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ENVIRONMENTAL EXPOSURE TO NONIONIZING RADIATION

U. S. ENVIRONMENTAL PROTECTION AGENCY
Office of Radiation Programs

ENVIRONMENTAL EXPOSURE

TO NONIONIZING RADIATION

Proceedings of a Session on Environmental Exposure to Nonionizing Radiation, Annual Meeting of the American Public Health Association

Atlantic City, New Jersey, November 14, 1972

May 1973

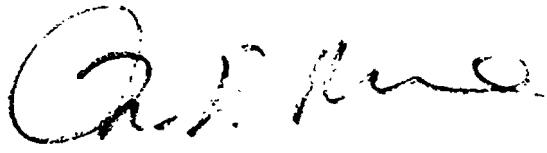
Cosponsored by
AMERICAN PUBLIC HEALTH ASSOCIATION
Radiological Health Section
and
U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Radiation Programs

FOREWORD

The Office of Radiation Programs carries out a National program designed to evaluate the exposure of man to ionizing and nonionizing radiation, and to promote the development of controls necessary to protect the public health and safety and assure environmental quality.

Within the Office of Radiation Programs, the Field Operations Division conducts programs related to sources and levels of environmental radiation and the resulting population exposure. Reports of the findings are published in *Radiation Data and Reports*, appropriate scientific journals, and special technical reports.

The technical reports allow comprehensive publication of the results of intramural, contract, and sponsored projects. Readers of these reports are invited to comment on their contents or to request further information.



W. D. Rowe
Deputy Assistant Administrator
for Radiation Programs

PREFACE

The session on environmental exposure to nonionizing radiation was held to promote an interchange of information, among investigators and health personnel, on various problems related to protection against possible hazards of such radiation.

Joint sponsorship by the American Public Health Association and the Office of Radiation Programs of the Environmental Protection Agency reflects growing concern about the impact of increasing uses and sources of nonionizing radiation. It is hoped that the published proceedings of this session will serve to stimulate interest and efforts to assure that the growth of technology in this field will be consistent with the protection of health.

We acknowledge with appreciation the contributions of the participants and of the editors whose efforts made early publication possible.

Charles L. Weaver
Director
Field Operations Division

William A. Mills, Ph.D.
Session Chairman

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INTRODUCTORY REMARKS

W. A. Mills, Session Chairman

Electromagnetic radiation has, for the sake of convenience in assessing environmental and public health implications, been characterized into two major categories, namely ionizing and nonionizing radiation. The point of differentiation between the two categories has been defined in terms of the amount of quantized energy (described in terms of wavelength) required to attain the ionization potential of atoms. The session on Environmental Exposure to Nonionizing Radiation concerns itself with that portion of the electromagnetic radiation spectra having energies sufficiently below the atomic ionization potentials such that the energy transfer occurring is primarily through atomic vibrations and rotations. Included in this spectrum are radiation popularly designated as microwaves, television waves, and radio waves.

These forms of nonionizing radiation, particularly microwave radiation, have recently become of national concern because of rapid increase in their industrial, communication, and consumer applications and their potential harm to public health; the latter a major point of controversy because of the lack of sufficient biologic data.

In planning this session, we have attempted, by the mechanism of invited papers, to outline a program which will scope the extent of nonionizing radiation in the environment, describe some of its applications and growth, including the potential for delivering solar energy as an alternative energy source, examine some of the nonbiologic "side effects," and conclude with an overview of the Federal activities in this area. The program was designed to exclude presentations on the biologic effects of microwaves and radio waves, since this has been the topic discussed in many recent scientific meetings.

THE MANAGEMENT OF THE RADIO SPECTRUM AND ITS RELATIONSHIP TO THE ENVIRONMENT

Donald M. Jansky, M.S.E., Office of Telecommunications Policy, Executive Office of the President, Washington, D.C.

In addressing this subject, one might first ask what constitutes use of radio in the United States such that it requires being managed? There has been some form of management of the use of radio in this country for over fifty years. Such management has been necessitated by the fact that man has learned how to build and design equipments which provide controlled radio emissions of various types for the transmission of information carrying energy from one point to another. These emissions consist of oscillatory radio energy. The specific frequency of these oscillations vary from very small, i.e., a few cycles per second, to many hundreds of millions of cycles per second. The required magnitude of the energy involved in these emissions to effectively send a signal to a particular destination is a function of the frequency involved, the amount of information to be sent and the distance over which that information is to be sent. During these fifty years communication system designers have found many needs for the use of radio frequencies as a means of communications and in the process have created many equipments to accomplish this. Management has been required to establish and enforce the boundary conditions which will permit the maximum number of such emissions to take place without simultaneously causing harmful interference to other systems attempting to do similar kinds of information transfer.

Presented at the Session on Environmental Exposure to Nonionizing Radiation, November 14, 1972.

The fact that limits must be placed on these emissions indicates that there is an upper boundary on the number of a particular kind and type of radio emission which may be utilized in a particular geographical area without causing such undue interference with other radio equipments in the same area. Because of these limitations on the availability of radio frequencies, they are often referred to as natural resources and are managed in a fashion which has many analogies to other natural resources such as water and land.

Furthermore, as with these other resources, the radio spectrum is increasingly being considered part of the environment to which man may, or already has done damage, and therefore must be put under increasing scrutiny to effectively conserve it. In this connection, during the past two years, it has become increasingly necessary for radio spectrum managers to be aware of the real and potential harm that radio energy could do to the biological environment and, in particular, man. It is this latter concern which serves as the nexus of this paper.

Dimensions of Radio Use

The next several charts and diagrams provide a basis for appreciating the terrific dependence that our society presently has on availability of radio frequencies. In fact, as these charts will illustrate, the United States has as much dependence on availability of radio frequencies as we do on availability of energy resources. The telecommunication systems that are supported by availability of radio frequencies provide a virtual nervous system of our society. Figure 1 indicates the vast range of the kinds of services performed by systems

RADIO SERVICE BY SOCIAL FUNCTION

SOCIAL FUNCTIONS	RADIO SERVICE
DEFENSE	COMMAND AND CONTROL, DETECTION, SURVEILLANCE, IDENTIFICATION, MISSILE GUIDANCE
PUBLIC INFORMATION AND ENTERTAINMENT	TV, AM, FM BROADCASTING
PRIVATE COMMUNICATION	RADIO RELAY OF TELEPHONE, TELEGRAPH, FACSIMILE, TWO-WAY TELETYPE
PUBLIC SAFETY	POLICE, FIRE, AVIATION, RAILROAD MARINE, HIGHWAY, FOREST PROTECTION
RECREATION AND EXPLORATION	AMATEUR RADIO, CITIZENS BAND, RADIO ASTRONOMY, SPACE
HEALTH	TV, AM, FM BROADCASTING, RADIO RELAY OF TELEPHONE, POLICE, FIRE
RESOURCE MANAGEMENT	FORESTRY CONSERVATION, WEATHER REPORTING, FUEL AND ELECTRIC POWER SUPPORT, AIR AND WATER POLLUTION, WILD LIFE CONTROL
INDUSTRIAL CONTROL	TAXI, TRUCK, BUS, OFFSHORE OILRIGS, INTRAPLANT COMMUNICATIONS

Figure 1

using the radio spectrum. Figure 2 shows the quantity of assigned frequencies to Federal Government systems as of July of this past year. These assignments give authorization to various Federal agencies to operate radio equipments. The subsequent charts (Figs. 3, 4 and 5) give an indication of the way the kinds of systems use these assignments.

An assignment may represent anywhere from one to several hundreds of equipments operating on the same frequency. These numbers are an indication of how only the Federal Government uses the radio spectrum. Authority to get these frequencies is obtained from the Office of Telecommunications Policy with advice from the Interdepartment Radio Advisory Committee. The non-governmental use of radio is managed by the Federal Communications Commission. Users of radio frequencies managed by this organization are much more widely known. They include your various business radio services, such as taxicabs, all your broadcasting stations (AM, FM, television both UHF and VHF) and the American Telephone and Telegraph Company (AT&T), which has extensive frequencies for microwave systems which crisscross the United States providing great volumes of communication service. Of course, to obtain an authority to operate under the jurisdiction of the Federal Communications Commission, one must have a license. A license and an assignment are roughly equivalent.

An indication of the economic impact of telecommunication systems which depend upon radio is indicated in Figure 6. Here, it is evident how there has been a tenfold growth in communication-electronic equipments and today the net worth of its presently owned communication-electronic equipment is $50 billion.

SUMMARY OF USERS

(As of July 1, 1972)

	Department/Agency	Assignments	%
	(Air Force	21,047	17.84
46.95%	(Navy	19,523	16.54
	(Army	13,760	11.66
20.69%	(FAA	15,816	13.40
	(Coast Guard	8,595	7.28
	(Interior	7,449	6.31
	(Justice	9,010	7.63
26.08%	(Agriculture	7,718	6.54
	(Commerce	4,289	3.63
	(AEC	2,297	1.94
7.17%	*Others -	8,464	7.17
	TOTAL	117,968 on	100.00
		12,571 Frequencies	

*EPA, FCC, Federal Reserve System, GPO, GSA, HEW, HUD, IBWC, DOT, Library of Congress, NSF, NASA, OMB, Department of Labor, OEP, Postal Service, Smithsonian Institution, Supreme Court, DOS, TVA, Treasury, Capitol Police, USIA, VA, Architect of the Capitol.

Figure 2

DEPARTMENT OF THE INTERIOR

EXTENT
- 13 Operating Bureaus & Agencies
- > 7400 Assignments
- > 950 Frequencies
- \- $68 Million Equipment Investment

Management & Law Enforcement

1/2 CONUS West of Denver
90% ALASKA

CIVIL COMMUNICATIONS --

Trust Territory of the Pacific Islands - American Samoa
- Mobile - 75 ships; 75 aircraft
- > 50,000 VHF portable/mobile stations

EXAMPLES -

NATIONAL PARK SERVICE -

Fire Suppression & Safety -- 200 Million Visitors/Year

BUREAU OF INDIAN AFFAIRS

Fire Suppression, Law enforcement, Management & Utility Operations.
1/2 Million Indians & Alaskan Natives.
50 Million Acres.

BUREAU OF LAND MANAGEMENT -

Management & Protection
- 1/5 of Nation's Gross Area -
Nearly 1/2 Billion Acres

Figure 3

FEDERAL AVIATION ADMINISTRATION
(3rd largest spectrum user)

FUNCTION -

To provide for the safe and expeditious movement of aircraft.

The Federal Aviation Administration uses radio frequencies for communications and radionavigation to carry out its responsibility to provide for the safe and efficient use of the airspace by both civil and military aircraft.

SUPPORT -

>15,800 Frequency Assignments.
>$440 Million Electronic Equipment.

INVESTMENT BY RADIO FREQUENCY BANDS -

200-415	kHz		$ 2,900,000
1.6-27.5	MHz		4,300,000
72-100	MHz	(Alaska Links)	380,000
75	MHz	(Markers)	1,608,000
108-118	MHz		77,140,000
118-136	MHz		32,000,000
162-174	MHz		3,360,000
225-400	MHz		18,400,000
328.6-335.4	MHz		10,780,000
406-420	MHz		100,000
960-1215	MHz		98,682,000
1300-1350	MHz		111,600,000
2700-2900	MHz		55,350,000
7125-8400	MHz		26,165,000
9000-9200	MHz		4,120,000
23,600-24,470	MHz		2,700,000
			$449,585,000

Figure 4

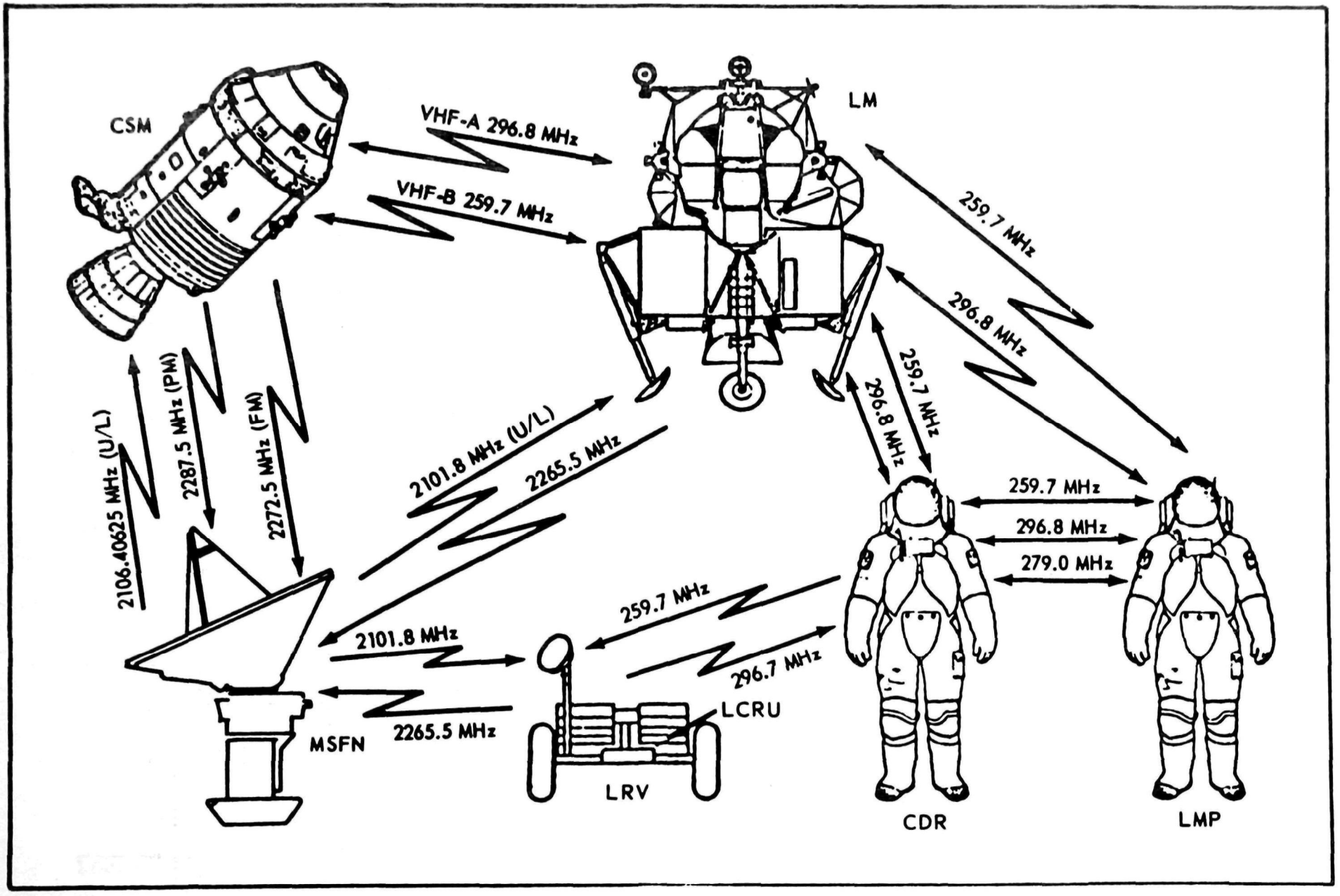

Figure 5

APOLLO FREQUENCY SUPPORT

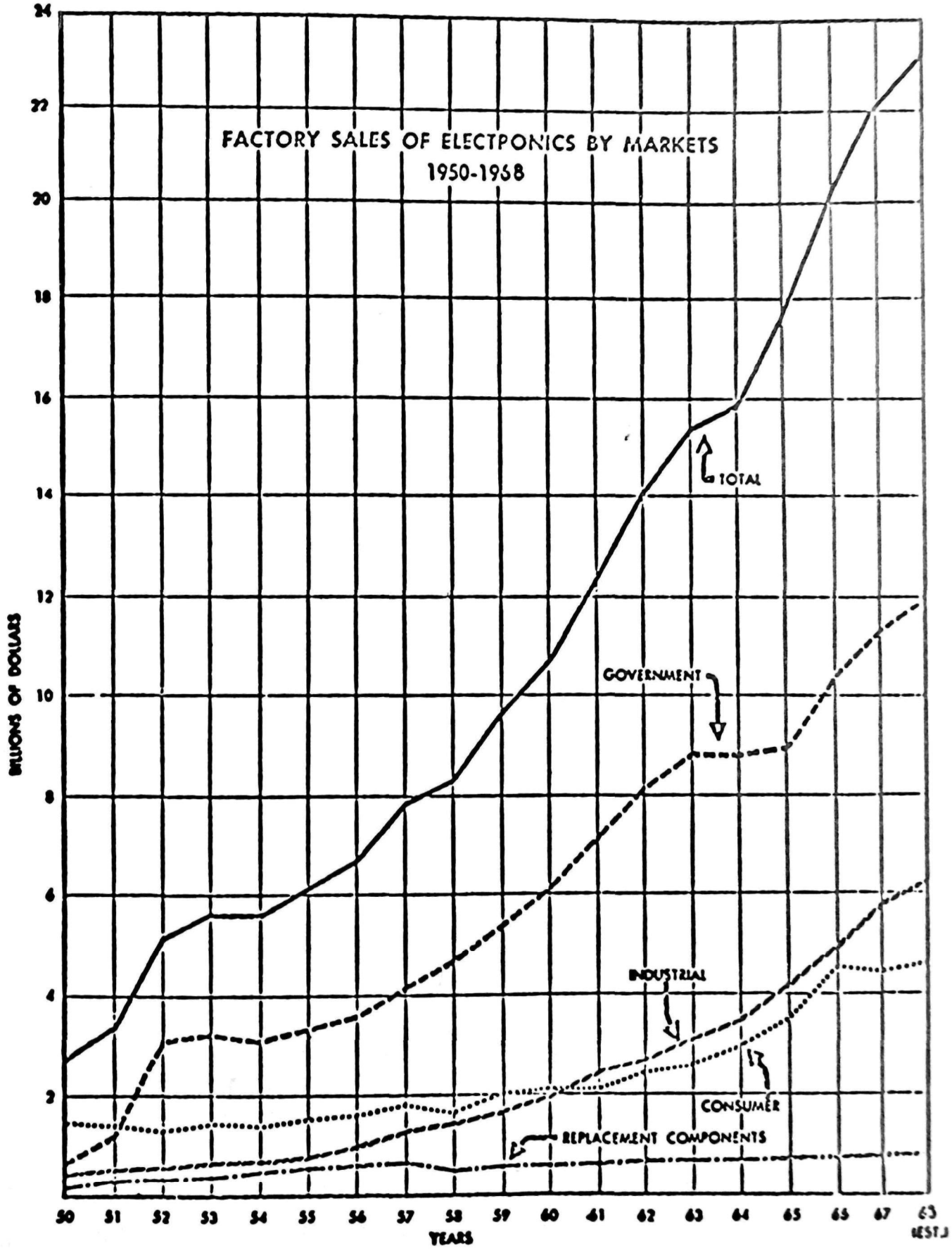
FACTORY SALES OF ELECTPONICS BY MARKETS
1950-1968
TOTAL
GOVERNMENT
INDUSTRIAL
CONSUMER
REPLACEMENT COMPONENTS
BILLIONS OF DOLLARS
YEARS
24
22
20
18
16
14
12
10
8
6
4
2
50
51
52
53
54
55
56
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Figure 6

As is evident, there are many resources that are inexorably entwined with availability of radio frequencies. As a consequence, any new boundary conditions or limitations imposed upon users of radio may have considerable ramifications in terms of the ability of a particular system to continue performing its intended information transfer function, and in doing so severely inhibit the effective accomplishment of numerous national goals. Therefore, it is incumbent upon the managers of the radio spectrum to be particularly alert to appreciating how radio energy may adversely affect the health of the people it is intending to serve.

Nature of Environment Impact

As alluded to earlier, the users of the radio spectrum have an environmental impact of two major varieties. The first concerns the impact that a new communication-electronic system has on the operation of existing communication-electronic systems. The second concerns how a communication-electronic system effects may impact on man.

The first type of environmental impact is termed electromagnetic compatibility. In this case the impacted environment consists of all other communication-electronic equipments which may be susceptible to functional modification by the radio energy of other communication-electronic equipments. In other words, the emissions from various radio transmitters may be received unintentionally by communication-electronic systems which were not intended to be receptors of such radio emissions. These unintended received emissions may be of sufficient magnitude or character that they prove deleterious to the ability of the receptor to actually receive its intended information

carrying signal. Therefore, it is becoming increasingly necessary that there be a comprehensive analytical study of the impact of any new radio system before its introduction into the radio environment where it intends to operate. Such an analysis may also include a determination as to whether the existing communication-electronic systems in the environment will do harm to the functioning of the new system. In the near future it will become a matter of policy that a new user of the radio system will not be permitted to operate until he has given conclusive proof that such compatibility does exist.

Needless to say, the ensuring that there are capabilities within the Federal Government to perform such analyses and that such analyses are being performed in the most congested parts of the radio spectrum are becoming an increasingly large part of the spectrum management process.

Another name for these analytical studies preliminary to implementation of a new radio system is spectrum engineering. Inevitably, if it appears that a radio system cannot satisfactorily operate and yet there is a sufficient demand for its information transfer function, remedial actions must be taken to permit the new system to operate. These remedial actions may take the form of additional filters, improved antennas and/or a decrease in the amount of emitted power. These modifications are predicated on conforming to a set of boundary conditions between the new system and the existing systems which will permit there mutual coexistence.

The second form of environmental impact is biological. This, of course, concerns the potential of radio energy to have biologically deleterious effects. This concern is increasingly being considered as one requiring environmental protection. As you may know, the Environmental Protection Act of 1970, Section 102, requires that Federal agencies file environmental impact statements. Already several such statements have been filed in connection with major Government communication-electronic systems and considerable research has been undertaken to ascertain the nature of these potential impacts. Additionally, the Federal Communications Commission has recently issued a Notice of Inquiry to ascertain what form of requirement it should place upon its licensees in connection with environmental impact. Furthermore, there are increasing instances of public concern being raised over the potentially deleterious effects of radio energy, and our uncertainty with regard to the nature of these effects is giving rise to heighted fears associated with the increasing population of radio transmitting equipment.

Therefore, it has become a matter of some urgency to come to grips with the nature of this biological impact in order to establish the necessary boundary conditions which on the one hand will be protective of health and on the other hand permit the functioning of telecommunication systems. In response to the need to adequately define this problem, the Office of Telecommunications Policy (OTP) has advising it the Electromagnetic Radiation Management Advisory Council. Almost a year ago, this Council recommended a program for coordinating efforts within the Federal Government with respect to research dealing with the biological effects of nonionizing electromagnetic radiation. The OTP approved this program and subsequently forwarded it to the various participating Government

agencies and organizations for implementation. You will hear more about where we stand on this effort later in this program.

What boundary condition or conditions will establish the basis for a meaningful protection guide in the area of potential and real biological effects of nonionizing electromagnetic radiation, particularly those emanating from Federal Government radio communication facilities? The answer is at present unknown. Today when confronted with the need for stating some form of number for protective purposes we fall back on the number of 10 $\mu w/cm^2$. The fact of the matter is that we are uncertain as to the biological effects of electromagnetic energy because we have not been systematically looking for the effects, particularly those which may occur over long periods of time at low levels. We have not performed the adequate experiments; we do not have the necessary dosimetry to know what we are measuring, and we have not investigated the low level effects of nonionizing radiations in anywhere near a fashion which is commensorate with the variety of modulation forms presently employed by communication-electronic equipment. Meanwhile we are continually confronted, particularly in highly exposed governmental positions, to an increasing number of public incidents and fragmentary evidence that in fact, nonionizing electromagnetic energy does cause some effects at levels below 10. It is incumbent upon the community who is knowledgeable about the various aspects of this problem, including both electronic and medical disciplines, to initiate the necessary research projects leading towards its resolution.

Formulation of Protection Guides in Relation to Radio Spectrum Use and Policy

There is no question that the juxtaposition of public health concerns, with the concerns of achieving national goals through the utilization of

various kinds of radio telecommunication emissions, poses national policy problems. There may in fact be a problem of real concern to public health. Support for such a view may be found in a recent law of the Peoples Republic of Poland where a safe level of exposure to nonionizing electromagnetic radiation is considered to be in the order of 10 $\mu w/cm^2$ fully one thousand times less than the presently accepted U.S. standard. On the other hand, were the United States to follow such a protection guide literally, we would probably create an even more hazardous situation for passengers on airplanes as the radars used in air traffic control would have to be turned off because they would not be able to conform to such a standard. Furthermore, our space program would be put into jeopardy and we would probably not be able to have broadcasting radio and television network systems similar to those we have today.

Should this disparity in protection guides present you with any great concern, let me also point out that in this same public law of the Peoples Republic of Poland there is an Article 10 which essentially states that the communication-electronic systems under the purview of the Ministry of the Interior and Defense need not pay any attention to it.

Finally, in addressing the relationship between environmental impact and management of the radio spectrum, I would like to make a special appeal to the medical people among you to exert particular effort in providing the necessary medical description of the deleterious effects that low-level nonionizing electromagnetic radiation may cause. The radio spectrum is to a large degree managed by people who have electrical engineering or telecommunication engineering backgrounds. And, while they and their colleagues are competent in developing techniques for

measuring levels of radio energy, they are dependent upon you for providing an adequate description of the effects that such energy may cause to the human body. At present we are deficient in this understanding and therefore I appeal to you to help us solve it. Thank you.

ELECTROMAGNETIC ENVIRONMENTS IN URBAN AREAS

J. C. Toler

Engineering Experiment Station
Georgia Institute of Technology
Atlanta, Georgia

1. Introduction

From conception until death, man is literally submerged in and buffeted by the environment within which he exists. This environment tends to be highly variable and the individual components of which it is composed are generally complex and innumerable. Many of these components are quite visible and are therefore readily recognizable; others are equally non-visible, and are recognized only by the technically trained and/or scientifically inquisitive.

Electromagnetic fields provide a good example of a component within the environment that is generally unrecognized. Yet these fields undoubtedly influence in significant ways the functioning of biological systems. At least in part, these influences can be attributed to the fact that numerous biological functions are in response to electrical stimuli. Many of the electromagnetic field influences on biological systems have been extensively investigated and are rather well understood. Others have been investigated in only a peripheral fashion such that the results are somewhat confused and subject to considerable controversy. It is also possible that still other electromagnetic field influences on biological systems have not as yet even been scientifically recognized. These influences may then provide challenging research areas in future decades.

The matter of electromagnetic radiation protection guides for biological systems is representative of areas in which only peripheral or limited investigations have been conducted to date. These investigations have resulted in the promulgation of radiation protection guides in the form of safe exposure levels as a function of time. However, these levels vary drastically depending upon the country within which they were developed and upon the primary effect radiation was assumed to have on biological systems. The most obvious of these exposure level variations is the United States limit of 10 mW/cm^2 relative to the Russian limit of 0.01 mW/cm^2. The United States limit is based primarily on thermal stress induced into the biological system while the Russian limit supposedly accounts for thermal as well as more subtle nonthermal effects of a behavioral nature. Both limits are specified for exposure to average power densities for given time periods, under normal environmental conditions, and over particular frequency ranges.

In view of the large magnitude difference in the exposure limits and the possibility that nonthermal biological effects have not been accounted for, it is not difficult to understand that the United States protection guide is under severe scrutiny. This scrutiny is directed to, among other things, (1) the adequacy of the exposure level magnitude, (2) the applicability of the 10 MHz to 100 GHz frequency range, (3) whether power density is a suitable electrical parameter for specifying damage to biological systems, and (4) near-field versus far-field effects of radiation exposure, etc. A further problem exists in the fact that the United States limits are applicable only over the 10 MHz to 100 GHz frequency range. Since there are high power electronic

systems operational at frequencies below 10 MHz, there is a tendency to assume that the 10 mW/cm^2 limit is equally applicable to these systems. This assumption ignores technical extrapolations which indicate the relationship between wavelength of the radiated field and power deposition in the biological system.

The uncertainties regarding radiation protection guides are attributable in part to the fact that there is a scarcity of data defining the ambient electromagnetic environments to which the public is continually exposed. Because of this situation, a limited research project was undertaken to (1) investigate technically feasible and cost effective techniques for the measurement of electromagnetic environments and (2) obtain electromagnetic environment data over at least a portion of the frequency spectrum. Since most of the United States public is concentrated in urban areas, the measurements were conducted in the Atlanta metropolitan area. This area was considered representative of urban areas with populations of approximately one million or more. The following paragraphs report the results of the research project.

2. Literature Review

The initial efforts consisted of compiling technical information regarding both past and current efforts to determine spectrum congestion. Reports on major work sponsored by the Federal Communications Commission (FCC), the Office of Telecommunications Management (OTM), and the National Academy of Engineering (NAE) were obtained for review. Additionally, numerous articles and editorials on spectrum management, engineering, and utilization were obtained from the commonly available

technical periodicals. All of these documents and publications were reviewed and analyzed in terms of their pertinence to the objective of this project. Of particular interest were the test equipments and equipment configurations that have been used to obtain band occupancy and ambient noise level data. These equipments and configurations directly influence the accuracy of resulting data, dynamic range over which data can be obtained, parameters that can be monitored, receiver spurious responses that must be accounted for, etc.

3. Band Occupancy Measurements

After the review and analysis of relevant literature, efforts were directed toward an experimental investigation of methods for determining the occupancy of selected frequency bands. The first method investigated consisted of various antennas used with a spectrum analyzer and strip chart recorder. The test configuration was as shown in Figure 1. Band occupancy data was initially taken over the 0 to 1.2 GHz frequency range of the spectrum analyzer, and is shown in Figure 2. An analysis of this data resulted in the following conclusions: (1) a large percentage of the transmissions in some frequency bands were not detected because they were intermittent and not intercepted by the spectrum analyzer sweep, (2) the frequency range covered was so broad and required so many different test equipments, test configurations, etc., that an indepth investigation of measurement methods was difficult, and (3) the spectrum analyzer/recorder configuration yields data difficult to reduce in terms of band occupancy.

