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# TECHNICAL REPORT

## U. S. NAVAL APPLIED SCIENCE LABORATORY

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DEVELOPMENT OF
RAD HAZ SUIT
AND
RF MEASURING TECHNIQUES

SF 013-15-04, TASK 2162
LAB. PROJECT 9400-20, PROGRESS REPORT 1

27 MAY 1965

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## SUMMARY

The Navy is increasingly concerned with the rapid increase in hazardous RF environmental areas on ships and at shore installations. This has necessitated the development of protective devices for personnel required to operate in these areas. A prototype RAD HAZ suit to be worn by personnel has been developed through the joint efforts of NSRDF and NAVAPLSCIENLAB. In the process of evaluating fabrics for the suit the Laboratory established low and high-power rf facilities, measurement procedures, and developed new techniques for conductivity measurements and insertion loss calculations. The latter enabled attenuation measurements to be made in the near field of receiving antennas.

The silverized nylon "lino" material used in the suit withstood laundering, dry cleaning, weathering, abrasion and open sea environments without degradation of rf attenuation properties. The suit provided a minimum of 25db attenuation for low-power fields at 5.2kmc (minimum of 30db at 425Mc) and better than 20db for high-power fields (BMEWS frequency, 200mw/sq. cm power density). Although the resistance of the material to salt spray and arc-over was poor, this problem will be overcome by the use of a coating and over-garment. Recommendation is made for adoption of the suit by the Navy (after improvements for salt spray and arc-over resistance are incorporated) and for use by personnel required to enter fields in excess of 10mw/sq. cm. Work on development of protective devices is continuing and will include further improvements for the RAD HAZ suit, such as the addition of a transparent visor.

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Lab. Project 9400-20
Progress Report 1

## ADMINISTRATIVE INFORMATION

Ref: (a) NAVAPLSCIENLAB Program Summary dtd 1 Nov 1964, SF 013-15-04, Task 2162
(b) BUSHIPS ltr SF 013-01-07, Ser: 450-387 of 9 Oct 1963

1. In accordance with references (a) and (b), the Naval Applied Science Laboratory is conducting research and development of devices and techniques for eye, head and body protection of personnel exposed to high-powered rf radiations. This report presents NASL developments on protective clothing and the rf measurement techniques and instrumentation developed in association with this effort.

## ACKNOWLEDGMENTS

2. The work reported herein was conducted by C. Christianson, A. Rutkowski and R. Morss, under the technical guidance of A. Clark, Senior Task Leader and the general supervision of T. Monahan, Head, Physics Branch. The Bureau of Ships Program Manager is G. Neuman, Code 361B, and the Project Engineer, G. Heimer, Code 452H. A complimentary work effort was conducted by Mr. C. Zemme and Mr. L. Weinstock of the U.S. Naval Supply Research and Development Facility, Naval Supply Center, Bayonne, New Jersey. The Naval Applied Science Laboratory wishes to express its appreciation to Mr. Johnson and other personnel of RCA for their assistance during the field test of the RF prototype suit.

## INTRODUCTION

3. For some time the Navy has become increasingly concerned with the rapid increase in RF environmental areas on ships and at shore installations. Up to the present time these RF environments have been of moderate levels and could effectively be controlled with precautionary procedures such as lock out cams on the radars, etc., in order to preclude the illumination of occupied deck areas with power levels greater than 10 milliwatts per square centimeter. Ten milliwatts per square centimeter is the established hazard level for humans. However, in the near future there is scheduled to be put into operation new and extremely powerful radars with peak output powers in the megawatt region. It has been estimated that some of these radars will cause RF environments up to a maximum of 150 mw/cm$^2$. This level of power density is a substantially hazardous field of radiation.

4. Selected naval personnel will be required to perform their duties in such an environment and as a consequence, BUSHIPS has requested the development of protective clothing for use by personnel in these RF environments.

The general requirements for a protective garment are:

a. Reduction of high-level fields external to the garment to safe levels inside the garment (below 10 mw/cm$^2$).

b. Protection against or elimination of high-voltage gradients built up on the garment and protection of personnel from HV shocks due to contact with charged ships structures.

c. Minimum restriction of visibility, mobility and dexterity.

5. Specifically, the protective clothing must have the following characteristics for naval application:

a. 20 db minimum attenuation over the range of frequencies from 200 MC to 10 KMC.

b. Garment to be used in RF environments generated by radar operating at C-band frequencies and with estimated field intensities up to 150 $mw/cm^2$.

c. Should be lightweight.

d. Should be porous, non air or moisture tight with natural ventilation.

e. Suit to be wearable in 100°F climates.

f. Should withstand washing abrasion, salt spray and other adverse environments occurring in shipboard use.

g. Suit to incorporate hood or face mask for eye protection.

h. Should have maximum optical visibility for face mask.

i. Suit for use by flight deck personnel therefore must enable these personnel to perform normal duties without restriction.

j. Suit to complement and/or become integral part of flight deck uniforms.

6. The task of development and procurement of these garments is administered by BUSANDA and implemonted by NSRDF. NSRDF has supplied the clothing materials and samples of seaming and closure techniques for use in the suit and conducted laundering, dry cleaning, weathering, abrasion, salt water exposure, ship and open sea environment and durability evaluations.

7. NAVAPLSCIENLAB has been assigned a complementary problem, RAD HAZ body protective devices. Under this authority the NAVAPLSCIENLAB has developed the facilities, instrumentation, techniques and procedures for measurements of RF shielding effectiveness, conductivity and arc-over properties. These measurements were utilized in the development of the suit and in investigating light-transmitting, conductive materials for possible use as a visor in the suit and for RF

protective goggles. After design and fabrication of prototype suits by NSRDF, these garments were evaluated at BMEWS and C-band frequencies in a distributed RF field at RCA, Moorestown, New Jersey in order to determine their efficiency for whole body protection. NAVAPLSCIENLAB presently has an X-band (9.3 Kmc) facility in use available for this work. The tests at RCA were performed specifically at BMEWS and C-band frequencies in order to more completely cover the operational frequencies of military radars.

8. The design and materials used in the Navy suit have been patterned to some degree after the RF suit developed by the Air Force[1,2]. However, the Navy's needs for RF protective clothing have been more difficult to fulfill because of the high temperature requirement and the necessity of naval personnel wearing these garments for extended periods of time. In addition the suit has to be naturally vented since artificial cooling, such as air pacs, is not practical in this instance. This requirement has modified the arc-over effectiveness but a compromise can be obtained by possible selective shielding of the suit for high potential arc-over.

## OBJECTIVE

9. The objectives of this task are to develop facilities, instrumentation, techniques, procedures and specifications for measurements on RF shielding materials; utilize these measurements in the development of RF protective devices (a RAD HAZ suit in this phase of the task); and, evaluate the devices in the field, using high-powered RF equipment.

## MEASUREMENT TECHNIQUES

### Laboratory Microwave Power Source

10. A laboratory unit consisting of a 0.25 megawatt modulator energizing a pulse-operated magnetron, model QK-172 (manufacturer Raytheon Co., Waltham, Mass.) provided the source of RF power for the investigation reported herein. The QK 172 magnetron, designed for X-band frequencies (9330-9420 megacycles) is rated to operate at an anode voltage of 30 KV, peak power output of 428 KW, and a maximum duty cycle of 0.001. The pulsing network was set for a 3 microsecond pulse width and the repetition rate was 360 pulses per second. The RF power generated was delivered to the specimens under test via an appropriately-sized microwave waveguide which was terminated in a 9.5 cm x 13 cm feed horn. The feed horn (transmitting antenna) was positioned so that the RF radiation emitted from it would be contained within a large power absorbing box thereby reducing any RF hazard to laboratory personnel and minimizing reflections at the receiver which was located inside the absorbing box. The receiver consisted of a 9.5 cm x 7 cm feed horn which

received the power and transmitted it through a waveguide to a detector (thermistor mount) where the power was monitored when used in conjunction with a HP 431A power meter.

