Review 3-81

AEROMEDICAL REVIEW

PROCEEDINGS OF A WORKSHOP ON THE PROTECTION OF PERSONNEL AGAINST RADIOFREQUENCY ELECTROMAGNETIC RADIATION

Research Study Group 2, Panel VIII
Defence Research Group, NATO

Editor: John C. Mitchell, B.S. (USAFSAM/RZP)

September 1981

USAF SCHOOL OF AEROSPACE MEDICINE
Aerospace Medical Division (AFSC)
Brooks Air Force Base, Texas 78235

RADIOFREQUENCY BURN HAZARDS IN THE MF/HF BAND

S. J. Rogers*

*Head of Radiation Hazards Section
Admiralty Surface Weapons Establishment (ASWE)
United Kingdom

1. INTRODUCTION

When a person touches an electrically energised object, he may experience an adverse effect. If the object is energised by a radio-frequency (**rf**) source, the predominant contact hazard is burning of tissue at the point of contact and arises when the current drawn from the object exceeds a certain value. This rf burn hazard exists on various transmitting aerials and simple precautions can be taken to avoid it. However, such a hazard can also arise on metallic objects excited by radiation from transmitting aerials in their vicinity and this paper is devoted to this aspect.

The various factors involved in this context combine in such a way that rf burn hazards arise mainly on structures taller than man and irradiated at frequencies in the MF/HF band. Typical shipboard structures of primary interest are wire rigging, boat davits, cranes and helicopters subjected to radiation from neighbouring communications aerials.

Although an rf burn in itself may be insignificant, the reaction to it can result in serious damage to the person and this emphasises the need to take precautionary measures. These can best be taken at the ship design stage by ensuring that there is sufficient separation between transmitting aerials and the structures of concern.

Where sufficient separation cannot be achieved, palliative measures may be taken such as bonding the structure to deck, applying overall insulation to the structure, breaking up the structure with insulators, or replacing the structure with a non-metallic equivalent.

Prevention of rf burn hazards by design is possible if one is able to predict the hazard potential of the metallic structures of concern. At present, prediction is based mainly on data obtained from measurements on existing installations. Some attempts have been made to estimate the minimum safe separations between transmitting aerials and structures by analytical means, but these are confined to simple structures in idealised situations.

The following is a brief description of:

a. the frequency dependence of the level of perception and the sensations produced by current in man

b. the work done to determine an rf burn hazard threshold current in the major band of concern, ie, MF/HF

c. an instrument for measuring the hazard

d. some typical measurement data

e. a simple theoretical analysis of rf burn hazards on monopole-like structures in the presence of radiation from a whip aerial.

2. PERCEPTION CURRENT

As the excitation of a metallic structure is increased, a person in contact with the structure will begin to perceive a sensation when the current passing through the point of contact reaches the so-called perception current level.

Investigations made by Dalziel and Mansfield [1] for frequencies below 200 kHz have shown that perception current is frequency dependent, having a minimum value (in the order of 1 mA) at main's frequencies and increasing with frequency to around 150 mA at 100 kHz for certain contact configurations. They also indicate that the sensation perceived depends on frequency.

2.1 Variation of Sensation with Frequency

An attempt is made in the following table to précis data given in [1] with regard to the sensations produced by cw current when 25–50% in excess of the perception level. The frequency ranges are approximate.

Table 1

	Frequency (Hz)	Sensation
1.	0	Warmth in palm of hand or wrist
2.	5–20	Muscles follow current alternations
3.	20–1000	Tingling or pricking at point of contact
4.	1000–10000	Smoother, softer, less piercing than 3
5.	10K–100K	Less intense than 4 but over larger area
6.	100K–200K	Abrupt change from 5 to internal heating
7.	above 200K	Believed to be only that of heating

2.2 Modulated Currents

The harmonics associated with pulsed currents or currents of irregular waveform range over the above frequency bands and produce effects associated with those bands, but the nerve stimulations produced by the lower harmonics may predominate.

Any rectifying action which occurs in the process of drawing current from a structure excited by modulated radiation may result in the perception current being that appropriate to the modulation frequency.

2.3 Perception Current in the MF/HF Band

Experiments have been carried out at ASWE to determine perception current levels in the MF/HF Band for a contact configuration common to the shipboard situation, i.e., one in which the person is standing on the deck in shoes and making contact with one hand with the excited structure. Contact with the back of the finger was made since this was found to be a more sensitive area than the finger tip. Prior to contact the finger was moistened with saline solution to minimise variations in contact resistance.

Figure 1 shows the experimental arrangement. The person is touching the excited structure (brass tube connected to output of rf generator) with back of forefinger whilst standing on an earthed aluminium plate. The current drawn by the person from the structure is measured near the point of contact by a meter which has been developed for shipboard rf burn hazard measurements.