In view of the above conclusions, it was decided to narrow the range of measurement effort to only the 25 to 50 MHz frequency band

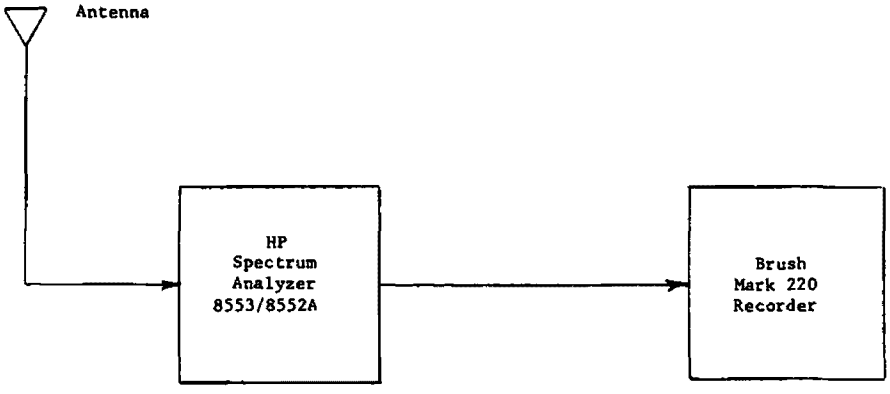


Figure 1. Test Configuration for Measuring Frequency Band Occupancy.

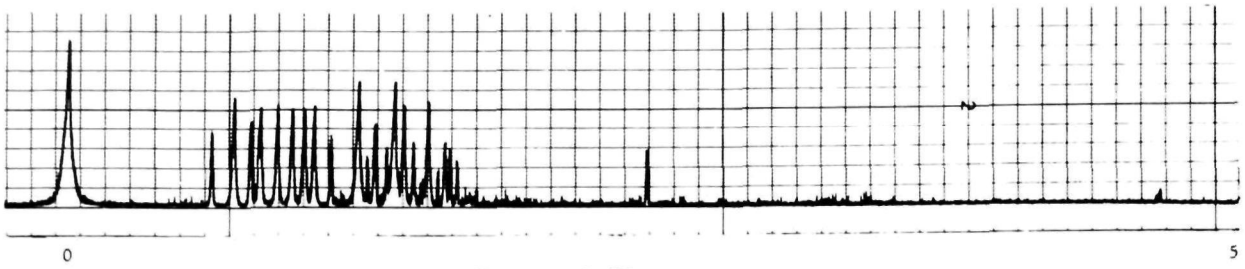


Figure 2(a). Band Occupancy Data Over the 0 to 5 MHz Frequency Range

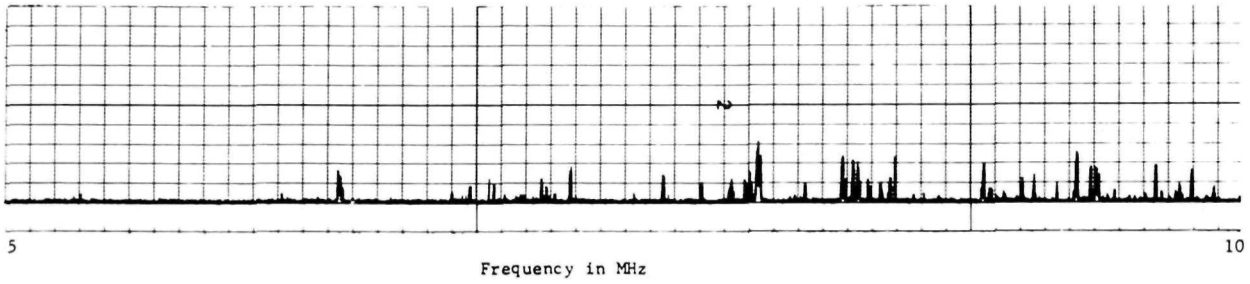


Figure 2(b). Band Occupancy Data Over the 5 MHz to 10 MHz Frequency Range.

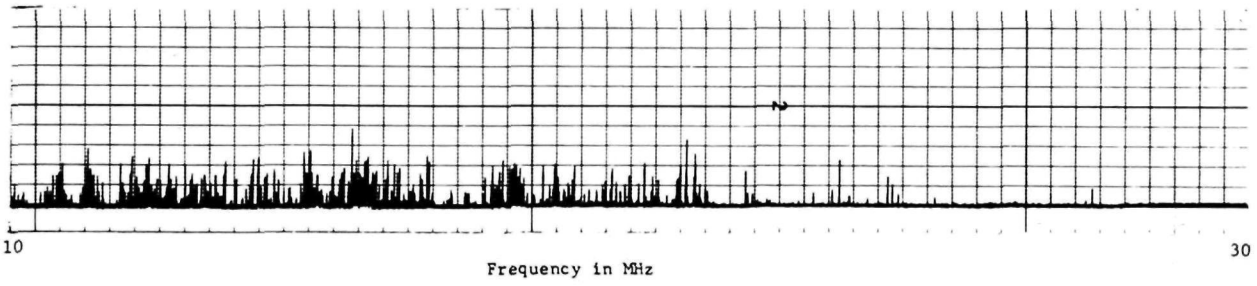


Figure 2(c). Band Occupancy Data Over the 10 MHz to 30 MHz Frequency Range.

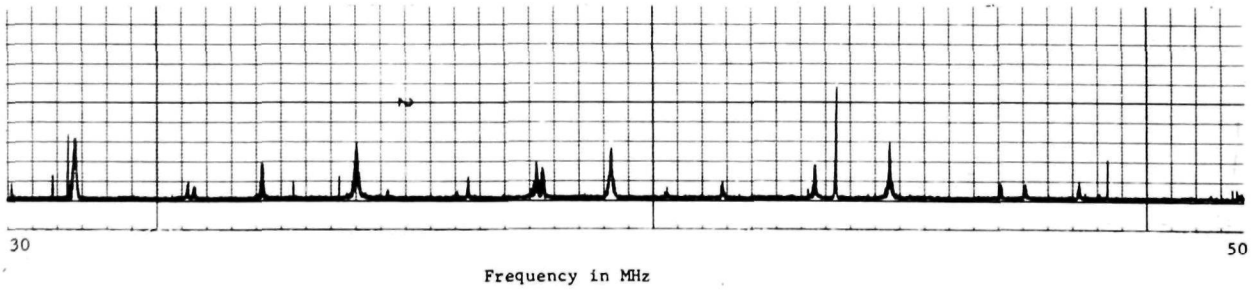


Figure 2(d). Band Occupancy Data Over the 30 MHz to 50 MHz Frequency Range.

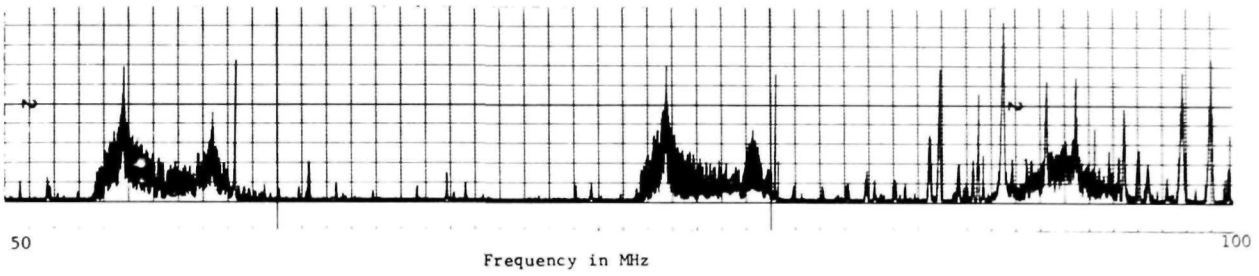


Figure 2(e). Band Occupancy Data Over the 50 MHz to 100 MHz Frequency Range.

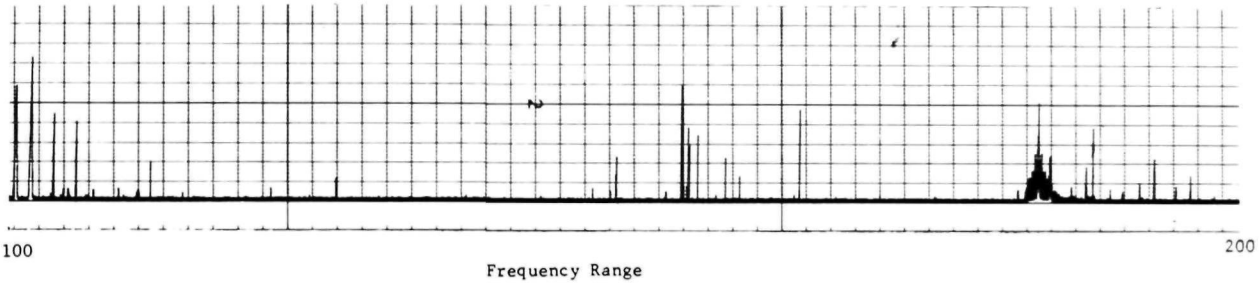


Figure 2(f). Band Occupancy Data Over the 100 MHz to 200 MHz Frequency Range.

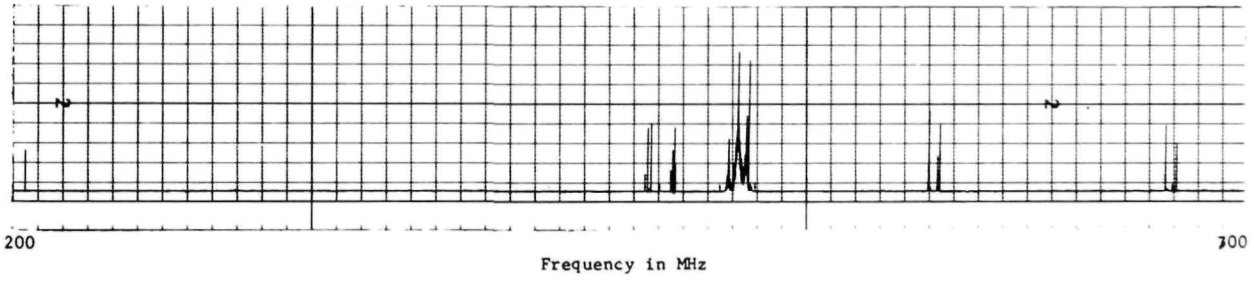


Figure 2(g). Band Occupancy Data Over the 200 MHz to 700 MHz Frequency Range.

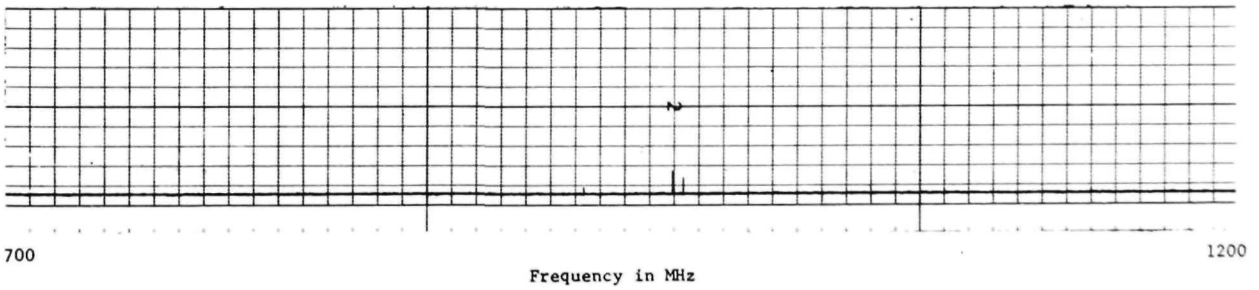


Figure 2(h). Band Occupancy Data Over the 700 MHz to 1200 MHz Frequency Range.

assigned for land mobile usage. This not only significantly limited the frequency range of concern, but assured that attention would be devoted to a severely congested range of frequencies within which intermittent transmissions are common. It was further decided that an improved means of monitoring the land mobile frequency bands was necessary in order to obtain reliable band occupancy data. Requirements that the improved band monitoring scheme must possess included the ability to (1) rapidly scan a frequency range which could be varied from test-to-test, (2) provide an indication each time a transmission was present within the established frequency range, (3) accumulate the data indicating transmissions at discrete frequencies within a given band, and (4) dump the data after scanning of the frequency range was complete. A block diagram of the system developed to fulfill these requirements is shown in Figure 3.

Major components of the improved measurement system were a Hewlett-Packard Model 8553/8552A Spectrum Analyzer, a Fabri-TEK Model 1070 Signal Averager, a differential comparator, a 2.5 second trigger oscillator, and an X-Y recorder. In the operational mode of the system, the spectrum analyzer provided the required frequency scan capability and the signal averager provided data processing and storage. The signal averager included a memory capable of storing 1024 18-bit words. During these measurements, this memory capability was utilized as 1024 bins within which incoming data was stored. The spectrum analyzer and signal averager were both operated in the external sweep mode and synchronized by the trigger oscillator. The vertical output of the spectrum analyzer, which was a DC voltage directly proportional to the RF

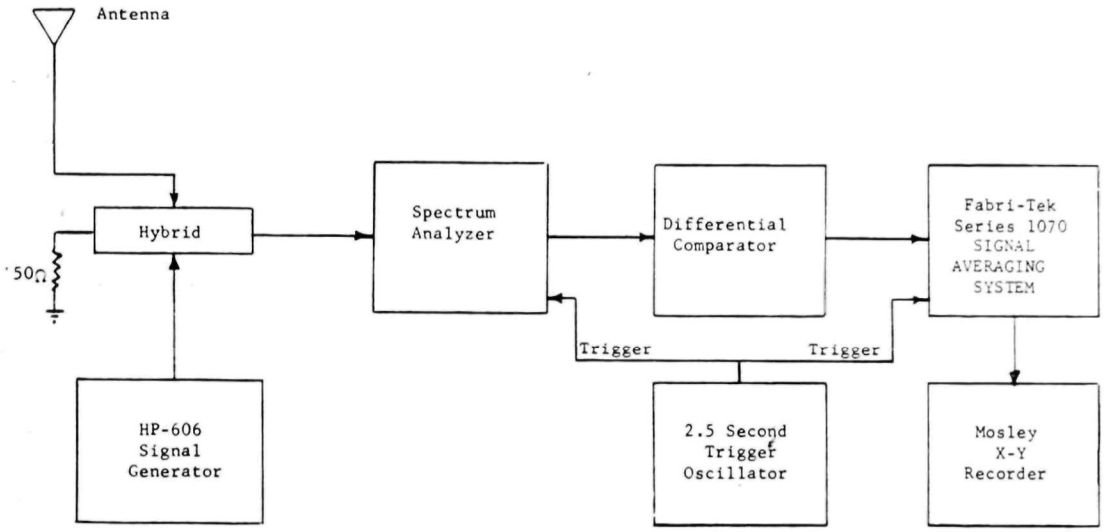


Figure 3. Test Configuration for Measuring Band Occupancy of Land Mobile Bands.

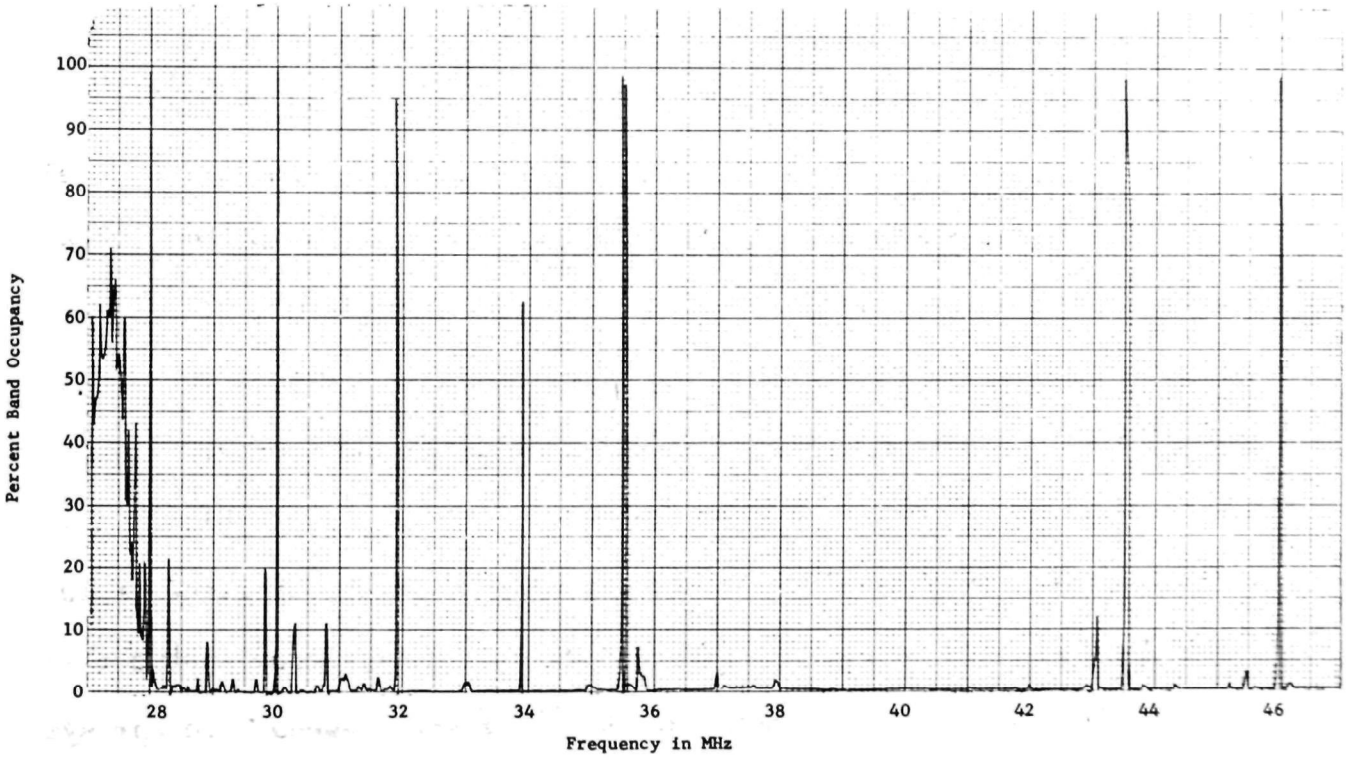


Figure 4. Percent Band Occupancy Over the Frequency Range of 27 to 47 MHz, 6:30AM to 8:30AM.

input signal, was coupled to the differential comparator. The comparator generated a constant amplitude square wave, with a time duration equal to that of the input signal, whenever the input signal exceeded the preset bias voltage of the comparator. This output was then coupled to the signal averager, digitized, and stored in the data bin corresponding to the measured frequency increment. This procedure was repeated at the rate of the trigger oscillator and percent usage of the frequency increment was obtained from the accumulation of stored signals. The accumulated signals in the 1024 data bins could be displayed (1) individually in a numerical form or all together in a composite form on a CRT scope, (2) in a composite form on an X-Y recorder, or (3) in a punched paper tape format. The probe antenna was a half-wave dipole tuned to 37 MHz. Preliminary scans were made to determine whether the antenna polarization should be horizontal or vertical. The resulting data indicated a vertical polarization was desirable; consequently, this polarization was used during subsequent testing.

For the measurements described herein, the spectrum analyzer was operated to scan the 27 to 47 MHz frequency band with a scan time of 2.0 seconds and an IF bandwidth of 3 kHz. The signal averager was operated with a scan time of 2.05 seconds, which gave a dwell time of 2.0 milliseconds for each of the 1024 data bins. Thus, each of the bins represented a frequency interval of 20 kHz. The total scanning period, controlled by the trigger oscillator, was 2.5 seconds resulting in a lapsed time of 0.5 seconds between scans. The comparator, in conjunction with the spectrum analyzer, was adjusted to generate an output for a received signal with an amplitude of -85 dBm or greater at the

spectrum analyzer input. The -85 dBm threshold signal level was used because it was 6 dB above the background noise level. The 6 dB margin was considered necessary since the band occupancy measurements were concerned with intentional and discrete manmade transmissions as opposed to the ambient noise level.

For calibration purposes, it was desired to add a discrete frequency signal to the input signal. This added signal would represent 100 percent usage of one of the frequencies within the 27 to 47 MHz range, and would provide an indication that the system was properly operating. Preliminary scanning of the 27 to 47 MHz band indicated no transmissions at 46 MHz; consequently, this frequency was chosen for continuously injected calibration signal.

The resultant test data is shown in Figures 4, 5, and 6. Scans with two-hour durations were conducted over the following time intervals: 6:30 to 8:30 a.m., 11:30 a.m. to 1:30 p.m. and 4:00 to 6:00 p.m. The data indicates that essentially continuous transmissions exist at 28, 30, 31.9, 35.45, 35.5, and 43.5 MHz. Also, the congestion in the 27 to 28 MHz region is obviously serious. In all other portions of the 27 to 47 MHz frequency range, the band occupancy is quite low. During the noon and late afternoon time intervals, the 43.5 to 44.4 MHz frequency band appears to be noticeably more occupied than it was during the early morning hours. Also, the 28 to 29 MHz band is considerably more occupied at noon than it is at either the early morning or late afternoon hours.

4. Background Electromagnetic Environment Measurements

At this point, the emphasis of the experimental investigations

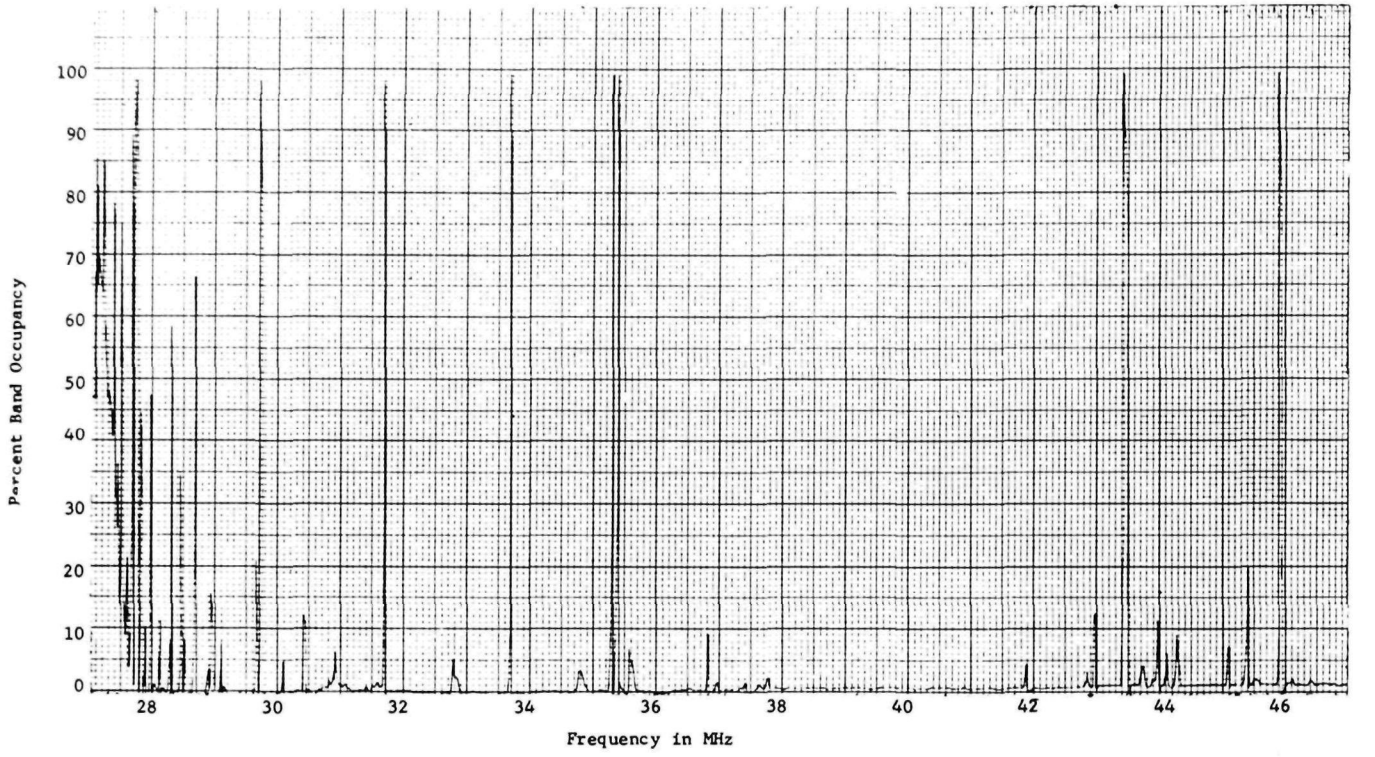


Figure 5. Percent Band Occupancy Over the Frequency Range of 27 to 47 MHz, 11:30AM to 1:30PM.

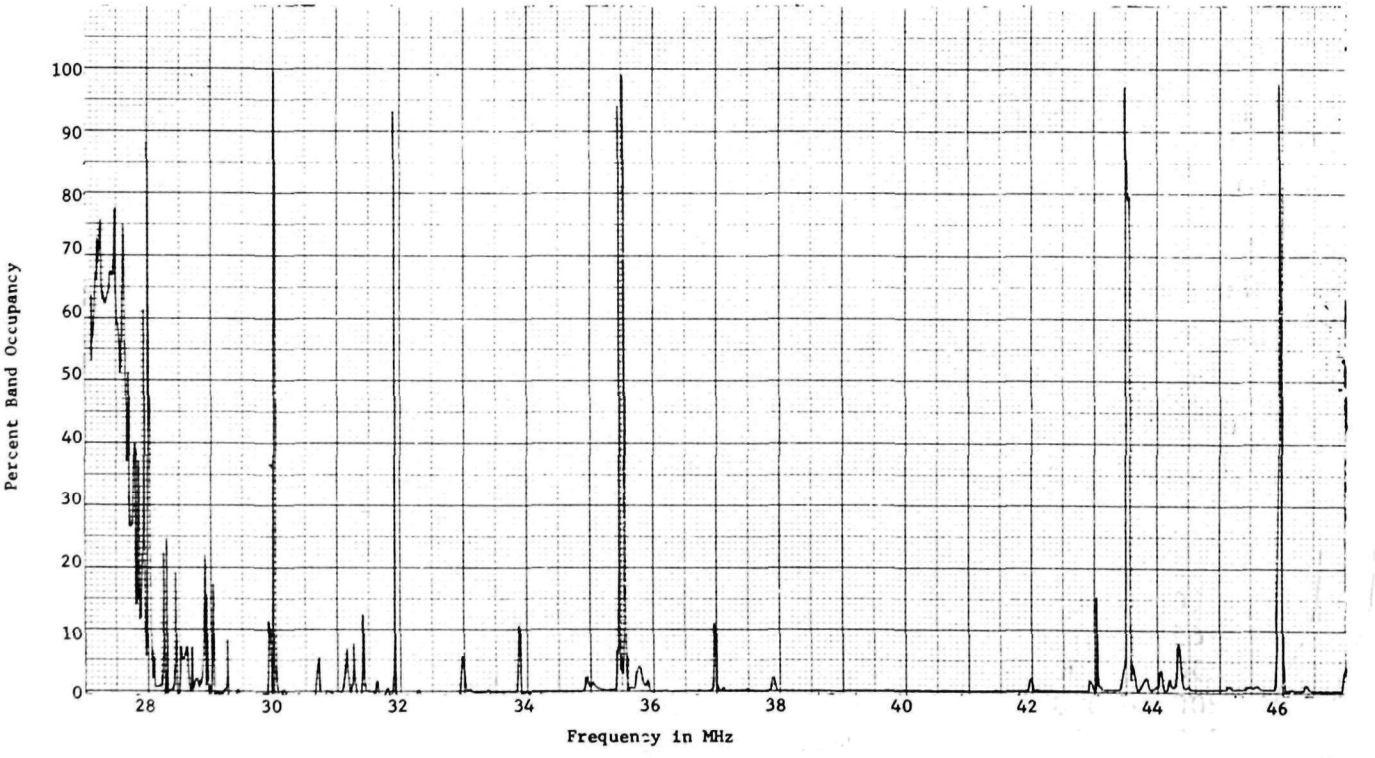


Figure 6. Percent Band Occupancy Over the Frequency Range of 27 to 47 MHz, 4PM to 6PM.

shifted from band occupancy measurement techniques to determination of the ambient electromagnetic background or noise level. Such a shift in emphasis was necessary at this point because only a limited amount of time remained before the project had to be completed. The noise level measurements were made over a 0 to 1.2 GHz frequency range and at three locations in the metropolitan Atlanta area. These locations were as follows: (1) a northwest location at 3540 Dunn Street in Smyrna, Georgia, (2) a northeast location at the Georgia Tech Field Site near Stone Mountain, Georgia, and (3) a downtown Atlanta location on the roof of the Systems and Techniques Department Building on the Georgia Tech campus. The test equipment consisted of a suitable antenna, spectrum analyzer, and strip chart recorder configured as shown in Figure 1. The video output of the spectrum analyzer was coupled to the recorder to provide a plot of spectral components as a function of frequency. It was necessary to divide the 0 to 12 GHz frequency range into 13 separate bands in order to provide measurement antennas. These bands and the antenna used for each are shown in the following:

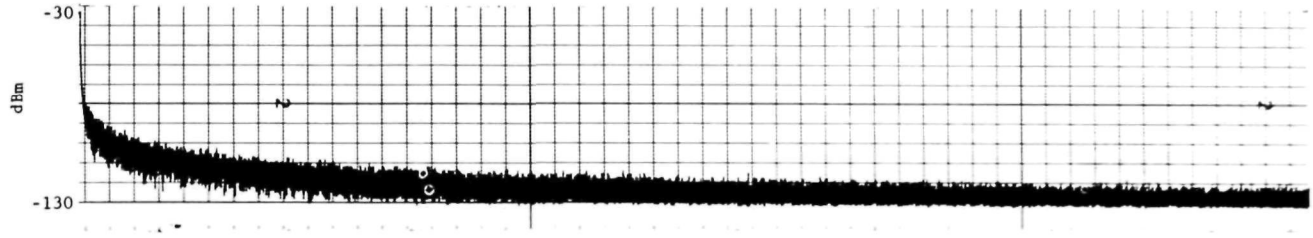
Frequency Band (MHz)	Antenna Type	Antenna Tuned Frequency
0 to 0.5	41" monopole	0.15 to 0.36 MHz band
0.35 to 0.85	41" monopole	0.36 to 0.75 MHz band
0.5 to 2.5	41" monopole	0.87 to 2.1 MHz band
1 to 6	41" monopole	2.1 to 5.2 MHz band
4 to 14	41" monopole	5.2 to 12.7 MHz band
11 to 31	41" monopole	12.7 to 30 MHz band
30 to 80	Half-wave dipole	55 MHz
65 to 115	Half-wave dipole	90 MHz
100 to 200	Half-wave dipole	150 MHz
200 to 300	Half-wave dipole	250 MHz
250 to 350	Half-wave dipole	300 MHz
350 to 850	Cavity-backed spiral	Broadband
800 to 1300	Cavity-backed spiral	Broadband

The measurement procedure for each frequency band consisted of first terminating the 50 ohm spectrum analyzer input with its characteristic impedance. The internal noise level of the measurement equipment was then recorded. Ambient noise levels were recorded next by substituting the appropriate antenna for the 50 ohm impedance at the receiver input.

