Building Simulation

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LOW FREQUENCY MAGNETIC INTERFERENCE IN HIGH-RISE BUILDINGS

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ABSTRACT

With increasing demands for electric power in large commercial buildings the problem of magnetic interference to sensitive equipment has increased. However, low-frequency (ELF) electromagnetic interference is not generally addressed in the design and installation of building electrical distribution systems. The development of the upper limit of the background magnetic field levels in office buildings is discussed in relation to the physical layout of current carrying conductors. A numerical computation method is described, and technical approaches or for magnetic field mitigation are discussed. To achieve a compatible magnetic environment good practice in the design for electrical installations are outlined.

INTRODUCTION

In Hong Kong, as in many Asian cities, high-rise, air-conditioned commercial buildings are important assets to economic activity. These kinds of buildings house increasingly sophisticated and sensitive electronic equipments and draw very significant power. To meet the ever-increasing tenant demands electrical distribution systems in such buildings require large current carrying conductors. Consequently, the incidence of extremely low frequency (ELF) magnetic interference in buildings has increased.

A number of ELF interference problems have been reported as the magnetic field strengths in buildings increase [1-5]. The most common problem reported is the instability on computer monitors. It is known [5-10] that instabilities such as jitter appears on monitor screens with the magnetic field is as low as 1μT. The lack of awareness by electrical installation designers and contractors has led to a not uncommon situation whereby the background level of magnetic fields exceeds the susceptibility levels of sensitive equipment.

A high-rise commercial building in Hong Kong will be provided with an 11 kV feed to several 1500 kVA: 11000/380 V transformers. Low voltage distribution by triple-pole and neutral (TPN) busbar risers (either air insulated copper bar or insulated busduct) or large multi-core cables is common practice. These risers carry currents approaching 2400A, and horizontal cabling to tenant floors typically carry up to 200A. Tenants loads, which generate significant harmonic currents due to lighting and computers, are fed from a common riser. Harmonic voltage distortion at high floors can be very high due to cumulative harmonic voltage drop [11], and neutral conductor currents caused by load unbalance and the load harmonics can exceed live conductor currents. For fully loaded circuits the neutral current can exceed the conductor current-carrying capacity resulting in overheating and failure.

CHARACTERISTICS OF ELF SOURCES

The power-frequency and harmonic frequency currents associated with the electrical distribution network create significant ELF magnetic environments in such buildings. Conductors carrying up to 2400A will be found near transformer rooms, main switchboard rooms, along corridors, and in vertical ducts. Since electrical equipment such as transformers and motors have low reluctance magnetic circuits (Figure 1) it is the heavy-current power cables and busbars which are the most significant sources of ELF magnetic interference in Hong Kong buildings.

Since the power cables or busbars in a high-rise building are relatively long and are run in parallel, simple expressions of the magnetic field produced by and surrounding the conductor system can be derived from the Ampere's law. Figure 1 shows several typical configurations of cable or busbar conductors, which are normally used in Hong Kong buildings.

Under the balanced current conditions, the magnetic field B is given by:

$$B = \frac{\mu_0}{2\pi} \cdot \frac{Id}{r^2} \tag{1}$$

for the single-phase configuration, by:

$$B = \frac{\sqrt{3}\mu_0}{2\pi} \cdot \frac{Id}{r^2} \tag{2}$$

for the flat three-phase configuration, and by:

$$B = \frac{\sqrt{6}\mu_0}{4\pi} \cdot \frac{Id}{r^2} \tag{3}$$

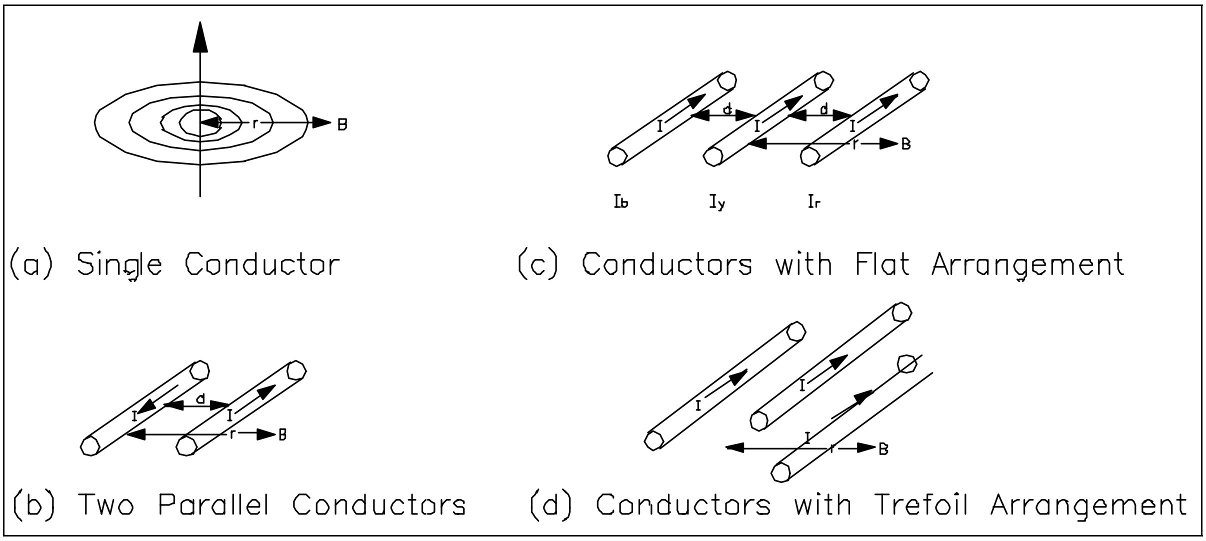


Figure 1 Common conductor configurations

for the trefoil configuration. It should be noted that these formulas are valid only if distance r to the observation point is much greater than conductor spacing d.

In some cases, cables or busbars may be short when compared with distance r. A point source is then used for their magnetic field modelling. The model of a point source consists of a number of magnetic dipoles. Each dipole is characterised by its dipole moment $\boldsymbol{m}$; defined as the product of current I and the area of a small loop A, i.e. $\mathbf{m} = IA$. The direction of the magnetic dipole moment is determined by the right hand rule with the current in the positive direction.

The magnetic field at point P from the magnetic dipole is written as:

$$\boldsymbol{B} = \frac{\mu_0}{4\pi}\left(-\frac{\boldsymbol{m}}{r^3} + \frac{3(\boldsymbol{m} \cdot \boldsymbol{a}_\mathrm{r})\boldsymbol{a}_\mathrm{r}}{r^3} \right) \qquad (4)$$

where $\boldsymbol{a}_r$ is a unit vector pointing to the observation point from the dipole. Generally, the use of point source modelling is applicable to any other distribution component, as long as its dimension is small compared with the distance.

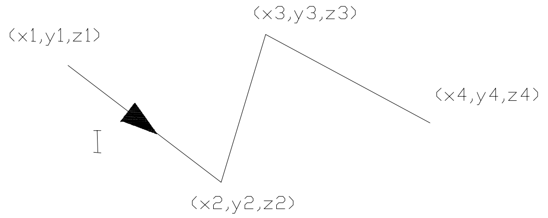
NUMERICAL COMPUTATION

In practical situations, conductors may not be infinite in length, or straight. To determine the resultant fields, numerical computation becomes necessary.

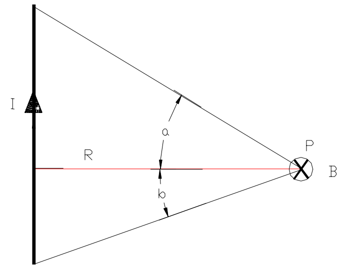
The Biot-Savart Law is often applied in the numerical computation of magnetic fields at ELF. When using the law, it is required to build up a wire or filament model based on the system information. The model may consist of a number of straight filament segments carrying currents, as illustrated in Figure 2(a). These elements emit separate magnetic fields. The resultant magnetic field emitted from the whole system of conductors is obtained using the method of superimposition. Such calculations are generally is performed automatically with the help of computer software. EQ (5) is considered as a generic numerical computation model at ELF for any system.

$$B = \frac{\mu_0 I}{4\pi R}(\sin a + \sin b) \qquad (5)$$

where R is the distance to the observation, and a and b are the angles of the straight filament illustrated in Figure 2(b).