Microwave Measurement System

11. A laboratory microwave measurement system for determining the attenuation of various RF shielding materials was assembled as indicated in Figure 1. This system utilized the previously described microwave modulator and magnetron as the source of power. The RF power generated was radiated into free space from a transmitting horn (rectangular standard gain horn, FXR Model No. W638A, 18 db gain at 7.6 Kmc) and directed at a receiving horn (rectangular standard gain horn 17.25 db gain at 9.3 Kmc). The material under test was inserted between the transmitting and receiving horn and its insertion loss determined.

12. Calibration of System - In order to effect an accurate calibration of the RF power being received, a fraction of the transmitted power was coupled from the main transmitting waveguide (utilizing a 43.2 db directional coupler) and monitored. This value of power when multiplied by the coupling ratio (refer to Appendix A) yields the power enamating from the transmitting antenna. Utilizing the appropriate equation (refer to Appendix A) the power being received can now be calculated. This value was verified within ±1 db by monitoring the power captured by the receiving antenna with a thermistor mount and power meter. An accurate calibration of the power density at the receiving horn can now be calculated as in Appendix A. This value can also be verified by inserting a Ramcor 1200 Densiometer (accurate to within ±1 db) in the field in place of the receiving horn and reading the power density directly in $mw/cm^2$. (The Ramcor cannot be used in fields higher than 20 $mw/cm^2$; however, using it to verify a calculated field of say 10 $mw/cm^2$ enables one to assume that further calculations of power density at higher levels are accurate). A further check on the power density is possible. Knowing the transmitted power and effective area of the transmitting antenna one can calculate the power density at the transmitting horn. Then, by applying the inverse-square law (the power density is inversely proportional to the square of the distance) one can calculate the power density at the receiver knowing the distance between antennas. This inverse-square relationship only holds however if the receiving horn is in the far field of the transmitter.

13. In order to make valid calculations of insertion loss of the metalized fabrics, it is necessary that the transmitted power before and after insertion of the fabric in the field be the same. The only time this will hold is if the fabric is placed in the far field of the transmitting antenna[3]. The far field of an antenna (for which calculations are shown in Appendix B) is that region where the antenna can be considered to be a point source emanating an equal amount of power in a

radial direction which decreases as the distance squared from the source. This is in contrast to the near field where effects on amplitude and phase are observed from different points of the source. This makes calculations extremely complex. Measurement of power in the near field will not suffice since the field variations are displaced to a different degree by the measuring instrument and the specimen. Where the measuring instrument may indicate a peak, the introduction of the specimen at the same point may result in a minimum of ambient power. Also the introduction of a specimen in the near field of the transmitting antenna would result in the interaction between specimen and antenna. This results in an impedance mismatch as seen by the generator which could result in a marked change in transmitted power.

Measurement of Insertion Loss of Shielding Materials.

14. Measurement of the RF attenuation of a specimen was obtained as follows: (a) the power that would be incident on the sample was measured at the receiving horn with no sample in place (b) the power transmitted through the sample to the receiving horn was measured. The decibel insertion loss or attenuation of the material is then given by:

$$\text{db loss} = 10 \log \frac{P_1}{P_2}$$

where: $P_1$ = power received before insertion of fabric
$P_2$ = power received after insertion of fabric

15. In making these measurements it was initially assumed that the insertion loss was independent of the position of the material in the far field. After a number of trials it was observed that this position was indeed critical. (The reason for this is explained in Appendix C). The procedures were therefore modified such that during the measurements the sample was moved to various arbitrary positions (within one wavelength of receiver) along the axis between the horns, and the received power variations noted. The maximum value of power ($P_2$) was used to calculate the results indicated in Tables 1, 2 and 3. Therefore, these values are minimum values of insertion loss that the fabric will provide.

16. The method of evaluating the seamed samples was essentially the same. In both the seamed and unseamed fabrics the measurements were made with the seam first in a vertical position and then rotated 90° in the plane of the specimen. This was done so that the seam could be subjected to both a vertical and horizontal polarization of the electromagnetic field. Again, the higher of the two transmitted power values ($P_2$) was used to insure that the calculated insertion loss be a minimum.

Measurement of Resistivity of RF Attenuating Materials

17. In order to measure the resistivity of the various materials, a simple apparatus, composed of two aluminum bus-bars and an impedance bridge, was devised. (See figure 2). A 3 1/4" x 3" sample of the material was clamped between the bus bars so that the exposed area of the material was 3 inches square. A General Radio Impedance Bridge (Type 650-A) was used to measure the d.c. resistance of the square sample in ohms per square. (See figure 3). During these measurements it was observed that the resistance of some materials varied with the tension applied to them. It was then decided to apply an ever increasing tension until a maximum (or minimum) resistance was observed or until the material slipped from the jig. A new jig, which will permit a standard tension to be applied to all the samples during measurement, is now in preparation. With this new apparatus it should be relatively simple to correlate the D.C. resistance, the coarseness of the weave, and the RF shielding capabilities of the material. For a detailed discussion of resistivity in ohms per square see Appendix D.

SHIELDING EFFECTIVENESS OF CLOTHING MATERIALS

18. Various conductive materials for possible use in an RF protective suit have been measured for attenuation at a frequency of 9.3 Kmc. In addition, various methods of seaming and closure have been evaluated for RF shielding effectiveness. The fabrics, seams, and closures which were determined to be most effective, were also exposed to laundering, dry-cleaning and weathering, and then retested for RF shielding capabilities. The results to date, are summarized in Tables 1, 2 and 3.

19. Table 1 contains the attenuation data of various shielding materials. The conductive fabrics are being considered for use as the principle covering material for the major portion of the suit, while the screening has possible use in the visor. From the figures of insertion loss, it can be seen that fabrics A and C provide approximately 30 db attenuation while Fabric T offers 27 db attenuation. These shielding capabilities are in excess of the 20 db requirement for the RF suit and are therefore more than acceptable from this standpoint.

20. It is to be noted that for fabrics R and T (which are made of the same material) the insertion loss values differ considerably. The reason for this is not readily apparent but it was felt that since fabric R was somewhat discolored it may have been subjected to various environments (such as salt water) which diminished its RF shielding properties considerably.

21. It will be noted from Tables 2 and 3 that complete tests were not performed on Fabrics A and T due to the fact that Fabric A did not have as large a percent open area as fabrics C and T, and that the insertion loss values of fabric T were considerably dependent on tension applied to the material.

22. An inspection of Table 2 will reveal that fabric A is suitable only when joined using seam #4. On the other hand, fabric C has a minimum insertion loss of 27.4 db with all four seam configurations. It can also be seen from Table 2 that zipper #10 was far superior to zippers #11, #12, and #13 in its shielding effectiveness. Zipper's #11, #12 and #13 were common zippers, which were later silverized while zipper #10 was a specially constructed metalized zipper which was designed for complete electrical continuity. The results obtained proved that the stitching of the zipper is of prime importance.

23. Table 3 shows the resultant insertion losses of fabrics C and T after cleaning. Since it was not possible to clean the same sample by the various methods no exact comparison of fabric T could be made because of its non-uniformity from piece to piece. It would be obviously unreasonable to claim that fabric T actually increased its insertion loss from 20.9 to 30.5 db after laundering. On the other hand, Fabric C has minor changes in insertion loss part of which could be attributed to the degree of accuracy of the transmitting and measuring instruments (±1 db overall).

24. Table 4 lists the various materials and their respective resistivities in ohms per square. When a range is given it is an indication that the resistivity varies when the tension applied to the material is changed. On some materials tension had no effect; this is indicated by a single value for the resistance. (A new jig, which will permit a standard tension to be applied to all the samples during measurement, is now in preparation). All other parameters being equal, the lower the resistivity of a material the better is the RF attenuation it will provide. For the materials listed in Table 4 the rule applies only in a general fashion since the coarseness of the yarn, number of threads per inch, etc., greatly influence their shielding effectiveness.