The resulting data, for each of the 13 frequency bands, taken on the Georgia Tech campus is shown in Figure 7. Recorder data for the other two locations is not presented because of its volume and the fact that it is nearly identical in appearance to that obtained from the campus location. Transmissions from AM radio stations are clearly evident in the data recorded over the 0.35 to 0.85 MHz and 0.5 to 215 MHz frequency bands. Further, FM radio station transmissions are obvious on the data recorded over the 65 to 115 MHz frequency band. Television audio and video transmissions for channels 2, 5, 11, 17, and 30 appear on the data at the following frequencies:

Channel	Video Transmission	Audio Transmission
2	55.25 MHz	59.75 MHz
5	77.25 MHz	81.75 MHz
11	199.25 MHz	203.75 MHz
17	489.25 MHz	493.75 MHz
30	567.25 MHz	571.75 MHz

Considerable discrete frequency activity not directly related to radio or television transmissions appeared in the general frequency range of 5 to 20 MHz. The specific ambient noise level data extracted from the recordings made on the Georgia Tech campus is presented in Table I. This table also shows the various factors which must be reflected in



Instrumentation Noise Calibration over the 0 to 0.5 MHz Frequency Band

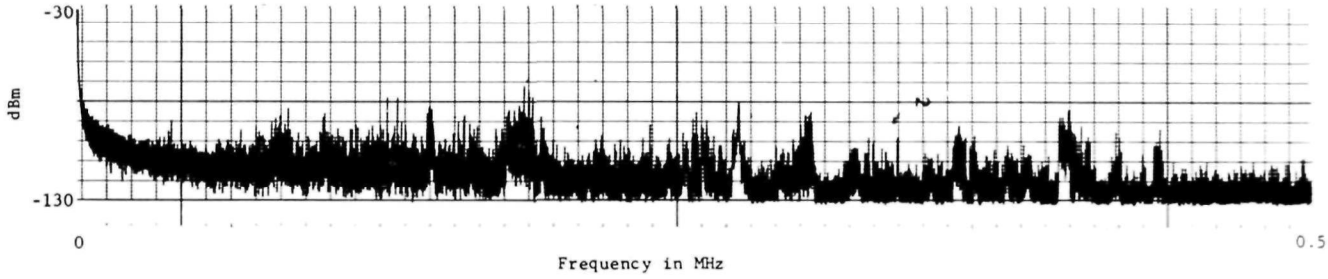
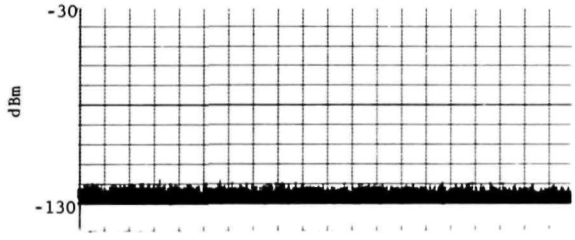


Figure 7(a). Spectral Components Measured from Roof of Electronics Research Building Over the 0 to 0.5 MHz Frequency Band.



Instrumentation Noise Calibration Over the 0.35 MHz to 0.85 MHz Frequency Band

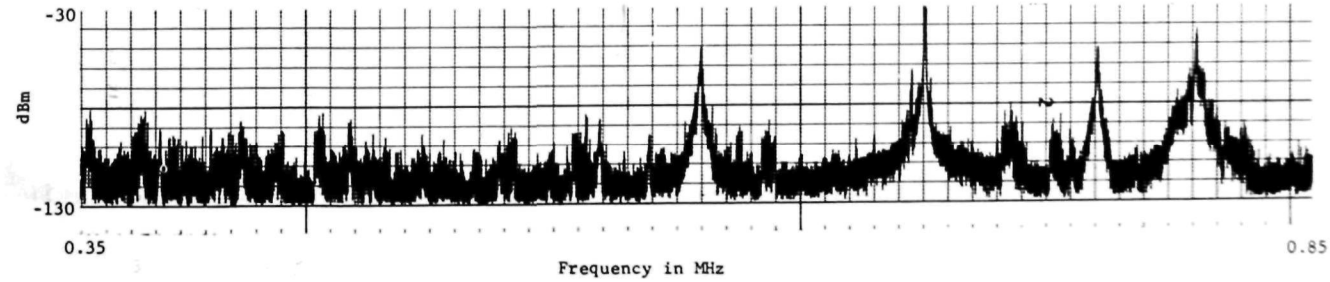
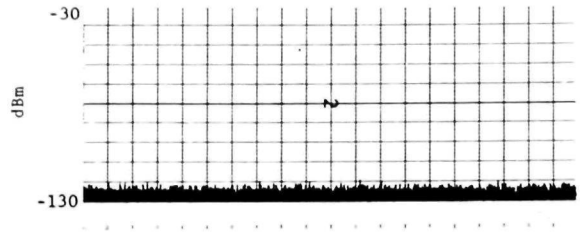


Figure 7(b). Spectral Components Measured from the Roof of the Electronics Research Building over the 0.35 MHz to 0.85 MHz Frequency Band.



Instrumentation Noise Calibration Over the 0.5 MHz to 2.5 MHz Frequency Band

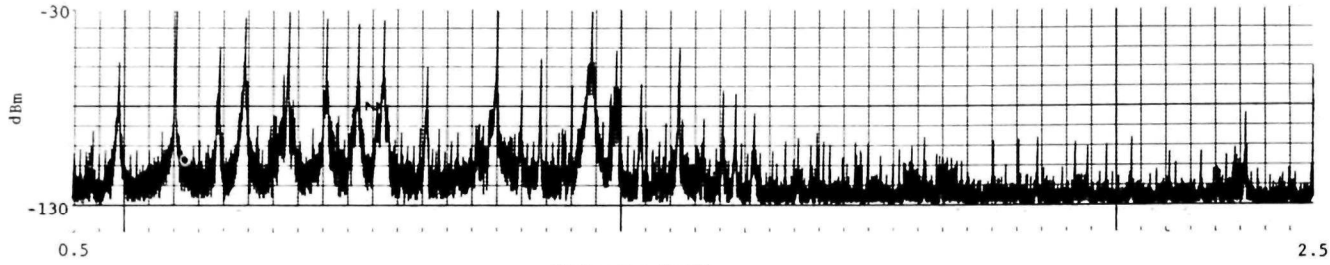
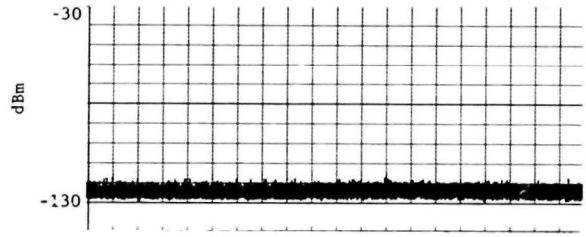


Figure 7(c). Spectral Components Measured from the Roof of the Electronics Research Building Over the 0.5 MHz to 2.5 MHz Frequency Band.



Instrumentation Noise Calibration over the 1 MHz to 6 MHz Frequency Band

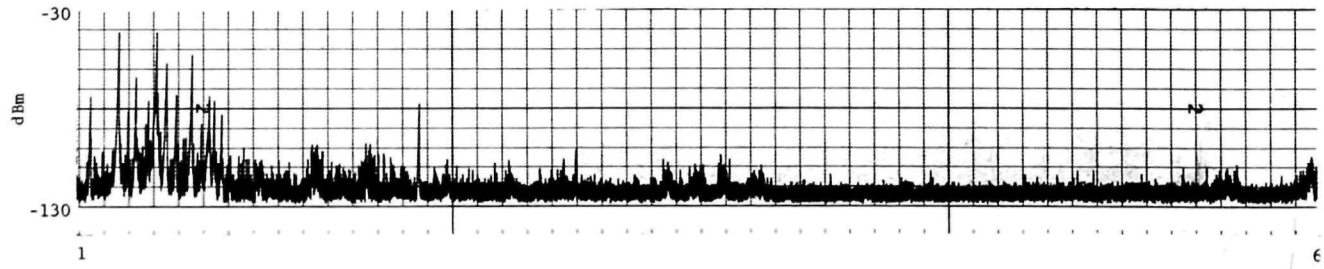
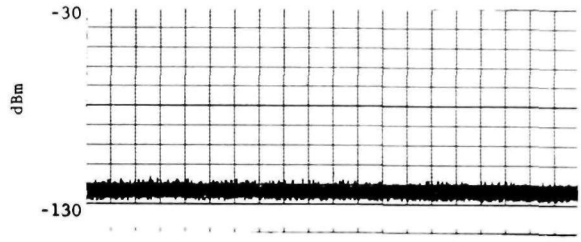


Figure 7(d). Spectral Components Measured from the Roof of the Electronics Research Building over the 1 MHz to 6 MHz Frequency Band.



Instrumentation Noise Calibration over the 4 MHz to 14 MHz Frequency Band

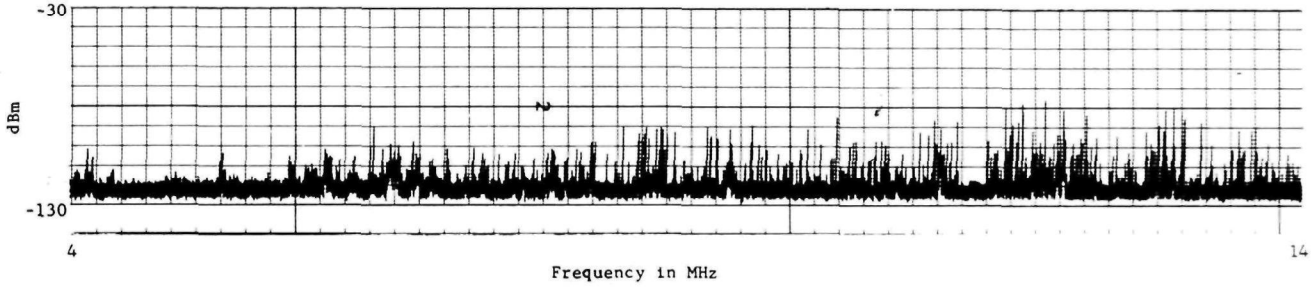
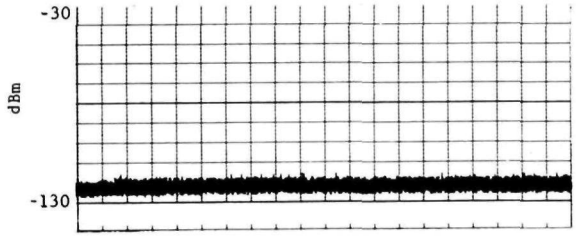


Figure 7(e). Spectral Components Measured from Roof of Electronics Research Building over the 4 MHz to 14 MHz frequency Band.



Instrumentation Noise Calibration over the 11 MHz to 31 MHz Frequency Band

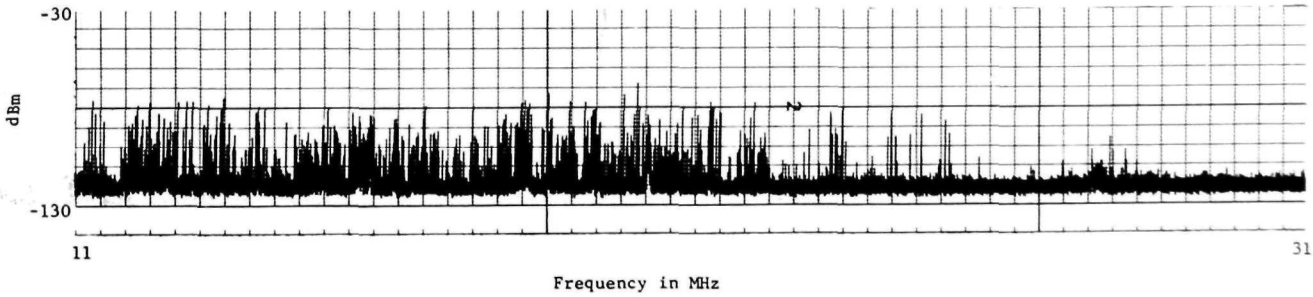
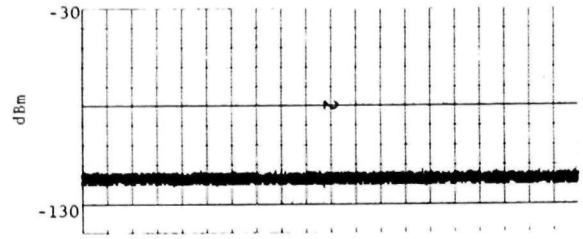


Figure 7(f). Spectral Components Measured from Roof of Electronics Research Building over the 11 MHz to 31 MHz Frequency Band.



Instrumentation Noise Calibration over the 30 MHz to 80 MHz Frequency Band

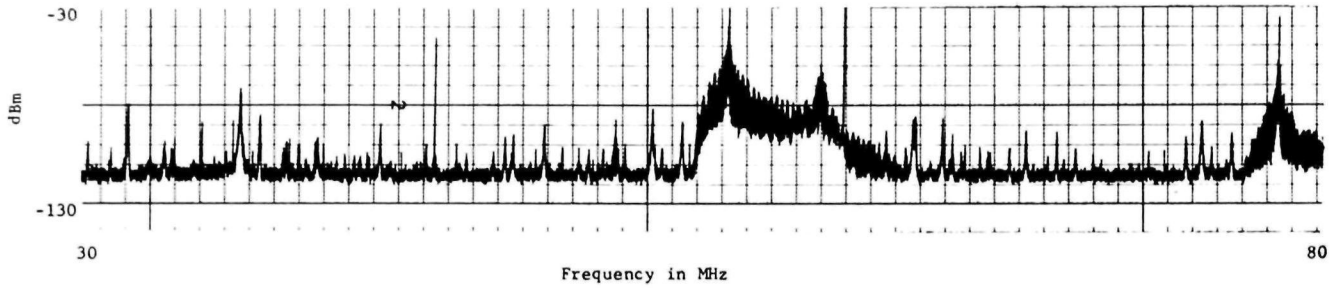
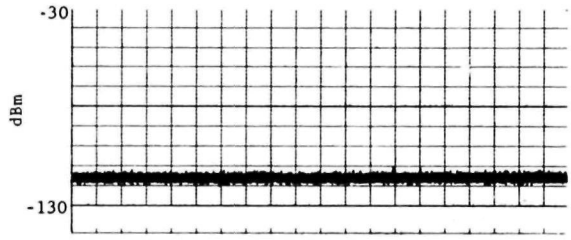


Figure 7(g). Spectral Components Measured From Roof of Electronics Research Building over the 30 MHz to 80 MHz Frequency Band.



Instrumentation Noise Calibration over the 65 MHz to 115 MHz Frequency Band

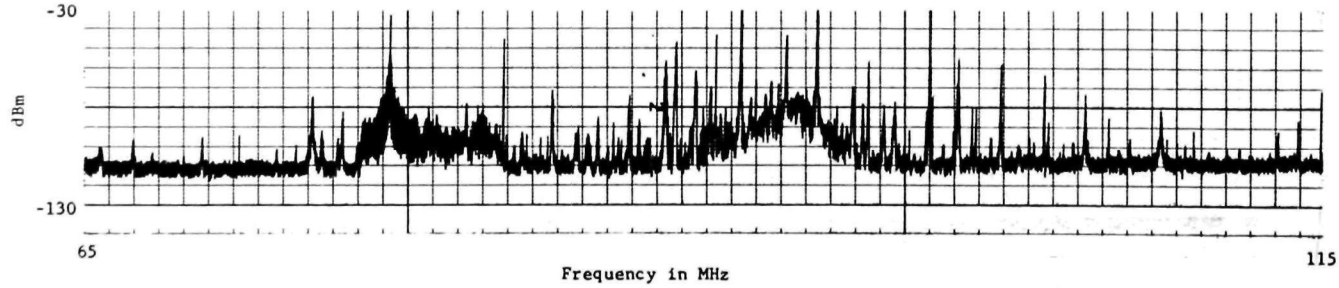
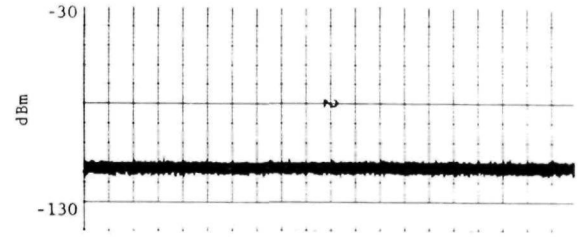
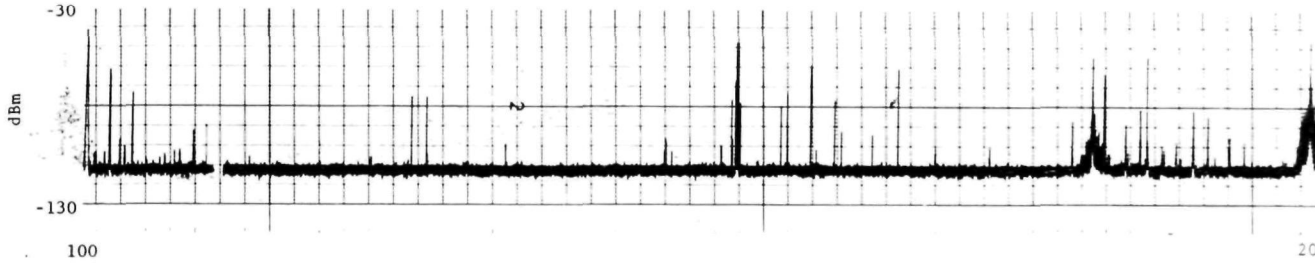


Figure 7(h). Spectral Components Measured from Roof of Electronics Research Building over the 65 MHz to 115 MHz Frequency Band.

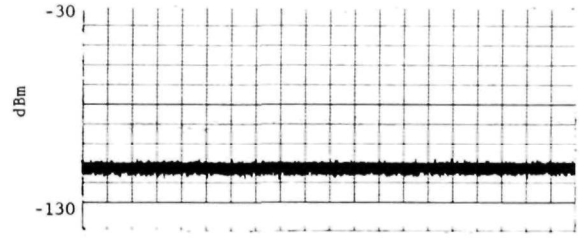


Instrumentation Noise Calibration Over the 100 MHz to 200 MHz Frequency Band

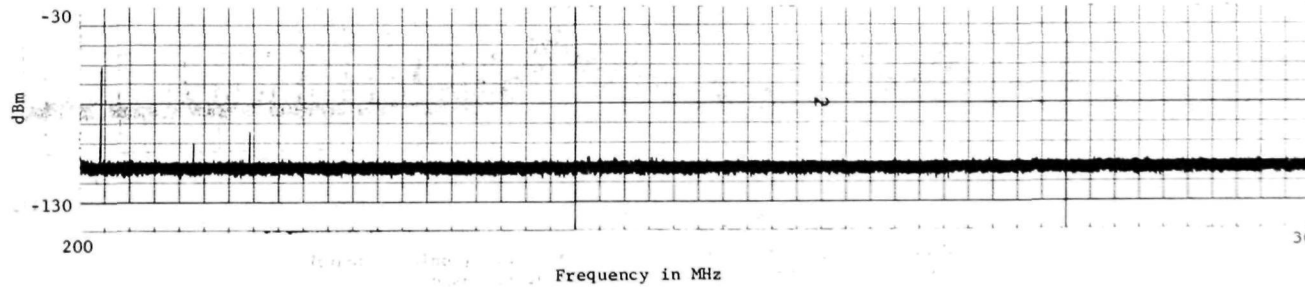


Frequency In MHz

Figure 7(i). Spectral Components Measured from Roof of Electronics Research Building over the 100 MHz to 200 MHz Frequency Band.

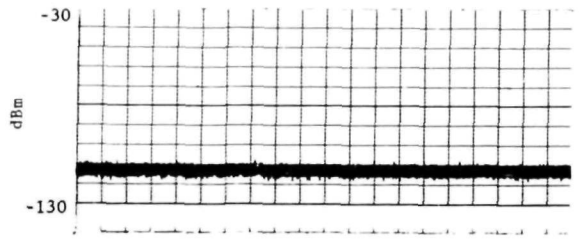


Instrumentation Noise Calibration over the 200 MHz to 300 MHz Frequency Band



Frequency in MHz

Figure 7(j). Spectral Components Measured from Roof of Electronics Research Building over the 200 MHz to 300 MHz Frequency Band



Instrumentation Noise Calibration Over the 250 MHz to 350 MHz Frequency Band

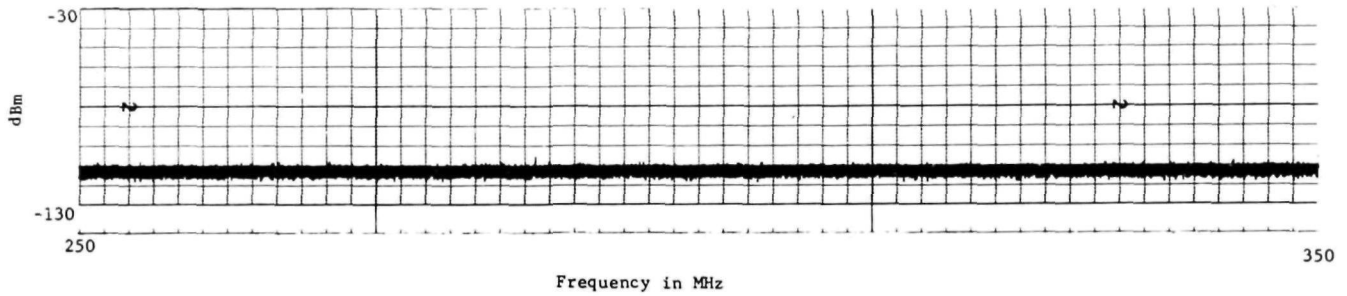
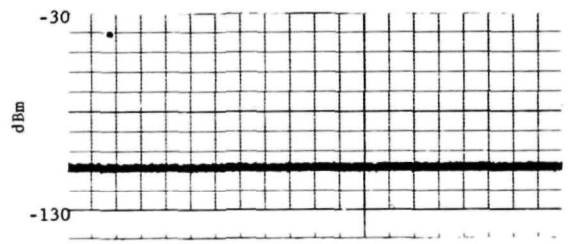


Figure 7 (k). Spectral Components Measured from Roof of Electronics Research Building over the 250 MHz to 350 MHz Frequency Band.



Instrumentation Noise Calibration over the 350 MHz to 850 MHz Frequency Band

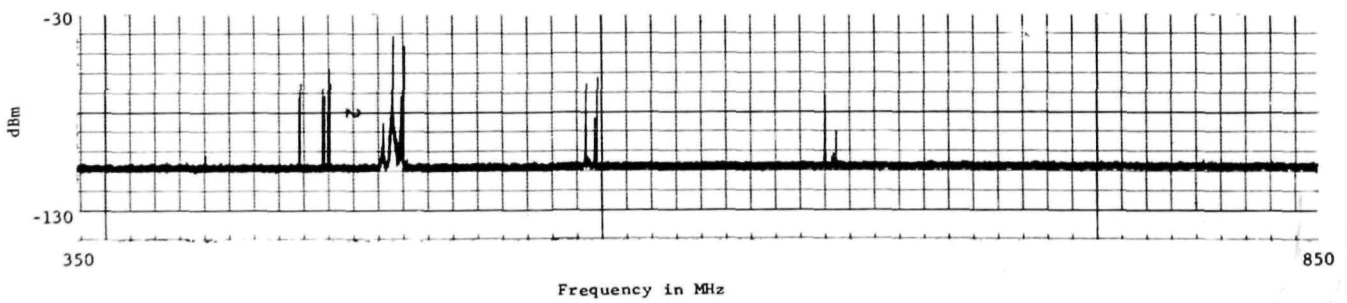
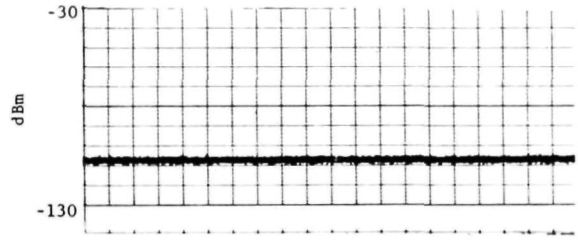


Figure 7 (l). Spectral Components Measured from the Electronics Research Building over the 350 MHz to 850 MHz Frequency Band.



Instrumentation Noise Calibration over the 800 MHz to 1300 MHz Frequency Band

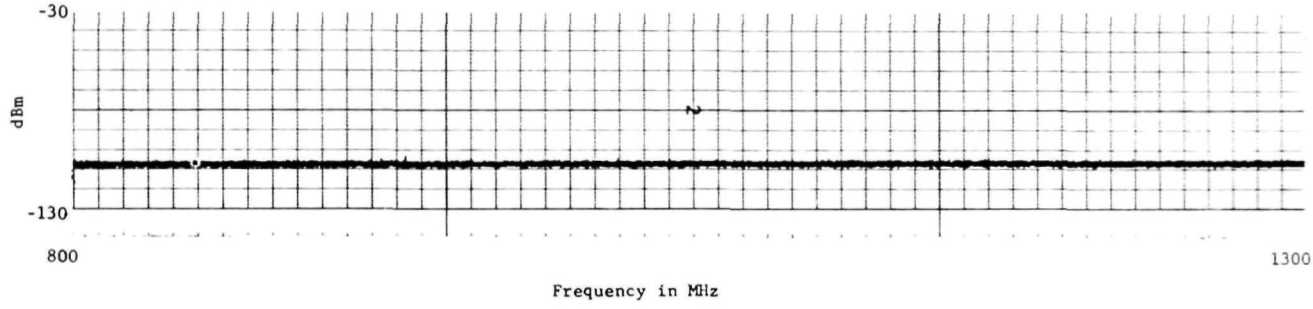


Figure 7 (m). Spectral Components Measured from Roof of Electronics Research Building over the 800 MHz to 1300 MHz Frequency Band.

TABLE I. Ambient Electromagnetic Noise Level Measured on the Georgia Tech Campus

Frequency Band MHz	Rcvr. Noise Level dBm	Rcvr. + Ambient Noise Level dBm	BW Factor dB	Adjusted Rcvr. Noise Level dBm/kHz	Adjusted Rcvr. + Ambient Noise Level dBm/kHz	Ambient Noise Level dBm/kHz	Antenna Factor dB	Ambient Noise Field Intensity $dBm/m^2/kHz$
0-.5	-116	-111	-4.8	-111.2	-106.2	-108	-35.6	- 72.4
.35-.85	-122	-112	-4.8	-117.2	-107.2	-107.7	-30.4	- 77.3
.5-2.5	-123	-118	-4.8	-118.2	-113.2	-114.8	-26.4	- 87.4
1-6	-120	-117	0	-120	-117	-120	-22.4	- 97.6
4-14	-120	-117	0	-120	-117	-120	-17.4	-102.6
11-31	-118	-116	0	-118	-116	-120.3	-14.4	-105.9
30-80	-114	-112	4.8	-118.4	-116.4	-120.7	+ 6.72	-127.4
65-115	-113	-108	4.8	-117.8	-112.8	-114.5	+ 1.64	-115.1
100-200	-110	-110	4.8	-114.8	-114.8	<-120	- 3.0	<-117
200-300	-110	-110	4.8	-114.8	-114.8	<-120	- 7.3	<-113
250-350	-110	-110	4.8	-114.8	-114.8	<-120	- 8.8	<-111
350-850	-106	-106	10	-116	-116	<-122	-10	<-112
800-1300	-106	-106	10	-116	-116	<-122	-12	<-110

the raw data before arriving at a final value for the ambient noise level. Corresponding ambient noise level data for the other two test locations is presented in Table II. As was expected, the highest ambient noise levels were recorded at the lowest frequencies. Another expected result was revealed in the fact that the ambient noise level was higher at the downtown location than either of the suburban locations. At frequencies above approximately 100 MHz, the measurement equipment was not sensitive enough to determine ambient noise levels. Only discrete frequency transmissions were measured above this 100 MHz frequency. A comparison of ambient noise levels in the Atlanta area relative to typical metropolitan areas can be made by referring to Table III. Data in this table is a compilation of typical noise levels in both suburban and urban areas as a function of frequency. For example, the typical urban noise level at 20 MHz is -95 $dBm/m^2/kHz$. In the Atlanta area, the corresponding level measured was approximately -127.4 $dBm/m^2/kHz$. The considerably lower level in the Atlanta area could be attributed to such possibilities as (1) the Atlanta area does not have many of the heavy industries which contribute significantly to the ambient noise level in many typical cities or (2) the single measurement location in Atlanta was not representative of the total urban area.

5. Conclusions

The research efforts undertaken were limited and consequently, the resulting data is correspondingly limited. Therefore, caution must be exercised in drawing firm conclusions from the measured results.

In terms of the review of literature available on spectrum monitoring, surveys, congestion, etc., it is concluded that an appreciable

TABLE II. Ambient Electromagnetic Noise Level Measured At Two Metropolitan Locations.