The meter is shown in Figures 2 and 3 and is simply a current transformer with diode detector and meter in the secondary circuit. The primary circuit is completed when the person holds the brass electrode in contact with the excited structure.

Currents were recorded for 2 conditions - one in which barely perceptible sensation is experienced (perception current) and one in which discomfort was felt (let-go current). A sub-threshold approach was used. The results for 50 persons are presented in Figures 4 and 5, and the latter indicates an approximate average hazard threshold current of 200 mA for the band 2-20 MHz.

It was noted that perception and let-go currents for finger-tip contact were about twice those for back-of-finger contact and even higher for large area contact with the palm. By grasping the excited electrode firmly in the hand it was found that currents of 500 mA or more could be drawn for short periods without discomfort.

It was possible therefore to use the current monitor to measure currents exceeding the hazard threshold, provided the metal handle was firmly grasped in the bare hand. However, universal use of such a monitor poses safety problems.

3. TYPE OF CONTACT BETWEEN MONITOR AND STRUCTURE

In measuring current drawn from excited structures one should ensure that bare metal contact is made between the monitor electrode and the structure so that the maximum possible current is measured, otherwise the current level will be reduced by the capacitance formed between the monitor electrode and the metal surface of the structure.

4. DUMMY MAN

Earlier investigations were made into alternative methods of monitoring current in a way which avoided putting the observer in the circuit. It was found that any device used to simulate man in this context tended to assume the dimensions of man.

A representative dummy is shown in Figure 6 and consists of a cardboard tube (2 m long and 100 mm diameter) coated with Aquadag and terminated at its 'head' with a wide copper strap and at its feet by a thermal ammeter comprising a vacuo-junction and low resistance micro ammeter. This device proved to be very cumbersome in shipboard measurements and was soon discarded in favour of the human body in the interests of convenience and rapidity of measurement.

5. RESULTS OF MEASUREMENTS

Figure 7 shows currents drawn by the body from various parts of a typical whip aerial/base-tuner installation and the effect on them of fitting bonding straps across the resilient mounts supporting the base tuner.

Figure 8 shows whip aerial installations in close proximity to various structures in a shipboard situation, and the currents drawn from these structures at various frequencies are shown in Figure 9. It is seen that rigging wires such as awning and boat davit stays are particularly potent sources of rf burn hazard.

Figure 10 shows currents drawn from the hook of a mobile crane in the proximity of a transmitting whip aerial on a land-based site.

Figure 11 shows currents drawn from the cab door handle of the same crane in similar circumstances.

The vertical electric field and associated magnetic field measured in the absence of the crane are shown in Figures 12 and 13 respectively.

6. PREDICTION OF RF BURN HAZARDS

A schematic circuit of man in contact with an excited structure is shown in Figure 14. Man is depicted as having impedance Z_b on the right of the dotted line, and the structure as having impedance Z_a on the left.

The other parameters required for predicting rf burn hazards on excited structures are the radiation characteristics of the transmitting aerial from which E is determined and the characteristics of the structure as a receiving aerial.

The following analysis is limited to simple monopole-like structures (1 cm diameter) for which the relevant parameters are readily available.

Further simplifying assumptions are:

a. The structure is suspended vertically over a perfect horizontal ground plane.

b. The electric field vector is parallel to the structure.

c. The person bridges the gap between the base of the structure and the ground plane with one hand touching the base and with both feet on the ground plane.

Figure 14 shows that under these conditions the voltage (V) across the gap due to the incident electric field (E) is given by

$$e = Eh = I(Z_a + Z_b) \quad \text{-------------} \quad 1$$

Where h = effective height of structure
I = current drawn by person from the structure
Z_a = impedance of structure
Z_b = impedance of body measured between hand and feet

6.1 Effective Height of Structure

The effective height of the monopole type structure was estimated using information given by KING and HARRISON [2].

6.2 Aerial Impedance of Structure

Values of radiation resistance (R_a) and reactance (X_a) for monopole structures of various heights (H) and diameter of 1 cm were determined from graphs given in [3].

6.3 Body Impedance (Z_b)

The impedances of 15 persons were measured using an rf bridge arranged as shown in Figure 15. The ground plane used was a 3-ft-wide aluminium sheet bent up as shown to form the connection to the ground terminal of the bridge. Contact was made between the back of the forefinger and a tubular electrode connected to the other terminal of the bridge.

The person operating the bridge was positioned on the opposite side of the bench away from the subject. The results of the measurements are shown in Figures 16, 17, and 18 with upper and lower limits being indicated by the curves.

6.4 Maximum Safe Permitted Field Strength for the Structure

By substituting the hazard threshold value for current of 0.2 A in equation 1 and re-arranging, the maximum safe permitted field strength for the structure is given by

$$E = (0.2/h)(Z_a + Z_b) \quad \text{-------------- 2}$$

Values of E are plotted in Figure 19 for 1 cm diameter wires using lowest (worst case) values of Z_b.

