MOTOROLA

Integrated Information Systems Group
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Exhibit 11 – RF Exposure Information

BiStatix™ BDR-1000

RFID Tag Reader/Programmer

FCC ID: E9U05866001T1

Model No. BDR-1000

11.0 RF Exposure Information

The BDR-1000 RFID Tag Reader/Programmer complies with human radiation emission requirements. These requirements are based on the Maximum Permissible Exposure (MPE) levels of ANSI/IEEE C95.1-1992 and 47 CFR 1.1310, Table 1 for an uncontrolled environment.

The access control reader is a low power device intended to be used as a desktop device. The access control reader can arguably fit the definition of a portable device as defined in 47 CFR 2.1093(b) (i.e. "designed to be used so that the radiating structure of the device is within 20 cm of the body of the user", specifically the hand). However, it does not fit any of the equipment classification criteria for portable devices requiring SAR testing as defined in 47 CFR 2.1093(c). All other portable transmitting devices "are categorically excluded from routine environmental evaluation for RF exposure prior to equipment authorization or use" per 2.1093(c) which includes the Access Control Reader.

An Evaluation of Electric and Magnetic Fields and Induced and Contact Currents Associated with Operation of the Motorola BiStatix™ BDR-1000 Access Control Reader

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Prepared for

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Introduction

Motorola's Indala Corporation has developed an electric field based radiofrequency identification (RFID) system based on Motorola's BiStatix™ technology. The BiStatix™ technology, employed with RFID tags (miniature transponders), can be used for monitoring and tracking packages, parcels, freight and other items. This technology makes use of very low frequency (VLF) electric fields at 125 kHz.

The Model BDR-1000 reader unit was evaluated in the measurements reported here to assess compliance with applicable human exposure limits for electric and magnetic fields. The BDR-1000 Access Control Reader is contained within a modest sized structure measuring nominally 8.0 x 10.0 inches and is to be placed on a counter or desk with the internal active electrode horizontal in orientation. Figure 1 shows the BDR-1000 unit.

This report documents a series of measurements to evaluate potential exposure of personnel to electric and magnetic fields produced by this reader and the induced body currents and contact currents that may result from personnel occupying areas near the reader or handling the reader.

Method of Evaluation

RF Fields

Radiofrequency (RF) fields were examined by measuring the spatial variation of electric and magnetic field strengths in the vicinity of the reader. This was accomplished by determining the resultant field strength from three orthogonal components of the field consisting of the vertical (z), and horizontal (x,y) polarization components. The reader unit was placed on a wooden support placing it 79 cm above the floor to simulate a typical installation. Figure 2 shows the test setup with the reader placed on a wooden desk (the reader is hidden from view in this figure by the cardboard measurement plane). To facilitate the field measurements, a measurement grid was drawn on the surface of a large cardboard sheet. The cardboard sheet was attached to the front edge of the desk such that the specific measurement points were positioned at the locations specified in the CENELEC standard. The reader unit was positioned on the desk, on top of a wooden support, to place at successively greater distances of 15, 30 and 45 cm from the center of the measurement probe used for measuring electric and magnetic fields. The test area was positioned over a concrete floor.

The reader was powered by connection to an external power supply that was connected to a 120 volt AC outlet. The power cable to the reader was positioned to lead directly away, in a straight line, from the rear of the unit for approximately 28 inches (approximately 71 cm) before dropping to the floor. Two identical models of the BDR-1000 reader were submitted for evaluation and field strength and contact current measurements were performed on both.

Electric and magnetic fields were measured in two different ways. The first method followed guidance contained in IEEE C95.1-1999 for obtaining the spatially averaged field strength.[1] In this case, three mutually orthogonal values of field strength were obtained at 15-cm intervals beginning at approximately 15 cm above the floor and extending up to a height of 175 cm. These measurements were made at a lateral distance of 15 cm directly in front of the reader assembly front surface. The spatially averaged fields were then computed by taking the average of the individual resultant values of fields at each measurement height following the recommendations in the IEEE standard.[2] Figure 2 shows the measurement setup for measurement of fields along the 175 cm long, vertical line.

A second approach to field measurements followed the recent Final Draft Rev. 2.4 from CENELEC designed for evaluation of human exposure to devices used in such applications as RF identification.[3] It was deemed important to also use this measurement protocol as it specifically states that it is applicable to determining compliance with the exposure guidelines published by the International Commission on Non-Ionizing Radiation Protection (ICNIRP).[4] The ICNIRP guidelines are used widely in Europe for evaluating human exposure to RF fields and are most likely to be used in certifying electronic products for sale within Europe as well as other regions in the world. Figure 3, taken from the draft CENELEC standard, illustrates the recommended measurement grid that was followed in these measurements.

The measurement grid was arranged to correspond to the recommendations in the Draft standard with the bottom most measurement points being located 85 cm above the floor surface. The specified grid includes 45 measurement points, 15 in each of three planes located at 15, 30 and 45 cm from the front surface of the reader unit. The smallest value (15 cm) was based on the assumption that the unit might be placed this close to the edge of a counter or desk. The CENELEC document indicates that the normal distance from the front edge of the reader unit would be 30 cm but that for shorter distances, occupational exposure limits would usually be used. The shorter distance used for this evaluation was used in the interest of conservatism in that any measured field strengths would be stronger than if the unit were placed further back from the front edge of the counter or desk. Three orthogonal field measurements were made at each of the 45

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[1] IEEE (1999). IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz. IEEE Std. C95.1, 1999 Edition. Institute of Electrical and Electronics Engineers, Inc., 345 East 47th Street, New York, NY 10017.

[2] Electric and magnetic field strengths were computed by finding the square root of the sum of the squares of the individual resultant field strength values at each height.