Frequency Band MHz	Ambient Noise Field Intensity $dBm/m^2/kHz$	
	Field Site	Smyrna Site
0-.5	- 78.7	- 80.7
.35-.85	- 77.0	- 69.8
.5-2.5	- 89.1	- 93.1
1-6	<-100	96.1
4-14	-101.6	-100.9
11-31	<-107	-107.6
30-80	-113.4	<-120
65-115	- 87.6	<-120
100-200	<-110	<-117
200-300	<-105	<-112
250-350	<-105	<-112
350-850	<-105	<-110
800-1300	<-103	<-107

TABLE III. Typical Urban and Suburban Field Intensities.*

Frequency MHz	URBAN		SUBURBAN	
	Field Intensity In $\mu V/m/10$ kHz (Graph)	Field Intensity In $dBm/m^2/kHz$	Field Intensity In $\mu V/m/10$ kHz (Graph)	Field Intensity In $dBm/m^2/kHz$
1	170	81.2	50	- 91.8
2	103	85.5	23	- 98.5
4	80	- 87.8	17	-101.2
8	53	- 91.3	13	-103.5
10	50	- 91.8	12	-104.2
20	35	- 95.0	11	-105.2
40	26	- 97.5	10.1	-105.7
80	20	-100	9.8	-106
100	18	-100.7	9.6	-106.1
200	14	-103	9.4	-106.3
300	12.5	-103.8	9.2	-106.5
400	11.4	-104.7	9.1	-106.6
500	10.6	-105.3	9.1	-106.6

*NOTE: Taken from Graphs in "Reference Data for Radio Engineer," 4th Edition, 1962.

amount of literature is available on the broad subject of ambient electromagnetic environments. Very little of this data is concerned with the possible influence of these environments on public health.

As for the investigation of feasible measurement techniques, it is concluded that the configuration involving signal averaging equipment is a significant improvement over that reported in the available literature. The extent to which a selected frequency band is utilized by either continuous or intermittent transmissions can be precisely determined with the signal averager. In fact, the occupancy of the 27 to 47 MHz frequency band was shown by the measured data to be considerably less severe than anticipated. The signal averaging measurement technique is considered to be worthy of further investigation.

The major conclusion drawn from the ambient noise level data was that the measure techniques, resulting data, and data usefulness are comparable to similar data obtained during other investigations. The ambient noise level in the Atlanta urban location appeared to be below published typical levels; however, firm conclusions to this effect would be difficult to draw without more data.

6. Future Efforts

Future efforts will be directed along three lines as follows:

a) The measurements will be repeated periodically to determine if increases in the magnitude of the electromagnetic environment are apparent.

b) The frequency bands over which the measurements are made will be expanded to include a significantly increased frequency coverage.

c) Antennas which are applicable over broader frequency ranges will be used in future measurements to reduce the number of equipment changes necessary between 0-12 GHz.

ENVIRONMENTAL NONIONIZING RADIATION EXPOSURE:

A PRELIMINARY ANALYSIS OF THE PROBLEM AND CONTINUING WORK WITHIN EPA

RICHARD A. TELL

U.S. Environmental Protection Agency
Office of Radiation Programs
5600 Fishers Lane
Rockville, Maryland 20852

ENVIRONMENTAL NONIONIZING RADIATION EXPOSURE: A PRELIMINARY ANALYSIS OF THE PROBLEM AND CONTINUING WORK WITHIN EPA

The fact that electromagnetic energy in the radiofrequency and microwave portions of the spectrum can induce dangerous effects on human tissues when applied with sufficiently high intensity has been known for many years. With the invention of radar in 1935 and its rapid development and deployment during World War II, it became common knowledge among radar workers that microwave frequencies could interact with tissue leading to significant heating, depending upon the relative heat dissipation capabilities of the particular part of the anatomy exposed. Warnings about the possible induction, from over exposure, of cataracts of the eye and temporary sterility became commonplace.

Since those early days of microwave hazard concern, the expanded use of radiofrequency, or RF, and microwave energy for various applications such as widespread communications systems and industrial operations has elicited a new and more critical concern over the possible health implications of this form of nonionizing radiation (1, 2, 3). This new concern is with low level exposure and it has arisen because (a) the environmental levels are unknown, (b) the number of sources is increasing, and (c) the controversy over nonthermal effects which is illustrated by the discrepancy between human exposure standards used in the United States and in the Soviet Union. The purpose of this presentation is to share some of our thoughts and planned activities within the Office of Radiation Programs and to discuss quantification of the population exposure to RF and microwave fields in our environment.

Table 1 illustrates some of the different maximum permissible exposure standards around the world. The most striking aspect of this listing is the apparent difference in recommended levels between the U.S.A. and the U.S.S.R., Czechoslovakia, and Poland. In general, this discrepancy can be summarized by simply stating that the United States's standard is 1,000 times higher than those in these other countries. For example, a difference between 10 mW/cm^2 power density in the U.S. and 10 $\mu W/cm^2$ power density in the U.S.S.R.

In order to better appreciate some of these quantities in the different exposure standards, several RF and microwave definitions are necessary. When I refer to the electromagnetic

Country and Source	Radiation Frequency	Maximum Recommended Level	Condition or Remarks
USA (USASI)	10 MHz to 100 GHz	10 mW/cm^2 1 mW hr/cm^2	Periods of 0.1 hr. Averaged over any 0.1 hr. period
US Army and Air Force	---	10 mW/cm^2 10 to 100 mW/cm^2	Continuous exposure Maximum exposure time in minutes at $W(mW/cm^2) = 6000W^{-2}$
		100 mW/cm^2	No occupancy
Great Britain (Post Office Regulation)	30 MHz to 30 GHz	10 mW/cm^2	Continuous 8-hr. exposure, average power density
NATO (1956)	---	0.5 mW/cm^2	
Canada	10 MHz to 100 GHz	1 mW hr/cm^2	Averaged over any 0.1 hr. period
		10 mW/cm^2	Periods of 0.1 hr.
Poland	300 MHz	10 $\mu W/cm^2$ 100 $\mu W/cm^2$ 1 mW/cm^2	8 hr. exposure/day 2 to 3 hr/day 15 to 20 min/day
German Soc. Republic	---	10 mW/cm^2	
U.S.S.R.	0.1 to 1.5 MHz	20 V/m 5 amp/m	Alternating magnetic fields
	1.5 to 30 MHz	20 V/m	
	30 to 300 MHz	5 V/m	
	300 MHz	10 $\mu W/cm^2$ 100 $\mu W/cm^2$ 1 mW/cm^2	6 hr/day 2 hr/day 15 min/day
Czech. Soc. Rep.	0.01 to 300 MHz	10 V/m	8 hr/day
	300 MHz	25 $\mu W/cm^2$ 10 $\mu W/cm^2$	8 hr/day, CW operation 8 hr/day, pulsed (for shorter exposures see Figures 11 and 12)

Table 1. Maximum Recommended RF Levels for Human Exposure

spectrum, I am encompassing all frequencies from zero Hertz, or the point at which an alternating current becomes a direct current, to the highest frequency emanations known. In this enormous frequency region, of course, lie the ultraviolet, visible, and infrared spectra, as well as the ionizing radiation spectrum. Generally, the radio-frequency spectrum is taken to cover the 30 kHz to 30 MHz region, the microwave spectrum from 30 MHz to 300 GHz, and an area not before mentioned, the ELF, or extremely low frequency area, between dc and 30 kHz. Table 2 gives the designations for the various nonionizing frequency bands.

FREQUENCY BAND NOMENCLATURE

Frequency Range		Band Designation	
3	30 kHz	VLF	Very-low frequency
30 -	300 kHz	LF	Low frequency
300 -	3,000 kHz	MF	Medium frequency
3,000 -	30,000 kHz	HF	High frequency
30 -	300 MHz	VHF	Very-high frequency
300 -	3,000 MHz	UHF	Ultra-high frequency
3,000 -	30,000 MHz	SHF	Super-high frequency
30 -	300 GHz	EHF	Extremely-high frequency
300 -	3,000 GHz	---	---

Table 2. Nonionizing Radiation Frequency Band Nomenclature

When an electromagnetic wave is propagated through some medium, such as space, there are two methods of describing the amplitude of this wave intensity. One approach usually employed in the microwave region is to specify the power density of the exposure field in terms of power flow per unit area in the wave. At lower frequencies in the RF spectrum, it is common practice to specify the field strength of the incident waves in units of volts per meter. Though this partition in the units of field specification is attributed to a basic difference in the instrumentation normally employed for these two different frequency ranges, fields specified in terms of one unit may readily be specified in terms of the other by a simple conversion. For plane waves in free space, this conversion is illustrated in Figure 1. From this graph, it is apparent that a field density of 10 mW/cm^2 is equivalent to a field strength of 194 V/m, while a field density of 1 mW/cm^2 corresponds to about 67 V/m.

Generally, we will be interested in two different forms of signals, those which are continuous wave, or CW, and those which are pulsed. Examples of CW signals, for our purpose include broadcast stations, both radio and television, two-way radio services, and satellite communications stations. An example of a pulsed source is radar where signals are sent in a series of

pulses. In a radar, the peak transmitted power may be many times the average power because the average power depends upon the pulse duration and how often the pulse is repeated.

Finally, it is important to understand the meaning of effective radiated power, or as it is abbreviated--ERP. The ERP of a source refers to an effective power which takes into account the focusing effect of the source's transmitting antenna. This concentrating effect of the antenna upon the emitted radiation pattern is measured by the gain of the antenna, the higher the

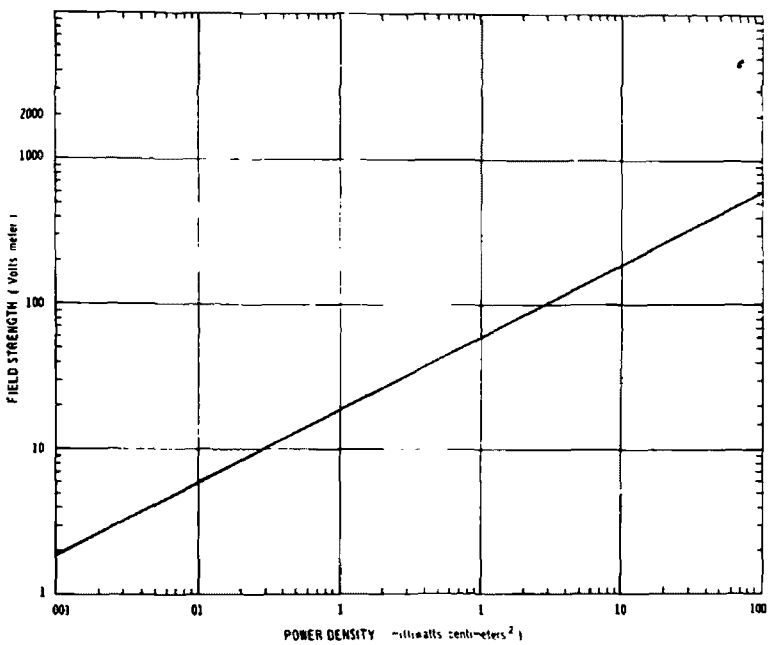


Figure 1. Relationship Between Field Strength and Power Density in Free Space

gain of the antenna, the greater its focusing effect. In short, rather than letting the transmitter's power be radiated uniformly in all directions, it limits the angular divergence of the power in order to concentrate it in some preferred direction. Thus, when viewing the source antenna from that particular orientation, it appears that the source has an effective radiated power of something greater than the actual transmitter power. The concept of ERP is important in estimating the distant exposure field from a particular source.

With these ideas in mind, let us take a quick look at the extent of some of the RF sources in our electromagnetic environment and then examine some of these sources in more detail.

Table 3 offers an introduction to the number of sources within the United States which are involved in creating the radiobackground in which we live. This chart indicates total numbers of some of the various sources by class. Keep in mind that this table does not take into account many sources, including mobile radio authorizations, amateur radio stations, microwave oven installations, and others, nor any type of classified source. Figures 2-6 give as examples, the geographical display for AM standard broadcast, FM, television, radar, and microwave sources revealing their quite widespread and homogeneous nature (4).

AM Standard Broadcast*	4,384
FM Broadcast*	2,859
TV Broadcast*	918
Unclassified Radar**	~2,900
Microwave Point-to-Point**	~72,000

* as of July 17, 1972

** as of June 1970

Table 3. Some Types and Numbers of Radiofrequency and Microwave Sources

Figure 2. Geographical Distribution of AM Broadcast Stations in United States

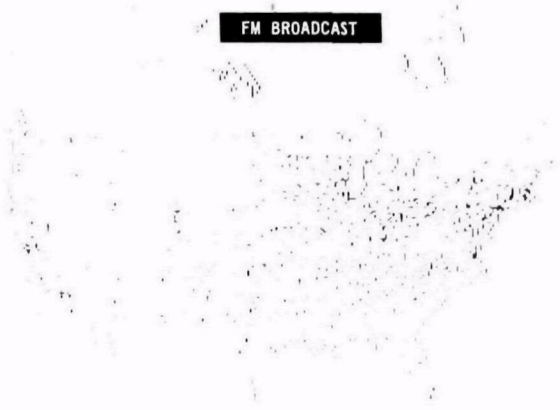


Figure 3. Geographical Distribution of FM Broadcast Stations in United States

Figure 4. Geographical Distribution of TV Broadcast Stations in United States

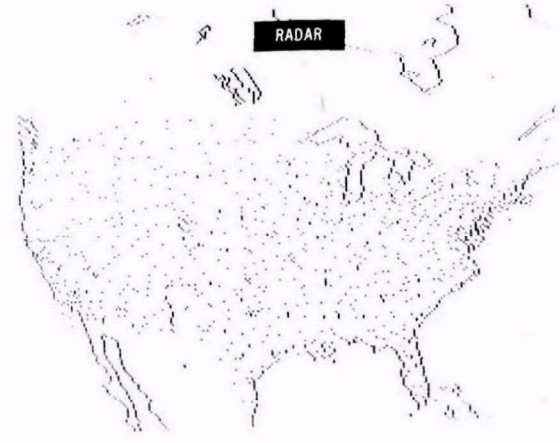


Figure 5. Geographical Distribution of Radar Facilities in United States (unclassified)

Figure 6. Geographical Distribution of Microwave Point-to-Point Installations in United States

A recent computer search by the Electromagnetic Compatibility Analysis Center, Annapolis, Maryland, has identified the most powerful sources in the United States. Figure 7 illustrates the distribution of the 20 most powerful nonpulsed, unclassified emitters found. The highest effective radiated power of this collection is 32 x 10^9 W or 32 GW produced by source number 1.

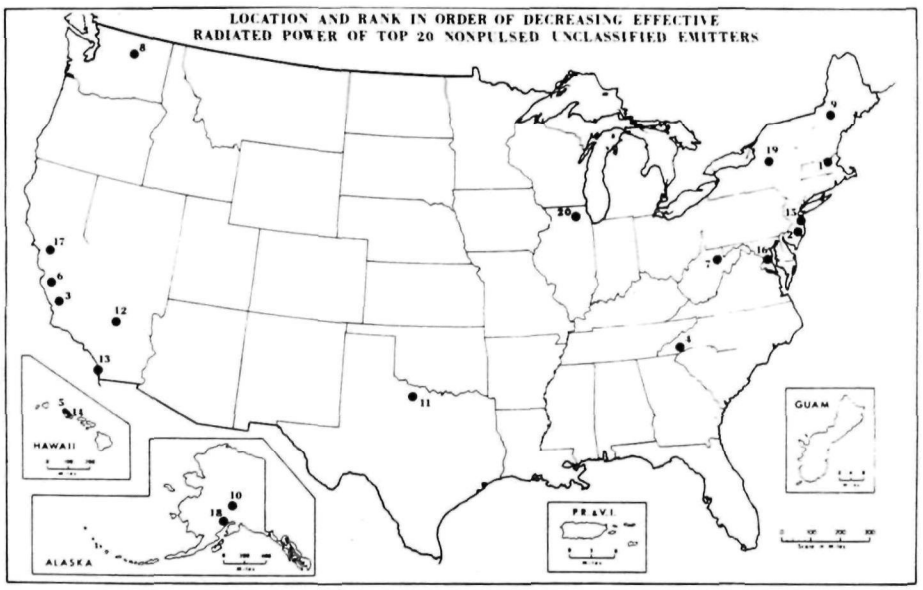


Figure 7. Location and Rank in Order of Decreasing Effective Radiated Power of Top 20 Nonpulsed Unclassified Emitters

Table 4 indicates that these sources descend in power to 5 GW for the 20th ranked source. The interesting aspect to this collection is that all are utilized for various satellite purposes. Since this original search was accomplished in August of this year, a new much higher powered source located in California has very recently initiated experimental operation. This new source has an effective radiated power of approximately 3.2×10^{12} or 3.2 TW average effective radiated power, placing it well above even the highest source on this display. Figure 8 illustrates a similar distribution for the 20 most powerful unclassified pulsed, or radar sources. Here we find that the number one source, again located in the Boston vicinity, has a peak effective radiated power, during its pulse, of 2.8 TW while the lowest one in this set has a peak power of 35 GW. Table 5 gives more details on these emitters. These presentations are illustrative of a practical type of indicator for us as to where to make field measurements. Assuming that an individual could get into the main beam of one of these satellite communications stations, a power density of 10 mW/cm^2 could be found at a distance from the source of three miles assuming it had an average effective power of 32 GW, or at a distance of about 32 miles for the new source in California. Distances with possible exposures this high imply the need for a careful look at the particular characteristics of the source to ascertain the possibility of a hazard.

Rank	City/State	Frequency (MHz)	Use	Average ERP (GW)
1	Westford, Mass.	7748	Satellite Communication	31.6
2	Lakehurst, N.J.	8004	"	20.0
3	Roberts, Calif.	7985	"	20.0
4	Rosman, N.C.	5925	"	11.3
5	Paumalu, Hawaii	5925	"	7.9
6	Jamesburg, Calif.	5925	"	7.9
7	Etam, W. Va.	5925	"	7.9
8	Brewster, Wash.	5925	"	7.9
9	Andover, Maine	5925	"	7.9
10	Bartlett, Alaska	5925	"	7.9
11	Archer City, Texas	217	"	6.4
12	Mojave Desert, Calif.	5985	"	6.4
13	Pt. Loma, Calif.	7997	"	5.0
14	Helemano, Hawaii	7990	"	5.0
15	Ft. Monmouth, N.J.	7990	"	5.0
16	Brandywine, Md.	7986	"	5.0
17	Camp Parks, Calif.	7990	"	5.0
18	Wildwood, Alaska	7986	"	5.0
19	Floyd Test Annex, N.Y.	7986	"	5.0
20	Elgin, Ill.	8004	"	5.0

144 nonpulsed, unclassified sources have average ERP's of 1 MW or greater.

Of 79 nonpulsed, classified emitters, none had an ERP greater than the 20th ranked emitter in the unclassified group.

Table 4. Source Parameters for Top 20 Nonpulsed Emitters

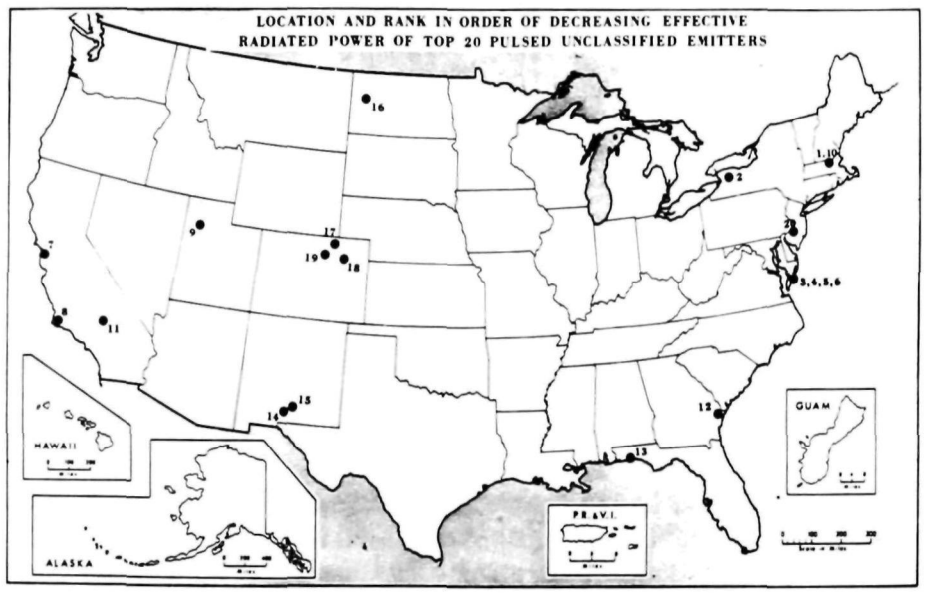


Figure 8. Location and Rank in Order of Decreasing Effective Radiated Power of Top 20 Pulsed Unclassified Emitters

Rank	City/State	Frequency (MHz)	Average ERP	Peak ERP
1	Tyngsboro, Mass.	7840	840 MW	2.8 TW
2	Newstead, N.Y.	2850	605 MW	2.2 TW
3	Wallops, Va.	9378	640 MW	1.0 TW
4	Wallops, Va.	2820	608 MW	0.95 TW
5	Wallops, Va.	2840	608 MW	0.95 TW
6	Wallops, Va.	5400	25.2 MW	0.63 TW
7	Pillar Pt., Calif.	5555	94.3 MW	0.59 TW
8	Vandenburg AFB, Calif.	5840	20.8 MW	0.52 TW
9	Lakeside, Utah	2900	115 MW	0.35 TW
10	Westford, Mass.	1295	9.6 GW	0.32 TW
11	Boron AFS, Calif.	5400	149 MW	99.8 GW
12	Savannah AFS, Ga.	5400	147 MW	99.8 GW
13	Elgin AFB, Fla.	5480	12.7 MW	79.2 GW
14	White Sands, N. Mex.	5490	8.7 MW	47.5 GW
15	White Sands, N. Mex.	5600	8.7 MW	47.5 GW
16	North Dakota	3100	---	39.8 GW
17	Grover, Colo.	2700	---	39.8 GW
18	Ft. Morgan, Colo.	2700	---	39.8 GW
19	Greeley, Colo.	2730	---	39.7 GW
20	Gibbsboro AFS, N.J.	2700	23.6 MW	35.4 GW

229 pulsed, unclassified sources have peak ERP's of 10 GW or greater.

Of 146 pulsed, classified emitters, none had an ERP greater than the 6th ranked emitter in the unclassified group.

Table 5. Source Parameters for Top 20 Pulsed Emitters

The number and variety of RF sources which produce emanations in the publicly accessible environment is large. Considering the divergent types and uses of RF and microwave energy which carry the potential of environmental electromagnetic pollution, I have selected two different categories of sources to focus our attention on this afternoon for examining possible exposure levels. One category includes the high power radar and satellite stations which employ very intense, focused beams. Though the chances of a person getting into a very directive antenna beam are small, because of the high powers involved, the greatest hazard may lie within this category of sources. The other category consists of the large number of lower power broadcast sources which purposely illuminate the population with their energy. Though small segments of the population may be exposed to the intense sources, all of the population is exposed to these lower powered sources.

A theoretical analysis of the radiation fields from broadcast stations can be divided among the different types of transmitting antennas utilized by the stations (3). AM broadcast stations occupying the 535 to 1605 kHz frequency band normally always use vertically polarized transmitting towers in order to propagate a ground wave signal to their primary audience in the surrounding area. In the United States, AM standard broadcast stations may use authorized maximum transmitter powers of 50 kW and when coupled with the low gain antenna towers that they use (low gain because a single tower will not concentrate the emitted wave into a particular direction) do not normally produce adversely high field intensities in their vicinity except, perhaps, at distances extremely close to the transmitting tower itself. Figure 9 graphically illustrates the field strength of a maximum powered AM station of 50 kW using a single vertical monopole antenna as a function of distance from the tower. Though the field strength varies according to the conductivity of the ground over which the wave passes, normally as an upper limit, a field strength on the order of 4 V/m may be expected at a distance of about 1/2 mile from the tower. This would correspond to an equivalent power density of about 4 $\mu W/cm^2$.

In some cases, AM stations will employ a series of towers in order to radiate their signal in some preferred direction, either to serve a selected audience or to minimize interference with some other station operating on the same frequency but in a distant town. In this case, the antenna system as a whole exhibits a higher gain, in some direction, than just a single tower. Consequently, the field intensity from a station of this sort will be higher than before according to the number and configuration of the towers. In practical instances, such tower combinations will account for a field density increase of only two to four times in the maximum direction. This would change our previous estimate to something on the order of 8 V/m, or 16 $\mu W/cm^2$ at 1/2 mile. And still, in terms of a thermal hazard level of 10 mW/cm^2 this seems to be well on the safe side.

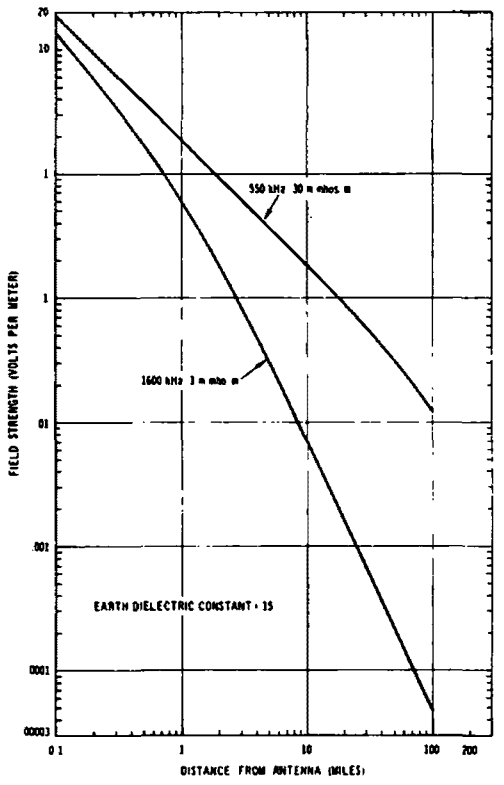


Figure 9. Groundwave Field Strength of 50 kW AM Standard Broadcast Station

Commercial FM and television broadcast stations may be analyzed as another type due to the similarity in the antennas used for transmitting. Due to the nature of propagation of waves in the VHF and UHF frequency bands used in FM and TV, most stations employ high gain antennas atop very tall supporting towers. Before one can accurately estimate the exposure from such a source, however, the radiation pattern of the particular station must be incorporated into the calculation to account for distance from the antenna supporting tower. With the antennas used in the VHF and UHF region, the tower is acting merely as a supporting member rather than radiating itself as is the case with AM stations. From the vertical gain pattern for a specific antenna as shown in Figure 10 and knowledge of the tower height, the field density at any given distance from the tower at ground level may be computed. Obviously, as one goes up in elevation along side one of these towers, the field density will increase since you are approaching the primary radiation beam which is normally aimed at the horizon. For the various authorized effective radiated powers for commercial FM and TV stations, Figure 11 illustrates field strength vs. exposure

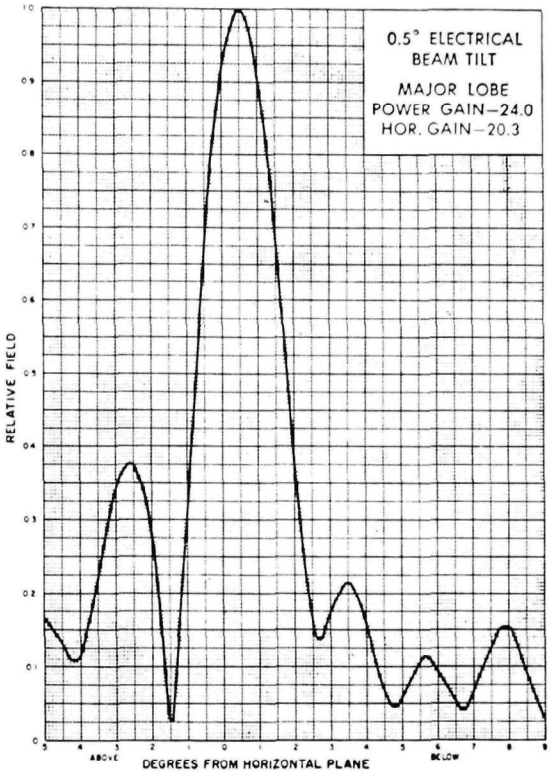


Figure 10. Vertical Gain Pattern of Typical Medium Gain UHF Transmitting Antennas (Courtesy RCA, Camden, N.J.)

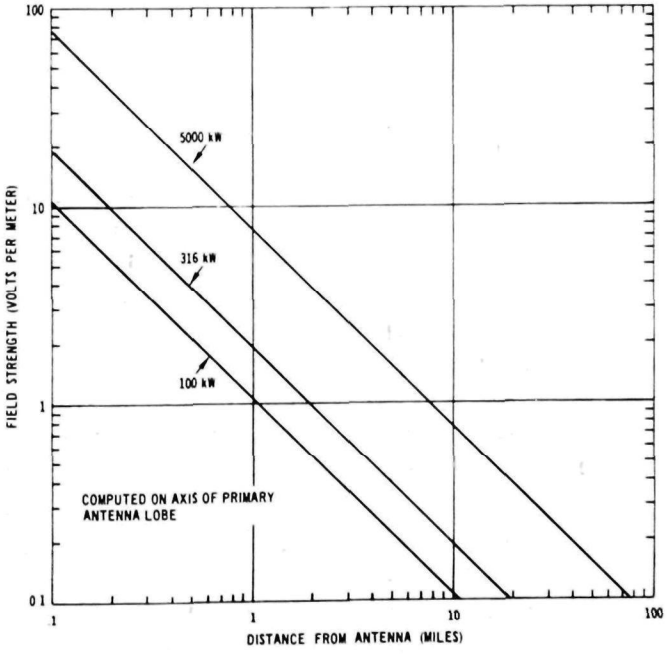


Figure 11. Field Strength vs. Distance for 3 ERP's Used in Broadcasting

distance from the source, assuming that one is in the main beam of the transmitting antenna. Obviously, for this to be applicable, a person would have to be in a tall building adjacent to one of these transmitting towers; however, such situations are very possible in certain metropolitan instances. Under many practical circumstances, the ground level intensities from most FM and TV emitters are found not to exceed about 1 V/m; see Table 6. In the case of UHF TV allocations with maximum effective radiated powers of 5 MW, a distance of 212 feet corresponds to an exposure of 10 mW/cm^2 in the main beam while if we relax the exposure level to the Russian standard of 10 $\mu W/cm^2$ we find that the distance has increased to 1.2 miles. In crowded metropolitan areas such an increase in the effective exposure area from something less than a square city block to 4 1/2 square miles could indicate that in some cases certain portions of the general population are routinely exposed to levels exceeding the Russian exposure standards.