As shown, the value of E required for rf burn hazard decreases uniformly as H increases up to about $\lambda/4$. Beyond this height E reaches a first minimum for $H \approx \lambda/3$, a first maximum for $H \approx 0.43\ \lambda$, a second minimum for $H \approx \lambda/2$ and so on.

The worst case field strength required for rf burn hazard in the frequency band 2-24 MHz is given by the dot-dash curve and the lower limb of the 24 MHz curve.

6.5 Calculation of the Minimum Safe Separation between Structure and Aerial

The curves in Figure 19 can be used to determine the minimum safe distance to be maintained between wires of 1 cm diameter and transmitting aerials provided the field strength characteristics of the latter are known or can be calculated.

Figure 20 shows the minimum safe separations between such wires and whip aerials based on measured field strengths and the worst case (dash-dot) curve shown in Figure 19. The worst case minimum safe distance for a wire of given height is indicated in Figure 20 by the dash-dot curve.

It is interesting to note that the measured minimum safe distance for the crane referred to earlier is about 3 times the height of its hoist wire which is that predicted by the dash-dot curve in Figure 20. This may be coincidental. However, simple theory suggests that for a monopole-type structure the minimum safe distance for the structure from a transmitting whip aerial is independent of the girth of the structure when the height of the structure is an integral number of quarter wavelengths.

7. CONCLUSIONS

The measurements described indicate an rf burn hazard threshold of about 200 mA for the HF Band and show that many shipboard structures can be excited sufficiently by own ship transmissions in this band to present rf burn hazards to personnel. They show also that cranes can be potent sources of rf burn hazards.

The simple method described for predicting rf burn hazards appears to be corroborated by the measurements on the crane, but much more practical data on various related structures is necessary to establish its validity.

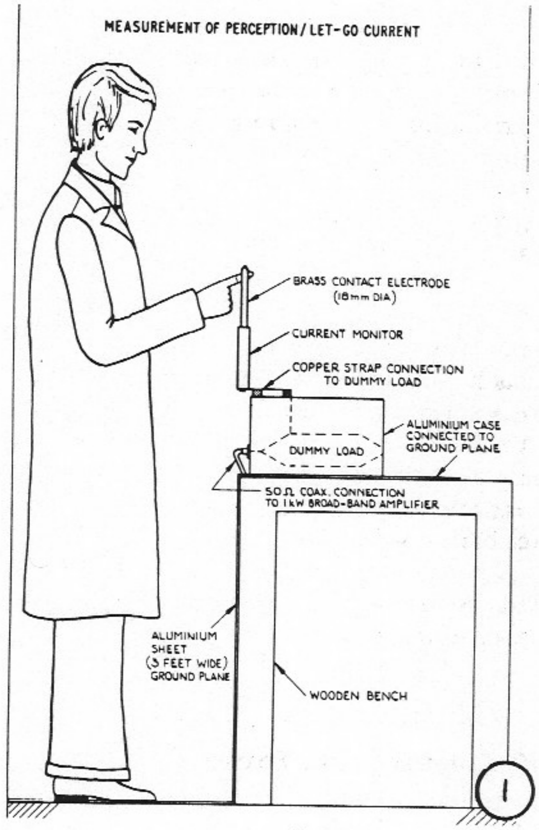
Further work is required to define prediction techniques for more complex structures and to design a safe measuring instrument for gathering corroborative data.

It is to be noted that rf burn hazards are present on structures when irradiated at field strengths much lower than the maximum permissible for human exposure. For example the measurements on the crane reported above show that the electric field for rf burn hazard threshold is about 10 V/m compared, for example, to the 630–63 V/m exposure limit being considered by the American National Standards Institute for the band 3–30 MHz.

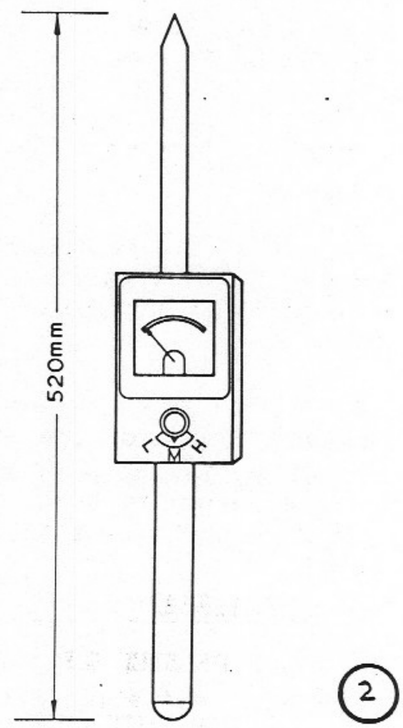
In this regard rf burn hazards should receive the same respect as rf radiation hazards to flammables and electro-explosive devices.

