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MEASUREMENT AND ANALYSIS OF ELECTROMAGNETIC FIELD EMISSIONS FROM 24 VIDEO DISPLAY TERMINALS IN AMERICAN TELEPHONE AND TELEGRAPH OFFICE WASHINGTON D.C.

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16. Abstract (Limit: 200 words) Electromagnetic field emissions were determined from 24 video display terminals (VDTs) located in a service office of an American Telephone and Telegraph (ATT) office in Washington, D.C. Health concerns had been expressed to their labor unions by employees using the 24 VDTs. Measurements were conducted on three different types of VDT models including 21 ATT Model 45 units, two TAB Model 132/15 units, and one ATT Model 6300 PC unit. The electric and magnetic field exposure levels at the position of the operator (30 centimeters) based on these measurements were well below all of the exposure standards. The operator's hand could be exposed to electric fields higher than the safety standards while contacting the screen or sides of the terminal. However, the currents induced in the body were significantly less than those induced by environmental far field exposures at levels below all the world's safety standards. The magnitudes of the highest static fields were no different from levels produced by static charges in the environment such as on fabrics and other articles in offices and homes. These fields were particularly low on screens of terminals equipped with anti glare filters.

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OBJECTIVES

This is a report on the measurement and analysis of the electromagnetic field emissions from 24 video display terminals (VDTs) located in the service offices of the AT&T Company, 1901 L St., Suite 450, Washington, D.C. The measurements were made in response to health concerns expressed by employees using the 24 VDTs and labor unions representing the employees. Dr. David Conover of National Institutes of Occupational Safety and Health (NIOSH) requested that the author assist him and other representatives of NIOSH to carry out the measurements during the period November 18 and 19, 1986. Dr. Ron Peterson of Bell Laboratories, also provided some equipment and assistance in making the measurements. The measurements were conducted on three different types of VDT models including 21 AT&T Model 45 units, 2 TAB Model 132/15 units and 1 AT&T Model 6300 PC unit. The measurements consisted of the following.

a) Oscilloscope recordings to quantify the peak-to-peak amplitude and time domain waveshapes of the maximum levels of emitted electric fields, emitted magnetic fields, and induced current in the body of exposed persons from one of each group of the three VDT models.

b) The rms electric and magnetic fields for each terminal at 1) location of maximum intensity, 2) face of VDT screen and 3) distance of 30 cm from the front of the VDT screen.

c) The rms electric field-induced current between the body of an exposed person and ground for each VDT under the following conditions 1) maximum current capacitively coupled between the VDT and the body by hand contact with the side or top of the VDT at the location of the highest electric field strength, 2) hand near or in contact with the screen and 3) hand on the keyboard.

METHODOLOGY USED FOR MAKING MEASUREMENTS

The measurement of the time domain and rms electric and magnetic fields followed the procedure discussed by Guy (1984).

Based on the pictorial sketch in Figure 1 it is clear that the electric field component of maximum strength will be that which is normal to the surface of the exposed body. In fact, this field can increase substantially with decreasing distance between the operator and the VDT. The magnetic field, shown in Figure 2, on the other hand, will not be significantly perturbed by the body. Most of the standard field survey instruments fail in one way or another in quantifying the fields that exist under actual exposure conditions. Since the human body is highly conductive at the frequencies where the major emitted energy lies, the electric fields incident to the exposed person will be perpendicular to the body surface and have magnitudes that vary according to the shape and position of the body with respect to the source. The exposed body which has approximately 100 pf of capacitance to space (floor and walls of the room) can be considered part of an electric circuit which is capacitively coupled to the fly back transformer high voltage wiring. A Maxwell's displacement current flows to the surface of the body from high voltage souces in the VDT corresponding to the electric field distribution between the unit and the exposed person. This is balanced by an equal flow of displacement current out of the body through its capacitance to space. In addition, these currents can also return to ground through the capacitance and conductivity of the shoes or through parts of the body in contact with conducting surfaces of office furniture and equipment. Thus, the closer the measuring instrument comes to quantifying these perpendicular electric fields under actual exposure conditions the more accurately one can quantitate the internal fields and current flow within the body. An ideal E-field instrument would be a sensor that could be put on the surface of the body to sense the perpendicular electric fields at various locations on its surface as shown in Figure 3. Kaune et al. (1980) made such measurements to quantify the induced current experimentally through the use of phantom models of rats and pigs exposed to 60 Hz high voltage powerlines. The author has previously developed a sensor for measuring VLF-LF electric fields normal to a large flat surface. The sensor was developed for measuring fields perpendicular to the ground in connection with an Air Force sponsored project for assessing hazards of VLF-LF frequencies (Guy and Chou, 1982). The device is relatively simple and takes advantage of the versatile and portable Fluke 8060A multimeter. The microprocessor controlled meter covers the entire frequency range of the significant emission frequencies of the VDT and has a built-in digital counter that will read the fundamental frequency of the fly back transformer fields. The meter will also measure true rms voltages and currents which are required to quantify the unique pulsatile VDT emissions for comparison with safe exposure standards.

Figure 4 illustrates the design and the configuration of the sensor. The electric field sensor is based on the amount of displacement current intercepted by a known area. The sensor consists of a double-back circuit board with an annular ring cut to isolate a 4 inch diameter disk from the rest of the conducting top surface. The relationship between the charging current, I, grounded through the input of the operational amplifier and the electric field, E, is given by equation

$$I(t) = S(dD/dt) = \varepsilon_o(SdE/dt) \quad (1)$$

where S is the area of the 4 inch diameter disk, $\varepsilon_o = 8.854\times10^{-12}$ is the permittivity of free space, D is the displacement vector and E is the electric field strength. Through the use of a capacitive feed back loop on the amplifier the output voltage will be given by

$$V_o = \frac{1}{C}\int(I(t)dt) = \varepsilon_o SE/C \quad (2)$$

The capacitor C is adjusted so that the operational amplifier output is 1 volt when a sinusoidal ac current that corresponds to the displacement current produced by 1 kV/m sinusoidal ac electric field strength is applied to the disk. The output of the device can be coupled by an RG 58 coaxial cable to an oscilloscope for observation of the time domain electric field characteristics or to a Fluke 8060A multimeter capable of providing accurate true rms voltage readings up to 200 kHz. The microprocessor controlled meter is also able to operate in a frequency counter mode so that the fundamental frequency of the applied signal can be easily determined. The operational amplifier and two 9 volt power supply batteries are shielded by means of a metal case with a removable bottom cover. In another Air Force supported project Guy and Chou (1983) developed a broadband loop sensor capable for measuring the true rms value of a complex magnetic field waveshape. A section of the report describing it, written for the Air Force, is included as Appendix A. The output of the operational amplifier used in this magnetic field sensor may be directed to a oscilloscope for recording the time domain waveshapes or to a Fluke 8060A voltmeter for measuring the rms magnetic fields.

The electric and magnetic field sensors were placed at three different locations at or near the VDT including:

a) Maximum electric field against side nearest flyback transformer as shown in Figure 5

b) Maximum magnetic field at top or side of terminal nearest magnetic deflection yoke

c) Electric fields nearest surface of cathode ray tube

d) Magnetic fields nearest surface of cathode ray tube as shown in Figure 6

e) Electric field 30 cm from front of VDT as shown in Figure 7

f) Magnetic fields 30 cm from front of terminal as shown in Figure 8

DC Electric Field at Front Surface of VDT

The electrostatic field at or near the surface of each VDT was measured by a NRD Model 5011 static field meter.

Maximum Induced Current in Body of Exposed Person

The maximum current induced in the body of a person exposed to uniform free space VLF and LF electric time varying fields occurs when the electric field vector is parallel to the long axis of the body while the person is standing and in contact with the ground. We may call this a worst-case environmental far-field exposure. This worst case exposure is the basis for setting safe exposure levels. The maximum current flowing from the body to ground for this case may be quantified by integrating Maxwell's displacement current density vector $J_d = dD/dt$ over the surface of the body to obtain the total short circuit current, I_{sc}, to ground

$$I_{sc} = S_{eff} dD/dt$$

where S_{eff} is the effective body area, and D is the displacement vector. The current may be expressed in terms of the electric field as

$$I_{sc} = \varepsilon_o S_{eff} dE/dt \qquad (4)$$

Deno (1977), has determined the effective area from empirical measurements during sinusoidal 60 Hz exposure as

$$S_{eff} = \pi r^2 \qquad (5)$$

where

$$r = h\tan(35.7^{o}) \qquad (6)$$

Thus for a 1.75 m tall person the effective area would be

$$S_{eff} = \pi(1.75 \tan 35.7)^2 = 4.97 \text{ m}^2. \qquad (7)$$

Most types of exposures, however, including those from VDTs consist of partial body, near-field exposures so the effective area S_{eff} is much smaller than that for a whole body, far-field environmental exposure. Therefore, for near-field exposures the body current, rate of energy absorbed by the body and any biological effects would be significantly less than that possible from the whole body environmental far-field exposure to the same field strength. We can, however, relate the partial body exposure condition to an equivalent environmental far-field exposure by quantifying the maximum induced current for the VDT exposure condition. This information along with the measured VDT E field emission levels will allow the determination of the equivalent surface area and the equivalent environmental exposure level for the VDT exposure condition. Because the E fields significantly decrease in strength with distance from the VDT the equivalent area will be considerably lower than for the case of an environmental far-field exposure. Therefore, the equivalent environmental exposure level to produce the same body to ground current will be considerably less. The equivalent environmental E field exposure levels may be determined by rewriting equation 4 as

$$dE_e/dt = I_m/S_e \varepsilon_o \qquad (8)$$

or

$$\Delta E_e = I_m \Delta t/S_e \varepsilon_o \qquad (9)$$

where ΔE_e is the peak-to-peak equivalent environmental far-field E field, Δt is the rise or fall time of the VDT electric field with waveshapes as given in Figures 10, 11, 16, and 19 and I_m is the peak measured current with waveshape given in Figures 14, 18, and 22. Based on the ratios of peak-to-peak to rms values of the electric R_e field and peak-to-peak to rms value of the electric current R_i we may express equation 9 as

$$R_e E_{erms} = \Delta t R_i I_{mrms} / 2 S_e \varepsilon_o$$

or

$$E_{erms} = t R_i I_{mrms} / (2 S_e \varepsilon o Re) \qquad (10)$$

where E_{erms} is the rms value of the equivalent environmental exposure field in units of V/m and I_{mrms} is the rms level of the measured current in units of A.

The maximum possible current density induced in the body by the emissions from the VDT are generally due to electric field exposure when the body or hand is very near or in contact with the device. The maximum possible induced current will occur for this case when the exposed user is grounded so the value can be quantified simply by measuring the current flow from the body to ground. The peak value and waveshape of the current were determined by an oscilloscope recording the voltage E(t) across a resistor R, connected between the body of a person exposed to the VDT and the ground. The current I(t) was obtained from the simple ohm's law expression I(t) = E(t)/R. The rms current was obtained by means of a broad-band rms multimeter (Fluke 8060A) set in the microammeter mode and connected between the exposed person and ground as shown in Figure 9. This meter was also used to measure the fundamental frequency of the VDT emissions by setting it to the frequency counter mode of operation. The body to ground currents were measured by taping a surface electrode behind the left elbow of the subject and measuring the current from that point to a grounded office appliance through the meter set in the microammeter mode of operation.

MEASURED DATA

Time Domain Waveshapes

AT&T Model 45 Terminal

Figure 10 illustrates the waveshape of the highest electric fields measured from the AT&T model 45 (serial number 222498) VDT. The measured location was at the top right rear corner of the unit corresponding to the nearest location to the flyback transformer. The peak-to-peak electric field strength was 6.6 kV/m and the rms strength was 1.9 kV/m. The recurrence frequency and width of the pulse are 21.8 kHz and 8 μs respectively. Though the narrow pulse portion of the wave is actually positive, the recorded waveshape is inverted due to an 180 degree phase shift in the instrumentation.

Figure 11 illustrates the electric field waveshape recorded with the E field sensor placed 1 cm from the screen. The peak-to-peak and rms electric field strength were 2.75 kV/m peak and 580 V/m rms respectively. Figure 12 illustrates the recorded waveshape of the magnetic field with the horizontal loop placed against the screen as shown in Figure 6. The peak-to-peak and rms magnetic field was 1.6 A/m and 0.48 A/m, respectively. The magnetic field flyback time was 8 μs and the sweep time was 40 μs.

Figure 13 illustrates the temporal relation between the E and H fields with the E field sensor 1 cm from the screen and the H field loop touching the back of the E field sensor with the plane of the loop horizontal (measuring vertical H field).

Figure 14 illustrates the time domain electric current to ground from an exposed male subject when the subject's right hand is flat against the screen of the VDT. The peak-to-peak and rms values of the current were 1.16 mA and 192.0 μA, respectively. Figure 15 illustrates the temporal relationship between the electric field at the bottom front right corner of the VDT and the induced current in the hand when it is in contact with the screen. The induced current is reduced from that shown in Figure 14 because of the shielding and perturbation effect of the adjacent E field sensor. Note that the shape of induced current waveform is consistent with the time derivative of the exposure field as predicted by equation (4). The waveshape corresponds approximately to a single 100 kHz cycle.

