About The Different Methods of Observing ESD

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Abstract: To design electrostatic discharge (ESD) robust equipment, the occurrence rate and the intensity of the pulses must be known. To check the efficiency of an ESD control program methods for observing ESD are necessary. Different methods are possible for monitoring of ESD. Some methods are presented and compared.

A new impulse monitoring system was designed. This system automatically detects ESD by the associated fields. This monitoring system records E and H field values, their peak derivatives and spectral distribution with more than 1 GHz bandwidth. Furthermore, environmental information (temperature and humidity) and time are recorded. The monitoring system is described. Methods for evaluation of the data are presented.

Introduction

Electrostatic discharge may present a serious threat to electronic systems. The very fast pulses, especially the initial peak, can cause serious problems for high speed digital systems. ESD may cause damage by its current and by its field.

High speed digital systems become more and more common. This increases the risk of ESD related problems especially for fast rising discharges. To apply the right protection method and test levels a distribution of the occurrence rate vs. severity of ESD must be known.

The aim of this project at the Technical University of Berlin is to improve the knowledge on the occurrence rate and severity of impulses and to build up a data base containing information on the occurrence of real ESD.

The occurrence of ESD depends on the type of environment and the activities in the environment.

To monitor ESD one have to take the following problems into account:

- The location of ESD is unknown.
- ESD is a stochastic process. Discharges can occur at any time.
- The type of ESD is unknown. Discharges differ extremely in their amplitude and shape. The voltage can vary, and for the same voltage the current derivative can vary to up to 3 orders of magnitude due to different arc length [1,2]. Each discharge configuration has its own particular radiation characteristics that influences the shape of the fields.

Occurrence rates for different severities in classified environments are a promising approach to solve the problems.

To achieve the needed database, automatic long term measurements in different typical environments are required. The accuracy of the database will increase with observation time and the number of environments investigated.

Methods of Observing ESD

Different methods can be applied to monitor the occurrence of ESD in real environments automatically. There is no perfect monitoring method. Every method has its advantages and disadvantages.

a) Static field monitoring

By measuring the static field, information on charge accumulation can be gained. A rapid decrease of the charge value can be used to indicate a discharge. Using these assumptions the discharge rate can be estimated. But large charge values not necessarily cause fast discharges. Many charged objects may never discharge through a spark and generate no high transient current or field amplitudes. Usually only fast discharges cause serious problems. Another disadvantage is the lack of information about the severity of a discharge.

b) Current monitoring

A critical effect of ESD is the current. It is desirable to know the exact amplitude and the rise time of each ESD current in the monitored space. But as the discharge locations are not known in advance it is impossible to place the needed current sensors in a real environment. Simonic [3] used another method. He was not interested in all ESD's, only the important discharges to electronic equipment (floor standing computers) were monitored by observing currents in the power cords. The voltage was estimated based on calibration data. This method can not achieve sufficient bandwidth.

c) Dynamic field monitoring

Each ESD is associated with a strong impulsive field. By measuring the fields one can get information on the occurrence rate in a limited space assuming that there are no other sources for impulsive fields, or that there are methods to discriminate between ESD impulses and other field impulses.

Takai [4] used this method. He developed a measurement system that detects impulsive fields and divides the pulses according to their amplitude into 4 classes of severity. The apparatus used by Takai has an insufficient bandwidth to capture fast ESD events.

By knowing just the amplitude a weak nearby discharge can not be distinguished from a strong ESD further away.

More information than just the amplitude is necessary.

Single site and multi-site techniques

For locating the sensors there are two methods possible: Single site and multi-site techniques.

Multi-site technique use locally distributed sensors. Assuming the positions of the sensors is well chosen, synchronous acquisition and a known dependency of amplitude to distance, the location of the field pulse can be calculated quite well.

Multi-site detection can also be done by the difference in arrival time if it can be determined with sufficient accuracy. If the time resolution is sufficient high then the calculation of the location of the source by the arrival time difference is more accurate than the calculation by the amplitude. Changing dependency of the relation of amplitude to distance, reflections or shields cause here less or no problems.

