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ABSTRACT

The radio-frequency (rf) dosimeter developed by the Oak Ridge National Laboratory is a portable, pocket-sized cumulative-dose recording device designed to detect and record the strengths and durations of electric fields present in the work areas of naval vessels. The device measures an integrated dose and records the electric fields that exceed the permissible levels set by the American National Standards Institute. Features of the rf dosimeter include a frequency range of 30 MHz to 10 GHz and a three-dimensional sensor. Data obtained with the rf dosimeter will be used to determine the ambient field-strength profile for shipboard personnel over an extended time. Readings are acquired and averaged over a 6-min period corresponding to the rise time of the core body temperature. These values are stored for up to 6 months, after which the data are transferred to a computer via the dosimeter's serial port. The rf dosimeter should increase knowledge of the levels of electric fields to which individuals are exposed.

1. INTRODUCTION

In an effort to assess the radio-frequency (rf) electric fields present on the decks of naval vessels and their long-term effects on shipboard personnel, a portable, pocket-sized rf dosimeter with cumulative-dose recording capabilities was proposed. The major objective of the proposed rf dosimeter was to develop an instrument capable of quantizing the level and duration of electric fields present in the work areas of shipboard personnel. Readings from the rf dosimeter can be compared to the permissible American National Standards Institute (ANSI) power-density levels and can be used to produce a profile of the wearer over a specified time. The ANSI-derived permissible exposure limits are shown in Fig. 1.

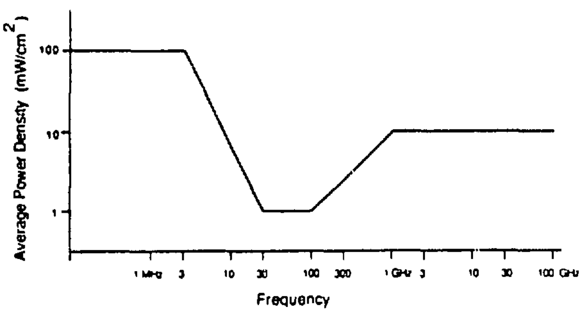

Fig. 1. American National Standards Institute–derived equivalent permissible exposure limits.

The proposed specifications for the rf dosimeter included a sensitivity range of 1 to 1000 mW/cm^2, an audible alarm for fields > 8 mW/cm^2, integration of dosage for later readout, autoranging capability, and possibly self-powering capability. The following sections show the design process, starting with the sensor, and describe the tests completed on the final product.

2. FAMILIARIZATION WITH EXISTING PROBES

The specifications for the antenna system chosen included measuring the magnitude of the electric field, an omnidirectional response, a frequency range of 30 MHz to 10 GHz, a frequency response either flat or equivalent to the human body's response, and a sensitivity range of 1 to 1000 mW/cm^2 or equivalently 61 to 1941 V/m. A design paper by Larsen and Ries[1] of the National Institute of Standards and Technology (NIST) discusses the trade-offs of different sensing phenomena. The five types of sensing phenomena listed in the paper are color change in liquid crystals, resistance change of a lossy dielectric, glowing gas probes, incandescent bulb probes, and thermocouple sensor probes. These sensing phenomena were determined to be insufficient because of poor response times, unsuitable sensitivity range, susceptibility to ambient temperature, and other problems. On the basis of the Larsen and Ries paper and other materials, a system of electrically short dipole antennas arranged orthogonally was determined to be the most feasible.

The three short dipole antennas arranged orthogonally not only meet the stated criteria but also seem the easiest to implement. Because the antennas have to be electrically short at all frequencies of interest, they are small enough to place in (or on) a small appendage to the microprocessor housing. Dipole antennas do not require special handling as do gas or liquid probes. Also, the dipole antennas are not very susceptible to high-voltage fields or ambient temperature changes. Thus, the dipole antennas were found to be the hardiest and most suitable sensing probe.

3. SENSOR DEVELOPMENT

After completing the literature research and initial experiments, the resistively tapered dipole antenna discussed in the Kanda and Driver[2] paper was chosen. The resistive taper allows the antenna to be longer and therefore more sensitive, without producing the resonances that occur on the standard conducting antenna. The mathematical basis for this design was developed by Wu and King.[3] Basically, the antenna incorporates the concept that the vector wave equation has outgoing waves only in its solution if the impedance is allowed to vary exponentially with length. Thus, the reflections that produce the standing waves are not present.