25. In addition to the results listed in the enclosed tables further destructive tests (salt water, fresh water, salt spray, actual sea water, abrasion and roof exposure) were performed by the Naval Supply Research and Development Facility on fabrics C and T and subsequently evaluated by NAVAPLSCIENLAB for RF shielding effectiveness[4, 5, 6]. As a result of these tests it was found that subjecting the fabrics to sufficient degrees of salt spray, salt water, and roof exposure would cause deterioration of their RF shielding effectiveness. It was then decided to coat samples of these fabrics with a Krylon acrylic spray, subject them to salt spray, roof exposure and salt water; and evaluate their RF shielding effectiveness. The results of these tests indicated that the spray coating offered some protection, but not knowing the length of exposure to salt water or other destructive tests the samples had to be subjected to, definite conclusions could not be made[6].

RF FIELD TEST OF PROTOTYPE RAD HAZ SUIT

26. A prototype RAD HAZ suit incorporating the optimum RF seam, zipper, and velcro closure was fabricated from specimen C of Table 1. This fabric provided better than the required 20 db attenuation, was permeable to air and had the least decrease in its RF shielding properties when subjected to various cleaning and destructive tests. The suit is shown in Figure 4. Due to the possibility of voltage gradients being built up on the suit, when in an electromagnetic field, rubber gloves and boots (not shown) were provided for arc-over protection at the extremities.

27. Arrangements were made for field evaluation of the RF suit at RCA, Moorestown, N.J. The suit was evaluated at the BMEWS frequency and at approximately 5 Kmc. Representatives of RCA, BUSHIPS, BUMED, NAVAPLSCIENLAB and NSRDF were present during the evaluation.

28. Prior to insertion of the suit in the field, a Laboratory evaluation of its shielding effectiveness was performed at the BMEWS frequency and 5200 Mc at RCA. The transmitting antenna was circularly polarized to permit simultaneous checking for vertically polarized or horizontally polarized flaws in the suit. The test apparatus is noted in Figures 5 and 6.

29. At the BMEWS frequency, intensity of the field was measured by an electrostatically shielded loop antenna approximately three-tenths of a wavelength in circumference fabricated from RG 55/U coaxial cable. A loop antenna is least affected by proximity of the metallic fabric of the suit. The loop was positioned approximately 10 feet from the transmitting antenna and oriented for maximum pickup as indicated on the VSWR amplifier. The loop antenna was now located in the suit which was then sealed up. Connection between the pickup loop and the receiver was made, through the suit, by means of an RF feed-thru connector. The loop was repositioned in its previous location for maximum meter indication and parts of the suit were passed in front of it. The meter indicated that attenuation of all areas of the suit (hands, arms, legs, neck, head, body) was greater than 30 db. It was not possible to obtain more accurate values due to limitations in the VSWR amplifier. Any further increase in scale range resulted in introduction of noise levels comparable to the signal level which would give erroneous indications of the attenuation.

30. The test set-up and procedure at 5.2 Kmc was similar to that described (See Figure 6) for the BMEWS frequency. The pick-up loop was 1/2 inch in diameter (about three-tenths wavelength in circumference) to allow for decrease in wavelength with increase in frequency. Since the transmitting antenna was vertically

polarized it was necessary to rotate the seams, zipper, and velcro closures 90° to test for possible flaws. It was found that the attenuation varied between 25 and 50 db throughout the suit with a minimum of 25 db occurring at the neck junction of the zipper and velcro closures. It is to be noted that in both tests the receivers (Narda - VSWR Amplifier and Polarad RM-T Receiver) were located outside the radiation pattern of the transmitting antennas. This was to insure that neither receiver would give erroneous meter indications due to stray pickup through its case.

31. A wooden stand was constructed and the suit hung on it. It was then placed in the field at the BMEWS frequency and the Ramcor 1200 Densiometer with the appropriate pickup antenna installed within it. The anticipated power density incident on the suit was to be approximately 100 mw/cm$^2$. The minimum field that the Ramcor 1200 can read accurately is 1 mw/cm$^2$. This is exactly a decrease of 20 db. Any further increase in attenuation that the suit would provide would not be indicated by the Ramcor. However, as long as the Ramcor read at most 1 mw/cm$^2$ while in a field of 100 mw/cm$^2$ the suit then provided the required 20 db of attenuation or better. It is to be noted that more accurate measurements had been conducted in the Laboratory and the Ramcor served as a check. Figure 7A shows personnel installing the suit in the field. The lead bricks placed on the feet were used to prevent the stand from toppling over. Figure 7B shows the Ramcor 1200 installed in the suit ready for readings. Figure 8A shows the suit, ready for testing facing the BMEWS frequency radar in the background. The radar was housed in the building shown and the antenna was depressed so that it could radiate at ground level. A series of fluorescent bulbs were located in the ground as shown in Figure 8B. These lights when exposed to a sufficient level of power density will glow and were used to locate the beam and center it on the suit. The distance from the suit to the radar was somewhere between a quarter to a half of a mile. Due to the size of the antenna this would locate the suit in the near field and therefore little or no advantage would be gained by moving the suit any closer. The power density at this point was already near the maximum available and would not increase much as one moved closer. Readings of the Ramcor were taken by personnel situated in a building which was located out of the beam of the radar. Use was made of a high-powered telescope which would indicate any meter deflection in the Ramcor and any possible arcing in the suit. With the beam (approximately 100 mw/cm$^2$) incident on the suit it was observed that there was no meter deflection of the Ramcor and no visible arcing.

32. Another prototype suit of the exact same design was Laboratory-evaluated using the techniques previously described. The attenuation being better than 20 db at all areas of the suit, one of the personnel present donned the suit and proceeded to the center of the beam to check for arcing. Use was made of an RCA power density meter specifically built to cover the BMEWS frequency range. Its maximum possible

reading is 100 mw/cm$^2$. It was observed that the needle pegged off scale, and it was later determined that the actual field was in the vicinity of 200 mw/cm$^2$. This is 50 mw/cm$^2$ in excess of the maximum required level where the suit will be used. A power density of 200 mw/cm$^2$ is definitely very hazardous and has been known to cause cataracts in the eyes of rabbits and even death to animals where the exposure was long enough. A metal rod was used to induce arcing between parts of the suit and the rod. Arcing was very evident in parts of the suit where there was an overlap of fabric such as the armpits and the neck area. The arcing was not observed in the suit hung on the stand for two reasons. As can be seen in Figure 8A the arms of the stand are outstretched and there is no overlapping of fabric. Arcing was obtained while placing the hands at one's sides thus causing an overlap of fabric. Also, it can be observed in Figure 8A that there is a hard hat on top of the stand which takes up most of the slack in the head area. A hard hat was not worn by the individual in this test and thus there was a large amount of slack. It is to be noted that at no time while in the field was there felt any burns, shocks, or a significant amount of heat being built up inside the suit. An examination of the suit showed burns and some holes in areas where arcing had been induced by the rod and by an overlap of fabric.

33. As a possible arc-over preventive, a raincoat and rubber gloves were donned over a new prototype suit (same design). In addition another individual donned the suit previously installed on the stand. His right arm instead of being in the arm sleeve of the suit was located in the suit's body. In his right hand was the Ramcor 1200. This enabled him to probe the inside of the suit for any possible meter indication. To prevent the right sleeve of the suit from flapping in the wind it was taped to the side of the suit. No meter indication on the Ramcor was observed and with the raincoat over the suit, arcing was no longer evident in the armpit area. After leaving the field an examination of the suit covered by the raincoat revealed no burns or holes in the area covered by the coat and gloves. An increase of heat in the metal rod (now separated from suit by rubber) was felt but not enough to cause it to be dropped. Observation of the other suit revealed that the right arm sleeve had fused to the suit where previously taped. Burns and holes were also evident in some areas of overlap.

34. One of the suits was then sprayed with a crystal clear acrylic spray. It was hoped that this would aid in the prevention of arc-over. The other individual put on, over his suit, a pair of Navy cotton coveralls (shirt and pants). These coveralls are permeable to air and are worn by Navy personnel aboard ship in warm weather. In addition to this, rubber gloves and boots were worn. The two then proceeded to the center of the beam where some arcing was observed on the sprayed suit, though less than that without a spray coating. At no time was there arcing in the suit covered by the Navy coveralls, rubber boots and gloves. (The overlap in the neck of the suit was now in contact with the cotton shirt rather than the suit itself).

