EMC and the ABB Group in the next millennium

Electromagnetic compatibility (EMC) is the property of electrical or electronic equipment that enables it to operate reliably in its electromagnetic environment without interfering with the operation of other equipment, especially third-party apparatus, such as radios, televisions and mobile communication systems. Today, EMC is an established scientific discipline based on mathematics, physics and theoretical electrical engineering. ABB is able to satisfy not only the legal stipulations, which should be considered as the minimum level of EMC required, but also the most demanding requirements in this extremely challenging field.

Within Europe, electromagnetic compatibility (EMC) is regulated by the EMC Directive and national laws. Whereas the EMC Directive covers and regulates the protective requirements, the technical requirements are always regulated by what are known as the 'European Harmonized Standards'. The legal requirements of the EMC Directive have to be considered as a minimum, as they do not always meet the full requirements of the product end-users.

As far as the EMC Directive is concerned, the biggest challenge in the future will most likely involve installations **1** and IT (Information Technology) equipment. In the case of the installations the main issue will be: who has legal responsibility for their EMC compliance. This is because EMC properties are widely perceived as being the joint responsibility of the manufacturers and assemblers. The second concern has to do with the widespread use of IT equipment, including personal computers, and the fact that new generations are developed and brought to market at very short intervals. Besides having an extremely short technological lifetime, this equipment is usually designed for domestic applications that bear no resemblance to most industrial environments.

Future products

The ABB Group supplies industry with a huge range of components, finished products, systems and installations. Designing electronic products to operate in an industrial environment largely involves mastering the art of making them electromagnetically compatible. The most difficult task the designer faces in connection with EMC is identifying differences between the ideal and actual properties of the electrical connections, the passive components and the active components. This is necessary, however, for correct computer-based modelling, simulation, calculation and trouble-shooting.

Industry is constantly demanding new technology. Usually, this is based on modern microprocessor systems and their peripherals. Industrial equipment will continue to feature high-performance analogue circuits and more and more functions for high-speed communications will be included in the design. New technology introduced to the market in the future will offer a previously unimaginable potential for increasing production and performance, while at the same time reducing costs, lessening environmental impact and improving quality.

Every manufacturer introducing new technology has to deal with two groups of people: one which looks upon it with enthusiasm and one which is sceptical.

Manufacturers and suppliers of new technology have both a responsibility and an obligation not to disappoint the enthusiasts, yet at the same time must convince the sceptics that the new technology has come to stay and really does 'deliver' the promised advantages.

Presumably there is no manufacturer who, if he wants to survive, will not strive to ensure that the equipment he is offering will live up to his claims. And it can also safely be assumed that every manufacturer will ensure that his product works properly in the development department and laboratory.

However, it has to be asked whether this is enough to guarantee trouble-free operation and satisfied customers? The answer is a simple yes, providing the sources of interference existing in the industries for which the product is intended are taken into account, and the manufacturer checks this by performing EMC tests relevant to the intended environment and application.

When this is done, and the equipment comes up to all expectations, it will be an easy matter to convince the pessimists that their doubts are unfounded.

The conclusion to be drawn from this is that the manufacturing company has to pursue a policy of ensuring that every circuit-board, product, system and installation satisfies the requirements for industrial use, and does it with generous margins. This must be

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verified by means of EMC tests. A policy of designing all products so that they are free of interference is crucial to a company's success, and the lack of such a commitment could spell disaster for the customer or supplier, or both.

Circuit theory

Electronics used in early control and supervision systems contained very simple electromechanical components and electron tubes. Such equipment was slow, and the interference signals that posed a risk were only in the low-frequency ranges. The philosophy adopted for the suppression of disturbances could be kept very simple and it was enough to use circuit theory based on Ohm's and Kirchhoff's laws.

Today, it is still common for theoretical EMC analyses to be based on electric circuit theory. However, such theory uses as its platform many scientific abstractions which more or less ignore the relevant facts. Also, the circuit parameters which are used, eg inductance, capacitance, electric resistance, magnetic resistance, are thought of as being fixed.

Any analysis of electromagnetic phenomena based on electric and magnetic circuit theory therefore gives approximate, imprecise results. In fact, such analyses will often produce meaningless results if they do not make use of electromagnetic field theory. The radiation and propagation of electromagnetic waves is a typical example of a problem which cannot be solved using ordinary circuit theory.

