A New Type of Furniture ESD and Its Implications

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A New Type of Furniture ESD and Its Implications

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Abstract: An investigation of an instance of upset in electronic equipment has led to the characterization of a new form of indirect furniture ESD. This ESD takes place inside of a chair cushion and radiates fields from metal chair legs. The radiated fields are very strong and can result in upset of nearby equipment. Results of the investigation including measurement methods, field data, and analysis are presented.

Background

An Interesting Problem

In the course of investigating an equipment malfunction, the cause was traced to radiated fields due to ESD internal to a nearby chair. The only evidence of this happening was the radiated electromagnetic fields sensed by monitoring equipment.

Initially, the equipment problem was difficult to diagnose because there was no obvious cause for it as far as the equipment operators were concerned. Normal ESD precautions had been taken and there was no observed ESD present. The only clue to the problem was that the malfunction seemed to be related to a person rising from a chair, the only one in the room.

Instrumentation was set up to monitor electrical disturbances in the area of the equipment. At the time, I did not know what to expect, if anything at all. It seemed possible that the malfunction was not related to the electrical environment of the equipment but to some other cause.

Electromagnetic fields which radiated from the metal legs of the chair due to multiple ESD events internal to the chair were found. The ESD was composed of a series of ESD events taking place over a period of about 10 seconds after a person rose from the chair, the time it took for the cushion to return to its normal shape. These internal ESD events resulted in strong fields being radiated from the metal legs of the chair. Data characterizing this effect are presented and implications are discussed later in this paper.

The radiated electromagnetic fields observed were very strong and capable of inducing several volts per centimeter in nearby conductors. The bandwidth of the fields extended beyond one GHz. Fields of this strength and bandwidth can cause upset in a wide variety of electronic equipment. The effect was aggravated by the presence of several pulses, as many as 10 to 15 have been observed, generated over a period of several seconds. The presence of a train of pulses over a relatively long period of time increases the probability that equipment upset will occur.

Observed Conditions for Chair ESD

Subsequent investigation has revealed several conditions that appear to affect the ability of a chair to produce this phenomena. Metal legs are required for the ESD to be able to radiate the substantial fields observed. When the cushion was removed from the legs of the chair involved in the equipment problem, no radiated fields could be observed. It is possible that the ESD was still occurring within the chair, but without the antenna effect of the legs, no strong radiated fields can occur. It is possible that charges generated within the chair induced a charge on floating metal inside the cushion which then sparked to the legs.

For a chair that has the physical characteristics to generate this type of ESD, the ambient humidity has a strong affect on the ability of the chair to produce the multiple internal sparking. The chair that originally caused problem was doing so when the outside temperature was below zero Fahrenheit and the relative humidity inside the heated building was only a few percent.

The multiple sparking can also be generated by charging a person sitting on a chair capable of the effect to several thousand volts and having the person rise from the chair. The effect was successfully generated this way under conditions where the outside temperature and indoor humidity were substantially higher than when the effect was first noticed, about 50 degrees Fahrenheit. This method of inducing the problem could form the basis for an industry standard describing a test method for determining the propensity of a chair to exhibit this form of indirect ESD.

Normal methods of ESD control, such as wearing wrist straps and using special floor finishes, have no effect on this phenomenon and indeed it has been observed in an "ESD safe" chair as well as in about one third of the chairs tested to date. Since there are no current methods that guarantee control of this type of indirect ESD, it must be assumed to be present anytime chairs with cushions and metal legs are present.

Measurement Methods

Equipment Used

Current measurements were taken on system cables as well as cables placed near the chair being tested. The equipment consisted of a Hewlett Packard 54512B oscilloscope, two Fischer Custom Communications matched F-33-1 current probes and cables, and a hand built coaxial current probe described later in this section.[1,2] The scope has a sampling rate of 1 GSa/sec with a 300 MHz analog bandwidth. The F-33-1 current probes also have a 300 MHz bandwidth.

Most of the measurements taken were bandlimited by the measurement apparatus to a few hundred MHz because of the need to use easily portable equipment under field conditions. Even with this limitation, the data is significant and shows how powerful a source of interference ESD of this type is. The data presented in the next section could only exhibit more interference potential if the bandwidth of the measurement equipment was increased.

Coaxial Current Probe Operation

Construction details of a coaxial current probe are shown in Figures 1a and 1b. It is constructed by placing a 47 ohm resistor in series with the center conductor of a coaxial cable with a 50 ohm characteristic impedance and then returning 2 ohms to the shield of the coaxial cable from the free end of the 47 ohm resistor.