Following NIST guidelines, a thick-film sensor design was derived from the similar thin-film probe developed by Kanda and Driver.[2] Thick-film methods were selected because design and manufacturing costs could be minimized. The thick-film manufacturing could be performed at Oak Ridge National Laboratory (ORNL) to give more flexibility in altering designs and in the design process. Also, the costs of the two methods differed significantly. A commercial thin-film probe costs ~$1500; however, a set of three

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dipole antennas could be fabricated at ORNL for <$200 with the thick-film process. The size of the circuit elements and the type of thick-film materials were chosen to maximize sensitivity and maintain the required bandwidth while confining the probe to a small substrate area.

Two modifications had to be made to the original thin-film design.[4] First was the incorporation of twisted high-resistance leads. Because thick-film technique dictates wider spacing between the leads, the loop area becomes larger and can increase the inductance along the length of the leads. The resulting inductive coupling can be canceled by an effective twisting of the leads. With proper layout, this modification was accomplished rather easily with a single crossover layer. Second, the dipole antenna design requires a geometrically sharp tip. Given the small overall dimensions, larger variations could arise from the location of the pattern relative to the screen mesh. To minimize process sensitivity as well as enhance resistive tapering, a high-resistance strip 3 mm long was printed underneath the dipole tips.

Eight dipole antenna circuits were printed on a scored alumina substrate. The circuits were printed in four layers, which were fired individually. All four layers were printed by 325-mesh screen. The first layer was a gold/platinum conductor (DuPont 9885), which formed the pads for diode attachment between the dipole elements, external leads at the other end of the substrate, and short paths for the crossovers in the twisted high-resistance leads. The second layer was a dielectric (DuPont 9950), which insulated the crossover points in the twisted leads. The third layer was a 10-kΩ/sq resistor (DuPont 1741), which formed the twisted high-resistance leads along the length of the substrate to the center of the dipole antenna. This layer also included two narrow strips at the tips of the dipole antenna to effectively increase the resistive tapering effect. The fourth layer was a 10-Ω/sq resistor (DuPont 1711), which formed the actual dipole elements consisting of short, tapering triangles set at a 54.7° angle to the twisted leads. (This angle was calculated to allow the dipole antennas to be orthogonal to each other when three dipole planes are mounted 60° apart in a triangular tube.)

The fine-line resolution required by the antenna design was somewhat greater than normal thick-film capabilities, but for this development project a lower than average yield could be tolerated.[5] The small size of the circuit lines strained the limits of normal thick-film practice; however, with careful alignment of the screens a 75% yield was achieved during prototype productions.

The antenna fabrication was completed with the attachment of the surface mount components. A Schottky beam-lead diode (HP 5082-2837) was attached with conductive epoxy to the center of the dipole antenna. The original substrate was lengthened to accommodate leads to the recording circuitry by bonding (with clear epoxy) a short piece of alumina substrate to the end of the sensor opposite the dipole elements. A 0.47-μF ceramic capacitor was positioned between the external leads to integrate the signal over longer times and to reduce power consumption by decreasing the need to sample data frequently. Three identical dipole antennas were epoxied together to form a triangular tube, thus completing the geometry for orthogonal dipole antennas. The finished size of the triangular tube was 33 mm long by 10 mm high.

4. SYSTEM HARDWARE DEVELOPMENT

The hardware for the rf dosimeter parallels in function the hardware for an electric field-strength meter. Early field-strength meters were analog, and only the instantaneous field strength was displayed on the meter. The advent of the microprocessor and its computational capability allowed the use of more sophisticated algorithms in processing the data measurements. With this new capability, it became possible to compute the average value of the intensity over a given time and to store only the average value at periodic intervals.The maximum frequency for operation of the microprocessor is 12 MHz. The minimum frequency, as stated in the Intel specifications, is 3.5 MHz. The operating frequency chosen was 3.579545 MHz. A crystal of this frequency is common and commercially available because it is used in almost all computer keyboards as well as for the color subcarrier oscillator in television sets. It was desired that the computer operation be at the low end of the range because speed is not a factor. The power consumption is directly proportional to the frequency of operation; therefore, a fixed amount of energy is required to execute a fixed number of instructions. It seemed desirable to have all three antennas sampled at nearly the same time so that the square root of the sum of the squares would represent the magnitude of the electric field, which required that the microprocessor be put into a powerdown mode immediately after sampling the three antennas to save battery energy. Recent updates in Intel's specifications indicate that the microprocessor can operate at <1 Hz in frequency. The microprocessor is essentially a static part.