35. It was thus concluded that arcing could be prevented by some sort of a non-conducting overgarment on the suit (which in the case of the Navy coveralls was also fairly permeable to air). Further investigation into some sort of a spray coating also was deemed worthwhile.

## CONCLUSIONS

36. Major phases in the task of providing devices for the protection of personnel against RF radiation hazards have been completed. A prototype RAD HAZ suit has been developed through the joint efforts of NSRDF and NAVAPLSCIENLAB. In the process of evaluating fabrics for the suit the Laboratory established low- and high-power RF facilities, measurement procedures, and developed new techniques for conductivity measurements and for insertion loss calculations. The latter enabled attenuation measurements to be made in the near field of receiving antennas. On the basis of good retention of RF attenuation and conductivity characteristics after exposure to laundering, dry-cleaning, weathering, abrasion and open sea environments, a silverized nylon "lino" material (specimen C of Table 1) was used in the fabrication of the suit. The fabric was overlapped at the seams and metalized "zipper" and "velcro" type devices were used for the closures. The suit provided a minimum of 25 db attenuation for low-power laboratory RF fields at 5.2 Kmc (minimum of 30 db at 425 Mc) and better than 20 db for high-power fields (BMEWS frequency, 200 mw/sq.cm. power density). Resistance of the material to salt spray and arc-over was poor and is expected to be improved by the use of a coating and an over-garment.

## RECOMMENDATIONS

37. It is recommended that the RAD HAZ suit described herein, after minor modification for improved salt spray and arc-over resistance, be adopted by the Navy for the protection of all personnel who are required to enter RF fields in excess of 10 mw/sq.cm.

## FUTURE WORK

38. Efforts on the development of devices and techniques for protection of personnel against RF radiations will be continued. Future work will include the evaluation of nylon mesh and cotton cloth over-garments to provide arc-over protection for the conducting under-garment. Also, the effectiveness of water repellants in imparting salt spray resistance to the metalized fabric, specimen C of Table 1, will be investigated. Upon completion of these investigations, specifications will be developed from which production quantities of the suit may be fabricated and placed into Naval Supply.

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5. Lab. Project 5115-4.2 Pt. 33, "Experimental Metalized Zipper Closures and Abraded Fabrics for Radar Protective Clothing", 21 Jun. 1963.

6. Lab. Project 9400-20, "Attenuation of Metalized Fabrics After Salt Spray, Roof Exposure and Salt Water Degradation Tests", 19 Nov. 1963.

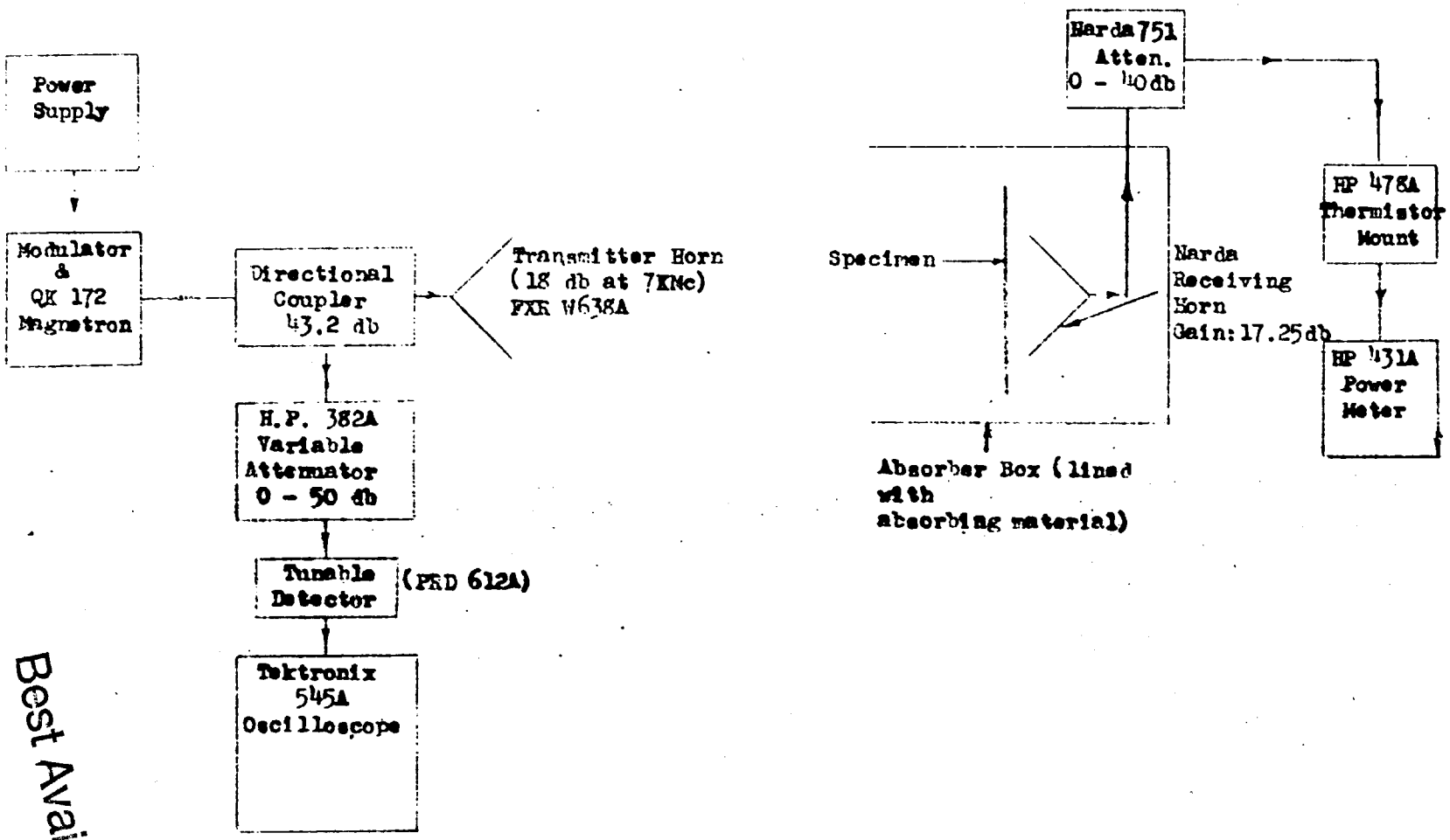


Fig. 1 Block Diagram of Microwave System (X Band - 9.3 Kmc)

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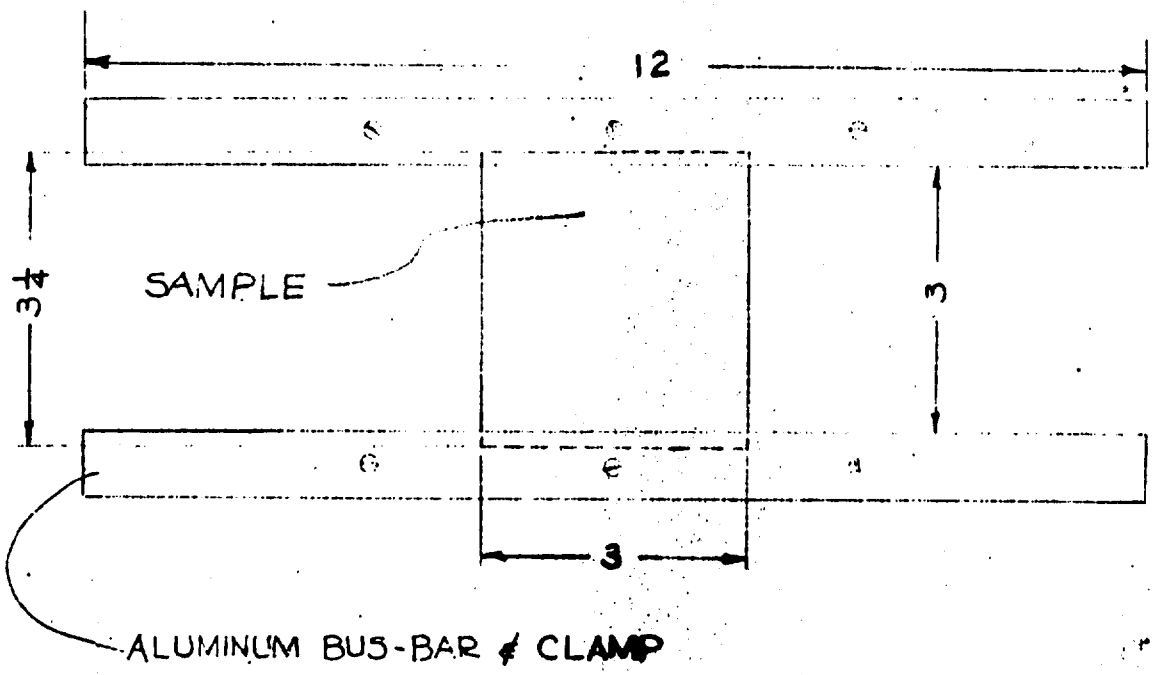