8. References

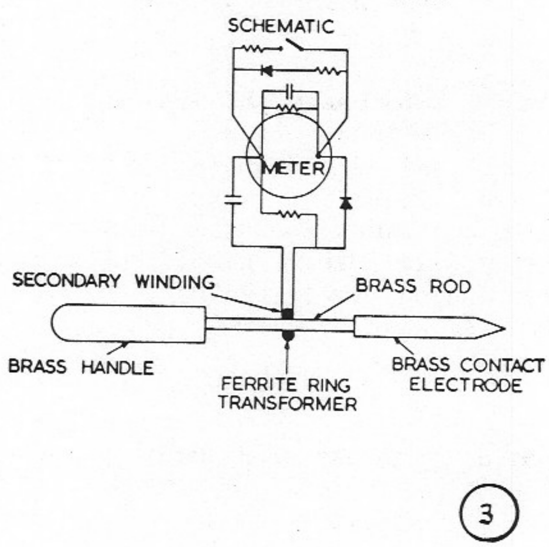
1. DALZIEL C F, MANSFIELD T H — "Effect of frequency on Perception Currents" AIEE Trans Vol 69 Pt II (1950) pp 1162–68
2. KING R, HARRISON C W — "The Receiving Antenna" PROC IRE Vol 32 No 1 (1944) pp 18–34
3. JORDAN E C — Electromagnetic Waves and Radiating Systems Prentice-Hall (1950).



RF BURN HAZARD METER



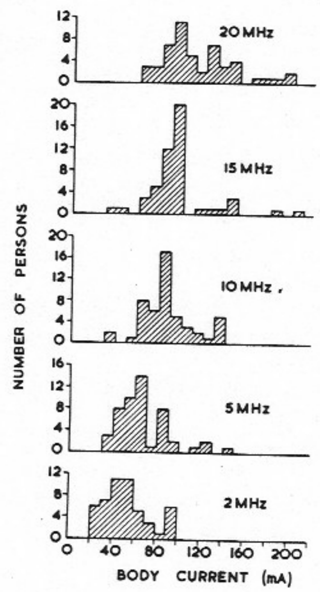
RF BURN HAZARD METER



PERCEPTION CURRENT LEVELS vs. FREQUENCY

CONTACT – BACK OF FOREFINGER ON 18mm DIAMETER BRASS TUBE

50 PERSONS

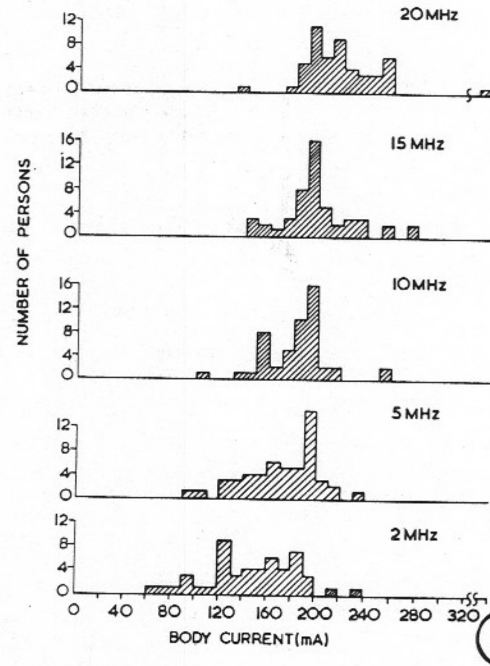


4

LET–GO CURRENT LEVELS vs. FREQUENCY

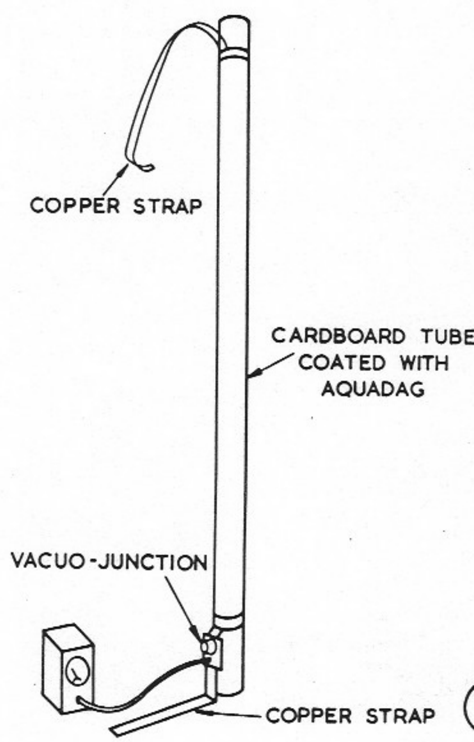
CONTACT – BACK OF FOREFINGER ON 18mm. DIAMETER BRASS TUBE

