INTEGRAL DOSE-RATE DETERMINATION

An electrical resistance calorimeter was developed which, when placed in the cavity, produces the same mode, cavity, and transmission line parameters as the head of an experimental subject. To develop this load, a monkey was placed in a restraining chair with his head protruding into the cavity, which was tuned to resonate at 383 MHz. The operating frequency and mode were determined and the coupling between the cavity and the transmission line was adjusted to yield a VSWR of 1.08. The monkey was then removed and acrylic cylinders in a variety of sizes, each containing a coil of nichrome heater wire, were filled with normal saline and placed one at a time in the cavity until one was found which produced the same mode and electrical measurements as those obtained with the monkey head as the load. This equivalent load is shown in Fig. 5. A motor driven stirrer was used to prevent temperature gradients during heating.

In order to determine the amount of RF power absorbed by the monkey's head, the equivalent-load calorimeter was heated by a known net RF power P_t (or forward power minus reflected power) for 3 min and the rise in temperature observed. Next the saline-filled cylinder was heated by applying dc voltage across the nichrome wire.

Using (1), the constant of proportionality K_{dc} relating the temperature change ΔT_{dc} to the dc power dissipation P_{dc} and the time interval Δt_{dc} was determined.

$$K_{dc} = P_{dc}\Delta t_{dc}/\Delta T_{dc}. \tag{1}$$

The fraction K_m of the net RF power absorbed by the equivalent load could be determined using (2),

$$K_m = P_m/P_t = K_{dc}\Delta T_m/P_t\Delta t_m \tag{2}$$

where P_t is the net power supplied to the cavity, P_m is the power absorbed by the equivalent load, and ΔT_m and Δt_m are, respectively, the rise in temperature and the duration of RF irradiation of the equivalent load. The integral dose rate ($\dot{\epsilon}$) to the monkey head irradiation in the cavity is then given by

$$\dot{\epsilon} = K_m P_t \quad \text{W}. \tag{3}$$

K_m was determined to be 0.619 ± 0.029 for the load electrically equivalent to a 5-kg monkey. Table I shows typical value recorded during these experiments.

DISCUSSION

This paper has described an irradiation system which permits the determination of the amount of power absorbed by a monkey's head. While the head and neck of the monkey are irradiated in a well-defined field, the rest of the body remains essentially in a zero RF level environment. This allows regular instrumentation to be used in monitoring many biological parameters such as ECG, blood pressure,

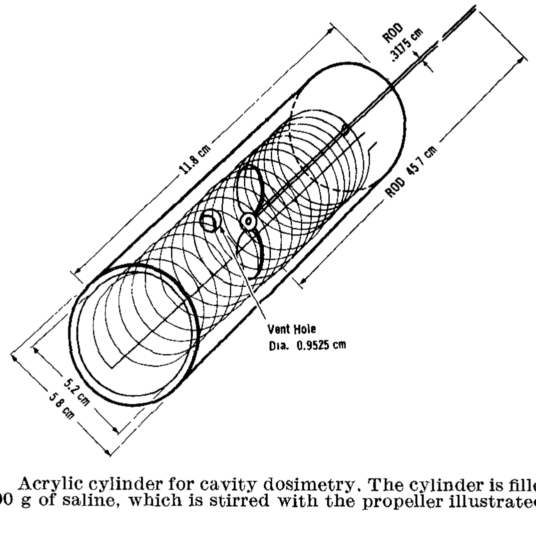

Fig. 5. Acrylic cylinder for cavity dosimetry. The cylinder is filled with 200 g of saline, which is stirred with the propeller illustrated.

