Manila, Philippines
October 23-27, 2000
CEPSI 2000
Powering the New Millennium:
TECHNOLOGY, PEOPLE & DEVELOPMENT

GIS Instrument Transformers: EMC Conformity Tests for a Reliable Operation in an Upgraded Substation

W. Buesch[1)] **G. Palmieri** **M.Miesch**
J. Marmonier **O. Chuniaud**

ALSTOM LTD

1) ALSTOM LTD
High Voltage Equipment
Carl-Sprecher-Strasse 3
CH-5036 Oberentfelden, Switzerland
Tel.: +41 (0)62 737 37 80 Fax: +41 (0)62 737 33 99
E-mail: werner.buesch@tde.alstom.com

ABSTRACT

When secondary systems are upgraded from conventional electromechanical to electronic equipment, an adaptation of an existing GIS installation may become necessary to achieve EMC conformity.

The paper considers in particular the situation for instrument transformers (IT), i.e. current transformers (CT) and voltage transformers (VT). For example, VT`s designed for electromechanical systems connected to the secondary circuits transmit in general transient overvoltage amplitudes in the range of several kV during disconnector operations without any influence on the equipment. These overvoltage amplitudes may be well above an acceptable overvoltage limit for a safe and reliable operation with electronic equipment. EMC conformity should therefore be proven by testing the transient overvoltage behaviour of the IT`s.

Appropriate testing procedures for GIS IT`s are discussed with reference to test procedures presently under consideration by IEC 60694 and IEC 60044 - 1/2:

a) HV on-site tests with the complete GIS in service during worst case disconnector operations and
b) low voltage tests with impulses of ns-rise time for the IT`s alone.

On the basis of the presented results the best possible method for testing the EMC conformity of GIS IT`s is selected. An appropriate acceptance criterion is proposed.

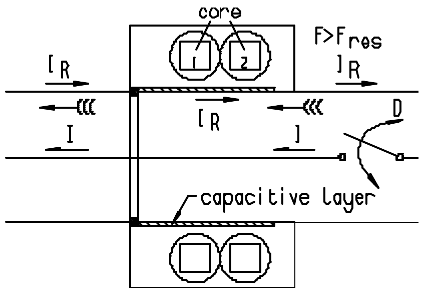
1. INTRODUCTION

Over the last 30 years, gas insulated switchgear (GIS) has been used for a wide range of application. Factors such as high immunity against adverse atmospheric conditions, less maintenance, higher reliability or space savings compared with open air substations are main reasons today for a preferable choice of GIS installations worldwide.

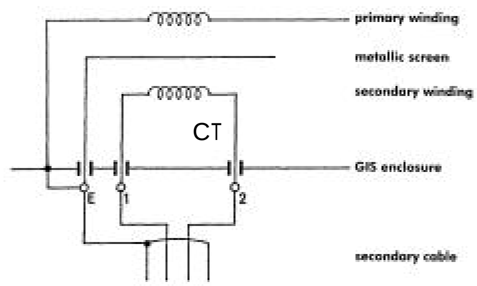
Continuous progress of technology resulted in a very compact design with extremely high reliability of GIS. Fig.1 shows such a modern design e.g. for a 145kV GIS (width of bay 1.2m). The inductive instrument transformers (current transformer CT and voltage transformer VT) integrated in the GIS are provided with special constructive EMC measures for reducing the transmitted transient overvoltages in the secondary circuits to a minimum. These measures are different for CT`s and VT`s.

Fig. 1: 145 kV GIS substation with advanced design

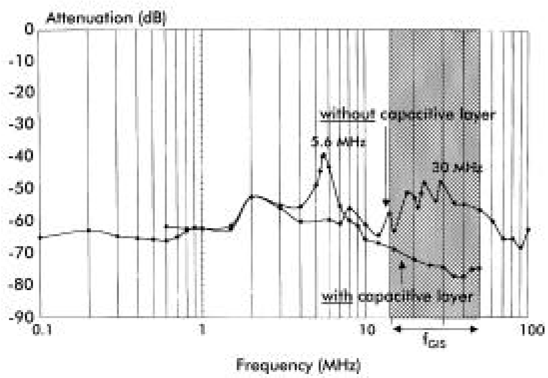
For CT`s, a capacitive layer is mounted parallel to the isolated gap of the inner enclosure of CT (see Fig. 2a and [1]). Fig. 2b shows the typical curve of attenuation for a CT with and without a capacitive layer. Due to the increased capacitance accross the isolating gap, the main resonance frequency corresponding to the lowest value