[3] "*Evaluation of Human Exposure to Electromagnetic Fields from Devices used in Electronic Article Surveillance (EAS), Radio Frequency Identification (RFID) and similar Applications.*" European Standard CLC/TC211/WG2 (Conv) 02, April, 2000. European Committee for Electrotechnical Standardization.

[4] ICNIRP (1998). Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz). *Health Physics*, Vol. 74, No. 4, April, pp. 494-522.

points for a total of 135 measurements. Figure 4 is a photograph showing the measurement setup with the series of 15 measurement points on the cardboard grid. Figures 5 and 6 show the author standing near the cardboard measurement grid for perspective in seeing how the grid corresponds to the trunk region of the body.

Electric and magnetic fields were evaluated by comparing them to specified Maximum Permissible Exposure (MPE) limits contained in the IEEE standard C95.1-1999 for uncontrolled environments and the guidelines of the ICNIRP for general population exposure. At the 125 kHz frequency of the BiStatix™ readers, the MPE limits for electric and magnetic fields and induced body currents and contact currents are shown below.

IEEE and ICNIRP Exposure Limits for Electric and Magnetic Fields at 125 kHz		
Electric field strength (V/m)	Magnetic field strength (mA/m)	Induced body current through each foot and contact current (mA)
IEEE C95.1-1999		
614	130,400	45
ICNIRP		
87	5,000	20

It is important to note that the electric and magnetic field strength limits given above are the mean values obtained by spatially averaging the fields. IEEE and CENELEC specify different methods for this process. In the case of the IEEE standard, the field limit is obtained from an average of the squares of the fields over an area equivalent to the vertical cross-section of the human body. In practice, the spatial average of the fields were determined by measuring along a vertical line at 15 cm intervals up to a height of 1.75 meters in accordance with the guidance provided in the IEEE standard in section 6.6 on Measurement Procedures. It is also important to understand that the MPEs for electric and magnetic fields are in terms of the unperturbed fields, those that would exist without the perturbing influence of the human body.

For applying the CENELEC draft standard, a linear average of the resultant field strengths obtained at the 45 measurement grid points was used for assessing exposure (section 5.1.2).

Induced and Contact Currents

Induced body current is generally defined as the magnitude of RF current that flows between the body of an individual exposed to RF fields and ground and is generally measured either at the foot or ankle of the exposed subject. The subject's body, acting similarly to a radio antenna, when exposed to an RF field, will exhibit an RF current flowing within it. The SAR in the body can be related directly to the local current density through the relationship:

$$SAR = \frac{J^2}{\sigma\rho}(W/kg)$$

where
SAR is the specific absorption rate in units of watts per kilogram (W/kg);
σ is the tissue conductivity in units of siemens per meter (S/m);
ρ is the mass density of the tissue (kg/m^3)(nominally 1,000 kg/m^3);
J is the local current density in units of amperes per square meter (A/m^2);

The IEEE standard for induced body current specifies a maximum current of 45 milliamperes (mA) through each foot or a total current of 90 mA through both feet together for RF exposure of individuals in an uncontrolled environment. This limit applies, in the present standard, up to a frequency of 100 MHz. The conductive cross-section of the ankle is approximately 9.5 cm^2 (Gandhi et al., 1985). A current of 45 mA flowing through the ankle would be expected to result in a local SAR of about 3.7 W/kg assuming that the conductivity of muscle tissue is 0.6 siemens per meter at 125 kHz.

The ICNIRP guidelines permit only 20 mA of contact current at 125 kHz but do allow up to 45 mA for induced limb current without direct contact. For purposes of this evaluation, the more stringent limit of 20 mA was used.

Contact current is generally defined as the magnitude of RF current that flows between the body and an object when touched. Contact current is normally measured at the wrist when the hand is placed in contact with the object. The same IEEE limits apply for contact currents, as induced body currents, and since the conductive cross-section area of the wrist is approximately the same as the ankle, due to bone sizes, the local SAR in the wrist with a contact current of 45 mA is about the same as for the ankle. Chatterjee et al. (1986) reported a wrist conductive cross-section area of 11.1 cm^2. Using this area, the projected local SAR for a contact current of 45 mA would be 2.6 W/kg.

The methodology used in these measurements for evaluating exposure included direct measurements of both induced body currents, measured at the ankle, and contact currents, measured at the wrist or forearm. Induced body currents were measured by placing a clamp-on current transformer about one ankle and having the subject stand near the electrode of the reader as it sat on the desk.

Contact currents were measured by placing the clamp-on current transformer about the arm approximately at the elbow and placing the hand flat against the reader unit (see Figure 9). The hand was then slid about the surface of the unit to identify the maximum possible reading of current.

Instrumentation and Calibrations

Electric and magnetic field strengths were measured with a Holaday Industries, Inc. Model HI-3603 VDT/VLF Radiation Measurement System (SN 75374). This device, illustrated in Figure 7, allows measurement of electric fields with a displacement current sensor, represented by two thinly spaced circular, flat plate type electrodes. Magnetic fields are sensed with a loop sensor that encircles the outer diameter of the paddle-like extension of the instrument. The diameter of the loop is nominally 20 cm. This instrument is designed to have a nominal frequency response of 2 - 300 kHz (±2 dB) for electric fields and 8 - 300 kHz (±2 dB) for magnetic fields, making it suitable for the fields associated with the BiStatix™ systems evaluated in this report. The dynamic measurement ranges for electric and magnetic fields correspond to 1 to 2,000 volts per meter (V/m) and 1 to 2,000 milliamperes per meter (mA/m) respectively. The Model HI-3603 makes use of a true RMS detector and is a single axis type of detector.