AT&T Model 6300 Personal Computer

Figures 16 and 17 show the recorded E and H field waveshapes for the AT&T Model 6300 Personal Computer (serial Number 0018399). The fundamental frequency of the emitted fields is 25.87 kHz. The peak-to-peak and rms E field recorded at the surface of the screen are respectively 4.4 kV/m and 1.098 kV/m and the pulse width is 7 μs. The peak-to-peak and rms magnetic field are 0.61 A/m and 0.17 A/m respectively. The flyback time is approximately 6 μs and the sweep time is 32 μs.

The peak-to-peak body-to-ground current for a male subject with the right hand flat against the AT&T Model PC (6300) VDT screen was 680 μA. However, if one considers the very narrow positive spike on the waveshape, the peak-to-peak current is 849 μA. The rms electric current was found to be improperly recorded in the data sheet so the value was estimated based on the difference in the waveshape of the current from that of the AT&T 45 terminal. Since the pulse is narrower by approximately the same percentage as the period is shorter and of similar shape to that of the AT&T 45 terminal we would expect the ratio of the peak-to-peak to rms value to be the same. Therefore, the rms value was calculated to be 680/6.04 = 113 μA.

TAB 132/15 Terminal

Figures 19 and 20 illustrate the recorded 23.52 kHz E and H field waveshapes for the TAB 132/15 (serial number 130-15860) terminal. The peak-to-peak and rms electric fields are 460 V/m and 90 V/m respectively at 2 inches from the screen. The pulse width was 5 μs. In Figure 20 the peak-to-peak and rms magnetic fields were 2.3 A/m and 0.707 A/m, respectively. The maximum E field recorded from the right side of the terminal is shown in Figure 21. The peak-to-peak and rms E field was recorded as 3 kV/m and 1.55 kV/m, respectively. The waveshape is somewhat different from that recorded from the screen as well as from recordings taken from other terminals. However, the electric field waveshape at the screen was of the same shape as recorded from other terminals. The recording of the maximum current waveshape from the body-to-ground of an exposed male with his hand in contact with the right side of the terminal is shown in Figure 22. The peak-to-peak and rms amplitudes are 200 μA and 40 μA respectively. Note that the width of the flat topped current pulse is 3 μs corresponding to the width of the negative slope section of the E field pulse (Figure 21) as expected from equation 4.

RMS ELECTRIC FIELD STRENGTHS, MAGNETIC FIELD STRENGTHS, AND BODY TO GROUND CURRENT FOR PERSONS EXPOSED TO VDTS

Appendix B of this report contains a copy of the original raw data sheets used for recording the electric field strengths, magnetic field strengths exposed person to ground currents, and other parameters measured for the 24 VDTs. This report deals only with static and radio frequency electromagnetic emissions from the VDTs. Table 1 provides a compilation of the measured dc and radio frequency electromagnetic parameters obtained from the data sheets. The first four columns of the table identifies the type (manufacturer, serial number, model and office identification number for each of the 24 terminals. The 5th column lists the measured flyback electromagnetic field frequencies. The 6th, 7th, and 8th columns give the rms electric field strengths measured respectively at the sides or top, face, and 30 cm away from the face of the terminal. The maximum levels were obtained from the sides or top of the VDT nearest the flyback transformer. The 9th, 10th and 11th columns give the rms levels of magnetic fields measured at the side or top, face and 30 cm from the VDT, respectively. The 12th, 13th, and 14th columns provide the values of body to ground current measured when the exposed subjects right hand was placed at the location of highest electric field on the top or side of the VDT (Figure 23), at the VDT face as if pointing at printed data (Figure 24) and at the keyboard (Figure 9) respectively while seated in the normal operating position. The final two columns of Table 1 give the measured static electric field strength measured at 1 cm and 30 cm from the screen respectively. A human subject consent form shown in Appendix C prepared and approved by NIOSH was read and signed by each subject who volunteered for the body-to-ground current measurements.

Analysis of Data

Tables 2, 3, and 4 provide a tabulation of the means and standard deviations of the measured E fields, H fields and body to ground current for exposure to the various terminals. Three of the AT&T model 45 terminals had exceptionally low E fields at the surfaces of the cover. A check with an ohmmeter indicated that the plastic covers for these units were loaded with a conducting material. The significance of the electric and magnetic field exposures can be determined in two ways. One way is to determine the level of induced current densities and compare them with levels known to cause biological effects and the other is to relate the induced currents to an equivalent uniform far-field, worst case, environmental exposure field which in turn can be compared to various safety standards. The current density induced from the E field exposure may be calculated based on the cross-sectional area of the body through which the current flows. The current density induced by the magnetic field exposure may be determined by estimating the average magnetic field passing through the body and calculating the level of eddy current density based on an equivalent ellipsoid.

Current Density Induced by Electric Field Exposure

The highest possible current density induced by electric field exposure is when the total induced current flows through the narrowest cross-sections of the body such as the wrists and ankles. The current density in the torso would be the lowest due to the larger cross-sectional area. The author has recorded the cross-sectional dimensions for various percentiles of the general population in connection with measurement of body impedance relating to research on human exposure to VLF fields. Table 5 lists the body dimensions for a 23 year old, 120 lb. female. The table lists the major and minor dimensions, circumference, and area of the body cross-section as a function of position. The area was obtained by assuming that the body is elliptical in cross section. This is a good approximation since the actual weight given at the top of the table agrees to within less than 5% of weight obtained by numerical integration of the elliptical sections of volume given in Table 5 over the entire length of the body assuming a density of 1 g/cm^3. The minimum cross-sectional area given in Table 5 is 17.3 cm^2 at the wrist where current densities will be highest when the hand is near the VDT screen or flyback transformer. With the public concern about VDTs and birth defects the current density in the region of the reproductive system is also of importance. Table 5 indicates that for the subject used as an example, the cross-sectional area of the body in the region of the reproductive system is 400 cm^2. Table 6 is a tabulation of the worst case current densities calculated from the currents given in Table 4 and the cross-sectional area of the wrist obtained from Table 5. Table 7 is a tabulation of the worst case rms current densities calculated for the lower torso based on the above tables. The maximum mean current density for the wrist and torso are 9.44 $\mu A/cm^2$ and 0.408 $\mu A/cm^2$ respectively corresponding to the case where the hand is in contact with the screen. In the normal operating position, these maxima would be 0.17 and 0.00735 $\mu a/cm^2$, respectively. It is not likely, however, that all of the current would ever pass through the hand in this latter case. Table 8 gives the peak current densities for this case based on the time domain current waveshapes of Figures 14, 18 and 22.

Based on equation 9 the equivalent environmental far-field electric fields for VDT E field exposures described above are given in Table 9 along with the measured external field. The means and standard deviations of the equivalent E fields are given in Table 10.

Current Density Induced by Magnetic Field Exposure

The maximum induced current for magnetic field exposures occurs when the magnetic field is perpendicular to the maximum cross sectional area of the exposed body. For the case where the hand is placed on top of the VDT, current would be induced in the hand based on its shape and cross-sectional area. When the operator is sitting in front of the VDT as shown in Figure 2, the magnetic fields of importance would be those passing vertically, parallel to the axis of the body. These fields would tend to induce circulating eddy current with maxima at the periphery of the torso. For our calculations, we will assume a worst case where the center of the body is at the point of measurement, 30 cm from the screen. Actually, during normal operation the operator's body would be farther away than this. However, since the fields were not measured at those distances, we will consider only the worst-case field coupling at 30 cm from the screen.

The highest possible energy coupling to the body will be calculated based on a representation of the body by an ellipsoidal model with incident H-field vectors perpendicular to the Y-Z plane of the an ellipsoid as shown in Figure 25. We may define the semiaxes a, b, and c of the ellipsoid along the x, y, and z axes of a cartesian coordinate system as specified by Durney et al. (1978). The dimensions of the ellipsoid that best approximates the human subject with the body dimensions given in Table 5 is b = 26.7/2 cm = 0.134 m and c = 19.1/2 cm = 0.0955 m. The value of (a) is irrelevant for this orientation of the H field. The maximum magnitude of a sinusoidal E field induced in the model as derived by Massoudi et al. (1977) is

$$E_e = -jkZ_oC_xcH_o \tag{11}$$

where

$$C_x = -b^2/(b^2 + c^2) \tag{12}$$

$$Z_o = 120\pi$$

$k = 2\pi f/v$, f is the frequency, and v is the velocity of light.

Theoretical expressions may be derived for the induced current in the simple ellipsoidal models exposed to the time varying H field by first expressing the time domain source field H(t) in the frequency domain by a Fourier series.

$$H(t) = \sum_{n=-\infty}^{\infty} H_n e^{jn2\pi ft} \tag{13}$$

The time domain E field induced in the tissue by the H field from equation (11) may be expressed as

$$E_h(t) = \sum_{n=-\infty}^{\infty} -jnkZ_oC_xbH_n e^{jn2\pi ft} \tag{14}$$

or

$$E_h(t) = -(Z_oC_xc/v)dH(t)/dt \tag{15}$$

but since $(Z_o/v)H = B$ where B is magnetic flux density

$$E_h = -(C_xc)dB(t)/dt. \tag{16}$$

The current density in the tissue is

$$J = \sigma E_h. \tag{17}$$

where σ is the electrical conductivity of the tissue assumed to be 0.6 S/m in this analysis.

The maximum induced current is proportional to the time derivative or time rate of change of the magnetic fields and the size (C_xc) of the exposed surface. The maximum induced current density for magnetic field exposure occurs at x = 0, y = 0 and z = c in the ellipsoidal model. This results from the fact that the eddy currents induced by the magnetic field are maximum at the periphery of the model.

Based on the data in Table 5 the equivalent elliptical dimensions of the hand are b = 18.2/2 cm = 0.091 m and c = 9.8/2 cm = 0.049 m. Therefore, the quantity $C_x c$ is

$$C_x c = \frac{(0.091)\ (0.049)^2}{[(0.091)^2 + (0.049)^2]} = 0.03799 \qquad (18)$$

and since the conductivity is sig = 0.4 S/m over the frequency range of interest, the maximum value of the magnetically induced current may be expressed as

$$J_h = 0.01519 \frac{\Delta B}{\Delta t} \text{ A/m}^2 \qquad (19)$$

Table 11 provides a tabulation of the maximum induced current densities in the hand based on equation 19 along with the exposure parameters, maximum rms, and rate of change with time of the magnetic flux density B. The current density is expressed in terms of both peak and rms values. The fields induced in the tissue by the savtooth magnetic fields should have the same waveshape as the electric field emissions from the flyback transformer. This is true, since the primary winding current has the same temporal characteristics as the magnetic deflection yoke current and magnetic fields and the induced voltage and electric fields of the flyback transformer windings are proportional to the time derivative of the primary current. Therefore, we may assume that the peak-to-peak and rms induced current density in the tissue is the same as that of the VDT electric field emissions. This ratio is tabulated in the last column of Table 11.

The data tabulated in Table 6 indicates that the maximum value of induced current density in the hand due to the magnetic field exposure is less than that induced in the wrist due to the electric field exposure. The quantity $C_x c$ for obtaining the maximum induced current density in the lower torso of an exposed subject may be calculated from the values, b = 0.134 m and c = 0.0955 m used for the electric field induced current density. Therefore

$$C_x c = \frac{(0.134)^2(0.0955)}{[(0.134)^2 + (0.0955)^2]} = 0.0633 \qquad (20)$$

and the maximum B field induced current density is

$$J_h = 0.0253 \frac{\Delta B}{\Delta t} \text{ A/m}^2 \qquad (21)$$

Table 12 provides a tabulation of the calculated maximum current density in the lower torso as compared with the exposure parameters in the same format as Table 11. For the lower torso and an exposure position 30 cm from the screen the magnetic field induced current densities (see Table 12) are higher than the electric field induced current densities (see Tables 7 & 8) for the AT&T 45 and TAB 132/15 terminals but lower for the AT&T PC terminal, though they are all within the same order of magnitude.

CONCLUSIONS

The various safety standards of the world covering the frequencies of VDT Table 13. The electric and magnetic field exposure levels at the position of the operator (i.e., at 30 cm) based on the measurements described in this report are well below all of the exposure standards listed in Table 13. Though the operators hands can be exposed to electric fields higher than the safety standards while contacting the screen or sides of the terminal the currents induced in the body are significantly less than those induced by environmental far-field exposures at levels below all of the worlds safety standards. Though there are no standards applying to the dc levels measured at the screens of the VDTs surveyed in this study, the magnitudes of the highest static fields are no different from levels produced by static charges in the environment such as on fabrics and other articles in offices and homes. These fields are commonly generated on and near the body in dry weather as a result of friction between the clothing and chairs and between the shoes and the floor. The measurements indicated that these static fields were very low at the screens of terminals equipped with anti-glare filters.