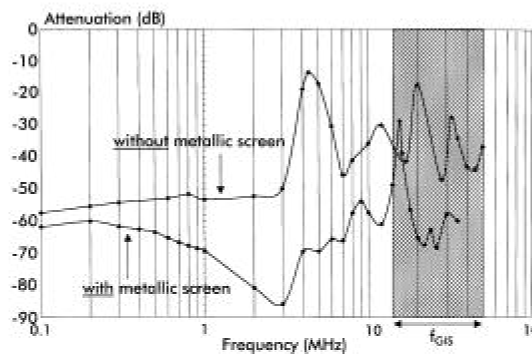
- a -



VT - a -



- b -



- b -

Fig. 2: Inductive CT with EMC shielding
- a - principle design with capacitive layer
- b - typical curve of attenuation for a CT with and without capacitive layer
f_{GIS} typical range of exiting frequencies at disconnector switching

Fig. 3: Inductive VT with EMC shielding
- a - principle design with metallic screen
- b - typical curve of attenuation for a VT with and without metallic screen
f_{GIS} typical range of exiting frequencies at disconnector switching

of attenuation shifts to a lower frequency, e.g. 5.6 MHz. As a consequence, the overvoltage amplitudes with frequencies higher than approximately 10 MHz are significantly reduced.
On the other hand, for VT`s an additional metallic screen is inserted between the HV and LV windings (see Fig. 3a). In contrary to the CT`s the curve of attenuation is reduced almost over the whole range of frequencies considered (see Fig. 3b).
Important for the real EMC behaviour of the instrument transformers (IT`s) integrated in a GIS are the exciting frequencies of the GIS initiated, for example, by switching operations. According to service measurements, their typical range is in general 15 MHz to 50 MHz for disconnector operations (see Fig.2b and 3b).
When an older GIS is upgraded, e.g. change of secondary systems from conventional electro-mechanical to electronic equipment, it is also important to check the EMC behaviour of the existing IT`s [2]. IT`s of older GIS are often designed for electromechanical equipment connected to the secondary circuit. Such equipment is insensitive to transient overvoltages, even for amplitudes of several kV`s. An upgrade to electronic equipment may cause severe problems: The electromagnetic disturbances induced in the secondary circuits should not exceed a peak value of 1600V [3]. The electronic burden is usually only some VA. In an extreme case, it may become necessary to replace the existing IT`s. For such a decision, EMC conformity tests are indispensable in order to correctly judge the transient overvoltage behaviour of the IT`s concerned and to avoid cost for a replacement.

2. HOW TO PERFORM EMC CONFORMITY TESTS?

Testing procedures for EMC conformity tests with GIS installations or in particular with IT`s are presently under consideration by several IEC Working Groups. The actual situation is not yet clear.

2.1 IEC 60694: EMC site tests

EMC site tests are described in an informative annex [4]. Such measurements are not specified as type tests, but may be performed in order to verify the correct performance of the secondary system, or to evaluate the electromagnetic environment in order to apply proper mitigation methods, if necessary.

Switching operations should be carried out at normal operating voltage and with trapped charges on the load side. As this condition may be difficult to obtain at testing, the procedure may be as follows:

– discharge the load side before the closing operation, to ensure that the trapped charge is zero
– multiply the recorded voltage values at closing operations by 2, in order to simulate the maximum trapped charge on the load side
– the resulting peak values of transient overvoltage should not exceed a limit value of 1600 V
– the measurements are to be made at representative ports in the interface between the secondary system and the surrounding network, e.g. at the input terminals of control cubicle, without disconnection of the system.

Fig.4 shows the transient voltage (differential mode) produced by the first restrike during a closing operation of a disconnector and is recorded at the input terminals of control cubicle of a CT. According to IEC 60694 the recorded peak value is to multiply by 2 resulting in an effective peak value of 1680 V.