In the other category, radar stations represent sources that operate in the microwave frequency range, use pulsed powers which are often extremely high, and usually utilize very high gain or directive antennas. In general, this means that radar stations may yield high exposure fields at relatively great distances if one is ever struck by the radar beam. In other words, because the antennas used are so directive, the probability of being in the main beam of a radar at any given time is generally quite low. Also, there is the rotational factor of many radars which further reduces the chances of prolonged exposure. Nevertheless, careful analysis of the radar exposure situation is warranted since there are cases in which the radar beam is intentionally swept near ground level for specific navigational purposes.

Service	Maximum Allowable ERP, kW	Tower Height, Meters	Field Intensity, mV/m
FM radio	100	152.4	1023
VHF television			
Channels 2-6	100	304.8	807
Channels 7-13	316	304.8	191
UHF television			
Channels 14-83	5000	304.8	380

Table 6. Maximum Powers, Typical Tower Heights, and Ground Level Field Intensities for Various Broadcast Services Estimated at One-Mile Upper Limits

The most powerful sources in the U.S., however, turn out to be the satellite communications stations with average effective radiated powers as high as 3.2 TW. An important comment is in order about average vs. peak power. Though a radar may have a much higher peak power, it is the time-averaged, or effective heating power to which the present U.S. standard of 10 mW/cm^2 applies. Considerable comment on the relative hazards of pulsed vs. continuous wave exposure has been made by foreign scientists. Yet, at this time, there have not been any demonstrations by American scientists that a pulsed field can be any more dangerous than a continuously applied field of the same average power density (5). Thus, for present hazard analysis purposes, we will consider only the level of a field from its average power density standpoint. It is possible, however, that pulsed emissions can cause detrimental interference with cardiac pacemakers and other health related electronic devices (6).

The crux of the problem in defining the RF exposure to humans in our environment lies in the relationship between potential exposure as calculated from technical data on a particular source, and the actual human exposure which takes place when individuals are living or working in the true exposure area of a source. It is a relatively easy task to determine the potential exposure level to which a person might become exposed but another much more difficult task to map a truly reliable, calculated exposure pattern into a population distribution in the source's area. A primary reason for this difficulty lies in the nonavailability or difficulty in obtaining accurate source antenna information and analytical solutions to complex environments filled with buildings, power lines, and other obstacles, and the highly dynamic nature of man-made RF levels, i.e., on-off times. In many cases, this information may be totally absent for the source or sources in question or be exceedingly laborious to obtain and utilize. Consequently, there does not exist any known source of information from which a very detailed and accurate computation of exposure can be quickly made on a multiple source basis. Antenna information will usually be dug out and calculations made on a specific individual source basis using simplifying assumptions about the exposure environment. As a result, any attempt to map the total exposure levels in a given geographical area from the totality of sources which exist in that general region will necessarily be only an approximation to what may really be the case. Any more sophisticated attempt, trying to take into account transmitter on-off times, actual radiation patterns, and building and terrain effects which can easily account for differences of several orders of magnitude in the actual levels as compared to calculated levels (7, 8), appears to be excessively prohibitive in cost in terms of the usefulness of the output data. Because of this rapidly fluctuating exposure environment (i.e., daily activity of the general population and mobility of many RF sources) the only possible, meaningful approach to mathematically describing nonionizing exposure would appear to be statistical in nature.

Nevertheless, if properly interpreted, exposure maps using the utmost in simplistic assumptions can be useful as indicators of points where actual field measurements should be made to determine the true hazard potential. Representative maps, showing simply the location of fixed sources are being prepared by us as guides to finding locations where the largest numbers of people are exposed. I must repeat my caution on interpretation of this type of display for purposes of estimating population exposure. If we ask from what class, type, or frequency range of sources do most people receive the greatest amount of nonionizing radiation exposure, we can see that it is not necessarily the housewife who stays at home all day in her house which is a few blocks away from the local radio or TV station that receives the greatest total RF exposure (i.e., a measure of radiation intensity and the duration of exposure). It may well be her husband who drives himself to work being radiated with the relatively intense ignition system for a short period of time, or the passengers in cabs who get periodic pulses of relatively intense exposure from the two-way radio system in the taxi. Thus, the questions of who receives the most radiation from what, where are the highest exposure environments in a city, and what is the daily average human RF dose, averaged over the whole population are very complex and difficult questions to accurately answer.

As interesting as these exposure maps which I have mentioned may be, because of the potentially wide variation between the actual environmental levels of RF and what one may theoretically predict from the best information available in large computer data files, actual field measurements are necessary in many cases to verify model predictions and indicate the real exposure level.

To this end, I will describe one of our forthcoming field studies and the instrumentation which goes into making RF field measurements.

You have seen that, from a gross, high power level analysis, the most potential for selected site hazardous exposure may occur at the superpower satellite communications stations about our country. We, in the Electromagnetic Radiation Analysis Branch, are in the process of selecting a few of these sources for detailed investigation including field density surveys to begin in the near future. Measurements will be made of field levels at locations, about each of the selected sources, at which unrestricted individuals might occupy from time-to-time. The exact subset of these sources which we will be surveying is being selected primarily on the basis of antenna orientation procedures for tracking of the various satellites which they service. Some satellite orbits require that tracking antennas use elevation angles approaching the horizon. In such cases, high fields may be observed at ground levels in the source vicinity. Results of these initial measurements will aid in determining the potential hazard from this class of sources.

At this time our branch is in the process of establishing an instrumentation laboratory which will be used as the basis for developing measurement systems to be applied to the environmental nonionizing radiation problem area and to support various field studies. The present measurement capability of the branch consists of wideband, relatively high level, frequency integrative devices such as will be used for our satellite station survey and uncalibrated spectrum signature instruments which allow us to determine the relative field intensities of signals in the electromagnetic background. Figure 12 illustrates what just the FM broadcast band spectrum signature looks like in the Washington, D.C., area. Relative field intensity is presented as a function of frequency. We are presently developing a system whereby such spectra as this one can be accurately collected, instrumentally, in terms of the true signal amplitude and then subsequently integrated over any desired frequency band to ascertain the true total integrated spectral power density; i.e., the summation of the field intensity of each of the individual signals comprising this composite spectrum.

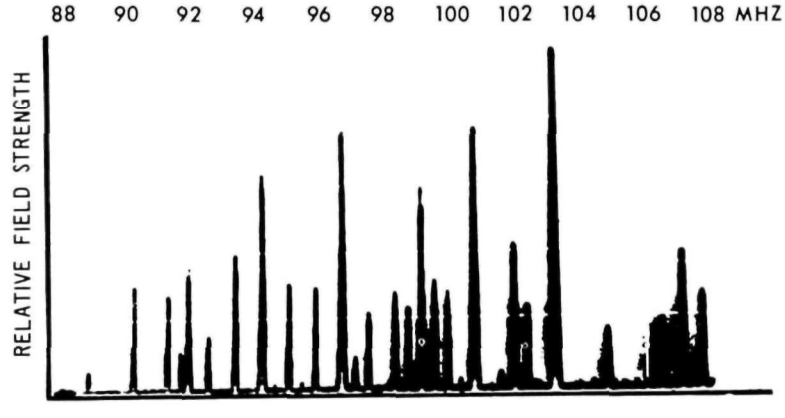
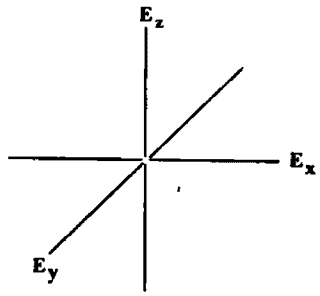


Figure 12. FM Broadcast Spectrum in Washington, D.C., Area

One of the most important aspects to making meaningful field measurements in the environment is to have a sensing antenna which is responsive to all spatial polarization components of the impinging waves at each frequency of measurement interest. This implies the use of isotropic receiving antennas such that, regardless of the nature of the mixed polarization of the incoming waves, for example, depolarization caused by propagation effects, the output of the antenna system will be proportional to the total isotropically

induced antenna power. We are currently working with orthogonal dipole systems to approximate such an antenna. This concept is diagrammatically illustrated in Figure 13. It is envisioned that several such orthogonal antenna systems will be employed to cover the wide frequency spectrum of interest. Our system depicted in Figure 14 is being configured around a spectrum analyzer, an instrument which produced the spectral display of the FM broadcast band, calibrated, equivalently isotropic reception antennas, and a data acquisition and processing system which will allow rapid acquisition and analysis of the incoming spectral data.

As a closing note, I would like to leave in your mind a feel for the potential magnitude of this nonionizing radiation pollution problem in our environment. Figure 15 shows the total number of sources within the U.S. which are capable of producing an exposure power density of 10 mW/cm^2 as a function of distance from the source. As you can readily see, as we increase the exposure distance, the number of emitters decreases, simply indicating that, as you might have suspected, there are fewer high powered sources than lower powered sources. However, look at the actual numbers of sources involved. Remember that this is for the currently accepted U.S. guide level of 10 mW/cm^2.



$$\text{TPD} \quad \frac{E_x^2}{Z_o} + \frac{E_y^2}{Z_o} + \frac{E_z^2}{Z_o}$$

$$\cdot \frac{E_R^2}{Z_o} \quad \text{where}$$

$$E_R \quad \sqrt{E_x^2 + E_y^2 + E_z^2}$$

Figure 13. Total Power Density Measurement with Orthogonal Dipoles

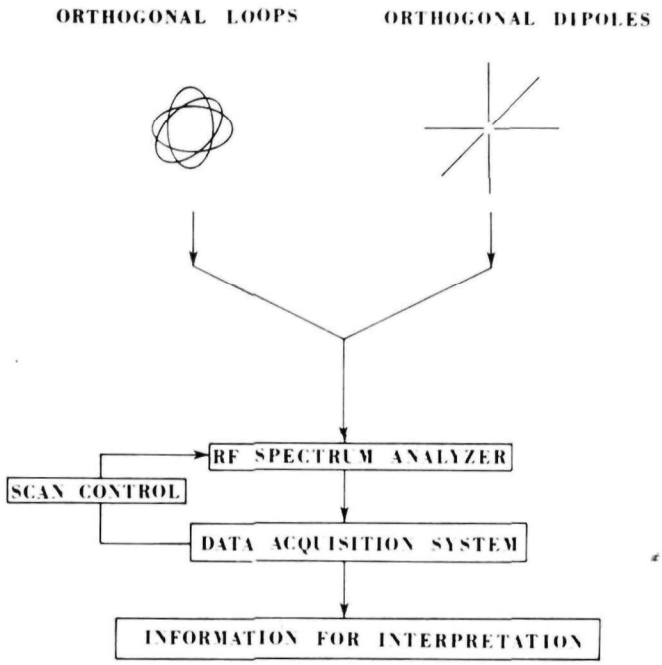


Figure 14. Conceptual System Approach to Environmental RF Measurements

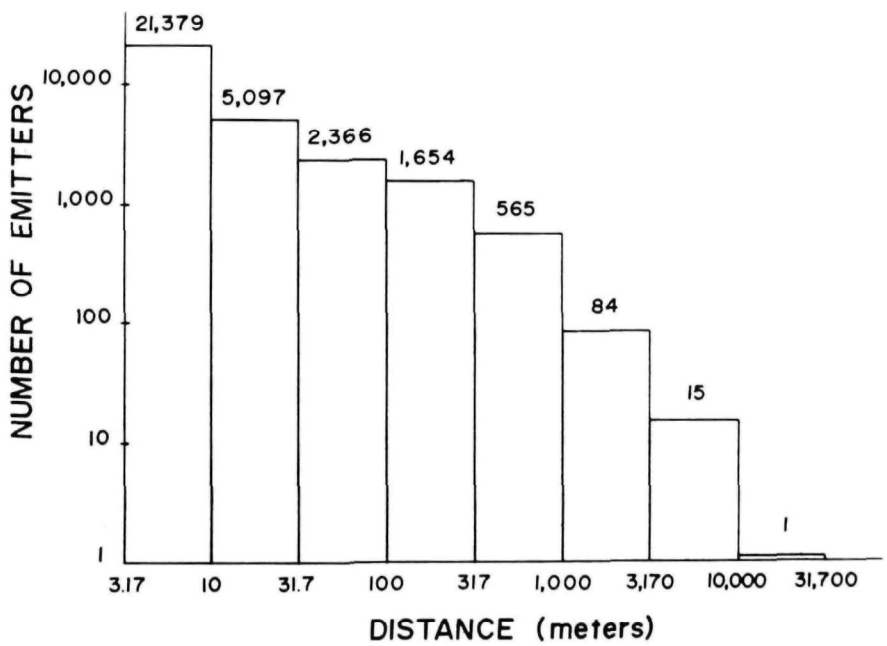


Figure 15. Cumulative Distribution of Emitters in the United States Capable of Producing a Power Density Equal to or Greater than 10 mW/cm^2, as a Function of Distance

Now let's reduce this allowable level to 1 mW/cm^2, see Figure 16. Obviously, more emitters are capable now of producing 1 mW/cm^2 in each given distance interval. Now let's reduce our allowable level to 0.1 mW/cm^2, see Figure 17. The numbers continue to grow. Finally let's look at what happens if we accept the Russian standard of 0.01 mW/cm^2 or 10 $\mu W/cm^2$, see Figure 18. Quite clearly, the dimensions of our problem have increased hundreds of times from what was the case utilizing the present U.S. guide. Thus, the controversy over thermal vs. nonthermal effects has serious implications in terms of U.S. environmental RF fields, should nonthermal effects be proven to exist and to be hazardous.

Through some of these ideas I have discussed today and the field measurements EPA will soon be implementing, we hope and expect to better define the actual RF levels to which we are exposed each day and, subsequently, to better understand any possible health implications of our electromagnetic environment.

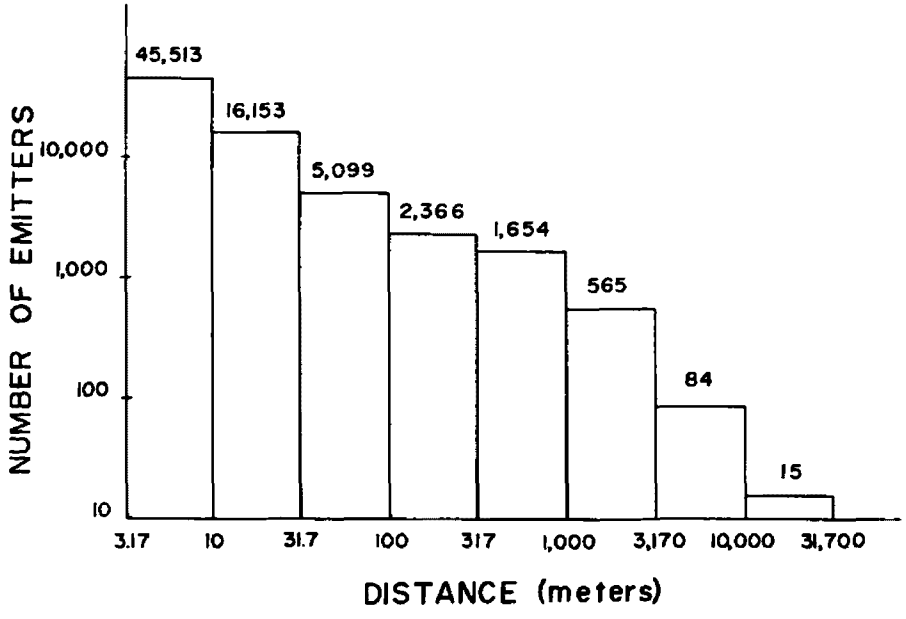


Figure 16. Cumulative Distribution of Emitters in the United States Capable of Producing a Power Density Equal to or Greater than 1 mW/cm^2, as a Function of Distance

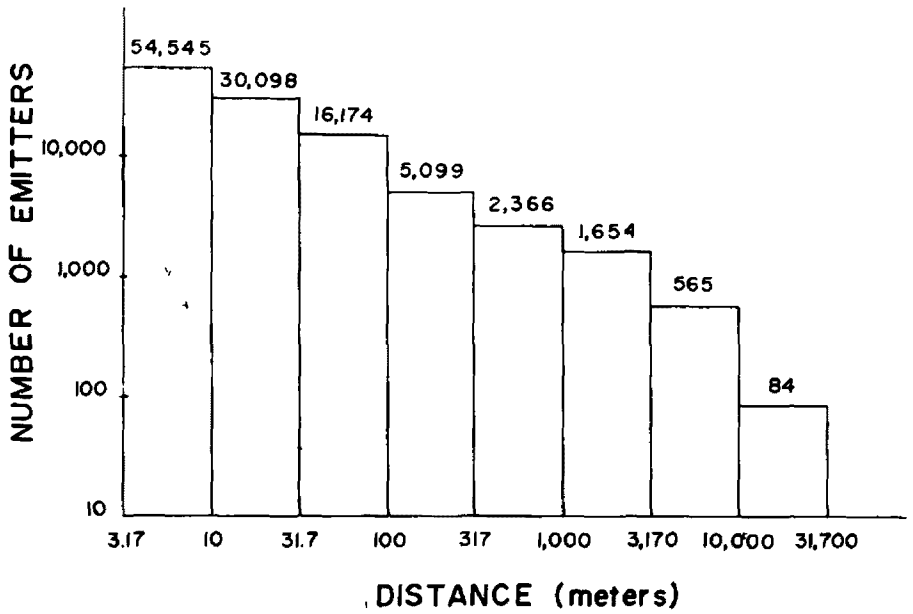


Figure 17. Cumulative Distribution of Emitters in the United States Capable of Producing a Power Density Equal to or Greater than 0.1 mW/cm^2, as a Function of Distance

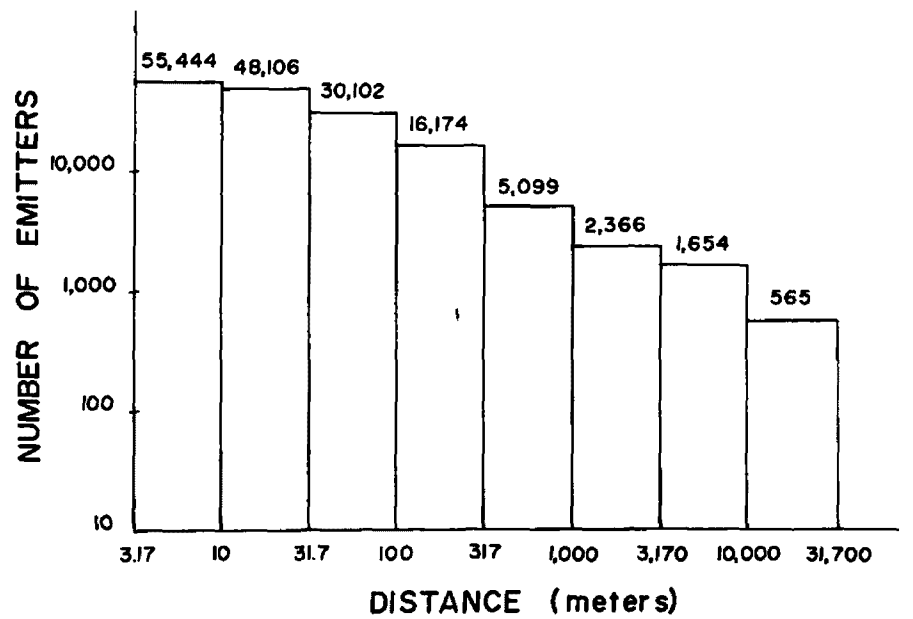


Figure 18. Cumulative Distribution of Emitters in the United States Capable of Producing a Power Density Equal to or Greater than 0.01 mW/cm^2, as a Function of Distance

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ELECTROMAGNETIC COMPATIBILITY, ELECTROMAGNETIC INTERFERENCE AND SUSCEPTIBILITY AS RELATED TO MEDICAL DEVICES

Paul S. Ruggera and Mays L. Swicord

Product Testing and Evaluation Branch
Division of Electronic Products

November 1972

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Food and Drug Administration
Bureau of Radiological Health
Rockville, Maryland 20852

ABSTRACT

This paper presents a review of cooperative work of the Bureau of Radiological Health with the U.S.A.F. School of Aerospace Medicine and the Society of Automotive Engineers in determining cardiac pacemaker susceptibility to electromagnetic interference. The preliminary results of surveys conducted in the hospital environment, directed at determining EMI levels present and their possible effect on medical electronic equipment, are also discussed.

ELECTROMAGNETIC COMPATIBILITY, ELECTROMAGNETIC INTERFERENCE AND SUSCEPTIBILITY AS RELATED TO MEDICAL DEVICES

The purpose of the Radiation Control for Health and Safety Act of 1968, Public Law 90-602, is to protect the public from hazardous exposure to radiation from electronic products. To accomplish this purpose, an electronic product radiation control program including the development and administration of performance standards has been established by the Secretary of the Department of Health, Education, and Welfare. The Food and Drug Administration's Bureau of Radiological Health has been made responsible for conduct of the program. As a part of the program, the Bureau is instructed by the Act to "study and evaluate emissions of, and conditions of exposure to, electronic product radiation and intense magnetic fields."

The concept of protecting the public health from excessive electromagnetic radiation has long been based on evidence of adverse biological effects. In the hospital environment, where sensitive electronic instrumentation is utilized to monitor physiological function, and maintain life function, the conditions of exposure to a patient may well be different from those assumed by the groups who have recommended human exposure control standards. In such an environment, the interaction of electromagnetic radiation with sensitive electronic instrumentation, rather than directly with the biological systems, may be the primary factor in

determining if a specific level of radiation is hazardous. The Division of Electronic Products of the Bureau of Radiological Health has undertaken a program to examine the basis of present exposure-limit criteria, and determine if new standards or legislation are necessary.

For the past two years, interference to a specific product, the cardiac pacemaker, was of primary concern. More recently, this effort has been directed to critical hospital areas which utilize instrumentation for monitoring or aiding patients. This discussion summarizes the past activity of the Bureau concerning an affected device, the cardiac pacemaker, and the present program aimed at determining what levels of potential interference exist in hospitals and elsewhere, and to pinpoint the sources of these interferences.

Implanted cardiac pacemaker dysfunction due to external electromagnetic interference (EMI) has been reported in the literature for several years. Most of the literature about sources of EMI concerns those products and frequency ranges that a person would most likely encounter in a normal existence. Pacemaker dysfunction has been reported to occur near electrocautery (1, 2) and diathermy apparatus (1, 3, 4), electric shavers (5), and internal combustion engine ignition systems (2, 4). In recent years, incidents of interference caused by radar (6), communication systems (3, 7), and microwave ovens (8) have been reported in the

literature. Because a pacemaker wearer could unknowingly expose himself to these high frequency sources, it was considered necessary to evaluate the interference potential of these sources.

After a series of meetings with representatives of the scientific, medical and manufacturing communities, it was surmised that the possibility of interference to some models did exist. With the cooperation of the Association for the Advancement of Medical Instrumentation, warning letters were distributed through professional channels in the fall of 1970. These letters were mailed to hospital administrators for general distribution to their staffs, and to physical therapists who daily utilize equipment known to be potential sources of interference. These letters mentioned several potential sources of interference, one of which was the microwave oven.

In April 1971, the Bureau published a report (9) which discussed the electromagnetic interference to cardiac pacemakers. This report, written in layman's language, was widely distributed and is available from the Bureau's Information Office.

Through the voluntary cooperation of pacemaker manufacturers and the Society of Automotive Engineers, AE-4 Committee, pacemaker models available in June 1971 were subjected to one set of prototype open-air test procedures. The results of this testing were given to the manufacturers for their individual evaluation of their product, as well as the suitability of the test procedure. A

representative of the Bureau of Radiological Health formally presented the results of this test procedure development to the Working Group on Environmental Interference of the Association for the Advancement of Medical Instrumentation in November 1971.

Concurrent with these activities, the Division of Electronic Products had been cooperating with the U.S. Air Force School of Aerospace Medicine in its studies utilizing pacemaker-implanted canines. In the spring of 1972, these canines were exposed to controlled sources of electromagnetic energy which simulated radar and microwave oven emissions. The complete results of these studies were published in the IEEE International Electromagnetic Compatibility Symposium Record (10) in July 1972. In general, both studies showed that the most easily determined effect of EMI, that of no pacemaker output, occurred under varied conditions of frequency, amplitude, and modulation. All pacemakers resumed normal operation after exposure.

The signal utilized to simulate microwave ovens was a half-wave modulated carrier with additional modulation to simulate the mode stirrer. Under these conditions the most sensitive implanted pacemaker produced no output at calculated average power densities of about 15 microwatts/cm^2. Assuming an inverse square relationship with distance, for a microwave oven leaking 5 milliwatts/cm^2 at 5 cm, an average power density of about 15 microwatts/cm^2 will exist at three feet. Under higher exposure, six other pacemakers

displayed some rate alterations, while two of the units appeared to be unaffected under these conditions of testing.

These findings indicate that a person wearing one of the more sensitive models tested might experience arrhythmia within a three foot radius of a microwave oven leaking at 5 milliwatts/cm^2. This could include ovens of all types manufactured both prior to and after the effective date of the recent DHEW microwave oven radiation emission standard, because the standard was not designed to restrict radiation leakage to the low levels found to affect pacemakers.

The signal utilized to simulate radar was a square wave modulated carrier with varied time interval between pulses. Under these conditions the most sensitive unit produced no output pulse at calculated average power densities of about 0.3 microwatts/cm^2. In general some effects were noted in all but two of the models tested under increased exposure and appropriate pulse repetition rates.

On May 17, 1972, as a result of these data, letters summarizing these findings were mailed to all known U.S. and foreign pacemaker manufacturers. In addition, questions regarding the specific steps taken to improve interference susceptibility of their products were asked. Shortly after the letters were sent, the Commissioner, Food and Drug Administration decided that the activities concerning the susceptibility of implanted cardiac pacemakers to interference could be more effectively administered by separating the responsibility into two disciplinary areas. The Bureau of Radiological Health is

currently responsible for investigating the technical aspects of the pacemaker problem in relation to the identification and control of the sources emitting radiation which would affect such devices. It also provides technical support to the Office of Medical Devices. The Office of Medical Devices has assumed responsibilities concerning the pacemaker itself since the pacemaker is a medical device which does not emit electromagnetic radiation. This includes attempting to determine the sensitivity of pacemakers to outside interference, developing standardized test procedures, and dealing with manufacturers in order to encourage the development of less susceptible pacemakers.

Since January 1972, the Division of Electronic Products has been developing the laboratory capability for generating and measuring electromagnetic fields, principally for calibrating and evaluating radiation detecting instruments for field use. Because of the administrative transfer of the cardiac pacemaker responsibility, more time can be devoted to these aspects of EMI. Having developed an adequate capability to measure electromagnetic radiation levels, the Bureau has recently responded to one request to investigate the level of EMI in critical areas inside hospitals. Other requests have been received including a municipal airport, and a Public Health Service Hospital which happens to be the tallest Federal building in the area with its roof being used for government communication antennas.

Electromagnetic field surveys were conducted on September 11-15, 1972, at the University of California Medical Center and at the USPHS Hospital in San Francisco, California. The primary purpose was to establish base line measurements of electromagnetic radiation levels in critical hospital locations which will be compared with similar measurements taken at a later date. Levels at some frequencies are expected to increase as a result of the construction of a large, multiple-frequency broadcast tower in the vicinity. The data collected at the two hospitals have been stored on two analog magnetic tapes. Approximately 400 orthogonal spectrum sweeps were recorded for frequencies between 30 hertz and one gigahertz.

At the present time the Bureau personnel are reducing the data for analysis and recalibrating checkpoints for the receiving antenna. A report will not be available until the return visit to the hospitals can be made, after the tower is energized, and these data can then be compared. Preliminary results indicate at present that the highest discrete signal levels in one polarization are approximately 10 microwatts/cm^2.

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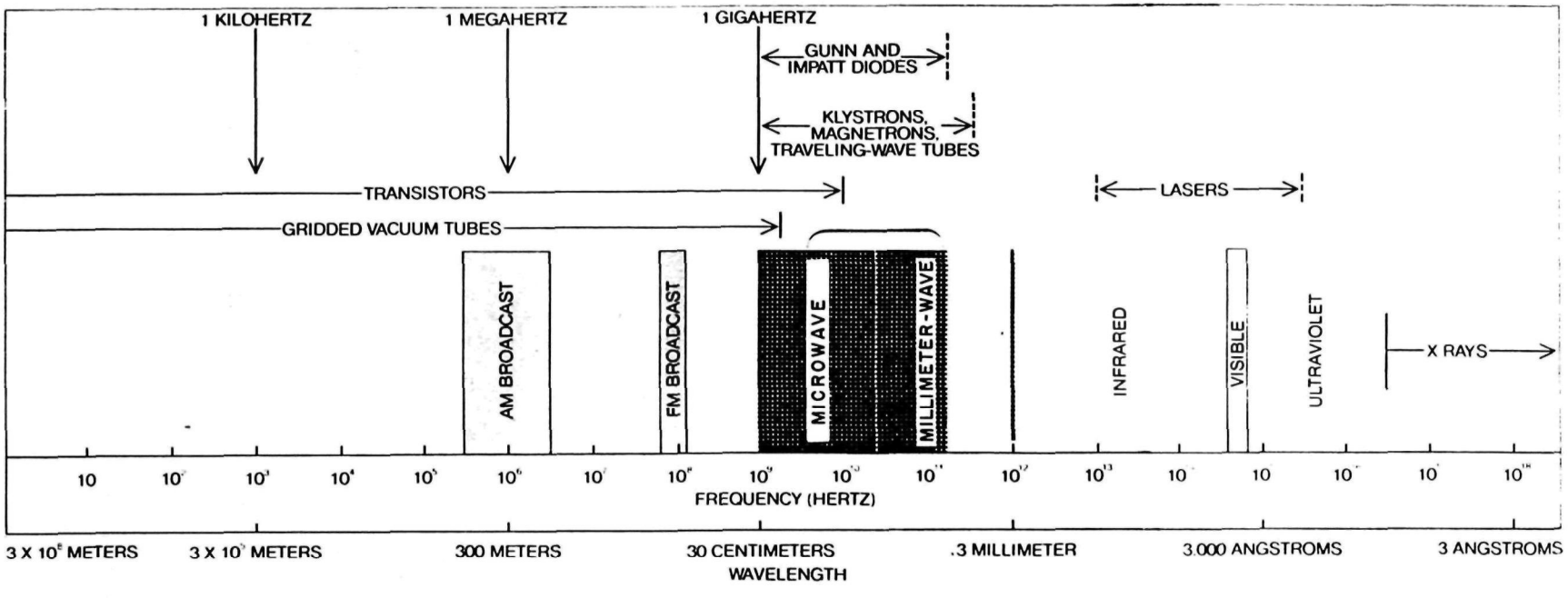
THE GROWTH OF MICROWAVE SYSTEMS AND APPLICATIONS

Jeffrey Frey, Ph.D.
School of Electrical Engineering
Cornell University
Ithaca, N. Y. 14850

The term "microwave" describes electromagnetic radiation occupying a particular portion of the spectrum of all such radiation; the microwave band is generally taken to mean the frequency range 10^9 to something over 10^{11} Hz, comprising radiation in free space with wavelengths from 30 cm. (at 10^9 Hz) to under 0.3 cm. The relationship of the microwave portion of the spectrum to other labeled bands is illustrated in Figure 1.