The disadvantage of multi-site methods is the complicated measurement set-up and the need to place sensors at different locations.

It is much more convenient to locate the ESD sources using just one receive site. Often it is the only possible way (limited space, limited acceptance). Using just one site may sacrifice accuracy and/or complicate the algorithms needed.

To improve the accuracy of all kinds of measurement, an additional observation with a camera system is advantageous. This allows the assignment of the measured events to the actions that happen in a room.

In most environments the acceptance of an observing camera system, which observes not only actions associated with ESD, will be low. Here the monitoring is limited to the measurements of the electric quantities.

A Single Site Measurement System For Monitoring Of Transient Fields

A system called IDES (Impulsive Disturbances Evaluating System) was designed. It monitors impulsive fields and strong time dependent continuous wave fields (with some limitations in accuracy). It calculates the severity and estimates information on the location of the field source. It can work as single site or as multi site system. Finding the location of a discharge can be done by comparing the measured amplitudes of the different stations.

To be able to identify the discharge type (e.g. furniture or human), to get the severity of a detected impulse and to allow parameter studies, the system needed to meet the following requirements.

- The peak value of the E-field is detected with a bandwidth of more than 1 GHz.

- The peak value of two perpendicular H-field components is detected (BW > 1GHz).
- The peak derivative values of E- and H-fields are measured.
- For E- and H-field a coarse spectral distribution is generated.
- Time, humidity and temperature are recorded

A block diagram of the system is shown in fig. 1.

The system consists of three analog pulse evaluating sub systems. Active self integrating H- and E-field sensors with bandwidths of 1 GHz. (fig. 3 and fig. 4) are connected to the input of each system. The figures 3 and 4 show simplified models of the sensors without active elements. More detailed information can be found in [5,6].

The system is controlled by a microcontroller.

A block diagram of the analog pulse evaluating unit is shown in fig. 2. The pulse is passed via a broad band amplifier to a power splitter that distributes the pulse to several evaluation units. Each evaluation unit extracts some properties of each pulse. Due to the short duration of the pulses a direct A/D conversion is extremely complicated. A very fast analog peak detector was developed. This peak detectors are the essential parts of each unit. A peak detector tracks one pulse and holds the maximum value of each pulse at the output until a reset signal is generated. Slower A/D converters can be applied to measure the amplitude of very fast pulses. The developed detector is able to stretch pulses with a 50% pulse width of less than 1ns with a dynamic range of 40 dB.

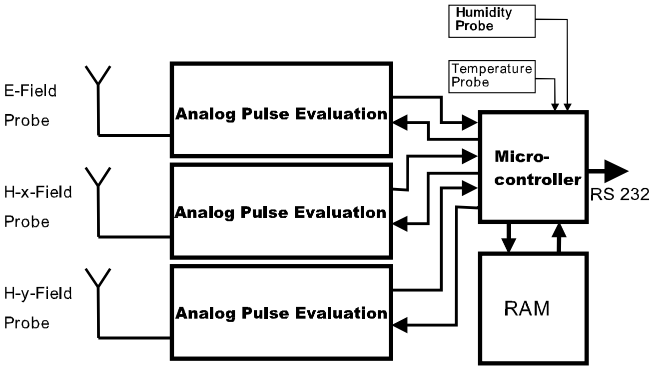

Fig. 1: Schematic structure of IDES (Impulsive Disturbances Evaluating System)

