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January 24, 1995

Mr. Gary Gill, Director
Office of Environmental Quality Control
220 S. King Street, 4th Floor
Honolulu, Hawaii 96813

Dear Mr. Gill:

Subject: Negative Declaration for PEACESAT 10 Meter Telecommunication Antenna Modification, TMK 2-8-15: 1, Honolulu, Oahu, Hawaii

The University of Hawaii has not received any comments during the 30-day public comment period which began on December 23, 1994. The agency has determined that this project will not have a significant environmental effect and has issued a negative declaration. Please publish this notice in the February 8, 1995 OEQC Bulletin.

We have enclosed a completed OEQC Bulletin Publication Form and four copies of the final EA.

Please contact Ms. Christina Higa at 956-8848 if you have any questions.

Sincerely,

Lori Mukaida, Director
PEACESAT
University of Hawaii

1995-02-08-OA-FEA- PEACESAT 10 meter Telecommunication Antenna Modification

FEB 8 1995

FINAL
Environmental Assessment

PEACESAT
10 Meter Telecommunication Antenna Modification

University of Hawaii
PEACESAT Program
Old Engineering Quadrangle Building #31
Honolulu, Hawaii 96822

January 24, 1995

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PEACESAT 10 Meter Telecommunication Antenna Modification

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INTRODUCTION AND BACKGROUND

The University of Hawaii is proposing minor modifications to the existing 10 Meter telecommunications antenna located next to the Hawaii Public Broadcasting Authority (HPBA) building near the corner of Dole Street and University Avenue. The street address of the site is 2350 Dole Street.

The antenna was originally installed in 1978 after an Environmental Impact Statement (EIS) found that there were no significant environmental impacts. This environmental assessment (EA) is intended to supplement the Final EIS issued in February, 1977 for the existing antenna.

The subject antenna is a *directional telecommunications antenna* and must be re-oriented 90 degrees West of its existing position in order to be aligned with the Geostationary Operational Environmental Satellite (GOES), a meteorological satellite, at 175 degrees West. Its current use is to receive transmissions.

The modifications of the telecommunications antenna include: (1) realigning the orientation of the dish antenna 90 degrees East and (2) converting the system electronics to support transmission capabilities.

The realignment of the antenna will use two of the three existing legs of the cement base. A third leg will be built to support the repositioned antenna. A shower tree will be located directly East of the antenna so that the antenna will have a clear line of site to the GOES satellite. The shower tree will provide visual screening of the dish from University Avenue. The UH Laboratory School and HPBA's entrances will be preserved.

The electronics modification will enable transmission as well as reception capabilities in the "S" and "L" band of meteorological frequencies (TX 2025 to 2033 Mhz/RX 1685 to 1695 Mhz) and "C" band frequencies in (TX/RX 5.9 Ghz to 6.4 Ghz).

Purpose of Modifications

The purpose of the modifications are to enable the Pan-Pacific Education and Communication Experiments by Satellite (PEACESAT) Program to continue ongoing telecommunications application experiments through the use of the GOES satellite(s) (175 degrees West, plus or minus 20 degrees) and to provide public service telecommunications (education, research, telemedicine, emergency management, community services, and economic development) to 22 countries in the Pacific. Users of PEACESAT are government, educational, and other non-profit organizations throughout the Pacific.

A partial list of PEACESAT users may be found in Attachment 1: List of PEACESAT Users. The list includes Pacific Island Country education and government institutions and regional government agencies such as the South Pacific Commission and the Forum Fisheries Agency, emergency management organizations such as the Federal Emergency Management Agency, Civil Defense and the American Red Cross, and others. Commercial communications are not permitted through PEACESAT.

The modifications are funded through a Cooperative Agreement between the UH and the National Telecommunications and Information Administration of the U.S. Department of Commerce. For a comprehensive description of the purposes and requirements of the PEACESAT Services Improvement Plan (PEACESAT SIP), refer to Attachment 2: *PEACESAT - A Regional Telecommunications Alliance in Transition.*

Compliance with Hawaii Environmental Impact Statement Law

The Department of Regulatory Agencies filed a negative declaration in June 1976 (published in the July 9, 1976 *OEQC Bulletin*) for the construction and operation of the existing telecommunications antenna. Since the construction and operation of the existing antenna over 17 years ago, there have been no significant impacts on the surrounding environment, nor have there been any known complaints or disputes in the surrounding community regarding this structure.

This Environmental Assessment is intended to supplement the Final Environmental Impact Statement dated February 1977 (Attachment 3). The action proposed in this EA is considered a minor modification to the existing Plan Review Use and a negative declaration is anticipated.

GENERAL DESCRIPTION OF THE PROPOSED ACTION:

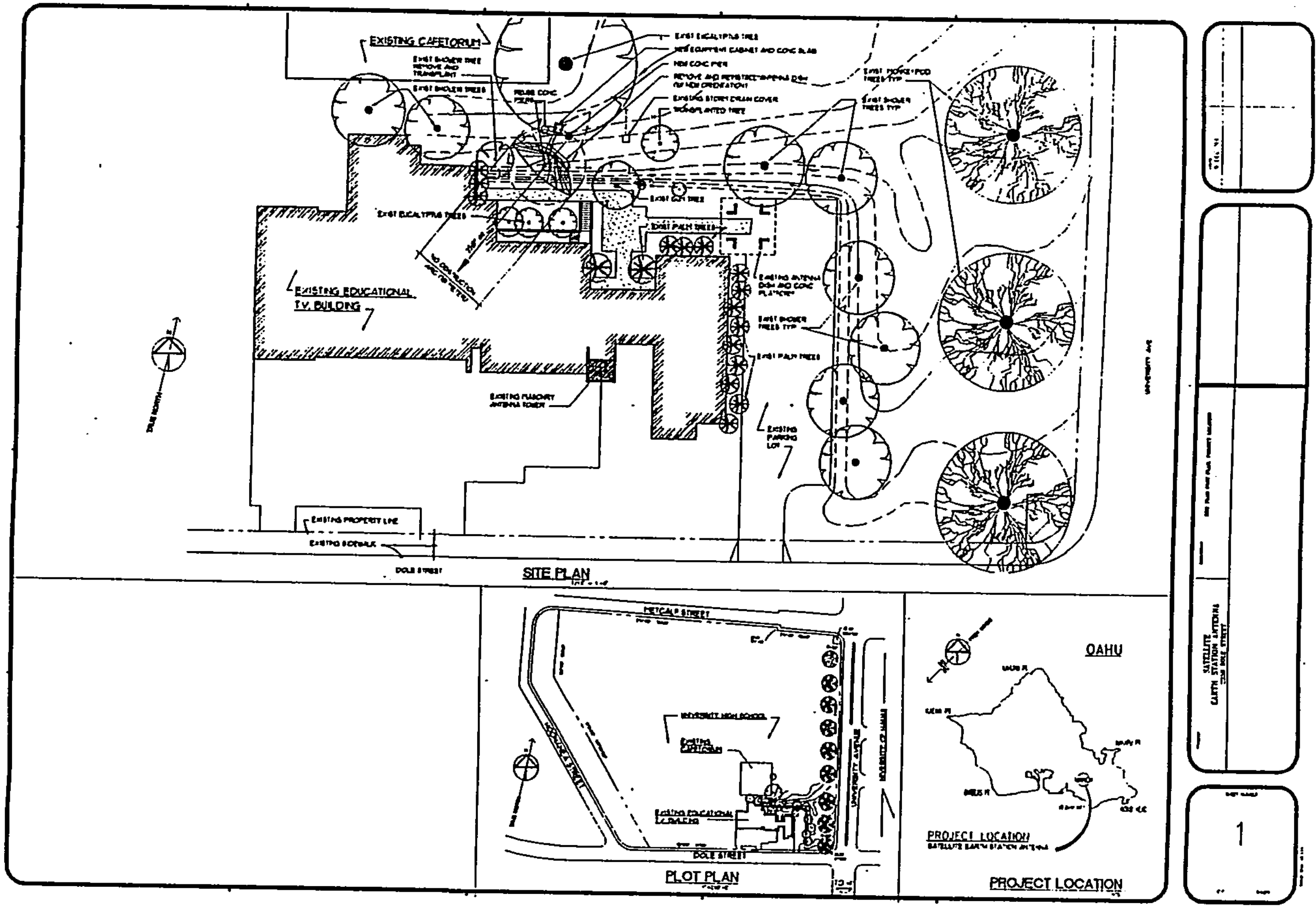
ENVIRONMENTAL CHARACTERISTICS

Site Location and Existing Use

The 10m telecommunications antenna has been located approximately 20 feet North of the Hawaii Public Broadcasting Authority (HPBA), for the past 17 years.

The HPBA building includes other telecommunications antenna systems, including microwave towers that transmit and receive signals from the Hawaii Interactive Television System (HITS) and an 8.5 meter antenna that receives signals from the satellite communication system of the Corporation for Public Broadcasting. The location is not in an environmentally sensitive zone.

The architectural drawings of the antenna realignment are shown the in following Diagrams 1 and 2, pages 3 and 4.

EXISTING CAFETORIUM
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EXIST EUCALYPTUS TREE
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EXIST GUM TREE
EXIST PALM TREES
EXISTING ANTENNA DISH AND CONC PLATFORM
EXIST SHOWER TREES TYP
EXIST PALM TREES
EXISTING PARKING LOT
EXISTING EDUCATIONAL T.V. BUILDING
EXISTING MASONRY ANTENNA TOWER
TRUE NORTH
EXISTING PROPERTY LINE
EXISTING SIDEWALK
DOLE STREET
UNIVERSITY AVE
SITE PLAN
METCALF STREET
UNIVERSITY HIGH SCHOOL
EXISTING CAFETORIUM
EXISTING EDUCATIONAL T.V. BUILDING
DOLE STREET
UNIVERSITY AVENUE
UNIVERSITY OF HAWAII
PLOT PLAN
OAHU
KAENA PT
MAKAPUU PT
DIAMOND HEAD
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SATELLITE EARTH STATION ANTENNA
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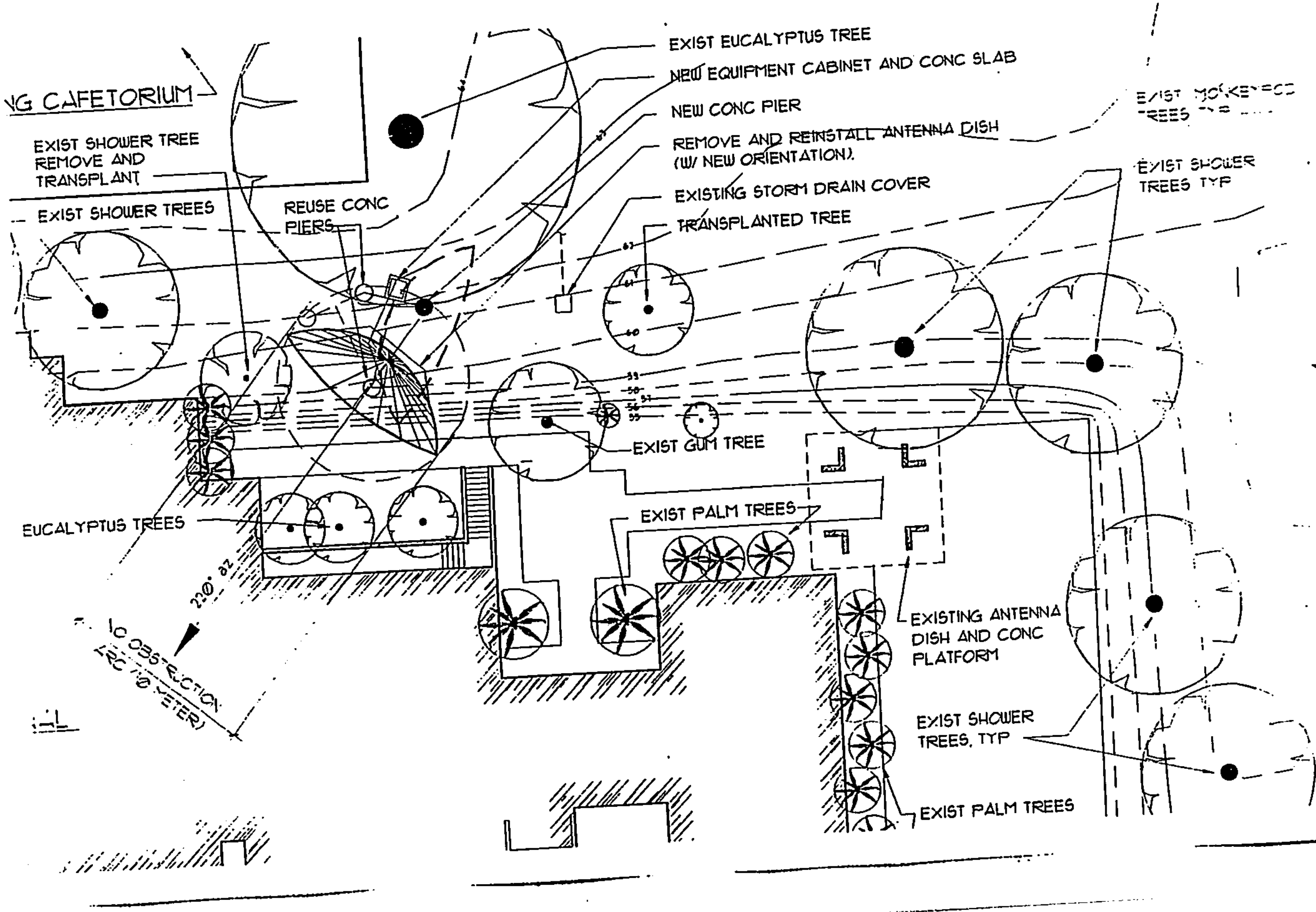
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EXISTING STORM DRAIN COVER
TRANSPLANTED TREE
EXIST MONKEYPOD TREES TYP
EXIST SHOWER TREES TYP
EUCALYPTUS TREES
220° az
10 OBSTRUCTION ARC (10 METER)
EXIST GUM TREE
EXIST PALM TREES
EXISTING ANTENNA DISH AND CONC PLATFORM
EXIST SHOWER TREES, TYP
EXIST PALM TREES

Surrounding land uses include the University of Hawaii Laboratory High School, commercial business and private residences.