TABLE I

CALORIMETRIC RECORDED DATA DURING DC AND RF EXPERIMENTS

No. of D.C. Exper.	T_{dc} C° Start - Finish	ΔT_{dc} C°	Δt_{dc} Sec.	P_{dc} watts	K_{dc}
3	19.4 - 23.3 ± 0.4	3.8 ±0.0	180 ±0.00	7.56 ±0.35	5.94 ±0.39
3	21.6 - 25 ± 0.2	3.4 ±0.1	180 ±1.0	7.79 ±0.01	6.90 ±0.38
3	23.0 - 25.1 ±0.1	2.11 ±0.1	180 ±0.00	3.03 ±0.12	7.15 ±0.22

No. of MW Exper.	T_m C° Start-Finish	ΔT_m C°	Δt_m Sec.	P_t watts	P_m watts (K_{dc} = 7.15)	K_m
6	23.1 - 25.1 ±0.1	2.0 ± 0.0	197.5 ± 10	7.24 ± 0.22	4.49 ± 0.27	0.619 ± 0.029

and body temperature, without mutual interference between the instruments and the radiation field. However, the determination of the distribution of absorbed RF power inside the head is still needed in order to understand microwave-induced effects upon the central nervous system. The equivalent load used in this investigation is insufficient for distributed dose-rate determinations, since the equivalent load represents the monkey head only in terms of the integral dose rate. A preliminary experiment using thermographic techniques and monkey-head models, made of brain equivalent material developed by Guy [6], indicates that the distributed dose-rate pattern produced in this facility is more uniform than reported dose-rate patterns produced in monkey heads by 2450-MHz radiation [7].

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Behavioral Suppression by 383-MHz Radiation

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***Abstract*—The heads of two rhesus monkeys were irradiated in a 383-MHz resonant cavity immediately before and during perform-**

Manuscript received March 13, 1974, revised August 6, 1974. This work was supported in part by the Environmental Protection Agency under the National Bureau of Standards Interagency Agreement EPA-IAG-0109.

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ance of a four-choice forced-choice serial reaction task. CW radiation at integral dose rates of 0.001–17.5 W were delivered to the head. No effects were observed below a critical dose level ($\simeq$23 W/kg) derived from integral dose rate and body mass. Above this level, behavioral suppression occurred, i.e., correct response rate was profoundly altered. The effect was completely reversible and repeatable in one of the subjects—the other subject did not recover completely and was sacrificed for histological examination which revealed no gross or microscopic damage. The nature of the effect suggests a neurochemical rather than an electrical or mechanical basis for the results.

INTRODUCTION

Heating caused by microwave radiation can cause tissue damage. While microwave exposures below 10 mW/cm^2 probably do not produce gross tissue damage, anecdotal reports in the scientific literature of Eastern Europe suggest that deleterious effects of microwaves can be observed in work performance and autonomic nervous system functioning. Furthermore, these reports conclude that the behavioral effects of microwave irradiation include a "general irritability syndrome" (agitation, increased aggressiveness, sleeplessness), and most prominently, a decreased sensitivity of one or more sensory systems [1]–[3]. In the United States, Baldwin, Bach, and Lewis [4], noted "a progressively generalized slowing and some increase in amplitude" of EEG patterns while exposing the heads of rhesus monkeys to 383-MHz CW radiation in resonant cavities. "The record seemed to change quickly from an aroused pattern to one indicative of a drowsy state." These changes were accompanied by an alternating pattern of agitation, drowsiness, and ataxia.

On the basis of these reports, a study was initiated to investigate the effects of RF radiation on a behavioral task sensitive to change in activation level.

METHOD

Subjects

Subjects were two male *rhesus* monkeys, one weighing 5.0 kg (#6), the other weighing 3.0 kg (#3).

Apparatus

The principal component of the microwave exposure apparatus was a right-circular cylindrical cavity resonator, described in detail by Edwards and Ho [5]. Briefly, the cavity wall was regular aluminum window screen 6.3 mesh per centimeter. The top and bottom plates were 0.32- and 0.64-cm-thick aluminum sheets, respectively. The cavity had a radius of 47.9 cm and a height of 45.2 cm. The loaded resonance frequency of the cavity was 383 MHz. The cavity was coupled to a 383-MHz RF source by a length of RG-8/U coaxial cable which terminated in a one-quarter-wavelength probe that extended through the cavity wall 6 cm above the bottom plate. An acrylic monkey-restraining chair was suspended from the bottom plate of the cavity. The monkey's head protruded into the cavity through a 9-cm-diameter hole in the center of the bottom plate. The head was oriented so that the probe was directed at approximately the middle of the face.

