# An Evaluation of Induced Body Current and Contact Current Reduction Effectiveness with the KW-GARD™ RF Protective Suit at a High Power AM Radio Broadcast Transmitter Site

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# An Evaluation of Induced Body Current and Contact Current Reduction Effectiveness with the KW-GARD™ RF Protective Suit at a High Power AM Radio Broadcast Transmitter Site

The KW-GARD™ RF protective suit has been evaluated for its ability to reduce radiofrequency (RF) energy absorption in the body of full-sized, human phantom models exposed to strong RF near-field conditions. Those tests have validated the suit's ability to substantially mitigate worker exposures to RF fields in terms of specific absorption rates (SARs). While the basis of almost all present-day RF protection standards is limiting the SAR, as averaged over the body mass, to a prescribed value, some standards, such at the recommendations of the Institute of Electrical and Electronics Engineers (IEEE) contained in ANSI/IEEE C95.1-1992, also include maximum permissible exposure limits in terms of the magnitude of induced body currents and contact currents. This report documents field testing of the KW-GARD™ suit to evaluate its ability to also mitigate induced body currents and contact currents during RF exposure at a high power AM radio broadcast transmitter site.

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:

$$SAR = \frac{J^2}{s\,r}(W / kg)$$

where
SAR is the specific absorption rate in units of watts per kilogram (W/kg);
$\sigma$ is the tissue conductivity in units of siemens per meter (S/m);
$\rho$ is the mass density of the tissue (kg/m$^3$);
J is the local current density in units of amperes per square meter (A/m$^2$);

The ANSI/IEEE standard specifies a maximum current of 100 milliamperes (mA) through each foot or a total current of 200 mA through both feet together for RF exposure to workers in a controlled environment. This limit applies, in the present standard, up to a frequency of 100 MHz. A current of 100 mA flowing through the conductive cross-section of the ankle will result in a local SAR of about 17 W/kg.

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 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 100 mA is essentially the same as for the ankle. So, compliance with the RF exposure limits imposed by the ANSI/IEEE standard requires not only exposure mitigation in terms of SAR within the body but also mitigation of possible induced body currents and contact currents.

The ability of the KW-GARD™ suit to mitigate these currents was explored through a practical approach at a high power AM radio station broadcast site near Las Vegas, Nevada. This site is the location of KVEG, a 50 kW AM radio station that serves the Las Vegas area during the day with a directional antenna pattern and operates on a frequency of 840 kHz. During night-time hours, KVEG operates with the same directional radiation pattern but with 25 kW of power.

A direct measurement method was used at the KVEG site since it is representative of many high-power AM radio broadcast sites and it was easy to gain access to the areas needed for testing. Two different locations at the site were used for the measurements, one for induced body current and another for contact current.

Induced body currents were investigated at a point approximately15 feet from tower 2 as seen in Figure 1. This point was located approximately 6 feet outside the periphery of a tall chain-link fence used to restrict access to the immediate base of the antenna tower. RF fields at the point where induced body current measurements were performed were found to be in the range of 65 to 100 volts per meter (V/m) from the ground surface to six feet in height. Electric fields were measured with an Instruments for Industry, Inc. Model EFS-1 electric field strength meter (SN 1705-F). This instrument has an essentially flat frequency response between 10 kHz and 220 MHz. The electric field strength was found to be weaker nearer the metal chain-link fence due to the shielding effect of the fence; the fence provides a surface along the top edge where strong RF electric fields terminate due to the much lower potential on the fence (it is grounded), thereby reducing the density of electric fields just outside the fence. The electric field increases with distance from the fence as the fence becomes less effective in shielding until a peak in the field exists, where after the field decreases with additional distance. By exploring the spatial variation of electric fields with the EFS-1 meter, the point of maximum field strength was selected for subsequent induced current testing.

RF fields were evaluated by holding the EFS-1 at arms length away from the body and observing the indicated field strength at different heights above ground. At the location selected for induced current testing, it was found that the vertical polarization component of the field was essentially uniform in strength at 65 V/m from the ground surface up to approximately waist height. From waist height to head height the field was found to increase approximately linearly up to a value of 100 V/m.