The 10m telecommunications antenna was originally installed to receive "C" band television signals from satellites located over the continental USA. The basic orientation of the antenna was therefore pointing towards the South-East. The PEACESAT Program currently uses a satellite located over the central Pacific, and the 10m telecommunications antenna must therefore be re-aligned to point towards the South-West.

TECHNICAL

Description of Proposed Modifications

In addition to the antenna rotation, the antenna and electronics will be modified to provide transmission and dual axis autotracking capabilities.

Transmission/Reception Facilities: The 10m telecommunications antenna was originally designed for "C" Band receive only purposes in broadcast frequencies ranging from 5.9 Ghz to 6.4 Ghz. The existing C-Band feedhorn will be replaced with an "S" band dual mode feedhorn that has the same physical characteristics but will enable both transmission and reception in the frequency bands used by the PEACESAT network. These frequencies are:

Transmit: 2025 Mhz to 2033.2 Mhz.
Receive: 1683 Mhz to 1695 Mhz.

Once the S-Band feedhorn is installed, it will allow PEACESAT to provide concurrent voice, data, and compressed video telecommunications services to other PEACESAT sites within the Pacific region.

The "C" band feedhorn capabilities will be retained should PEACESAT require use of a satellite with C-Band frequencies in the future.

HPBA is providing space within the building for indoor electronic components.

The University of Hawaii is providing PEACESAT with use of the existing fiber optic cables between HPBA and UH campus needed to transmit and receive signals from the 10m telecommunications antenna and PEACESAT Headquarters located on the 7th Floor of Porteus Hall.

Autotracker and Outdoor Electronics: The jackscrews of the antenna will be modified to enable motorized step-tracking of the satellite. An outdoor electronics box that houses the transmission/reception electronics will be installed as depicted in the drawings.

ECONOMIC (Time Frame and Costs)

The antenna rotation and modifications are scheduled to take place in late February or early March 1995. It is estimated that the modifications will require 1 month.

The cost of construction for the proposed modifications (including communication electronics for the antenna) is estimated at $90,000.

The use of an existing telecommunications antenna for this project was determined to be the most cost-effective system alternative by the PEACESAT Program and the National Telecommunications and Information Administration. Purchasing and installing a new antenna would have doubled the cost and would have further delayed the project.

SOCIAL IMPACT

The existing use of the 10m telecommunications antenna has not resulted in any known negative impact to the surrounding community. The modifications to the antenna are not expected to create any new negative impacts to the community.

The use of the antenna by PEACESAT is anticipated to have positive impacts, especially in the areas of distance education and emergency management.

SUMMARY OF MAJOR IMPACTS (Short and Long Term)

Physical Environment

The proposed antenna modifications will maintain existing structural relationships. The existing antenna is located 10 feet from the University of Hawaii Laboratory High School Multipurpose Building and will remain at that distance. The integrity of the Hawaii Public Broadcasting Authority's entrance will be preserved.

Additional landscaping will be provided to enclose the main entry court yard and to visually screen off the antenna from building occupants and visitors. Existing flora and fauna will not be threatened or endangered. A shower tree must be removed to create a clear line of site the satellite. The tree, or one of similar size, will be replanted directly East of the antenna after construction work is completed.

The new antenna foundation will use two of the existing cement legs. A third cement leg will be installed to support the new antenna position. The foundation design will adhere to soil condition and concrete standards as specified in E.I.A. standard RS-222-C Section 7, i.e. 19.5 Tons (Metric)/Square Meter (4000 Pounds per Square Foot) bearing capacity. Effort will be made to keep site construction noise levels to a minimum.

Scenic Views

The modified antenna will be visible from no new public vantage points. It will be readily visible only in the immediate vicinity of the University of Hawaii, namely at the intersection of University Avenue and Dole Street, with a very small aperture of viewing from the H-1 Freeway. Beyond this immediate area, views of the antenna will be obscured by existing buildings and trees.

The 90 degree rotation of the dish will eliminate the frontal view of the dish from the University Avenue and will decrease the antenna visibility. In addition, the proposed re-location of the shower tree, directly East of the antenna, will further decrease visibility of the antenna from University Avenue.

The only public area from which it will be possible to see the antenna is at the high vantage point of Tantalus, with no obstruction. At no point will the antenna detract from any of the significant views from Tantalus.

Radio Frequency (RF) Radiation

The University of Hawaii hired an independent contractor, Marine-Air Systems, to analyze and assess the radio frequency radiation emission safety levels for the proposed 10m telecommunications antenna.

Based on the standards set by the Institute of Electrical and Electronics Engineers (IEEE C95.1-1991) and the American National Standards Institute (ANSI C95.1-1992), Marine-Air Systems found that the radiation levels to be produced by the 10 Meter telecommunications antenna "in both the main beam and surrounding area are well within the ANSI standards and are safe for continuous exposure."

The maximum power density in the **main beam** of the antenna was calculated to be 1.02 mW/cm^2. The maximum permissible continuous (24 hours-a-day) exposure rate, according to the IEEE C95.1 standard, is 1.35 mW/cm^2. It has therefore been determined that there are no existing radiation safety issues surrounding transmissions from the 10 meter dish antenna.

For discussion of these standards and the radiation assessment, please refer to the report that was prepared for the University of Hawaii by Marine-Air Systems in Attachment 4: *Radio Frequency Radiation Emission and Safety Levels for the Proposed Network Hub Antenna System of the Pan-Pacific Education and Communication Experiments by Satellite (PEACESAT) Program of the University of Hawaii.*

SUMMARY OF IMPACTS AND MITIGATION MEASURES

The existing telecommunications antenna and structure have not resulted in any significant environmental impact nor has there been any public controversy for the past 17 years. The proposal to rotate the dish 90 degrees with additional landscaping will reduce visibility of the dish from University Avenue.

The only other proposed modification to this existing structure is to add transmission capability to the antenna. Radiation safety issues concerned in this matter have been analyzed and the radiation emission is not considered a health risk to the surrounding environment and people.

LAND USE APPROVALS REQUIRED

HPBA File No. 92/w-26

HPBA received approval by the Department of Land Utilization to install the 8.5m antenna which exceeds the permitted maximum height with a condition that the 10m telecommunications antenna, which is the subject of this EA., is dismantled. An extension of proposal to rotate the dish 90 degrees with additional landscaping will reduce visibility of the dish from University Avenue.

The only other proposed modification to this existing structure is to add transmission capability of the antenna. Radiation safety issues concerned in this matter have been analyzed and the radiation emission is not considered a health risk to the surrounding environment and people.

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HPBA File No. 92/w-26

HPBA received approval by the Department of Land Utilization to install the 8.5m antenna which exceeds the permitted maximum height with a condition that the 10m telecommunications antenna which is the subject of this EA, is dismantled. An extension of this term may be granted upon approval by the Director of Land Utilization. PEACESAT has submitted the request to retain the antenna and is awaiting approval. PEACESAT met with the Department of Land Utilization on this matter and has been advised that permission to retain the antenna for "good use" is anticipated.

FINDINGS AND REASONS SUPPORTING DETERMINATION

The following findings are based on the information provided above and supplement the findings in the original EIS:

a) *The proposed project will not involve an irrevocable commitment to loss or destruction to any natural or cultural resources;*

b) *The proposed project will not curtail the range of beneficial uses of the environment;*

c) *The proposed project will not conflict with the State of Hawaii's long-term environmental policies;*

d) *The proposed project will not substantially affect the economic or social welfare of the community of the State of Hawaii;*

e) *The proposed project will not involve any secondary impacts, such as population changes or effects on public facilities;*

f) *The proposed project will not involve a substantial degradation of environmental quality;*

g) *The proposed project will not substantially affect any rare, threatened or endangered species of flora or fauna or habitat. No endangered species of flora or fauna are known to exist in the site location;*

h) *The proposed project will not detrimentally affect air or water quality or ambient noise levels; and*

i) *The various elements of the proposed project will not be located in any environmentally sensitive area, such as flood plain, tsunami zone, erosion-prone area, geologically hazardous land, estuary, freshwater or coastal waters.*

FINAL DETERMINATION

In accordance with Chapter 343, Hawaii Revised Statutes and § 11-200-12, Hawaii Administrative Rules, the proposed PEACESAT 10 Meter telecommunication antenna modification will not cause any significant negative impacts to the environment.

ATTACHMENT 1

User Institutions and Organizations of PEACESAT

4-H Youth Development Officers
Adi Cakobau School, Fiji
Agriculture Development in the American Pacific
Agriculture Liaison Officers
AIDS Programs
American Red Cross--Pacific Chapters
American Samoa Community College
Archives and Library Associations
Bah'ai Faith Church
Bureau of Planning, Guam
Chuuk State Hospital, Chuuk, FSM
Civil Defense, United Nations Association of New Zealand
Coastal Resources- State and Non-Profit
College of Micronesia
Community Action Agency
Community College Business Incubator
Community College Financial Aid
Community College of Micronesia Computer Training Institute, Pohnpei, FSM
Community College of Micronesia, Pohnpei, FSM
Consortium of Pacific Education
Cultural Affairs Department and Ministries
Curriculum Research & Development Group, University of Hawaii, Hawaii, USA
Department of Agriculture, Hawaii, USA
Department of Agriculture, Niue
Department of Agriculture, Palau, FSM
Department of Education, Chuuk, FSM
Department of Education, Kosrae, FSM
Department of Education, Majuro, Marshall Islands
Department of Education, Yap, FSM
Department of Foreign Affairs & Trade, FFA
Department of Health & Environment, Majuro, Marshall Islands
Department of Health Services, Kosrae, FSM
Department of Health Services, Pohnpei, FSM
Department of Human Resources, Pohnpei, FSM
Department of Public Health & Environment Services,
Department of Public Health, Saipan, Northern Marianas
Disabilities, UH, Hawaii, USA
Division of Curriculum & Instruction, DOE, Pago Pago, American Samoa
Elementary Schools--Various throughout the Pacific
Family Involvement Coordinator, PSS, Saipan, Northern Marianas
Fisheries and Marine Resources
Forum Fisheries Agency
Girl Guides (Girl Scouts)
Governor's Council on Alcohol & Drug Abuse, American Samoa
Governor's Office Programs--Various
Governor's Pacific Health Promotion and Development Center, Hawaii, USA
Hawaii Department of Health, Hawaii, USA
Hawaii Medical Technology Faculty
Hawaii University Affiliated Programs for Development
Health Department and Ministries
Health Education Program, Ministry of Health, Majuro, Marshall Islands
High Schools--various throughout the Pacific
Honolulu Academy of Arts, Hawaii, USA
Hospitals--various throughout the Pacific
International PEACESAT Users Group
Island Meteorological Service, Solomon Islands
Juvenile Justice Program and Planning, Koror, Palau
Kalaheo Elementary Library, Hawaii, USA
Kauai High School Library, Hawaii, USA
King George VI School, Honiara, Solomon Islands
Land Grant Colleges
Land Grant Programs
Le Vaomatua, Conservation Society of American Samoa
Marine Resources Development, Yap, FSM
Maritime Authority--Various
Marsville Project
McKinley High School, Hawaii, USA
Medical Officer School
Micronesian Occupation College