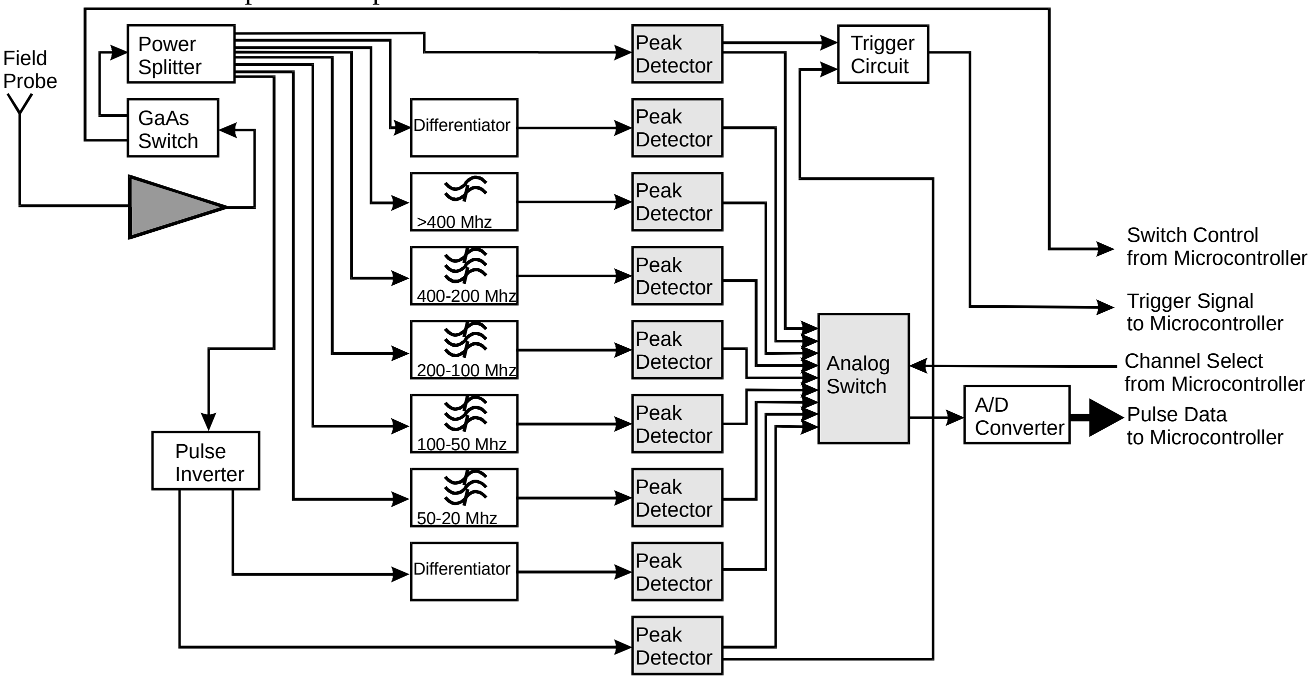

Fig.2: Block diagram of one analog pulse evaluating circuit for one field component

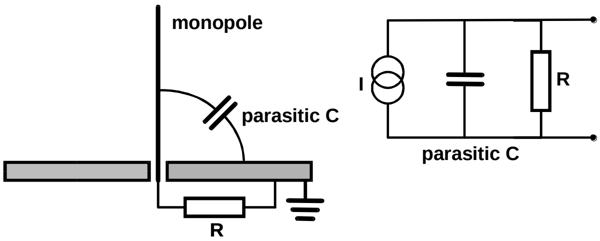

Fig.3: E-field sensor and simplified equivalent circuit model

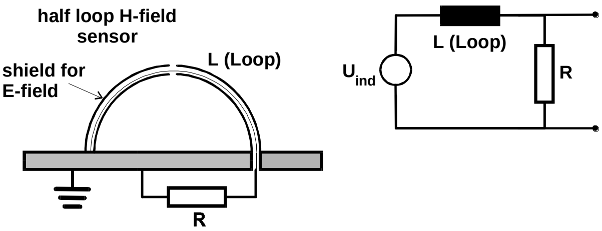

Fig.4: H-field sensor and simplified equivalent circuit model

The output voltages of each peak detector is converted by a fast A/D converter. The digital signals are stored in a memory device. It can store information on up to 5400 events. A special software algorithm detects periodical signals and prevents the storage of these signals. Otherwise, strong periodical signals may use up the available memory very fast.