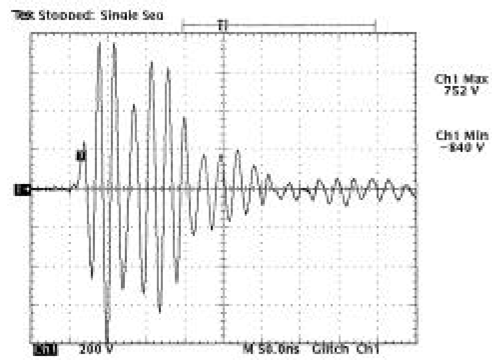


Fig. 4: Transient overvoltage (differential mode) related to the first restrike at disconnector closing measured in the secondary circuit of a CT without EMC measures.

In practice, this procedure may lead to significantly higher overvoltages compaired to service conditions. For example, when a VT is integrated in a section of GIS which should be switched on and off, trapped charges are not retained on the isolated section. On the other hand, reflections of the overvoltage waves at open ends of the main circuit must be taken into account. According to our experience, representative overvoltage amplitudes occurring during disconnector operations in the main circuit are in general:

– sections of GIS with VT: 1.6 p.u.
– sections of GIS with CT: 2.0 p.u.
– sections of GIS with VT and CT: 1.6 p.u.

The peak values of transient overvoltage measured in the secondary circuit correspond to the primary overvoltage values given above. It is obvious that their multiplication by 2 may lead to an unrealistically high secondary overvoltage level which does not occur in service.

A more appropriate procedure is, for example, to look at the overall phenomenon, i.e. all restrikes, which appear during a closing and opening operation of a disconnector. Fig. 5a (closing operation) and Fig. 5b (opening operation) show typical measurement results. Only the highest positive and negative overvoltage amplitude for each restrike during the overall phenomenon is recorded. The conditions are the same as for Fig. 4.

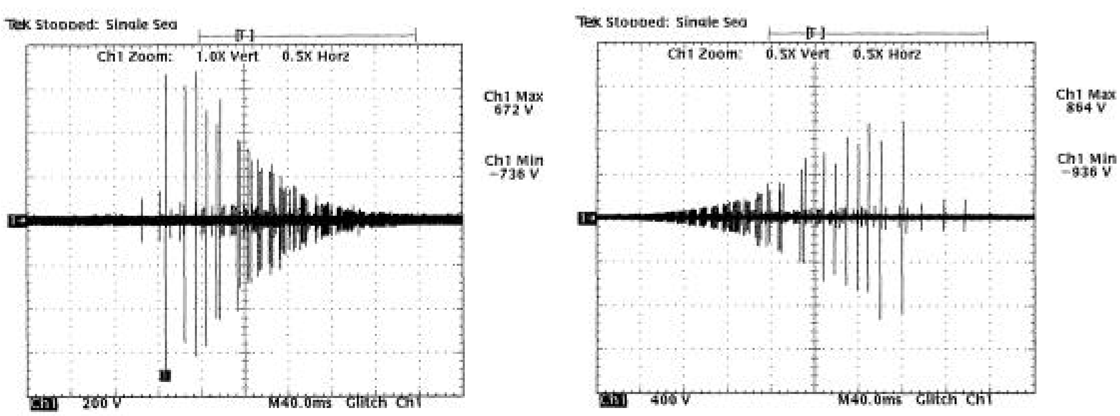


Fig. 5: Transient overvoltages (differential mode) related to the complete phenomenon, i. e. all restrikes, at disconnector switching (same conditions as for fig. 4)
- a - closing
- b - opening

Note the different time scale of figure 4 (50 ns) and figure 5a,b (40 ms).The maximum overvoltage amplitude of 936 V occurred at the opening operation. These measurements include effects such as trapped charge and reflections in the GIS. A multiplication by 2 is not necessary. Since transient overvoltages vary statistically the maximum overvoltage amplitude is determined from the mean value of e.g. 5 opening or closing operations for which the higher overvoltages occurred. It should be also noted that for these measurements a digital oscilloscope with a memory of = 10 k for each channel is required.

2.2 IEC 60044-1,2 (Instrument transformers): Measurement of the transmission factor at high frequency transient overvoltages

Low voltage impulse tests for CT (IEC Draft 38/252/CDV, [5]) and for VT (IEC Draft 38/250/CDV, [6]) are recommended to perform as type tests in the factory in order to check the transmitted overvoltage behaviour of the IT`s. The proposed method applicable for GIS IT`s is summarised in Table 1.