Ministry of Education, Rarotonga, Cook Islands
Ministry of Pacific Island Affairs, Wellington, New Zealand
Ministry of Woman's Affair, Western Samoa
National Library of New Zealand
National Tropical Botanical Garden Library, Kauai
Natural Disaster Committee, Western Samoa
Niue High School, Niue
Office of International Relations, University of Hawaii, USA
Office of Planning & Statistics, Yap
Pacific Basin Deaf-Blind Project, University of Hawaii, USA
Pacific Basin Development Council, Hawaii, USA
Pacific Basin Development Countries
Pacific Basin Rehabilitation Research and Training Center
Pacific International Center for High Technology Research
Pacific Island Affairs Department and Ministries
Pacific Island Health Officers Association
Pacific Islanders Coalition
Pacific Islanders in Communication, Hawaii, USA
Pacific Islands Bilingual Bicultural Association
Pacific Islands Network, University of Hawaii, Hawaii, USA
Pacific Region and Educational Laboratory
Pacific Resource Learning Groups
Pacific Women's Resource Bureau, South Pacific Commission
Pago Pago, American Samoa
Pago Pago, American Samoa
Palau Community Action Agency, Koror, Palau
Papaaroa Adventist College, Rarotonga, Cook Islands
Pharmacies--Various throughout the Pacific
Police Department, Rarotonga, Cook Islands
Polynesian Language Forum, University of Hawaii, Hilo, USA
Polynesian Voyaging Society, Honolulu, Hawaii, USA
Prostitute Collectives, Wellington, New Zealand
Public Health Nursing Services, Department of Health,
Public Radio Broadcasting
Queen Victoria School, Suva, Fiji
Resource And Development Department and Ministries
Saipan Public School System, Saipan, Northern Marianas
Schools of the Pacific Rainfall Climate Experiment, SPaRCE
Science Section, Division of Curriculum & Instruction, DOE,
Sea Grant Extension, University of Hawaii, Hawaii, USA
Siosiomaga Society
Social Science Research Institute, University of Hawaii, Hawaii, USA
Somens Federations
South Pacific Commission
SPC/FAO Regional Fruit Fly Project
Special Education Program, Public School System, Saipan, Northern Marianas
Sustainable Development Network Steering Committee, SPC
Teacher Support Services--Various
Teleclass International, New Zealand
Titikavaka College, Cook Islands
Tonga Defense Service, Tonga
Tongan Family Support Services, New Zealand
Transportation and Communication Department and Ministry
Tuturumuri Elementary School, New Zealand
University and College Newspapers
University of Auckland
University of Hawaii Lab School
University of Hawaii Libraries
University of Oklahoma, USA
University of South Pacific
Veterinarian Network--Pacific Region
Vocational Education, PREL
Waialua High School, Hawaii
Waialua Intermediate School, Hawaii
Wellington College of Education, New Zealand
Wellington Polytechnic, Wellington , New Zealand
Western Regional Resource Center, University of Oregon
Women's Division, Fisheries Department
Yap State Hospital, Yap, FSM

ATTACHMENT 2

PEACESAT: A REGIONAL TELECOMMUNICATIONS ALLIANCE IN TRANSITION

Norman H. OKAMURA* and LORI MUKAIDA**

* Associate Specialist, Social Science Research Institute, University of Hawaii
** Director, PEACESAT, University of Hawaii

1. ABSTRACT

The Pan-Pacific Education and Communications Experiments by Satellite (PEACESAT) Program, sponsored by the U.S. Congress and the Department of Commerce's National Telecommunications and Information Administration (NTIA), was re-established in 1989 through the use of the National Oceanic and Atmospheric Administration's (NOAA) GOES-3 satellite. Since its formal opening in 1992, the PEACESAT regional telecommunications alliance has grown to 36 sites in 25 countries.

The objectives of this paper are to provide a brief overview of the program, review some of its current challenges, and describe how the PEACESAT program is preparing to meet these challenges. The paper describes PEACESAT's plan to meet the needs of users in the short and intermediate-term. The plan calls for PEACESAT to optimize the use of the GOES-3 capacity by increasing the number of analog carriers, establishing a digital carrier network, applying technologies that optimize the use of full duplex channels for concurrent voice and data communication, and to establish multiple video teleconferencing channels. PEACESAT's plan will constitute a major transition of the telecommunications alliance.

2. BACKGROUND

The PEACESAT program was initiated in 1971 to experiment with distance learning, emergency information, and teleconferencing applications through the use of a single push-to-talk voice communication using the ATS-1 satellite by sites in the Pacific.[1] In 1985, the PEACESAT program became temporarily limited when the ATS-1 satellite ran out of fuel and could no longer support the needs of its users.[2] The program was re-established by United States Congress through the efforts of Senator Daniel Inouye of Hawaii, NTIA, users, and the University of Hawaii.[3] The missions, re-establishment, use, and potential of PEACESAT are discussed in several documents and reports and are not described in this paper.[4]

The re-establishment was made possible through repositioning of the National Oceanic and Atmospheric Administration's (NOAA) geostationary weather satellite, GOES-3, in 1990. GOES-3 was one of a series of satellites used by NOAA for weather data gathering.[5] Through the repositioning of the satellite, the GOES-3 footprint covers parts of the West Coast of the USA, most of the Pacific Rim, and all of the Western and South Pacific Islands countries.

Since the PEACESAT program was formally re-established in 1992, the growth of the network has been tremendous. As of November, 1993, 36 sites in 25 countries have acquired terminal equipment (antenna, power, transceivers) to access voice and data services throughout the Pacific. There are also 20 additional sites that have committed to come on-line in the Federal Fiscal Year 1993/1994 (October 1, 1993 to September 30, 1994).[6] In addition, more sites are considering becoming part of the PEACESAT network.

2.1 Challenges

The re-establishment of PEACESAT has occurred smoothly and the program is providing services as planned and designed. PEACESAT has also received enthusiastic support from its users in the Pacific.

At the same time that the re-establishment may be viewed as a success, PEACESAT faces several challenges. One challenge centers around how PEACESAT will meet the increased demands by users for more full-duplex data access, concurrent voice/data services, and video teleconferencing based educational services. A second challenge is how PEACESAT should maintain, strengthen, and extend services in the short- and intermediate-terms. A third challenge for PEACESAT is the *selection of a long-term* satellite solution that can support the needs of PEACESAT.

2.1.1 Level of Services and User Demands

One of the pressing challenges for PEACESAT is the level of services that are provided through the GOES-3 satellite system. Island governments, educational institutions, regional organizations, and other users have made their needs known to NTIA and PEACESAT. In the near term, PEACESAT users desire access to increased data channels and are requesting concurrent access to dedicated data channels. Some users also are requesting concurrent voice, data, and compressed digital video. Over the long-term, PEACESAT users desire high speed data networking and full-motion video.

2.1.2 Short and Intermediate-Term Solutions

Until a long-term solution is developed, there is a need to meet the needs of users during the short and intermediate terms. This challenge is directly addressed in this paper and may be achieved by optimizing the use of the existing GOES-3 satellite. This approach is consistent with NTIA's recommendation issued in a 1992 report which states that: "NTIA should work toward extending PEACESAT's use of the GOES series of satellites to provide more time to search for the long-term satellite configurations [to meet the needs of users]."[7]

2.1.3 Selection of a Satellite for Future Programming

The selection of a satellite to provide long-term services is important for two reasons. First, the agreement between NTIA and NOAA to use GOES-3 will end in 1995 even though there are indications that the agreement will be extended for the life of the satellite. Secondly, and just as important, the GOES-3 satellite will probably run out of fuel sometime around the Year 2000 and is expected to have problems in maintaining its geostationary orbit. Finally, there are inherent limitations in the capacity of the GOES system to meet the growing needs of its users.

In response to this challenge, NTIA and PEACESAT have initiated studies to define user needs and alternatives for providing a long-term satellite system for PEACESAT. The selection of an alternative satellite to deliver the services is critical to the long-term success of the PEACESAT program. The studies by NTIA and PEACESAT have been documented most recently in a December, 1992 report issued by NTIA entitled <u>PEACESAT: Communications Satellite Services for the Pacific Islands: Satellite Feasibility Study</u>.[8] Although the report does not contain recommendations for a long-term solution, progress toward analyzing alternatives has been made.

2.2 NTIA and PEACESAT Assessments of User Needs

NTIA and PEACESAT have been continuously working toward identifying and defining the needs of users. This is always a critical but difficult task. Identifying requirements is important since they impact the definition of alternative solutions. At the same time, defining user requirements is difficult since users' needs are dynamic and change with experience, environmental factors including budgets, and developments in technology. The NTIA and PEACESAT reports describe some of the user requirements in the near- and long-term future (2007) and include:

- Increased data circuits for Internet and other data driven information services;

- Concurrent voice and multiple data access support;
- Channels for sensitive voice and data communication;
- 64 Kbps transmission for higher speed data transfer;
- Compressed video teleconferencing;
- High Speed data communication; and,
- Full motion video.

Based on the report and response from users, the long-term needs for improved communication services to the Pacific will require significant communication capability, and some requirements such as full-motion video may never be able to be delivered through a PEACESAT type program, with the exception, perhaps, of public broadcasting video. These general needs will be further studied to determine their relative importance.

In the short and intermediate-terms, it is clear that PEACESAT needs to provide concurrent voice and data services, and support concurrent data access services for information access.

Since introducing data services, the needs and demands for data access have grown steadily. The anticipation over the introduction of INTERNET services and other planned data-driven information programming (BBS) has been overwhelming. PEACESAT needs to improve access to the high-volume usage areas. It is hoped that these users will be able to access data-driven information services on an ongoing basis without operator assisted circuit switching that in itself does not optimize data transmission.

Any user of Internet or other on-line information services knows the problems of trying to schedule time for the use of such circuits. A reservation system may be initially acceptable, but it will not be acceptable for long, especially when the service is shared by 35 different sites. The contention for the use of the channel has already resulted in conflicts between and among voice and data users. The conflicts are expected to grow.

More and higher speed digital channels are also needed since compressed digital video transmission may be important to the overall development of the PEACESAT program given its current mission (e.g., telemedicine applications and distance education). It may become even more important as PEACESAT provides support for the promotion of regional economic development activities.

2.3 PEACESAT Program Priorities

PEACESAT, as with any other program, must, of course, prioritize where it will concentrate its resources. Any PEACESAT program activity must be guided by a set of priorities. NTIA suggests the following priority scheme for PEACESAT to use in its program planning:

1. Maintain existing services;
2. Strengthen existing services;
3. Make existing services more widely available (both to current users and new users); and,
4. Develop new services.[9]

The priority scheme implies that PEACESAT plans to improve services in a way that maintains the existing services, strengthens them, and increases their availability to the Pacific Basin and Rim before introducing new services. The priorities are reasonable given limited budget and satellite resources.

3. OPTIMIZING USE OF GOES-3 FOR THE SHORT- AND INTERMEDIATE-TERMS

Until a long-term satellite solution is found to meet the needs of the Pacific Basin and Rim, GOES-3 could be used to provide improved voice, data, and compressed video service for the short- and intermediate- terms.

The PEACESAT/GOES-3 transponder operates in S and L Bands and has an 8 MHz bandwidth (2025-2033 MHz Transmit and 1683-1691 MHz Receive). The current voice and low-speed data carriers are 16 KHz and are spaced 50 KHz apart. A full-duplex channel uses two of these carriers.

The capacity of the GOES-3 transponder is not being fully utilized. There is additional carrier and bandwidth capacity that could potentially be used by PEACESAT to meet the needs of users in the short- and intermediate-term. There are also technologies that may be used to optimize the use of the carriers. The following is a brief discussion of how these opportunities could be realized by PEACESAT.

3.1 Increasing Number, Type, and Capacity of GOES-3 Carriers

PEACESAT could increase the number, type, and capacity of GOES-3 carriers.

3.1.1 Increase the Number of Analog Carriers

PEACESAT could increase services to meet the *demands of users by increasing the number of* analog carriers and to increase the accessibility to these carriers by remote sites.

The current design of the PEACESAT mesh network means that users can only transmit a single carrier that can support either a simplex voice or a full-duplex voice/low speed (9.6 Kbps) data link. The design allows Pacific Island and Rim sites to communicate with each other through 9 existing simplex carrier circuits and 3 full-duplex carrier circuits. The full-duplex carriers support low-speed (9.6 Kbps) data.

The design provides the benefits of inter-networking many different locations throughout the Pacific using a minimum number of carriers. The downside of the system are that: (1) the carriers only support a single use, (2) 35 PEACESAT sites must share only 3 full-duplex circuits, and (3) PEACESAT Headquarters (PHQ) currently only has 1 transceiver that can be used for data purposes. To improve access to more GOES-3 full-duplex carriers, PEACESAT could modify the terminals to access new analog transmit/receive carrier frequencies.

3.1.2 Increase the Number of Concurrent Carriers at PEACESAT Headquarters (PHQ)

Increasing the number of analog carriers that can be used by PEACESAT sites will not by itself resolve the problem of concurrent data access to PEACESAT Headquarters. The use of the current 3-Meter antenna and power amplifier inherently limits the number of carriers that can be handled by PHQ. These antennas and power amplifiers were designed to support a single analog carrier.

Since PHQ has two antennas, it can currently have two simultaneous sessions. However, if PHQ has a voice conference and data session established, it will not be able to provide any hub administrative services such as contacting users of impending meetings.

PEACESAT could increase the number of carriers that PHQ can receive and transmit to in order to provide concurrent access to multiple voice and data channels.

There are two alternatives by which this could be accomplished. First, PEACESAT could install a new terminal (antenna, power amplifier, indoor electronics) for each channel that PEACESAT wants to establish. This would create an antenna farm and is not very practical given the space and cost factors. Second, PEACESAT could upgrade the size of one of its existing antennas, purchase a new power amplifier, and install a rack mounted GOES-3 transceiver channel bank to save space and power. Increasing the size of the antenna, power amplifier, and installing a transceiver bank clearly appears the better solution when compared to installing an antenna farm.

3.1.3 Establish a Digital Carrier Network

Increasing the number of analog carriers and increasing the capability of PHQ to concurrently support multiple carriers will not solve the needs of certain sites to transmit voice and data simultaneously.

To resolve these problems, PEACESAT could establish a digital carrier network concurrent with the existing analog FM network to increase the capacity to support multiple voice, data, and compressed video channels by sites. By creating a digital carrier network, PEACESAT may be able to support the simultaneous transmission of voice, data, and possibly compressed video communications. Digital carriers are generally favored over analog FM modulation since it is more cost-effective in the use of satellite resources.

Naturally, there are limitations to the number and capacity of digital carriers that can be established. The limitations will depend largely on the power budget, bandwidth, capability of the satellite transponder, and potential impact on the analog carriers.