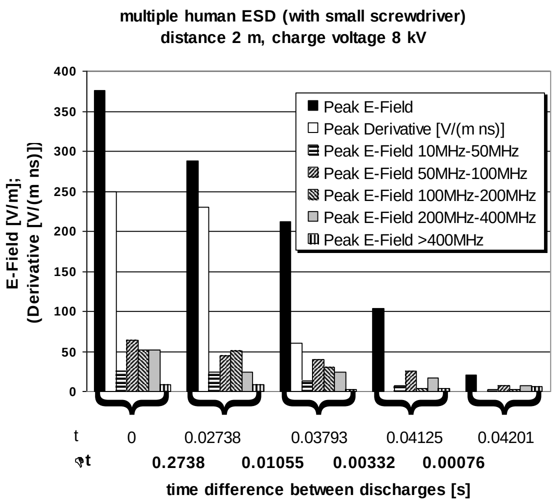

Fig. 5: Multiple discharges measured with IDES

Most impulsive events consist of succeeding pulses. The succeeding pulses and the time difference between pulses provides additional information about the type of field source. Subsequent ESD-pulses can be separated by a time period ranging from 10 µs to 200 ms [7]. A high repetition rate is necessary to get as many as possible of the subsequent pulses. The maximum pulse repetition rate of the measurement system is 24 kHz. One example of a subsequent pulse measurement is shown in fig. 5.

An Example For A Measurement

Fig. 6 shows an example of a measurement recorded in an electronic laboratory for students with linoleum floor. The activities in this room were repairing and assembling of electronic devices. 2-5 persons were working in this room (humidity: 35% - 45%, temperature ≈20°C).

In less than 5 days, 190 events were recorded. It is difficult to determine which event is an ESD event and which is caused by another source of impulsive fields but certainly less than 50% were ESD. This statement can be made because the measured pulses caused by some switching actions were counted. The counted switching events caused already more than 50% of the events. In the subsequent chapter some methods for filtering data will be presented.

Fig. 7 shows the occurrence rate of different classes of E-field strength generated from the data shown in fig. 6.