Stimuli for the behavioral task were provided by four 0.32-cm-diameter acrylic light pipes placed through the cavity wall and terminating in a diamond-shaped pattern, 2.2 cm on a side, located 14.0 cm in front of the monkey's head. The light pipes could be transilluminated individually by #1820 light bulbs, located outside the cavity. A response lever which could be moved in each of four directions, corresponding to the arrangement of the stimulus lights, was attached to the cavity supports within easy reach of the subjects' hands. A feeding tube was placed immediately in front of the mouth of the subject. Using their lips and tongue, the subjects could easily remove food pellets deposited in the tube. Programming of the behavioral task was accomplished through logic modules located in another room. Lever-press responses were recorded on impulse counters. The entire cavity apparatus was housed in a darkened, sound-attenuated, electrically shielded room. White noise, sufficient to mask extraneous sound, was provided.

Procedure

A four-choice forced-choice serial reaction task was employed to serve as a sensitive indicator of alterations in the arousal (Webb and Agnew [6]) of two well-trained rhesus monkeys. The task was self-paced. Experimental sessions were conducted daily. Subjects were adapted to restraint and trained to move the lever in each direction for food reward. Discrimination training was then begun, during which one of the stimuli was lighted at a time. The subject was required to move the lever in the direction indicated by the light. For example, if the top light was on, the lever was to be moved up; if the right light was on, the lever was to be moved to the right, etc. Criterion performance required 100 correct lever presses to obtain a food pellet. During criterion performance, stimuli were presented in random order, changing after each response. Correct responses produced an immediate stimulus change and 0.75-s presentation of a 1-kHz tone. Errors produced a 3-s time-out, during which all stimulus lights were extinguished and lever presses had no consequence.

For each session, subjects were placed in the restraining chair for 60 min prior to initiation of the behavioral program. Behavioral sessions lasted 120 min, or until the subject obtained his entire daily food ration of 60 pellets (monkey #3) or 80 pellets (monkey #6), whichever came first.

Experimental sessions were conducted without RF irradiation until errors were less than 2 percent of the total number of responses for each of five successive days. This training required 285 days for monkey #6 and 255 days for monkey #3. At this point, a radiation series was initiated. On irradiation days, subjects were irradiated during the 60-min waiting period, as well as during the behavioral session. In order to protect the monkeys from possible permanent damage prior to completion of the experiment, integral dose rates were presented in an increasing sequence. Thus both monkeys received their doses in the following order: 0.001, 0.01, 0.1, 1.0, 10.0, and 15.0 W $\pm$ 10 percent. Additionally, monkey #6 received 17.5 W. At each power level, subjects were irradiated for 2 h each day for 5 days, then were allowed 2–7 days for recovery of baseline prior to irradiation at the next higher power level. Monkey #3 was sacrificed and a histological examination of his brain conducted when his performance failed to recover following irradiation at 15.0 W.

RESULTS

Integral dose rates of less than 10 W had no effect on the performance of either monkey. Correct response rates at lower levels of radiation fell within the range obtained during sham irradiation. Incorrect response rates remained low under all experimental conditions. Fig. 1 shows that at 10 W, the correct response rate[1] of monkey #3 declined markedly by the third day of irradiation and, on the fourth and fifth irradiation days, improved only to the lowest levels exhibited previously. The figure shows that behavioral suppression for monkey #3 was accentuated at 15 W. Suppression increased throughout the five irradiation sessions at this integral dose rate. Fig. 2 shows that at 17.5 W, monkey #6 also exhibited profound suppression, particularly during the last three irradiation sessions. This effect of RF radiation proved reversible in monkey #6. There also may be some indication of recovery on day 5. In any case, following irradiation his performance returned to normal. In the 14 days following irradiation at 15 W, the correct response rates of monkey #3 increased to about six times the corresponding rate on irradiation day 5. However, monkey #3 failed to recover baseline performance and was sacrificed for histological examination. Neither gross

[1] Correct response rate was calculated by dividing the number of correct responses by the session duration in minutes. Note that the 3-s time-outs produced when the monkeys made errors biased the determination of correct response rates. The reported rates are approximately 1–2 percent too low. Criterion performance would not have been met without the use of time-outs. High rate, chance level behavior, even with a requirement for sequentially correct responding, was observed prior to the imposition of the time-out contingency.