Microwave radiation possesses two particular advantages over radiation at lower frequencies, advantages which assure the application of microwaves to certain problems, regardless of the cost involved. First, microwave radiation covers a very wide portion of the frequency spectrum (note that the abscissa of Figure 1 is logarithmic). The large bandwidth available for microwave beams allows these beams to carry more information than beams at lower frequencies. Second, the small wavelength of microwave radiation allows microwave beams to be focused and pointed relatively easily. While the frequency range above 10^{11} Hz is even more advantageous from these points of view, as yet no devices to generate and control energy in this frequency

Radiological Health Section, 14 November 1972.


1 KILOHERTZ
1 MEGAHERTZ
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GUNN AND IMPATT DIODES
KLYSTRONS, MAGNETRONS, TRAVELING-WAVE TUBES
TRANSISTORS
GRIDDED VACUUM TUBES
LASERS
AM BROADCAST
FM BROADCAST
MICROWAVE
MILLIMETER-WAVE
INFRARED
VISIBLE
ULTRAVIOLET
X RAYS
FREQUENCY (HERTZ)
3 X 10⁸ METERS
3 X 10² METERS
300 METERS
30 CENTIMETERS
.3 MILLIMETER
3,000 ANGSTROMS
3 ANGSTROMS
WAVELENGTH

Figure 1

range are available that match the output power, cost, and reliability of analogous devices in the microwave band. In addition, at very high frequencies signals are much more subject to attenuation due to moisture in the atmosphere than at microwave frequencies.

The bandwidth and directionality properties of microwave radiation have dictated the general types of uses to which these systems have historically been put. The first microwave system to be developed, just before and during the 1939-45 war, was radar, which utilizes the directional properties of microwave radiation. The second major application of microwave systems was in relaying network TV programs across the country; in this case the wide-band capability of microwaves was as important as beam directionality, which enabled precise aiming of the beam from transmitter to receiver. Microwaves, then, are useful for guidance and control (e.g., radar) and communications. The trend of development of microwave systems since their first application has been from very expensive systems, purchased by armies and communications monopolies, to somewhat less expensive ones, purchased by smaller functional units, such as airlines. Recent technological developments, however, indicate that a large proliferation in the numbers of microwave systems in use can be expected, with microwave system ownership reaching the individual level.

Current Microwave Systems and Applications

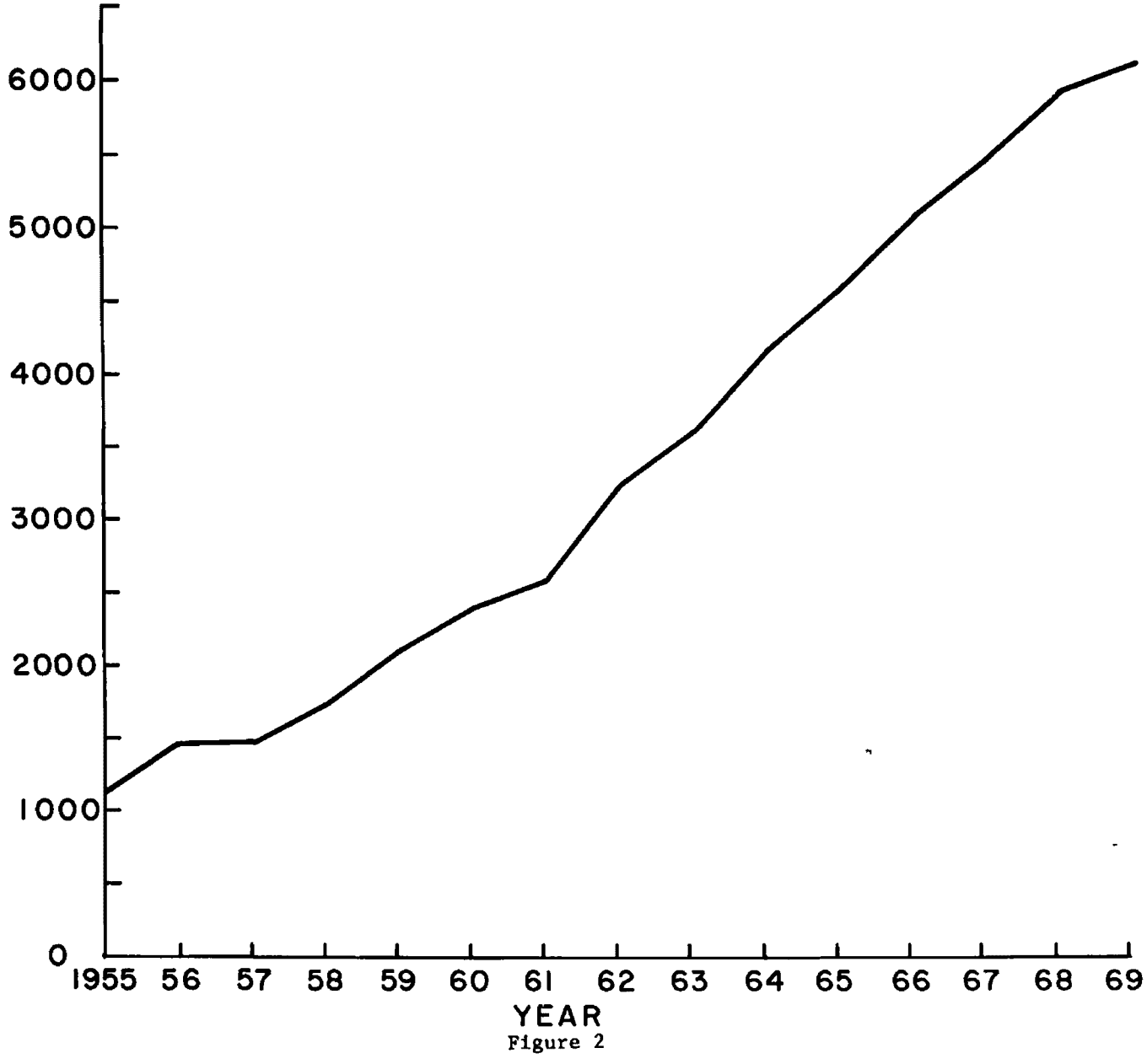
The least expensive widespread microwave system now available is the microwave oven, ubiquitous in snack bars and increasingly appearing

in homes as the price reaches the $200 level. With prices around $400, 345,000 of these ovens were sold for home use in 1970.[1]

Most systems currently in use, however, cost several thousands of dollars, rather than several hundreds. Radar, of course, is universal on military aircraft and on civilian passenger aircraft costing more than $100,000. A very large percentage of the 73,602 (as of 1970) US registered yachts and other vessels exceeding 4.5 tons displacement are also equipped with radar. Microwave communication systems in the civilian sector have been operated primarily by A.T.& T. and Western Union; cumulative data for FCC authorizations for such stations, to 1969, is shown in Figure 2.[2] Since the 1969 FCC decision to allow carriers other than A.T.& T. and Western Union to compete with the common carriers in providing wide-band microwave links for data and other private communications, roughly two thousand applications for new microwave stations, from firms not previously involved in the field, have been filed with the FCC.

New Technology and Microwave Proliferation

Microwave technology has changed considerably over the last 10 years, and new developments are now beginning to mature into production units. A relative measure of the impact of these developments is shown in Figure 3. In the last 10 years the invention of new solid-state microwave generating devices has increased the radio frequency (r.f.) power available from low-cost solid state units four orders of magnitude; simultaneously, the application of integrated circuit techniques to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4000
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2000
1000
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1955 56 57 58 59 60 61 62 63 64 65 66 67 68 69
YEAR
Figure 2

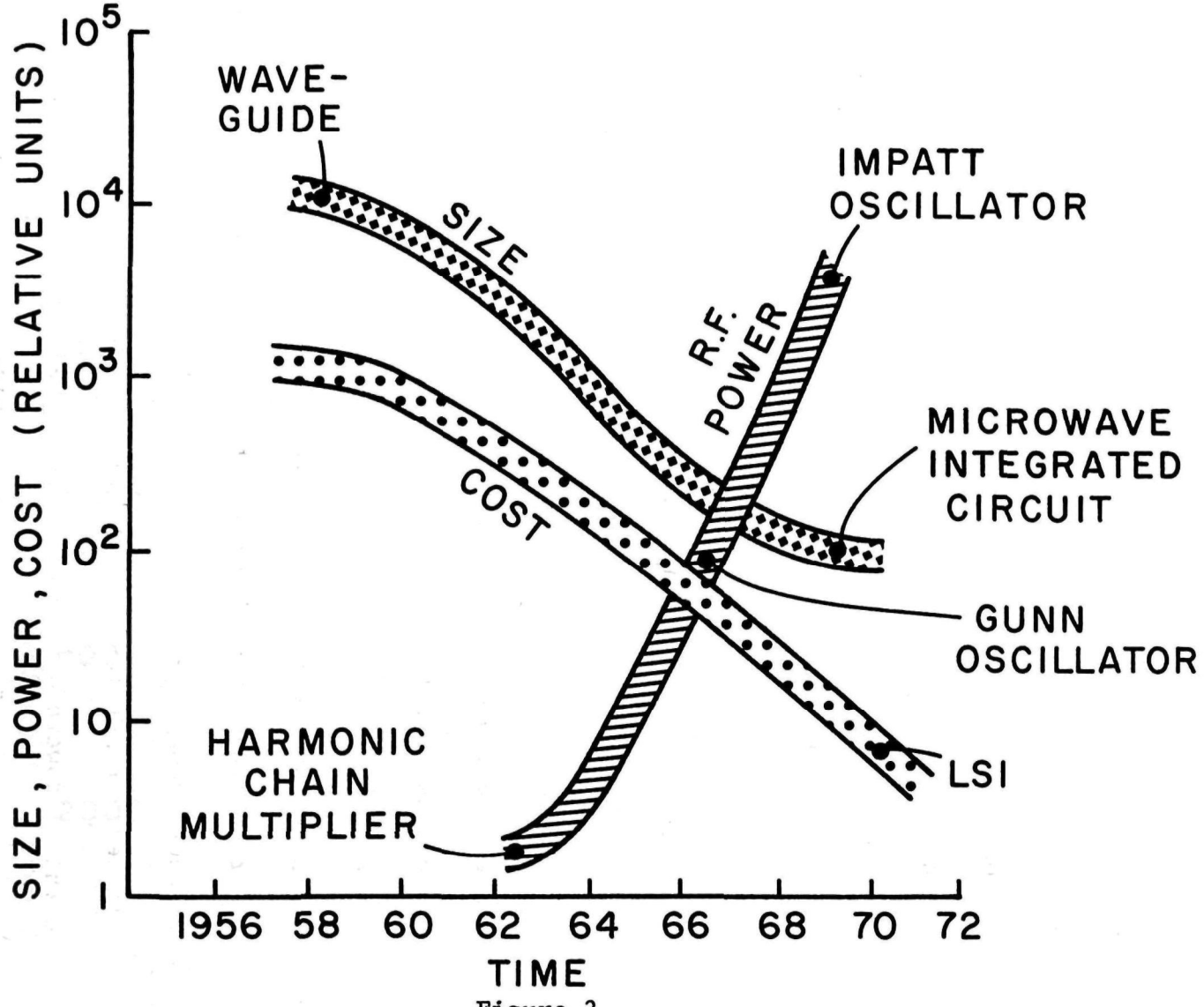

SIZE, POWER, COST (RELATIVE UNITS)
10^5
10^4
10^3
10^2
10
1
WAVE-GUIDE
SIZE
IMPATT OSCILLATOR
R.F. POWER
MICROWAVE INTEGRATED CIRCUIT
COST
GUNN OSCILLATOR
HARMONIC CHAIN MULTIPLIER
LSI
1956 58 60 62 64 66 68 70 72
TIME

Figure 3

microwave systems has reduced their size and cost two orders of magnitude. Further, through the use of automated analysis and design procedures, the engineering costs of microwave systems have also been greatly reduced. On an absolute scale, reliable microwave sources, adequate for use in such systems as small radars or for communications over a distance of several miles, can be purchased now for $20 to $50; klystron sources, typical of the devices that would have had to be used in such systems until recently, sell for upwards of $500. Consequently, microwave systems for use in individual homes, automobiles, boats, and private aircraft, can be expected to proliferate, and the use of microwaves by commercial organizations can also be expected to increase.

Developments in computer technology, and increases in computer usage, will also stimulate the growth of microwave systems. Transmission of information between remote computer terminals and a central computer--say, between a branch bank and its central office--can be performed using telephone lines; however, a private microwave system, with the capability for transmitting a thousand times as much information in the same time as the telephone system, may be more efficient. Further, wideband data links are required in order to hook computers up. These computer-oriented uses of microwave systems can be expected to increase regardless of any new developments in microwave technology, but the microwave developments described above will facilitate the use of computers as, for example, by enabling the personal data link to accompany the personal computer, when it becomes available.

At least one factor may mitigate against great proliferation of microwave systems: crowding of the electromagnetic spectrum. Unless great attention is paid to monitoring and controlling spectrum use, and to requiring most-efficient system design, there soon may not be enough spectrum to go around.

Microwave Applications

New cost parameters and the development of complementary technology will lead, as shown above, to new applications for microwave systems, and more widespread use of these systems to perform historically important tasks.

In the field of guidance and control, microwave systems should soon appear on commercial vehicles, trucks and buses, for collision avoidance and automatic braking. There are roughly 20 million such commercial vehicles on American roads today. Eventually, microwave systems should appear on private automobiles, for collision avoidance, triggering of passive restraint systems, and backup warning; with a manufacturing cost of $10 per unit foreseen, the Department of Transportation foresees the entire new car market--10 million units per year--equipped with such systems.

It will soon be possible for light aircraft to carry both altimeter and collision-avoidance radars at costs comparable to those for other general aviation electronic equipment. For example a small radar, which indicates by audible signal the presence of another aircraft within a sphere of surveillance surrounding the observing aircraft,

has recently been announced at a price of about $2000. Within the decade, collision avoidance radar might be required on all aircraft equipped for instrument flight--a significant fraction of the 200,000 private aircraft registered.

Radars for small boats will become practical, particularly for operation at night or in areas where fog is frequent. A hand-held unit selling for $695 has already been announced.

Small radars can be used for any purpose where a process is triggered by motion. Systems are on the market which automatically open hospital doors or detect when beer bottles have been filled to the proper level. The same principles apply to intrusion alarms also; microwave units for this purpose can alrady be bought at prices below $300. Similar principles are used in shoplifting alarms, in which a radar set is made sensitive not to motion in general, but only to the presence of a coded reflecting tag hidden on items in a shop. The alarm is triggered if the tag passes a detector at the exit of the shop. About 600 of these units are already installed.[3]

Microwaves can be used for the control of industrial processes. Microwave systems have already been applied to monitoring the thickness of latex applied to the back of carpeting, and experiments with other processes involving parameters to which microwave systems are sensitive are being performed.

A large expansion in microwave systems can be expected due to increased needs for wideband communications, and the growth of entirely

new communications systems, particularly satellites. As frequencies at the lower end of the microwave band become filled with stations, communicators will have to move upward in frequency. However, the higher the frequency, the greater the attenuation of microwave radiation by the atmosphere, and the greater the increase in attenuation in the presence of atmospheric moisture. Thus, higher-frequency systems require either high-power microwave sources, or relay stations between sources. For example almost 15 times as many microwave transmitters are required to cover a long distance in a 18 GHz system as in an 8 GHz system.[4]

Satellite communications systems can utilize direct transmission from satellite to home. A system is under investigation in Germany that would utilize such direct transmission to add three to five channels to the crowded terrestrial German television bands. The ATS-F satellite, shortly to be launched, will be used to conduct an experiment with the relay of instructional TV programs from New Delhi to thousands of village receivers in India. In this country the use of satellites for the relay of network programs to CATV installations, two-way voice communication, and general TV networking, has been proposed.[5] Possibly over a hundred satellites, and thousands of earth stations--millions, if direct satellite broadcasts to homes are utilized--may be in use by the end of this century.

In addition to being used for the trunk systems that connect city to city, it is now feasible to use microwaves in local distribution--say,

from a suburban telephone switching plant to its downtown central office or between the trunk terminal of a data carrier to a local subscriber. The Bell system has had an experimental pole-mounted microwave relay station, intended for such use, in operation for 4 years.[6]

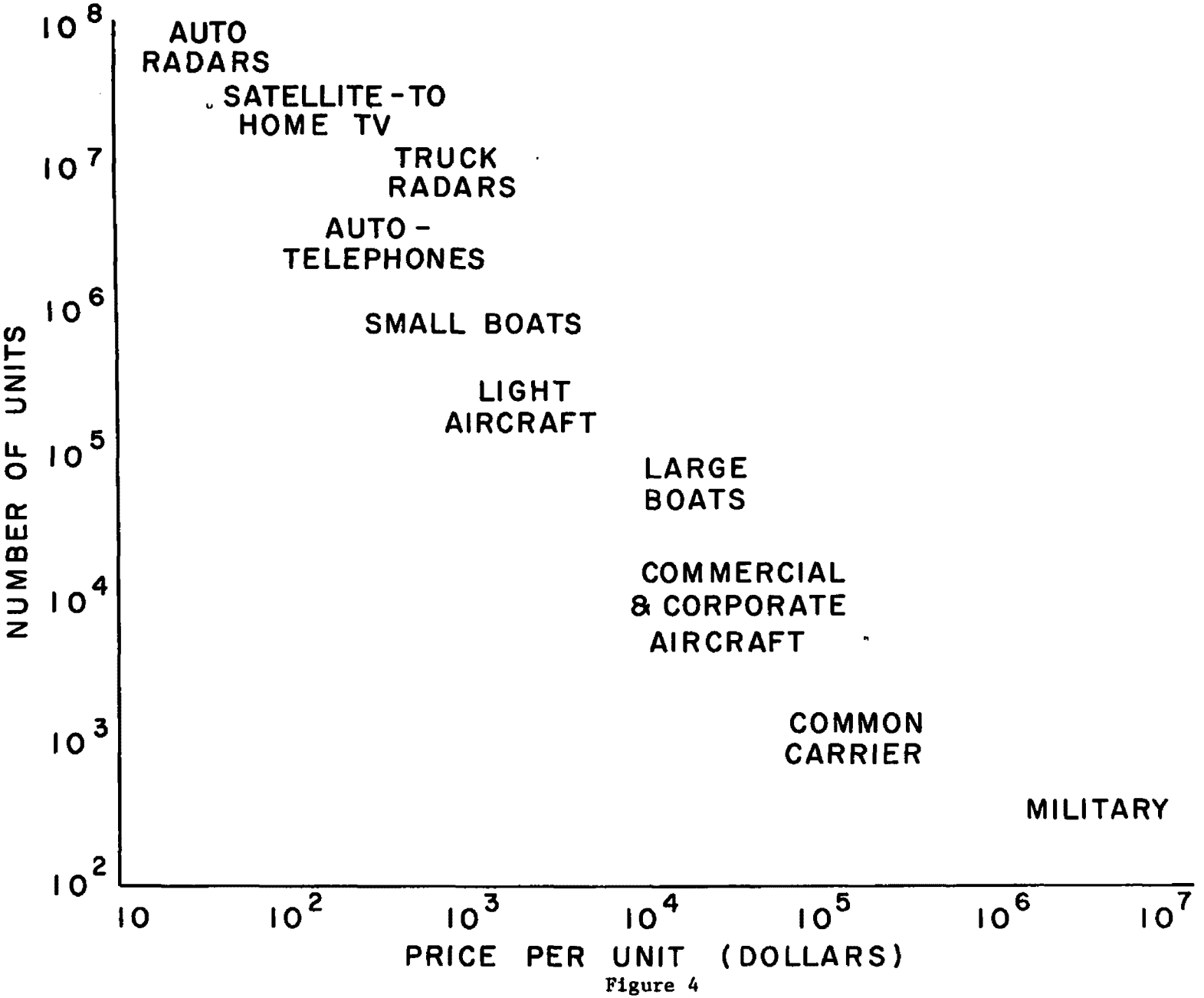
Automobile telephones may become very common if microwaves are used. The band currently assigned to auto telephone systems is too narrow to accommodate even a small fraction of the cars on the road; microwave bands are needed. However, the directionality of the microwave radiation will necessitate specialized car-tracking equipment associated with microwave transmitters so placed as to be always within line of sight of a telephoning car. A microwave transmitter on every street-sign in big cities may become necessary.

The use of microwaves in the home will be much increased with the general acceptance of the microwave oven. As was the case for color television, there might well be a take-off point for sales of microwave ovens, beyond which social pressure becomes as important as utility in stimulating purchase. Oven manufacturers are forecasting sales of a million units per year in 1980 and eventually a significant penetration of the sixty million American households should be achieved. Microwave heating can also be used in industrial applications: the use of microwaves to dry towels in a laundry has been proposed, as has the use of microwave heating to break rock through the excitation of localized thermal stresses. It is not clear that these microwave industrial

heating processes are any more efficient than more well-known processes, and the extent of their application is questionable.

Finally, the development of technologies only now foreseen, not yet reduced to hardware, may also result in a proliferation of microwave systems. At a recent long-range planning symposium sponsored by the Electronics Industries Association[7] a number of technological events, with years considered likely for their realization, were forecast; those events relevant to the growth of microwave applications include: individual portable two-way communications devices carried by most Americans (1990); computer-controlled network stock transfer system (1978); integrated financial services, with automated transfer of funds (1978); TV systems used for instruction in 10% of all schools (1977); TV networks linking campuses (1980); use of radar prosthetic devices, e.g., radar for the blind (1985).

An idea of the magnitude of growth of microwave systems use can be obtained by correlating the current size of the market for the systems concerned with an approximate estimate of penetration of that market as a function of price. For example, $2000 is currently the level of acceptability for electronics equipment in aircraft; $10-100 is the level appropriate to private automobiles. A chart summarizing the data is given in Figure 4. It is seen that by the time that microwave systems reach the $10-100 level--which may be within the next decade--hundreds of millions of small microwave systems will be brought into use.


AUTO
RADARS
SATELLITE-TO
HOME TV
TRUCK
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AUTO-
TELEPHONES
SMALL BOATS
LIGHT
AIRCRAFT
LARGE
BOATS
COMMERCIAL
& CORPORATE
AIRCRAFT
COMMON
CARRIER
MILITARY
NUMBER OF UNITS
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10
10^2
10^3
10^4
10^5
10^6
10^7
PRICE PER UNIT (DOLLARS)
Figure 4

Consequences of the Proliferation of Microwave Systems

Large increases in the number of microwave systems in use can be expected to result in considerable crowding in the microwave portion of the spectrum, with consequent increases in mutual interference among neighboring systems, and problems in the satisfaction of competing interests. In addition, individual exposure to microwave beams will be much more likely than it is now, and the health hazards of such exposure have not yet been satisfactorily quantified.

Spectral congestion will be an international problem once communications satellite proliferate, but even now this congestion is severe in some localities. Table 1 shows some of the results of a recent study done for the FCC[2]; the table lists the ratio of FCC-authorized stations to the total number of frequency assignments available in each band, for Los Angeles, New York City, and Venice, Louisiana. In bands where the ratio exceeds unity, advantage must be taken of the directional properties of microwave radiation, or space between transmitters. In New York and Los Angeles, which are commercial and entertainment centers, the 4, 6, and even the newer 11 GHz common carrier bands are virtually saturated; in Venice, La., the safety and special services bands are nearly full, with microwave communications links among offshore oil-drilling platforms almost saturating the safety and special service bands. Spectral congestion can only be expected to increase and techniques for regulating spectral allocation and mutual interference must be kept abreast of needs.

TABLE 1.

Ratio R of authorized stations to individual frequency assignments available

Band	R for Los Angeles	R for New York	R for Venice
1.850-1.990 GHz Operational fixed (industrial and public safety)	3.8	0.5	1.8
1.990-2.110 TV pickup, TV intercity	0.9		
2.500-2.690 Operational fixed (industrial, instructional TV)	0.5	0.5	
3.700-4.200 Fixed public (common carrier & Comm. satellite)	1.9	4.0	
5.925-6.425 Fixed public (common carrier & comm. satellite)	1.3	3.2	0.1
6.575-6.875 Operational fixed (industrial, public safety)	4.1	0.5	0.9
6.875-7.125 TV pickup, TV relay	0.7	0.2	
10.700-11.700 Fixed public (common carrier)	2.4	3.2	

Since very large numbers of microwave systems can soon be expected to be in the relatively unsupervised control of private individuals, it is necessary that the biological effects of microwave radiation be fully quantified. Microwave radiation can certainly cause profound effects on living animals; the oven that can roast a turkey in 5 minutes can roast a child's hand in even less time. Legislated standards and safety interlocks can render such heating apparatus reasonably safe, but no standards exist for the regulation of low-power microwave systems. For, no one really knows the effect of long-term exposure to very low levels of microwave radiation such as would, for example, be impinging on a traffic policeman monitoring an intersection through which radar-equipped cars were passing.

Conclusions

In a large part because of advances in microwave technology resulting in much cheaper microwave systems than were heretofore possible, the use of microwave radiation for guidance and control, communications, and industrial processing, can be expected to increase in the next several decades to a point where millions of small microwave systems will be in active use. This proliferation will result in great pressure on the microwave frequency spectrum, and in a great increase in environmental exposure to microwave radiation. The former problem carries with it the implication that regulatory processes must be modernized to properly balance the forces competing for the spectrum; the latter fact should cause concern that not enough is yet known about the biological effects of such exposure.

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SPACE SOLAR POWER:
AN OPTION FOR POWER GENERATION

Peter E. Glaser, Ph.D.
Vice President
Arthur D. Little, Inc.
Cambridge, Massachusetts

ABSTRACT

Recently solar energy has been reexamined as a viable alternative to produce power on a very large scale. The potential of this source of energy is discussed against the background of presently perceived energy demand and supply. The major concepts for the large-scale use of solar energy are briefly reviewed to provide a basis for examination of a satellite solar power station which would have the capability to convert solar energy to microwaves which are beamed to a receiving antenna on Earth. The principles of this satellite solar power station are reviewed with particular attention to technical feasibility. The economic, social, and environmental impacts of this alternative to power production are presented.

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Peter E. Glaser, Ph.D.
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I. INTRODUCTION

The energy crisis generated by the massive production and use of energy is today a major public concern.[1] As various solutions are offered to overcome the crisis, inadequate consideration is often given to technical developments, economic constraints, resource conservation, public health, international trade and politics, environmental protection, and social equity which are typical of the issues involved in the massive production and use of energy. Attempts are being made to grapple with the interacting, conflicting, and cumulative effects of actions already taken or planned for the future. A consensus is emerging that new research initiatives, institutional mechanisms, and criteria have to be developed and coordinated to evolve a rationale for national energy policies of benefit to society.

The use of energy has been the key to the social development of man and an essential component to improving the quality of life beyond the basic activities necessary for survival. The striking feature of the history of exploitation of energy sources and their comsumption is its exponential growth over the last century. This growth cannot continue forever. In a world with limited natural resources and a

finite ceiling upon undesirable interactions of energy production systems with the environment, an assured availability of energy resources poses a multitude of problems. Projected increases in energy demand indicate that the pressures on energy resources will be experienced world-wide because each nation will aspire to attain a larger share of finite resources to maintain and improve the quality of life for its people.

The common objective must be to meet energy demands as far as reasonable, while preserving the natural environment in the face of increasing pollution. The public is demanding substantially more electrical power and is expecting the power to be available—without shortages or rationing. At the same time the public is expressing an unprecedented concern about environmental quality and has not yet faced up to the price it may have to pay to achieve this quality. One major fact emerging as a result of the pressures generated by the ever-increasing energy demands is that alternative energy production methods will have to be developed. Among the different sources of energy, whether they be non-renewable--such as fossil or nuclear fuels--or continuous--such as tidal or geothermal--none has a greater potential than solar energy.

Man worshipped the sun aeons ago, but today feels less beholden to it and has forgotten how intricately all life is linked to it. The sun is the controlling influence over the planet Earth. A high level of sophistication is required to apply solar energy for society's long-term benefit consistent with the balance of nature. Indications are that this point is now being reached. Several concepts have recently been advanced to achieve the large-scale use of solar energy.[2,3,4,5]

One concept is based on the evolving ability to utilize space for practical purposes.[6] The technology developed to reach out beyond the confines of the Earth opens up the possibility of tapping the most basic energy source available to man--the sun.

II. SOLAR ENERGY CONVERSION IN SPACE FOR USE ON EARTH

Maximum utilization of solar energy can be made in an orbit around the sun. The first step towards the fullest use of solar energy is represented by a satellite in orbit around the Earth. There, solar energy is available nearly 24 hours a day. This approach permits solar energy conversion to be carried out where it can be most effective with only the final step arranged to take place on Earth. Similar to the impact on worldwide communications of already existing satellites, power from space has the potential of providing an economically viable and environmentally and socially acceptable means of meeting future energy requirements.