4.1 MICROPROCESSOR DESCRIPTION

Within the past two years, the Intel Corporation has produced a powerful complementary metal-oxide semiconductor (CMOS) microprocessor that combines both analog and digital functions on a single chip. The chip includes a 10-bit analog-to-digital (A/D) converter coupled with an eight-channel multiplexer on the input to the microprocessor. The microprocessor has a very powerful instruction set that includes multiplication and division instructions. It also has a built-in communications port for uploading and downloading data. And most important, it can be put into a powerdown mode when computations are no longer necessary, conserving the battery supply. The chip has a 256-word internal memory for temporary storage and for pointers to external memory. The instructions are 16-bit and can be stored in either a 16-bit word or 8-bit bytes. To hold down the chip count, the 8-bit mode of operation was chosen. This mode requires slightly more energy to execute some instructions but is well worth the penalty because only a single electrically programmable read-only memory (EPROM) program storage chip is needed. The EPROM is an 87C257 with the unique feature of not requiring the addresses from the microprocessor to be latched because latches are built internal to the chip. A latch is required for the random-access memory (RAM), so this feature is wasted for this implementation. Static RAMs will soon be available with this same feature, so no latch will be required in future designs, thus reducing the total integrated circuit (IC) chip count to three. Intel has announced that the 80C196 microprocessor will be available soon with either 8 Kbytes of EPROM or read-only memory (ROM). This feature would bring the total IC chip count down to two, further reducing the total pin count. A reduced pin count can lead to higher reliability, smaller circuit size, and lower fabrication cost.

4.2 SYSTEM ARCHITECTURE

The system block diagram is shown in Fig. 2. The sensor consists of three short dipole antennas connected directly to the multiplexed input of the A/D converter. Three internal registers accumulate the square of the field intensities (256 values) measured at periodic intervals by the three orthogonal antennas. At the end of a prescribed period (typically 2 min), the three registers are added together and the square root is taken. This value, which is the average magnitude of the electric field strength over the prescribed period, then is placed in RAM for storage and readout. The RAM chosen for this memory is a Toshiba TC5565APL-15L, an 8-Kbyte static RAM. This RAM allows the storage of 4096 sixteen-bit numbers. The circuit board is also wired for a 32-Kbyte chip such as the TC55256PL-15, which gives four times the memory capacity. This memory chip was not available when the memory was purchased.

The program is stored in a 32-Kbyte CMOS EPROM. The memory capacity of this chip is more than adequate for this task, leaving room for the addition of more sophisticated programs for self-testing and calibration. To change the program, the chip must be erased with an ultraviolet light source and electrically redefined in a

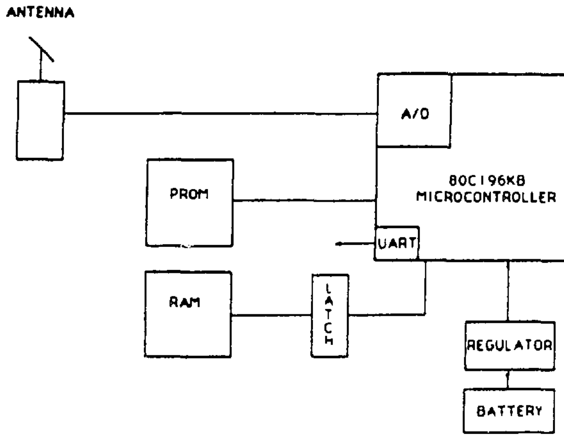

Fig. 2. Block diagram of rf dosimeter.

programmable read-only memory (PROM) burner. The new flash EPROMs would be ideal for this application because they can be erased and programmed while they are connected in the circuit. Several features necessary for this application are still unavailable in these new EPROMS. An internal universal asynchronous receiver/transmitter (UART) provides access to an external computer through the serial data link.