Table 1: Low voltage impulse method for checking the transmission factor at high frequency transient overvoltages [5], [6]

– type of impulse: • front time • tail length • amplitude	 10 ns ± 20 % > 100 ns not defined
– connected burden:	50 O coaxial cable terminated with the 50 O input impedance of an oscilloscope of bandwidth > 100 MHz at the open secondary terminals
– relationship to the operational conditions of the GIS: • highest peak value of the applied primary voltage (1 p. u. = U_m v2/v3)	 1.6 p. u.
– transmitted overvoltage peak value limits	1.6 kV

Fig. 6 shows the results obtained with the low voltage impulse method, for example, for a 245 kV CT equipped with a capacitive layer for reducing the transmitted overvoltages. From these results, a maximum transient overvoltage amplitude of 487 V may be expected in the secondary circuit under service conditions (U_m = 245 kV). The characteristic natural frequency of this CT is approximately 5.7 MHz (see Fig. 6). The burden used was 10 O in contrast to Table 1. The reason is that the burden affects essentially the peak value of transmitted overvoltages. Electronic burdens connected to the secondary circuits of IT`s have in general very low values, e.g. in the range of 10 VA. Corresponding values of burden would be for example:

CT 10 O (I_2=1 A); 0.4 O (I_2=5 A)
VT 333 O (U_2=100/v3 V); 1333 O (U_2=200/v3 V)

Test results show that a change of burden of CT from 50 O to 10 O decreases the overvoltage amplitude approx. by a factor 3. On the other hand, a change of burden of VT from 50 O to 333 O increases the overvoltage amplitude approx. by a factor 2. As a consequence, a better adaptation of the burden to service conditions used for the low voltage impulse test seems to be necessary. An appropriate proposal could be:

for CT: a non-inductive resistor corresponding to the rated burden but not exceeding a value of 20 O
for VT: a non-inductive resistor corresponding to 25% of rated burden but not exceeding a value of 1000 O

In that case, the transmitted overvoltage should be measured at the burden connected to the secondary terminals of the IT`s (cables disconnected) using a high impedance oscilloscope probe.

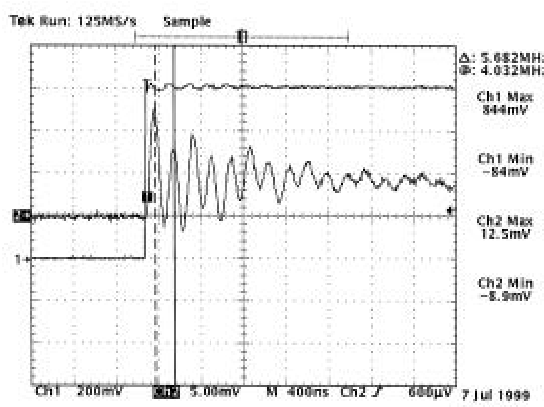


Fig. 6: LV impulse method applied to a 245 kV CT with capacitive layer (R_{burden} = 10 O, without cable)
U_1 = 8 V, U_{2max} = 12.5 mV; k_{tr} = 0.156 %
U_{2max} = 1.6 p. u. x k_{tr} = 487 V (at U_m = 245 kV)
$f_{natural}$ = 5.6 MHz

2.3 Comparison of HV/LV tests

The LV impulse method has been validated by HV tests in a GIS installation taking into account the proposals presented earlier. The results are shown in Fig.7 for a 245 kV CT and in Fig.8 for a 123 kV VT. The details of the test conditions are given in the text of the figures. The measured characteristic of attenuation of the IT`s is added.The typical range of frequencies excited by a GIS installation during disconnector operations in service is in general 15 MHz to 50 MHz.

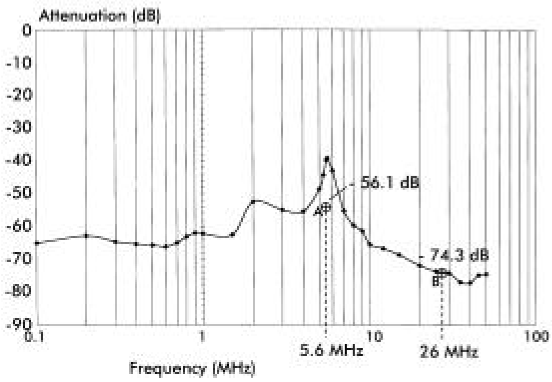


Fig. 7: Comparison of test methods for a 245 kV CT with a capacitive layer
- A LV impulse method (same condition as for fig. 6)
- B HV method with disconnector switching (R_{burden} = 10 O, 8 m cable connection to control cubicle)
  U_{1max} = 1.61 p. u. = 322 kV
  U_{2max} = 62 V at opening, $f_{typicGIS}$ = 26 MHz