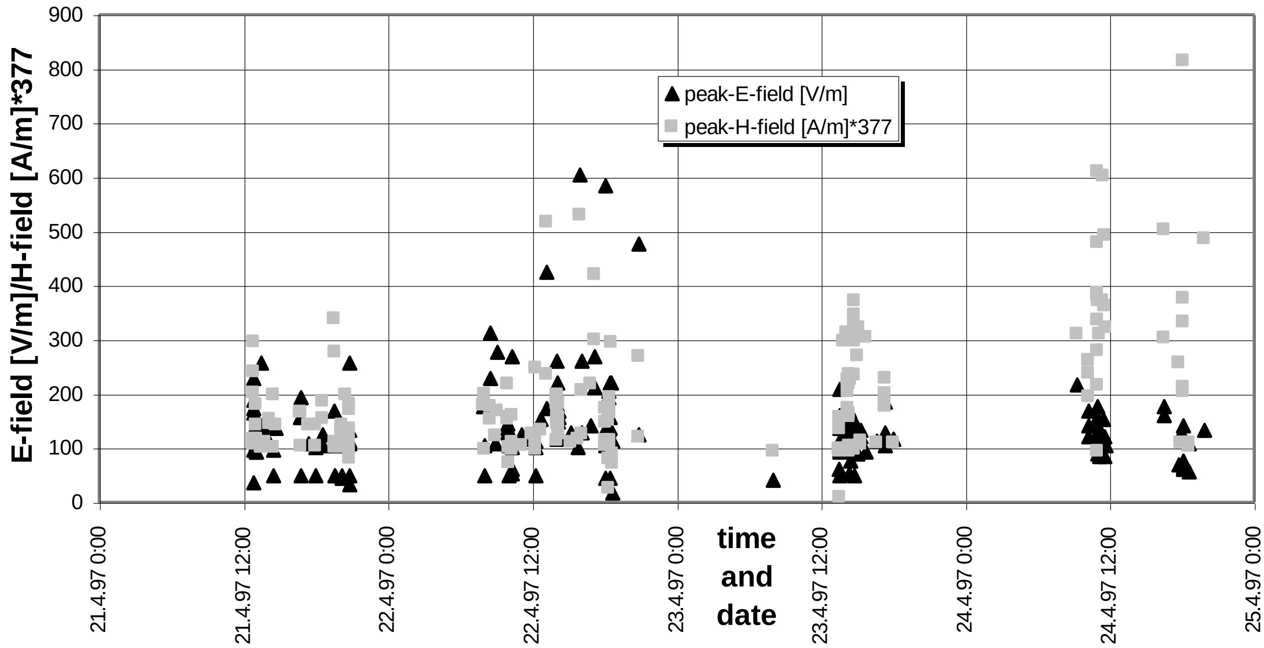

Fig. 6: Example of a measurement of the occurrence of impulsive fields; events displayed as a function of time; all events are shown (ESD, switching actions...), no evaluation of the source were done.

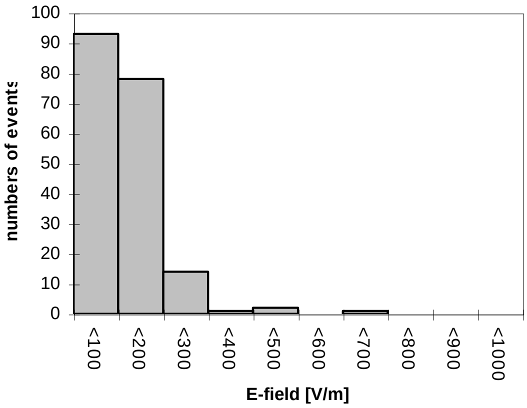

Fig. 7: Frequency of the occurrence of different classes of field strength

Calibration Of The System

A coarse calibration of the assembled system was done by mounting the sensors on a metal plane. Impulses were applied by an IEC 1000-4-2 ESD simulator [8]. The fields of a simulator that discharges into a metal plane are well known from former measurements.

The following values were measured:

min. detectable E-field: ≈ 30 V/m

max. detectable E-field ≈ 1000 V/m

min. detectable H-field: ≈ 0.1 A/m

max. detectable H-field ≈ 3 A/m

The system dynamic range is approximately 30 dB. The system can detect 1 kV simulator discharges into a small floating metal plane (28x28cm) at a distance of 3 m.

Identification Of The Pulses

IDES collects field data automatically. Normally the data will be read out after a few days of data collection for evaluation of the results.

Many sources (fig. 8) can cause impulsive noise , for example switches, lightning etc. These impulsive noises normally causes no problems to electronic systems but can be misunderstood as ESD. This would bias the database. Such events need to be identified.

Every field source has its typical properties. Fig. 9 shows an example of different waveforms for two different discharge configurations, human and charged piece of metal (spanner).

Typical properties which can be used to determine the type of source are the spectral density, the field impedance and the repetition rate. For example furniture ESD shows by far more ringing than human ESD.

Data measured with IDES contains a lot of information on the field source type. This data may allow classification. However, in reality classification is not always possible. Limitations are caused by overlapping properties, the fixed field impedance in the farfield (the field impedance is used to estimate the distance to a discharge), reflections and the limited dynamic range of the measurement system

To filter data a criteria is necessary. The input vector (data generated by IDES) needs to be mapped to an output (e.g. class of field source, location) vector.

Two methods for automatic data evaluation were tested, Fuzzy Inference Systems and Neural Networks.

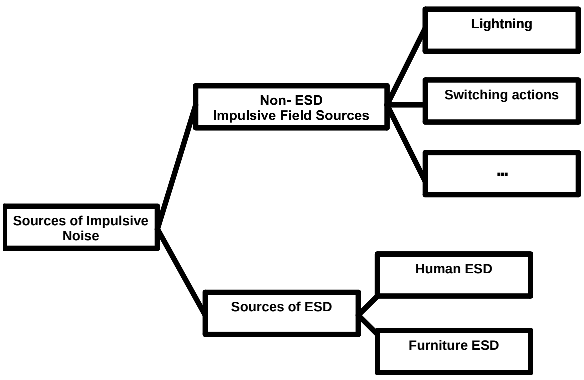

Fig. 8: Overview on possible sources of impulsive fields (the ... represents other non-ESD sources)