The 2 ohm resistance is formed by using five 10 ohm resistors in parallel equally spaced around the cable. This construction is necessary to minimize inductive effects in such a low value resistor and to help maintain a coaxial geometry for shield currents. Carbon composition 1/4 watt, 5% resistors are well suited for this application. In practice, the resistor network would be covered with heat shrink tubing or other insulation for protection.

The construction of the coaxial current probe is such that it has a transfer impedance of about 1 ohm to current flowing into the probe tip (junction of the 2 and 47 ohm resistors) from an external source. That is, it delivers a signal to the 50 ohm load at the measuring instrument that is 1 ohm times the current flowing in the 2 ohm resistance connected to the shield of the cable. For instance, 1 amp of current flowing in the 2 ohm resistance generates about 2 volts. About one half of this is dropped across the 47 ohm resistor and about one half, or 1 volt, is delivered to the coaxial cable and ultimately its load, the measuring instrument.

The probe injects about 2 ohms in series with the current. This is small enough not to have much effect on the amount of current flowing from the probe tip onto the shield of the coaxial cable.

A current probe of this type can have a wide bandwidth extending from DC to hundreds of MHz or higher. Its small size, just 6 resistors at the end of a coaxial cable, allows placement in tight spots. It is important to remember that the current to voltage transformation takes place at the location of the resistor network.

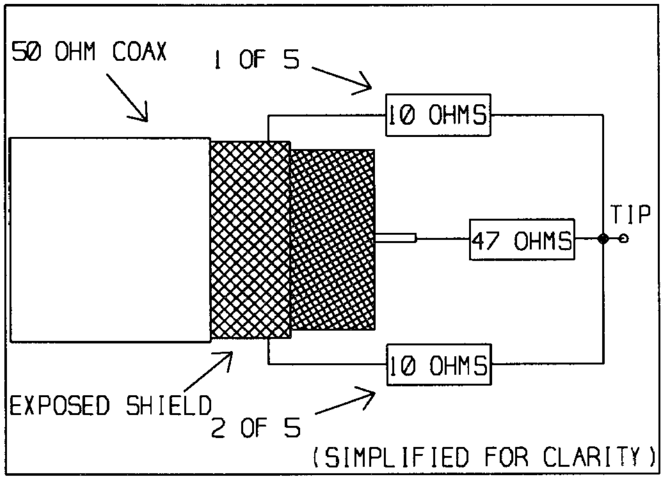


Figure 1a. Coaxial Current Probe, side view.

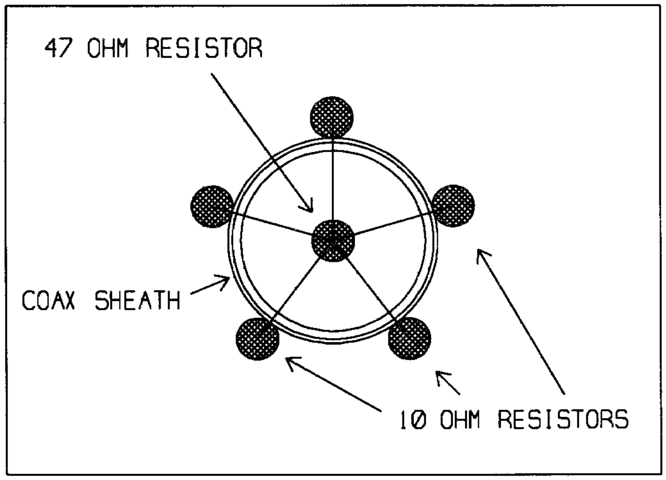


Figure 1b. Coaxial Current Probe, end view.

Figure 1c shows a typical use of this probe, measuring the current flowing between an antenna wire and the shield of the probe cable due to local electromagnetic fields. A measurement of this type can be used as an indication of the strength of fields radiated by ESD events.

Current flowing on the antenna wire results in a voltage being launched inside of the coaxial cable (about one volt per amp). This voltage is the signal displayed by the scope. Remember that the current measurement takes place at the location of the resistor network. A standard current probe placed over the resistor network will indicate the same current as the output from the coaxial current probe, limited by the frequency response of the standard probe.