50 PERSONS



5

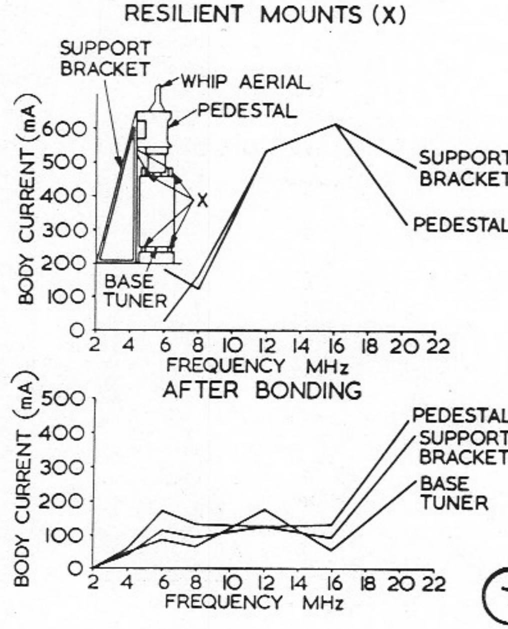
DUMMY MAN



6

VARIATIONS WITH FREQUENCY OF CURRENT DRAWN BY BODY FROM WHIP AERIAL INSTALLATION

PRIOR TO BONDING ACROSS RESILIENT MOUNTS (X)