OHMS PER SQUARE TEST APPARATUS

FIGURE 2

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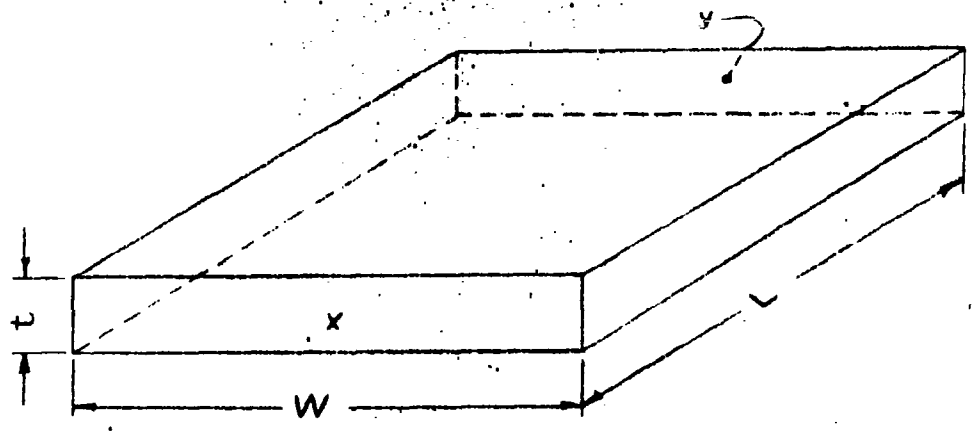


RESISTIVITY = $\rho$ (CONSTANT)

$$R_{xy} = \frac{\rho L}{Wt}$$

OHMS PER SQUARE CALCULATION

FIGURE 3

APPLIED SCIENCE LABORATORY LAB PROJECT 9400-20

Figure 4 Prototype RAD HAZ Suit

PHOTOL-19647-1

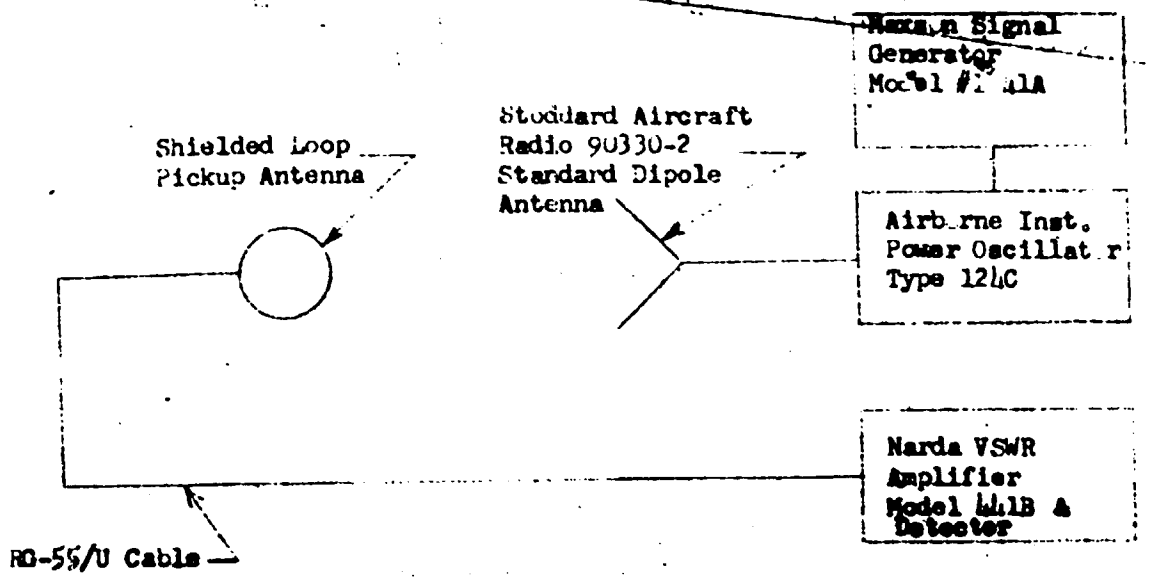


Fig. 5 - Block Diagram of RCA Laboratory Test Setup (425 mc)

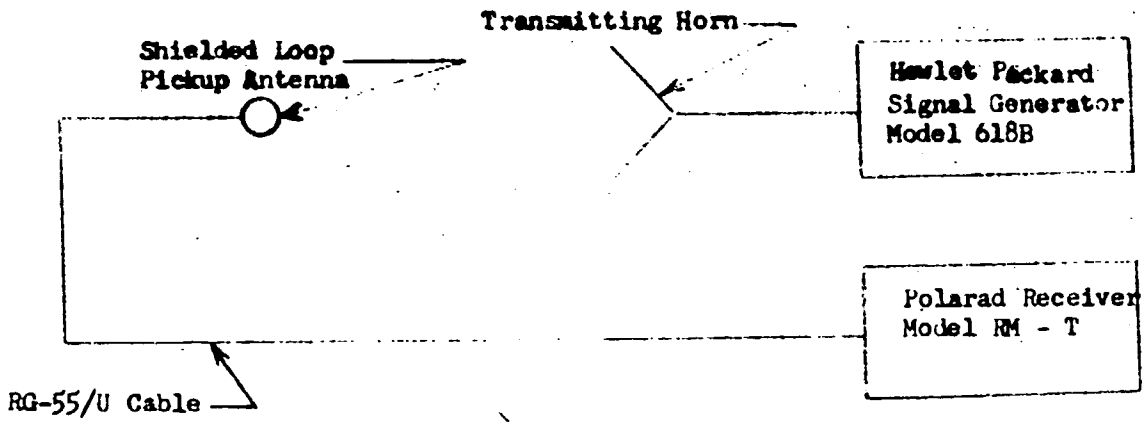


Fig. 6 Block Diagram of RCA Laboratory Test Setup (3.2 kmc)

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APPLIED SCIENCE LABORATORY LAB PROJECT 9400-20

Figure 7
A-Left Preparing RAD HAZ Suit for Evaluation at BMEWS Radar Test Site
B-Right Location of Ramcor 1200 Densiometer Inside Suit