At this point, induced body current (ankle current in the left ankle) was measured with the 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). Measurements of ankle currents were performed without and with the KW-GARD™ suit on the exposed subject. Figure 2 shows the subject standing at the point where body current was measured with the current probe around the left ankle region. Work boots, manufactured by Alp, with 5/8th inch thick oil resistant soles (1 inch thick heels) were worn during all of the induced and contact current measurements.

As a test of the potential for interference with the operation of the induced current meter that might be caused by the strong RF fields, the HI-3702 current probe was removed from the ankle of the exposed subject and laid on the ground where the field measurements and induced body current measurements were made. At the location where body current was measured on the subject in the field, a reading of 0.8 mA was measured with the meter removed from the ankle.

To evaluate the KW-GARD™ suit's effectiveness, a suit with special modifications was made that could accommodate the size of the Model HI-3702 current probe. The method used for the measurement was to place the current probe around the ankle and then to bring the enlarged conductive sock up and over the outside of the current probe assembly (see Figure 3). Velcro™ straps were used in an attempt to support the current probe slightly above the ankle to provide for more contact area between the lower pant leg and the sock at the ankle. This was accomplished by cinching the top of the enlarged sock tightly around the upper calf to help hold the current probe above the ankle (see Figure 4). Next, the pant leg of the suit was dressed down over the conductive sock and cinched against the sock at the lower ankle area (see Figure 5). A small hole was made in the side of the sock to accommodate the two fiber optic cables that connect the HI-3702 probe with the associated readout module. With the subject facing the AM radio tower, a maximum induced body current of 6.08 mA was measured without the KW-GARD™ suit on the subject. This value was obtained by making use of the maximum hold feature on the HI-4416 readout module and allowing the meter to acquire readings of induced current over a period of approximately 30 seconds during which peaks in current could be noted due to the amplitude modulation of the station's signal. This measurement was repeated several times by moving away from this spot and then resuming the same position and noting the indicated current. Under this repetition scenario, the measured maximum body current was found to vary by approximately 0.15 mA.

When the induced body current reading was repeated with the KW-GARD™ suit on the subject, the maximum current was found to be 1.60 mA at the same location. By removing the current probe from inside the sock to outside the sock, but with the suit still on the subject, the induced current increased to 6.85 mA.

These results indicate that wearing the KW-GARD™ suit, with supplied conductive socks, can, if the suit is worn properly, provide a reduction in induced body currents at frequencies as low as 840 kHz. The actual reduction observed in body current was 3.80 times relative to the unmitigated value without the suit and socks. Since SAR is proportional to the square of the current density, this corresponds to an SAR reduction of 14.4 times or 11.6 dB in the ankle.

Contact currents were obtained by grasping a guy wire attached to the southwest leg of tower 2 at the KVEG antenna site. The clamp-on current probe was placed around the forearm to measure the contact current. Different contact currents could be observed depending on the exact location along the guy wire that was grasped. A specific location was selected which resulted in approximately 25 mA of contact current for all of the measurements conducted as a part of this study.[1] Figure 6 shows the subject grasping the guy wire used for these measurements. With the current meter around the forearm, wrist currents were measured for several conditions including (a) without any glove on the hand, (b) with the KW-GARD™ suit plus conductive gloves and socks and (c) with the KW-GARD™ suit with the gloves and socks with the addition of an outer work glove. A special pair of conductive gloves were fabricated for this test that were substantially enlarged to accommodate the diameter of the Holaday Industries current probe. Figure 7 shows how the fiber optic leads for the remote readout module were brought through the glove for connection to the meter. The results of these measurements are summarized below.

| **Summary of Contact Current Guy-wire Measurements at the KVEG AM Radio Broadcast Station Transmitter Site with and without the KW-GARD™ suit and Conductive Gloves and Socks** | |
|---|---|
| Condition | Contact current (mA) |
| Bare wire, no gloves of any kind | 25 |
| With KW-GARD™ suit, gloves and socks | 3.51 |
| With KW-GARD™ suit, gloves and socks with addition of conventional work gloves | 3.50 |

These data indicate that the conductive gloves used with the KW-GARD™ suit and conductive socks resulted in a very substantial reduction in contact current under the conditions of the test. The actual reduction was 7.12 times which corresponds to an SAR reduction in the wrist of 50.7 times or 17.1 dB. The addition of conventional work gloves had virtually no effect on further reducing the contact current.

