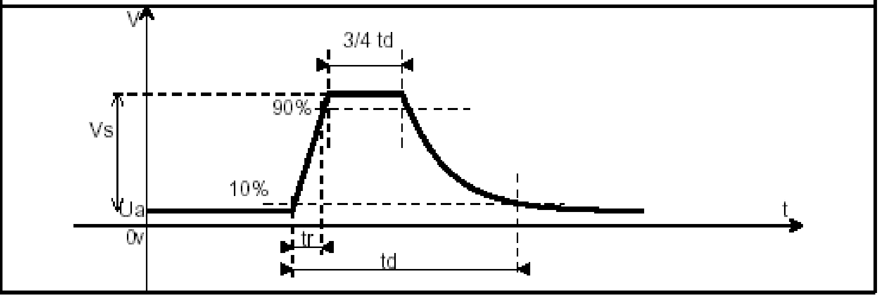
Réseau 42 V	Impulsion 5b
$U_a = 42$ V $V_s = 16$ V $R_i \le 3\ \Omega$ $t_d = 400$ ms $t_r \le 10$ ms	

Figure 12: Specification of the Peugeot PSA B21 7110(B) for 42V supply system

This is a typical waveform specification that requires an equipment based on a programmable DC amplifier to generate. There is no way to generate such a waveform with a traditional transient generator using an energy storage capacitor being discharged across a passive pulse-forming network. The waveform will not change depending on the load but will remain as programmed.

Comparison of energy applied to the DUT

Looking at how the different load dump waveforms are generated it is worthwhile and important to also take into account who much energy is applied to the DUT. Recalling the fact that as per ISO 7637-2 and requirements referring to the same the pulse width and amplitude decrease the smaller the connected load gets. As we have introduced above this requirement can only be fulfilled by using a generator using an energy storage capacitor and a passive pulse-forming network.
If we would use a programmable DC amplifier to generate the same pulse then we might be able to set the amplitude more or less correctly but we can't properly adjust the pulse duration. Figure 13 summarises the waveforms recorded from two different types of generators.

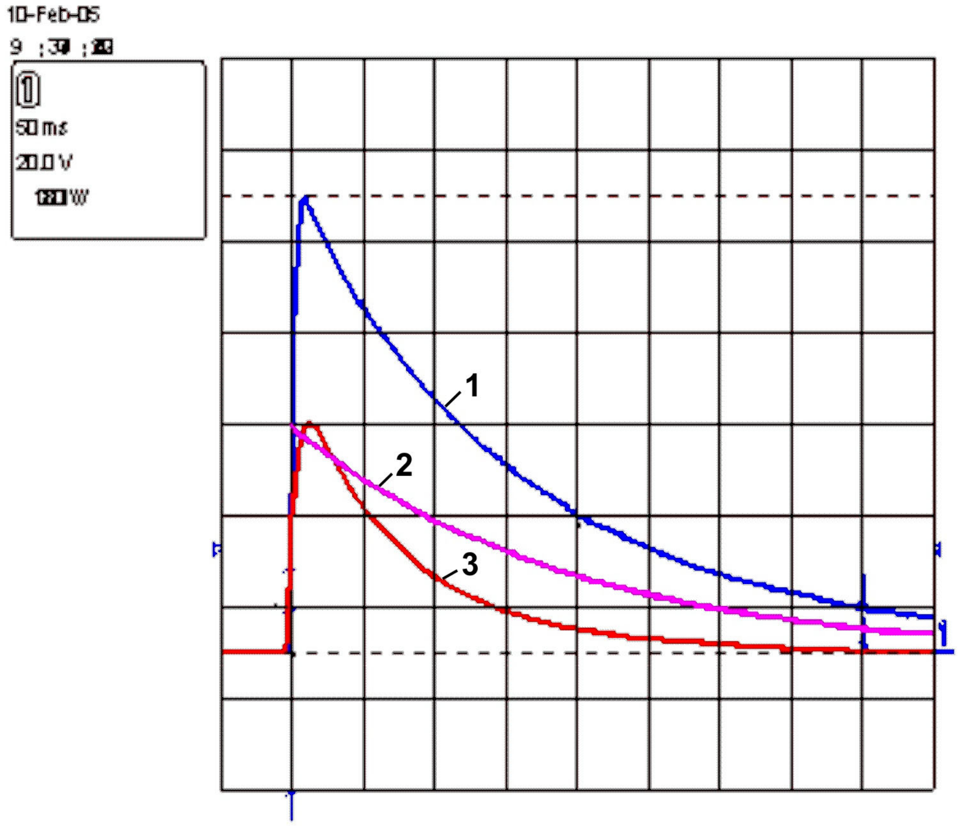


Figure 13: Comparison of waveforms

The blue line (curve 1) shows the open circuit waveform that is about equally generated by both types of generators. The purple line (curve 2) represents the loaded waveform generated by a DC amplifier based generator while, finally, the red line (curve 3) is the loaded waveform generated by a energy storage capacitor based load dump generator. Comparing the area below the area underneath the purple line to the area underneath the red line it becomes obvious that the area is considerably smaller. As the area directly represent the energy of the transient pulse we can conclude that the DC amplifier based generator outputs considerably more energy being applied to the DUT.