4.3 POWERDOWN CIRCUIT

The rf dosimeter features the powerdown circuit, which allows the unit to operate for extended periods without battery replacement. The circuit is developed on the premise that the microprocessor can be inactive while rectification is taking place on the diodes at the center points of the dipole antennas. Even if the electric field on the antennas comes from a pulse-modulated signal, the direct current (dc) voltage on the antennas represents the average field on the antennas. The time constant for the discharge of the antennas is 1.38 s.

4.4 POWER SUPPLY

The energy-to-weight ratio of the lithium battery is far greater than that of other available batteries, and the cost is reasonable. A typical battery with a capacity of 5000 mAh has an energy-to-weight ratio of 144 Wh/lb. The new lithium batteries are no longer corrosive and thus are highly safe. They have a wide operating temperature range and a shelf life of 10 years. For these reasons, the lithium battery was selected to power the rf dosimeter; and a two-cell, 6-V model was chosen. This model has the advantage of wide distribution because it is used to power small portable computers. A disadvantage of the lithium battery is the relatively poor voltage regulation. The open-circuit voltage of the two-cell battery is 6.8 V. Because the microprocessor will be going into powerdown mode, the battery voltage will fluctuate between essentially no-load value and full-load value. The microprocessor operates between 4.5 and 5.5 V. Thus, a regulator had to be designed to prevent the no-load voltage from exceeding the supply specifications of the microprocessor. With two transistors, a zener diode, resistors and capacitors a small regulating circuit was built that consumed very little power during the power down periods. Input-voltage swings from 5 to 7 V will cause the output to change from 4.88 to 5.26 V, which is well within the microprocessor specifications.

5. SOFTWARE DEVELOPMENT

The antenna system was designed to mate with a microprocessor, and the Intel 80C196 was chosen as the central processing unit (CPU) to be used during development. The necessary software for receiving inputs from the antenna system and for processing and storing the data had to be developed. This software was written in 8096 assembly language and was ported to the CPU through an Allen Systems FX-97 prototyping board. The board was used to interconnect the CPU with extra memory storage, analog inputs, and a display unit for testing purposes. The display unit consisted of an inexpensive hand-held calculator to display the outputs and to house part of the circuitry.

The programming tasks included interfacing the CPU with the other components and processing the data. The normal operation of the rf dosimeter included sampling the A/D converters, calculating the magnitudes of the electric field strength, averaging these magnitudes over a 2-min period, storing the results, and sending outputs to the display. For testing purposes, the average was shortened to 2 s to increase the sampling rate.

Another important feature of the software was the capability to enable the powerdown mode. This capability included placing the CPU in a low-power operating mode that used only ~10 μA of current and received a signal every 50 ms that restarted the normal operating sequence. A resistor-capacitor (RC) circuit was used to provide the restarting signal. Including this feature reduced power consumption by ~97% over a given period. This method was chosen over the option of having the CPU turn on only when significant fields were present because this method yields a more predictable life span for the instrument.

5.1 CODE DEVELOPMENT

Because of ease of use, low cost, and the need for microprocessor specific commands, the Allen Systems 8097-based development system was chosen. The CA-96 cross-assembler for this computer uses an IBM-compatible personal computer (PC) as the host computer. The package consists of an integrated editor and an 8096 cross-assembler. The program is placed on the hard disk of the host PC. When the program runs, it displays a menu that allows the choice of editing, viewing the assembled program, printing the assembled program, or writing the assembled program to a file. The system monitor software is listed in the technical manual and offers good examples for help in writing subroutines. There are now 11 monitor command groups that can be sent to the single-board computer.

The software was written in steps. The first step was to check out the A/D converter integral to the microprocessor. Because neither the FX-97 nor the prototype rf dosimeter boards had any kind of readout, a small hand-held calculator was interfaced to the output port of the 8097. The digital readout on the calculator allowed the digital presentation of the analog input voltage into the A/D multiplexer. The initial presentation showed the binary (bin) number of the A/D converter from zero to 1023. Later, the program was modified to display the input voltage in four decimal digits.

Different prototypes were built, including a wire-wrapped version. The different prototypes aided in locating problems such as reset circuitry that was too slow and components that used too much power. Also, in the intermediate stages it was discovered that the Allen Systems assembler did not include the power down instruction, so the hexadecimal object code for the power down instruction was added to the code after compilation.