(a) Filament model for a current-carrying conductor



(b) Generic computation model

Figure 2

Source codes were developed for calculating magnetic fields from current-carrying conductors. When using this software, it is required to collect two types of data: field source data and calculation points. The source data includes co-ordinates (x, y, z) of each turning point of conductors, and current magnitude I_{mag} and phase angle I_{angle} for individual conductors, as illustrated in Figure 2(a). The calculation points, however, refer to the spatial positions where the magnetic field is required to be calculated. After inputting the data, the software will perform the computation and generate the output graphically.

It should be remembered that the effect of magnetic shielding is excluded due to the limitation of the Biot-Savart law. Therefore, only the objects without metallic enclosure or having negligible shielding effect can use this 3-dimensional magnetic field solution. Again, the following assumptions shall be considered in using this software:

- the current is concentrated in the centre of a conductor; and
- each element or segment of a conductor is a straight line.

EXAMPLE OF SIMULATION

Shown in Figure 3 is a transformer room located on the 18th floor of an office building in Hong Kong. To evaluate the magnetic field level on the office floor above, it is necessary to build up a filament model for the sources on the 18th floor. Generally speaking, it is impossible and not necessary to include all magnetic field sources in the model. The sources that carry relatively small currents or conductors whose orientation is such as to produce insignificant magnetic fields are not included in the simulation. In this case, only the overhead busbars were modelled.

After obtaining the necessary information regarding busbar geometry and currents, it is possible to perform computer simulation with the software developed based on the equation (5). Figure 4 shows the simulation result for the magnetic field on a plan 1m above the floor level (19/F).

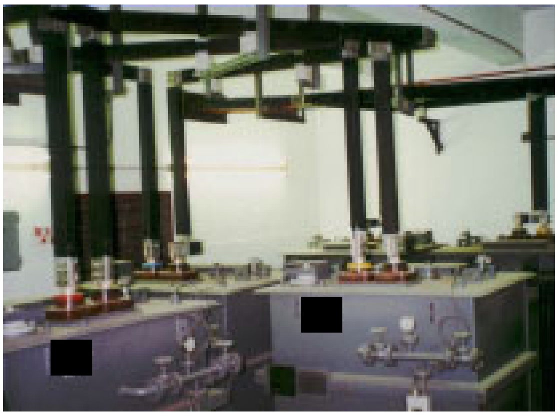

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Fig 3 Transformer Room under the office floor

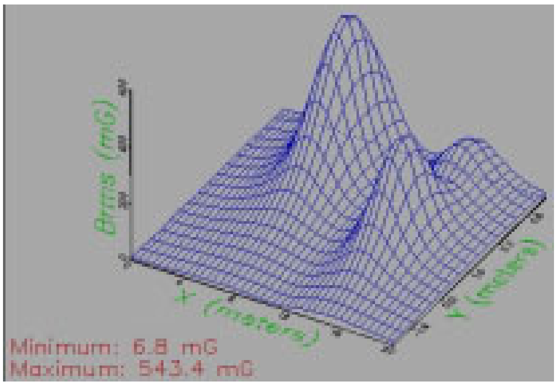


Figure 4 Magnetic field profile

MAGNETIC FIELD MITIGATION

Excessive magnetic fields have been experienced several commercial buildings. In many cases, the problems were attributed to the inappropriate design and installation of electrical equipment or conductor systems. By using proper strategies in design and installation of wiring systems, the magnetic fields in a building can be significantly reduced, and the magnetic interference to sensitive equipment avoided. Mitigation measures in the design of electrical installations can achieve low-level ELF magnetic field environments in buildings and can significantly reduce the potential for interference.

There are a number of mitigation measures to be considered. The principles are relatively straight forward, even obvious, and can be categorized under to the following strategies:

- reducing system or equipment current;
- increasing separation between source and affected equipment;
- reducing conductor spacing;
- rephasing conductors; and
- magnetic shielding.