Electromagnetic field theory

New developments in electronics have been at the center of many technological achievements in recent years, and the electronics sector is certain to carry on evolving dramatically in the future. Industrial equipment does, in fact, already today constitute high-tech electronics, and is destined to become faster and smaller with each new advance.

Offshore platforms are among the many industrial installations that depend on electromagnetic compatibility for reliable operation. **1**

The electromagnetic environment will also change dramatically; for example, modern radio and telecommunications equipment will be located closer and closer to the electronics, while the frequency range that is used will increase to several GHz. Also, maintenance crews will need to use modern telecommunications equipment in their jobs. This means that they will be increasingly confronted with electromagnetic field phenomena.

Obviously, a closer look needs to be taken at electromagnetic compatibility using electromagnetic field theory as a basis.

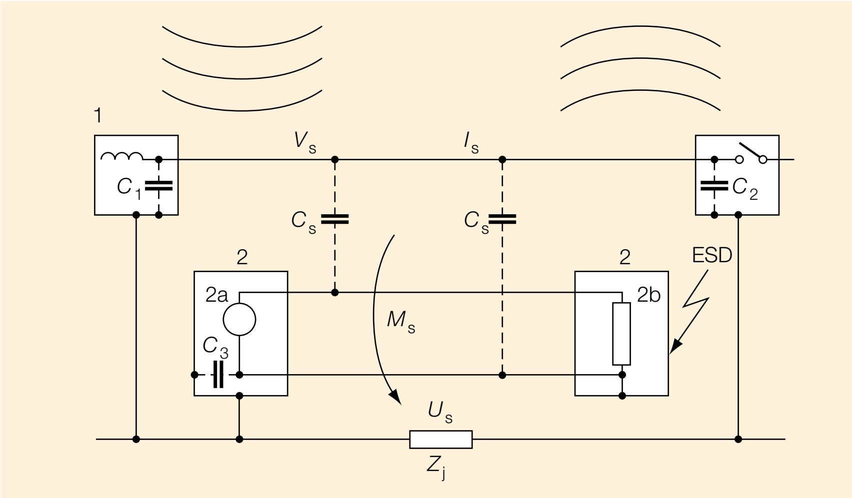
In order to correctly calculate circuit conditions it is necessary to first identify both the electric and the magnetic fields that exist in energized circuits. Knowledge of these electromagnetic fields is necessary not only to establish the circuit parameters but also to establish the characteristics of the electromagnetic phenomenon.

A complete analysis of the electromagnetic phenomenon can be performed on any item of equipment providing the current density, electric field strength and magnetic field strength, including their rates of change, are known. However, detailed studies are only possible when the characteristic field quantities are also known. Only by using Maxwell's equations can it be certain that solutions are reliable and complete.

Installations

In accordance with the 'Guide for the Application of the EMC Directive' (issued in 1998 by the Third Directorate of the European Commission and accepted by all member states), components with a so-called direct function and finished products for distribution or final use, as well as the systems in which they are used, have to carry the CE mark. However, the guide to application of the Directive only requires an installation to fulfil the essential EMC requirements; no requirements exist with regard to CE-marking of installations or approval by the competent body.

In everyday usage, the word 'installation' has come to mean a combination of different types of equipment, designed and assembled to perform a specific task; the end-user decides which equipment is used in its construction, and the combination as such is



Ways in which interference can be coupled into circuits **2**

1 *Interference source*
2 *Victim*
2a *Signal source (transmitter)*
2b *Electronics*

ESD *Electrostatic discharge*

$C_1 – C_3$ *Stray capacitance*
C_s *Coupling capacitance*
I_s *Current*
M_s *Mutual inductance*
U_s *Voltage*
V_s *Potential*
Z_j *Earth-line impedance*

not intended for sale on the open market as a single functional unit. Such installations obviously have to be treated legally as systems without additional EMC requirements, since the EMC Directive will already have been applied to the individual items of equipment.