The observations obtained from these measurements support the contention that the KW-GARD™ RF protective suit, when worn with the provided conductive socks and gloves, can provide considerable reduction in the magnitude of both induced body currents and contact currents when used in an 840 kHz AM radio broadcast environment. An important insight associated with these measurements was the necessity of a good degree of contact between the pant leg and conductive sock, for reducing body current, and between the sleeve and conductive glove, for reducing contact current. Based on observations during the various measurements, it was found that a substantial overlap of

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[1] It should be noted that in preliminary measurements at the site, it was found that the measured contact current was as great as 106 mA when the subject was wearing rubber soled tennis shoes.

the pant leg material, or sleeve material, and the upper part of the sock or glove, as well as a snug fit, was important to realize the measured current reductions. The KW-GARD™ suit cannot reduce either induced body currents or contact currents if the electrical bond between the garment and the socks and gloves is not sufficient. This was realized during the tests by using Velcro™ straps to cinch the outer garment fabric to the underlying sock or glove material. The pant leg and sleeve must be firmly cinched to ensure a sufficient electrical bond.

The induced body current reduction found in this study may not indicate the full capacity of the suit to reduce these currents. The nature of the special suit that was fabricated just for these tests did not provide sufficient leg length to affect as complete an overlap area as was possible for the sleeve during the contact current tests. Hence, the area of the pant leg that was able to be securely cinched against the underlying sock was not as great and this may have accounted for the lesser noted reduction in body current when compared with the contact current measurement.

It is important to note that the KW-GARD™ suit is composed of a highly conductive fabric that contains approximately 25% stainless steel in the form of fine filaments. The fabric is conductive on its surface and continuity can be measured across the material. The potential difference between the guy wire, for contact current measurements, and the body of the subject was sufficient to result in small electrical arcs between the wire and the surface of the fingers just before contacting the wire. These arcs carry the potential to cause point RF burns on the skin, particularly if the wire is not quickly grasped. For example, if the bare hand is drug loosely across the wire, a flurry of sparks, and resulting pin point burns would result. It was observed that when wearing the conductive glove, the sparks, during the arcing process from the wire to the glove surface, could lead to burning of the glove material at those points. While the physical sensation of the burn was significantly reduced by the presence of the KW-GARD™ glove, these burns ultimately led to small holes in the glove that left the bare skin exposed. Figure 9 illustrates this observation with a small electrical arc occurring and a separate hole on the adjacent knuckle that had previously resulted from such an arc. When conventional leather work gloves were worn over the KW-GARD™ conductive gloves, no sparking or burning was noted. These observations suggest that, as is true in any high voltage RF environment, care must be used in approaching energized conductors to avoid surface arcing and RF burns. It appears that, at least for moderate conditions of potential RF burns, the use of leather work gloves can mitigate the impact of surface arcing while the KW-GARD™ gloves mitigate the contact current flowing in the arm and wrist.