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TABLE 1. MEASURED FIELD PARAMETERS FOR PERSONS EXPOSED TO EMISSIONS OF VARIOUS TYPE VDTS

Type	Terminal Ident. S/N	Terminal Ident. ID No.	Flyback Freq. (kHz)	RMS Field Strength E Field (V/m) Max	E Field (V/m) Face	E Field (V/m) 30 cm	H Field (A/m) Max	H Field (A/m) Face	H Field (A/m) 30 cm	Max Body Current (µA) Cover	Max Body Current (µA) Face	Max Body Current (µA) Keyboard	Static Fie (V/in) 1 cm	Static Fie (V/in) 30cm
Unshielded covers														
AT&T 45C	270687	DD119	21.78	1930	690	3.0	2.63	0.5	0.04	60.0	30.0	5.0	50	<10
AT&T 45	193359	DD118	21.79	1950	630	7.2	2.30	0.54	0.04	65.0	25.0	24.0	<10	<10
AT&T 45	029818	DD109	21.78	1340	560	7.4	2.76	0.54	0.03	68.0	25.0	5.1	<10	<10
AT&T 45	220300	DD116	21.78	1913	620	9.5	2.70	0.30	0.033	50.0	27.0	2.9	50	10
AT&T 45C	270290	DD121	21.78	570	570	7.8	2.66	0.53	0.050	7.0	5.0	2.0	<10	<10
AT&T 45	072140	DD112	21.78	2300	582	5.7	1.95	0.53	0.06	71.0	20.3	3.6	50	<10
AT&T 45	205927	DD111	21.78	1960	470	4.2	2.05	0.48	0.05	51.9	12.4	1.6	<10	<10
AT&T 45	098495	DD117	21.78	1950	570	5.7	2.1	0.48	0.06	52.0	19.0	2.9	50	<10
AT&T 45C	270572	DD096	21.8	2300	540	6.5	2.52	0.5	0.03	75.0	120.0	1.6	<10	<10
AT&T 45	101491	DD103	21.78	1900	570	8.0	2.67	0.56	0.04	60.0	--	1.4	10	<10
AT&T 45	213800	DD093	21.78	2300	535	6.8	2.4	0.57	0.07	64.0	--	2.4	<10	<10
AT&T 45	166659	DD099	21.78	2200	620	10.0	2.65	0.54	0.06	78.0	150.0	6.2	50	<10
AT&T 45	200886	DD101	21.78	1950	320	4.5	2.63	0.5	0.076	54.0	--	1.5	<10	<10
AT&T 45	244178	DD102	21.78	2010	730	8.3	2.63	0.55	0.05	55.0	--	5.0	<10	<10
AT&T 45	042065	DD094	21.78	1900	800	8.9	2.35	0.54	0.03	64.0	--	2.6	<10	<10
AT&T 45	231448	DD091	21.78	1700	460	3.7	2.5	0.48	0.043	62.0	18.3	3.4	<10	<10
AT&T 45	222498	DD097	21.8	1900	580	6.9	2.54	0.48	0.06	60.0	20.0	1.1	50	<10
AT&T 45	157105	DD104	21.78	1900	375	4.4	2.7	0.42	0.03	48.0	12.6	0.88	50	<10
Shielded covers														
AT&T 45	160075	DD095	21.78	33	800	9.6	2.74	0.55	0.06	--	192.0	0.40	50	<10
AT&T 45	007804	DD098	21.77	<10	630	10.2	2.59	0.54	0.054		191.0	4.96	1200*	90
AT&T 45C	306619	DD107	21.78	94	307	7.0	2.51	0.50	0.07	65.0	25.0	3.6	50	<10
Other models														
AT&T PC	001839	-	25.87	52	1098	7.7	1.67	0.17	0.0 03	5.0	8.9	0.9	1000	50
TAB 132/15	130-15860	-	23.52	1550	90	4.5	1.52	0.70	0.026	40.0	--	1.8	1200*	200
TAB 132/15	130-02552	-	23.52	2000	71.1	4.6	1.46	0.73	0.073	32.5	--	3.6	1200*	150
Range		Min.	21.78	<10	71.1	3.0	1.46	0.17	0.003	5.0	5.0	0.4	<10	<10
		Max.	25.87	2300	1098	10.2	2.76	0.57	0.076	78	192	6.2	1200	200

* 5 cm rather than 1 cm

TABLE 2. MEANS AND STANDARD DEVIATIONS OF VDT E FIELD MEASUREMENTS

No. of Units	VDT Type	Flyback Frequency (kHz)	E Field (V/m) Maximum Mean	Maximum SD	Screen Mmean	Screen SD	30 cm From Screen Mean	30 cm From Screen SD
21	AT&T 45	21.78	1887.*	±400.	569.	±132.	6.58	±2.495
1	AT&T PC	25.87	52.	---	1098.	---	7.7	---
2	Tab 132/15	23.52	1775.	±318.	80.6	±13.4	4.55	±0.0707

*Values for 18 units, Mean is 45.7 and SD is +43.4 for 3 units with shielded covers

TABLE 3. MEANS AND STANDARD DEVIATION OF MEASURED RMS H FIELD VDT EMISSIONS

VDT Type	Flyback Frequency (kHz)	H-Field (A/m) Maximum Mean	Maximum SD	Screen Mean	Screen SD	30 cm From Screen Mean	30 cm From Screen SD
AT&T 45	21.78	2.50	±0.232	0.502	±0.0628	0.0493	±0.00145
AT&T PC	25.87	1.67	---	0.17	---	0.003	---
Tab 132/15	23.52	1.49	±0.0424	0.0202	±0.0163	0.0495	±0.0332

TABLE 4. MEANS AND STANDARD DEVIATIONS OF MEASURED RMS E FIELD INDUCED BODY-TO-GROUND CURRENT FROM VDT EXPOSURES

VDT Type	Flyback Frequency (kHz)	Induced Current (μA) Maximum Mean	Maximum SD	Screen Mean	Screen SD	30 cm From Screen Mean	30 cm From Screen SD
AT&T 45	21.78	54.0	±18.8	55.788*	±66.23	3.911	±4.879
AT&T PC	25.87	5.0		8.9		0.9	
Tab 132/15	23.52	36.3	±5.3	----	----	2.70	±1.27

*Finger pointing at VDT screen, increasing to 163.3 +34.8 for hand on screen

TABLE 5. BODY CROSS-SECTIONAL AREAS AS A FUNCTION OF POSITION FOR HUMAN

Subject No. 115 18:27:06 22-Aug-84, Sex F, Age 23 Yrs., Height=164.0 CM, Weight=120.0 LBS

	Position (cm)	Major Dim (cm)	Minor Dim (cm)	Circumference (cm)	Area (cm2)
Bottom OF Foot	0.0	23.0	10.1	54.0	182.6
	4.8	15.0	7.6	36.5	89.9
	5.0	11.2	7.0	29.0	61.8
Ankle	10.0	8.2	6.4	23.0	41.1
	15.0	9.5	9.0	29.0	66.9
	20.0	11.7	10.2	34.5	94.1
	25.0	12.3	11.2	37.0	108.6
	30.0	12.5	11.4	37.5	111.6
	35.0	11.7	11.2	36.0	103.1
	40.0	11.2	10.1	33.5	88.9
Knee	45.0	13.1	11.3	38.4	116.4
	50.0	14.0	12.6	41.8	138.5
	55.0	15.0	14.3	46.0	168.3
	60.0	16.1	15.4	49.5	194.9
	65.0	17.5	16.6	53.5	227.6
	70.0	18.8	17.6	57.2	259.9
	75.0	19.8	18.0	59.4	279.9
	80.0	20.2	18.0	60.0	285.1
Perineum	85.0	21.0	19.4	63.5	320.1
	90.0	33.6	21.4	87.4	563.7
	95.0	31.0	24.7	87.8	601.9
Ilium Ridge	99.0	26.7	19.1	72.5	401.5
Navel	100.0	24.5	19.3	69.0	370.8
	105.0	23.3	16.9	63.5	308.7
	110.0	23.5	17.7	65.0	326.2
	115.0	25.5	18.1	69.0	362.8
	120.0	26.0	22.3	76.0	455.6
	125.0	25.8	22.4	75.8	453.8
Axilla	130.0	28.2	21.2	78.0	469.7
Sternum Notch	134.0	24.7	23.0	75.0	446.8
Collar	135.0	19.2	15.1	54.0	227.0
Nech	140.0	10.1	9.2	30.4	73.3
Chin	145.0	16.2	9.8	41.5	125.1
	150.0	18.6	10.0	46.0	146.7
Nasion	155.0	19.5	16.7	57.0	256.3
Forehead	158.0	19.1	15.8	55.0	237.6
Top OF Head	164.0	0.0	31.7	0.0	0.0
Bottom of Hand	-4.0	18.2	9.8	45.0	140.4
Reference for Arm	0.0	6.1	6.0	19.0	28.7
Wrist	5.0	5.1	4.3	14.8	17.3
	10.0	5.3	4.9	16.0	20.3
	15.0	7.0	5.4	19.5	29.5
	20.0	7.2	7.1	22.5	40.3
	25.0	8.2	6.4	23.0	41.1

TABLE 5. (Cont) BODY CROSS-SECTIONAL AREAS AS A FUNCTION OF POSITION FOR HUMAN

Subject No. 115 18:27:06 22-Aug-84, Sex F, Age 23 Yrs., Height=164.0 CM, Weight=120.0 LBS

	Position (cm)	Major Dim (cm)	Minor Dim (cm)	Circumference (cm)	Area (cm2)
Elbow	28.0	7.7	6.9	23.0	42.0
	30.0	7.8	7.0	23.2	42.7
	35.0	7.8	7.8	24.5	47.8
	40.0	8.3	7.3	24.6	47.8
	45.0	8.7	7.0	24.7	47.7
Axilla	50.0	9.8	8.3	28.5	64.0

Calculated Weight in Kilograms= 57.0938 In Pounds= 125.6063

TABLE 6. WORST-CASE RMS E-FIELD CURRENT DENSITIES INDUCED IN WRIST OF EXPOSED VDT OPERATOR

VDT Type	Flyback Frequency (kHz)	Induced Current Densities ($\mu A/cm^2$) Maximum Mean	SD	Screen Mean	SD	30 cm From Screen Mean	SD
AT&T 45	21.78	3.12	±1.087	3.225*	±3.828	0.226	±0.282
AT&T PC	25.87	0.289	---	0.514	---	0.0520	
Tab 132/15	23.52	2.10	±0.306	---	---	0.156	±0.0734

*Value is for finger pointing at screen which increases to 9.44 ±2.01 $\mu A/cm^2$ for hand on screen

TABLE 7. WORST-CASE RMS E-FIELD INDUCED CURRENT DENSITIES IN LOWER TORSO OF EXPOSED VDT OPERATOR

VDT Type	Flyback Frequency (kHz)	Induced Current Density (μA/cm^2)					
		Maximum		Screen		30 cm From Screen	
		Mean	SD	Mean	SD	Mean	SD
AT&T 45	21.78	0.135	±0.047	0.139*	±0.166	0.0098	±0.0122
AT&T PC	25.87	0.0125	---	0.0223	---	0.00225	---
Tab 132/15	23.52	0.0908	±0.0133	---	---	0.00675	±0.003175

*Value is for finger pointing at screen which incrreases to 0.408 ±0.087 μA/cm^2 for hand on screen

TABLE 8. WORST-CASE PEAK CURRENT DENSITIES INDUCED IN LOWER TORSO OF EXPOSED VDT OPERATOR

VDT Type	Flyback Frequency (kHz)	Induced Current Denisity (μA/cm^2)					
		Maximum		Screen		30 cm From Screen	
		Mean	SD	Mean	SD	Mean	SD
AT&T 45	21.78	0.815	±0.284	0.8398	±1.0030	0.0592	±0.0737
AT&T PC	25.87	0.0755	---	0.135	---	0.0136	---
Tab 132/15	23.52	0.454	±0.0665	---	---	0.03375	±0.015875

TABLE 9. COMPARISON OF MEASURED VDT EXPOSURE PARAMETERS WITH CALCULATED EQUIVALENT FAR-FIELD ENVIRONMENTAL EXPOSURE FIELDS

