MEASURING THE SHIELDING PERFORMANCE OF MATERIALS

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Abstract – **Principles and applications are described for a new method for measuring the shielding performance of materials. The new method avoids the problems of common mode signal linkage to observations circuits, is fair to materials of various constructions and provides the basis for matching shielding performance to specific practical applications.**

I. INTRODUCTION

'Shielding' by materials is the attenuation of a signal on one side of the material in relation to that on the other side. The 'signal' may be as an electric or a magnetic field.

There are two aspects of shielding that are of practical significance:

- the ability of materials to provide shielding against fast electric field transients. These transients may arise from direct or nearby electrostatic spark discharges. In this context shielding is mainly relevant to the protection of semiconductor devices and microelectronic assemblies in carriage through uncontrolled static environments. It is also relevant to the protection of microelectronic systems against upset of operation by spurious signals and to shielding equipment against specific radiation sources.
- the ability to understand the fastest route for charge migration available within materials and the relevance to the risks of ignition of flammable gases.

This paper is concerned with ways to measure the shielding performance of materials against electric field transients in ways that are fair to various types and constructions of materials and that provide information on which the suitability of materials may be judged for various practical applications.

II. BACKGROUND

Electric field transients associated with electrostatic spark discharges at voltages of a few kV can have risetimes down below 1ns [1]. At higher sparking voltages front edge risetimes tend to be longer. The protection of semiconductor devices and microelectronic devices and operating systems against electrostatic spark discharges hence requires a shielding performance for frequencies up to near 1GHz. Body voltages, and hence the voltage of carried items, can be 20kV or more in uncontrolled environments – e.g. walking over a nylon carpet. Protection of devices against transient voltage excursions over, say, 100V if packages contact an earthy conducting surface hence requires protective packaging to provide attenuation performance of at least 200:1 over a frequency range up to about a GHz.

Risks from static electricity in cleanrooms can arise is relation to surface voltage generated by rubbing the overall garments worn by personnel [2]. A less appreciated risk is that arising from static charge on undergarments. If these are of inappropriate materials they may become charged. Body and garment movements may create low frequency electric fields in proximity to the garment. There may also be the occurrence of spark type discharges between inner surfaces. The nearby influence that such static charges and discharges may have depends both on the degree of charging and on the shielding performance of the outer garments over a rather wide range of frequencies.

For the ignition of flammable gases it is usually taken that it is the energy dissipated in a spark type electrostatic spark discharge that is relevant [3]. The effectiveness of the discharge energy in initiating combustion of flammable gases may increase with the duration of the discharge [4]. It is likely that discharges longer than the timescale for formation of the initial flame kernel, which is about 1ms, will become less incendive. Electrostatic sparks between metal objects involve very short timescale electrostatic discharges (down to 1ns, as noted above) and essentially all the capacitively stored energy is dissipated in the discharge. Electrostatic discharges from an earthed projection to charged dielectric materials are more complicated. A discharge will be initiated when the local electric field exceeds the electrical breakdown strength of air. For the discharge to involve significant amounts of charge and energy the conditions must be right for the discharge to spread out and draw charge from an appreciable area of the charged dielectric surface. Limiting the incendivity of such discharges may hence be achieved by preventing this discharge spread. One way to limit the spread of a electrostatic discharge over a charged dielectric surface is to provide some resistive dissipation in the surface of the material. The concept here is to limit the electric field at the outer boundary of the electrostatic discharge in the gas immediately above the surface responsible for discharge propagation. Studies have indicated that resistivities around 10^8 ohms are needed [5]. The radial spread of a discharge may perhaps also be limited by the proximity of localised conductivity at or near the surface of the dielectric. This type of limiting mechanism may be relevant to personnel protective clothing and FIBC fabrics that include stripe or grid patterns of conductive threads. To avoid a risk of direct spark type discharges to these conductive threads (if they are not be reliably bonded to earth) requires that these threads have an appropriate 'resistivity' in themselves.

The shielding attenuation by a uniform resistive layer can be predicted. The problem in practice is that with many practical shielding materials the resistive feature is covered with insulating or dissipative layers. For example, with shielding bags the metalisation may be on an inner surface of a multilayer structure. With cleanroom garment fabrics the conductive threads may be within the structure of the fabric and the conductivity of the threads may be within an insulating outer sheath. In such situations the relevant resistivity is not directly or reliably accessible for measurement.

III. METHOD OF MEASUREMENT

A. Introduction

Non-contact methods are needed to measure the shielding performance of materials and to gain information relevant to assessing the risks of ignition of discharges to charged dielectric material surfaces. Existing methods do not address these requirements very well.