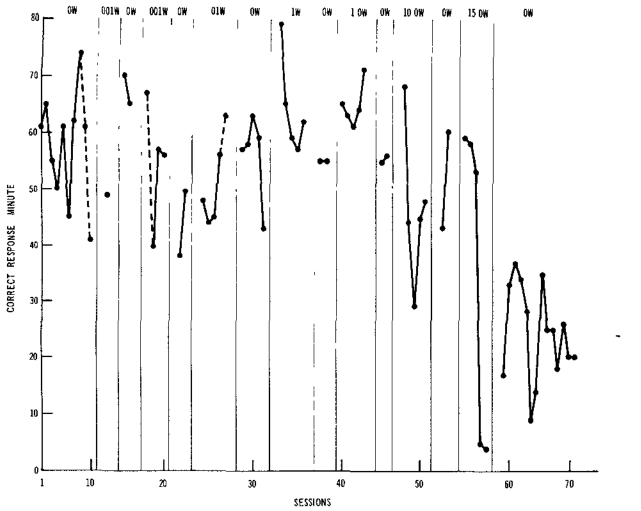

Fig. 1. Performance of monkey #3 on each daily session. Irradiation conditions are separated by vertical lines with the integral dose rate for each condition indicated at the top of the figure. Points connected by dotted lines were not conducted on successive days, usually due to some form of equipment failure.

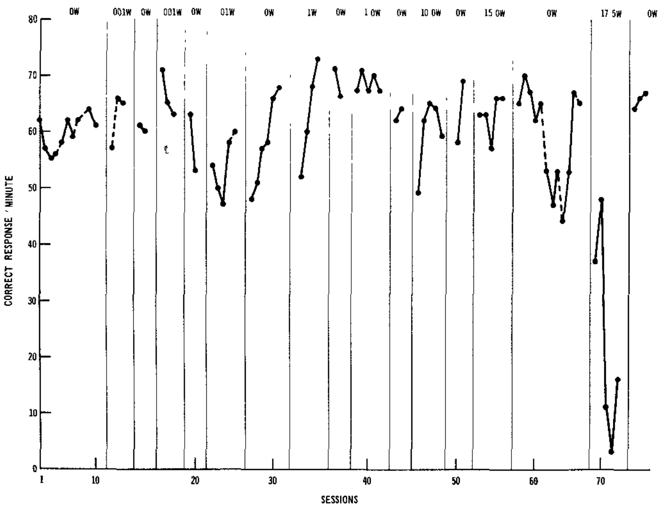

Fig. 2. Performance of monkey #6 on each daily session.

nor light-microscopic examination of the brain showed any abnormalities.

It should be noted that the declines in correct response rate observed with the higher doses were accompanied by declines in overall responding rate. Thus the proportion of errors made under high dosage did not necessarily show correspondingly large increases over the proportion of errors under lower dosage.

DISCUSSION

These results confirm and elaborate the casual observations of a RF-induced disturbance in arousal level and performance reported in the Eastern European literature [1]–[3] and in Baldwin, Bach, and Lewis [4]. Critical levels of RF irradiation were shown to produce extreme deficits in performance. The deficits appeared after a delay, increasing until the response rates were only 5–10 percent of the first day levels. Observation of the monkeys by way of low-light-level closed circuit television revealed a pattern of initial agitation and subsequent drowsiness and flacidity, similar to that described by Baldwin *et al.* Typically, after several minutes of struggling, the monkeys sat motionlessly, with either staring or closed eyes. Performance for one monkey was completely recovered on the day following the 17.5-W irradiation series, even after repeated series at this level.

Attempts were made to record electroencephalographic data during the 60-min waiting periods. Needle electrodes were inserted under the scalp of the occipital region of the head. Because of the high artifact level generated during the monkey's period of agitation, little useful data were collected. Unfortunately, the use of implanted electrodes was ruled out because of the possibility of arcing during irradiation. For these reasons, electroencephalography was discontinued. No conclusive changes were observed.