PHOTO L-19647-2

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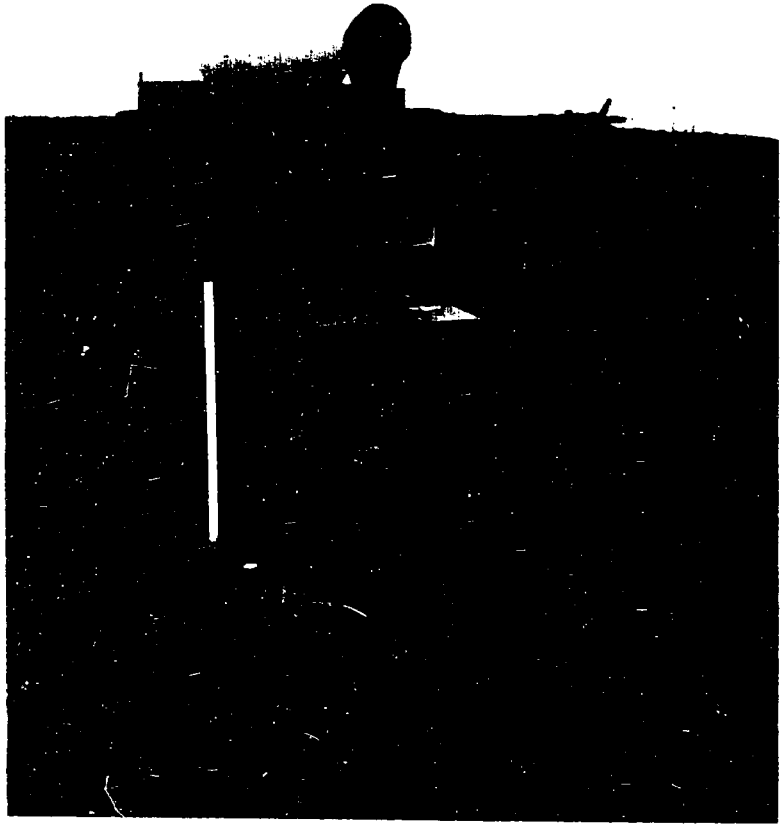
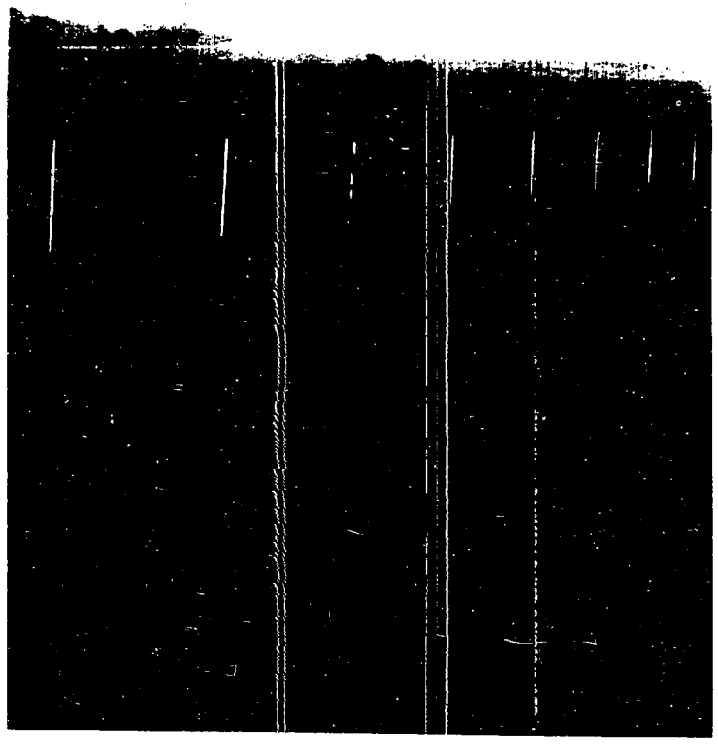
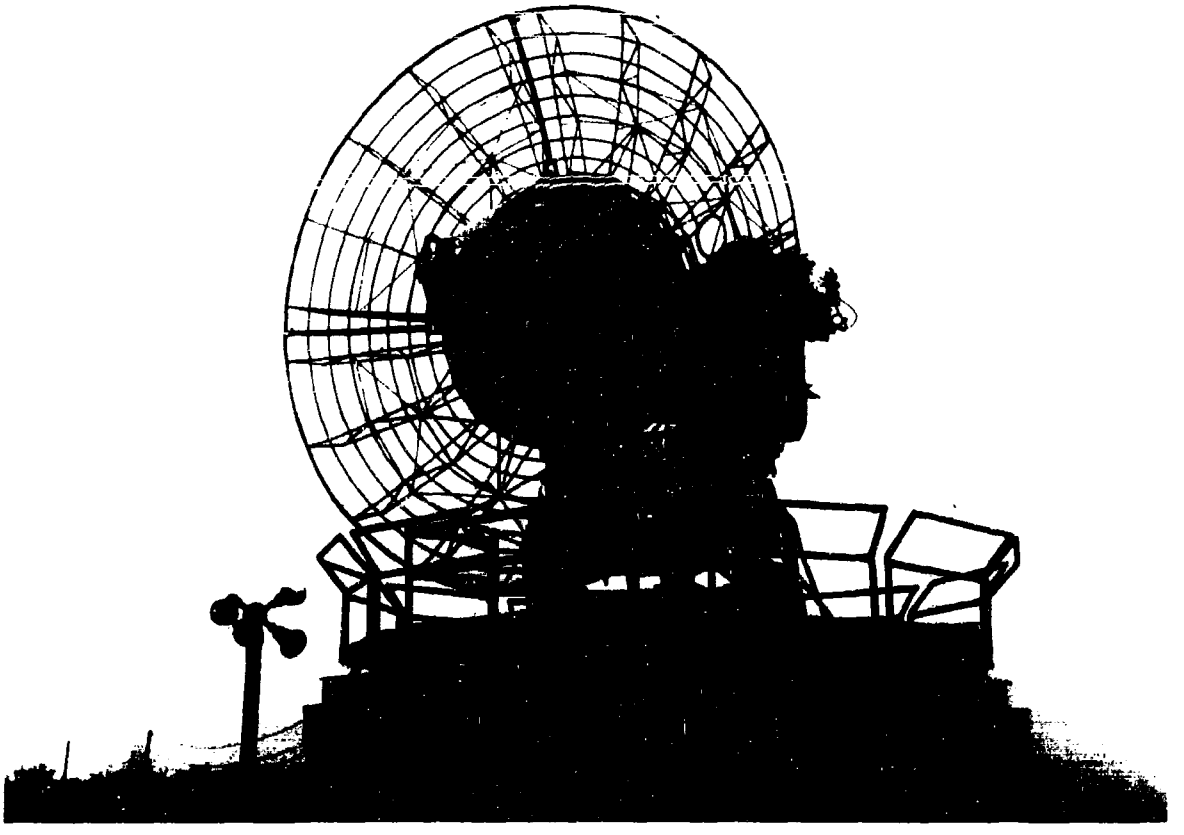




APPLIED SCIENCE LABORATORY LAB PROJECT 9400-20

Figure 8
A-Left Rear View of RAD HAZ Suit, Facing BMEWS Radar
B-Right RAD HAZ Suit in Field, Fluorescent Lights Used to Locate Center of Beam



APPLIED SCIENCE LABORATORY LAB. PROJECT 9400-20

Figure 9 Transmitting Antenna of RCA 5.2Kmc Test Facility

PHOTO L-19647-4

TABLE 1

Attenuation of Various Materials to RF At a Frequency of 9.3 Kmc
(specimens are origin continuous samples without seams)

| Specimen | Material Description | Incident Power (watts) | Transmitted Power (watts) | Insertion Loss (DB) |
|---|---|---|---|---|
| A | Metalized Fabric Rip Stop (Mfr. A*) | 3.0 | $2.6X10^{-3}$ | 30.6 |
| B | Knitted Mesh of Aluminum Vacuum Deposited Mylar (Mfr. B*) | 2.3 | $8.1X10^{-2}$ | 14.5 |
| C | Silverized Nylon Lino, Heavy Marquisette (Mfr. A*) | 3.0 | $2.5X10^{-3}$ | 30.8 |
| D | Silverized Knitted Nylon Mesh, (Mfr. C*) | 2.3 | $3.1X10^{-2}$ | 18.7 |
| E | Silverized Nylon Lino, Overcoated with Vinyl (Mfr. A*) | 3.0 | $1.45X10^{-1}$ | 13.2 |
| F | Scotch Shield Brand Aluminized Fabric (Mfr. D*) | 2.3 | 2.3 | 0 |
| G | Same as (F) with Neoprene coated back | 2.3 | 2.3 | 0 |
| H | Vacuum deposited Aluminum Fabric | 2.3 | $1.2X10^{-2}$ | 22.8 |
| I | Combination of polyethylene and metalized mylar yarns in woven mesh | 2.3 | $2.3X10^{-1}$ | 10 |
| J | 200 mesh, stainless steel, bolting cloth, aluminized one side | 2.7 | $3.5X10^{-3}$ | 28.9 |