B. Existing methods

There are two main standard methods at present for assessing the shielding capabilities of materials: MIL-STD 285 and EIA 541 [6].

The 'window method' (MIL-STD 285) involves the sealing of an area of material over the aperture between two separate shielded enclosures. Attenuation is measured as the ratio of the signals observed with and without the test material. This approach should generally overcome the problem of operating in the near field region at frequencies where the enclosures are small compared to the equivalent wavelength. Measurements are also sometimes made over an aperture between two waveguide systems. The problem here is that the frequencies involved are actually too high for normal practical requirements and materials may be rejected which are adequate. Both these approaches have the problem of earth bonding the material to the edges of the aperture.

The method of test described in EIA 541 [6] appears simple and practical but in fact is neither. The main problem is that the signal required appears as the difference between two probe signals and the higher the attenuation the smaller the relative difference signal to be measured in the presence of what may be a large common mode signal component. The electric field stressing pulse in only a 'human body model' and measurements are only required to be made with a 50 MHz oscilloscope. These features are clearly inadequate, as spark discharges can involve frequency components to a GHz and (as will be shown) attenuation does vary with frequency. The more recent ESD Association Standard [7] overcome the common mode signal problem with the EIA 541 approach by use of a current transformer for signal observations. It bases assessment of material on the energy transferred through the material. While an 'energy' shielding criterion may appear to match a specific requirement for the protection of microelectronic devices it does not give any understanding of the basis of the shielding performance or the prospective suitability of materials for alternative applications that may have different frequency performance requirements.

C. New method

The three basic features of the new approach [8] which has been developed are:

a) that the electric field test stress is applied to a defined planar area of the material as a balanced bipolar signal covering a wide range of frequencies.

b) that as the symmetry of electric field stressing impresses no common made signal on the sample. Observations can hence be made either as the difference signal between matching electrodes on the other side of the sample or as either of these signals relative to earth

c) that performance is assessed as the ratio of signals observed with the material present compared to those without

d) that observations are analysed and presented as the variation of shielding performance with frequency

The basic physical arrangement of the new approach is shown in Fig 1. In the two test assemblies made so far, the electrodes have been 15mm wide and mounted flush in earthed plates to be parallel and with their centre lines 50mm apart. In the first test assembly the electrodes were 50mm long and in a more recent assembly 100mm long. The longer electrodes were to allow studies on the characteristics of fabrics including conductive threads where the threads may be spaced as much as 25mm apart. The arrangement of the observation electrodes has matched the electric field stressing electrodes. The inner surfaces of the plates mounting the electrodes have been 10mm apart. The plate mounting the observation electrodes is covered with a rigid sheet of insulation 3mm thick. The sample is clamped against this insulating sheet with another sheet of insulating material. This arrangement ensures the sample is held flat and in a well defined position relative to the stressing and observation electrodes.

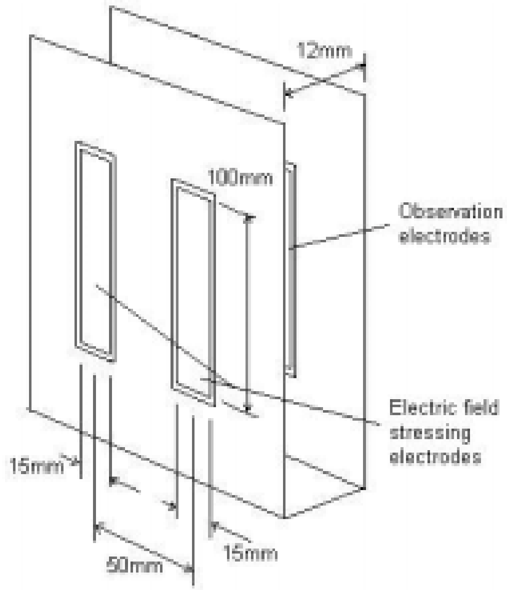

Fig 1:General arrangement for shielding measurements

In the first test assembly [9,10] the stressing electric field was generated by bipolar high voltage pulses of amplitudes up to 10kV. High test voltages were used to give adequate signal strength at high attenuation and to allow opportunity for testing with spark discharges directly to the test sample surface. The rise time was around 3ns at 10kV and 1ns at lower pulse voltages. Fall times were over 0.1s. This was achieved with the composite circuit shown in Fig 2 that combines the high voltage pulse source with the basic observation circuit. The stressing electric field involved a wide range of frequencies from the lowest likely to be