The Model HI-3603 was used with a Holaday Model HI-3616 Fiber Optic Remote Control unit (SN 75235) which connects to the HI-3603 sensor via a pair of plastic fiber optic cables. Use of the fiber optic remote control permits reduction of operator influence on the local electric fields for certain measurements.

All measurement distances were referenced from the front surface of the reader unit to either the active surface or center of the field sensor, whichever was applicable at the time of measurement. For example, magnetic field measurements were always made with the center of the sensor placed at the specified distance. For measurement of the radial component of the electric field, the distance was to the active surface of the probe plate.

The Model HI-3603 was calibrated for its specific response to electric and magnetic fields at 125 kHz on July 20, 2000 at the Holaday Industries, Inc. factory. Correction factors were determined by Holaday to correct meter readings at 20, 125 and 232 kHz as shown in the chart below. Figure 8 shows the calibration label affixed to the HI-3603 during calibration at the Holaday Industries factory.

Holaday Industries Model HI-3603 (SN 75374) Calibration Data	
Frequency (kHz)	Correction factor
20 Magnetic	1.00
125 Magnetic	0.96
232 Magnetic	1.00
20 Electric	1.00
125 Electric	1.01

Induced and contact currents were measured with a Holaday Industries, Inc. Model HI-3702 Clamp-on Induced Current Meter (SN-61201) connected to a Holaday Industries, Inc. Model HI-4416 Fiber Optic System Readout module (SN-97091). This device can be clamped about either the wrist, for measuring contact currents, or about the ankle, for measuring induced body currents. The Model HI-3702 has a specified frequency response of 9 kHz - 110 MHz (±2 dB) and a dynamic measurement range of 2 - 1000 mA. This device was also calibrated for its specific response on July 18, 2000, at 125 kHz by driving a known current through a wire, in series with a 50.8 ohm resistor, that was configured through the aperture of the current transformer. The indicated response of the meter was then referenced to the actual current flowing through the test wire to obtain an appropriate correction factor to apply to all subsequent readings taken with the meter. At 125 kHz, the correction factor for measurement of current was determined to be 0.983. All measurement results are reported in terms of values that have been corrected by multiplying indicated readings by the appropriate correction factors. Figure 9 shows the Model HI-3702 meter placed about the arm during measurement of contact currents.

Measurement Results

RF Fields

For assessing conformance with the IEEE electric and magnetic field strength limits, the fields were measured along a 175-cm vertical axis located in front of two identical reader unit models (D3 and D4) are given in Tables 1 and 2. The resultant value of three orthogonal field readings at each point were first computed by squaring each of the polarization components, summing them, and then taking the square root of this value. The spatial average values in Tables 1 and 2 were then determined by squaring each indicated resultant field strength value, summing these squares, then finding the average of the summed squares and then taking the square root of these averages. These data indicate that the spatially averaged field values were 60.5 V/m and 55.5 V/m for the D3 and D4 reader units respectively. Magnetic field strengths for any of the measurements were equivalent to the minimum detectable field level of the meter or 0.88 mA/m. Squared values of field strength are shown in Tables 1 and 2 for the 175-cm tall vertical measurement axis at 15 cm from the reader surface.

The extensive measurements in accordance with the CENELEC draft standard are also summarized in Tables 1 and 2 for electric and magnetic fields respectively for both units evaluated. Using the resultant electric field strengths found at the 45 measurement points, the overall average of these values was determined to be 35.7 V/m and 33.5 V/m for the D3 and D4 reader units respectively. Magnetic fields at all measurement points did not exceed the minimum detectable field level for the meter, or 0.88 mA/m.

Contact and Induced Currents

The contact and induced current measurements revealed that the only condition in which detectable current could be obtained was when a subject directly contacted the top surface of the reader unit as illustrated in Figure 9. When contact was broken with the surface of the reader unit, the indicated current reduced to the minimum detection limit for the HI-3702 meter of about 0.88 mA. Hence, induced currents were below the detection threshold of the meter. The maximum arm current for the D3 reader was found to be 2.23 mA with the subject standing barefooted on the concrete floor. The measured current when the subject wore conventional tennis shoes dropped to 1.7 mA. Ankle currents were observed to be the same as the arm current when touching the top of the reader unit. The barefooted arm current for the D4 unit was 2.18 mA. The contact currents, while virtually the same, followed the same trend as the electric field strength measurements with the D3 unit resulting in slightly greater values.

Discussion and Conclusions

The measurement data obtained on the BiStatix™ Model BDR-1000 access control reader demonstrate that electric and magnetic field strengths and contact and induced currents comply with exposure limits specified by both the IEEE and ICNIRP as implemented through the measurement protocol defined by the CENELEC draft standard. For example, the maximum spatially averaged electric field strength, for comparison with the IEEE limits, was 60.5 V/m compared to the IEEE limit of 614 V/m. Spatially averaged magnetic field strength was 0.88 mA/m compared to the IEEE limit of 130,400 mA/m.

Using the CENELEC draft protocol for measurements, the spatially averaged electric field strength was found to be a maximum of 35.7 V/m compared with the ICNIRP exposure limit of 87 V/m for the general public.

The maximum possible contact current was found to be 2.23 mA from either of the two reader units tested. This may be compared to either 45 mA as a limit for contact current by the IEEE or 20 mA in the ICNIRP guidelines. In either case, the actual current is substantially lower in value than the limits.

Based on these measurement data, it is concluded that the BiStatix™ Model BDR-1000 reader complies with both the IEEE and ICNIRP exposure limits in terms of electric and magnetic field strengths as well as contact and induced currents.