TABLE 1 (Cont'd)

| Specimen | Material Description | Incident Power (watts) | Transmitted Power (watts) | Insertion Loss (DB) |
|---|---|---|---|---|
| K | 200 mesh, stainless steel, bolting cloth | 2.3 | $2.4X10^{-3}$ | 29.8 |
| L | Neoprene coated nylon (target sleeve fabric) | 2.7 | 1.4 | 2.85 |
| M | Same as (C) different batch of cloth | 3.0 | $3.9X10^{-3}$ | 28.9 |
| N | 40 mesh screening | 2.7 | $2.5X10^{-3}$ | 30.3 |
| #13 | 145 mesh, stainless steel, bolting cloth | 2.7 | $8X10^{-3}$ | 25.3 |
| R | Silverized bylon dobby (Mfr. A*) | 3.0 | $3.4X10^{-2}$ | 19.5 |
| T | Same as (R) different batch of cloth | 3.0 | $5.8X10^{-3}$ | 27.1 |
| U | Neoprene insulation fabric | 2.7 | 2.7 | 0 |
| X | Mylar with gold film deposited on it | 3.0 | $2.7X10^{-1}$ | 10.5 |
| Y | Carbon impregnated cotton fabric | 2.7 | 2.7 | 0 |

* See Table 5 for List of Manufacturers

TABLE 2

Attenuation of Various Materials to RF at a Frequency of 9.3 Kmc
(Specimens are virgin and contain various seams and/or closures)

| Specimen | Material Description | Incident Power (watts) | Transmitted Power (watts) | Insertion Loss (DB) |
|---|---|---|---|---|
| A-1 | Fabric A-Seam #1 | 3.0 | $5.8X10^{-2}$ | 17.1 |
| C-1 | Fabric C-Seam #1 | 3.0 | $3.8X10^{-3}$ | 29.0 |
| A-2 | Fabric A-Seam #2 | 2.7 | $9.0X10^{-1}$ | 4.8 |
| C-2 | Fabric C-Seam #2 | 3.0 | $4.4X10^{-3}$ | 28.3 |
| A-3 | Fabric A-Seam #3 | 2.7 | $2.3X10^{-1}$ | 10.7 |
| C-3 | Fabric C-Seam #3 | 3.0 | $4.8X10^{-3}$ | 28.0 |
| A-4 | Fabric A-Seam #4 | 3.0 | $2.3X10^{-3}$ | 31.1 |
| C-4 | Fabric C-Seam #4 | 3.0 | $5.4X10^{-3}$ | 27.4 |
| C-8 | Fabric C-with velcro closure | 3.0 | $1.0X10^{-2}$ | 24.8 |
| C-10 | Fabric C-with #10 zipper | 3.0 | $2.1X10^{-3}$ | 31.5 |
| A-11 | Fabric A-with #11 zipper | 3.0 | $9.0X10^{-2}$ | 15.2 |
| A-12 | Fabric A-with #12 zipper | 3.0 | $7.8X10^{-1}$ | 5.8 |
| A-13 | Fabric A-with #13 zipper | 3.0 | $6.0X10^{-2}$ | 17.0 |
| C-11 | Fabric C-Seam #1 backed with nylon taffeta | 3.0 | $4.2X10^{-3}$ | 28.5 |
| T-1 | Fabric T-Seam #1 backed with nylon taffeta | 3.0 | $4.8X10^{-3}$ | 28.0 |
| C-12 | Fabric C-Seam #4 backed with nylon taffeta | 3.0 | $3.1X10^{-3}$ | 29.9 |
| T-2 | Fabric T-Seam #4 backed with nylon taffeta | 3.0 | $4.3X10^{-3}$ | 28.4 |

TABLE 3

Attenuation of Various Materials to RF at a Frequency of 9.3 Kmc
(After Laundering, Dry-Cleaning and Weathering)

| Specimen | Incident Power (watts) | Transmitted Power (watts) | Insertion Loss (DB) |
|---|---|---|---|
| C - (original no destructive tests) | 3.0 | $4.8X10^{-3}$ | 28.0 |
| T - (original no destructive tests) | 3.0 | $2.45X10^{-2}$ | 20.9 |
| C - (after 1 laundering) | 3.0 | $2.9X10^{-3}$ | 30.1 |
| T - (after 1 laundering) | 3.0 | $2.7X10^{-3}$ | 30.5 |
| C - (after 5 launderings) | 3.0 | $3.5X10^{-3}$ | 29.3 |
| T - (after 5 launderings) | 3.0 | $4.8X10^{-3}$ | 28.0 |
| C - (after 10 launderings) | 3.0 | $1.7X10^{-3}$ | 32.5 |
| T - (after 10 launderings) | 3.0 | $4.6X10^{-3}$ | 28.1 |
| C - (dry cleaning perchloroethylene) | 3.0 | $6.1X10^{-3}$ | 26.9 |
| T - (dry cleaning perchloroethylene) | 3.0 | $5.5X10^{-3}$ | 27.4 |
| C - (dry cleaning Stoddard Solvent) | 3.0 | $3.4X10^{-3}$ | 29.5 |
| T - (dry cleaning Stoddard Solvent) | 3.0 | $3.0X10^{-3}$ | 30.0 |
| C - (after 40 hours weatherometer) | 3.0 | $3.5X10^{-3}$ | 29.3 |
| T - (after 40 hours weatherometer) | 3.0 | $1.03X10^{-2}$ | 24.6 |
| C - (after 80 hours weatherometer) | 3.0 | $5.8X10^{-3}$ | 27.1 |
| T - (after 80 hours weatherometer) | 3.0 | $8.3X10^{-3}$ | 25.6 |

TABLE 4

Resistivity (Ohms per square) of Various Virgin RF Attenuating Materials

| Specimen | Material Description | Specimen Size | Resistivity (Ohms per square) |
|---|---|---|---|
| A | Metalized fabric rip stop (Mfr. A*) | 3" X 3" | 25 - 90 |
| B | Knitted mesh of aluminum vacuum deposited mylar (Mfr. B*) | 3" X 3" | 230 - 400 |
| C | Silverized nylon lino (Mfr. A*) | 3" X 3" | 0.36 |
| D | Silverized knitted nylon mesh, (Mfr. C*) | 3" X 3" | 0.75 |
| E | Silverized nylon lino overcoated with vinyl (Mfr. A*) | 3" X 3" | 0.75 - 6.5 |
| F | Scotch shield brand aluminized fabric, (Mfr. D*) | 3" X 3" | > 1 Meg. |

* See Table 5 for List of Manufacturers

## APPENDIX A

### Power Monitoring and Calculation of Power Density

1. The HP 431A power meter used to monitor power transmitted and received has a maximum range of 0-10 mw. Since the power transmitted in the waveguide is much greater than 10 mw, use is made of a directional coupler to sample a fraction of this main power. The directional coupler consists of a main guide, installed directly into the transmitting waveguide setup, and an auxiliary guide to which the thermistor mount and power meter are connected. Coupling is obtained through a series of graduated holes which permit coupling of power in the forward direction but not in the reverse. The ratio, expressed in db, of forward power in the main guide to the power out of the auxiliary guide is the coupling ratio.

Example:

Given a reading of 2 mw on HP 431A power meter (connected to the auxiliary arm of a directional coupler); a coupling ratio of 30 db; calculate the power in the main arm of the directional coupler (power transmitted)

Power read X numerical coupling ratio = Power transmitted
2 mw X R = Power transmitted

but $30 \text{ db} = 10 \log_{10} \frac{P_o}{P_i}$

or $3 = \log_{10} \frac{P_o}{P_i} = \log R$

$\therefore R = 1000$

where R = numerical coupling ratio
= ratio of power transmitted to power received

$\therefore$ 2 mw X 1000 = 2000 mw = 2 watts.