The data taken for this paper using the coaxial current probe was taken with an arrangement that is a variation on that shown in Figure 1c. The probe was connected to a ground lug on a metal wall, a good high frequency ground, by a 1 foot length of wire between the probe tip and the ground lug. The length of coaxial cable to the scope was about 8 feet.

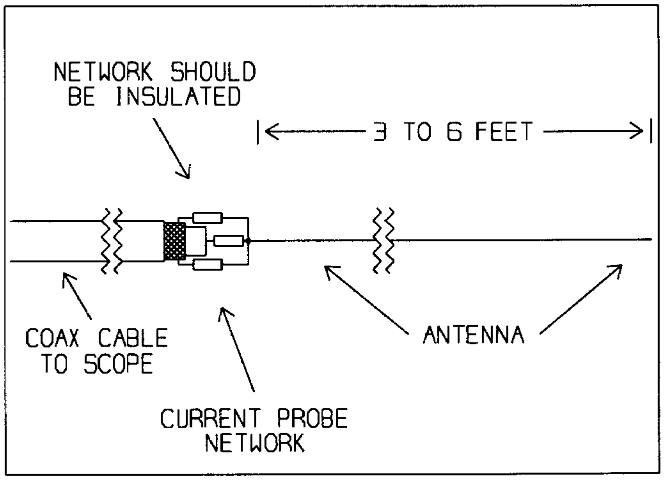


Figure 1c. Coaxial Current Probe, typical use.

Field Data

The data taken in the field consisted of current measurements made near the chair using the coaxial current probe and on system cables using the matched F-33-1 current probes. Figure 2 shows the current on a cable that was draped horizontally about one foot from the chair. The waveform represents only one of several ESD events that occurred within the first 10 seconds after a person rose from the chair. The scale factors are 50 ma/div for current and 20 ns/div for time.

The current reached a peak amplitude of 200 ma with the envelope of oscillations and reflections decaying to about 10% in about 200 ns. Figure 3 displays the same waveform at 5 ns/div to show high frequency detail.

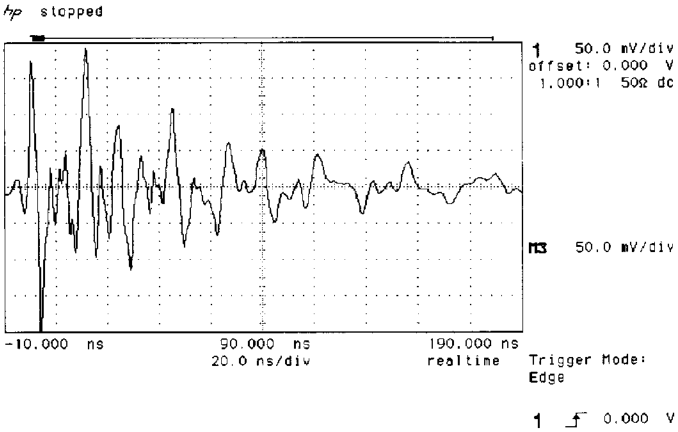


Figure 2. Coaxial current probe output, cable one foot from chair. (50 ma/div, 20 ns/div)

The current waveform is seen to have a risetime of less than one nanosecond, the sampling period of the scope. Even if the waveform is taken to have a 1 nanosecond rise/fall time, still the potential for interference from this induced current is great.

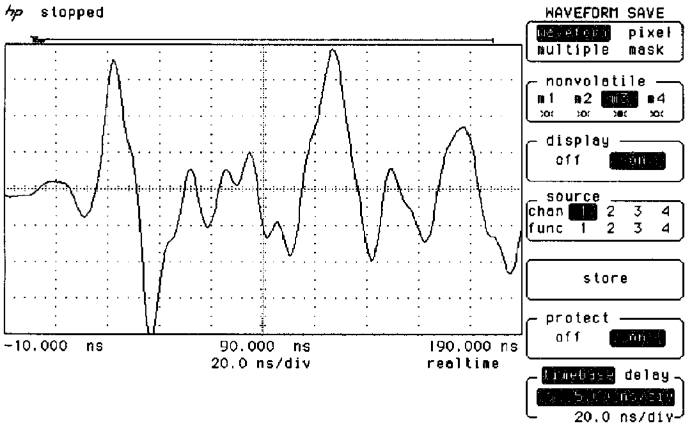
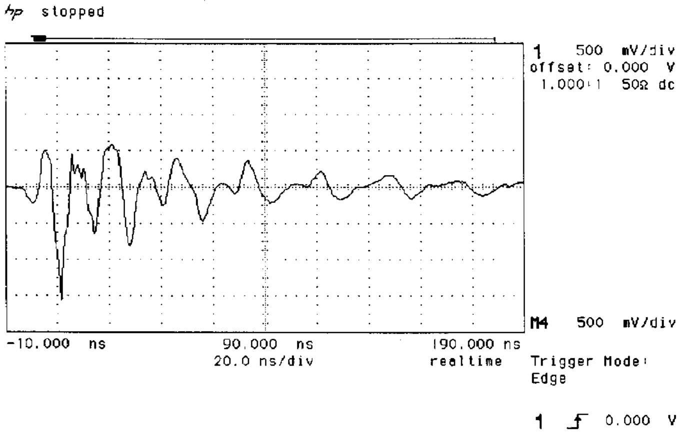