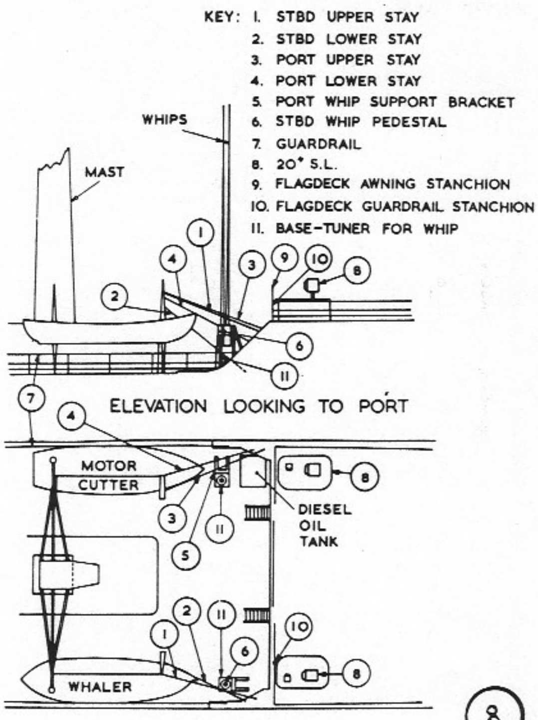


7

CONTACT AREA ON BACK OF FOREFINGER WITH 18mm → DIA ROD, R. TELL

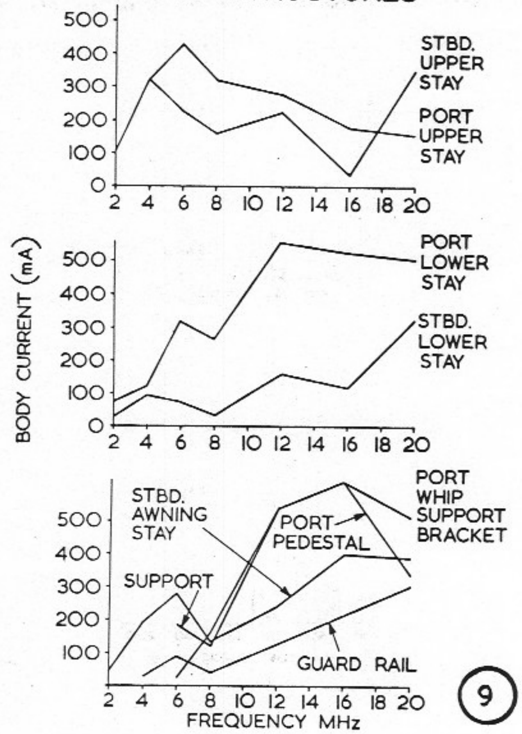
$A \sim 1.13\,cm^2$

WHIP AERIAL INSTALLATIONS AND STRUCTURES AT RISK TO RF BURN HAZARDS



8

VARIATION WITH FREQUENCY OF CURRENT DRAWN BY BODY FROM VARIOUS STRUCTURES

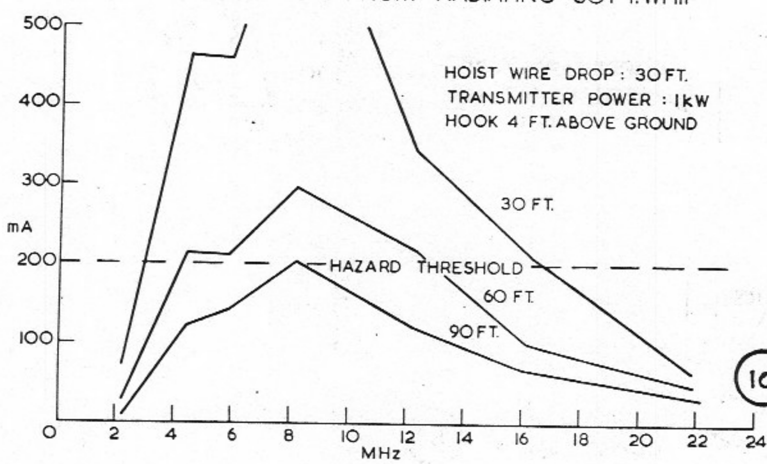


9

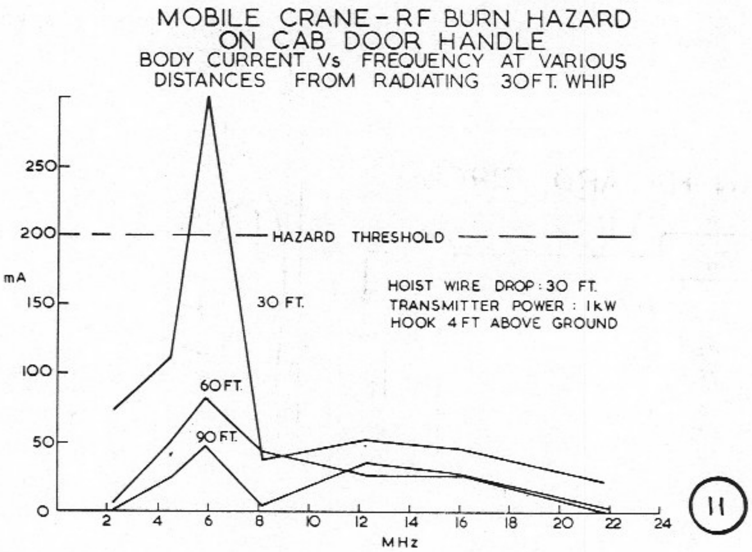
MOBILE CRANE - RF BURN HAZARD ON HOOK

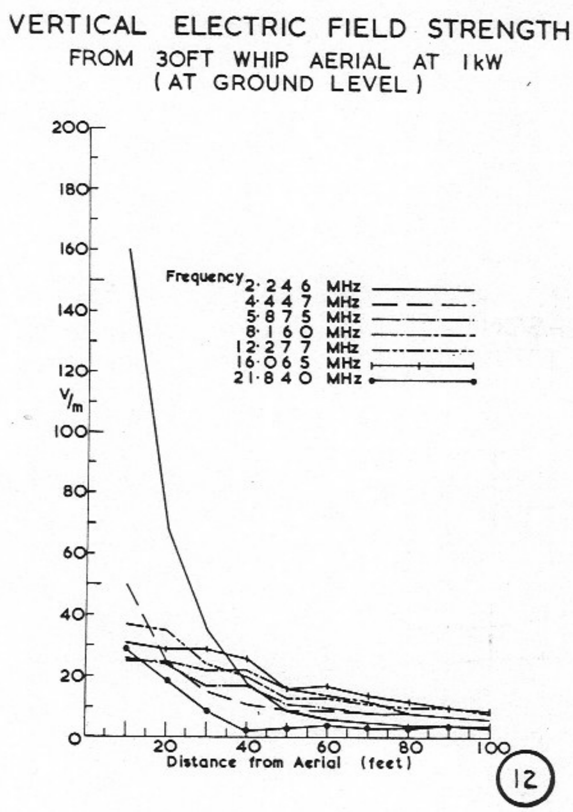
BODY CURRENT Vs FREQUENCY

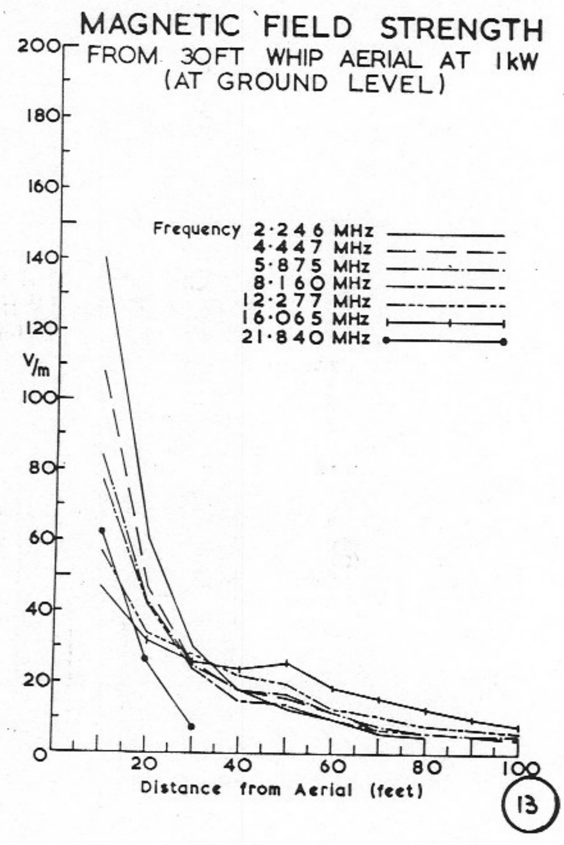
AT VARIOUS DISTANCES FROM RADIATING 30 FT. WHIP