3.1.4 Compressed Video Mesh Network Carriers

Digital carriers capable of supporting 64+ Kbps could be established to support compressed digital video applications. It may be possible to design the use of the carrier capacity of the GOES-3 to support a single digital carrier with a data rate of up to 768 Kbps. The question is what data rates should PEACESAT support for compressed video teleconferencing given the other needs for voice/data.

3.1.5 Planning Model for PEACESAT

Table 1: Capacity Planning Model shows the number and capacity of various carriers that could potentially be established using the 8 MHz bandwidth of the GOES-3 satellite. The table presumes that there is about 1.5 Mbps of digital capacity available for use. This is equal to about 768 Kbps in full-duplex mode.

Table 1: Capacity Planning Model

Carrier Type	Quantity
Analog FM	**Existing** 9 Analog Simplex for Voice and 3 Analog Full-Duplex for Voice/Data
Analog FM	**Potential New** 10 Analog Simplex for Voice or 5 Analog Full Duplex for Voice/Data
Voice/Data Digital RF	**Potential New** 8 to 16 – 32 Kbps FD Channels
Digital Video Digital RF	**Potential New** 2 – 128+ Kbps FD Channels

The planning model shows GOES-3 potentially supporting about 10 new analog FM carriers and 16 digital carriers with 32 Kbps capacity. The model also shows GOES-3 supporting 2 new digital carriers that have 64/128+ Kbps in carrier capacity for compressed video or higher speed data transfers. If these capacities can be realized, then, GOES-3 could potentially strengthen existing services and make them more widely available to meet the needs of the Pacific Islands and Rim. The extent to which GOES-3 can meet these needs will be subject to philosophy, technical system constraints, design, and costs.

Digital bandwidth tests on GOES-3 have been conducted by MAS with 64 Kbps channels. The success of the tests show that higher bandwidth carriers could be established and supported using the existing 3-Meter antennas and 50W power amplifiers.[10] However, the planning model is theoretical and the real questions remain:

- How many concurrent analog and digital carriers can be supported for enhanced services?
- What digital data rates can the digital carriers support?
- How can these carriers best be used?

3.2 Optimization of Carrier Capacity

Presuming that a digital carrier system can be established using the GOES-3 satellite, there are several technologies that could be used to optimize the voice, data, and compressed video communication over the digital carrier. The optimization may be realized by using voice compression, data concentrators, and a Digital Bandwidth Manager (DBM) that supports different digital transmission schemes such as circuit, packet, and frame relay over digital channel capacities less than 256 Kbps.

3.2.1 Voice Compression

Voice can be converted into digital data through pulse code modulation that can then be "compressed" through bit sampling algorithms.

The "compressed voice" is then communicated as digital data streams from one site to another. When decompressed, the data is converted back into audio voice signals.

Today, some vendors have acceptable quality voice carried over a CELP bit sampling algorithm requiring 4.8 Kbps of transmission. By compressing the voice to lower bit rates, it is possible to carry more voice channels on a carrier. For example, a single full-duplex digital circuit capable of supporting 9.6 Kbps can provide 2 voice circuits at 4.8 Kbps, assuming that bandwidth is used for in-band signaling.

3.2.2 Data Concentration

The current use of a 9.6 data channel over a full-duplex analog carrier by a single user is not an *efficient use of the GOES-3 resource.* To make better use of the available bandwidth, data multiplexing technologies could be used to share resources among more users. X.25 packet data switching could be effectively deployed by PEACESAT to enable more users to share full-duplex data channels for access to on-line and Internet services.

Response time and throughput in an X.25 network is dependent on the number of concurrent users and best applied in an on-line data access environment where users interact with host system(s). X.25 is not optimized for bursty data and large data file transfers.

Response time should not be a problem for many PEACESAT sites that are limited through the "land line" connections to lower speeds. Response time could become a problem for users with good telecommunication local land lines and are doing large data file transfers.

3.2.3 Voice and Data Multiplexing

Since both data and voice can be compressed as digital data, it is possible to use a single digital transmission carrier to carry multiple channels of digital voice and data traffic. The capacity of the transmission facility, level of voice and data compression, nature of application, and quality of voice acceptable will determine what the usefulness of a transmission facility for a particular application.

To optimize the use of a digital channel, PEACESAT could use a Digital Bandwidth Manager (DBM) to transmit simultaneously compressed voice and X.25 packet switched data. Using technologies that are commercially available, it is possible to share a 19.2 Kbps digital channel to support 2 voice (at 4.8 Kbps) and multiple data users concentrated through X.25 packet switch through a DBM.

This basic approach is well established through many different vendor technologies and allows further optimization of voice and data communications over scarce PEACESAT carrier resources. Some vendor systems can take multiple analog voice inputs, digitize the signals, and apply a compression algorithm for the voice and concentrate data transmissions. This enables, depending on the voice and data compression algorithm, the systems to transmit multiple concurrent voice sessions over a 14.4 Kbps and higher full-duplex channel.

These systems can further route the voice as circuit data and packetized X.25 data to the destination. The routing for data is dynamic. Depending on the capacity of the full-duplex channel and the level of technology that is deployed, the routing of the voice traffic can be done dynamically or through an external switch.

3.2.4 Video Compression and Higher-Speed Data Channels

Once a higher speed digital carrier is established, it can be used to support compressed video and higher speed data file transfer applications.

The DBM could also be used for routing of nx64 Kbps data. Support for fractional T-1 services is important for higher-speed data file transfers and for compressed video. The CCITT has developed standards for video transmissions based on "px64" digital data rates.

Sites that may have more than one location that need to be inter-networked for compressed video would be served best through a single communications technology that can redirect the signal to multiple interface channels. A PEACESAT site, for example, might have a need to establish a video conference session with another local site through a microwave network as well as through the PEACESAT network. A DBM with the ability to route the px64 video codec traffic from one channel interface to another would be useful and minimize the amount of manual rewiring that may need to be undertaken.

4. GOES-3 SERVICES IMPROVEMENT PLAN

PEACESAT has proposed a GOES-3 Services Improvement Plan (SIP) to NTIA. The plan calls for PEACESAT to: [11]

- Maintain 9 current carriers for command, voice mesh network and 3 full-duplex channels for data applications (The number of analog carriers may be reduced and replaced with mesh network digital data carriers);
- Establish a digital network hub that can support concurrent voice and data uses between a minimum of 10 sites in the Pacific and PEACESAT Headquarters;
- Introduce integrated voice, data, and 64+ Kbps digital bandwidth managers to optimize the voice, data, and compressed video communication uses enabled by the digital carriers;
- Establish a voice bridge between mesh network and digital network carriers for voice communications; and,
- Establish multiple digital carriers capable of supporting a minimum of 64 Kbps for compressed video applications.

From a program perspective, the PEACESAT design maintains existing services, strengthens existing services by improving their operation (e.g. concurrent voice/data and concurrent data access from sites), and makes the services more widely available to PEACESAT users by providing concurrent access to more users at sites. The design also enables more sites to become part of the mesh network may be internetworked with other systems and networks through the Pacific Basin and Rim such as the Japanese ETS-V and the State of Hawaii's HAwaii Wide Area Integrated Information Access Network (HAWAIIAN).

From a technical perspective, the design is based on the strategy of supporting and enhancing the existing analog services network while taking advantage of the capacity of the GOES-3 satellite through establishing a digital data network with a hub at PHQ. The design also includes a capacity for new services such as compressed digital video teleconferencing in a cost-effective mesh network design.

5. IMPLEMENTATION PHASES

The overall project plan calls for PEACESAT, NTIA, AND MAS to:

1. Develop the GOES-3 Services Improvement Plan
2. Develop PEACESAT Partners and Participants
3. Install an 8.5-Meter Antenna (Power amplifier, etc.) at PHQ
4. Install a Transceiver Bank and Testing of 19.2 Kbps Analog or 32 Kbps Phased Shift Modems
5. Operationalize Data Services
6. Install a 6-Meter Dish at MAS
7. Conduct Satellite Transmission Tests
8. Install Digital Bandwidth Managers
9. Conduct Voice, Data, and Compressed Video Tests
10. Develop GOES-3 Services Deployment Plan (Including Frequency Allocation)
11. Deploy the Network

The implementation of these tasks could be accomplished in three phases. Phase I would increase the number of full-duplex carriers that can be simultaneously received at the PEACESAT hub and for testing the capacity and the ability of the 19.2/32 Kbps full-duplex carriers to handle multiple channels of concurrent voice and data over limited bandwidth.

Phase II would focus on the experimentation and testing of the various transmission resources of GOES-3 and to test the ability of the terminals to support voice, data, and compressed digital video at various capacities.

Phase III would focus on the deployment of the services based on the results of Phase II.

6. IMPLICATIONS

There are several implications that will arise from the conceptual design of the GOES-3 SIP. These implications need to be considered in the final design and implementation of the plan.

6.1 User Groups

Establishing a digital or star network design to complement the existing PEACESAT mesh network will create two basic types of "users." One group of users will use the analog "mesh" network. A second group of users will be linked to the PHQ in a digital star or hub and spoke network. All sites using the digital services will have multiple concurrent voice and data services and be internetworked to the mesh users through bridging at PHQ.

The creation of different "user groups" may create an impression that there are different "classes" of users in PEACESAT. The concept of "classes" may be viewed from at least two perspectives. On the one hand, it could be viewed as detrimental to the concept of PEACESAT, which has historically stressed a system that provides the same capabilities equally to its user community. On the other hand, the plan may be viewed as a means of meeting the needs of different users. It should be understood that users will select which user group the site will participate in, constrained, of course, by the number and capacity of digital carriers that can be provided through GOES-3.

6.2 Cost of Network

There are cost implications of the proposed network for both the PHQ and user sites. PHQ would need to install a larger antenna and power amplifier, additional analog and digital transceivers and RF modems, a bridge to interface the analog and digital channels, and the additional networking capacity to access other systems and networks in Hawaii which users wish access to (e.g. UH libraries system). PEACESAT would also need personnel and space to support the technology upgrades.

PEACESAT sites, depending on the tests, will not need to upgrade their antennas or power amplifiers for single 32 or 64 Kbps channels. These sites would need to acquire a voice/data DBM and the additional peripherals to support multiple concurrent voice and data applications.

However, if a site requires use of higher-speed video channels beyond 64 Kbps or concurrent voice and data with a 64 Kbps video link, then, the site will incur additional costs. The major costs that will be incurred by a site will be for a larger antenna and power amplifier, and a voice bridge if one is not already present. There will also be costs for interfacing the systems to the local public service telephone network.

6.3 Technical

There are several technical issues that will need to be resolved. The major technical issue is the number of digital carriers and capacity that can be established without interrupting or degrading the mesh network analog carriers. Other issues include the design of the terminals to support two digital and one analog carriers, level of interference with analog FM carriers, how the mesh and star network voice services would be bridged through the network, and whether the DBMs will function the way it is currently projected over a satellite carrier. None of the issues are significant enough to invalidate the conceptual design of the GOES-3 SIP. The major technical concerns revolve around the ultimate capacity of the carriers and design alternatives.

These concerns will be addressed in the Phase III GOES-3 Services Deployment Plan that would be prepared at the conclusion of the tests conducted in Phase II.

The technical issue of how the "mesh network" user would interface to "digital" users is one issue that merits some discussion here since a major program objective is to enable sites to communicate with each other. PEACESAT would need to bridge the analog mesh network communications carrier channels with the digital voice carrier channel through either a voice bridge or voice switch that supports voice conferencing. The optimal solution will depend on PHQ's other local telephone, data, and video teleconferencing bridging requirements.

6.4 Operational Implications

There are operational implications that will also need to be considered by PEACESAT. From a systems point of view, some of the operational implications will include: network management functions; bridging mesh with star network voice; developing new scheduling systems for compressed video programming; bridging pass-through communications between Hawaii video conference and HITS studios to the network, and so on. There will be a measure of added complexity for the PHQ since the technology that is being implemented is far more complex than the technology being used today.

7. SUMMARY

The re-establishment of PEACESAT has been successful. However, there is a need to extend and strengthen services to the Pacific. The services requested by current PEACESAT users include more voice and data channels, concurrent voice and data communications, non-interrupted data services, higher bandwidth data, and compressed video. Most important of these services in the short-term is to provide concurrent voice and data access.

Although NTIA and PEACESAT are studying the long-term solution, there are short- and intermediate-term steps that could be taken to improve services. PEACESAT has developed a plan to provide more analog carriers, establish a digital carrier network using the additional bandwidth capacity, and optimize the use of the digital carriers through multiple access digital telecommunication technologies.

PEACESAT, NTIA, and Marine-Air Systems are currently evaluating this plan and may initiate trials to resolve outstanding technical questions. The major technical question is the number of carriers and the capacity of such carriers that can be created.

Should these tests be successful, PEACESAT will be able to develop and implement a service improvement plan to maintain, strengthen, and extend existing services, and experiment with the delivery of new services such as compressed video conferencing. Realization of such a plan will effectuate a major transition in the regional telecommunications alliance called PEACESAT.

ENDNOTES

This paper is based in part on a report prepared for the PEACESAT Program at the University of Hawaii by Norman Okamura entitled Preliminary Assessment and Conceptual Design for the Use of GOES-3 to Provide Improved Services to the Pacific.