The power transmitted = 2 watts.

Note: In the laboratory investigation, a calibrated variable attenuator was also located in the auxiliary arm of the directional coupler. In this case the total coupling ratio is the sum, in db, of the dial setting on the attenuator and the coupling ratio of the directional coupler.

2. Knowing the power being transmitted in the guide and assuming this is the power being radiated from the horn (actually there will be a small loss due to a standing wave in the guide) the power being received at the receiving antenna

may now be calculated from the following equation:

$$P_r = \frac{P_t\, G_t\, G_r\, \lambda_o^2}{(4\pi d)^2}$$

where $P_r$ = power received in watts
$P_t$ = power transmitted in watts
$G_t$ = power gain of the transmitting antenna (a numerical ratio; not db)
$G_r$ = power gain of the receiving antenna (a numerical ratio; not db)
$d$ = distance between antennas
$\lambda_o$ = free space wavelength

Note (1) This equation is valid only if both antennas are in each others far field.*
(2) The power gain of an antenna is an indication of how well the antenna concentrates the beam in a specific direction. The higher the gain the more collimated the beam.
* See Appendix B

**Example:**

Given: A transmitted power of 100 watts being radiated from an antenna having a gain of 20 db. The receiver has a gain of 15 db and is located at a distance of 200 cm (far field) from the transmitter. The frequency of operation is 3 Kmc. (The gains of the antennas have been found at this frequency).

Problem: Calculate the received power

$$G_t = 20 \text{ db} = 10 \log_{10} R_t \qquad (R = \text{power ratio})$$
$$\log_{10} R_t = 2$$
$$\therefore R_t = 100$$

$$G_r = 15 \text{ db} = 10 \log_{10} R_r$$
$$\log_{10} R_r = 1.5$$
$$\therefore R_r = 31.6$$

$$\lambda_o = \frac{3X10^{10}}{f} \text{ cm} = \frac{3X10^{10}}{3X10^9} \text{ cm} = 10 \text{ cm}$$

$$\therefore P_r = \frac{P_t\, G_t\, G_r\, \lambda_o^2}{(4\pi d)^2}$$

$$= \frac{(100)(100)(31.6)(10)^2}{[(4)(3.14)(200)]^2}$$

$$= 5.02 \text{ watts}$$

3. In order to calculate the power density at the receiving horn one must first know the effective area of the receiving antenna. The effective area of an antenna is an indication of how well the antenna captures the power impinging on it. It can be determined from the following equation:

$$A_e = \frac{G_r \lambda_0^2}{4\pi}$$

where $A_e$ = effective area in $cm^2$
$G_r$ = power gain of receiving antenna (numerical number; not db)
$\lambda_0$ = free space wavelength in cm

This equation is again only valid in the far field.

The power density is now defined as

$$P_D = \frac{P_r}{A_e}$$

where $P_D$ = power density in $mw/cm^2$
$P_r$ = power received in mw
$A_e$ = effective area of receiver in $cm^2$

## APPENDIX B

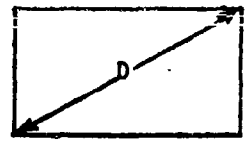
### Calculation of Far Field

1. Given two standard gain horns (horns where the value of gain is known at specific frequencies), one to act as a transmitting antenna the other as a receiving antenna. In order to make valid measurements with these horns, each one must be located in the other's far field. The minimum distance to the far field from a standard gain horn may be found from the following relationship:

$$R = \frac{2D^2}{\lambda_o}$$

where D is the major dimension of the horn (diagonal of rectangle shown below), and $\lambda_c$

Side View of Horn



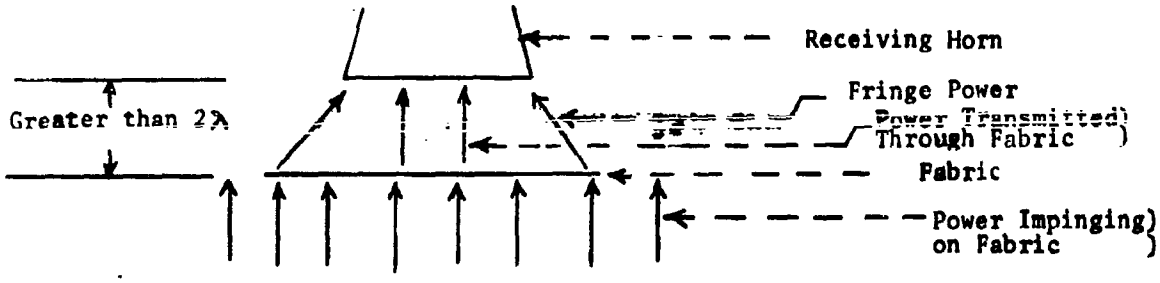

Front View of Horn

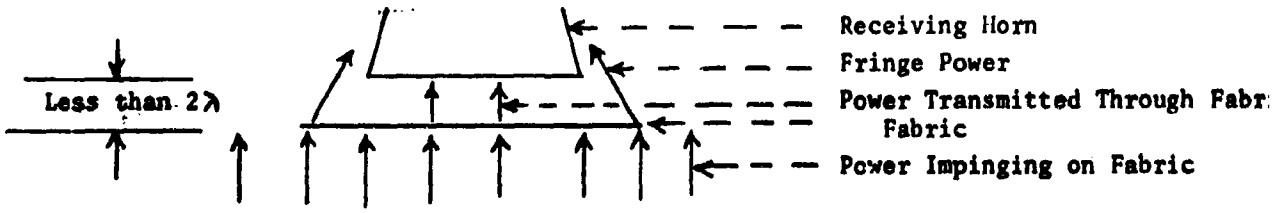
is the free space wavelength. In the case where two horns are used (one as a transmitter the other as a receiver) D is the major dimension of the largest antenna and R is the minimum spacing between them.

APPENDIX C

Determination of Attenuation of Fabrics Installed in Near Field of Receiver

1. It was previously stated that in order to make valid measurements of insertion loss, the metalized fabric under test had to be located in the far field of the transmitting antenna. The size of the fabrics being tested were 15 cm x 15 cm. The size of the receiving horn was 9.5 cm x 7 cm. The radiated beam of power was wider than the fabric, which in turn was comparable in size with the horn. Therefore location of the specimen at distances greater than approximately two wavelengths (6.5 cm) from the receiving antenna would cause a fringing effect at the sides of the fabric which would result in erroneous power readings. (see figure below)




However, placement of the fabric within two wavelengths of the receiving horn located it in the near field of this antenna. This resulted in a mismatch between specimen and horn that altered the horn's receiving pattern. Thus any small variation in the position of the fabric resulted in a marked change in the received power that did not adhere to the inverse square law. It was therefore decided to take a maximum received power reading (as the fabric position was changed within one wavelength of the receiver) and calculate the minimum insertion loss of the fabric.

Note: Since the transmitting and receiving horns are separated by a distance of

175 cm movement of the fabric within a wavelength of the receiving horn ( 3 cm) does not appreciably alter the power impinging on the fabric.

APPENDIX D

Ohms Per Square

1. The resistance of 3-dimensional materials is widely expressed in "ohms per square". It can be shown that this resistance is constant whether we talk about a square inch, a square foot or a square meter, etc. Refering to figure 3, we sample a material having the following characteristics: length (L), width (W), thickness (t), and resistivity (P), (an electrical constant characteristic of the particular material). The resistance of this sample between face X and face Y is expressed as:

$$R_{xy} = \frac{PL}{A}$$

where: $R_{xy}$ is the desired resistance (unknown) and A is the cross-sectional area of the material.

But $A = Wt$

so therefore $R_{xy} = \frac{PL}{Wt}$

Now if the material is a square we therefore specify that:

$$L = W$$

and then: $R_{xy} = \frac{P}{t}$

Since P is a constant and the thickness (t) of the material is uniform the resistance ($R_{xy}$) must also be constant and the conclusion being that, no matter what the dimensions of the square, the resistance from one face to the opposite face be invariable.