Fixed installations

Articles 1(1) and 2(1) of the EMC Directive apply to installations containing electrical and/or electronic components. A fixed installation, in the broadest sense, is defined as a combination of several types of equipment, systems, finished products and/or components (hereafter referred to as 'parts') assembled and/or erected by an assembler/installer at a given place and intended to operate together to perform a specific task in a defined environment, but not intended to be placed on the market as a single functional or commercial unit.

In a fixed installation thus defined there could also be parts which are not intended for use in the marketplace as single functional and commercial units (ie, *not* CE-marked). It makes no difference whether the parts come from one or more manufacturers, as the ultimate electromagnetic effect of the combined parts in the installation is simply not known by the vendor(s), who can only assume responsibility for each individual part officially placed on the market.

EMC problems involving equipment used in fixed installations are solved on a case-by-case basis, through cooperation between the manufacturers of the parts, the user and, when applicable, the installation contractor. The combined expertise of these parties ensures correct operation of the installation as a whole.

The people responsible for the design, engineering and construction (assembly and erection) become the 'manufacturer' in the context of the Directive, and assume responsibility for the installation's compliance with all applicable provisions contained in the Directive on being taken into service.

The EMC instructions provided by manufacturers of parts and also the method of installation have to correspond to good engineering practice as understood in the national, regional or local installation regulations. However, the design and manufacture of equipment already conforming to the Directive must not be influenced by this.

Such installations are not allowed to move freely within the EU market. No requirement for CE-marking exists; neither EC DOC (Declaration of Conformity) nor the involvement of a competent body is needed.

Coupling factors

It is extremely important to understand how interference arises in electronics and how its effect can be avoided or mitigated.

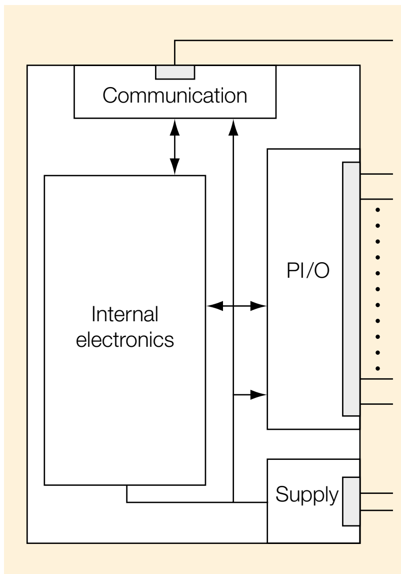
Interference is coupled into electronics in every technically conceivable way **2**, namely by:

- Induction
- Capacitance
- Conduction
- Radiation

Unwanted effects are avoided by reducing the degree of coupling into the equipment

Block diagram of an apparatus showing the interference barriers (grey areas) **3**

PI/O *Process input/output*



electronics. This applies particularly to high-frequency signals, where the interference signal and the useful signal are in the same frequency range (this is a new situation which has not been encountered in the past).

All interference can take the form of common-mode voltage (CMV) or normal-mode voltage (NMV).