Table 1. Summary of measured electric field strength data for BDR-1000 reader unit D3													
At 15 cm in front of reader						At 30 cm in front of reader				At 45 cm in front of reader			
Point	Ex(V/m)	Ey(V/m)	Ez(V/m)	Eres(V/m) corrected	$Eres^2$	Ex(V/m)	Ey(V/m)	Ez(V/m)	Eres(V/m) corrected	Ex(V/m)	Ey(V/m)	Ez(V/m)	Eres(V/m) corrected
1	7.38	6.24	14.73	17.79	316.61	7.91	6	10.88	14.88	7.20	4.44	8.16	11.87
2	5.86	4.99	15.04	17.06	291.18	6.95	4.94	11.14	14.17	6.55	4.13	8.16	11.36
3	3.33	6.46	12.52	14.62	213.78	5	5.99	9.67	12.55	5.05	4.95	7.25	10.23
4	14.52	11.55	27	33.09	1094.80	13.93	8.66	15.35	22.69	10.74	6.20	9.82	15.98
5	11.32	9.36	27.1	31.13	969.26	12.12	7.5	15.28	21.10	9.60	5.92	9.92	15.17
6	5.8	12	21.2	25.29	639.68	8.24	9.63	12.67	18.10	7.33	7.06	8.65	13.49
7	37.3	24	41.6	61.42	3772.18	26	12.4	18.72	34.70	14.95	7.91	10.90	20.32
8	30.5	18.29	43.4	56.67	3211.62	23.1	11.67	18.99	32.42	13.60	8.04	10.92	19.40
9	11.2	26.6	29.7	41.83	1749.56	12.66	14.82	15.17	24.95	9.82	9.50	9.55	16.84
10	84.7	40.2	46.3	105.61	11153.59	39.6	16.88	16.65	46.62	18.91	8.98	9.60	23.26
11	76	39.7	48.7	99.60	9919.23	35.7	16.4	17.42	43.41	17.00	9.42	9.82	21.99
12	21.3	50.3	28.2	62.09	3854.98	20.4	22.8	13.1	33.61	12.00	11.39	8.63	18.85
13	112.1	49.3	38.4	129.62	16802.54	43.5	17.55	16.8	50.32	22.60	9.26	10.10	26.69
14	103.8	47.7	40.7	122.48	15001.82	39.7	18.3	16.8	47.30	20.40	10.22	9.83	25.09
15	19.1	57.5	22.6	65.31	4265.87	21.2	24.8	12.3	35.22	12.66	12.12	8.12	19.51
16	39.5	24.2	53.5	71.48	5108.80	IEEE spatially averaged electric field strength over 175 cm high axis (22 measurement point) = 60.5 V/m							
17	11.78	9.3	33	36.62	1340.67								
18	5.36	4.95	19	20.56	422.56	CENELEC spatially averaged electric field strength over 45 measurement points = 35.7 V/m							
19	1.65	1.4	10.4	10.73	115.11								
20	0.4	0.3	7.17	7.26	52.70								
21	3.64	3.33	9.1	10.45	109.30								
22	2.14	2.01	5.66	6.44	41.47								

Table 2. Summary of measured electric field strength data for BDR-1000 reader unit D4

At 15 cm in front of reader						At 30 cm in front of reader				At 45 cm in front of reader			
Point	Ex(V/m)	Ey(V/m)	Ez(V/m)	Eres(V/m)	Eres^2	Ex(V/m)	Ey(V/m)	Ez(V/m)	Eres(V/m)	Ex(V/m)	Ey(V/m)	Ez(V/m)	Eres(V/m)
1	7.4	2.6	14.3	16.5	271.7	7.6	5.79	11.18	14.9	6.56	4.46	7.98	11.4
2	6.1	5.6	14.6	16.9	286.0	6.54	3.8	11.27	13.7	6.04	3.8	8.04	10.9
3	3.6	7.3	12.1	14.7	216.4	4.58	6.38	9.76	12.7	4.6	4.9	7.23	10.0
4	14.5	3.8	26.1	30.4	924.1	13.13	7.49	15.02	21.5	10.14	5.8	9.54	15.2
5	11.9	9.9	26.5	31.0	960.4	11.6	7.7	15.58	21.1	9.3	5.5	9.52	14.5
6	6.6	13.0	20.0	25.0	625.4	7.43	9.8	12.64	17.8	7	6.8	8.33	13.0
7	37.6	3.8	39.6	55.3	3056.6	25.3	11.68	18.25	33.6	14.66	7.44	10	19.4
8	30.7	18.7	40.8	54.9	3016.3	19.19	11.2	18.75	29.4	13.13	7.7	10	18.4
9	12.0	27.7	27.4	41.2	1695.5	11.75	14.2	14.48	23.7	9.42	9.4	8.8	16.1
10	83.0	0.7	43.5	94.6	8958.2	38.5	14.9	16.05	44.7	18.48	9.34	8.4	22.6
11	80.0	35.2	49.3	101.4	10271.9	34.7	16.4	15.96	42.0	16.6	9.48	8.6	21.2
12	16.8	49.0	26.4	58.7	3448.1	17.7	19.3	12.2	29.2	11.6	11.3	7.5	18.0
13	109.9	3.0	0.8	111.0	12330.7	42.6	15.9	17	49.0	19.8	9.27	8.96	23.9
14	99.5	42.1	5.0	109.2	11932.3	37.6	16.02	16.36	44.5	17.9	9.98	9.1	22.6
15	18.2	55.4	2.2	58.9	3473.7	18	23.6	12	32.3	12.23	11.8	7.55	18.8
16	34.1	23.2	50.0	65.5	4285.5	IEEE spatially averaged electric field strength over 175 cm high axis (22 measurement point) = 55.5 V/m							
17	10.3	10.4	32.3	35.8	1282.8								
18	4.7	5.2	19.0	20.4	417.5	CENELEC spatially averaged electric field strength over 45 measurement points = 33.5 V/m							
19	1.5	2.5	10.6	11.1	123.3								
20	0.2	1.0	7.4	7.5	56.9								
21	3.2	3.6	9.4	10.7	114.0								
22	2.4	2.2	6.2	7.0	49.7								