Figures 1 and 2 show the design concept for a satellite solar power station (SSPS). Photovoltaic solar energy conversion with two large, symmetrically arranged solar cell arrays represents the basic principle of the SSPS which will be designed to produce electricity in synchronous orbit. This electricity is fed to microwave generators, arranged to form an antenna located between the two arrays. The antenna directs a microwave beam to a receiving antenna on Earth where the microwave energy is efficiently and safely converted back to electricity. In synchronous orbit around the equator, the satellite will be stationary with respect to a desired location on Earth. The use of the microwave beam allows

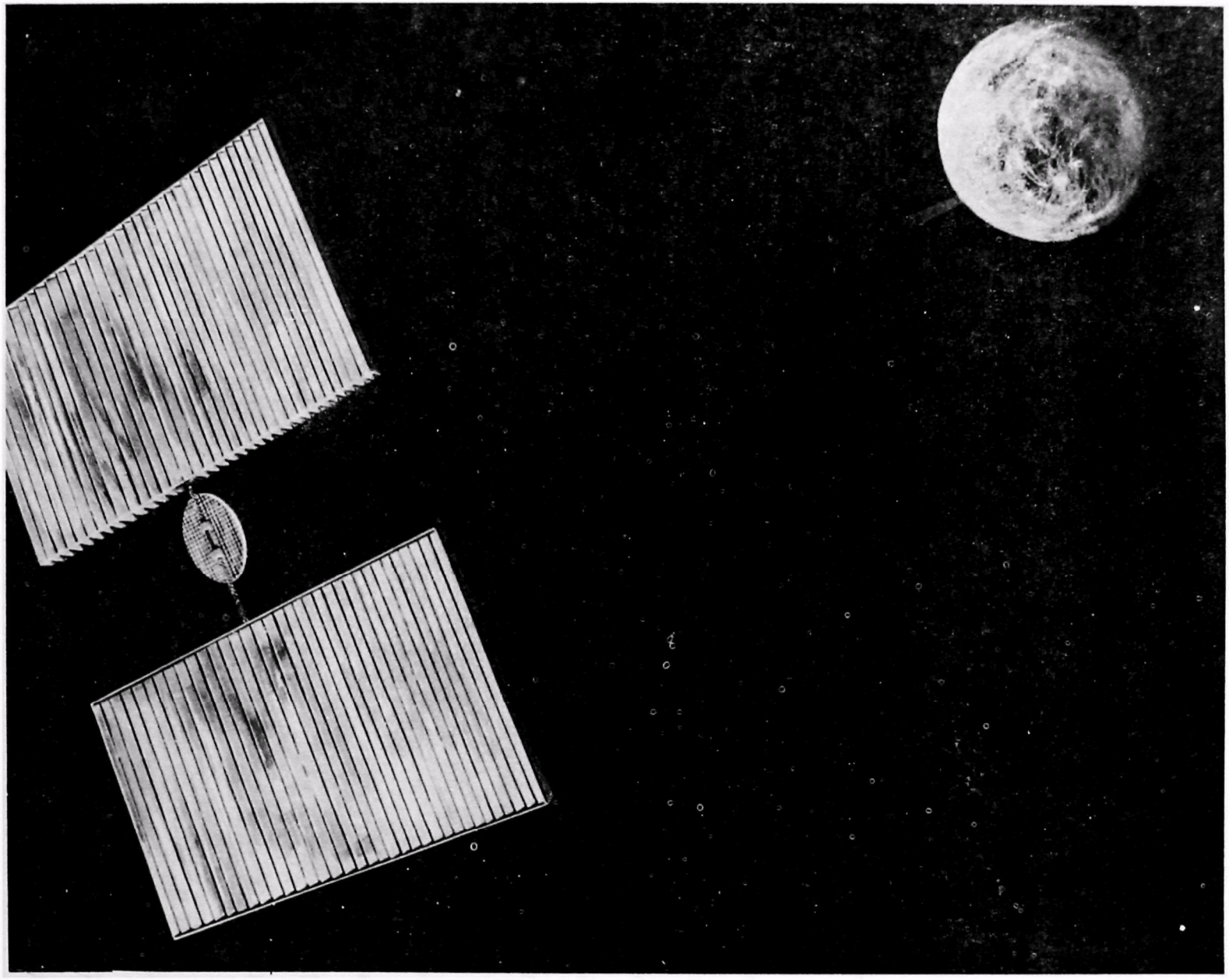


FIGURE 1 DESIGN CONCEPT FOR A SATELLITE SOLAR POWER STATION

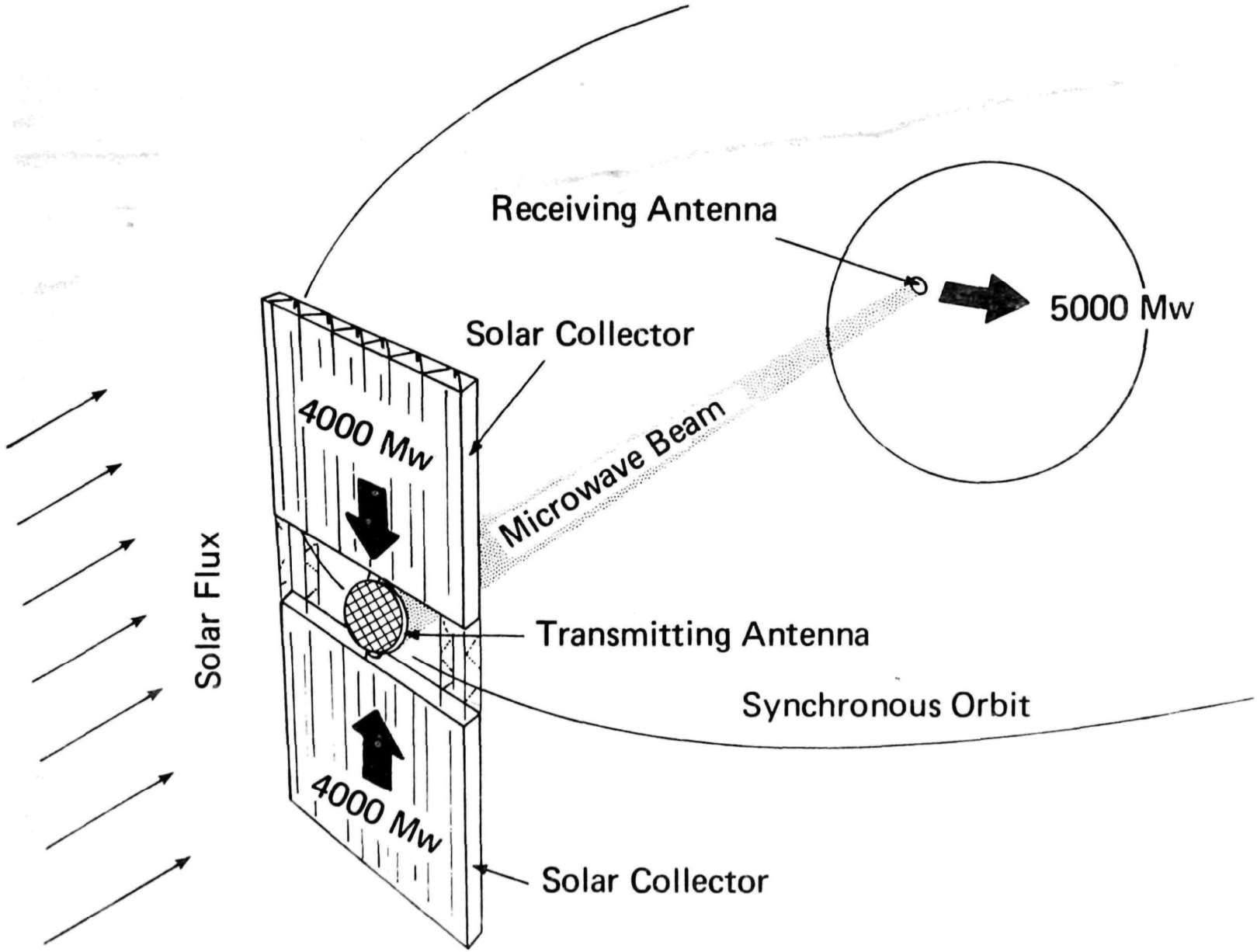


FIGURE 2 DESIGN CONCEPT FOR A SATELLITE SOLAR POWER STATION

all-weather transmission so that full use can be made of the nearly 24 hours of solar radiation available. This availability, except for short periods near the equinoxes, when the satellite enters the Earth's shadow for a maximum of 72 minutes a day, provides a 6- to 15-fold advantage of solar energy conversion in space compared to a terrestrial installation where useful operations are limited by weather conditions and the day-and-night cycle and require energy storage techniques. This advantage is translatable in terms of reduced land use and capital costs. The very high efficiency of direct microwave energy rectification into electricity by the receiving antenna on Earth reduces the waste heat generated on Earth to a fraction compared with any thermodynamic conversion method.

The SSPS can be designed so that it can generate electrical power on Earth at a specific power output ranging from 3,000 to 15,000 MW. Over this range, the orbiting portion of the SSPS exhibits the best power-to-weight characteristics. Power can be provided to a receiving antenna in a desired geographic location. These antennas could either supply major load centers individually, or when a number of SSPS's are operating, be tied into a transmission grid to meet a significant portion of the energy demands on a national and eventually a world scale.

The status of a significant technology required to achieve an operational SSPS is reviewed in the following sections.

A. Solar Energy Conversion

Solar energy conversion into electricity by the photovoltaic process is well suited for the purposes of an SSPS. In contrast to any process based on thermodynamic energy conversion, there would be no moving parts

no material would be consumed, and in principle the operation of a photovoltaic solar cell could continue for long periods of time without maintenance. There has been a substantial development in photovoltaic energy conversion since the first laboratory demonstration of efficient silicon solar cells in 1953. Today, they are a necessary part of the power supply system of nearly every unmanned spacecraft, and considerable experience has been accumulated to achieve long-term and reliable operations under the conditions existing in space. As a result of many years of operational experience, a substantial technological base exists on which further developments can be based. These developments are directed toward increasing the efficiency of solar cells to about 18%, reducing their weight to about 2 lb/kW, and their cost to about $1/W and achieving efficient operation over a 30-year lifetime. Although solar cells produced from single-crystal silicon have been most widely used, recent advances in gallium arsenide solar cells indicate that further increases in efficiency and weight reduction may be possible.

III. MICROWAVE POWER GENERATION, TRANSMISSION, AND RECTIFICATION

An electromagnetic beam link can transmit power from the SSPS in synchronous orbit to a receiving antenna on the Earth.[7] The choice of wavelengths for this beam are dictated by the desire to (1) obtain efficient transmission of large amounts of power across long distances with minimal losses in the ionosphere or atmosphere, (2) maintain power flux densities at levels low enough so that undesirable environmental and biological effects can be avoided, and (3) use devices based on known technology to generate, transmit, and rectify the beamed power with very

high efficiency. These conditions can best be met when the microwave portion of the spectrum is selected for the beam link.

Considerable background and experience exist in high-power microwave generation, transmission, and rectification. Already in 1963, it was demonstrated that large amounts of power can be transmitted by microwave.[8] The efficiency of microwave power power transmission will be high when the transmitting antenna in the satellite and the receiving antenna on Earth are large, thus excluding the efficient transmission of small amounts of power. The size of the transmitting antenna is influenced by the efficiency of the microwave generator, the area required for radiators to reject waste heat to space, and structural considerations. The antenna size and weight will be reduced as the average flux density on the ground is reduced and as higher frequency microwave transmission is used. The size of the receiving antenna is influenced by the choice of the microwave power flux density, the illumination pattern of the antenna, and the minimum flux density required for efficient microwave rectification.

Microwave generators can convert DC to microwaves with demonstrated efficiencies of about 76%. The use of a newly developed, permanent magnet material--samarium cobalt--will lead to substantial weight reductions. Thus, the output of an individual microwave generator, weighing a fraction of a pound, can range from 2 to 5 kW. The use of pure metal, cold cathodes will greatly increase the reliability and operational lifetime of this device. An efficient microwave generator can radiate waste heat directly into space by means of heat radiators. A series of microwave generators can be combined into subunits with individual phase

controls. The subunits are assembled into a slotted array-type transmitting antenna to obtain a microwave beam of a desired distribution.

For efficient microwave transmission, the transmitting antenna should have a diameter of about 1 km. With this size antenna, about 99% of the microwave beam will be received on Earth. A receiving antenna diameter of about 7 km will intercept about 90% of the beam.

Ionospheric attenuation of microwaves having wavelengths between 3 and 30 cm will be less than 1% if microwave power flux densities are less than about 50 mW/cm^2. Atmospheric attenuation is low for microwave wavelengths of about 10 cm. Moderate rainfall attenuates microwave transmission by approximately 10% at a wavelength of 3 cm and 3% at a wavelength of 10 cm. Thus, a 10-cm microwave wavelength corresponding to a frequency of 3000 MHz appears to be a reasonable choice. The receiving antenna intercepts and rectifies microwaves into DC which can then be fed into high-voltage DC transmission lines or converted into 60-Hz AC. Rectification is accomplished by diodes combined into circuit elements which act as half-wave dipoles. The dipoles are uniformly distributed throughout the receiving antenna. Rectification efficiencies of about 75% have already been demonstrated, and 90% efficiencies should be achievable with improved circuits and diodes. The overall efficiency of microwave transmission from DC in the SSPS to DC on the ground is projected to be about 70% with further device development.

IV. SYSTEM CONSIDERATIONS

Figure 3 indicates the major dimensions of the SSPS to generate 5000 MW on Earth. Each half of the solar collector is about 5 by 5 km. As these dimensions indicate, the SSPS orbital system is orders of

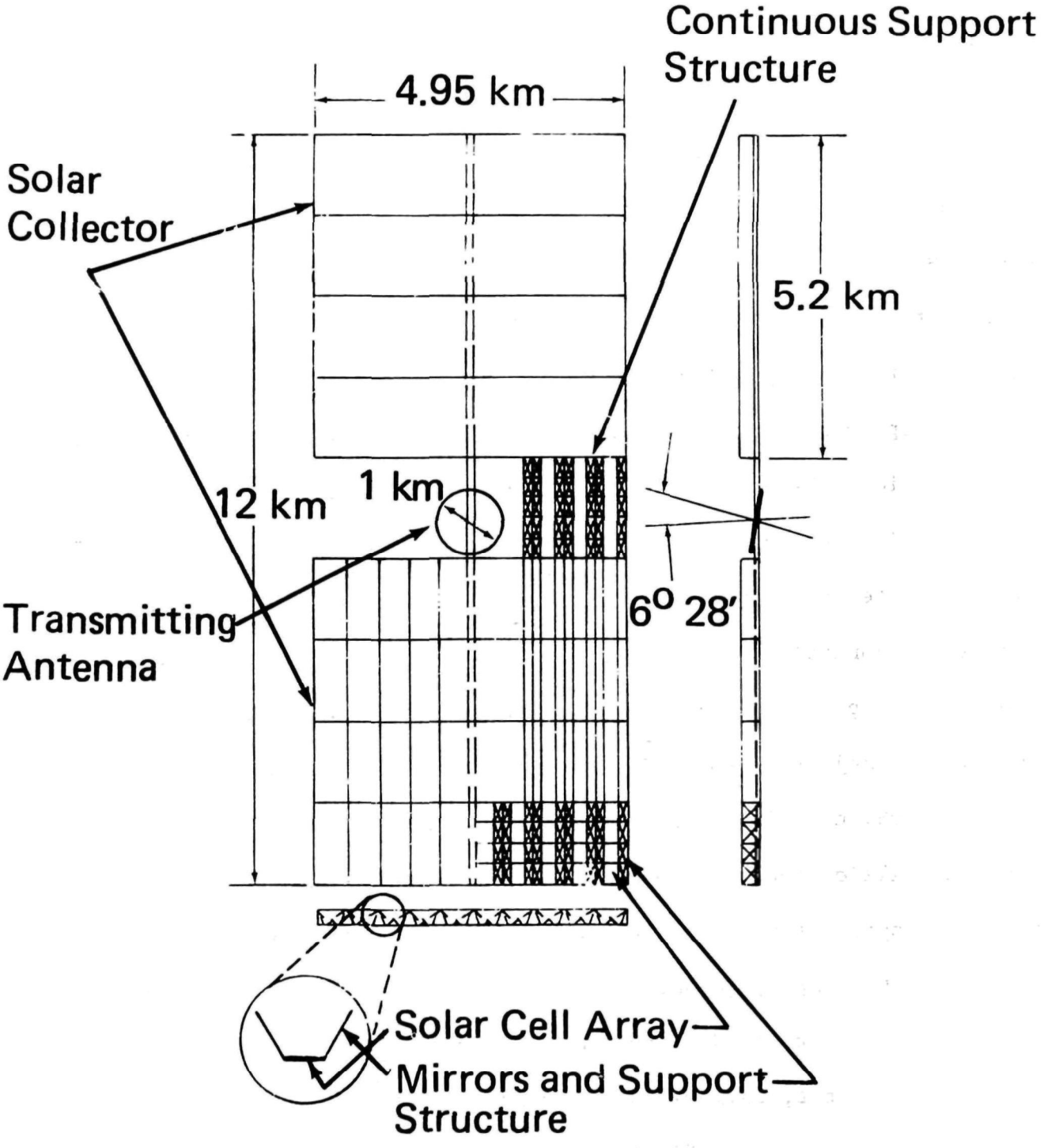


FIGURE 3 SSPS DIMENSIONS

magnitude larger than any spacecraft launched today. From an overall spacecraft design standpoint, the basic technology problems involved are related to its large size and the goal of a 30-year operating lifetime. However, the principles governing the design are founded on advances from an existing technology base.

The SSPS structure is composed of high current-carrying structural elements which will induce loads or control forces into the structure by electromagnetic effects. New design approaches will have to be developed to satisfy orientation requirements of such a large spacecraft. Flexible spacecraft structures, such as the large solar cell array for space stations, have been studied in the past, including the maintenance of inertial pointing capabilities of structures such as a large 1000-foot diameter antenna. Low-thrust, ion propulsion systems appear promising for flight control purposes, particularly because of their continuous short-term impulse capabilities and lifetimes which are compatible with the overall objective to achieving 30 years of operation.

An SSPS, capable of providing 5000 MW of power on Earth, will weigh about 25 million pounds. Such a massive satellite will require a transportation system from Earth to synchronous orbit which will be an outgrowth of the present space-shuttle development. This transportation system will have to be designed for high-volume transport of payloads to low-Earth orbit, followed by delivery of partially assembled elements to synchronous orbit for final assembly and deployment. A second-generation space shuttle, utilizing returnable boosters rather than present space-shuttle solid propellants, would have inherent cost advantages. An ion engine propelled tug which, over a period of 6 to 12

months followed a spiralling trajectory to synchronous orbit, could provide an effective complement to the space shuttle. For a combined chemical/ion propulsion system, about 500 Earth to orbit flights would be required to deliver the elements of a 25-million-pound spacecraft to synchronous orbit. Cost projections for this type of transportation system are about $100 per pound to synchronous orbit.

An interesting possibility exists to launch payloads into orbit with high-power lasers.[9] A laser propulsion system has the advantage that almost all of the equipment needed is on the ground, rather than requiring massive rocket engines. Laser propulsion, which would operate only a few minutes for each launch, would have an immense capacity for putting payloads into orbit. It would be possible to orbit masses that are huge compared to those presently orbited with rocket propulsion devices. Air is used as a propellant medium; thus polluting substances would not be contaminating the atmosphere. Although the possiblity of high-power laser propulsion is still largely unexplored, new possibilities are opened up, particularly for a concept such as the SSPS.

A prototype SSPS can be demonstrated by 1990, based on the necessary steps required for the development of such a system. Figure 4 shows the program schedule by which the development could proceed in a logical and well laid out fashion.

A series of well-formulated development goals with identified objectives would assure that R&D expenditures during the development phase could be limited and controlled. Major funding commitments would not have to be made until system verification tests had demonstrated the capability of meeting stated objectives.

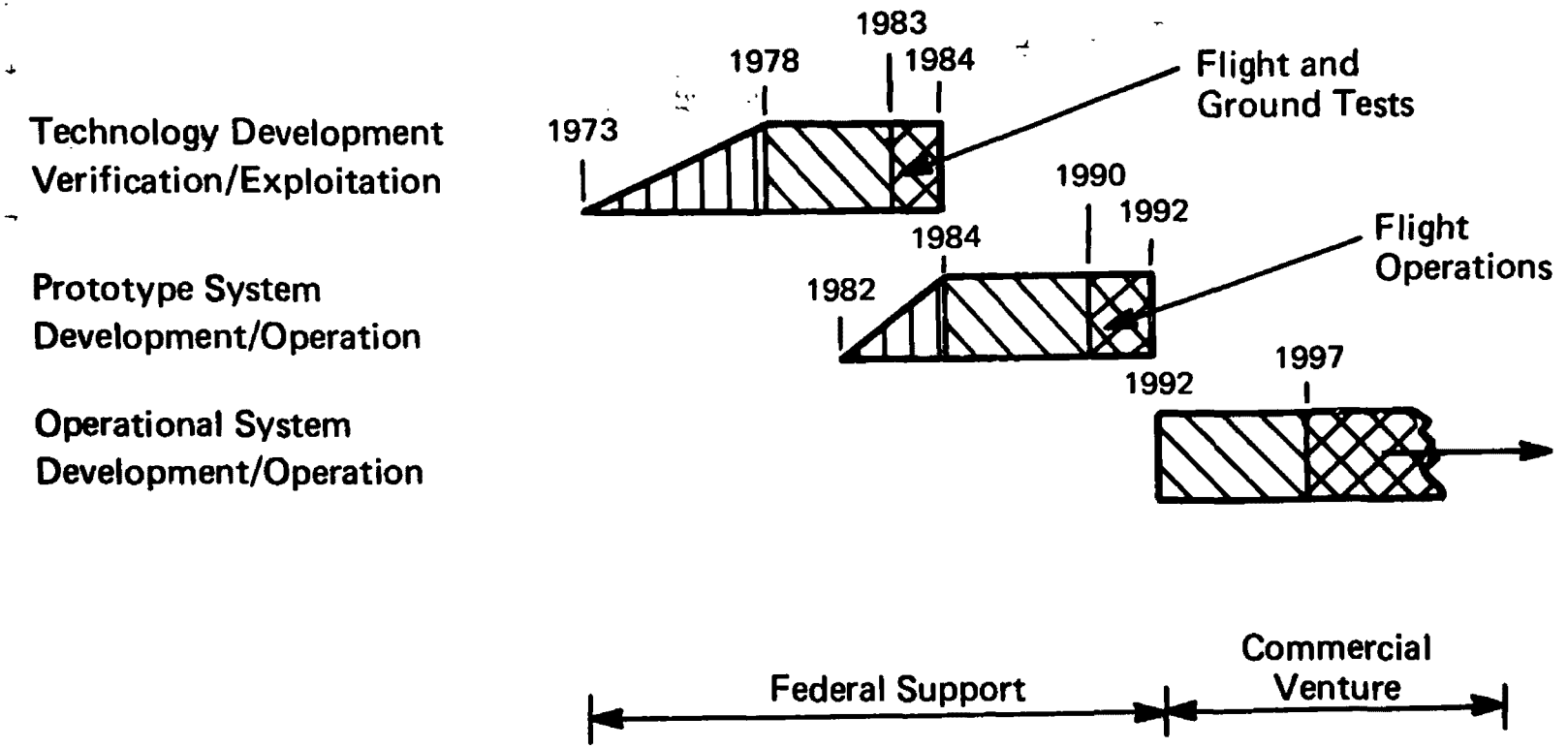


FIGURE 4 PROGRAM PHASING

V. ENVIRONMENTAL CONSIDERATIONS

The impact of any new technology must be assessed. Such a technology assessment must include, in addition to the purely physical impact of SSPS, the economic and social impacts. The key environmental effects of an SSPS are discussed below.

1. Microwave Biological Effects

An extensive and coordinated effort to establish biological effects of microwaves is presently planned by the Office of Telecommunications Policy as part of a program to control electromagnetic pollution. At present, various standards for microwave exposures have been established, ranging from 10 mW/cm^2 for the United States[10] to 0.01 mW/cm^2 for the Soviet Union. The major difference in these standards can be traced to the uncertainty in the interpretation of laboratory observations of microwave exposure.

The U.S. standard is based on microwave heating of body tissues. On the basis of experience with microwave equipment over several decades and the resulting exposure of a significant population to microwaves, there are remarkably few reported incidences of biological damage. Soviet investigators have indicated that the central nervous system is affected by microwaves, even at very low exposure levels. These considerations have lead the Soviet Union to set a continuous exposure standard at 0.01 mW/cm^2.

In view of this very basic difference in interpretation of the effects of microwave exposure, there is a need to develop experimental procedures so that certain byproducts of microwave-generating equipment operation, such as X-rays, ozone, and oxides of nitrogen, in addition to extraneous environmental conditions imposed on laboratory test objects, would not lead to a misinterpretation of the laboratory observations.

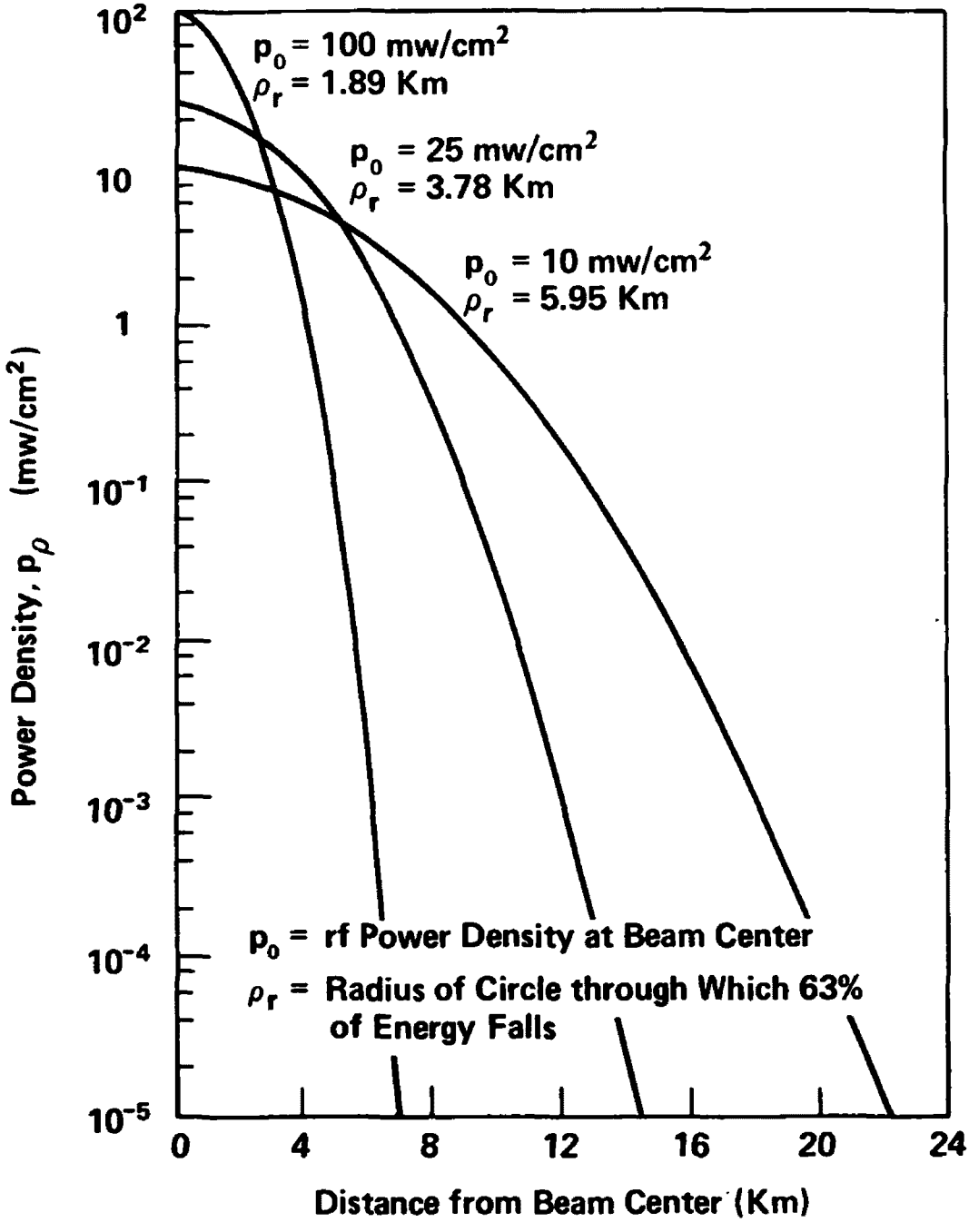
The design approach for an SSPS must recognize that a range of frequencies and microwave power flux densities may have to be accommodated and design features will have to be adjusted accordingly. An understanding of the specific SSPS-induced environment, predictions, analyses, and measurements will be an essential component of the development program.

Precise control of the microwave beam through transmitting antenna stabilization and automatic phase control will assure that the microwave power will be efficiently transmitted to the receiving antenna. The antenna size, the shape of the microwave power distribution across the antenna, and the total power transmitted will determine the level of microwave power flux densities in the beam reaching the Earth.

The SSPS design will incorporate several fail-safe features, including a self-phasing signal transmitted from the ground to the transmitting antenna, to assure precise beam-pointing. Loss of acquisition of the signal will lead to demodulation of the microwave beam. In addition, remotely operated switches in the SSPS solar collector will instantaneously open-circuit the solar cell arrays and shut off power to the microwave generators.

A wide latitude in microwave power flux densities can be obtained by selecting the transmitting and receiving antenna diameters. The receiving antenna has to cover only an area consistent with achieving overall high efficiency of operation. A guardring of a few kilometers can be provided so that the level of microwave exposure outside this ring will be less than 1 $\mu W/cm^2$ which is one order of magnitude below the Soviet microwave exposure standard. (See Figure 5.)

In addition to direct biological effects, interference with electronic equipment, medical instrumentation, or electro-explosive devices must be



Note: Total power held constant at 1.17×10^7 kilowatts.