The assistance and support of the personnel and consultants of PEACESAT Headquarters in the preparation of this paper must be acknowledged. This includes Lori Mukaida, Director, Christina Higa, Operations Manager, Thomas Okamura, Programming Manager, and Calvin Fujioka, Fiscal Specialist. I am particularly indebted to Calvin for checking figures out and to Thomas for all of the graphics. The paper has benefited substantially from the discussion and dialogue that has been conducted with PEACESAT during the past five months.

The contributions of Mr. Ray Jennings and Mr. Bill Cooperman of the National Telecommunications and Information Administration, as well as Mr. Peter Williams and

Mr. John Yaldwin of Marine-Air Systems must also be acknowledged since many of the ideas and issues discussed in this paper were developed as a direct result of issues raised and information provided by these organizations.

1. The PEACESAT program was initiated in 1971 with a single voice channel on ATS-1. Cooperman, W., Mukaida, L., Topping, D. 1991. "The Return of PEACESAT". <u>Proceeding: Pacific Telecommunications Conference.</u> Honolulu, Hawaii.

2. When the ATS-1 ran out of fuel in 1985, the PEACESAT program continued operations at the University of Hawaii using a high-frequency radio until Congress re-established the program.

3. The PEACESAT Program was re-established through a Congressional appropriation to the U.S. Department of Commerce's National Telecommunications and Information Administration (NTIA) in 1989. Funds are made available to the University of Hawaii for the PEACESAT program through a PEACESAT Re-Establishment Cooperative Agreement.

   Once the Congressional budget has been approved, PEACESAT will submit a proposed contract amendment to NTIA. As part of the proposed contract amendment, PEACESAT will be proposing ideas on how services may be improved in the Pacific through the use of the GOES-3 satellite system.

4. See: Mukaida, L., Topping D. 1989. "Appropriate Technology: The PEACESAT Experiment". <u>Proceeding: Pacific Telecommunications Conference.</u> Honolulu, Hawaii;

   <u>Proceeding: PEACESAT Policy Conference.</u> 1992. Sendai, Japan. Mukaida, L. 1992.

   "PEACESAT Program Strategic Plan (Draft)", University of Hawaii, Honolulu, Hawaii.

5. The GOES series of satellites was built by Ford and Hughes and are used to transmit satellite imagery for weather data gathering. The image camera and/or transmitter of the GOES-3 satellite became dysfunctional. GOES-7 also experiences the same problem and may be possibly used by PEACESAT for other purposes some time in the future.

6. The Federal Emergency Management Agency (FEMA) plans to install 14 PEACESAT terminals in the Pacific during FY 93/94. FEMA became interested in PEACESAT as a result of its usefulness during Hurricane Iniki.

   In addition to the 14 FEMA sites, there are 6 other Pacific sites that are planning to install PEACESAT terminals.

7. Cooperman, W., & Connors, D. <u>PEACESAT: Communications Satellite Services for the Pacific Islands: Satellite Feasibility Study,</u> (US Department of Commerce, National Telecommunication and Information Administration, December, 1992. P.2.

8. Ibid.

9. Cooperman, W. "Re: GOES Improvement Plan". Memo to: to Dr. Donald M. Topping, Principal Investigator, PEACESAT, 16 November 1993.

   The memorandum does not provide specific guidance regarding the priorities of the program but was intended to raise issues regarding the effort required to expand services through creating a digital carrier network for PEACESAT.

10. There are several reports that describe the technical characteristics of GOES-3:

    Williams, P. & Yaldwyn, J. 1991. "Designing an Inexpensive and Innovative S-Band Earth Station Network: The Challenge". <u>Proceeding: Pacific Telecommunications Conference.</u> Honolulu, Hawaii.

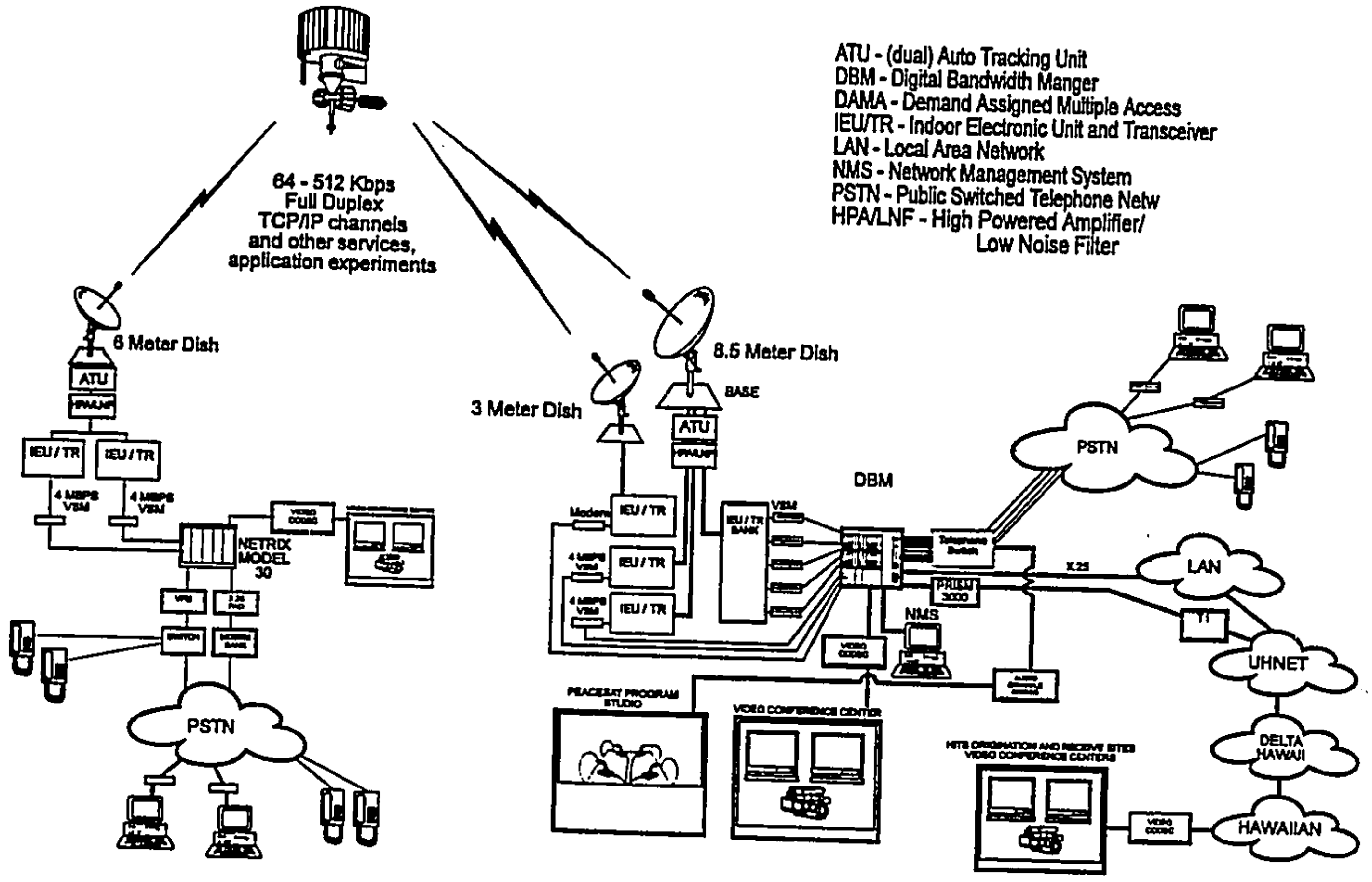
    Leary, J. 1993. "Provision of PEACESAT Links Operating at 64 Kbps to 124 Kbps".

MAS Technical Report. Wellington, New Zealand.

Leary, J. 1993. "Satellite Downlink Level Variations of GOES-3". MAS Technical Report. Wellington, New Zealand.

11. Okamura, Norman. 1993. "Preliminary Assessment and Conceptual Design for the Use of the GOES-3 to Provide Improvement Services in the Pacific". University of Hawaii, Honolulu, Hawaii.

FIGURE 1: PEACESAT GOES 3 - SERVICES IMPROVEMENT PLAN

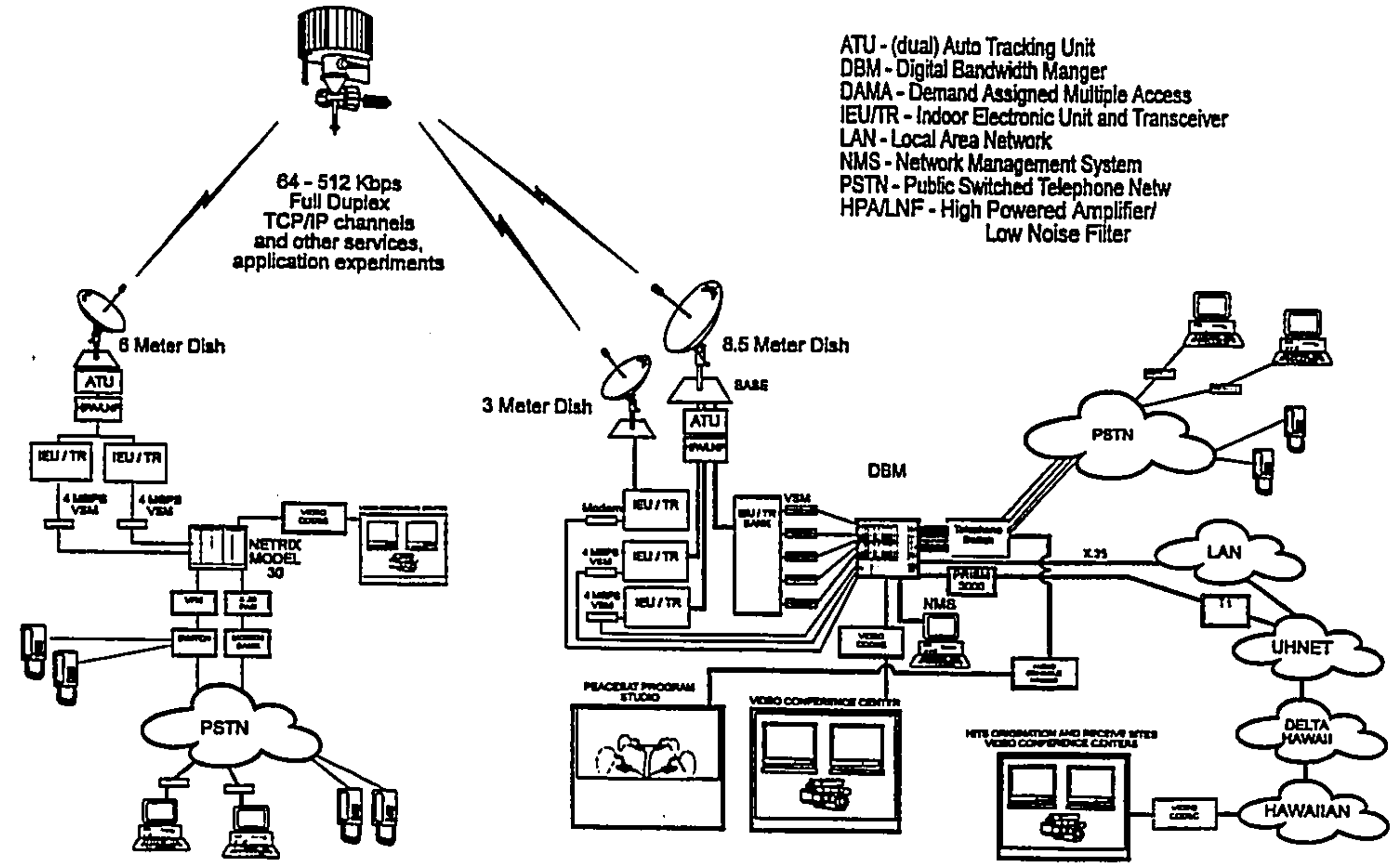


MAS Technical Report. Wellington, New Zealand.

Leary, J. 1993. "Satellite Downlink Level Variations of GOES-3". MAS Technical Report. Wellington, New Zealand.

11. Okamura, Norman. 1993. "Preliminary Assessment and Conceptual Design for the Use of the GOES-3 to Provide Improvement Services in the Pacific". University of Hawaii, Honolulu, Hawaii.

FIGURE 1: PEACESAT GOES 3 - SERVICES IMPROVEMENT PLAN



ATTACHMENT 3

Hawaii Public Broadcasting Authority
Exhibit A, February 15, 1977

Environmental Impact Statement

1. The construction proposed herein involves a "major" environmental action under Section 1.1305(a)(5) of the Commission's Rules and Regulations because it involves a satellite earth terminal having an antenna diameter of 11 meters or 36.1 feet.

2. The proposed facilities will not be located in any of the kinds of areas listed in Rule Section 1.1305(a)(6).

3. The proposed ground terminal facility will be located on a grass-covered area between the existing KHET-TV studio building and a wing of the University High School on the Manoa campus of the University of Hawaii. The proposed site has an embankment running east to west through the middle of the plot with a drop of approximately 1.8 meters (6 feet) to the south. A special foundation with a possible retaining wall will be designed to support the ground terminal antenna on this grade. No new provisions for grading or drainage will be required. Three existing eucalyptus trees to the east of the site must be removed in order to provide antennae beam clearance. No other obstructions exist within the orbital arc as the antenna has clear viewing over the KHET-TV building. Power and signal transmission lines will be routed underground from the earth station antenna to the KHET-TV studio, a distance of approximately 27.4 meters (90 feet).