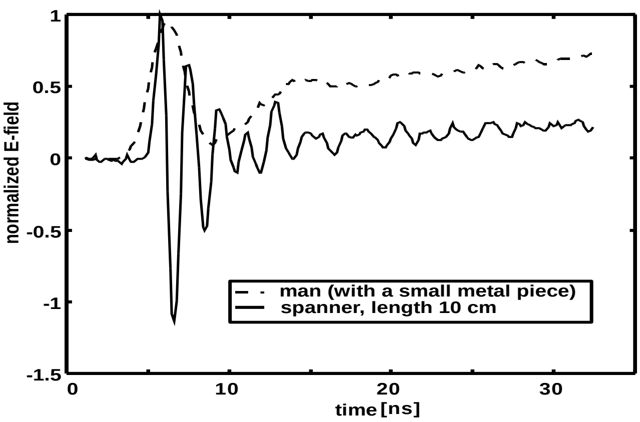

Fig. 9: E-field of discharges in two different configurations

Data Evaluation with Fuzzy Inference Systems

Fuzzy Inference Systems [9] are based on fuzzy logic and can map a given input vector to an output. Fuzzy logic has been applied often for impulse classification problems (e.g. [10]). It allows to formulate the criterion for classification of data in natural language and is tolerant to imprecise data.

Classification with Fuzzy Inference Systems

For example, some coarse rules to distinguish between human ESD and furniture ESD formulated as Fuzzy Rules (E-field data is normalized on maximum E-field value) are given below:

if (*Frequency Band(100MHz-200MHz*) is *big*) and (*E-field peak* is *medium*) then (*ESD is furniture*)

if (*Frequency Band(200MHz-400MHz*) is *big*) and (*E-field peak* is *medium*) then (*ESD is furniture*)

otherwise human

These rules assign a numeric value to its output. To defuzzify the output values a thresholds has to be defined.

This example allowed fuzzy logic to distinguish between two types of ESDs. Only two rules were formulated. In real environments the list of rules will be very long and it is difficult to define the rules.

Data Evaluation with Neural Networks

Another more convenient way to evaluate data is the use of Neural Networks. Neural Networks also map an input vector to an output vector. The way a network maps an input vector to an output vector is determined by training and not by rules. The network needs to be trained on known data sets. With an 'error back propagation algorithm, the network can be trained to produce the desired output with a given input data set. Other input vectors that are similar to a training vector will lead to a similar output. The Neural Network has generalization properties. If it was trained on a representative data set, it can produce good results without being trained on all possible input/output combinations.

Classification with Neural Networks

Neural Networks were already applied to similar problems for classification of lightning electromagnetic waveforms [11]. Due to the difference between the fields and geometries the methods can not be applied directly.

For a perfect classification, all possible sources must be known. This can often be approximated by calibration. The calibration obtains the needed training data. But it is not always possible to know the type of disturbances in a monitored environment. Some uncertainties remain. In practice it can be assumed that the type of disturbances and the number of classes is limited. This allows a reasonable training of the Neural Network with calibration pulses.

As an example it was possible to train a Neural Network on three different classes of discharges (human-metal plane, human with metal piece – metal plane, isolated tool – metal plane) with a set of 60 data sets. The network was tested with 15 different data sets. Of the 15 data sets 14 were correctly classified.

Fuzzy Logic compared to Neural Networks

Neural networks for pulse identification have some advantages compared to Fuzzy Logic. With appropriate training data for every environment an individual net can be generated which considers the given conditions. A big disadvantage is the lack in transparency. It may often happen, that a net fits the training data excellent but cannot approximate real data. The size of a net, the transfer functions, the initial weights and biases must be chosen carefully. Fuzzy Logic Systems are more transparent. But for complicated problems it is very difficult to construct the Fuzzy Inference System rules.

Finding the Location of ESD with Neural Networks

For identification of the location of a source, techniques also used for locating lightning discharges (e.g. [12]), can be applied.