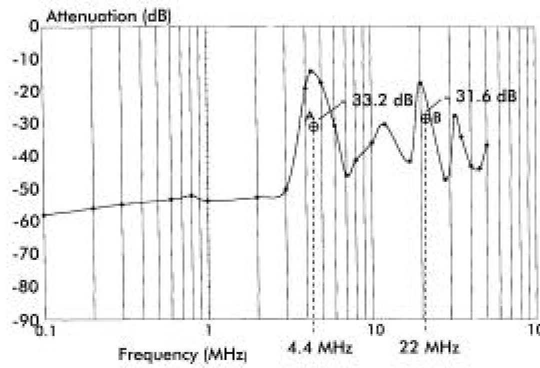


Fig. 8: Comparison of test methods for a 123 kV VT without metallic screen
- A LV impulse method (R_{burden} = 560 O, without cable)
  U_1 = 8.8 V, U_{2max} = 192 mV; k_{tr} = 2.18 %
  U_{2max} = 1.6 p. u. x k_{tr} = 3132 V (at U_n = 110 kV)
  $f_{natural}$ = 4.4 MHz
- B HV method with disconnector switching (R_{burden} = 560 O, 8 m cable connection to control cubicle)
  U_{1max} = not recorded (U_{supply} = 90 kV)
  U_{2max} = < 3800 V at opening, $f_{typicGIS}$ = 22 MHz

From these and many other test results, it may be concluded:

- The typical frequency (= natural frequency) of an IT obtained by the application of the LV impulse method is in most cases that frequency which corresponds to the lowest value of attenuation of an IT (see Fig. 7 and 8).
- The typical main frequency excited by disconnector switching in a GIS installation may differ from the natural frequencies of an IT. As a consequence, the amplitudes obtained by the LV impulse test may be also differ significantly from those of HV tests carried out in a real GIS configuration. Hence, not only the amplitude of transmitted overvoltage but also the typical frequencies excited by a GIS installation are important for a correct judgement of the transient behaviour of an IT (see Fig. 7 and 8).
- The type of impulse given in Table1 is therefore not representative of voltage oscillations due to switching operations in a GIS installation.

2.4 Proposed EMC test procedure

Taking into account the results discussed above the transient overvoltage behaviour of the existing IT`s should be preferably checked by measurements with the complete GIS installation under normal switching operations. Experience has shown that the results obtained under these conditions differ little compared to those recorded at final verification tests after replacement of the secondary systems. The fundamental transient behaviour remains practically unchanged.

The best possible test procedure is to look at the overall phenomenon, i.e. all restrikes occuring during closing and opening of a disconnector as shown in figure 5 a,b. The time-dependent overvoltage characteristic related to the first restrike at disconnector closing is additionally recorded (see Fig. 4). The application of the Fast Fourier Transform (FFT) for analysing the frequency behaviour of the transmitted overvoltage at the same time is a great advantage (compare Fig. 9). This function is offered by advanced digital oscilloscopes. The use of the proposed procedure allows for a correct judgement of the transient behaviour of IT`s on site.

3. TO REPLACE IT`S OR NOT

The decision to replace the existing IT`s completely, partly, or not at all is also important from an economical point of view. A thorough evaluation of the existing situation is required.

The EMC conformity test method described in section 2.4 has been successfully proven. As an example of measurement, for a 123 kV VT Fig.9 shows the time-dependent overvoltage characteristic of the first re-strike recorded at closing of a disconnector. That switching condition in the GIS installation was selected for which the highest transmitted overvoltage in the secondary circuit occurs. At the same time a FFT analysis was applied showing a typical exiting frequency of the GIS installation of 21.5 MHz in the given situation. The tested VT`s are not equipped with an appropriate metallic screen for EMC shielding. As a result, transmitted overvoltage amplitudes up to 3.6 kV were measured. When electronic equipment is integrated in the secondary circuits of a GIS installation induced electromagnetic disturbances should not exceed a peak value of 1.6 kV [3]. The VT`s have been replaced.