Reducing Current I

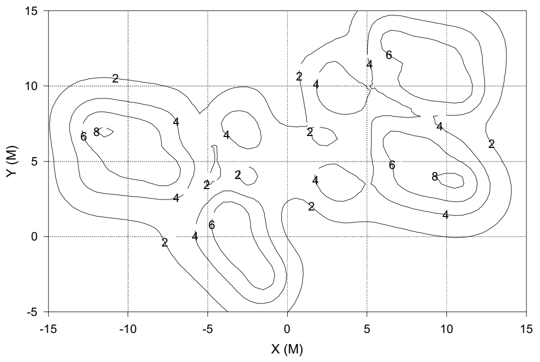
The magnetic field at any point is obviously directly proportional to the currents in the conductors. Reducing the current may be feasible in practice if system voltage can be raised (e.g. 11kV in building distribution) or more efficient load equipment installed (e.g. energy efficient lighting).

Increasing Distance r

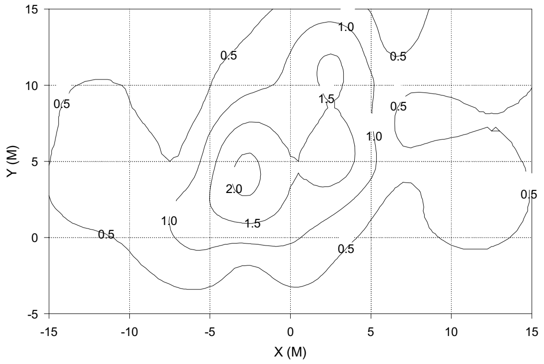
Distance r has a great influence on magnetic field reduction. According to EQ (1-4), the magnetic field can reduce to one fourth for a line source or oneeighth for a point source if the distance *r* is doubled. The strategy is to distance sensitive equipment from the field-producing equipment.

However, relocating affected equipment away from the source may not always be practical. Relocating the source equipment can be considered. In large commercial buildings, single-core cables are often employed for the secondary connections between transformers and switchboards. They are normally installed in a duct, which are very close to the floor underneath. If magnetic interference is of concern on that floor, an installation using cable tray on the ceiling could be considered.

The increase of separation from the source significantly reduces the magnetic field on the affected floor. Figure 5 shows computer simulation results in a commercial building. The magnetic field on the 49/F reaches as high as 8 μT at the desk level when the cables are in trench on the 50/F, and drop down to 2μ T or lower on tray.



(a) Cable-in-Trench Method

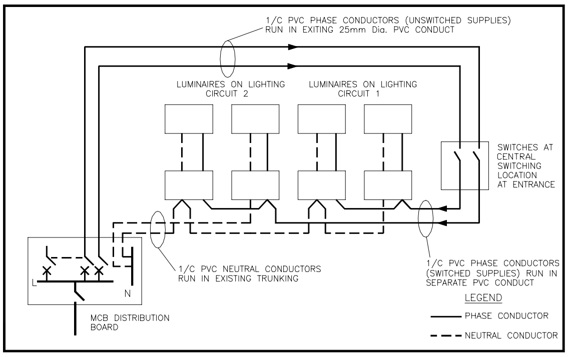


(b) Cable-in-Tray Method

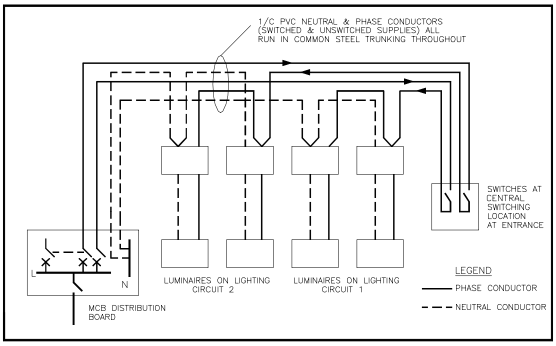
Figure 5 Magnetic fields (μT) above different cable installations

Reducing Spacing d

The impact of conductor spacing is straightforward, as illustrated in EQ (1-4). However, engineers in design and installation practices may not appreciate this. A practical wiring problem related to large conductor spacing was found in aone building. A tenant complained that the computer monitors wavered unsteadily when running a Windows program. It was diagnosed as a magnetic interference problem. The wiring system in the premises was closely examined, and it was found that the neutral conductors were separated from their phase conductors and given their own route, as illustrated in Figure 6. The spacing was unusually large, and an excessive field of 4.0 μT occurred adjacent to the monitor. The problem was completely resolved after placing both phase and neutral conductors in the same conduit.