4. The proposed ground terminal facility will include an 11-meter (36.1 foot) diameter parabolic antenna, ground mounted on a rigid frame with support members attached to a concrete slab or piers. The overall height of the antenna above the base will depend on the angle of the elevation but will not exceed 41.4 feet. The base of the antenna will extend approximately 0.3 meter (1 foot) above the lip of the embankment.

5. The primary objective in site selection was to collocate the earth terminal with the master control for KHET, if possible from the point of view of frequency coordination and without significant environmental effect. The studio and master control for KHET are located on the Manoa campus of the University of Hawaii. In this case it was possible to clear the desired satellite area from a location adjacent to the KHET studio building. Upon consideration of the site, it was concluded that its use would involve no significant environmental effect because of the following factors:
    a. The proposed site is I an unused area between the existing KHET studio building and a wing of the University High School.
    b. The antenna will be shielded from public view from the north and south by existing buildings.
    c. The proposed construction, including the removal of three eucalyptus trees, was reviewed by the University Environmental Center. It was the opinion of the Center's representative that the facility will have no significant impact on the environment.
    d. Visual considerations are as follows:
        1) North: a wing of the University High School is immediately north of the site. This wing is a gymnasium used as a cafeteria and auditorium ("cafetorium"). The gymnasium wall adjacent to the site is windowless.
        2) East: Lawn extends for approximately 225 feet to University Avenue.
        3) South: The KHET Studio building is adjacent to the site.
        4) West: A transformer pad is immediately behind the site. Beyond the pad is a fence marking the property boundary and then a University pre-elementary school.

6. A diagram of the site layout is included as Exhibit D of this application.

7. The city plan for Honolulu classifies the University's property as "public use." The applicant has been advised by the Honolulu Department of Land Utilization that the proposed facility is an acceptable use. The Hawaii Environmental Quality Commission, which has jurisdiction over the environmental impact of public projects, did put the proposed facility on public notice and received no comments from the public. Aside from the aforementioned contacts and proceedings, there have been no other communications or proceedings before zoning, planning , environmental or other local, state or Federal authorities on matters relating to environmental effect. The proposed construction has not been a source of controversy on environmental grounds in the local community.

8. In light of the foregoing, it is not believed that there will be significant environmental impact as a result of the proposed construction. The site is not presently in use nor would construction interfere with any proposed land use.

ATTACHMENT 4

MAS

RADIO FREQUENCY RADIATION EMISSION AND SAFETY LEVELS FOR THE PROPOSED NETWORK HUB ANTENNA SYSTEM OF THE PAN-PACIFIC EDUCATION AND COMMUNICATION EXPERIMENTS BY SATELLITE (PEACESAT) PROGRAM OF THE UNIVERSITY OF HAWAII

Prepared for the University of Hawaii by :

Marine-Air Systems Limited
Wellington
New Zealand

September 1994

RADIO FREQUENCY RADIATION EMISSION AND SAFETY LEVELS FOR THE PROPOSED NETWORK HUB ANTENNA SYSTEM OF THE PAN-PACIFIC EDUCATION AND COMMUNICATION EXPERIMENTS BY SATELLITE (PEACESAT) PROGRAM OF THE UNIVERSITY OF HAWAII

CONTENTS

RADIO FREQUENCY RADIATION EMISSION AND SAFETY LEVELS FOR THE PROPOSED NETWORK HUB ANTENNA SYSTEM OF THE PAN-PACIFIC EDUCATION AND COMMUNICATION EXPERIMENTS BY SATELLITE (PEACESAT) PROGRAM OF THE UNIVERSITY OF HAWAII

1. Summary

This report is an assessment of the expected radio frequency radiation levels around the proposed 10 meter Network Hub antenna system of the Pan-Pacific Education and Communications Experiments by Satellite (PEACESAT) Program of the Social Science Research Institute, University of Hawaii. The report was prepared in accordance with policies and procedures relating to radiation safety followed by the UH Radiation and Safety Office under the Facilities Management Office.

Based on the standards set by the Institute of Electrical and Electronics Engineers (IEEE C95.1-1991) and the American National Standards Institute (ANSI C95.1-1992), the report finds that the radiation levels produced by the PEACESAT antenna system in both the main beam and surrounding area are well within the ANSI standards and are safe for continuous exposure.

The ANSI standard is more stringent than earlier standards adopted by ANSI, and is in the process of being adopted by State Department of Health.

2. Background information

2.1 PEACESAT

The Pan-Pacific Education and Communications Experiments by Satellite (PEACESAT) Program provides telecommunications services and enables communications, education, and technical experiments to be conducted using satellite communications in the Pacific. PEACESAT users include University academic, research and training programs, and country, regional and international organisations.

The PEACESAT Program is sponsored by the U. S. Congress and the Department of Commerce's National Telecommunications and Information Administration (NTIA).

The PEACESAT network currently comprises over 50 installed or planned satellite terminals around the Pacific region.

The Headquarters of the PEACESAT Program is at the Social Science Research Institute of the University of Hawaii at Manoa. Network co-ordination and management is presently performed using two 3m antennas located at the Old Engineering Quadrangle site at the University.

In order to provide more PEACESAT telecommunications services to the Pacific islands, a Services Improvement Plan (SIP) has been developed, and has been allocated funds by the U. S. Congress. The SIP will enable Pacific Island countries to access additional voice, data, and compressed video telecommunications services.

The Network Hub for the SIP will be located in at the University of Hawaii. To support the increased number of services, it will be necessary to use a larger antenna than the existing 3m terminals. The system design calls for an antenna diameter of around 10m to be used at the Network Hub.

In order to implement the SIP within the budget allocated by the U. S. Congress, PEACESAT obtained ownership of the existing 10m antenna at the 2350 Dole St. site of the Hawaii Public Broadcasting Authority (HPBA). That antenna is no longer needed by the HPBA, as their operations have been transferred to the new antenna recently constructed at the same site. Existing cables are available to carry the communications signals between the HPBA site and the PEACESAT Headquarters located nearby.

The 10m antenna was originally installed to receive television signals from satellites located over the continental USA, and the basic orientation of the antenna is therefore towards the South-East. The PEACESAT Program uses a satellite located over the central Pacific, and the HPBA antenna must therefore be re-aligned to point towards the South-West.

The proposed solution is that a new foundation oriented towards the South-West should be constructed adjacent to the existing antenna position, and that the antenna should then be re-located onto the new foundation.

2.2 Proposed Network Hub antenna system

The 10m antenna is Type ESA10-46B manufactured by Andrew Corporation, and was installed in 1978. The antenna has an X-Y mount with manual drive system, Gregorian optics, and a C-Band receive-only feed unit with linear polarisation.

The existing C-Band feed unit will be replaced with an S-Band dual-mode horn designed and manufactured by Marine-Air Systems Limited (MAS).

The frequency bands used by the earth stations in the PEACESAT network are :

Transmit :	2025 MHz to 2033.2 MHz
Receive :	1683 MHz to 1695 MHz.

2.3 Antenna elevation angle

The PEACESAT network operates on the GOES-3 satellite, which is in geosynchronous orbit above the central Pacific at a Longitude of 175°W.

The minimum elevation angle for the Network Hub station in Honolulu is 43°.

2.4 Network Hub transmit power amplifier

The Network Hub station will be equipped with a solid-state power amplifier (SSPA) rated at 200 W, designed and manufactured by Marine-Air Systems Limited (MAS).

The total loss between the SSPA and the feed unit is estimated to be 1.0 dB. This loss is produced by the output coupler, cables, and diplexer.

In normal operation, the SSPA will be operated with a minimum backoff of 2.0 dB, in order to minimise intermodulation and other distortion effects.

The maximum total power at the input of the feed unit of the Network Hub antenna will therefore be 100 W (that is, 200 W -1.0 dB - 2.0 dB).

In normal operation of the Network Hub, the number of transmitted signals will vary with time, so that the antenna will not operate continuously at the maximum power level calculated above. In practice, the typical average power level at the input of the feed unit will be around 70 W.

In order to demonstrate that the Network Hub antenna fully meets the relevant standards, the analysis is based on the assumption that the full 200 W power level is applied continuously to the antenna feed unit. This situation cannot arise in practice, and the calculated power level is therefore some 2.8 times the typical value which would be generated in the centre of the transmit beam.

2.5 Site layout

The antenna will be located at the top of a bank to the North of the HPBA building.

The antenna will point towards the South-West, so that the beam will pass above the HPBA building.

For correct performance of the PEACESAT Network Hub station, the lowest point of the antenna beam must have a minimum clearance of 3m over the building and all other obstructions. If the beam is blocked by an obstruction, the antenna system cannot achieve the required receive performance levels, as the effective gain of the antenna is reduced and the received noise power is increased. Both of these effects degrade the quality of the received signal, and prevent the Network Hub station achieving the required performance characteristics.

In practice, for the proposed site layout and the elevation angle of the antenna beam, the minimum clearance of the lowest point of the antenna beam will be at least 5m. The centre of the transmit beam (where the highest power levels exist) will therefore be at least 10m clear of the roof of the HPBA building.

3. Relevant standards

3.1 IEEE C95.1 - 1991

The relevant standard is taken to be (see Annex 1):

IEEE C95.1 - 1991
" IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz".

IEEE C95.1 - 1991 has been adopted by the American National Standards Institute (ANSI) as ANSI C95.1-1992, and is in the process of being adopted by State Department of Health.

IEEE C95.1 - 1991 *defines an uncontrolled environment* in the following terms :

> " Exposure associated with an uncontrolled environment is the exposure of individuals who have no knowledge or control of their exposure. The exposures may occur in living quarters or workplaces where there are no expectations that the exposure levels may exceed those shown in Table 2."

Table 2 on Page 15 of IEEE C95.1 - 1991 gives the Maximum Permissible Exposure (MPE) for human exposure in uncontrolled environments. Between 300 MHz and 3000 MHz, the MPE is expressed as a power density of :

$$f / 1500 \quad mW/cm^2$$

where f is the radio frequency in MHz.

The MPE at the PEACESAT transmission band of 2030 MHz is therefore :

$$2030 / 1500 \quad mW/cm^2 \; :$$

That is :

Maximum Permissible Exposure = 1.35 mW/cm^2.
(continuous exposure)

Table 2 of the IEEE C95.1 - 1991 standard defines the maximum radiation level which is permissible for continuous exposure.

Table 2 also specifies an averaging time of 30 minutes for radiation in the PEACESAT transmission band of 2030 MHz, where averaging time is defined as :

> " The appropriate time period over which exposure is averaged for the purpose of determining compliance with an MPE."

That is : in cases where the radiation level varies over time, the 30 minute average figure is compared with the MPE to determine compliance.

This report analyses the effect of a continuous power level radiated by the PEACESAT Network Hub antenna, and no time-averaging is involved.

3.2 Radiation calculation methods

Radiation levels around the PEACESAT Network Hub station are calculated using the following standard procedures for assessing the radiation levels produced by large-aperture antennas.

The important regions of radiation associated with large-aperture antennas are the radiating near-field (Fresnel) region and the far-field (Fraunhofer) region.

The radiating near-field is that portion of the radiation field lying approximately between a wavelength λ from the antenna and a distance given by twice the square of the diameter of the antenna divided by the wavelength (that is, from λ to $2D^2/\lambda$). This is the region in which the beam is formed, and both the antenna gain and beamwidth vary with the type of antenna illumination and the distance from the antenna.

Beyond the radiating near-field region is the far-field region where the secondary pattern characteristics are well defined. At the far-field distance ($2D^2/\lambda$), the on-axis radiation level is given by :

$$S = \frac{\pi P}{16 D^2} \qquad (1)$$

where :
S = power flux density (W/m^2)
P = power transmitted (W)
D = diameter of the antenna (m).

The procedure used for calculating the maximum radiation level produced by a large-aperture antenna is :

(a) calculate the power flux density at the far-field distance (equation 1 above)
(b) evaluate the maximum gain correction factor (the factor by which the maximum near-field radiation exceeds the level at the far-field distance)
(c) multiply values (a) and (b) to produce the maximum near-field radiation level.

This procedure is derived from :

> Antenna Power Densities in the Fresnel Region
> R. W. Bickmore and R. C. Hansen
> Proceedings of the Institute of Radio Engineers, December 1959.

A copy is provided in Annex 2 of this report.

The method of Bickmore and Hansen has been used for the following reasons :

- it is a seminal work on this topic, and has been referenced widely in subsequent published work

- the authors (in particular R. C. Hansen) are acknowledged experts in the field of antenna design

- the method of Bickmore and Hansen has been accepted in radiation calculations forming part of previous Environmental Assessments

- the method of Bickmore and Hansen forms the basis of the current New Zealand and Australian standards on the prediction and measurement of radio frequency radiation from large-aperture antennas.

4. Radiation levels around the PEACESAT Network Hub antenna

4.1 Maximum radiation level

A satellite earth station antenna has a carefully optimised radiation pattern, with a very high percentage of the radiated power contained in the main beam of the antenna, and very low levels of spillover and scattered radiation in other directions. The maximum radiated power level exists at the centre of the transmit beam.

The antenna system would be incapable of achieving high transmission efficiency or performing its intended functions if significant levels of radiation existed outside of the main beam.

For these reasons, when considering the radiation levels around satellite communications antennas, it is usual to approach the problem by first assessing the worst-case figure: that is, the *radiation level at the centre of the main beam*. If the radiation level at the centre of the main beam complies with the relevant standards for human exposure, then the radiation level at other points around the antenna is known to be below the permissible level.