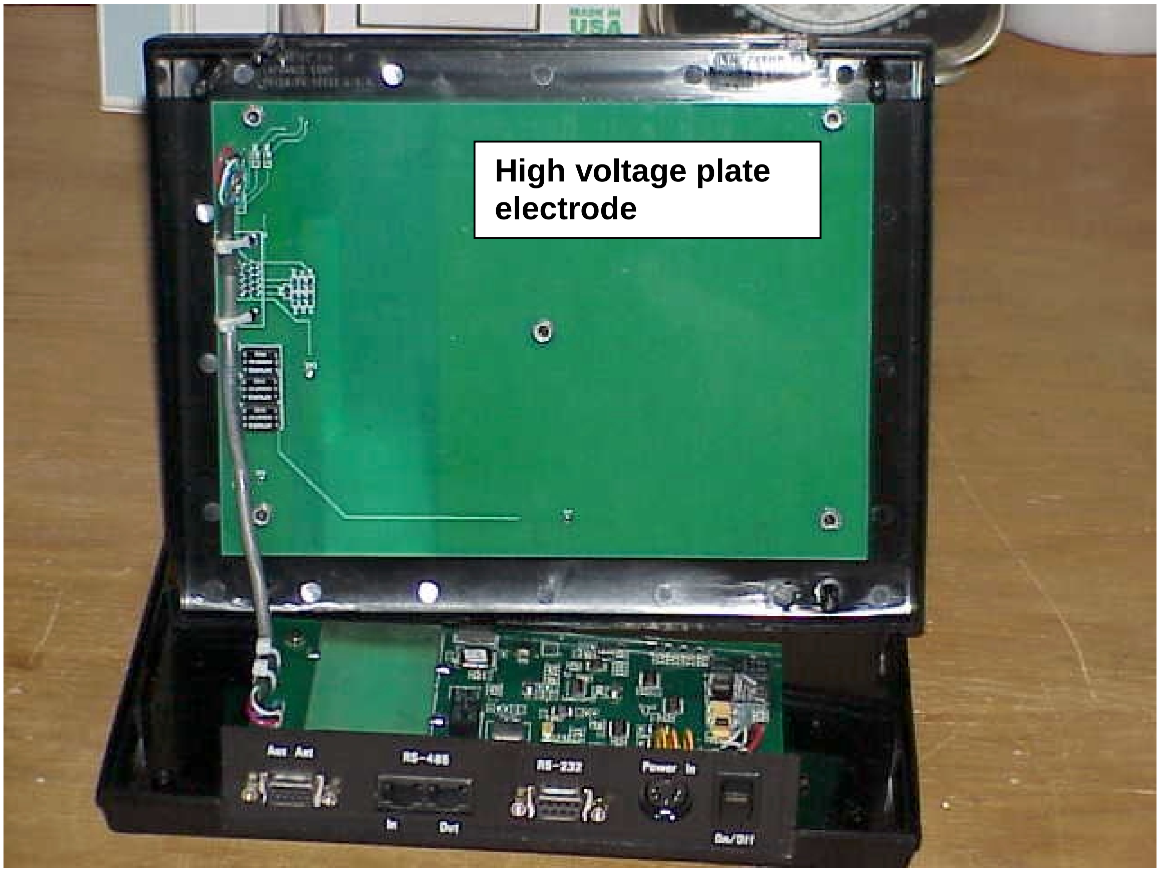

Figure 1. Photograph showing the interior of the BiStatix™ Model BDR-1000 access control reader. The plate electrode is the primary source of electric fields.