Terminal Identification			Flyback	Measured RMS Field Strength and Current						Equivalent Calculated Far-Field Eenvironmental rms E field (V/m)		
			Freq.	E Field (V/m)			Body Current (μA)					
Type	S/N	ID No.	(kHz)	Max	Face	30 cm	Max	Face	Keyboard	Max	Face	Keyboard
						Unshielded Covers						
AT&T 45C	270687	DD119	21.78	1930	690	3.0	60.0	30.0	5.0	3.53	1.76	0.294
AT&T 45	193359	DD118	21.79	1950	630	7.2	65.0	25.0	24.0	3.82	1.47	1.41
AT&T 45	029818	DD109	21.78	1340	560	7.4	68.0	25.0	5.1	4.00	1.47	0.300
AT&T 45	220300	DD116	21.78	1913	620	9.5	50.0	27.0	2.9	2.94	1.59	0.171
AT&T 45C	270290	DD121	21.78	570	570	7.8	7.0	5.0	2.0	0.412	0.294	0.118
AT&T 45	072140	DD112	21.78	2300	582	5.7	71.0	20.3	3.6	4.17	1.19	0.212
AT&T 45	205927	DD111	21.78	1960	470	4.2	51.9	12.4	1.6	3.05	0.729	.0094
AT&T 45	098495	DD117	21.78	1950	570	5.7	52.0	19.0	2.9	3.06	1.12	0.171
AT&T 45C	270572	DD096	21.8	2300	540	6.5	75.0	120.0	1.6	4.41	7.06	0.094
AT&T 45	101491	DD103	21.78	1900	570	0.8	60.0	--	1.4	3.53	--	0.082
AT&T 45	213800	DD093	21.78	2300	535	6.8	64.0	--	2.4	3.76	--	0.141
AT&T 45	166659	DD099	21.78	2200	620	10.0	78.0	150.0	6.2	4.59	8.82	0.365
AT&T 45	200886	DD101	21.78	1950	320	4.5	54.0	--	1.5	3.18	--	0.088
AT&T 45	244178	DD102	21.78	2010	730	8.3	55.0	--	5.0	3.23	--	0.294
AT&T 45	042065	DD094	21.78	1900	800	8.9	64.0	--	2.6	3.76	--	0.153
AT&T 45	231448	DD091	21.78	1700	460	3.7	62.0	18.3	3.4	3.65	1.08	0.200
AT&T 45	222498	DD097	21.8	1900	580	6.9	60.0	20.0	1.1	3.53	1.18	0.065
AT&T 45	157105	DD104	21.78	1900	375	4.4	48.0	12.6	0.88	2.82	0.741	0.052
						Shielded Covers						
AT&T 45	160075	DD095	21.78	33	800	9.6	--	192.0	0.40	--	11.3	0.024
AT&T 45	007804	DD098	21.77	<10	630	10.2	--	191.0	4.96	--	11.2	0.292
AT&T 45C	306619	DD107	21.78	94	307	7.0	65.0	25.0	3.6	3.82	1.47	0.212
						Other Models						
AT&T PC	0018399	-----	25.87	52	1098	7.7	5.0	8.9	0.9	0.258	0.458	0.0464
TAB 132/15	130-02552	-----	23.52	2000	71.1	4.6	32.5	--	3.6	1.19	--	0.1318
TAB 132/15	130-15860	KEW047	23.52	1550	90	4.5	40.0	--	1.8	1.465	--	0.0659
Range		Min.	21.78	<10	71.1	0.8	5.0	5.0	0.4	0.258	0.29	0.0094
		Max.	25.87	MODEL	1098	10.2	78.	192	24.0	11.3	11.3	1.41

TABLE 10. EQUIVALENT ENVIRONMENTAL UNIFORM (RMS VALUES) E FIELD EXPOSURE CORRESPONDING TO VDT E FIELD EXPOSURES

VDT Type	Flyback Frequency (kHz)	rms E-Field (V/m) Cover Mean	SD	Screen Mean	SD	30 cm From Screen Mean	SD
AT&T 45	21.78	3.176	±1.106	3.274*	±0.894	0.226	±0.289
AT&T PC	25.87	0.258	---	0.458	---	0.0464	---
Tab 132/15	23.52	1.3275	±0.388	---	---	0.09885	±0.0466

*Indicated value for finger on screen increases to 9.46 ±2.01 with hand on screen

TABLE 11. MAGNETIC FIELD, RATE OF CHANGE OF MAGNETIC FIELD AND MAXIMUM MAGNETIC FIELD INDUCED CURRENT DENSITY IN BOTTOM OF HAND OF PERSON EXPOSED TO VDT FIELDS AT TOP OF TERIMINAL

VDT Type	Flybåck t(μs)	B (μT)	Brms (μT)	B/Brms	Peak dB/dt (T/s)	Peak J (μA/cm2)	rms J (μA/cm2)	Peak/rms J
AT&T 45	8.0	10.47 ±0.972	3.14 ±0.292	3.33	1.31 ±0.122	1.99 ±0.185	0.573 ±0.0533	3.47
AT&T PC	6.0	7.53	2.10	3.59	1.255	1.906	0.476	4.01
TAB 132/15	5.0	6.08 ±0.173	1.87 ±0.0533	3.25	1.2155 ±0.03468	1.85 ±0.0527	0.362 ±0.0103	5.11

TABLE 12. MAGNETIC FIELD, RATE OF CHANGE OF MAGNETIC FIELD AND MAXIMUM POSSIBLE MAGNETIC FIELD INDUCED CURRENT DENSITY IN LOWER TORSO OF PERSON EXPOSED TO VDT FIELDS AT TOP OF TERIMINAL

VDT Type	Flyback t(μs)	B (μT)	Brms (μT)	B/Brms	Peak dB/dt (T/s)	Peak J (μA/cm2)	rms J (μA/cm2)	Peak/rms J
AT&T 45	8.0	0.206 ±0.00607	0.062 ±0.00182	3.33	0.0258 ±0.00076	0.0653 ±0.00192	0.0188 ±0.0055	3.47
AT&T PC	6.0	0.0135	0.00377	3.59	0.00225	0.00569	0.00142	4.01
TAB 132/15	5.0	0.202 ±0.136	0.0622 ±0.0417	3.25	0.0404 ±0.0272	0.102 ±0.0135	0.0200	5.11

TABLE 13a. WESTERN COUNTRY EXPOSURE STANDARDS 0.01 TO 3.0 MHz

	NATO	NATO	ANSI	ACGIH
Freq. (MHz)	0.01 - 1.0	1.0 - 3.0	0.3 - 3.0	0.01 - 3.0
E Field (V/m)	1000	660	618	618
H Field (A/m)	2.6	1.3	1.58	1.58
Pwr. Den. (mW/cm^2)	265	66	100	100

	USAF	IRPA	MASS.	PORTLAND
Freq. (MHz)	0.01 -3.0	0.3 - 3.0	0.3 - 3.0	0.1 - 3.0
E Field (V/m)	434	307 - 205	275	43
H Field (A/m)	1.15	0.814-0.295	0.729	0.114
Pwr. Den. (mW/cm^2)	50	11	20	0.5

TABLE 13b. USSR AND EAST EUROPEAN STANDARDS 0.01 to 3.0 MHz

	POLAND	CZECH	USSR(OCC)	USSR(GP)
Freq. (MHz)	0.1 - 3.0	0.03 - 3.0	0.06 - 1.5 1.5 - 3.0	0.03 - 0.3 0.3 - 3.0
E Field (V/m)	20 -1000	50	50 50	20 10
H Field (A/m)	2 - 250	----	5	----
Pwr. Den. (mW/cm^2)	0.1 - 265 151 - $2.4x10^6$	0.66	0.66 943	0.1 0.027

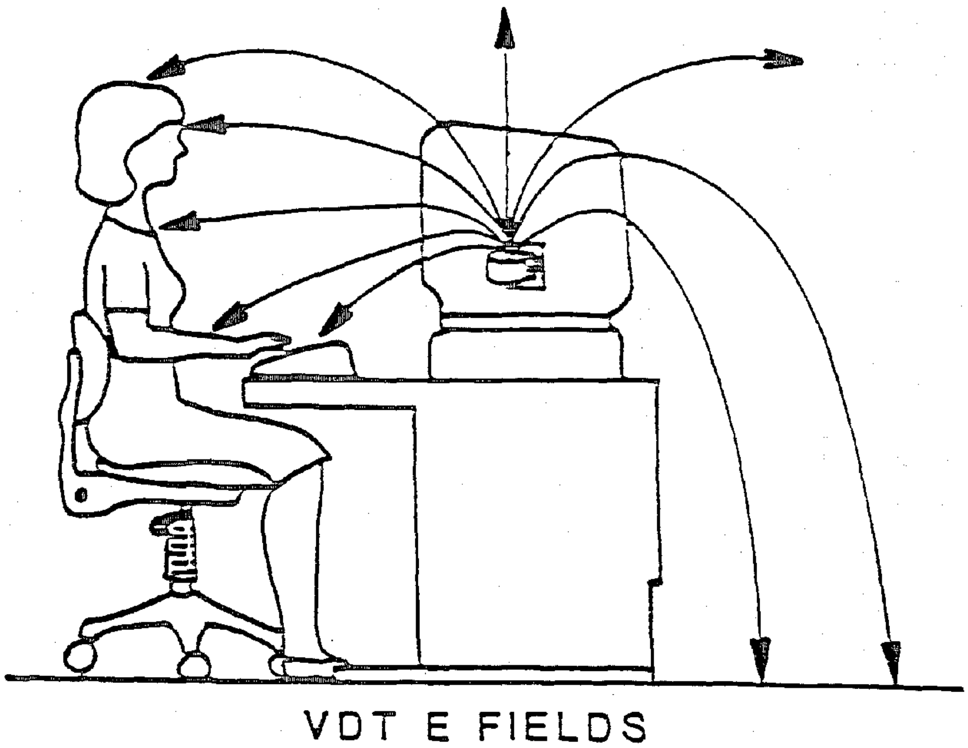


Figure 1. Sketch of electric field emissions in vicinity of operator

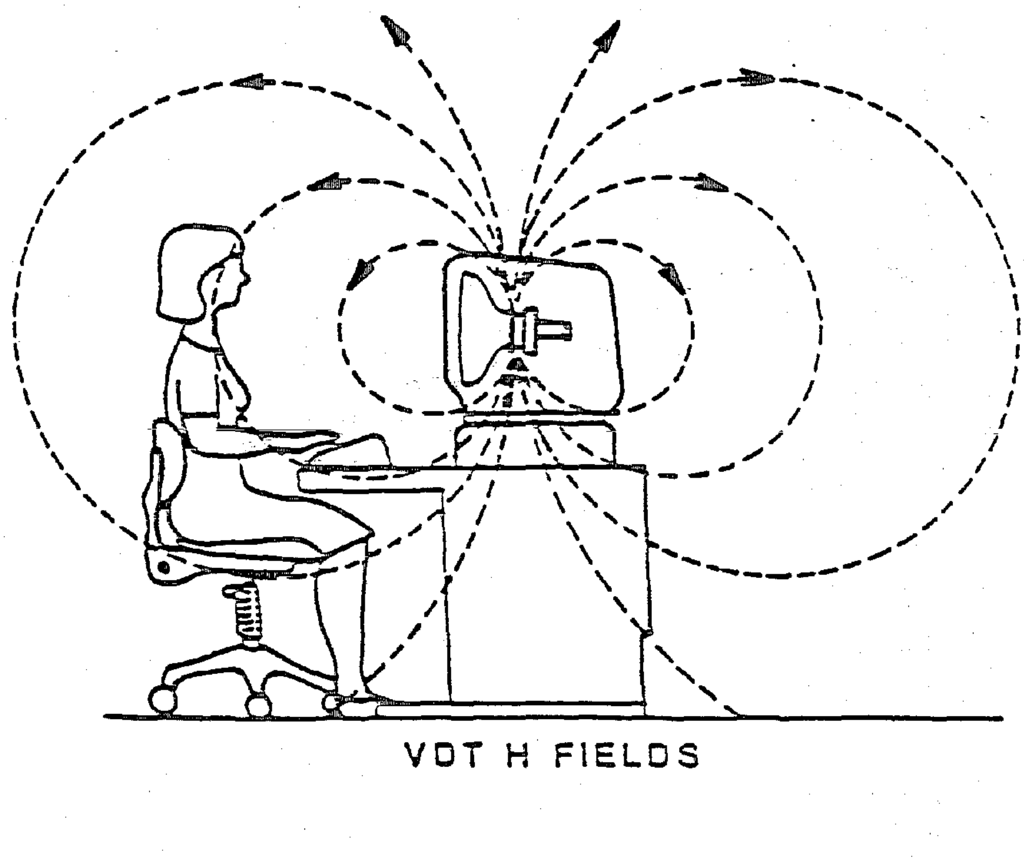
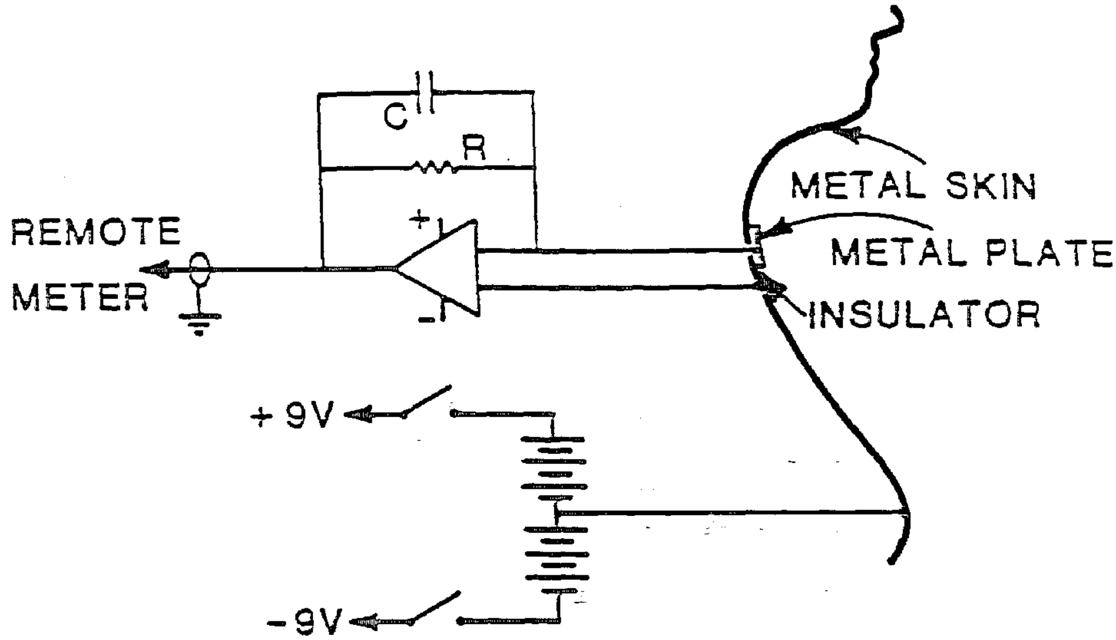
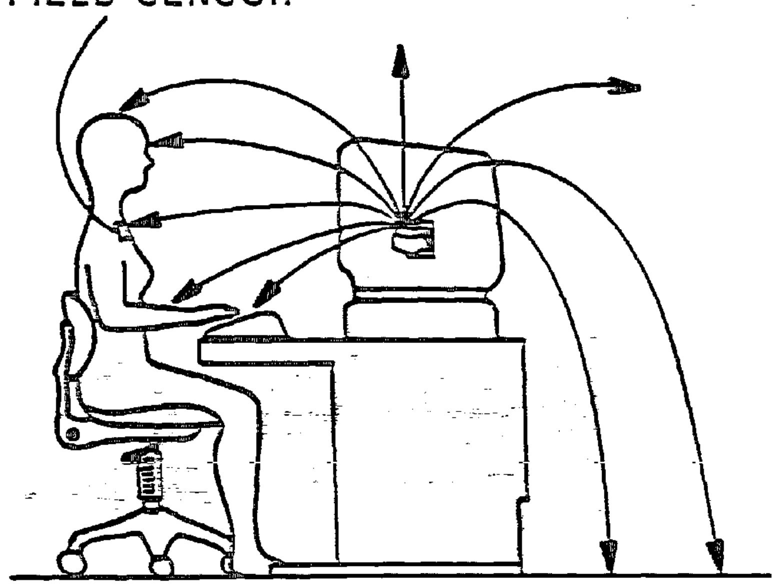