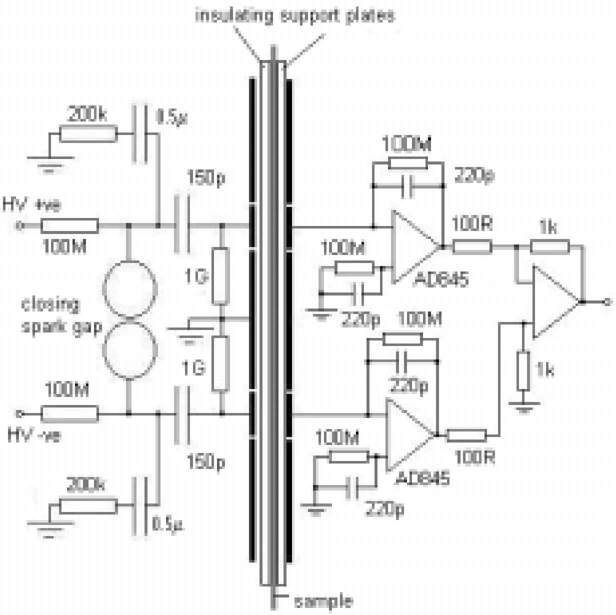

Fig 2: HV pulse and basic difference observation circuit

significant, 10Hz, to the highest likely to arise, around 1GHz. Because it was expected that the highest frequency structure of test pulses might not be reproducible a rather special arrangement was developed for obtaining full information on the variation of attenuation with frequency from individual test pulses. The signals from the observation electrodes were buffered and divided into 9 frequency bands using bandpass filters centered on each decade of frequency from 10Hz to 1GHz. Because the filters needed to respond well to single pulse signals and a narrow bandwidth was not needed the Q was set to unity for all channels except the GHz channel where it was 0.7. With 2 stages of 2 pole filtering the signals at the neighbouring decade frequencies were 52 dB down. For the GHz channel the attenuation at the 100MHz channel was about -34dB. Peak detector and hold circuits were used on the outputs of each filter channel. The stored signals were scanned and fed to a local microcomputer, using a single 12 bit ADC, for analysis, display and data recording. At the higher frequencies it was necessary to stretch the timescale of the observed signals in progressive stages to match the maximum current drive capability of the filter output buffer into the initial signal storage capacitor. To allow direct comparison between signals observed with and without the test material a second set of electric field stressing, observation electrodes and signal processing circuits was arranged so that reference observations 'without material' could be recorded on each and every test pulse. With software controllable gain switching between the filter stages each channel provided a dynamic measurement range of 500:1 from 10Hz to 10MHz. At 100MHz, and particularly at 1 GHz, performance was poorer and also less consistent. Further circuit development work was clearly needed for these highest frequencies.

A much simpler approach was taken in a more recent test assembly. This is appropriate for frequencies from 10Hz up to 10MHz or so. The stressing electric field is provided by buffer amplifiers providing balanced antiphase sinewave signals at a frequency that can be scanned over the range of interest. Because operation is more stable it has not been necessary to measure the reference signals at the same time as observations with the test material. The front end of the signal difference observation circuit is shown in Fig 2.

The balance between the observation channels is tested over the full frequency range using a high conductivity test sample – for example, a sheet of copper or aluminium. Attenuation is measured as the ratio of signals observed with the material present compared to that without. Measurement performance is calibrated by checking the linearity of observational response with source signal amplitude. Calibration can be extended to high level of attenuation by similar measurements of the attenuation of high conductivity 'aperture plates' that have simple uniform width slots spanning over the stressing electrodes.

IV. EXPERIMENTAL RESULTS

Two examples of shielding tests with the first test assembly are shown in Fig 3 and 4 for a metallised shielding bag material and for a carbon filled 'black bag' material.