Following the calculation method of Bickmore and Hansen (see Annex 2) for a 10m antenna with uniform illumination and a 200W input power level, the maximum near-field power density in the main beam of the antenna is :

Maximum near-field power density factor (Figure 3 of Annex 2) : 26

Far-field power density (Equation 7 of Annex 2) : $\pi P/(16D^2)$

where : P = power transmitted (W)
D = diameter of the antenna (m).

Therefore :

Maximum power density on the main beam of the antenna (near-field) :

$$\frac{26 \cdot \pi \cdot 200}{16 \cdot 10^2}$$

$$= 10.2 \text{ W/m}^2$$

$$= 1.02 \text{ mW/cm}^2$$

Conclusions :

Maximum power density in the main beam of the antenna : 1.02 mW/cm^2

In the main beam of the Network Hub antenna,
the peak radiation level is less than the standard specified value.

4.2 Radiation levels outside of the main beam

A satellite earth station antenna has a carefully optimised radiation pattern, with a very high percentage of the radiated power contained in the main beam of the antenna, and very low levels of spillover and scattered radiation in other directions. The technical references and published literature provide detailed assessments of the radiation levels in the main beam of the antenna, but contain little information on the radiation in other directions since radiation in those directions is very low.

In the case of antennas used for deep-space projects, where the transmitter powers are exceptionally high and radiation hazards do exist in the main beam of the antenna, some general predictions and measurements of radiation levels have been made.

A typical example is the 64m antenna system operated by the Jet Propulsion Laboratory at Goldstone, California, which is equipped with a 400 kW transmitter system : that is, a transmit power 2,000 times greater than the proposed PEACESAT Network Hub station. An assessment of the radiation levels around that antenna was published in 1974 : a copy is provided in Annex 3

Certain key conclusions may be drawn from the report :

(a) The measured results agree with those predicted by the analysis method of Bickmore and Hansen (second paragraph on page 59 in Annex 3). The same analysis method is used in the present analysis of the radiation levels in the centre of the beam of the PEACESAT Network Hub antenna.

(b) The measured results confirm that most of the radiated power is contained in a tubular beam (third paragraph on page 59 in Annex 3).

(c) The measured results confirm that scattering and spillover around the antenna result in power levels much lower than those in the main beam (Table IV on page 60 in Annex 3).

(d) The measured results show that radiation levels behind the antenna are insignificant, and are safe for indefinite exposure (Section 6 on page 58 and also Table IV on page 60 in Annex 3).

In view of the fact that a school and play-area are located behind the proposed location of the PEACESAT Network Hub antenna, it is important to emphasise this aspect of the findings of the Goldstone investigation :

Even though the Goldstone transmitter is 2,000 times more powerful than that of the PEACESAT Network Hub, the radiation levels behind the Goldstone antenna are considered safe for indefinite exposure.

5. Findings

Based on the information given above :

(a) In the main beam of the antenna where the highest radiation levels exist, the radiation levels produced by the PEACESAT Network Hub antenna system meet the relevant US standards and are classified as safe for continuous exposure.

(b) The radiation levels behind the antenna (in the direction of the school and play area) are insignificantly small, and are classified as safe for continuous exposure.

End of Report

3 Annexes follow.

Annex 1 : IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz. IEE C95.1-1991

IEEE C95.1-1991
(Revision of
ANSI C95.1-1982)

IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz

Sponsor

**IEEE Standards Coordinating Committee 28
on Non-Ionizing Radiation Hazards**

Approved September 26, 1991

IEEE Standards Board

Abstract: IEEE C95.1-1991 gives recommendations to prevent harmful effects in human beings exposed to electromagnetic fields in the frequency range from 3 kHz to 300 GHz. The recommendations are intended to apply to exposures in controlled, as well as uncontrolled, environments. They are not intended to apply to the purposeful exposure of patients by or under the direction of practitioners of the healing arts. The recommendations at 300 GHz are compatible with existing recommendations of safe-exposure in the infrared frequency range (starting at 300 GHz). A rationale that describes how the recommendations were arrived at, and the factors taken into account in formulating them, is included.

Keywords: Electromagnetic fields, exposure limits, microwave, MPE, nonionizing radiation, radiation protection, RFPG, radiofrequency, safety levels.

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Foreword

(This Foreword is not a part of IEEE C95.1-1991, IEEE Standard for Safety Levels With Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz.)

In 1960, the American Standards Association approved the initiation of the Radiation Hazards Standards project under the co-sponsorship of the Department of the Navy and the Institute of Electrical and Electronics Engineers.

Prior to 1988, C95 standards were developed by an accredited standards committee C95, and submitted to ANSI for approval and issuance as ANSI C95 standards. Between 1988 and 1990, the committee was converted to Standards Coordinating Committee 28 under the sponsorship of the IEEE Standards Board. In accordance with policies of the IEEE, C95 standards will be issued and developed as IEEE standards, as well as being submitted to ANSI for recognition.

The present scope of IEEE SCC28 is:

"Development of standards for the safe use of electromagnetic energy in the range of 0 Hz to 300 GHz relative to the potential hazards of exposure of man, volatile materials, and explosive devices to such energy. It is not intended to include infrared, visible, ultraviolet, or ionizing radiation. The committee will coordinate with other committees whose scopes are contiguous with SCC28."

The IEEE Standards Coordinating Committee 28 is responsible for the present revision. There are five subcommittees concerned with:

I Techniques, Procedures, and Instrumentation
II Terminology and Units of Measurements
III Safety Levels With Respect to Human Exposure, 0-3 kHz
IV Safety Levels With Respect to Human Exposure, 3 kHz-300 GHz
V Safety Levels With Respect to Electro-Explosive Devices

Three standards, one guide and two recommended practices have been issued. Current versions are:

IEEE C95.1-1991, IEEE Standard for Safety Levels With Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 100 GHz. (Replaces ANSI C95.1-1982).

ANSI C95.2-1981, American National Standard Radio Frequency Radiation Hazard Warning Symbol; Reaffirmed in 1989.

ANSI C95.3-1973, IEEE Standard Techniques and Instrumentation for the Measurement of Potentially Hazardous Electromagnetic Radiation at Microwave Frequencies. Reaffirmed in 1979.

IEEE C95.3-1991, IEEE Standard Recommended Practice for the Measurement of Potentially Hazardous Electromagnetic Fields—RF and Microwave. (Replaces ANSI C95.3-1973 and ANSI C95.3-1981.)

ANSI C95.4-1978, American National Standard Safety Guide for the Prevention of Radio-Frequency Radiation Hazards in the Use of Electric Blasting Caps.

ANSI C95.5-1981, American National Standard Recommended Practice for the Measurement of Hazardous Electromagnetic Fields—RF and Microwave.

Changes in the latest revision include an expanded frequency range, limits on induced body current to prevent radio-frequency (RF) shock or burn, a relaxation of limits on exposure to magnetic fields at low frequencies, and exposure limits and averaging time at high frequencies that are compatible at 300 GHz with existing infrared maximum-permissible exposure (MPE) limits. Important improvements in rules for valid measurement of electromagnetic fields have been introduced, and expanded rules for relaxing the exposure limits for the case of partial body exposure have been developed.

Also, a distinction is made between controlled and uncontrolled environments relative to safe exposure limits.

This standard prescribes MPEs to prevent biological injury from exposure to electromagnetic radiation. Revisions of the original version of this standard (ANSI C95.1-1966) were made in 1974 and major revisions of ANSI C95.1-1974 were made in 1982 to take into account the significant expansion of the data base, improvements in dosimetry, and the increasing number of people in the general population exposed to RF fields. The changes in the standard included a wider frequency coverage, frequency dependence resulting from the recognition of whole-body resonance and incorporation of dosimetry. In addition to those changes, the present standard also includes a distinction between controlled and uncontrolled environments and guidelines for partial-body and near-field exposures. Exposure limits in the uncontrolled environment are lower than in a controlled environment under certain conditions, such as resonance, or when exposure is complicated by associated hazards like RF shock or burn.

This standard contains a detailed discussion of both the rationale and the limitations of the recommended guidelines based on the present data base.

This standard was prepared by the Subcommittee IV on Safety Levels and/or Tolerances with Respect to Personnel, of IEEE Standards Coordinating Committee 28, and had the following membership at the time this standard was prepared:

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1. Scope and Purpose

Recommendations are made to prevent harmful effects in human beings exposed to electromagnetic fields in the frequency range from 3 kHz to 300 GHz. These recommendations are intended to apply to exposures in controlled, as well as uncontrolled, environments. These recommendations are not intended to apply to the purposeful exposure of patients by or under the direction of practitioners of the healing arts. The recommendations at 300 GHz are compatible with existing recommendations on safe exposure in the infrared frequency range (starting at 300 GHz). See ANSI Z136.1-1986 [B2].

2. Definitions and Glossary of Terms

average (temporal) power (P_{avg}). The time-averaged rate of energy transfer.

$$P_{avg} = \frac{1}{t_2 - t_1}\int_{t_1}^{t_2} P(t)dt$$

averaging time (T_{avg}). The appropriate time period over which exposure is averaged for purposes of determining compliance with an MPE. For exposure durations less than the averaging time, the maximum exposure, *MPE'*, in any time interval equal to the averaging time is found from

$$MPE' = MPE\left(\frac{T_{avg}}{T_{exp}}\right)$$

where T_{exp} is the exposure duration in that interval expressed in the same units as T_{avg}. Restrictions on peak power density limit T_{exp}.

continuous exposure. Exposure for durations exceeding the corresponding averaging time. Exposure for less than the averaging time is called short-term exposure.

controlled environment. Controlled environments are locations where there is exposure that may be incurred by persons who are aware of the potential for exposure as a concomitant of employment, by other cognizant persons, or as the incidental result of transient passage through areas where analysis shows the exposure levels may be above those shown in Table 2 but do not exceed those in Table 1, and where the induced currents may exceed the values in Table 2, Part B, but do not exceed the values in Table 1, Part B.[1]

duty factor. The ratio of pulse duration to the pulse period of a periodic pulse train. A duty factor of 1.0 corresponds to continuous-wave (CW) operation.

electric field strength (E). A field vector quantity that represents the force (*F*) on a positive test charge (*q*) at a point divided by the charge.

---

[1] The means for the identification of these areas is at the discretion of the operator of a source.

$$E = \frac{F}{q}$$

Electric field strength is expressed in units of volts per meter (V/m).

energy density (electromagnetic field). The electromagnetic energy contained in an infinitesimal volume divided by that volume.

exposure. Exposure occurs whenever and wherever a person is subjected to electric, magnetic or electromagnetic fields or to contact currents other than those originating from physiological processes in the body and other natural phenomena.

exposure, partial-body. Partial-body exposure results when RF fields are substantially nonuniform over the body. Fields that are nonuniform over volumes comparable to the human body may occur due to highly directional sources, standing-waves, re-radiating sources or in the near field. *See* **RF "hot spot"**.

far field region. *That region of the field of an antenna where the* angular field distribution is essentially independent of the distance from the antenna. In this region (also called the free space region), the field has a predominantly plane-wave character, i.e., locally uniform distributions of electric field strength and magnetic field strength in planes transverse to the direction of propagation.

hertz (Hz). The unit for expressing frequency, f. One hertz equals one cycle per second.

magnetic field strength (H). A field vector that is equal to the magnetic flux density divided by the permeability of the medium. Magnetic field strength is expressed in units of amperes per meter (A/m).

magnetic flux density (B). A field vector quantity that results in a force (*F*) that acts on a moving charge or charges. The vector product of the velocity (*v*) at which an infinitesimal unit test charge, q, is moving with *B*, is the force that acts on the test charge divided by *q*.

$$\frac{F}{q} = (v \times B)$$

Magnetic flux density is expressed in units of tesla (T). One T is equal to 10^4 gauss (G).

maximum permissible exposure (MPE). The rms and peak electric and magnetic field strengths, their squares, or the plane-wave equivalent power densities associated with these fields and the induced and contact currents to which a person may be exposed without harmful effect and with an acceptable safety factor.

mixed frequency fields. The superposition of two or more electromagnetic fields of differing frequency.

near-field region. A region generally in proximity to an antenna or other radiating structure, in which the electric and magnetic fields do not have a substantially plane-wave character, but vary considerably from point to point. The near-field region is further subdivided into the reactive near-field region, which is closest to the radiating structure and that contains most or nearly all of the stored energy, and the radiating near-field region where the radiation field predominates over the reactive field, but lacks substantial plane-wave character and is complicated in structure.