According to field experience with different substation configurations, a criterion of judgment of the EMC conformity of IT`s with electronic equipment connected to the secondary circuits is presented in Table 2. It may be used to assess the existing situation with respect to the EMC conformity of IT`s.

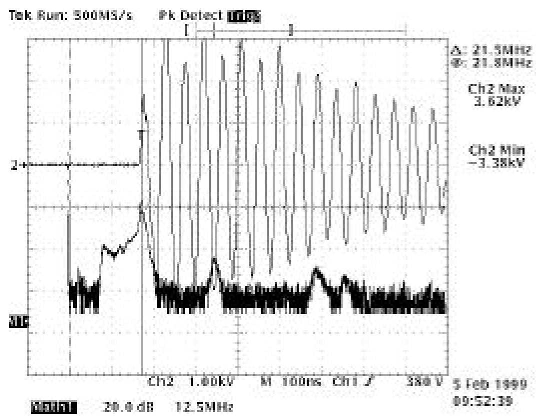


Fig. 9: Transient overvoltage (time-dependent characteristic) recorded for the first restrike at disconnector closing for a 123 kV VT without EMC measures, including a FFT frequency analysis
(R_{burden} = 560 O, 8 m cable connection to control cubicle)

Table 2: Criterion of judgement of the EMC conformity for IT`s

Instrument transformers (VT and CT)	
Highest value of transmitted overvoltage recorded	Decision
= 1600 V	replacement not necessary, application of additional measures not necessary
> 1600 V - 4000 V	replacement not absolutely necessary, however application of damping elements (e.g. ferrite cores) may be required, final EMC verification test recommended
> 4000 V	replacement recommended, improved EMC shielding necessary

If the highest amplitudes recorded for both differential and common mode voltages are lower than 1600 V, additional measures are not necessary and EMC conformity is achieved. Experience indicates that the safety margin is sufficient compared to the test voltage of electronic equipment of 2.5 kV for the damped oscillatory wave test [7], provided that the frequency of test wave was 1 MHz,10 MHz and 50 MHz as recommended by IEC 60694 [3]. If the overvoltage level at the input terminals of control cubicle exceeds the limit value of 1600 V slightly, the measurements may be repeated at the input terminals of electronic devices.The criterion for EMC conformity is the same as before.

Finally, it should be noted that any decision for replacement of an IT must also consider other important aspects such as the influence of change of burden on IT specification [2].

4. CONCLUSIONS

– A modification of secondary equipment, i.e. upgrade from electromechanical equipment to electronic may also require an adaptation of the existing IT`s to achieve EMC conformity for the upgraded GIS installation.

- The EMC conformity of the existing IT`s should be checked by measurement. An appropriate testing procedure is presented. Its validity is proven by on-site tests.
- IEC methods for testing EMC conformity, actually under consideration by IEC 60694 and IEC 60044-1,2, have been tested in practice. A need of further improvement with respect to real service conditions is demonstrated.
- A criterion of judgement of EMC conformity of IT`s with electronic equipment connected to the secondary circuits is proposed. It may help to justify the measures on existing IT`s including replacement and to select a technically and economically optimal solution.

5. REFERENCES

[1] European Patents: "Current transformer with annular core to be built in a metal clad high voltage switchgear", No. EP0063636 B2 and No. EP0665561 B1

[2] W. Buesch, M. Miesch, G. Palmieri: "User Guide for GIS adaptation when upgrading secondary technology", CIGRE, 23-206, 1996

[3] IEC 6094: "Common specifications for high voltage switchgear and controlgear standards", second edition, May 1996

[4] IEC 17A/510/CD: "Draft Amendment to IEC 694: Common specifications for high voltage switchgear and controlgear standards - EMC tests", September 1997

[5] IEC 38/252/CDV: "Amendment 3 to IEC 60044-1, Ed. 1: Current transformers - Measurement of the transmission factor at high frequency transient overvoltages", April 2000

[6] IEC 38/250/CDV: "Amendment 2 to IEC 60044-2: Inductive voltage transformers - Part 2: Measurement of the transmission factor at high frequency transient overvoltages", April 2000

[7] IEC 61000-4-12: "Electromagnetic compatibility (EMC) - Part 4: Testing and measurement techniques - Section 12: Oscillatory waves immunity tests", 1995