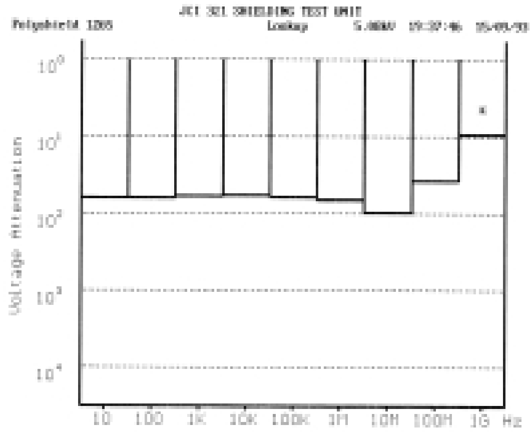

Fig: 3 Shielding performance of metallised shielding bag

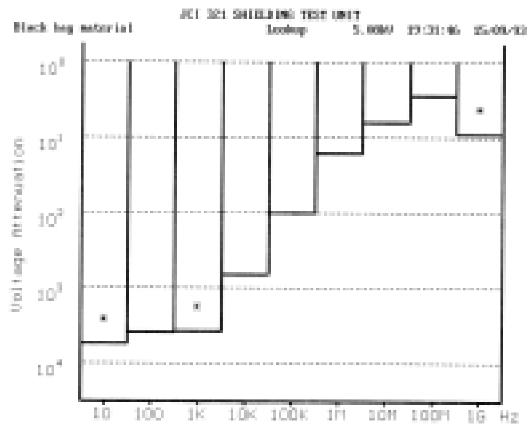

Fig 4: Shielding performance of carbon loaded 'black bag'

Fig 5 shows shielding tests for a number of materials with the second test assembly using the continuous sinewave electric field stressing signal.

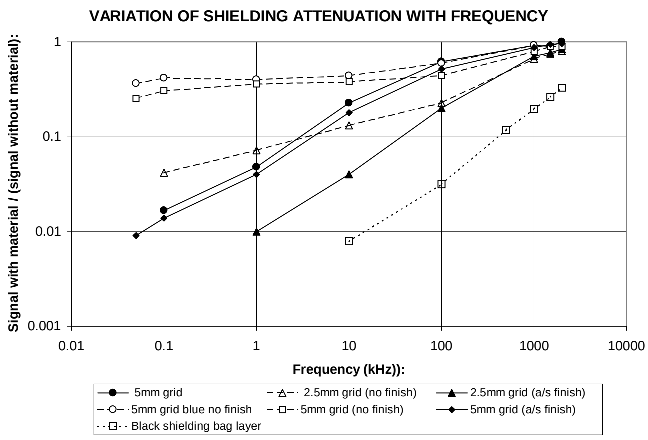

Fig 5: Shielding performance for various materials

Where conductivity in materials and fabrics is provided by metallic conduction then it is observed that there is little variation of shielding performance with frequency. Where the conductivity in materials is provided by features that are ‘resistive’, such as the carbon in the ‘black bag’ material or resistive threads in cleanroom garment fabrics then the shielding performance rather clearly decreases with increasing frequency. In the case of the cleanroom garment fabrics the influence of the ‘resistive’ threads seems to become essentially non-existent by frequencies of 1-2MHz.

The shielding provided by fabrics that include conductive threads, as shown in Fig 5, indicate:

a) that treatment with an antistat makes a significant difference to the shielding performance at the lower frequencies. Antistat treatments seem to start having an influence for frequencies below about 100kHz.
b) that the shielding provided by fabrics with resistive threads is higher the closer the spacing of the resistive threads. This applies at the lower frequencies both with and without an antistat treatment. The 2.5mm grid spacing gives about four times the shielding provided by a 5mm grid spacing.

V. DISCUSSION

It is clear that the variation of shielding performance with frequency both shows the presence of some conductive feature in the material and provides information that has some relationship to the ‘resistivity’ of this conductive feature. The form of this relationship is not yet clear. What does seem clear is that this frequency variation means that the ‘resistive’ threads in fabrics will limit the flow of charge from a large area of charged fabric into a normal spark type electrostatic discharge.

What is now needed is a comparison of the variation of shielding performance with frequency to the incendivity performance of electrostatic discharges to various ‘resistive’ materials. It is also desirable to match shielding performance to expectations for layers whose resistive characteristics can be measured reliably. For the case of well separated resistive threads it seems plausible that the variation of the shielding with frequency might be modelled mathematically from the resistive and capacitance features of fine conductive threads.

VI. CONCLUSIONS

Present methods of measuring the shielding performance of materials give little help in matching capabilities to applications. The method of measurement described is applicable to materials of various construction and provides information on the shielding performance as a function of frequency. This makes is easier to understand the performance of materials, to make fair comparisons between materials and to match material performance to applications.

The variation of shielding capability with frequency, at frequencies up to a few MHz, reveals interesting differences between materials that relate to constructional features and treatments. Certainly this shows the presence of conductive features and probably indicates something of the ‘resistivity’ of these features. It is considered plausible that these characteristics will be found to relate to the possibility of incendive electrostatic discharges to such charged surfaces. In this case such measurements will give a very useful preliminary assessment of the suitability of materials without the need for expensive and time consuming gas ignition tests.

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