Figure 2. Sketch of magnetic field emissions in vicinity of operator



E FIELD SENSOR IN METAL FOIL MANIKIN



MEASUREMENT OF CURRENT DENSITY
FROM VDT EMISSIONS
WITH METAL FOIL MANIKIN

Figure 3. Method of measuring electric field at surface of subject exposed to electric field emission from VDT

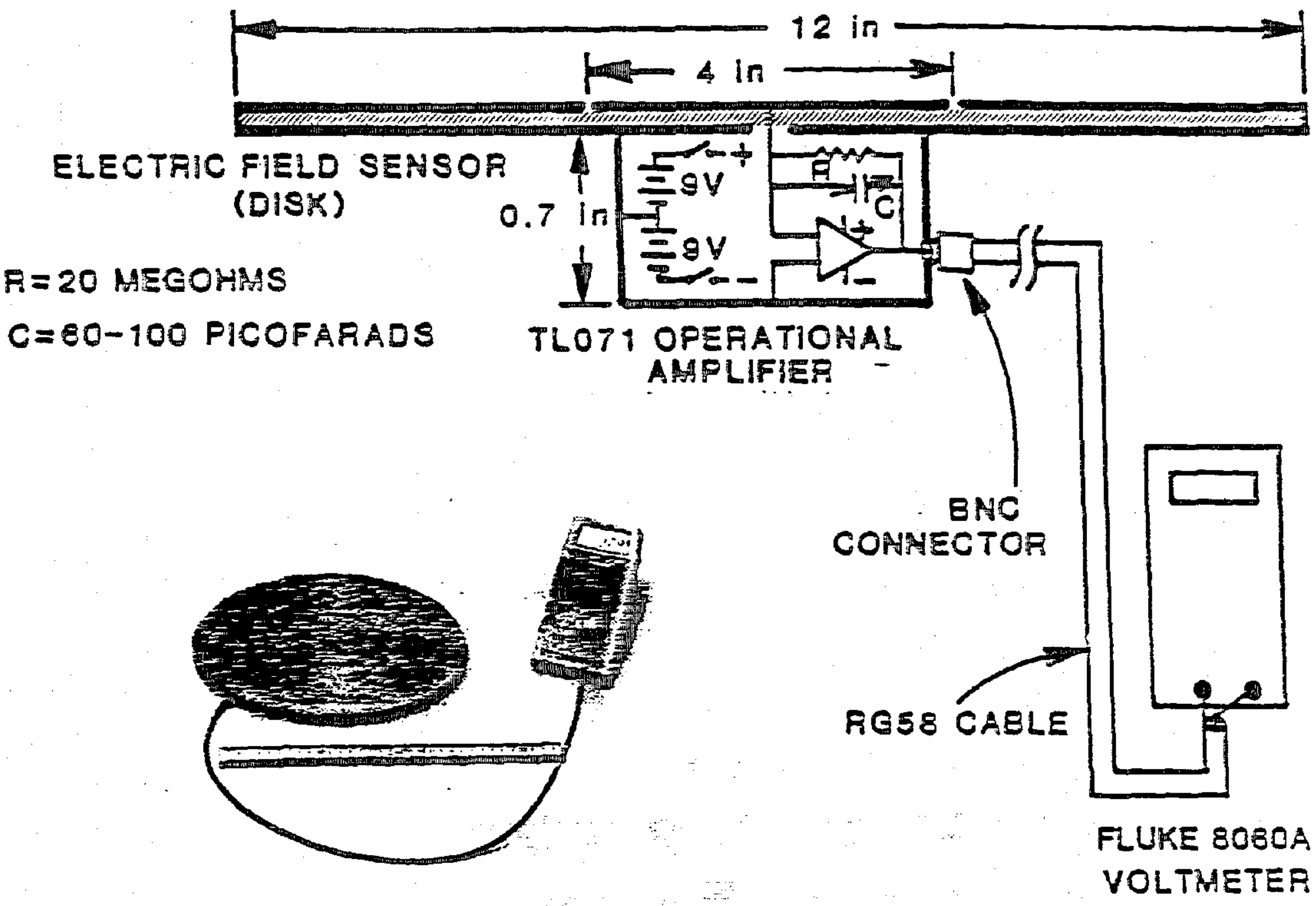


Figure 4. Diagram :and photograph of VLF electric field measuring device

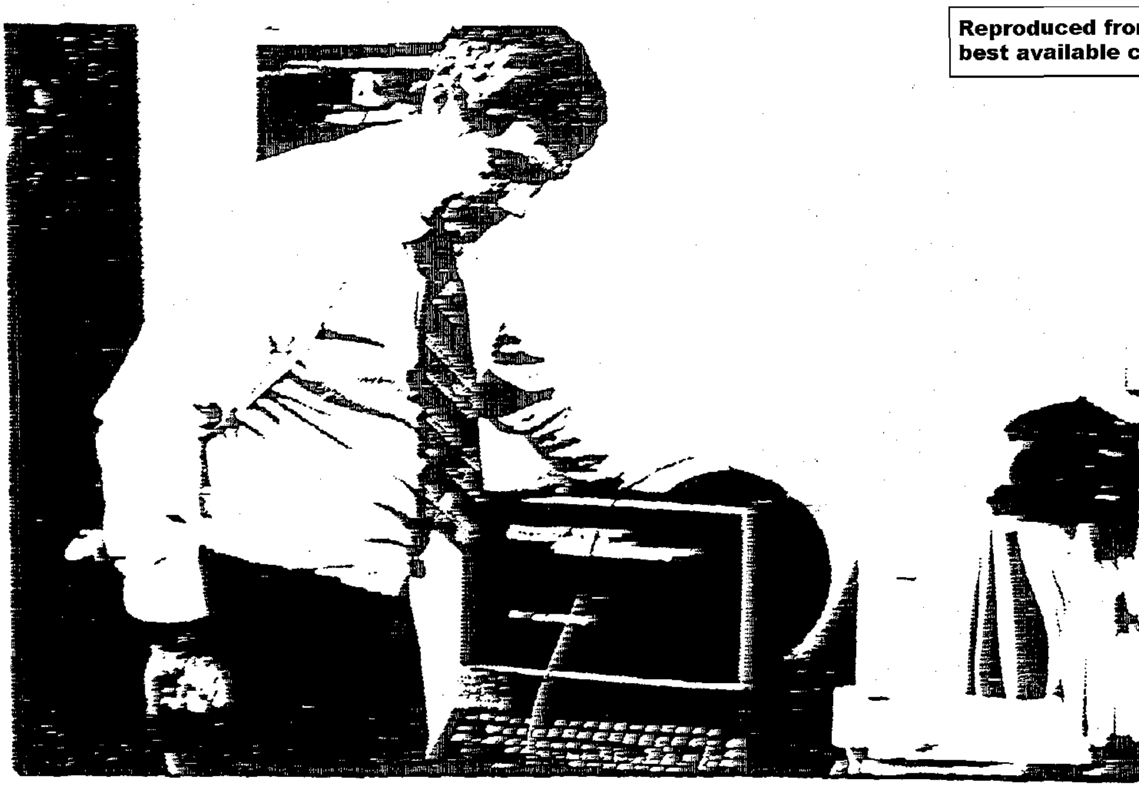


Figure 5. Measurement of electric fields nearest flyback transformer of VDT

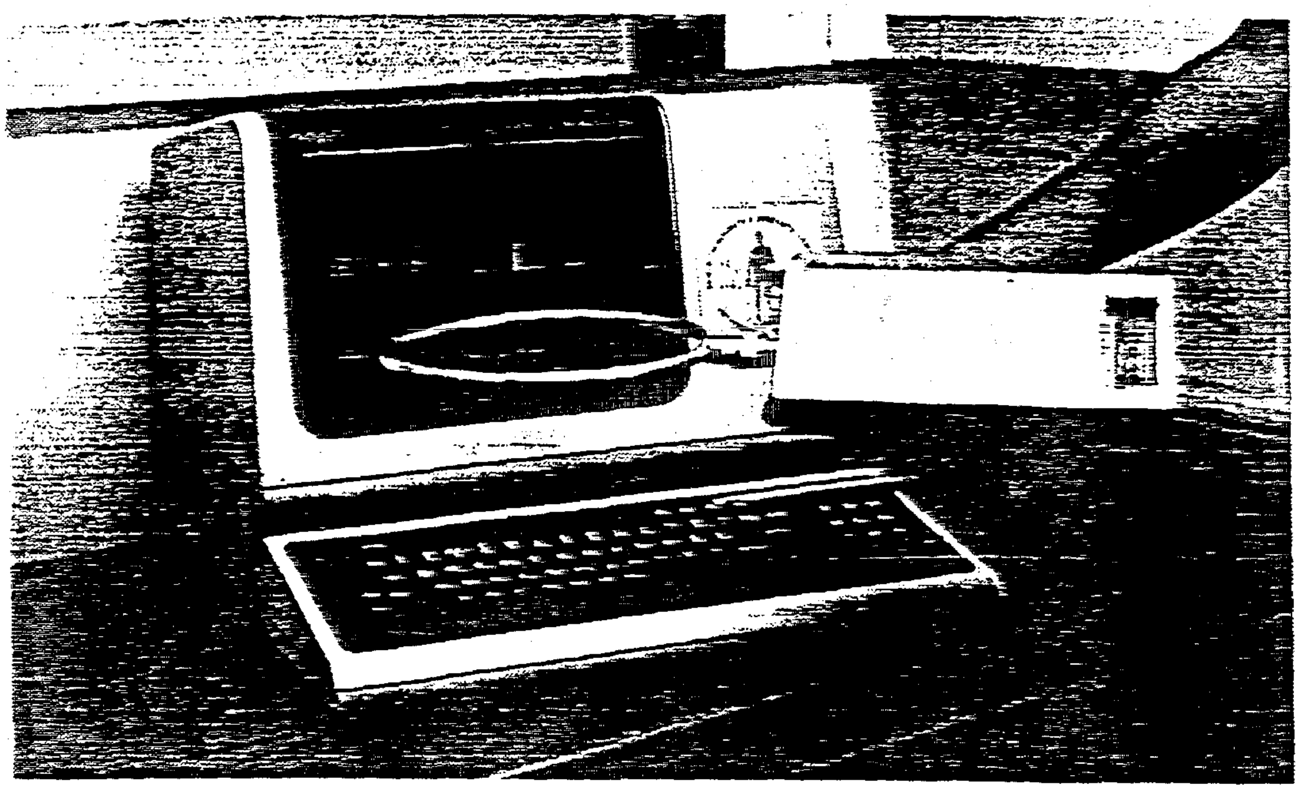


Figure 6. Measurement of magnetic fields nearest screen of VDT

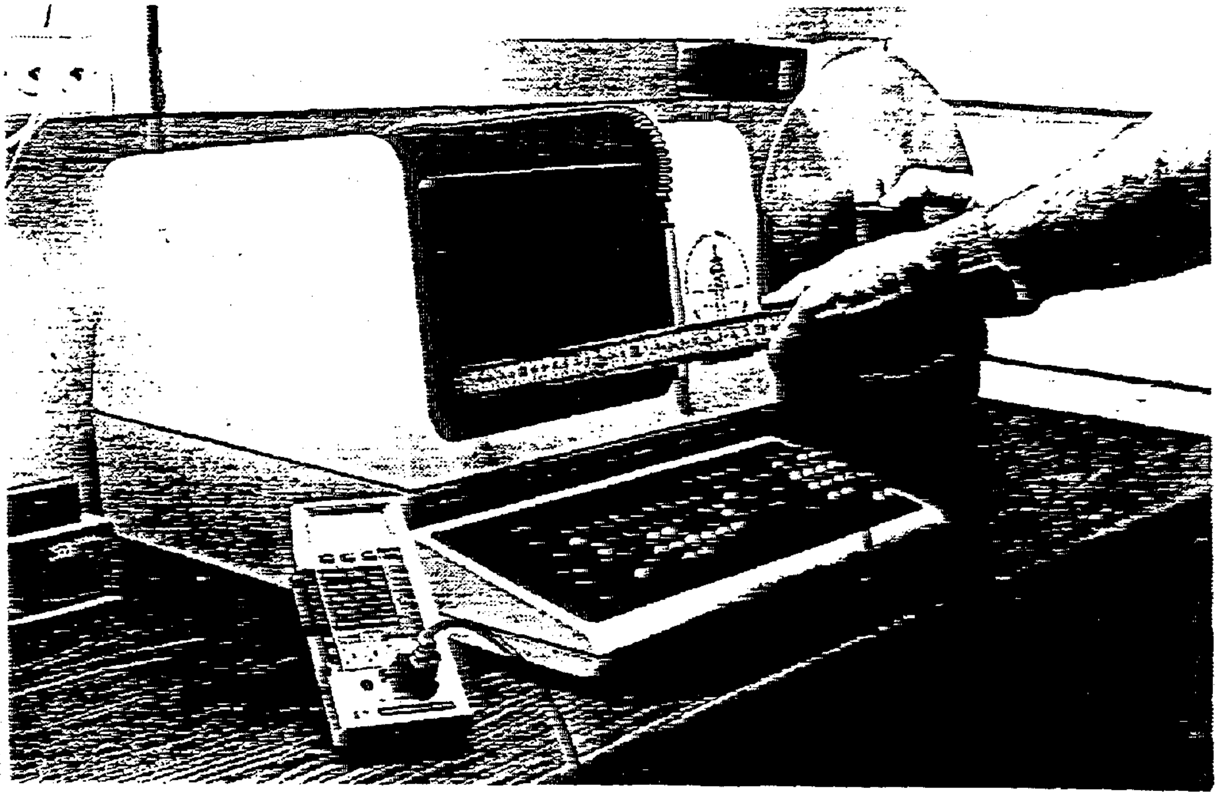


Figure 7. Measurement of electric field 30 cm from front of VDT