Figure 3. Coaxial current probe output, cable one foot from chair. (50 ma/div, 5 ns/div)

One measure of the interfering potential of a current is to express it as an inductive voltage drop per unit length on a conductor. I like to use volts per inch. This is approximately calculated by multiplying 20 nh/inch (estimate of the partial inductance of an inch of wire)[3] by di/dt, the rate of change of the current with respect to time. A value of tens of millivolts/inch is generally not enough to affect digital logic whereas values over one volt/inch are potentially a problem.

The current depicted in Figure 3 produces an inductive drop of 4 volts per inch. However, this is a lower bound for the real inductive drop because the risetime, and probably peak value, was limited by the measuring equipment. This amount of inductive drop can certainly develop a logic threshold on very short paths of a circuit board and is therefore dangerous to logic signals.

Figure 4 shows the current indicated by the coaxial current probe when its cable was placed on the edge of the chair cushion. The scale factors for this figure are 500 ma/div for current and 20 ns/div for time. At this range, a single negative pulse reaching 1.5 amps dominates the scope picture, followed by a oscillatory response which damps out over the 200 nanoseconds displayed.



1 500 mV/div
offset: 0.000 V
1.000:1 50Ω dc
M4 500 mV/div
Trigger Mode: Edge
1 0.000 V

Figure 4. Coaxial current probe output, cable on chair. (20 ns/div)

High frequency detail of the waveform can be seen in Figure 5 at 5 ns/div. A change of current of about 1 ampere occurs in less than one nanosecond yielding an L·di/dt lower bound of about 20 volts/in. This is indeed a dangerous waveform! Perhaps the unlikely probability of equipment being this close to the chair makes the interference less of a problem for practical situations.

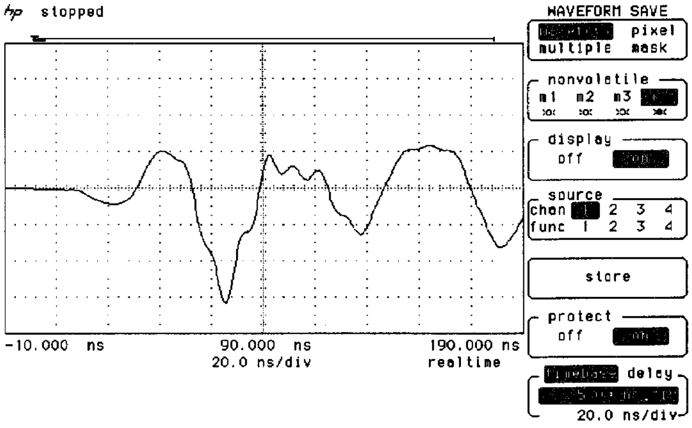
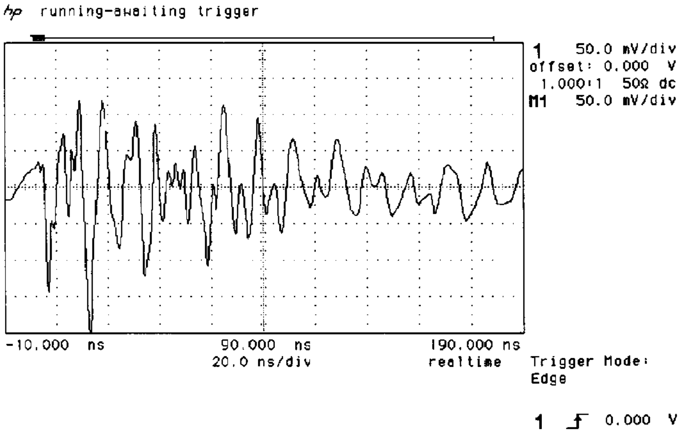


Figure 5. Coaxial current probe output, cable on chair. (5 ns/div)

The "ESD" chair was then placed in its normal position about one foot from the front of the equipment experiencing upset. The chair's nearest leg was 1.5 feet from the equipment and about 2 feet from an external system cable. Current on the system cable was monitored with the F-33-1 current probes while a person rose from the chair.