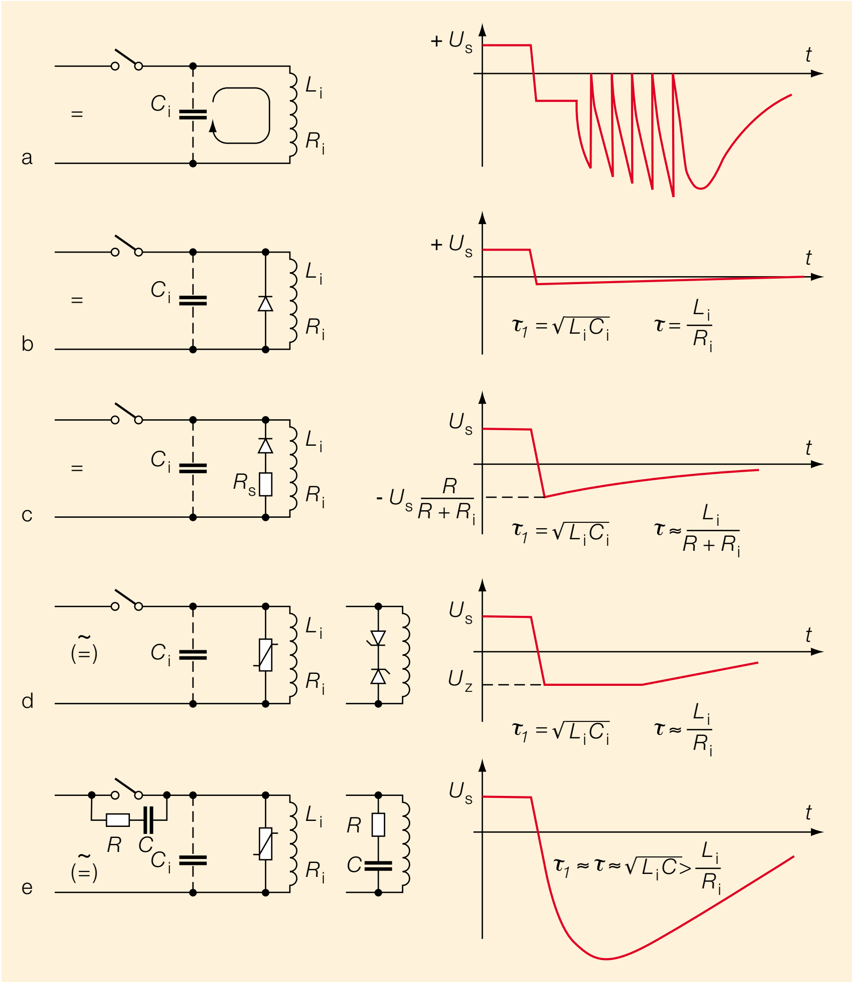
Mitigating the effects of EMI

When working on any new product, the electronics designer alone is responsible for incorporating the interference immunity and emission aspects. The designer's awareness of this responsibility will be rewarded when the installed and commissioned system operates smoothly and without disturbance.

The interference immunity of an electronic product is mainly decided by the earthing, grounding and screening of the installation as well as the quality of the zero-volt plane and the barriers **3** in the electronics. Nevertheless, correctly designed and carefully chosen power supply units, analogue and digital circuit boards as well as communications, remain a prerequisite for a successful configuration.

The principle 'decrease the amplitude and frequency of the source as well as the coupling between the interfering circuit and the victim' should be adopted in order to successfully suppress electrical interference. This can be achieved by following certain rules:

- Use an uninterrupted power supply.
- Separate the cables.
- Locate very sensitive cables as close as possible to the earth line or in the conduits.
- Use properly grounded (ie, with 360° connection) screened cables with acceptable transfer impedance.
- Use twisted-pair cables.
- Use overvoltage protection.
- Suppress interference sources **4**.



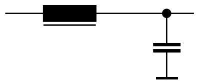
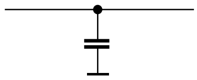
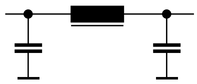
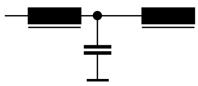
Methods of suppressing interference **4**

a *Not suppressed*
b *Suppressed with diode*
c *Suppressed with diode and resistor (DC circuit)*
d *Suppressed with varistor, TransZorb or 2 back-to-back zener diodes (AC circuit)*
e *Suppressed with capacitor and resistor (AC circuit)*

C *Snubber capacitance*
C_i *Stray capacitance*
L_i *Load inductance*
R *Snubber resistance*
R_i *Load resistance*
R_s *Suppressing resistance*

τ *Time constant of switching phenomenon*
τ_1 *Time constant of inductive load*
t *Time*
U_s *Source voltage*
U_z *Clamping voltage*

- Improve the environment (humidity) if electrostatic discharges cause a problem.
- Use a filter in power circuits **5**.
- Use a filter in signal circuits.
- Use 'chokes' **6**.
- Ensure correct connection of the cable screen.
- Protect against corrosion.
- Locate signal and return wire in same cable.
- Use conduits.
- Use an earth-line network.
- Use isolated circuits.
- Employ a total electromagnetic shielding concept.