Figure 8. Measurement of magnetic field 30 cm from front of VDT

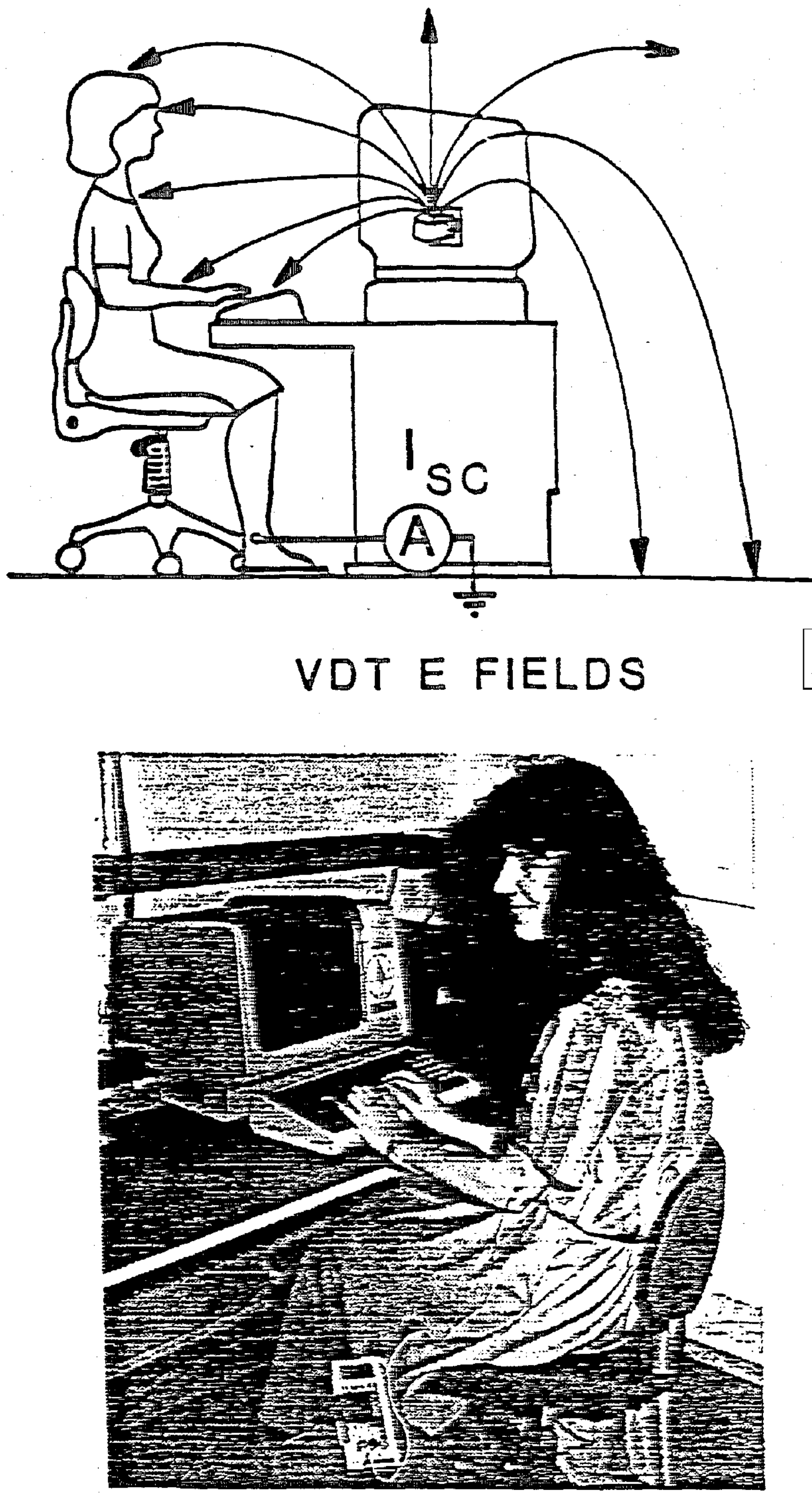


Figure 9. Measurement of body-to-ground current due to exposure to VDT electric fields

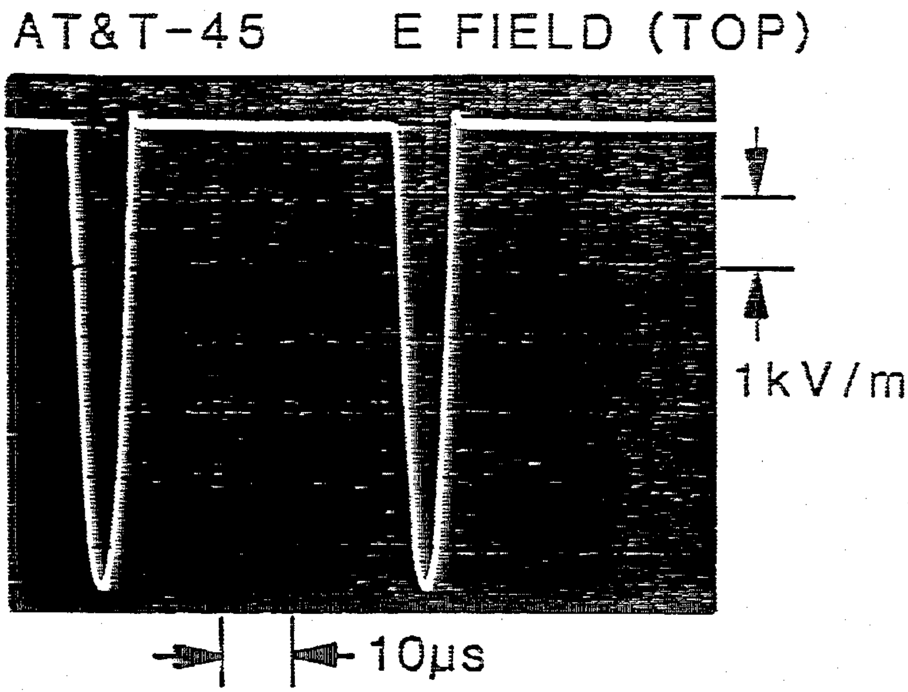


Figure 10. E field waveshape measured at top of AT&T model 45 terminal (peak-to-peak field is 6.6 kV/m and rms value is 1.9 kV/m)

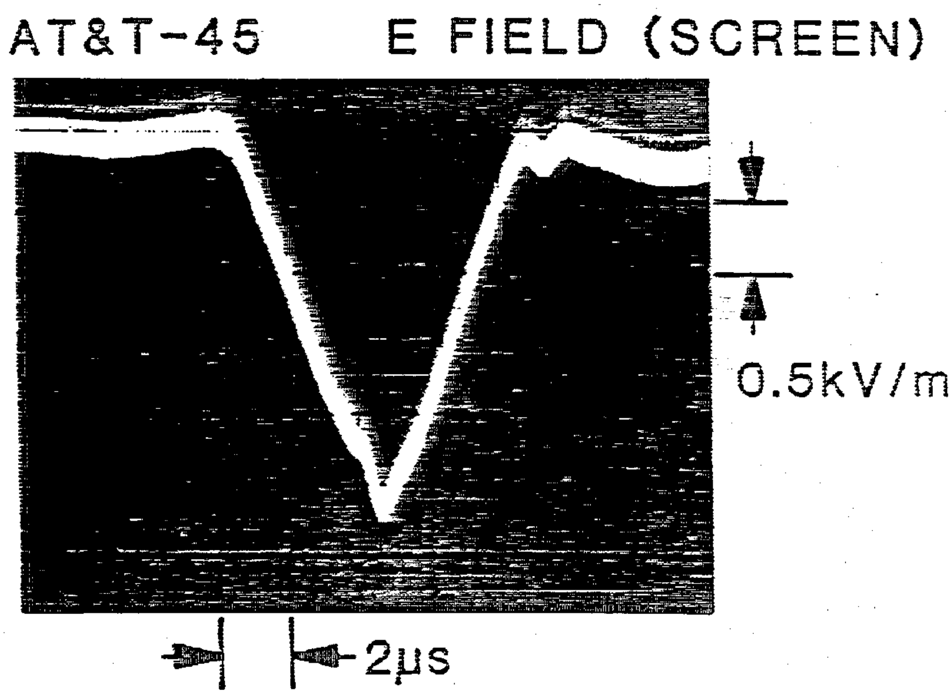


Figure 11. E field waveshape measured 1 cm from screen of AT&T model 45 terminal (peak-to-peak field is 2.75 kV/m and rms value is 580 V/m)

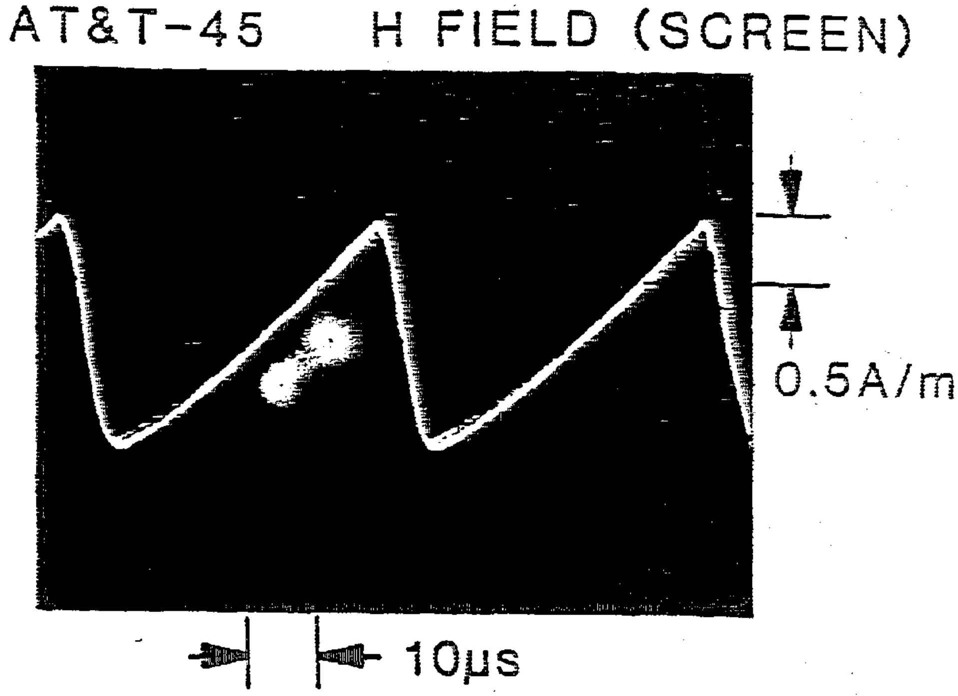


Figure 12. Recorded waveshape of magnetic field with horizontal loop placed against screen of AT&T model 45 terminal (peak-to-peak and rms magnetic fields are 1.6 and 0.48 A/m respectively)