This study differs from earlier ones in that irradiation level was measured by use of integral dose rate rather than by field density. Dosimetry is thus in terms of power absorbed by the monkey's head (watts) rather than by incident power density (watts per square centimeter). Details of the dosimetry may be found in Edwards and Ho [5].

Although it appears that the critical dose rate differs for each monkey, it should be noted that there was a considerable mass difference between subjects. (Monkey #3 weighed 3.0 kg, and monkey #6 weighed 5.0 kg.) Since the head mass/body mass is a constant for the monkeys (approximately 0.15), and since thermographic measurement suggests that the integral dose rate is evenly distributed throughout the head (see the following), we can calculate the approximate maximum dose rate to the head as

$$15\ \text{W}/(0.15)(3.0\ \text{kg}) = 33.3\ \text{W/kg for } \#3$$

$$17.5/(0.15)(5.0\ \text{kg}) = 23.4\ \text{W/kg for } \#6.$$

If we take the integral dose rate during which the effect is first noticed, i.e., 10 W for monkey #3 and 17.5 W for monkey #6, an estimate of the critical dose rate may be

$$10\ \text{W}/(0.15)3\ \text{kg} = 22.2\ \text{W/kg for } \#3$$

$$17.5/(0.15)5\ \text{kg} = 23.4\ \text{W/kg for } \#6$$

figures which compare well.

The nature of the effect (its dependence on critical dose levels, its delayed onset, and its reversibility in at least one animal) suggests a neurochemical rather than an electrical or mechanical process. One may speculate that such a neurochemical change could be induced by localized heating of the head since core body temperature measurements made on these monkeys with a rectal thermometer showed no changes during irradiation. Preliminary distributive dose measurements using thermographic procedures described by Guy [7] indicated that the RF energy penetrated beneath the "skull," producing a generally even heat distribution in the space occupied by the "brain." These measurements were made on a "phantom" head—a molded model of a monkey head constructed of materials which closely approximate the dielectric properties of bone and brain tissue.

If this effect is indeed neurochemical, serotonin is likely to produce it. This hypothesis is suggested by previous reports that microwave irradiation produces alterations in the states of wakefulness and by concomitant evidence that serotonin plays a major factor in the regulation of sleep states [8].

For these reasons, research has been suggested to investigate the possible role of the serotonergic system in microwave effects. Currently, the authors are studying the ability of serotonin inhibitors and antagonists to enhance or decrease the RF-induced changes observed in behavioral performance.

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The Double-Swept-Frequency Locating Reflectometer

ITSUO YAMAURA AND TAKEHIKO HIDAKA

***Abstract*—A swept-frequency-type reflectometer is newly developed which is capable of measuring the distances to the reflection locations and reflection magnitudes in the coaxial line or waveguide, using a double-swept-frequency (DSF) source and a bandpass filter. The principle of this reflectometer and experimental results obtained at 2 GHz are given.**

INTRODUCTION

In the measurements of coaxial-line or waveguide systems, it is often required to know the locations of reflections and their magnitudes. For this purpose, two types of reflectometers have been developed. One is the time-domain reflectometer, and the other is the swept-frequency-type reflectometer. In the latter-type reflectometer, we make a frequency analysis of the beat signal between the reference and reflected waves when the frequency of the incident wave is swept. In this type, Hollway's comparison reflectometer [1] and Somlo's locating reflectometer [2] are useful. Further, the set of this kind of reflectometer with the audio spectrum analyzer is commercially available [3]. These swept-frequency-type reflectometers are characterized by the beat frequency analysis. On the contrary, without making the frequency analysis of the beat signal, a successful reflectometer is newly designed by using a DSF source and a bandpass filter.

PRINCIPLE

Let us consider a transmission line without frequency characteristics. When the input signal is fed to the transmission line, the reflected wave returns to the incident port with time delay proportional to the distance from a reflection location. As the frequency of the incident wave is swept with the triangular waveform, a slight difference of the frequency occurs between the incident and reflected signals. Then the beat frequency (f_b) is given as follows [4];

$$f_b = 4f_r \Delta f l / v_p \tag{1}$$

where f_r is the repeating frequency (we define this repeating as the primary sweeping) of the triangular waveform signal, Δf is the swept microwave bandwidth, l is the distance from the incident port to the reflection location, and v_p is the phase velocity in the transmission line. When there are a number of reflection locations in the line, the beat signal consists of many frequency components.