Line impedance	Low-pass filter configuration	Load impedance
Low		High
High		High
High or not known		High or not known
Low		Low
Low or not known		Low or not known

Filter types for different applications **5**

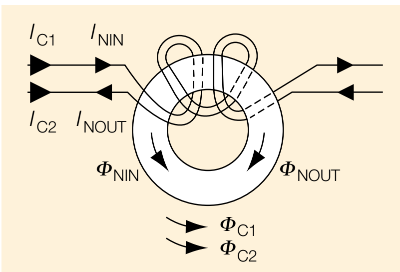
Electromagnetic shielding for total EMI protection

Only a total electromagnetic shielding concept, complete with filtering, will provide the desired overall protection against electromagnetic fields in every case. Assuming that the shield completely surrounds the object being protected, the electromagnetic wave will partly penetrate the shield and be partly reflected by it. If the material is sufficiently thick, the electromagnetic wave will be completely attenuated. (The shield has a dual function, ie it also protects the environment from electromagnetic fields originating inside the enclosure.)

Physically, the shield function is explained by eddy currents which are produced in the shielding material and which form an internal field that opposes the outer field. The required minimum shield thickness depends on the wavelength of the electromagnetic field. An electromagnetic wave is, in principle, completely attenuated in a conductive environment when the ratio of the amplitude before and after the shield is 0.00185.

Choke with high-frequency core for interference protection **6**

$I_{C1,\,C2}$ *Noise current (common mode)*
$I_{NIN,\,NOUT}$ *Load current (normal mode)*
$\Phi_{C1,\,C2}$ *Flux caused by noise*
$\Phi_{NIN,\,NOUT}$ *Flux caused by load current*



Magnetic shielding

To provide protection against undesirable magnetic fields, completely encapsulated enclosures made of ferromagnetic materials must be used. These enclosures, inside which the field is very much weaker than outside, are called magnetic shields **7**.

The use of ferromagnetic materials, which have a much higher permeability than space ($\mu \gg \mu_0$), results in concentration of the magnetic field density and passage of the field where the magnetic resistance is lowest. Thus, no field passes into the encapsulated space.

Protection against magnetic fields is often realized in steps (cascades) by means of 'enclosures within the enclosure'.

Nuclear electromagnetic pulses (NEMP)

While everyone hopes that civilization will never be confronted with NEMP, some buildings and installations of crucial importance to society must be protected against this phenomenon **8** to avoid the total collapse of society in the event of war or terrorist attack.

The same knowledge and principles can also be applied to provide protection against non-nuclear EMP pulses, eg pulses caused by certain atmospheric phenomena.

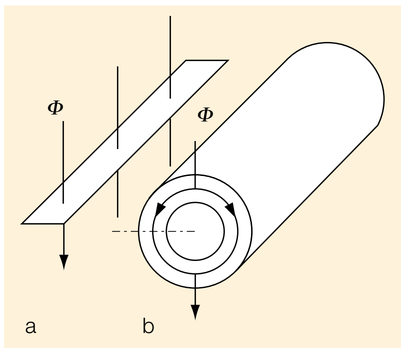
Strategy for dealing with NEMP effects

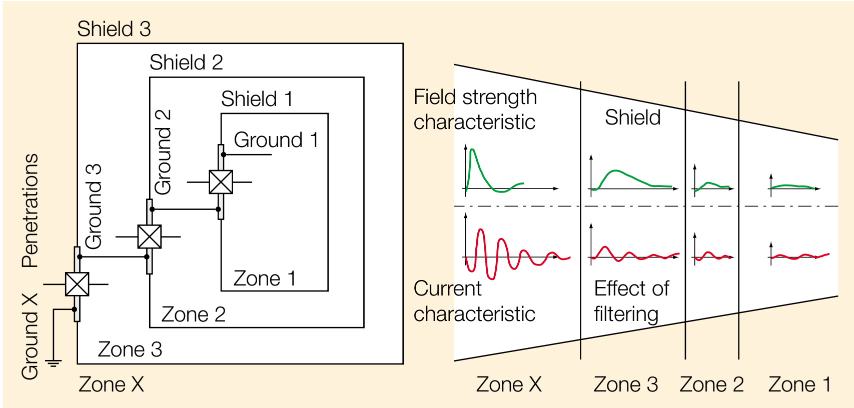
Before a project is started, an analysis is necessary to establish initial guideline estimates of the threats in the form of voltages, currents and fields expected at the interfaces. These are obtained by means of computations performed during the preparation of the technical specifications.

Large-area systems have to be divided analytically into subsystems which can be handled by test technology.