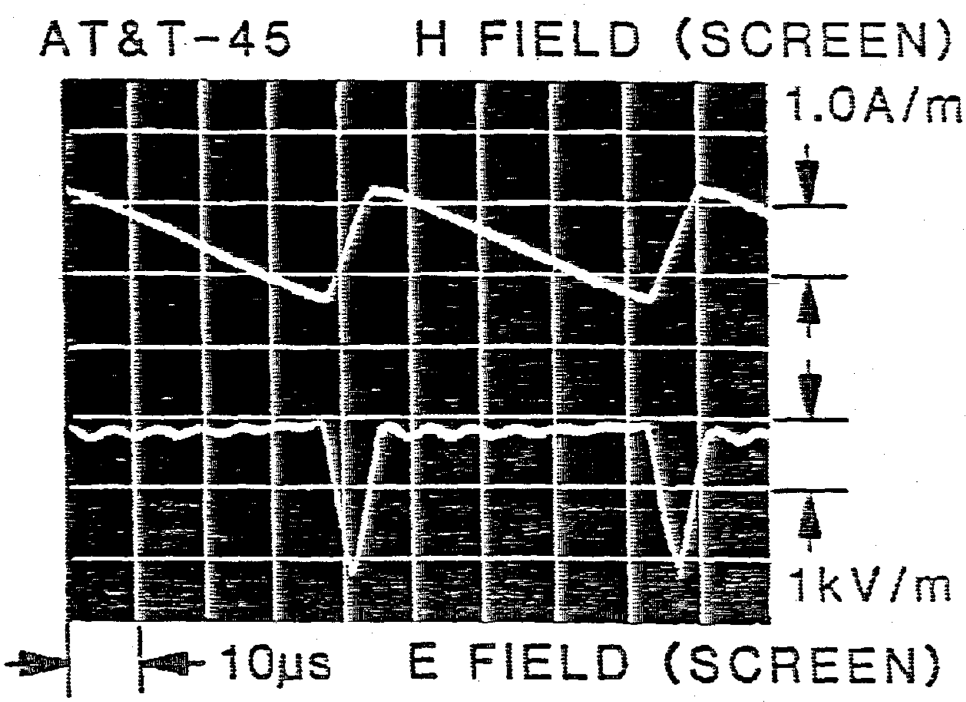


Figure 13. Recorded E and H fields at screen of AT&T model 45 VDT

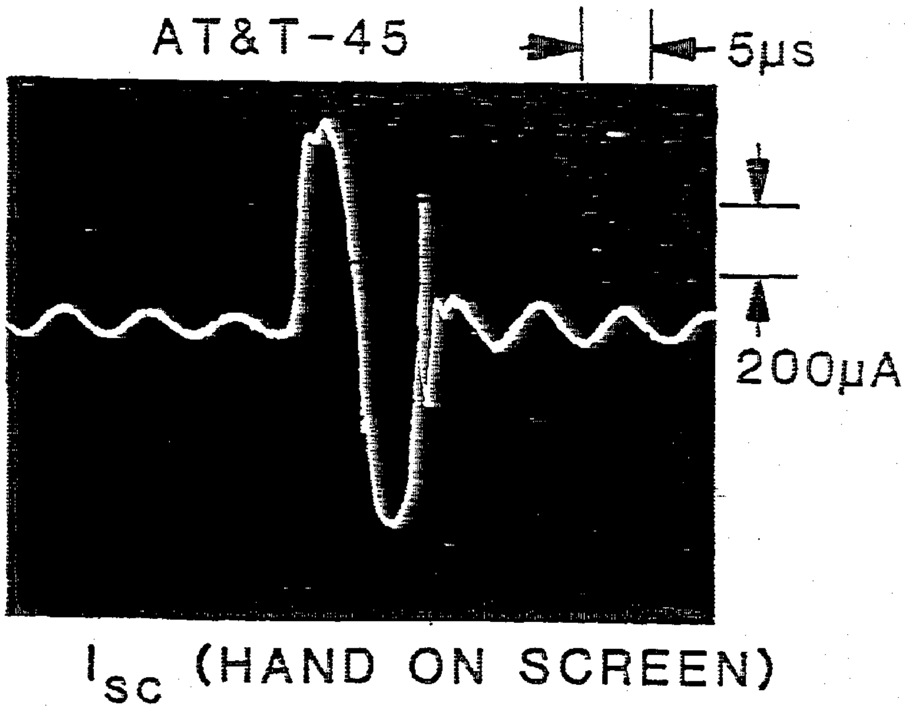


Figure 14. E field induced body-to-ground current when male subject's right hand is flat against screen of AT&T model 45 VDT (peak-to-peak and rms values are 1.16 mA and 192.0 uA respectively)

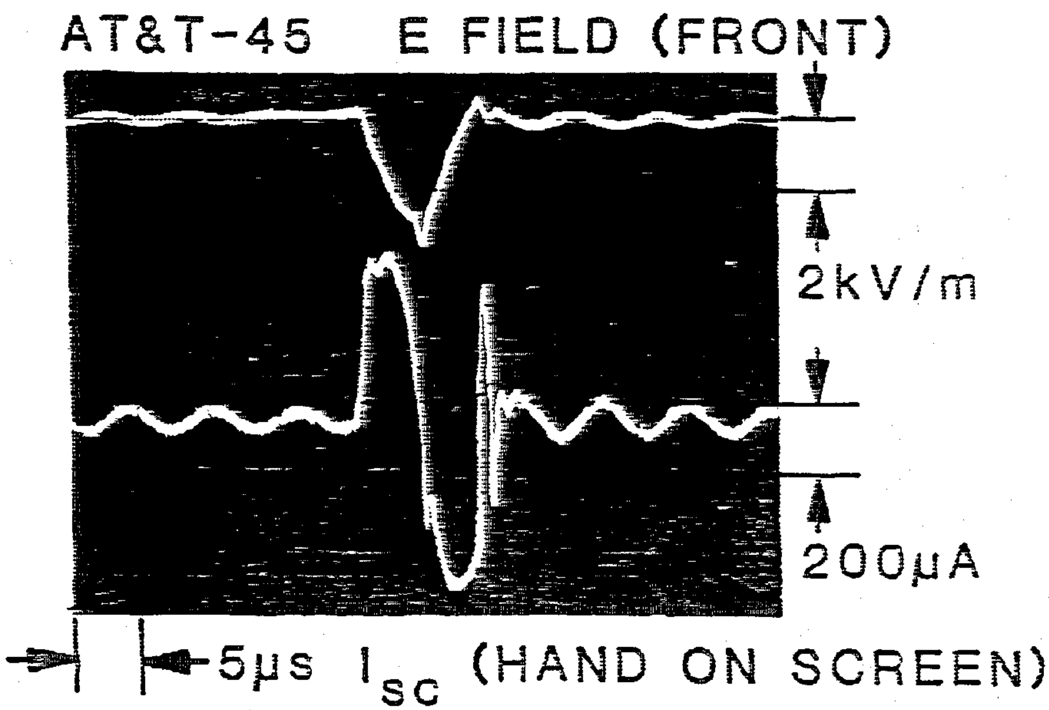


Figure 15. Comparison of measured E field and body-to-ground current waveshapes

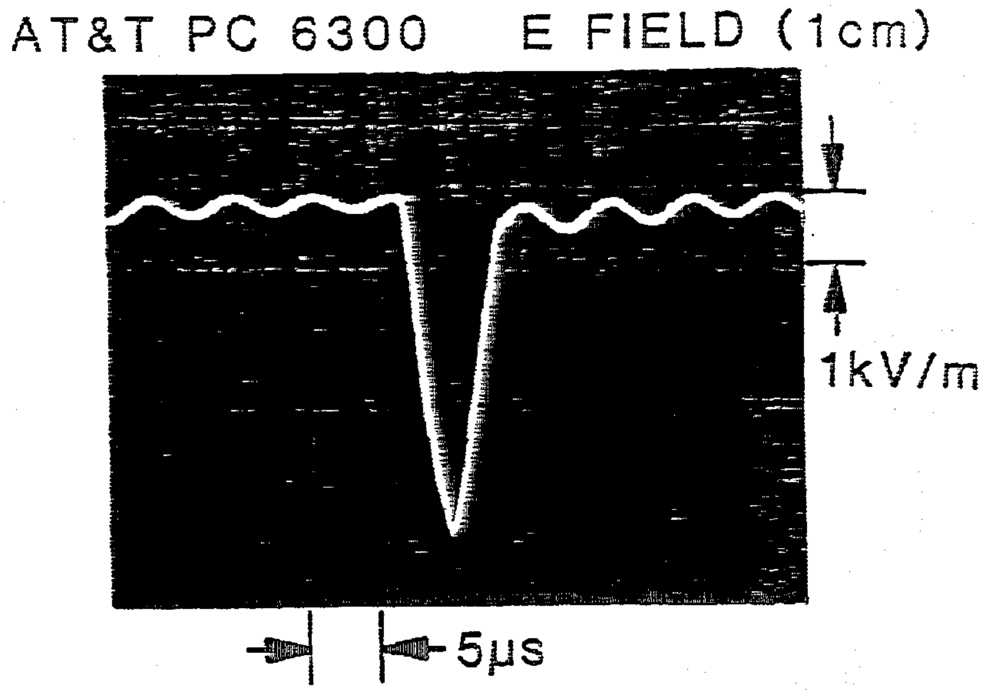


Figure 16. Recorded E field with sensor 1 cm from screen of AT&T PC6300 VDT (peak-to-peak and rms values are 4.4 and 1.098 kV/m respectively)

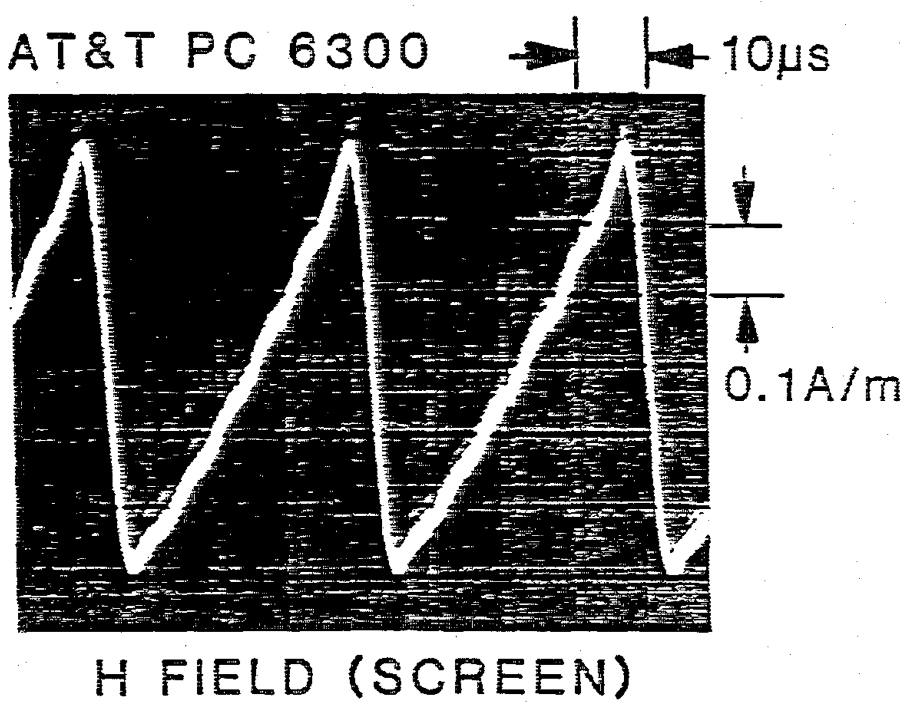


Figure 17. Recorded H field with magnetic loop touching screen of AT&T PC6300 VDT (peak-to-peak and rms values are 0.61 and 0.17 A/m respectively)