Figure 6 shows the measured waveform for one of the many discharges that occurred each time someone rose from the chair. The F-33-1 current probe has a transfer impedance of 5 ohms, so the vertical scale is 10 ma/div and as before, the horizontal scale is 20 ns/div. The peak current reached about 40 ma and continued to experience reflections and ringing to beyond 200 ns.

Measurements using the F-33-1 probes were checked by null experiment.[1,2] In this case, it was accomplished by using the current probes in pairs for each measurement. The two probes were installed on the cable to be measured with opposite polarity. If the displayed waveform were truly due to the current response of the probes, the two waveforms should be mirror images of each other. A subtraction can also be performed in the scope and the difference of the two current probe signals displayed. This difference represents the error of the measurement which includes: electric field response of the current probes, false signals due to the shield transfer impedance of the cables or connectors, and interference to the scope itself.



1 50.0 mV/div
offset: 0.000 V
1.000:1 50Ω dc
M1 50.0 mV/div
Trigger Mode: Edge
1 0.000 V

Figure 6. System cable current, chair in front of equipment. (20 ns/div)

All of the nonvolatile memory of the scope was used to return field data for downloading so the null experiment results were not stored. They did indicate that for Figure 6, there was significant error in the about the first 20 ns. In the past, the HP-54512B scope and F-33-1 current probes have proved very reliable in the presence of strong fields generated by ESD, so I suspect that either the cables or the BNC connectors used had a higher than desired shield transfer impedance at hundreds of MHz The error did decrease to near zero at about 20 to 30 ns.

Figure 7 shows the waveform of Figure 6 expanded to 5 ns/division. At about 30 ns into the waveform a current change of 10 ma in 1 ns was recorded. Remembering the bandwidth limit of the scope and current probes, this translates to a minimum L·di/dt of 20 mv/in. This is a relatively small value relative to logic noise margins so I expect that the equipment problem was due to the radiated fields directly affecting the equipment rather than induced in the measured cable (there were only a few signal cables attached to the system and these were close to the one measured).

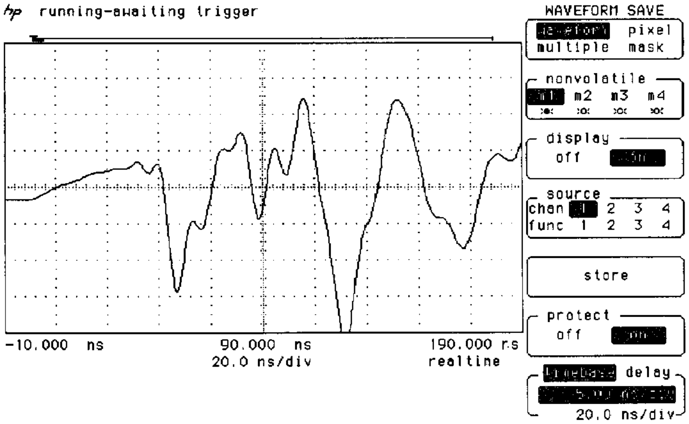


Figure 7. System cable current, chair in front of equipment. (5 ns/div)

The same cable current was measured with the chair in back of the system resulting in the shown in Figure 8. As for Figures 6 and 7 the vertical scale is 10 ma/div and the horizontal scale is 20 ns/div. The waveform is expanded to 5 ns/div in Figure 9. The peak amplitudes and di/dt values are similar to those in Figures 6 and 7 except there are three large peaks instead of only one in the negative direction and the positive peaks are about 50% larger.