FIGURE 5 DISTRIBUTION OF MICROWAVE POWER DENSITY FROM THE BEAM CENTER

avoided. The lack of sensitivity of this equipment to a low level of microwave exposure will have to be confirmed, and if required, industry-wide standards will have to be established.

The effects on birds flying through the beam is not known. Research on the effects of microwave on birds at the level to be encountered in the microwave beam will have to be carried out as well. Preliminary evidence indicates that birds can be affected at levels of microwave exposure of 25 to 40 mW/cm^2 of radiation in the X-band. The evidence suggests an avoidance reaction by birds to the exposure.

The effects of microwave exposure on aircraft flying through the beam must also be considered. The shielding effects of the metal fuselage and the very short time of flight through the beam would not result in significant human exposure. The means for protecting aircraft fuel tanks from electrical discharges are now standard design features, but the absence of microwave-induced hazards will have to be confirmed. In addition, the extent of possible interference with aircraft communications and radar equipment will have to be established.

2. Interference with Radio Communications

World-wide communications are based upon internationally agreed-upon and assigned frequencies. Because a frequency band spanning the most desirable operating frequency of the SSPS (S-band) is already in heavy use, the potential for radio frequency interference (RFI) of the SSPS with existing communication systems is high. The design of the microwave generators used in the SSPS can eliminate most spurious output characteristics, but RFI could occur during the shutdown of the generators as the SSPS enters the Earth shadow, or result from noise side-bands about the operating

frequency or from inadequate suppression of frequency harmonics. RF filtering can greatly reduce these undesirable effects. However, the very large power output of the SSPS may pre-empt certain frequencies which are now in general use. The understanding of RFI effects and international agreement on frequency assignments represent issues which will have to be faced at various stages during the SSPS development.

3. Environmental Effects

The SSPS represents an approach to power generation which does not use naturally occurring energy sources, but relies on a constant and inexhaustible energy source. Thus, environmental effects associated with mining, transportation, or refining of natural energy sources are absent. Natural resources will have to be used to produce the components for the SSPS and the propellants for transportation to orbit. Nearly all the materials to be used for the components are abundant. Rare materials, such as platinum or gallium, would require less than 2% of the yearly supply available to the United States for each SSPS. Electrical power required to manufacture the various components and to launch the SSPS into orbit will be equivalent to about 9 months of power generated during SSPS operation.

Environmental effects include a slight heat addition to the atmosphere due to absorption of the microwaves as the beam passes through the atmosphere. The possible effects of this heat addition on atmospheric circulation patterns will have to be established.

Heat will also be added to the atmosphere during launch operations. Because a substantial launch frequency is required to place each SSPS in orbit, e.g., 500 launches for a 25-million pound SSPS, local heating effects will have to be investigated as well as the addition of products of

combustion of chemical propulsion systems (primarily water vapor). If laser propulsion should prove to be feasible, the air could serve as the propellant medium, reducing the environmental impact of repeated launches. Noise pollution from the high-frequency launch operation would be of concern in the immediate vicinity of the launch facility and would have to be reduced by suitable design techniques and the choice of a suitable location for the launch facilities.

The very high efficiency of microwave to DC conversion at the receiving antenna, e.g., 90%, will greatly reduce the waste heat addition to the environment compared to any other power generation method based on thermodynamic principles. The heat exchange to the surrounding atmosphere from the receiving antenna element can take place by natural convection. This may lead to the formation of a "heat island" of about the same magnitude as encountered over an urban area.

The visual impact of the large receiving antenna, e.g., 7 km diameter, can be decreased either by suitable landscaping or by incorporating the antenna in an industrial park.

4. Land Use

Substantial flexibility exists in choosing a suitable location for the receiving antenna. The area has to be contiguous, but need not be completely flat terrain. The location can be in a region where land is available which is not suitable for other uses, e.g., a desert, previously strip-mined land, or in an area where major electrical power users, e.g., aluminum smelters, are located. The antenna could be located in an industrial park to serve several major users. Roofs and covered roadways could be designed to exclude microwaves from working areas completely.

The antenna structure can be designed to be mostly open so that sunlight and rain can reach the land beneath it. Vegetation growing beneath the antenna would be effectively shielded from microwaves and could be harvested, precluding the land from becoming a biological desert.

IV. ECONOMIC CONSIDERATIONS

Business feasibility and cost to consumers have been overriding considerations concerning energy production in the past, and it cannot be assumed that it will be otherwise in the future. However, as the population grows, pressure on resources, environmental constraints, and almost certain requirements for vast increases in the availability of electricity will make it equally unsafe to assume that established economic criteria will be enough to decide the choice of a particular power generating system. Based on present estimates, a prototype SSPS will cost about 3 to 5 times more than comparable available energy-production technology, based on fossil or nuclear fuel. Inspection of the components making up the cost projection indicates major costs are contributed by the solar cell arrays and by the Earth-to-orbit transportation system. There are reasonable expectations that these costs can be substantially reduced through well-directed research and development programs using approaches which, although definable, are now beyond the present state-of-the-art.

Standards to establish the true cost for energy production will have to be developed and hidden costs, which at present are not charged to other methods, will have to be identified so that relative costs of other systems can be established on a comparable basis. There is as yet no consensus on the procedures which will have to be used; agreement on appropriate standards will be essential to meaningful analysis of economic impact.

Major capital expenditures will be required independently of the specific energy-production technology to provide electrical power to meet demands. These capital requirements are projected to be at least $600 billion over the next 30 years, with an additional $30 billion required during that time to carry out the necessary research and development on energy conversion, transmission distribution, and environmental controls. Therefore, energy production will continue to require a significant fraction of available capital, indicating that one important limit to the exponential growth of energy consumption will be the rate of capital formation.

The economic and technical feasibility and the environmental and social desirability of the SSPS will have to be established prior to any major commitment to the development of this alternative energy-production method based on solar energy. What is required is that sufficient information be made available so that the option represented by the SSPS can be pursued, if other approaches should appear to be less attractive, whether as the result of energy resource, environmental, or social considerations.

VII. SOCIAL CONSIDERATIONS

To deal with the social impact of the SSPS, an assessment is required which will serve to identify all of the effects of the specific technologies employed (physical, environmental, economic; direct and derivative, immediate, intermediate, and long term), so that the social desirability or undesirability of these effects can be evaluated.[11]

Panels, commissions and committees have addressed the questions of social desirability over the last few years. Agreement, however, has not yet been reached on how to express "social costs" either on the most detailed

level or on an accounting basis for American society as a whole. Social indicators of society's health and growth will have to be identified to determine costs of the SSPS to society as a whole in the same way that today the gross national product is used to express our status in the field of economics.[12] Appropriate standards and criteria which are developed during a process of social impact analysis will have to be tested with various groups having an interest in energy production methods, and appropriate comparisons between solar and other energy production systems will have to be made as well.

Many groups, individuals, and sectors of American society as well as institutions will interface in relation to SSPS. To some degree, each of these interfaces must be analyzed and understood. Various communication methods will have to be employed to inform the public of the projected impact of the technologies being developed at appropriate stages of the development program in support of the SSPS objectives.

VIII. CONCLUSION

There are several other energy sources in addition to solar energy which have the potential of meeting future energy requirements, but only very few have a limited impact on the environment and are conserving the finite resources of the Earth. Solar energy applications, such as represented by the SSPS, are still in an early stage of development. Thus, it is too early to tell which of the approaches now being studied will be judged to have the greatest potential to be of overall benefit to society. As more is learned about the operating characteristics of potentially competitive electrical energy generating systems, the views on what "best" performance represents will continue to evolve. Thus, the criteria for

decision-making - whether based on cost, resource conservation, or environmental protection - may be quite different over the next decades, and will continue to change as long as technical developments continue actively on the various energy-production systems.

Development of energy-production systems, such as the SSPS, over the next few decades will permit society to look beyond the year 2000 with the assurance that future energy requirements will be met without endangering the planet Earth. But even successful development of large-scale applications of solar energy still will require that efforts be made to reduce energy consumption and to slow growth for growth's sake.

Technology change is creating a climate leading to institutional and social changes which, in their overall impact, can be expected to rival the 19th century industrial revolution. Those individuals and groups which are charged by society with responsibility for leadership must face these new challenges and opportunities. Instead of creating "dark satanic mills," there must be the realization that to survive, man must learn to "replenish the Earth" and not just "subdue it."

IX. ACKNOWLEDGEMENT

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FEDERAL PROGRAM ON BIOLOGICAL EFFECTS OF ELECTROMAGNETIC ENERGY*

H. Janet Healer
Office of Telecommunications Policy
Executive Office of the President
Washington, D.C. 20504

I. INTRODUCTION

When speaking of the interaction of electromagnetic radiation with the environment, it is no longer adequate to treat less than the total environment, physical and biological. Most commonly we have focused on the interaction with physical environment--particularly, on the compatibility of sources and receivers of radiation with each other and, more recently, on the degradation of electronic components and circuit performance. Of equal importance, however, is the interaction with the biological environment as a whole, and man in particular. Unintended effects (often referred to as "side effects") from the purposeful use of electromagnetic energy can affect our use of the spectrum. Therefore, such effects can be significant factors requiring consideration by both Government and the technical community in the design, installation, and operation of radiating systems.

The impact of this energy on man and the biosphere must be adequately assessed in order to ensure their protection without unnecessarily restricting our use of the spectrum resource and the benefits it provides.

Recent legislation in the consumer, environmental, and health fields already calls for the establishment of safety standards and regulations.

Rapid technological and economic developments in recent times have resulted in an ever-increasing proliferation of sources and uses of nonionizing electromagnetic radiation (EMR), providing valuable service to mankind: communications systems, radio and television broadcasting, radars, plus a host of other uses--power production, medical practice, industrial processing and many consumer products. At the same time, these benefits may introduce new forms of pollution--electromagnetic pollution--which can result in annoying and hazardous interference, physical degradation of electronic systems, and, at sufficient energy levels, biological hazards.

Biological effects and potential hazards of electromagnetic radiations (0 Hz - 3000 GHz) even at relatively low power densities are a matter of concern to a number of Federal agencies and non-Government organizations.

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* Presented at the American Public Health Association Centennial Annual Meeting, Session on Environmental Exposure to Nonionizing Radiation, Atlantic City, N.J., November 14, 1972.

II. THE ENVIRONMENT

Man-made radiation is relatively new as an environmental factor. Knowledge of its possible biological consequences is limited and incomplete.

Since approximately 1948, the growth in radiation sources has been phenomenal and is continuing at an accelerated rate. World War II stimulated the demand for widespread communication networks and the application of science and technology resulted in new and expanded technology which spawned today's electronics industry. In 1940, a construction permit was issued for the first FM radio station and in 1945 the first commercial communications using microwaves were established between New York and Philadelphia. Microwave communication stations now number over 71,000. By 1968 the FCC had authorized over 6 million transmitting devices. This number is exclusive of Federal Government systems. The estimated depreciated capital investment of the U.S. Government alone in communications and electronics equipment currently exceeds $50 billion.

To illustrate, Figure 1, based on FCC data, shows the increase in radio and television stations in the United States from 1945-1969. It is interesting that these curves are very similar to the population growth curve over this same period.

Figures 2-6 illustrate the distribution of some EM sources in the United States: microwave relay towers, radar stations (unclassified), and television, FM and AM broadcast stations. As would be expected, the density distribution of Figs. 4-6 together corresponds to that of the population distribution.*

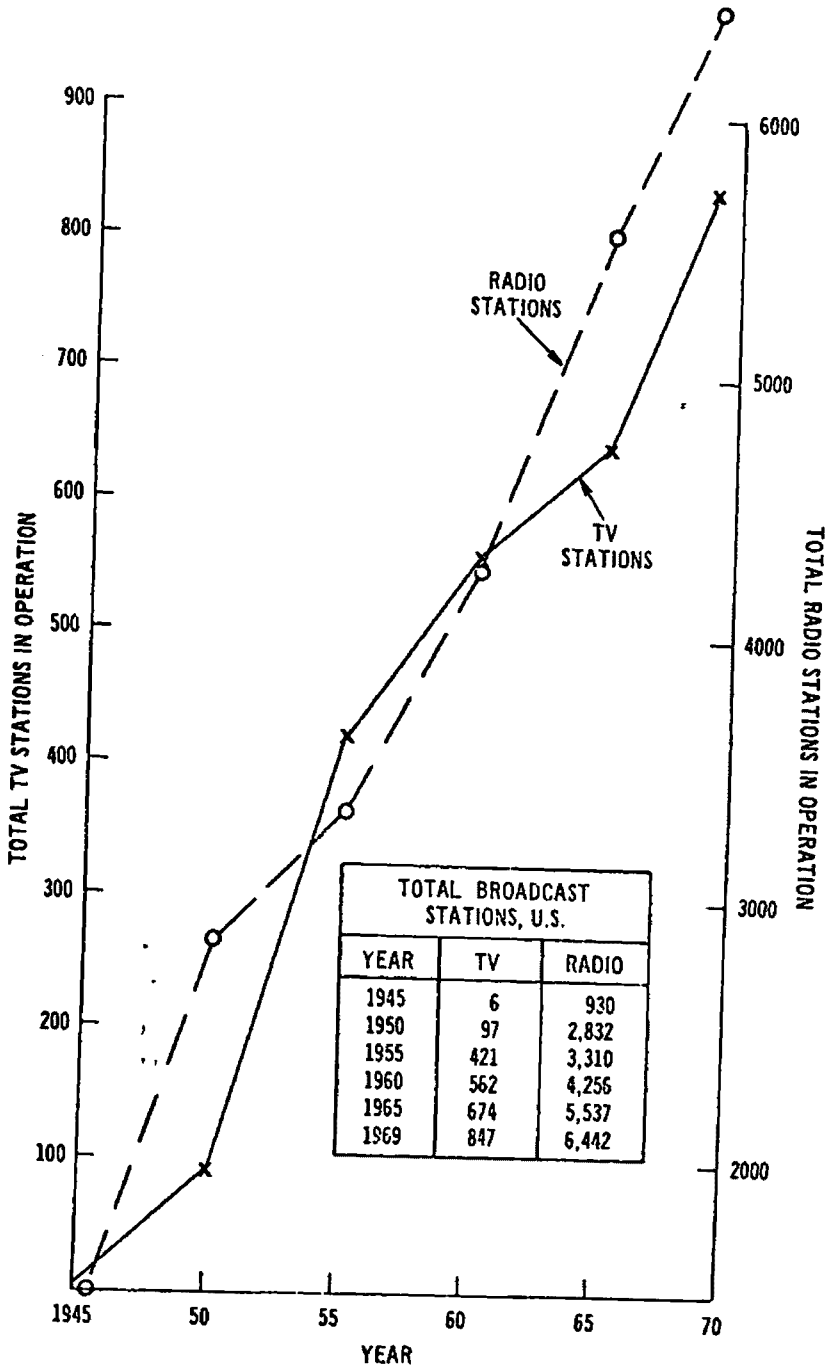
In terms of consumer products, it is predicted that by 1975 the annual sales of microwave ovens for the home will reach 375,000 with a total in use of approximately 800,000. Power levels in and around American cities, airports, military installations, and tracking centers, ships and pleasure craft, industry and the home may already be biologically significant.

Power outputs of many radio frequency (RF) sources are increasing also.

III. THE EFFECTS

Microwave and other RF radiations at sufficiently high intensity are known to cause adverse biological effects due to the generation of heat in the organism. Effects observed at high levels include pathologically observable lesions, secondary injury from hyperthermia and cataract formation. The extent and importance of more subtle changes (e.g., biochemical, functional or behavioral) which may occur at lower intensities particularly with continued or long-term exposure are not known adequately.

* Figures and data above courtesy of EPA based on FCC and ECAC data.



TOTAL BROADCAST STATIONS, U.S.

YEAR	TV	RADIO
1945	6	930
1950	97	2,832
1955	421	3,310
1960	562	4,256
1965	674	5,537
1969	847	6,442

FIGURE 1

Increase in Radio and TV
Broadcast Stations in the U.S.

Figure 2. Geographical Distribution of Microwave Point-to-Point Installations in the United States

Figure 3. Geographical Distribution of Radar Facilities in the United States (unclassified)

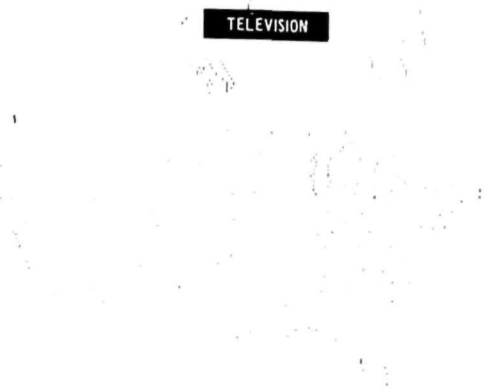


Figure 4. Geographical Distribution
of TV Broadcast Stations in the United States

Figure 5. Geographical Distribution
of FM Broadcast Stations in the United States

Figure 6. Geographical Distribution
of AM Broadcast Stations in the United States

Within the Federal Government a coordinated multiagency program* was promulgated by the Office of Telecommunications Policy (OTP) of the Executive Office of the President in January 1972 to develop the necessary understanding for assessing this situation and a rational scientific basis for establishing safety and remedial measures where and as warranted.

The OTP's concern stems from its responsibilities for Government use of the spectrum and the fact that the U.S. Government is the largest single user of the spectrum. Inherent in these responsibilities is OTP's concern for establishing rational risk/benefit criteria to assure protection of the public while permitting effective use of radiative equipments.

The Federal Communications Commission (FCC) is responsible for authorizing the use of radio by non-Government entities; all Government use on the other hand is the responsibility of the President. The Director, Telecommunications Policy carries out this responsibility. He

- serves as the principle advisor to the President on telecommunications matters;
- coordinates Government use of communications-electronics; and
- presents Administration views on national matters concerning telecommunications policy.

The Electromagnetic Radiation Management Advisory Council (ERMAC) was formed in 1968 to assist the Director advising on side effects and the adequacy of control of electromagnetic radiations arising from communications activities. The Council reviews, evaluates and recommends measures to investigate and mitigate potential undesirable effects on the environment.

As an early undertaking the Council conducted a comprehensive assessment of current knowledge, ongoing programs and potential problems pertaining to biological effects. Representatives of cognizant Government agencies participated and contributed.

Concluding that we do not know the potential impact of nonionizing electromagnetic radiations on man with sufficient confidence and that ongoing efforts were inadequate to resolve current issues and those that could be anticipated in the future, the Council recommended a Government-wide program.

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* "Program for Control of Electromagnetic Pollution of the Environment: The Assessment of Biological Hazards of Nonionizing Electromagnetic Radiation" -- December 1971.

Studies of effects around and above 100 mw/cm^2 led to the general acceptance in the United States and most western countries of a power density of 10 mw/cm^2* as a safe level below which injury from heating would not be expected except under conditions of moderate to severe heat stress.

Despite some limited evidence of less definite effects including psychological and functional changes, there is a lack of definitive scientific data on the genetic/developmental, clinical, physiological, and behavioral effects of EMR at low power densities, e.g., around and below the 10 mw/cm^2 level. Without these data, the picture is incomplete and the deduction of sound conclusions regarding hazards cannot be made.

Moreover, with the exception of thermal effects induced by the agitation of polar molecules by the rapidly alternating electric field, little or nothing is known about basic mechanisms of interaction between the electromagnetic field and the molecular and cellular constituents of the body, limiting our ability even to hypothesize or predict either effects or hazards. This is in contrast to ionizing radiation where the basic mechanisms of energy transfer to atoms and molecules are reasonably well understood.

It is important to keep in mind that all effects are not necessarily hazards. In fact, some effects may have beneficial applications under appropriately controlled circumstances. However, RF induced changes must be understood sufficiently so that their clinical significance can be determined, their hazard potential assessed and the appropriate benefit/risk analyses applied to establish tradeoffs. Such tradeoffs are an integral and accepted part of our existence. For example, many common factors in our daily lives can produce biological change or effects--coffee which appears to affect chromosomes in somatic or body cells and has an accelerating action on the cardiovascular system. Even common drugs such as aspirin have contraindications.

It is important to determine whether an observed effect is irreparable or merely transient or reversible, disappearing when the electromagnetic field is removed or after some interval of time. Of course, even some reversible effects may be unacceptable under some circumstances. For example, subtle functional central nervous systems effects, even if reversible, might affect the judgment or reactions of individuals performing critical tasks--airline pilots, automobile drivers, factory workers, etc. Thus some transient physiological and psychological change or discomfort, even if not associated with permanent biological damage, could pose indirect potential hazards.

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* For example, see USASI, C95.1, 1966.

Controversy exists among different groups as to the significance or even presence of low level effects. Over a considerable period of time Soviet and other Eastern European scientists have extensively published research results dealing with low level, chronic exposure effects on the nervous system of humans and experimental animals. Little complementary or supplementary research has been performed by Western scientists. There has even been a tendency to dismiss the Soviet literature because of difficulties in interpretation due to its frequently summary nature. Permissible exposure levels in the USSR are, roughly speaking, lower than those of those in the USA by an apparent factor of 1000 for long term exposures and a factor of 10 for exposures less than 6 minutes. To some extent, differences in interpreting effects and what one considers a hazard may account for some of the difference in permissible levels.

Growing concern and awareness in the Government, scientific community, and public are evidenced by recent and proposed legislation relevant to the question of biological effects. This legislation has, in turn, stimulated the examination of biological effects, hazards, and safety standards.

The "Radiation Control for Health and Safety Act of 1968" (PL 90-602), administered by HEW, is intended to protect the public health and safety from the dangers of electronic product radiation including ionizing, nonionizing, or particulate radiation.

Another recent enactment is "National Environmental Policy Act of 1969" (PL 91-190), intended to promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man. It establishes the Council of Environmental Quality to advise the President and requires all agencies of the Federal Government to file environmental impact statements.

Associated with this is Reorganization Plan No. 3 of 1970, which established the Environmental Protection Agency (EPA). This agency has standard-setting authority for environmental problems, including radiation.

"The Occupational Safety and Health Act of 1970" (PL 91-596) is intended to ensure safe and healthful working conditions. It authorizes the Secretary of Labor to establish mandatory occupational safety and health standards. He is also to conduct and publish studies of the effect of chronic or low-level exposure to industrial materials, processes, and stresses on the potential for illness, disease or loss of functional capacity. Under this authority a standard for nonionizing electromagnetic radiation from 10 MHz to 100 GHz has been promulgated. (This is the ANSI, C95, 10 mw/cm^2 standard.)

The existence of a scientifically undefined possible hazard to large numbers of people can and has already presented problems. Among these is the establishment of defensible regulatory legislation and safety standards required by these existing laws. There are medico-legal controversies--some already in the courts--which may be improperly resolved with long-term consequences by court or diplomatic actions without benefit of adequate scientific basis for decision.

Radar and communication equipment operated by the U.S. Government at overseas sites are vulnerable because of international differences in safety criteria. Should host countries apply their own exposure limits, the United States must have sufficient research data to argue their reasonableness and practicality, in order to avoid unnecessary restraints to operations.

IV. THE PROGRAM

In December 1971, the ERMAC recommended a coordinated program of survey, testing and research among the cognizant Federal agencies. The estimated 5 year expenditure for this program was approximately $63 million over the period FY 74-78, with annual expenditures of between $10 and $15 million/year. For comparison, FY 72 appropriations were estimated to be approximately $4 million--principally in DOD which provided roughly half and in HEW and EPA which, together, accounted for somewhat less. FY 73 levels are approximately $6 million.

This program outlines fundamental research needs and program elements. It provides guidelines and a framework for a coordinated national effort to generate pertinent and dependable data for the evaluation of biological hazards. It emphasizes low-level RF exposures and their significance.

Included are controlled laboratory experimentation, epidemiological studies, and ecological studies where appropriate. Investigations of basic mechanisms of interaction and the development of measurement techniques, instrumentation, and dosimetry are particularly critical. Surveys will be conducted as of power density levels in selected urban areas, airports, military installations, occupational and special situations with estimates of the population(s) at risk. Initial biological research priorities include:

1. Long-term genetic effects (and developmental)

2. Nervous system effects.

3. Gross physical condition.

4. Basic mechanisms of interaction between the EM field and the living systems.

A primary requisite is that findings be extrapolatable to man. (This may be difficult to assure.)

Studies will cover a wide range of frequencies from quasistatic to 3000 GHz, a variety of wave forms and different exposure regimes. The biological effect may be determined by various properties of the EMR environment. Consideration must be given to near and far field effects, polarization, cross modulations, harmonics, etc. There is little knowledge of effects of different frequency regions and whether or not there are biologically significant, narrow frequency regions, such as molecular absorption resonances or natural body frequencies. (This is important in determining permissible exposure levels--e.g., U.S. safety criteria currently apply one intensity level to the entire range of frequencies from 10 MHz - 100 GHz.)

Early priorities should reflect frequencies affecting the largest numbers of people.

In approximate order of priority these are:

	Particular Regions
1. Microwave	915, 1850-2450, 2700-3700, 3700-4200, 6000-8000, and 8000-12000 MHz (Includes: radars, microwave radio, medical diathermy, microwave ovens, etc.)
2. MF-UHF	2-50 MHz, 50-900 MHz (Includes: radio and TV transmitters, fixed and mobile radar, land mobile, etc.)
3. ULF-LF	0-5 Hz, 5-100 Hz, 10-50 kHz (Includes: military communication systems, radio navigation, etc.)

Effects of multiple frequencies and of RF in combination with other factors will be examined. Emphasis is placed on chronic, long-term exposures at the lowest intensity levels compatible with a biological effect.

Another priority area is dosimetry. Early emphasis is needed in instrumentation and measurement, particularly to enable the determination of the field at the biological point of interest and to relate external to internal fields.

V. STRUCTURE

Structurally, this is a multiagency program in which research and funding responsibilities are shared. This is necessary since the problem is not exclusively within the domain of any one agency. Many agencies whose operations involve the use of RF energy or who may be affected by its use have been and are currently conducting research appropriate to their own responsibilities and missions. In aggregate, however, the effort has been fragmented and current economy measures together with competition for priorities and dollars within agencies could perpetuate and exacerbate this situation. In the new program, participating agencies roles are based on their particular responsibilities and special capabilities which are coordinated to eliminate fragmentation and maximize the application of resources in eliminating question marks which today exist in this field.

The OTP is responsible for coordinating the overall program and for the elimination of unintended duplication and voids in the effort. The ERMAC advises and assists OTP. For coordination within the Government an interagency working group (Side Effects Working Group) was formed. Comprised of agency representatives, this group has been meeting monthly since April this year and is part of the Interdepartment Radio Advisory Committee (IRAC) which advises OTP on the use of radio within the Federal Government.

The agencies' roles are broadly outlined. Each develops the elements and specifics of its own program and controls the administration of funds recommended. The major participants are HEW, EPA and DOD which together will account for approximately 80% of the effort.

As an example, in the plan HEW is responsible for a major biological research program including controlled animal experimentation, basic mechanism studies and effects on people. Emphasis is on long-term exposures involved in situations pertaining to public health and safety, assessing hazards relating to the general public and to industry, occupational uses and exposures, and, of course, nonionizing radiation from electronic products.

EPA is concerned with assessing and determining control mechanisms necessary for nonionizing radiations in the environment. Involved are biological effects research, environmental surveillance including supporting data banks; and the capability to provide review and analysis as to nonionizing electromagnetic aspects of environmental impact statements.

The Defense Department ensures that the research programs of the three military departments are coordinated in detail and complementary with the programs of other agencies. Electronics systems under DOD management (e.g., SANGUINE, SAFEGUARD, Shipboard, Air Traffic Control, Field Radars, Air Defense Command Systems, etc.) will be assessed.

The Army effort emphasizes research particularly related to specific frequency ranges, device characteristics and operational environments of their personnel. The Navy and Air Force activities are oriented similarly.

The Department of Commerce is responsible for developing new methods of instrumentation, dosimetric methodologies, and standardization of measurement devices.

The National Science Foundation's role is to encourage and support activities to fill the void of knowledge of basic mechanisms involved in EMR interactions with biological systems.

Similarly, other agencies--involved in the use and management of the radio spectrum--have responsibilities coincident with their basic missions:

The Federal Communications Commission, which licenses all non-Government use of the spectrum, is concerned with associated exposures and safety.

The Federal Aviation Administration is concerned with exposures of passengers, employees and the public in flight and airport environs.

The U. S. Information Agency operates very high powered HF band communication systems.

The Department of Agriculture operates a forest service communications network and is concerned with effects on crops and livestock.

The National Aeronautics and Space Administration operates extremely high powered tracking stations and is responsible for EMR effects in space environments.

To summarize our present status, the programs of the various agencies have been coordinated and the overall research effort is growing. Since full implementation is expected in FY 74, current emphasis is on ensuring the availability of adequate funds. We look forward to having substantive results to report to you at future meetings.

VI. CLOSING REMARKS

In closing we--the public health community and the Government--are unable, on the basis of current knowledge, to provide definitive answers to the growing number of questions concerning the health hazards of electronic systems involving exposures to energy levels below those known to produce biologically significant heating.

The public and Congress are increasingly aware of health and environmental issues including the question of EMR hazards. This is manifest

in the press, recent legislation, claims of RF injury, and inquiries as to the safety of various sources resulting in the reexamination of some defense and other systems--e.g., SANGUINE, MW ovens, diathermy devices, industrial processors, etc.

These factors further underscore the timeliness and need for this program.

The program described today represents an exciting opportunity in which the technical community and the Government, together, can delineate and mitigate if necessary, a potential environmental problem of considerable complexity before it has assumed the magnitude and dimensions of others which have beleaguered you.

The public health community is a vital resource for this effort. We need your experience and help. Thank you.

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ENVIRONMENTAL EXPOSURE TO NONIONIZING RADIATION, EPA/ORP 73-2. Proceedings of a session: Annual Meeting of the American Public Health Association, Atlantic City, N.J., November 14, 1972. Cosponsors: American Public Health Association and Office of Radiation Programs, U.S. Environmental Protection Agency (May 1973)

ABSTRACT: A series of papers discussing problems and activities related to commercial, medical, and domestic implications of nonionizing radiation.

KEY WORDS: Biological effects program; electromagnetic spectrum; environment; monitoring; nonionizing radiation; power generation; research.

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