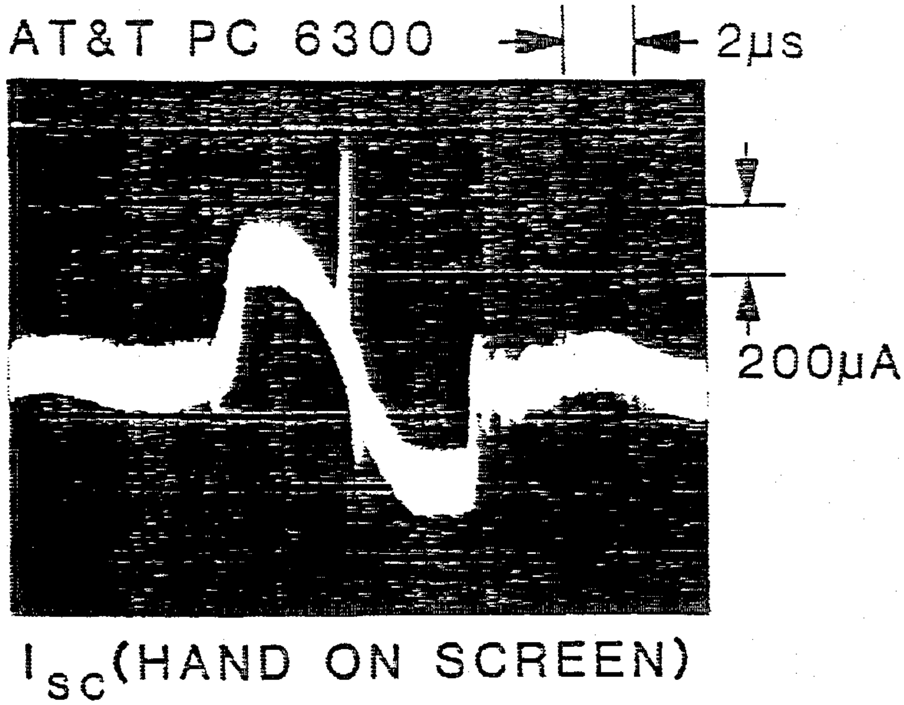


Figure 18. Recorded E-field induced body-to-ground current waveshape for male subject with the right hand against the screen of an AT&T PC6300 VDT (peak-to-peak and rms values are 680 and 8.9 uA respectively)

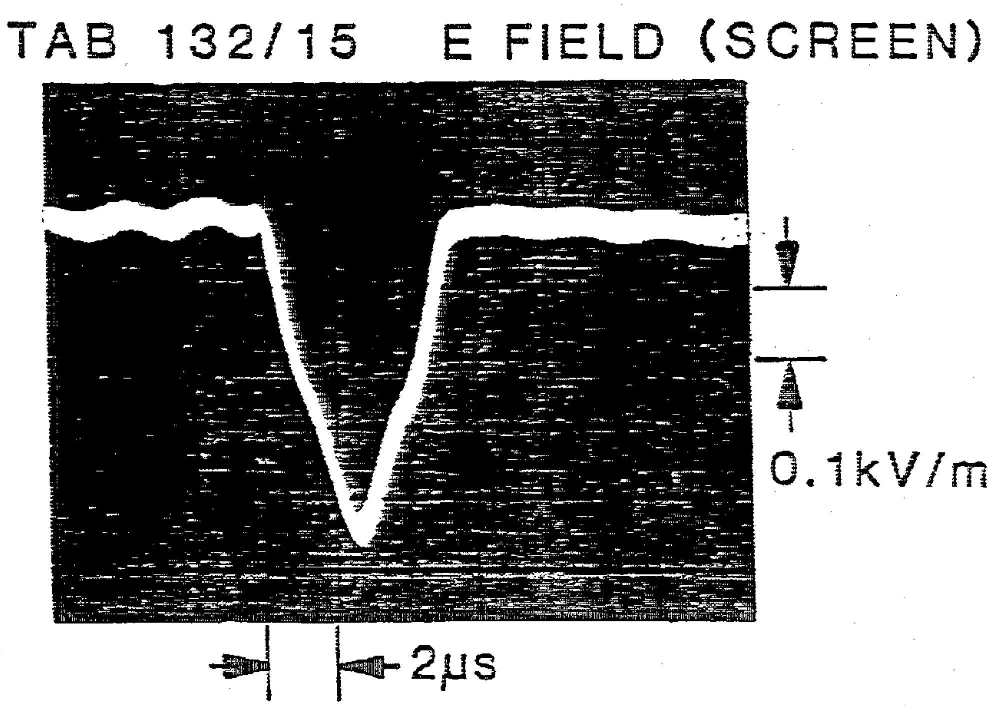


Figure 19. Recorded E field waveshape 2 inches from screen of TAB model 132/15 VDT (peak-to-peak and rms values are 460 and 90 V/m respectively)

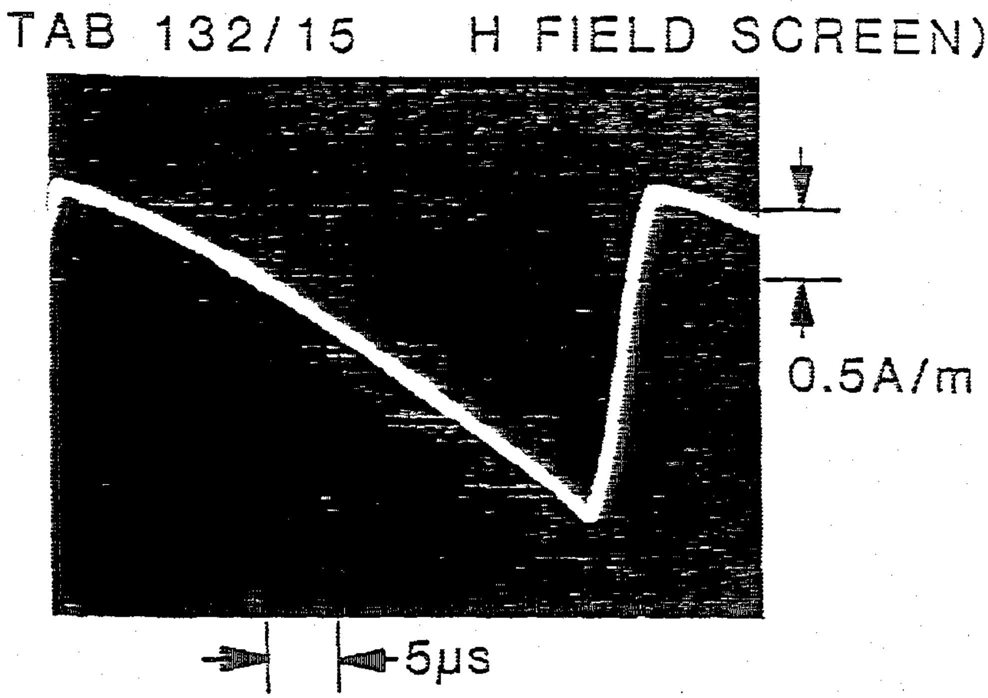


Figure 20. Recorded H field with magnetic loop touching screen of TAB 132/15 terminal (peak-to-peak and rms values are 2.3 and 0.707 A/m respectively)

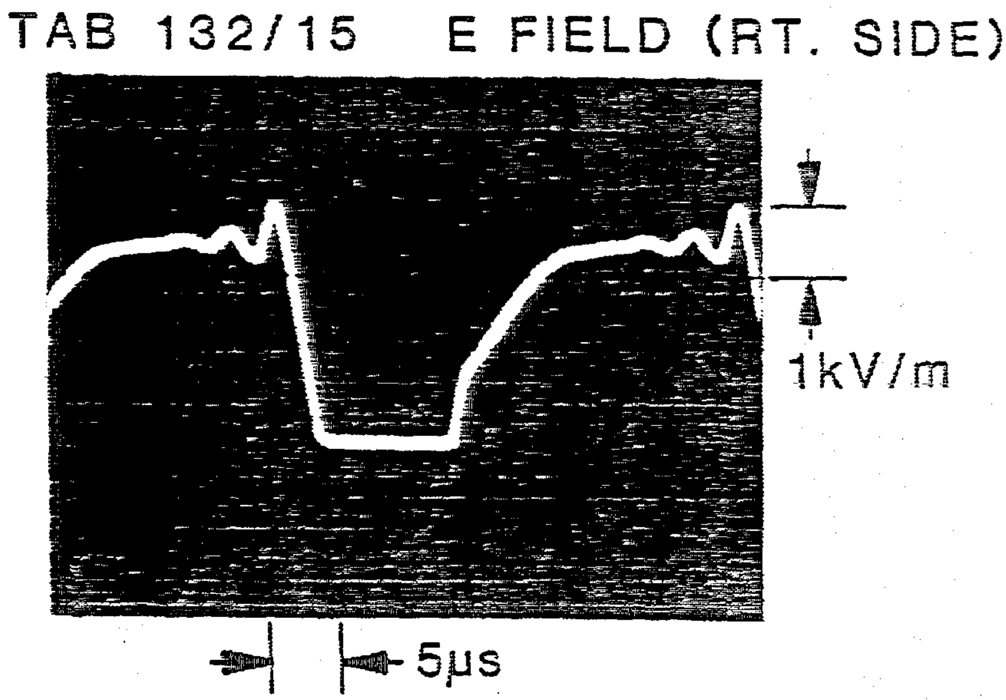


Figure 21. Maximum E field recorded from right side of TAB 132/15 terminal (peak-to-peak and rms values are 3 kV/m and 1.55 kV/m respectively)

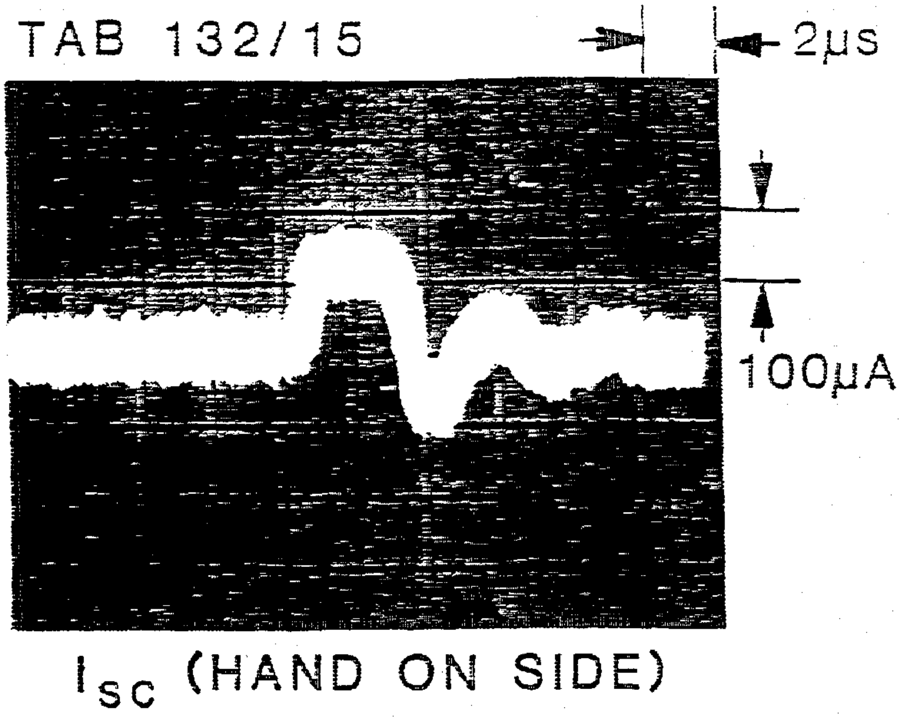


Figure 22. Recorded E-field induced current waveshape from body-to-ground of an exposed male with hand in contact with the right side of TAB 132/15 terminal (peak-to-peak and rms values are 200 and 40 uA respectively)

Figure 23. Measurement of maximum E-field induced body-to-ground current (hand closest to flyback transformer)

Figure 24. Measurement of body-to-ground current with finger contacting screen

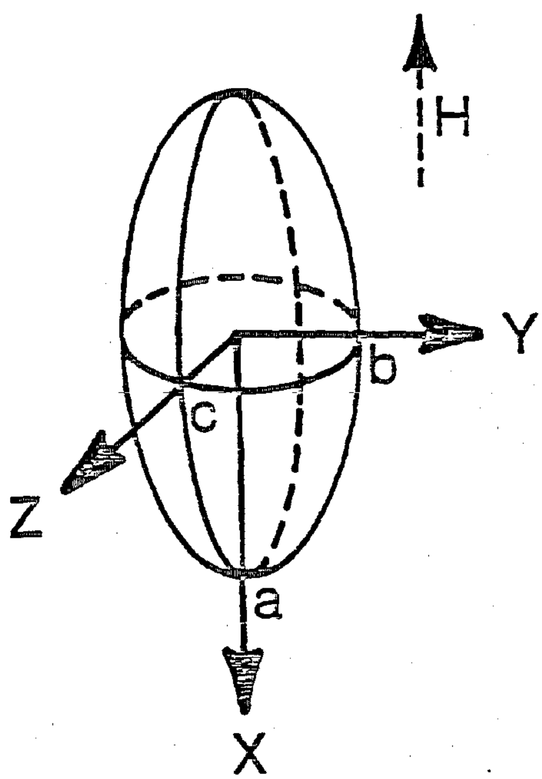


Figure 25. Ellipsoid geometry for calculating magnetic field induced currents