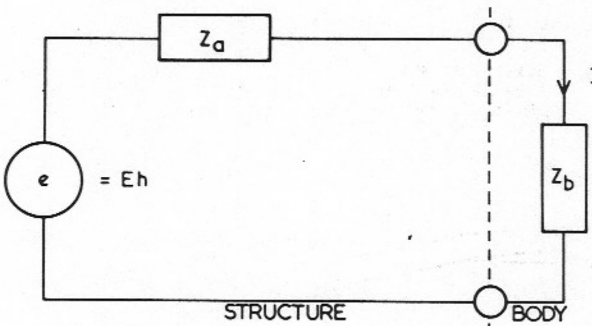
10


MOBILE CRANE - RF BURN HAZARD
ON CAB DOOR HANDLE
BODY CURRENT Vs FREQUENCY AT VARIOUS
DISTANCES FROM RADIATING 30FT. WHIP
mA
HAZARD THRESHOLD
HOIST WIRE DROP: 30 FT.
TRANSMITTER POWER: 1kW
HOOK 4FT ABOVE GROUND
30 FT.
60 FT.
90 FT.
MHz
11


VERTICAL ELECTRIC FIELD STRENGTH
FROM 30FT WHIP AERIAL AT 1kW
(AT GROUND LEVEL)
V/m
Frequency 2·246 MHz
4·447 MHz
5·875 MHz
8·160 MHz
12·277 MHz
16·065 MHz
21·840 MHz
Distance from Aerial (feet)
12


MAGNETIC FIELD STRENGTH
FROM 30FT WHIP AERIAL AT 1kW
(AT GROUND LEVEL)
V/m
Frequency 2·246 MHz
4·447 MHz
5·875 MHz
8·160 MHz
12·277 MHz
16·065 MHz
21·840 MHz
Distance from Aerial (feet)
13

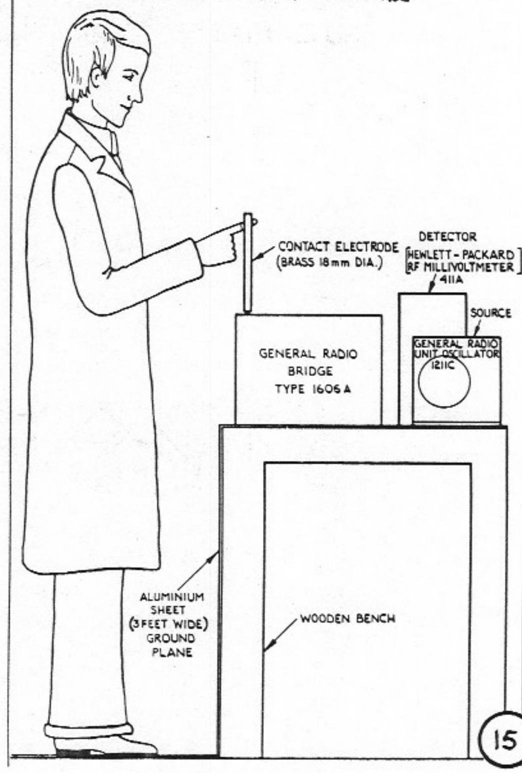
RF BURN HAZARD CIRCUIT



E = Electric field strength $= (I/h)(Z_a + Z_b)$
h = Effective height of structure
Z_a = Impedance of structure
Z_b = Impedance of body
I = Body current

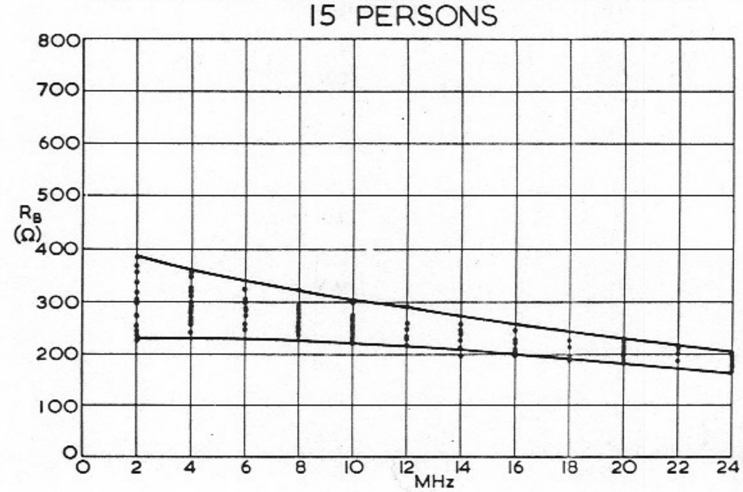
(14)