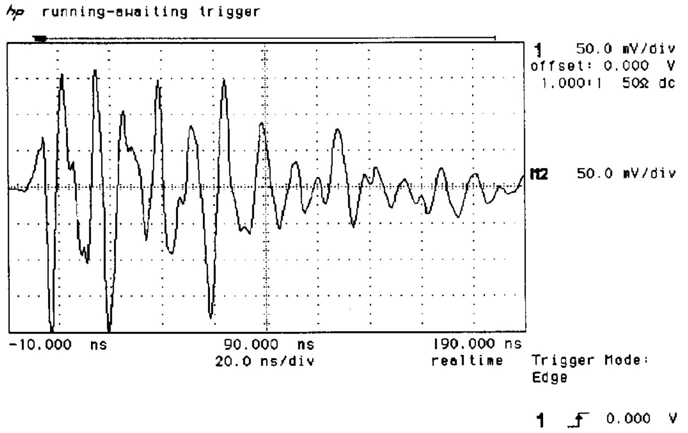


Figure 8. System cable current, chair in back of equipment. (20 ns/div)

The interference potential with the chair in back of the equipment is similar to that when the chair was located in the front, that is the system cables were not carrying excessive currents or high di/dt values. This is possibly due to the fact that the cables were routed along a substantial metal support for most of their length. The metal support probably provided some shielding for the cables.

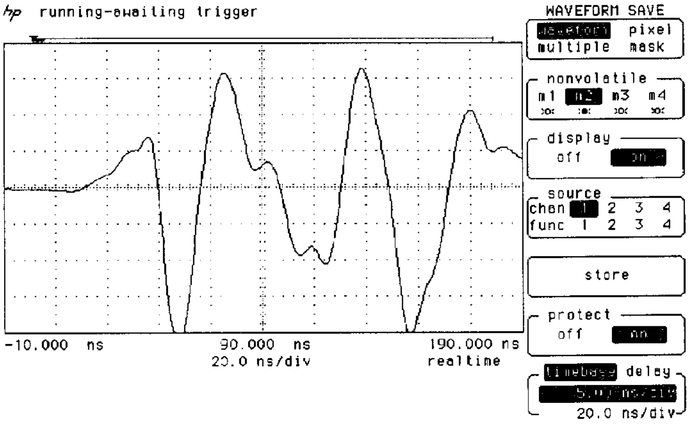


Figure 9. System cable current, chair in back of equipment. (5 ns/div)

Summary

Some types of common laboratory stools and office chairs have the ability to radiate a series of impulsive fields from metal legs due to internal ESD when a person rises from the chair. As many as a dozen pulses have been recorded in the 10 seconds after a person rises from the chair. This mechanism has been observed in a wide variety of chairs including the author's office chair and an "ESD safe" chair intended for use in factories. Induced voltages of several volts/inch were observed in cables near one such chair. The presence of multiple discharges over several seconds increases the interference potential of this effect.

Normal methods of ESD control such as wrist straps, floor wax, as well as "ESD safe" chairs have no effect on this problem. Therefore an equipment problem may exist in a location and ESD not be suspected as the cause.

Conclusions

It is clear that chairs, such as described in this paper, should not be used around mission critical equipment such as medical equipment, airport control towers, and communication equipment. Although such equipment is designed with immunity in mind, it is not prudent to test the equipment's immunity during everyday operation.

In addition, there are no standards that model this effect well. So it is possible to have equipment that meets all modern immunity standards and yet still be susceptible to this type of interference. Designing to immunity standards is no guarantee of proper equipment function in the field, and internal chair ESD is one example that proves it!

The lack of standards for measurement or chair construction also means that it is not possible to buy chairs for critical applications that are guaranteed not to exhibit internal ESD unless non-metallic legs are specified. At this point, the only safe chairs appear to be those without metal legs or without cushions.

Areas for Further Work

Due to the seriousness of the interference caused by internal chair ESD, a standard immunity test should be developed for it. This would allow one to assure that an equipment design is immune to this source of interference.

A standard should also be developed to allow chair manufacturers to market a chair that would meet some criteria for avoiding this problem. The construction techniques for such a chair are simple. For example, one would only need to make all of the material in the chair cushion (surface and internal as well) ESD dissipative and the required voltage difference to result in a discharge could not be developed.

The physical and electrical characteristics of the chair that contribute to this effect should be investigated. It is possible that this form of indirect ESD is related to discharges from small floating metal objects, within the cushion, such as described by Honda[4] or even to the Charged Device model[5].

Relating the phenomena reported in this paper to other well known mechanisms, such as mentioned above, may help efforts to develop a standard for testing chairs for this effect or for construction of chairs free from it. At a minimum, such an understanding of the physical basis of the observed effects reported in this paper will help in identifying those chairs that are likely to exhibit this effect.

Acknowledgments

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