5.2 PROGRAM OPERATION

During the initialization phase, RAM that has been storing the averaged readings is dumped to the serial RS-232 line. The communications program in the PC captures these readings for later evaluation. RAM storing the values has the addresses beginning at location 8000H. Location CX in the internal register file is reserved as a pointer to the place in memory where the next piece of data will be written. Upon initialization this location is sent over the serial link to be displayed under the header. The value of the location tells the operator how much of the memory is filled. The value then is set back to the value 8000H, and the root mean square (RMS) values stored in the memory are displayed. In the dump-memory routine after each word is read, this location is written over with 0FH so that on start-up it is clear that the memory is set and ready to go.

Computing the square root of the sum of the squares is the only involved process in the program. The algorithm is rather lengthy but allows a faster processing time. The squared value is a 32-bit number; the square root is a 16-bit number. The squared value is shifted left until a carry is detected. The number of shifts is treated like a negative exponent. The number now has been converted into a floating-point number with a 32-bit magnitude and an 8-bit negative exponent. The next step is to figure the square root of the 32-bit magnitude. The algorithm chosen to accomplish this is to make a best guess of the square root, divide this guess into the magnitude, and then figure the average of the guess and the dividend. This algorithm converges quite rapidly. Five trials are allowed for convergence. The exponent is divided by 2 and used to convert the answer to an integer. This number represents the square root of the sum of 3 × 256 squares.

At this point the answer is divided by the square root of the number of samples and multiplied by 5 to convert to millivolts. It then is stored in RAM. With storage capability for only 4096 data points, the memory would fill up in 5 days. Most of the readings would be zero because exposure is not continuous. A form of coding was added to eliminate the recording of no-field conditions. The number of consecutive zero readings was stored in a temporary register. When a field strength appears above the threshold, FFFF is placed in the memory along with the number of zero readings. Because FFFF hex will not appear as a legitimate value, it indicates that the next location contains the number of zero values in a form of run-length encoding.

When a memory-readout reset occurs, the contents of the temporary register are displayed immediately following the display of the pointer to the last memory location used. If more data than it can hold are put in the memory, the software causes the microprocessor to go into the powerdown mode until it can be reset externally. The program returns to the beginning, where it dumps the memory through the readout unit.

6. PACKAGING

The proposed specifications for the rf dosimeter called for an instrument approximately the size of a deck of playing cards. The case of the prototype rf dosimeter is 9.8 cm (3.875 in.) high, 6.4 cm (2.5 in.) wide, and 3.2 cm (1.25 in.) thick. Thus, the rf dosimeter is approximately the size of a deck of playing cards and can be equipped easily for transport by shipboard personnel. Figure 3 shows the assembled rf dosimeter.

Earlier developmental versions of the rf dosimeter were larger than the size called for in the proposal specifications, so several options were explored to reduce the size of the instrument. The number of IC chips and discrete components was minimized, and the Intel 80C196KB microprocessor was used because it houses both a CPU and A/D converters. The number of latches was reduced to one, and memory devices were chosen on the bases of their size and power consumption. Also chosen were IC sockets that already had filter capacitors connected between the power-supply voltage and ground. The circuitry of the rf dosimeter was divided between two printed-circuit boards that were stacked to reduce the instrument length. This alteration did not add significantly to the thickness of the casing, because accommodating the battery had already forced the instrument to be at least 2.5 cm (1 in.) thick. The selected battery was a two-cell lithium battery connected in series to yield 6 V. Lithium was chosen because of its high energy density, optimum energy per pound ratio, and availability in a convenient size and voltage output for the rf dosimeter application.