(a) Original wiring diagram



(b) Revised wiring diagram

Figure 6 Illustration of the wiring problem

The following are obvious means to reduce magnetic fields in respect of conductor spacing:

- installing phase and neutral conductors along the same route, and minimising the spacing;

- considering the following order of choice for a feeder or riser:
  - armoured multi-core cables,
  - non-armoured multi-core cables,
  - fully-insulated busbars,
  - single-core cables, then
  - air-insulated busbars;

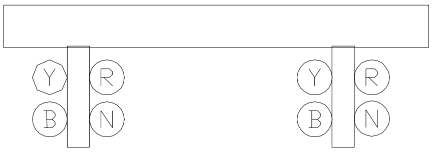
- avoid using bare busbars or single-core cables for connections, unless some special measures, such as magnetic shielding are taken to minimise their effect;

- considering the trefoil configuration for single-core cables.

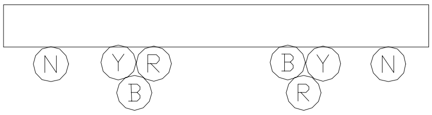
Phasing Conductors

The magnetic field is both a spatial vector and a temporal phasor. By properly arranging the phases of multiple parallel conductors, the magnetic field can be reduced significantly. The field reduction is mainly achieved by the cancellation effect of the magnetic fields from the parallel conductor currents. This method is only recommended if there are multiple conductors per phase and the phase currents be out of balance by less than 10%. Normally, no extra cost is required to cover the implementation of this strategy.

Figure 7 shows a typical example of conductor re-phasing in an exiting building. In this case, there are two parallel three-phase circuits under the floor concrete slab carrying currents of 600 A. The fields under two different configurations, as illustrated in Figure 7, were evaluated, and presented in Table 1. Under the proposed arrangement, the field from two circuits orientates almost in the opposite directions. Consequently, the total resultant field is very small because of cancellation. The magnetic field may be reduced to only 15% of the original level at a height of one meter above the floor slab.



(a) Original Arrangment



(b) Proposed Arrangment

Figure 6 Three-phase cable arrangements

ELF SHIELDING

Magnetic shielding has been studied for several decades. At extremely low frequency, shielding performance of both planar and cylindrical shields has been extensively investigated. Theoretical formulas have been developed, under a uniform field or with the excitation of a loop or parallel current source. Normally, trunking used in low-voltage electrical installations is of rectangular shape, and made from galvanized iron. Shielding performance of such a non-linear ferromagnetic shield, however, has not been addressed significantly.

Table 1 Field Comparison between two cable arrangements

Distance to the floor slab	B-Fields in original scheme (a)	B-Fields in proposed scheme (b)
0.5m	20.7 μT	15.1 μT
1.0m	13.6 μT	2.0 μT

Shielding effectiveness, which is defined as a ratio of the measured magnetic fields with the trunking absent, to that when present, is used for the purposes of comparison and discussion. In this definition, a small value of shielding effectiveness, which is generally less than one, indicates good shielding performance.

Galvanized iron trunking is normally used in buildings for protecting distribution conductors (cables and busbars) against mechanical stress [12,13]. It is a cost-effective measure for ELF magnetic shielding. Because of the nonlinear nature of galvanized iron, the source factors, such as, current distribution and magnitude play a significant influence on magnetic shielding. Shielding performance is enhanced further as current magnitude or cable spacing is increased. However, the external ELF field will not be reduced if current magnitude or cable spacing is increased as the source field also increases.

Shielding performance of GI trunking is affected by several factors, such as, size, thickness and material properties. The better shielding performance is observed if the trunking is thicker, as well as being relatively small in size (Figures 8 and 9).

