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

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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 VHF and UHF 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:

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

where
SAR is the specific absorption rate in units of watts per kilogram (W/kg);
σ is the tissue conductivity in units of seimens per meter (S/m);
ρ 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 for 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 large broadcast site on Tucson Mountain west of Tucson, Arizona. Twelve broadcast stations, including six high-power FM radio stations and six VHF and UHF television (TV) stations, operate from this site including the following:

Summary of broadcast stations operating from Tucson Mountain, Tucson, Arizona			
Call sign	FM or TV	Frequency (MHz)/Channel	Effective radiated power (kW)
KWFM*	FM	92.9	93
KIIM*	FM	99.5	93
KMXZ*	FM	94.9	100
KLPX*	FM	96.1	100
KHYT	FM	107.5	92
KRQQ	FM	93.7	94
KOLD	TV	13	302
K56ED	TV	56	13.8
K65FO	TV	65	1.0
KHRR	TV	40	1550
KTTU	TV	18	2510
KTVW	TV	52	17.7

A direct measurement method was used at the Tucson site since this kind of site is representative of many high-level RF sites where RF protective clothing may be used. Two different locations at the site were used for the measurements, one for the induced body current and another for contact currents.

Induced body currents were investigated at a point approximately 20 feet from a tower supporting four of the above FM radio stations designated with a asterisk. Figure 1 shows the bottom most elements of the FM antennas on the tower. Each antenna of the four FM stations was an eight element array. The lowest antenna elements on the tower are 25.6 feet above the ground. Relatively strong RF fields exist in this region and at the point where the induced body current was measured, measurements of the field levels were obtained with a Narda Model 8742 broadband, isotropic electric field probe (SN 03005) connected to a Narda Model 8718 digital electromagnetic field survey meter (SN 01592). The Model 8742 field probe is designed to measure RF fields over the frequency range of 300 kHz to 2.7 GHz and possesses a shaped frequency response that causes the probe to produce an output indication directly in terms of a percentage of the maximum permissible exposure (MPE) limit set by the ANSI/IEEE C95.1-1992 standard.

RF fields were evaluated in terms of the peak value and spatially averaged value obtained over a six-foot vertical height centered over the point where the induced body current measurements were taken. To more completely evaluate the exposure, measurements were performed by facing each of four directions relative to the point.

At this point, induced body current (ankle current in the left ankle) was measured with use of 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. The body orientation corresponding to the maximum indicated induced current without the suit on was determined and used for the comparison measurements. Figure 2 illustrates the placement of the current probe around the 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. The results of these measurements are summarized below.

Summary of RF Field Measurements and Induced Currents Without KW-GARD™ Suit

	RF field level (% of MPE for workers)		
Facing direction	Spatial average	Spatial maximum	Ankle current (mA)
East	131	248	86
South	106	211	44
West	102	159	64
North	71.3	103	109

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 metal walkway surface where the field measurements and induced body current measurements (above) were made. In the configuration where 109 mA of body current was measured on the subject in the field, a reading of 4.9 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). Tape was 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 (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 North, the orientation associated with the maximum induced body current, an induced body current of 17 mA was measured with the KW-GARD™ suit on the subject. The measurement was repeated several times by moving away from this spot and then resuming the same position and noting the indicated current. The suit and conductive socks were subsequently removed and the body current was once again measured to verify the non-suit condition of 109 ± 2 mA.

These results indicate that wearing the KW-GARD™ suit, with supplied conductive socks, can, if the suit is worn properly, provide substantial reduction in the induced body current for RF fields at approximately 100 MHz. The actual reduction observed in body current was 6.41 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 41.1 times or 16.1 dB.

Contact currents were obtained by grasping a guy wire attached to one of the six towers at the site that was accessible from a building rooftop. 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 100 mA of contact current for all of the measurements conducted as a part of this study. With the current meter around the forearm, wrist currents were measured for several conditions including (a) without any glove on the hand, (b) with a conventional leather palmed-canvas backed work glove (see Figure 6), (c) with the KW-GARD™ suit plus conductive gloves and socks and (d) with the suit, gloves and socks with the addition of the 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 the arrangement of bringing the conductive glove up and over the current probe before bringing the sleeve down over the probe and glove. Figure 8 illustrates the final configuration with the sleeve over the probe and glove as used during the contact current measurement. The results of these measurements are summarized below.

Summary of Contact Current Guy-wire Measurements at the Tucson Mountain Site with and without the KW-GARD™ suit and Conductive Gloves and Socks	
Condition	Contact current (mA)
Bare wire, no gloves of any kind	111
Conventional work glove	110
With KW-GARD™ suit, gloves and socks	7.2
With KW-GARD™ suit, gloves and socks with addition of conventional work gloves	7.0

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 15.4 times which corresponds to an SAR reduction in the wrist of 238 times or 23.8 dB.

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 a VHF/UHF 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 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 taping the outer garment fabric to the underlying sock or glove material through a firm wrapping with two-inch wide tape. 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.

Figure 1. Induced body current measurements were performed near a tower supporting four high-power FM radio stations. Lowest element of the four antennas was 25.6 feet above ground.

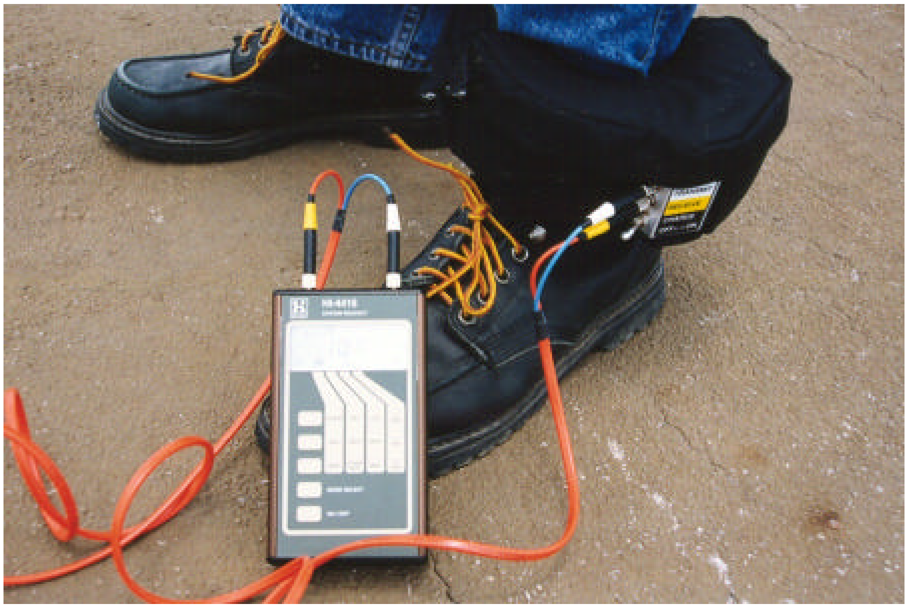

Figure 2. Holaday Industries Model HI-3702 clamp-on current probe was placed around the ankle region to measure induced body current. The remote readout module is fiber optically coupled to the current probe to avoid RF interference and distortion in current measurements.

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. Nonconductive tape was used 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 taped to the conductive sock just above the top of the shoe to form an electrical bond between the suit and the sock.

Figure 6. Grasping a guy wire with a conventional work glove and measuring the contact current flowing in the arm with the Holaday Industries clamp-on current probe.

Figure 7. The conductive glove was brought up and over the current probe to allow the probe to measure the contact current flowing in the wrist and arm.

Figure 8. The sleeve of the KW-GARD™ suit was brought down and over the glove region and taped to form an electrical bond between the sleeve and glove.