MEASUREMENT OF BODY IMPEDANCE



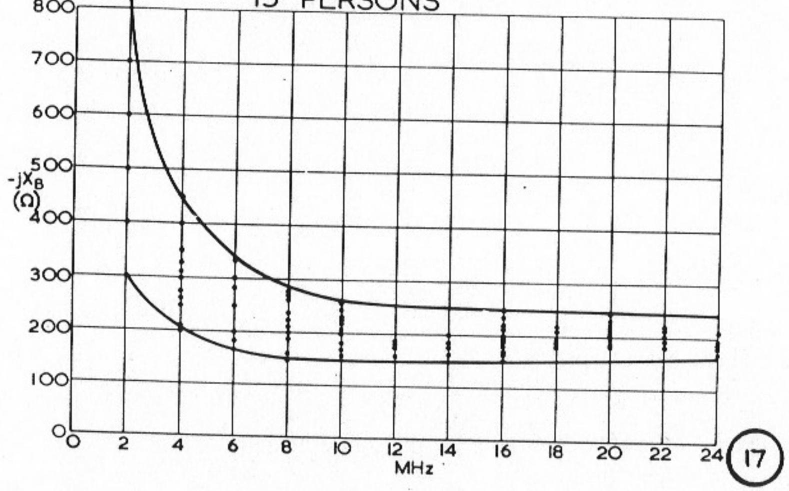
(15)

RESISTANCE OF HUMAN BODY (R_B) vs FREQUENCY MEASURED BETWEEN HAND AND FEET 15 PERSONS

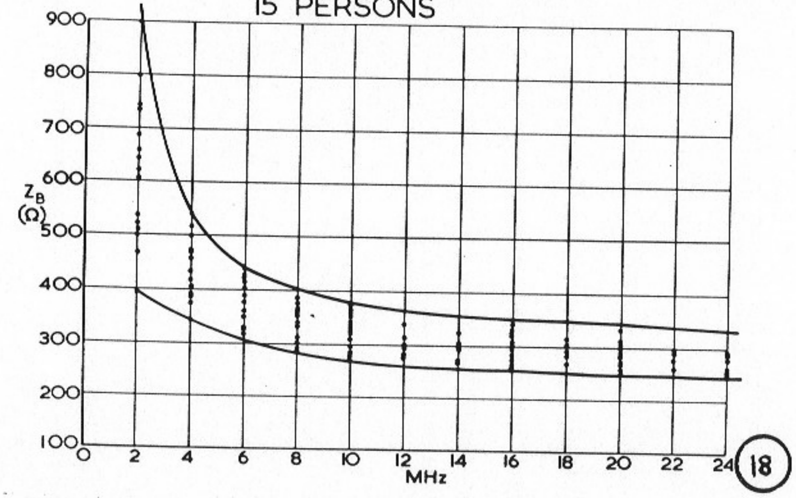


(16)

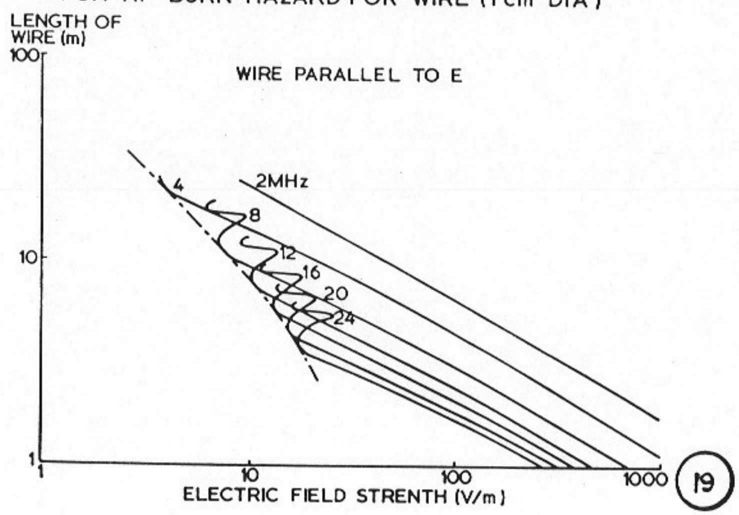
REACTANCE OF HUMAN BODY (X_B) vs FREQUENCY MEASURED BETWEEN HAND AND FEET 15 PERSONS



IMPEDANCE OF HUMAN BODY (Z_B) vs FREQUENCY BETWEEN HAND AND FEET 15 PERSONS



MINIMUM ELECTRIC FIELD (E) FOR RF BURN HAZARD FOR WIRE (1 cm DIA)



MINIMUM SAFE DISTANCE FOR VERTICAL WIRES FROM TRANSMITTING WHIP AERIAL

WIRE DIAMETER = 1 cm
Tx POWER = 1 kW