Other packaging considerations included attaching the dipole antenna system in a manner that would be mechanically secure and reasonably compact. The final design included a cylindrical plastic cover for the dipole antenna system, a metal support for the cover,

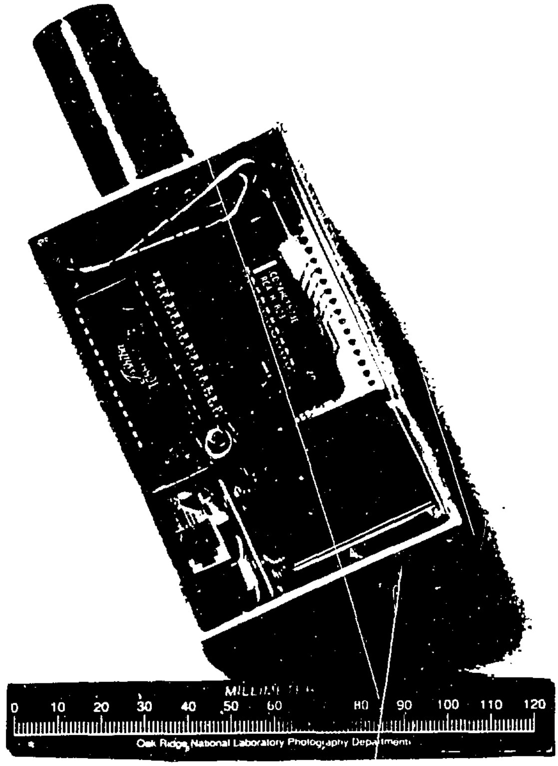

Fig. 3. Assembled rf dosimeter.

and three feedthrough capacitors. Excluded in an earlier design, the feedthrough capacitors were added to improve the shielding integrity of the case. The choice of feedthrough capacitors choice was based on their attenuation characteristics at frequencies above 1 GHz, threaded mounting mechanism, and overall size.

A 3.175-mm-thick (0.125-in.) aluminum case with a top-mounted lid was used to house the rf dosimeter. Along with the lithium battery, the two printed-circuit boards were stacked and mounted in the case on an insulator pad to provide support against vibrations. Small openings were drilled in the instrument case to accommodate the antenna system connection, by way of feedthrough capacitors, to the internal circuitry. The threaded feedthrough capacitors were used to attach the cover support to the case. The antenna system then was glued to the case, and the leads were soldered to the capacitors. The last step was to attach the plastic cover to its support with small plastic screws.

As indicated earlier, feedthrough capacitors were not originally used; instead a hole large enough to accommodate the antenna leads was drilled in the case. However, when the instrument was tested in the 10-GHz frequency range, it failed at power-density levels > 200 mW/cm^2. Thus, feedthrough capacitors were used to reduce the susceptibility of the instrument at high frequencies. As an additional shielding measure, conductive aluminum tape was placed over the edge of the case to serve as a gasket for the lid interface.

7. READOUT INTERFACE UNIT

The readout unit incorporates an interface between the serial output of the microprocessor and the serial input to an IBM-compatible PC. Within the unit are the interface chips to convert transistor-transistor logic (TTL) signals to RS-232 format. The serial output from the microprocessor has logic levels between 0 and +5 V, which is converted to levels between +15 and −15 V by the 1489 integrated circuit. Provision is made to convert the RS-232 signals from the PC to the TTL levels of the microprocessor, but it was not necessary to implement this feature. At some point it could be practical to put a flash EPROM in place of the ultraviolet EPROM because EPROM can be programmed in its socket. A line was included that runs from the reset pin to a switch on the readout unit. This line allows the operator to reset the microprocessor, starting the process of dumping the memory of the rf dosimeter.

8. TESTING AND EVALUATION

8.1 TESTING

After completion of a prototype rf dosimeter unit enclosed in a shielded package, the unit was taken on two occasions for testing to the Naval Surface Warfare Center (NSWC) in Dahlgren, Virginia. The facilities at NSWC include antennas and power generation systems that can provide relatively high-power fields over the frequency range of the instrument. These systems operate over a large ground plane that emulates the deck of a ship. These features made NSWC an appropriate testing ground for the rf dosimeter.

With the aid of on-site personnel, the rf dosimeter was tested for sensitivity and susceptibility. The power at each of the test frequencies was varied in 3 to 5 steps from an attenuated level to the maximum available power. In this manner, the instrument's sensitivity to low-power fields, as well as to high-power fields, was determined.

8.2 EVALUATION

From the test results, the frequency response of the rf dosimeter (shown in Fig. 4) was derived. In general, the results showed that the instrument was sensitive enough to measure below the permissible levels given by the ANSI standard. The results also showed that the sensitivity decreased with increasing frequency as was desired to match the sensitivity of the human body.