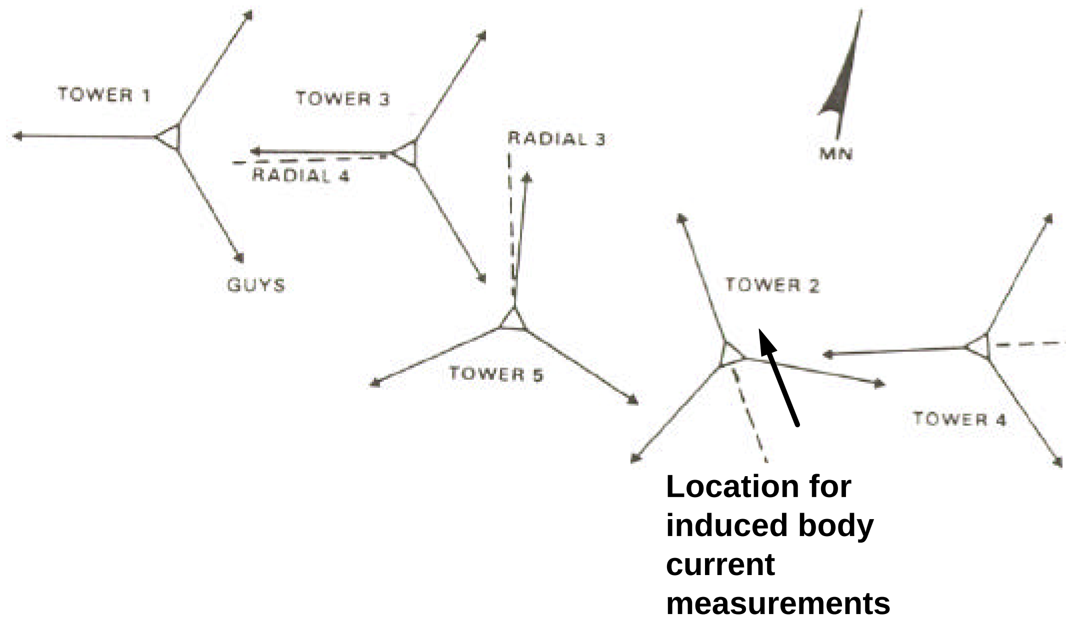


**Figure 1.** Induced body current measurements were performed near tower 2 at the KVEG AM radio facility located near Las Vegas. Tower 2 produces the highest RF field strength on the site.

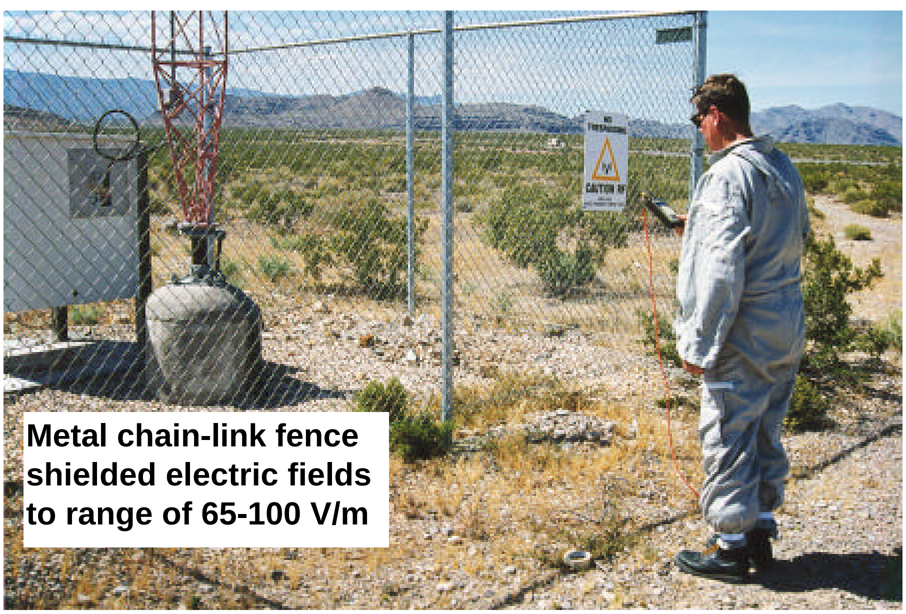


**Figure 2.** Holaday Industries Model HI-3702 clamp-on current probe was placed around the left ankle region to measure induced body current. The remote readout module is fiber optically coupled to the current probe to avoid RF interference and distortion in current measurements.

**Figure 3.** The current probe was placed around the ankle but beneath the conductive sock to measure the body current flowing in the ankle as opposed to the current flowing in the suit fabric.

**Figure 4.** Velcro™ straps were used to bind the upper portion of the special sock to the calf to help support the current probe just above the ankle. The fiber optic leads were routed through a small hole in the conductive sock.


**Figure 5.** After attaching the current probe around the ankle and bringing the conductive sock up and over the probe, the KW-GARD™ pant leg was then brought down over the sock and probe and strapped to the conductive sock just above the top of the shoe using Velcro™ straps to form an electrical bond between the suit and the sock.

**Figure 6.** Contact currents were measured at the base of a guy anchor by grasping one of the guy wires that resulted in the maximum current.