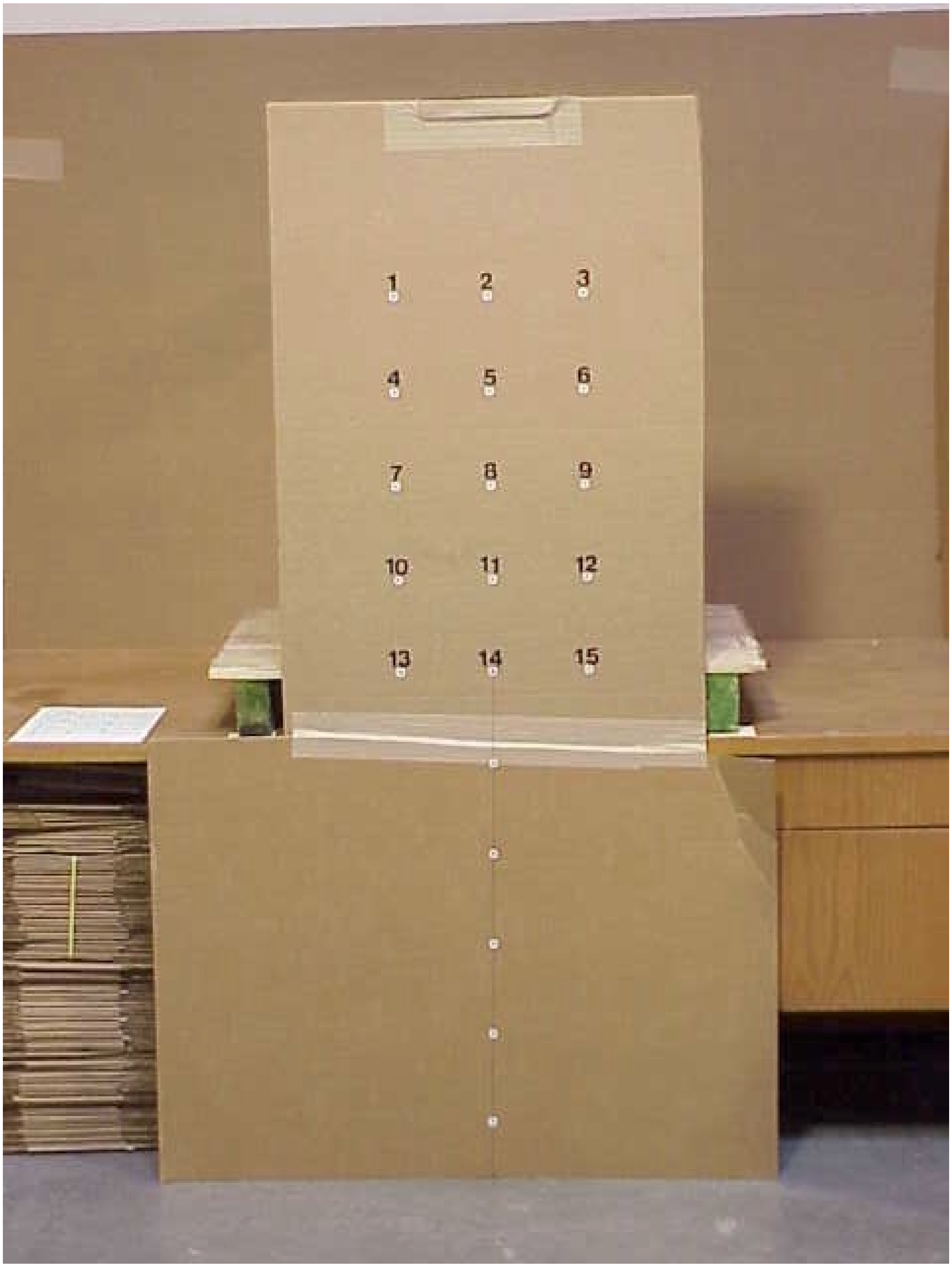

Figure 2. The reader unit was mounted on a wooden platform placed on a wooden desk such that the reader was 79 cm above the floor. A cardboard sheet was used to establish the location of a measurement grid for measurement of electric and magnetic fields.

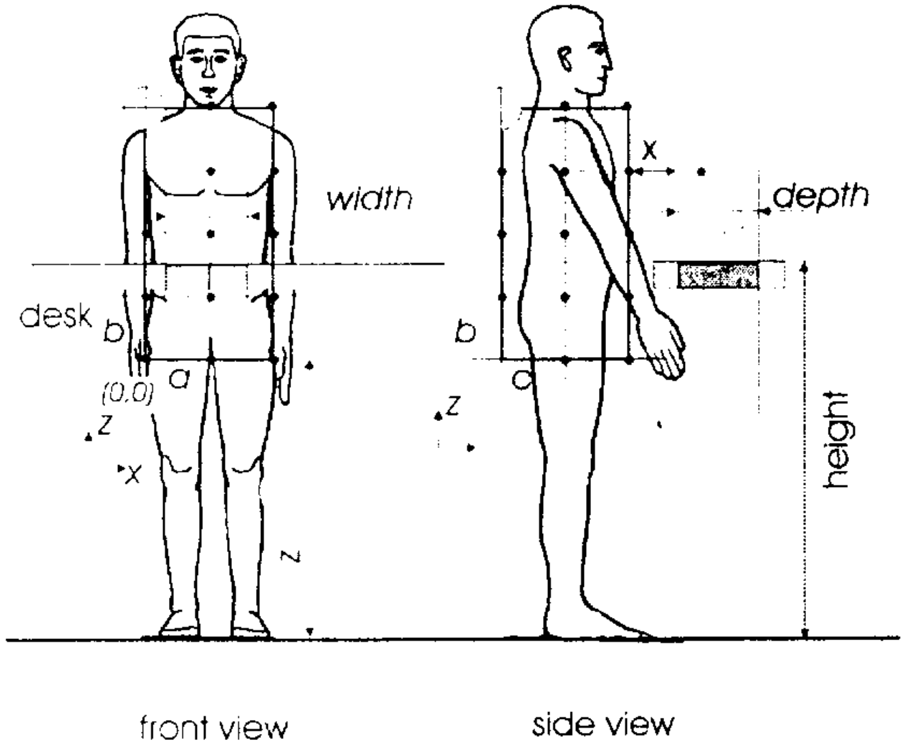

Figure 5.1.2 (g)
Horizontal, Desk or Counter Top
Mounted Antenna

Figure 3. Illustration taken from CENELEC draft document showing measurement grid configuration for a horizontal, desk or counter top antenna similar to the BDR-1000 access control reader when mounted according to the manufacturer's recommendations.