Although the general results were good, some problems remain. First, the sensitivity vs frequency was not an exact representation of the sensitivity of the human body. The sensitivity of the instrument decreased at ~20 dB/decade of frequency, while the decrease for the human body (as given by the ANSI permissible level curves) is ~10 dB/decade. Also during the first series of tests, the instrument failed to function properly at combinations of high power and frequency. At frequencies near the upper limit of 10 GHz, the instrument failed at field strengths above 1000 V/m.

The sensitivity problem could possibly be corrected by altering the impedance in parallel with the diode. The problem may be ignored if the instrument's sensitivity is considered accurate enough to determine whether harmful dosages are present in the work area because the instrument's main function is to give a long-term approximate history of the daily rf fields encountered by personnel.

The susceptibility problem was addressed with modifications to improve the shielding integrity of the rf dosimeter. The enclosure housing was redesigned to incorporate feedthrough capacitors for passing the antenna values through the enclosure surface to the microprocessor. This and other minor improvements such as conductive contacts for the lid and better overlap of the case body and lid were also implemented. The results of these improvements were verified when the instrument was retested on a second trip to NSWC. With these modifications in place, the rf dosimeter indicated no susceptibility problem.

9. CONCLUSIONS

The primary goals of the project were achieved. An instrument the size of a deck of playing cards was made with an "on" time of ~125 days with unselected microprocessors. When the minimum powerdown current of the microprocessors is specified at purchase, the life of a single battery will be >1 year. The antenna can be fabricated fairly inexpensively and seems to meet the general

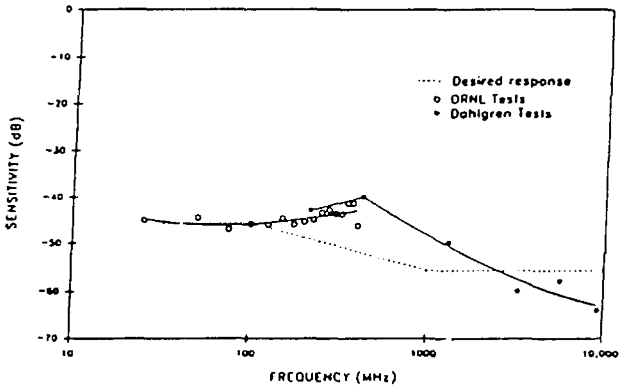

Fig. 4. Frequency response of rf dosimeter.

specifications. Now that the software and hardware have been developed, the rf dosimeter will make a good platform for future tests on the antenna characteristics. The 8-Kbyte static memory used may not have enough capacity for some measurements. If the unit is assigned to an individual and only a history of that individual's exposure to nonionizing radiation is desired, the smaller memory should be adequate. Installing a larger memory is simple because the printed-wiring boards were made to accommodate the larger chip. Experience must be gathered in the intended environment to size the memory properly. The software was easy to develop because of the powerful instruction set of the 80C196 microprocessor. Maintenance of the software should be fairly easy.

Several features in the original project specifications were set aside as the project proceeded. It was thought originally that the instrument should have an audible alarm when a preset level of field strength was exceeded. This feature can be accomplished with minimum effort, but it was decided that the alarm might cause personnel to leave the area without performing their assigned functions, possibly jeopardizing a mission. Another goal was to develop a unit that would be powered by the electric field the instrument measures. Because the instrument has to be returned for readout, it was thought that it would be just as easy to replace the small battery at that time. Autoranging on the antenna inputs was not necessary, because the 10-bit A/D converter covers the full dynamic range.

The instrument was designed to record the average field strength during a 2-min period. To conserve memory, however, this period should be as long as possible. Six minutes is apparently the internal-temperature time constant of the human body. Three samples in the 6-min period would be a compromise between adequate sampling and memory conservation. Experience should dictate the proper recording time. The first units incorporated a recording time of less than 2 min so that the operational tests could be accelerated.

The readout of the memory has been very satisfactory. A program was written for Lotus 1-2-3 software to display a graphical time history of the readouts immediately after readout, giving the operator an instant view of exposure.

Three identical units have been built and tested. The test results showed that the instrument had adequate measurement sensitivity and could survive high-power fields. A group of units will be fabricated at low cost and placed in their intended environment to determine how well they define the rf field-strength environment.

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