As we make the frequency analysis of the beat signal, the reflection locations and the magnitudes become known. Each beat frequency corresponds to the distance l, and the amplitude of this beat component is proportional to the reflection coefficient at l. Calibration by the standard mismatch gives the exact reflection coefficient.

In general, we obtain the location and the magnitude of reflections using an ordinary spectrum analyzer [3]. Instead, in this paper, we propose a new method to separate the reflections without the spectrum analyzer.

From (1),

$$l = f_b v_p / (4 f_r \Delta f) = k f_b / f_r \tag{2}$$

where $k = v_p/(4\Delta f)$. If we extract a constant f_b component from the beat signal by a bandpass filter, l is obtainable from the sweeping either f_r or Δf. If Δf is fixed, the final form of (2) is available. This form means that the distance l can be obtained by varying primary sweep frequency f_r (we define varying the primary sweep frequency f_r as the secondary sweeping) since k and f_b are constant. In conclusion, it is obvious that the reflection locations and the magnitudes can be taken by doubly (primary and secondary) sweeping the oscillator frequency instead of the spectrum analyzing. We call this method the DSF locating reflectometer.

EXPERIMENTAL METHOD

Fig. 1 shows the experimental arrangements of the DSF locating reflectometer. The frequency of the sweep oscillator is frequency-modulated (primary sweeping) with the triangular waveform signal by the function generator. The primary sweep frequency is f_r. The swept microwave bandwidth Δf is preset in the oscillator. The output signal of the function generator is swept repetitively (secondary sweeping) by the internal sweep function. The period of the secondary sweeping is taken to be much longer (over ten times) than that of the primary sweeping. Therefore, the primary sweep frequency f_r is gradually increased. These aspects are shown in Fig. 1. The signal, synchronized with the secondary sweep, is connected to the X axis of a CRT, and indicates the reflection location. The microwave output power of the sweep oscillator is leveled by ALC system, and fed to a 3-dB directional coupler, where the incident and reflected waves from the test line are sampled. To use the 3-dB directional coupler for the sampling [2] is useful to obtain good linearity up to full reflection. The crystal detecter, which plays as a homodyne mixer, connected to the coupler yields the beat signal. This beat signal is filtered by the bandpass filter (center frequency: 1 kHz, corresponds to f_b, bandwidth: 100 Hz). The output signal of the filter is amplified by the audio amplifier, and rectified by a diode. The rectified signal connected to the Y axis of the CRT shows the reflection magnitude.

The test line used is the cascade connection of the coaxial line (5D2V: 50 Ω) and the waveguide (WRJ-2: 1.7–2.6 GHz). The coaxial-line system is composed of two parts; ca 100-cm and ca 30-cm lines connected with the coaxial adaptor. The waveguide system is composed of a coaxial-to-waveguide transducer, a stub section, and a dummy load. The stub section is used for checking the reflection effect of a stub.

The microwave frequency range swept in the sweep oscillator is 2.00–2.45 GHz (Δf = 450 MHz), and the primary sweep frequency f_r is swept from 20–100 Hz by the secondary sweep signal with the frequency of 1 Hz or less. Hence the CRT display is obtained at a rate of once per second or less.

RESULTS AND DISCUSSIONS

Fig. 2 shows the experimental results. Fig. 2(a) is the CRT display when the stub is removed and Fig. 2(b) is the result when the stub is inserted into the waveguide by 1 cm. The test line used is shown in

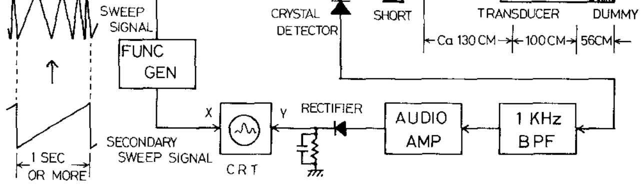

Fig. 1. Experimental setup of the double-swept-frequency locating reflectometer.

Manuscript received April 12, 1974; revised September 9, 1974.
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