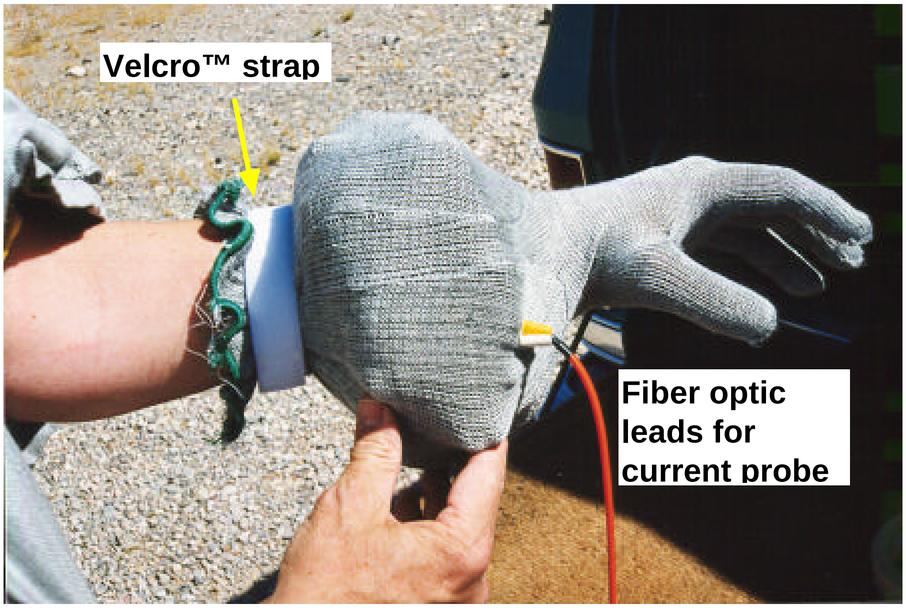


**Figure 7.** The enlarged conductive glove was brought up and over the current probe and then cinched tightly to the fore arm prior to bringing the sleeve down and over the glove.

**Figure 8.** The fiber optic leads were placed through a small hole in the knit fabric of the conductive glove to allow connection to the Holaday Industries clamp-on current probe.

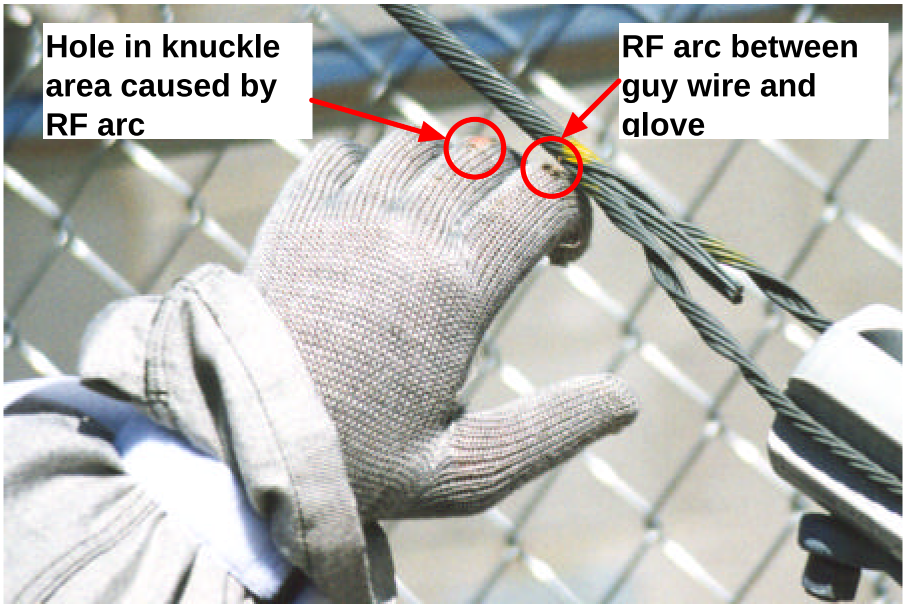


**Figure 9.** When the hand was raised near the guy wire, small electrical arcs occurred just before contact. In this photograph, the hand was purposely held near the wire in an attempt to sustain an arc. The arc resulted in immediate burning of the glove material, first turning it black and then forming small holes in the material as illustrated above.