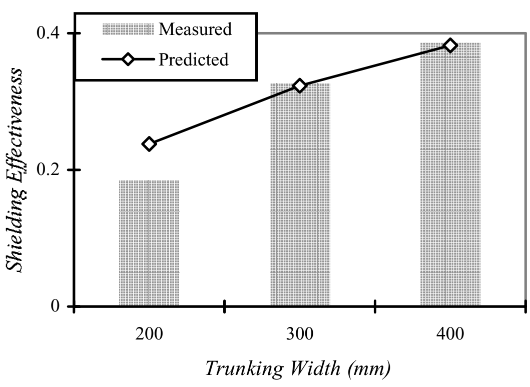


Figure 8 Shielding and Trunking Size

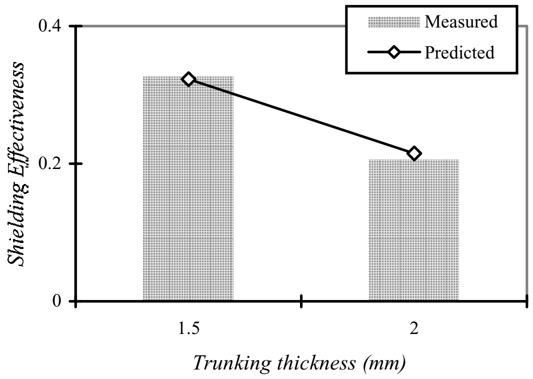


Figure 9 Shielding and Trunking Thickness

A planar metallic sheet is considered as another type of shield, which is commonly used in commercial buildings [14]. In practical situations, several sheets may be jointed to form a large size shield for dividing the shielded region from the sources. It is usually used for shielding larger sources such as, a transformer room. For example, for a room right next to a transformer room, a shield can be installed on the side facing the transformer. A shield installed on the ceiling or under the floor can be also considered for a zone of an office area, to shield the source is located on an adjacent floor.

Figure 10 shows the results of shielding performance for a simple planar shield (1.5mm thick GI sheets) by both experimental measurements and computer simulations. The testing setup is illustrated in Figure 11. It is found that the agreement is good with an error of less than 10%. It should be mentioned that the performance of a practical planar shield is affected by many factors. They include shield thickness, material, size, joint method, edge effect, etc. The influence of non-linearity, however, is not significant for the low-mu material (e.g., GI).

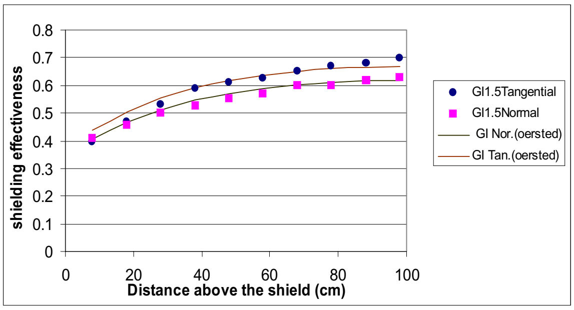


Figure 10 Shielding by 1.5mm thick GI planar sheets

CONCLUSIONS

Large current-carrying conductors, with relatively large spacing, generate ELF magnetic fields in commercial buildings. The ELF field level can be greatly affected by poor design of electrical installations, but can be mitigated by a number of 'common sense' measures, which are essentially based on minimising conductor spacing or separating sensitive equipment from ELF sources.

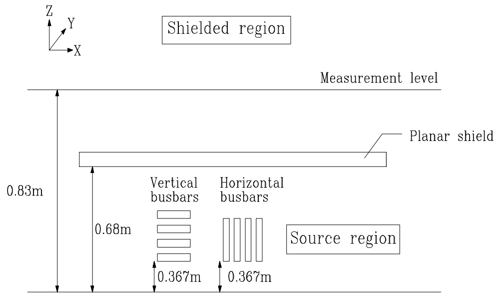


Figure 11 Measurement setup

For cabling arrangements where ELF shielding is minimal it is possible to compute ELF fields at distances from the cables, using fundamental equations. Shielding effectiveness of ferromagnetic trunking can be estimated, and use of trunking is advocated whenever circumstances allow. Where this is not the case, sheets of ferromagnetic materials fixed to floor slabs or ceilings may provide sufficient attenuation for ELF. Given the complexity of the theoretical analysis it is not worthwhile to compute shielding effectiveness, but expectations as to the order of shielding effectiveness can be gained from analysis of simple configurations or experimental evidence.

Where this proves difficult in an existing installation there is recourse to magnetic shield. Essentially this involves the use of enclosures, such as metal trunking, or sheets of metal interposed between source and sensitive equipment.

In applying various mitigation measures, the primary concern is to minimize the cost of such measures. In establishing the cost of implementing any technical solution, intangible costs such as the cost of down time of power supply or a computer system need to be considered as well as the direct costs of material and installation. It is always preferred to consider or applying the mitigation measures at the onset of design of systems.

ACKNOWLEDGEMENTS

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