Figure 14 here below illustrates a practical example.

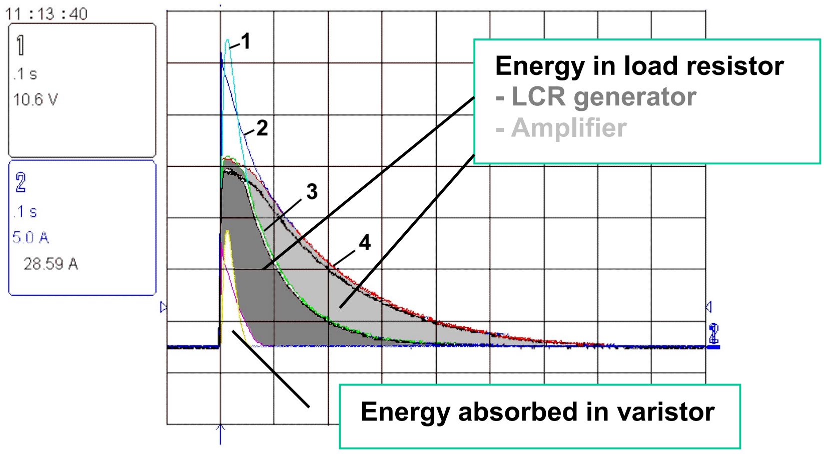


Figure 14: Comparison of the energy distribution in the test circuit

The light-blue (curve 1) and the blue line (curve 2) each show a loaded load dump pulse generated by the two different load dump generators. We can clearly recognise the difference in the decaying part of the waveform.
The light-green line (curve 3) represents the loaded suppressed load dump pulse generated by a generator as recommended by ISO 7637-2:2004, Annex E. The red lined waveform (curve 4) shows a clipped load dump pulse under loaded originating from a amplifier based type.
The white area shows the energy absorbed by a varistor (representing the input protection of the DUT. The grey areas indicate the energy that the DUT is actually exposed to during this test. In the actual example calculation results in a 70% higher energy being applied to the DUT by an amplifier based generator compared to the energy generated by an energy capacitor based generator. Just imagine the harm this additional 70% of pulse energy could do to a DUT!

Conclusion

The load dump transients represent a high-energy and potentially destructive pulse. Even if equipped with a load dump suppressor device the amplitude and energy generated will affect all systems, sub-assemblies and components being connected to the battery supply system in a vehicle. Vehicle manufacturers will for sure continue demanding load dump transients to be tested despite of the fact that neither the new European Directive 2004/104/EEC nor the first draft for a European Product Family Standard for aftermarket electronic equipment in vehicles do consider this.

Tendencies show that the load dump test pulses is likely to be separated from the other transient tests and combined with battery supply tests in a different standard. Whether this will have any influence on how the pulse is generated (design and method used to built a load dump generator) is difficult to predict.

The load dump phenomenon is a dynamic one. The amplitude, the pulse duration and the source impedance considerably depend on the characteristic of the alternator. It is therefore important that the generator offers a variable source impedance to be matched as being appropriate.

In order to generate the load dump pulse specified by the various requirements (international or national standards as well as manufacturer requirements) two different methods and designs of test generators are introduced. Depending on the requirement(s) to be followed the test engineer has to choose the appropriate test equipment to generate the specified test pulse. Using an inappropriate generator could lead to under-testing as well as over-testing.

References

[1] ISO 7637-2:2004 Road vehicles - Electrical disturbance by conduction and coupling - Part 2: Electrical transient conduction along supply lines only

[2] GMW 3097 (2.2004) General Specification for Electrical/Electronic Components and Subsystems, Electromagnetic Compatibility (EMC)

[3] 2004/104/EC Commission directive; adapting to technical progress Council Directive 72/245/EEC relating to the radio interference (electromagnetic compatibility) of vehicles and amending Directive 70/156/EEC on the approximation of laws of the Member States relating to the type-approval of motor vehicles and their trailers.

[4] First Draft prEN (10.2005) Electromagnetic compatibility (EMC) – Product family standard for aftermarket electronic equipment in vehicles drawn up by CENELEC technical committee 210 Working Group 8.

And various vehicle manufacturer specifications.

Biographical Notes

A graduate from the Basel Institute of Technology and holder of a Bachelor degree in Electrical and Industrial Electronics Engineering, registered European Engineer (EUR ING). Has worked in the high voltage test field installing and commissioning high voltage test systems all over the world, training the users in operation and application of HV test installations for eight years. Working for the last nine years in the EMC field as an International Sales Supporter for one of the world's leading companies manufacturing and supplying EMC test equipment for the conducted immunity and emission testing, mainly in the automotive and telecom industry and for CE marking.

A graduate from the Basel Institute of Technology and holder of a Bachelor degree in Electrical and Industrial Electronics Engineering, registered European Engineer (EUR ING). Has worked in the high voltage test field for 15 years and was responsible for impulse generators and the development of their electronic control.
Working since 1994 for EM Test. He is responsible for the CE marking and the support of technical questions for customer service and sales. He makes customer instruction, training and gives seminars all over the world, in operation of EM Test equipment and EMC application.