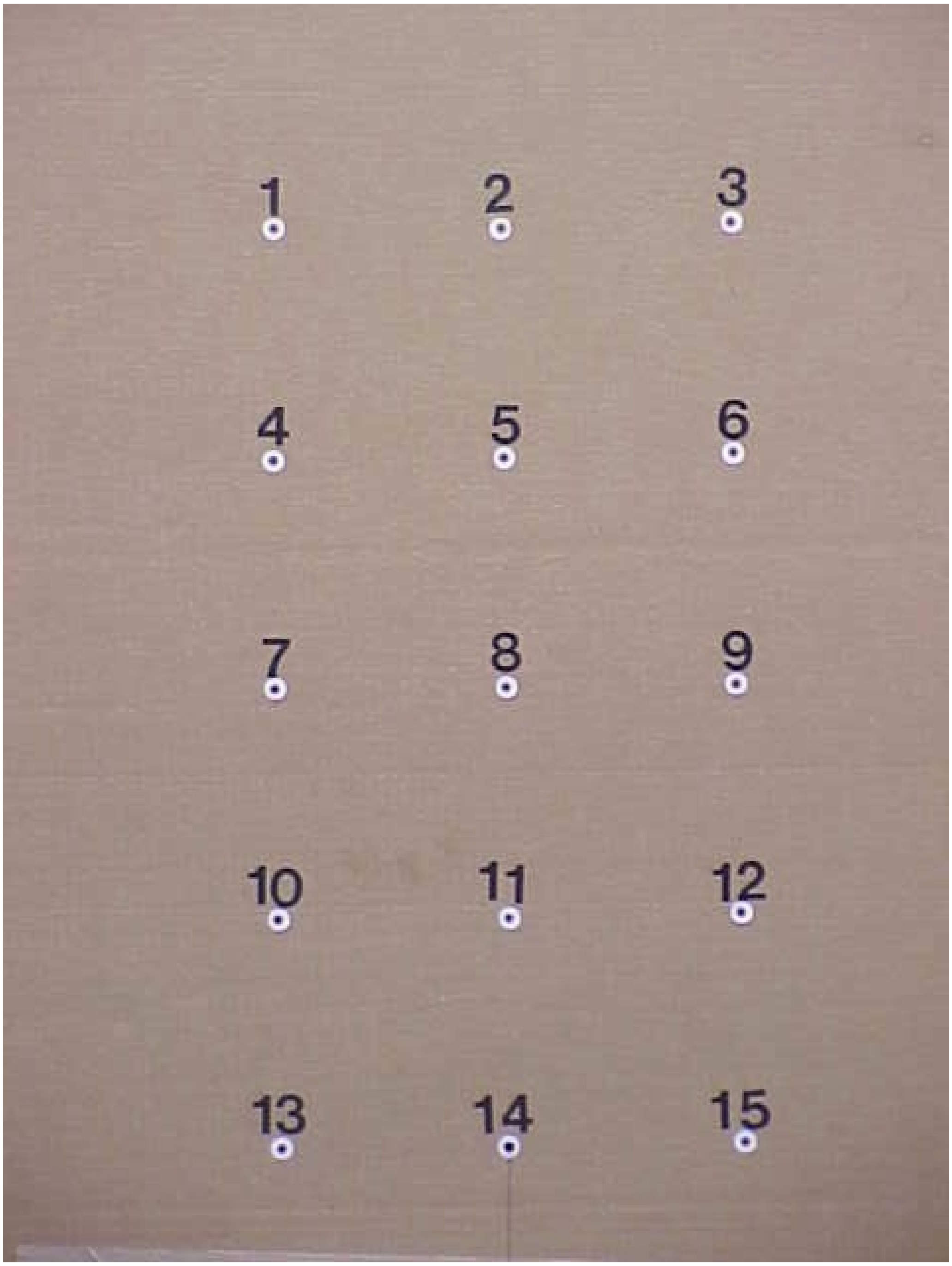

Figure 4. Close up photograph of CENELEC measurement grid drawn on a sheet of cardboard that was attached to the front edge of a wooden desk for measurements. Grid spacing is 15 cm in the vertical and horizontal directions. Three different planes, relative to the cardboard sheet, were used in compliance with the CENELEC draft standard, these planes being located at 15, 30 and 45 cm from the front surface of the reader. A total of 45 measurement points represent the grid.

Figure 5. Illustration of the placement of the measurement grid relative to the author standing in front of the cardboard sheet.

Figure 6. Illustration of the placement of the measurement grid relative to the author standing perpendicular to the cardboard sheet.

Figure 7. Photograph of the Holaday Industries Model HI-3603 measurement probe showing the attachment of a plastic cup on the sensitive side of the sensor for maintaining a constant measurement distance relative to the cardboard measurement plane.