The distance can be roughly estimated. If the impedance of the field is different than Z_0 (Free space field impedance) one can be sure that the discharge happens very close to the measurement system. The inverse statement is not possible, ESD may also generate fields that have a field impedance of Z_0 in the proximity of the source. Additional information is needed to determine the distance to the source.

If the Poynting Vector can be extracted the direction to the source can be calculated. This is limited by the fact that only three sensors are used and that the system does not record the exact time at which the maxima occurred.

The first condition does not limit the ability to calculate the direction if the excitation is such that its E-field vector is parallel to the E-field probe or if the sensors are mounted an a large ground screen.

The second condition limits the ability if the signals are oscillating such that the positive and the negative peak values are similar.

Beside the already mentioned problems there exist a few other:

Systematic problems:

- If the system is too close to a distributed source different parts of the wave will originate from different direction. The same may occur if strong environmental reflections disturb the signal.

Problems of the measurement system

- limited selectivity of the H-field sensors.
- limited dynamic range
- the peak detectors are not absolutely linear

Nevertheless Neural Networks can do a good job for direction finding, source identification and severeness assessment. With good training they can overcome the nonlinearity of the peak detectors.

More Detailed Example For Direction Finding With Neural Networks

As an example one result for direction detection with Neural Networks is presented. In a half circle with a radius of 3 m, 120 different measurements were recorded. IDES was positioned on the floor of a room (fig. 10) and on all points marked with an arrow, pulses with voltages in the range from 1 kV to 8 kV were applied in both polarities.

The distance varied between 1 m and 3 m. At each discharge position the selected event (voltage/polarity) was applied once, i.e. no parameter set occurs twice in the data. This is important to check the generalization capabilities of the used Neural Network.

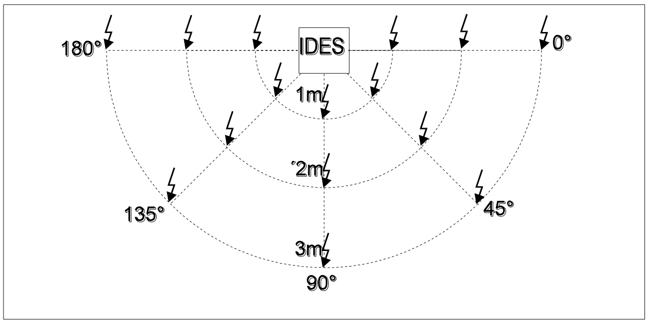

Fig 10: Geometry for measurement of data for training and checking a Neural Network

An ESD simulator according to IEC 1000-4-2 standard was used in the contact mode (In contact mode the charging capacitor of the simulator is discharged via a relay, there is no arc. This method has the advantage, that it generates well reproducible pulses.) to generate the pulses. The discharges were applied to a small (28 cm x 28 cm) metal plane.

Two layer feed forward Neural Networks with different numbers of neurons per layer were generated and trained with 100 measured data sets. The 6 peak values from E- and H-field (positive peak E-field, negative peak E-field, positive peak Hx-field, negative peak Hx-field, positive peak Hy-field, and negative peak Hy-field,) were used as input vector, the angle (0°-180°) as the output vector. For speed reasons a Levenberg-Marquardt-algorithm was used as a Back-Propagation-Training algorithm. The training results were evaluated using the remaining 20 data sets. A net with 6 neurons in the input layer (logarithmic sigmoid transfer function), 3 neurons in the hidden layer (logarithmic sigmoid transfer function) and one neuron (due to the single output) in the output (linear transfer function) layer produced the best results. It was possible to generate a net that produces an average error of less than 11 degrees from the actual origin.

Conclusion

A new impulsive disturbances evaluation system was designed. This system monitors the occurrence rate of impulsive fields. It captures important properties of the field. With the knowledge of certain properties of each pulse it is possible to find the type of source. Neural Networks and Fuzzy algorithms have been tested to identify recorded pulses automatically. Neural Networks offered better results. With the system it is possible to collect the severity and occurrence rate data of ESD.

Acknowledgment

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