Magnetic flux, Φ, diverted by the magnetic shield **7**

a *Cross-sectional area*
b *Cable with magnetic shield*





NEMP protection zone concept **8**

The entire analysis, planning and testing procedure, including project management, is shown in simplified form in **9**. It is important to incorporate these measures in the project procedures at the earliest possible stage to avoid cost-intensive, and in some cases unsatisfactory, retrofitting later.

NEMP protection philosophy

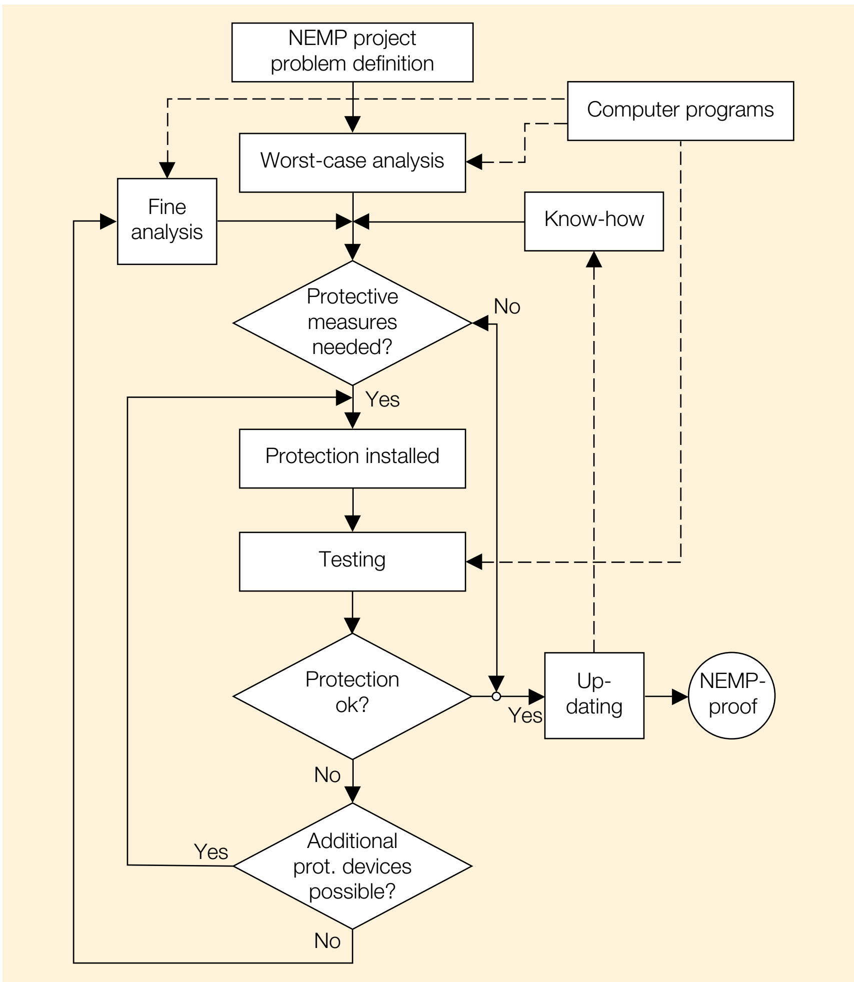
American NEMP specialists divide the protection concept for 'earth-based systems' into three areas:

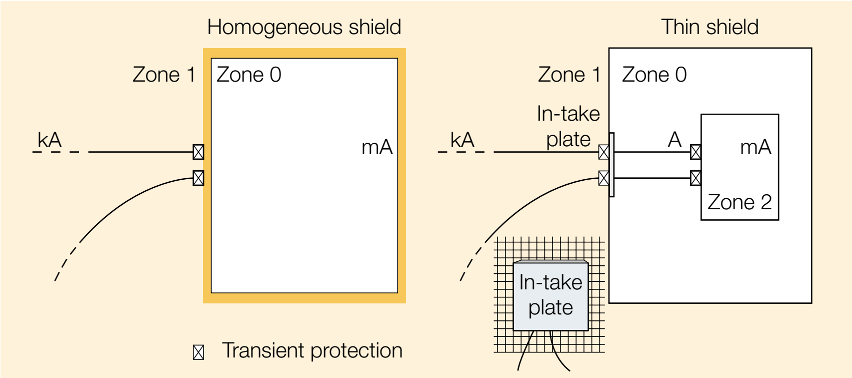
- *Topology* **10** (division into zones)
- *Penetrating conductors*
  Emphasis is justifiably placed on the great importance of shield-penetrating conductors. Here, decisive improvements can often be achieved by simple means, eg by bonding the cable screens at the apparatus input (360° connection). Spare leads are to be eliminated.
- *Aperture control*
  Only one aperture in the building **10** is to be used (and has to be as small as possible) at the buildingentrance. Apertures in a shield (for cooling pushbuttons, switches, potentiometer shafts, etc) are generally unavoidable. In fact, these apertures act as waveguides, and the shielding effectiveness in the case of certain frequencies can be altered by designing them correctly. To maintain good shielding effectiveness the cut-off frequency must be much greater than the operating frequency. Honeycombs are generally used for ventilation apertures. (Honeycombs are multiple waveguide elements arranged side by side, but the shielding effectiveness at frequencies well below the cut-off frequency is reduced by the number of elements.)

Theoretical analysis

Since simulators normally cannot be used to study NEMP phenomena in large systems, theoretical analysis often has to be applied instead. Small software packages based on several simple subprograms and allowing fast, low-cost solutions are available for this. These are expected to replace the large and hence unwieldy computer codes still widely used for certain applications, and which require huge amounts of data as input as well as long data processing times.

Typical NEMP project procedures **9**





Topology zone concept. More zones can be connected as cascades. **10**

EMP-protected installations

When designing new NEMP-protected installations, eg facilities covered with layers of earth, it might be advantageous to include the steel reinforcement skeleton in the zonal concept **11**. In the low-frequency range (10 kHz) this could result in a gain of approximately 20 dB in magnetic shielding effectiveness. A prerequisite, however, is correct welding of the reinforcement bar crossings.

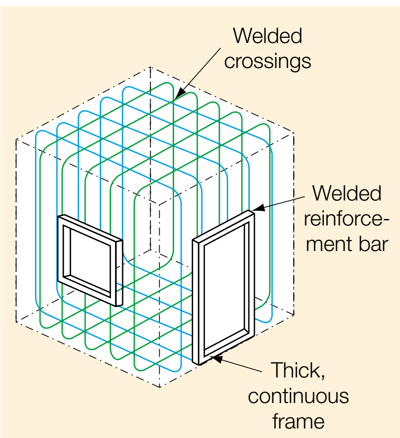
Special filters for NEMP and EMP applications

The electromagnetic radiation caused by nuclear explosions depends on the height at which the explosion takes place. An explosion at a very high altitude generates a very powerful field of about 50 kV/m. The electromagnetic pulse has a very short rise time, typically less than 10 ns. A special, technologically advanced filter can be included in the NEMP protection. NEMP filters are a part of the general protective configuration, usually with specific features such as:

- A primary protective arrangement designed to shunt the majority of the undesired energy to ground.
- A delay arrangement in which the incoming pulse is slowed prior to entering the filter. The filter is very often fitted some distance away from the primary protection, eg on the other side of the wall.
- A secondary protective arrangement, normally provided in the form of a zinc-oxide varistor fitted across the filter terminals (attachment contacts) which reduces the electromagnetic pulse.
- A filter in each phase and in the neutral. Filtering by means of a common core is not recommended as a powerful pulse can cause the cores to lose their low-frequency features.
- Multiple filters. More filters can be connected in parallel to increase the nominal value of the current without increasing the losses. The current can be distributed in the particular branches by means of busbars. Special attention must be paid to shielding as well as to electrical safety.

The NEMP filter should be used in shielded rooms as well as in all facilities in the ground, water and air designed to provide NEMP protection.

Cost-effective shielding concept **11**



Conclusions

Sound theoretical knowledge of all the problems involved is essential in order to fulfil the legal and specific EMC requirements of customers. The ABB Group is able to meet not only the legal stipulations, which should be considered as the minimum level of EMC required, but also the most demanding requirements in this extremely challenging and controversial field. Furthermore, the ABB Group can transfer this know-how through consultation and training to anywhere in the world.

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