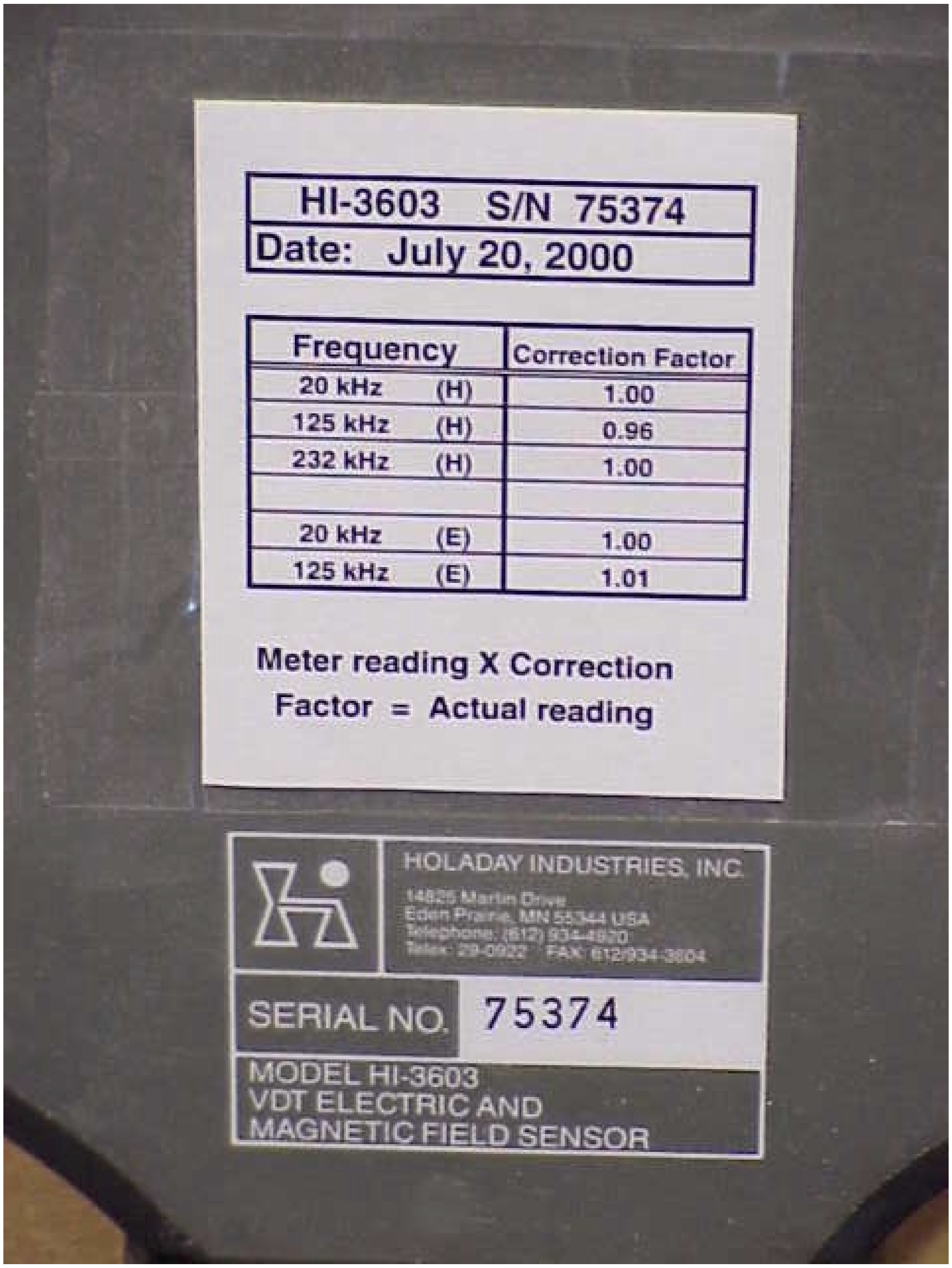

Figure 8. Calibration label on the Holaday Industries Model HI-3603 VDT electric and magnetic field sensor.

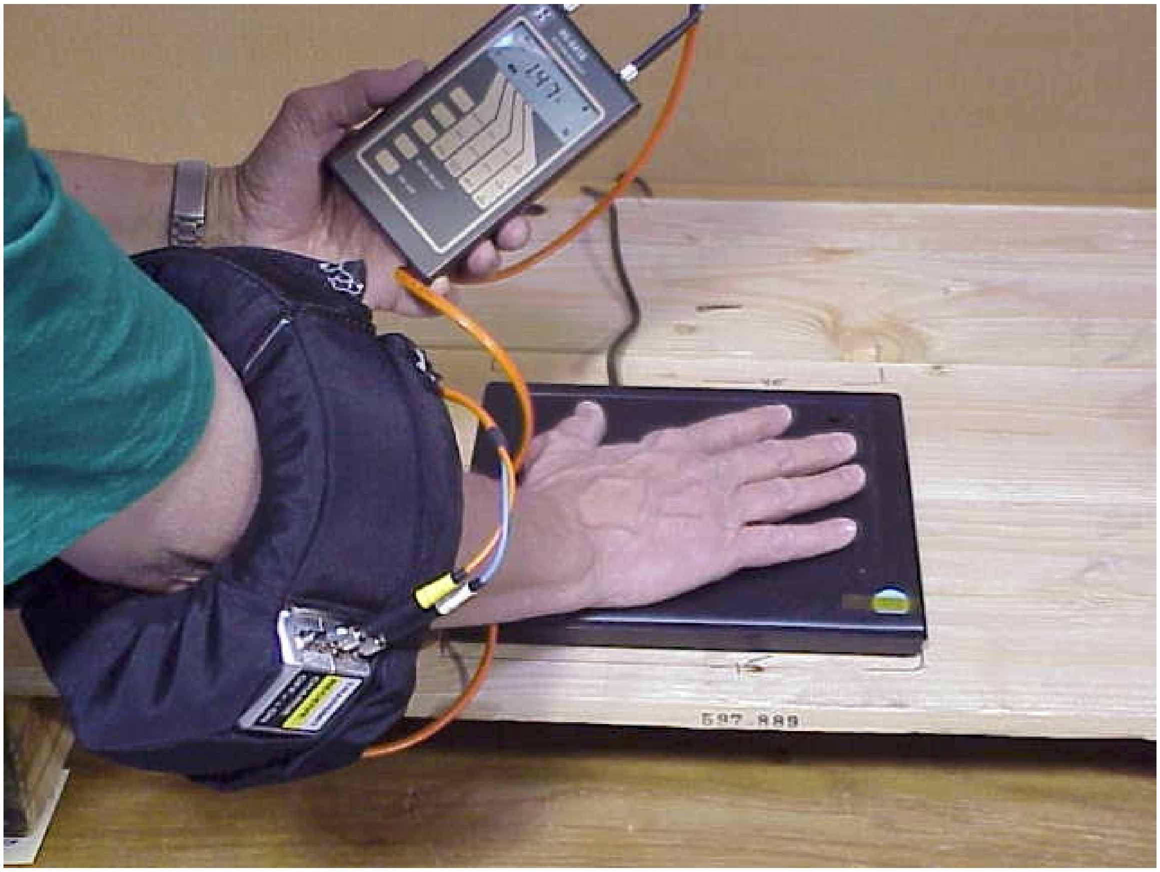

Figure 9. Measurement of contact current was accomplished by placing the RF current transformer around the forearm of the subject and placing the hand in direct contact with the front surface of the reader unit to achieve a maximum indicated current. The subject stood in bare feet for an enhanced electrical connection with the concrete floor.