NOTE: For most antennas, the outer boundary of the reactive near field region is commonly taken to exist at a distance of one-half wavelength from the antenna surface.

penetration depth. For a plane electromagnetic wave incident on the boundary of a medium, the distance from the boundary into the medium along the direction of propagation in the medium, at which the field strengths of the wave have been reduced to 1/e (36.8%) of the boundary values.

power density, average (temporal). The instantaneous power density integrated over a source repetition period.

power density (S). Power per unit area normal to the direction of propagation, usually expressed in units of watts per square meter (W/m^2) or, for convenience, units such as milliwatts per square centimeter (mW/cm^2) or microwatts per square centimeter (μW/cm^2). For plane waves, power density, electric field strength (E) and magnetic field strength (H) are related by the impedance of free space, i.e., 377 ohms. In particular,

$$S = \frac{E^2}{377} = 377\, H^2$$

where E and H are expressed in units of V/m and A/m, respectively, and S in units of W/m^2. Although many survey instruments indicate power density units, the actual quantities measured are E or E^2 or H or H^2.

power density, peak. The maximum instantaneous power density occurring when power is transmitted.

power density, plane-wave equivalent. A commonly-used term associated with any electromagnetic wave, equal in magnitude to the power density of a plane wave having the same electric (E) or magnetic (H) field strength.

pulse modulated field. An electromagnetic field produced by the amplitude modulation of a continuous wave carrier by one or more pulses.

radio frequency (RF). Although the RF spectrum is formally defined in terms of frequency as extending from 0 to 3000 GHz, for purposes of this standard, the frequency range of interest is 3 kHz to 300 GHz.

re-radiated field. An electromagnetic field resulting from currents induced in a secondary, predominantly conducting, object by electromagnetic waves incident on that object from one or more primary radiating structures or antennas. Re-radiated fields are sometimes called "reflected" or more correctly "scattered fields." The scattering object is sometimes called a "re-radiator" or "secondary radiator". *See* **scattered radiation.**

RF "hot spot". A highly localized area of relatively more intense radio-frequency radiation that manifests itself in two principal ways:

(1) The presence of intense electric or magnetic fields immediately adjacent to conductive objects that are immersed in lower intensity ambient fields (often referred to as re-radiation), and

(2) Localized areas, not necessarily immediately close to conductive objects, in which there exists a concentration of radio-frequency fields caused by reflections and/or narrow beams produced by high-gain radiating antennas or other highly directional sources. In both cases, the fields are characterized by very rapid changes in field strength with distance. RF hot spots are normally associated with very nonuniform exposure of the body (partial body exposure). This is *not* to be confused with an actual thermal hot spot within the absorbing body.

root-mean-square (rms). The effective value, or the value associated with joule heating, of a periodic electromagnetic wave. The rms value is obtained by taking the square root of the mean of the squared value of a function.

scattered radiation. An electromagnetic field resulting from currents induced in a secondary, conducting or dielectric object by electromagnetic waves incident on that object from one or more primary sources.

short-term exposure. Exposure for durations less than the corresponding averaging time.

specific absorption (SA). The quotient of the incremental energy (dW) absorbed by (dissipated in) an incremental mass (dm) contained in a volume (dV) of a given density (ρ).

$$SA = \frac{dW}{dm} = \frac{dW}{\rho dV}$$

The specific absorption is expressed in units of joules per kilogram (J/kg).

specific absorption rate (SAR). The time derivative of the incremental energy (dW) absorbed by (dissipated in) an incremental mass (dm) contained in a volume element (dV) of given density (ρ).

$$SAR = \frac{d}{dt}\left(\frac{dW}{dm}\right) = \frac{d}{dt}\left(\frac{dW}{\rho dV}\right)$$

SAR is expressed in units of watts per kilogram (W/kg).

uncontrolled environment. Uncontrolled environments are locations where there is the exposure of individuals who have no knowledge or control of their exposure. The exposures may occur in living quarters or workplaces where there are no expectations that the exposure levels may exceed those shown in Table 2 and where the induced currents do not exceed those in Table 2, Part B. Transitory exposures are treated in 4.1.1.

wavelength (λ). The wavelength (λ) of an electromagnetic wave is related to the frequency (f) and velocity (v) by the expression $v = f\lambda$. In free space the velocity of an electromagnetic wave is equal to the speed of light, i.e., approximately 3×10^8 m/s.

3. References

This standard shall be used in conjunction with the following documents:

[1] IEEE C95.3-1991, IEEE Recommended Practice for the Measurement of Potentially Hazardous Electromagnetic Fields—RF and Microwave.[2]

[2] IEEE Std 100-1988, IEEE Standard Dictionary of Electrical and Electronics Terms (ANSI).

4. Recommendations

4.1 Maximum Permissible Exposure (MPE)

4.1.1 MPE in Controlled Environments. For human exposure in controlled environments to electromagnetic energy at radio frequencies from 3 kHz to 300 GHz, the MPE, in terms of rms electric (E) and magnetic (H) field strengths, the equivalent plane-wave free-

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[2] IEEE publications are available from the Institute of Electrical and Electronics Engineers, Inc., Service Center, 445 Hoes Lane, Piscataway, NJ 08854-1331, U.S.A.

yspace power densities (S) and the induced currents (I) in the body that can be associated with exposure to such fields or contact with objects exposed to such fields, is given in Table 1 as a function of frequency. Exposure associated with a controlled environment includes: exposure that may be incurred by persons who are aware of the potential for exposure as a concomitant of employment, exposure of other cognizant individuals, or exposure that is the incidental result of passage through areas where analysis shows the exposure levels may be above those shown in Table 2, but do not exceed those in Table 1, and where the induced currents may exceed the values in Table 2, Part B, but do not exceed the values in Table 1, Part B.[3]

Table 1
Maximum Permissible Exposure for Controlled Environments

Part A
Electromagnetic Fields*

1 Frequency Range (MHz)	2 Electric Field Strength (E) (V/m)	3 Magnetic Field Strength (H) (A/m)	4 Power Density (S) E-Field, H-Field (mW/cm²)	5 Averaging Time $\|E\|^2$, $\|H\|^2$ or S (minutes)
0.003 - 0.1	614	163	(100, 1 000 000)†	6
0.1 - 3.0	614	$16.3/f$	$(100, 10\,000/f^2)$†	6
3 - 30	$1842/f$	$16.3/f$	$(900/f^2, 10\,000/f^2)$†	6
30 - 100	61.4	$16.3/f$	$(1.0, 10\,000/f^2)$†	6
100 - 300	61.4	0.163	1.0	6
300 - 3 000			$f/300$	6
3 000 - 15 000			10	6
15 000 - 300 000			10	$616\,000/f^{1.2}$

Part B
Induced and Contact Radiofrequency Currents‡

Frequency Range	Maximum Current (mA) Through both feet	 Through each foot	Contact
0.003 - 0.1 MHz	$2000/f$	$1000/f$	$1000/f$
0.1 - 100 MHz	200	100	100

f=frequency in MHz

*The exposure values in terms of electric and magnetic field strengths are the values obtained by spatially averaging values over an area equivalent to the vertical cross-section of the human body (projected area).

†These plane-wave equivalent power density values, although not appropriate for near-field conditions, are commonly used as a convenient comparison with MPEs at higher frequencies and are displayed on some instruments in use.

‡It should be noted that the current limits given above may not adequately protect against startle reactions and burns caused by transient discharges when contacting an energized object. See text for additional comment.

(a) In a controlled environment, access should be restricted to limit the rms RF body current (averaged over any 1 second) and potential for RF shock or burn as follows:

  (i) For freestanding individuals (no contact with metallic objects), RF current induced in the human body, as measured through each foot, should not exceed the following values:

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[3] The means for the identification of these areas is at the discretion of the operator of a source.

(i) For freestanding individuals (no contact with metallic bodies), RF current induced in the human body, as measured through each foot, should not exceed the following values:

$I = 450\,f$ mA for $(0.003 < f \leq 0.1$ MHz)
$I = 45$ mA for $(0.1 < f < 100$ MHz)

(ii) For conditions of possible contact with metallic bodies, maximum RF current through an impedance equivalent to that of the human body for conditions of grasping contact [see 4.3(1)], as measured with a contact current meter, shall not exceed the following values:

$I = 450f$ mA for $(0.003 < f \leq 0.1$ MHz)
$I = 45$ mA for $(0.1 < f < 100$ MHz)

(b) The MPEs refer to exposure values obtained by spatially averaging over an area equivalent to the vertical cross-section of the human body (projected area). In the case of partial-body exposure, the limits can be relaxed, as described in 4.4. In nonuniform fields, spatial peak values of field strengths may exceed the MPEs if the spatial average value remains within the specified limits. The MPEs may also be relaxed by reference to SAR limits in 4.2.1 by appropriate calculation or measurement.

(c) The MPE refers to values averaged over any 6-min to 30-min period for frequencies up to 3 000 MHz, and over shorter periods for higher frequencies, down to 10 s at 300 GHz, as indicated in Table 2.

(d) For near-field exposures at frequencies less than 300 MHz, the applicable MPE is in terms of rms electric and magnetic field strength, as given in Table 2, columns 2 and 3. For convenience, the MPE may be expressed as equivalent plane-wave power density, given in Table 2, column 4.

(e) For mixed or broadband fields at a number of frequencies for which there are different values of the MPE, the fraction of the MPE [in terms of E^2, H^2, or power density (S)] incurred within each frequency interval should be determined, and the sum of all such fractions should not exceed unity. See Appendix C for an example of how this is accomplished.

In a similar manner, for mixed or broadband induced currents at a number of frequencies for which there are different values of the MPE, the fraction of the induced current limits (in terms of I^2) incurred within each frequency interval should be determined, and the sum of all such fractions should not exceed unity.

(f) For exposures to pulsed radio frequency fields in the range of 0.1 to 300 000 MHz, the peak (temporal) value of the MPE, in terms of E field, is 100 kV/m.

(g) For exposures to pulsed radio frequency fields of pulse durations less than 100 ms, and frequencies in the range of 0.1 to 300 000 MHz, the MPE, in terms of peak power density for a single pulse, is given by the MPE (Table 2, E-field equivalent power density), multiplied by the averaging time in seconds, and divided by 5 times the pulse width in seconds. That is:

$$\text{Peak MPE} = \frac{\text{MPE} \times \text{Avg Time (seconds)}}{5 \times \text{Pulsewidth (seconds)}}$$

A maximum of five such pulses, with a pulse-repletion period of at least 100 ms, is permitted during any period equal to the averaging time [see 4.1.2(c)]. If there are more than five pulses during any period equal to the averaging time, or if the pulse durations are greater than 100 ms, normal averaging-time calculations apply, except that during any 100 ms period, the energy density is limited per the above formula, viz

$$\Sigma \ Peak\ MPE \times Pulsewidth\ (seconds) = \frac{MPE \times Avg.\ Time\ (seconds)}{5}$$

4.2 Exclusions

4.2.1 Controlled Environment. At frequencies between 100 kHz and 6 GHz, the MPE in controlled environments for electromagnetic field strengths may be exceeded if:

(a) the exposure conditions can be shown by appropriate techniques to produce SARs below 0.4 W/kg as averaged over the whole-body and spatial peak SAR, not exceeding 8 W/kg as averaged over any 1 g of tissue (defined as a tissue volume in the shape of a cube), except for the hands, wrists, feet and ankles where the spatial peak SAR shall not exceed 20 W/kg, as averaged over any 10 g of tissue (defined as a tissue volume in the shape of a cube), and

(b) the induced currents in the body conform with the MPE in Table 1, Part B.

The SARs are averaged over any 6-min interval. Above 6 GHz, the relaxation of the MPE under partial body exposure conditions is permitted (see 4.4).

At frequencies between 0.003 and 0.1 MHz the SAR exclusion rule, stated above, does not apply. However, the MPE in controlled environments can still be exceeded if it can be shown that the peak rms current density, as averaged over any 1 cm^2 area of tissue and 1 s does not exceed $35f$ mA/cm^2 where f is the frequency in MHz.

4.2.1.1 Low-Power Devices: Controlled Environment. This exclusion, consistent with the provision of 4.2.1, pertains to devices that emit RF energy under the control of an aware user. This exclusion addresses exposure of the user. For such devices, the exposure of other persons in the immediate vicinity of the user will meet the exclusion criterion for the uncontrolled environment. (See 4.2.2.)

At frequencies between 100 kHz and 450 MHz, the MPE may be exceeded if the radiated power is 7 W or less.

At frequencies between 450 and 1 500 MHz, the MPE may be exceeded if the radiated power is $7(450/f)$ W or less where f is the frequency in MHz.

This exclusion does not apply to devices with the radiating structure maintained within 2.5 cm of the body.

4.2.2 Uncontrolled Environments At frequencies between 100 kHz and 6 GHz, the MPE in uncontrolled environments for electromagnetic field strengths may be exceeded if :

(a) The exposure conditions can be shown by appropriate techniques to produce SARs below 0.08 W/kg, as averaged over the whole body, and spatial peak SAR values not exceeding 1.6 W/kg, as averaged over any 1 g of tissue (defined as a tissue volume in the shape of a cube), except for the hands, wrists, feet and ankles where the spatial peak SAR shall not exceed 4 W/kg, as averaged over any 10 g of tissue (defined as a tissue volume in the shape of a cube), and

(b) The induced currents in the body conform with the MPE in Table 2, Part B.

The averaging time for SARs is as indicated in Table 2. Above 6 GHz, the relaxation of the MPE under partial body exposure conditions is permitted (See 4.4).

At frequencies between 0.003 and 0.1 MHz, the SAR exclusion rule does not apply. However, the MPE in uncontrolled environments can still be exceeded if it can be shown that the peak rms current density, as averaged over any 1 cm^2 area of tissue and 1 s, does not exceed $15.7f$ mA/cm^2, where f is the frequency in MHz.

4.2.2.1 Low-Power Devices: Uncontrolled Environment. This exclusion, consistent with the provisions of 4.2.2, pertains to devices that emit RF energy without control or knowledge of the user.

At frequencies between 100 kHz and 450 MHz, the MPE may be exceeded if the radiated power is 1.4 W or less.

At frequencies between 450 and 1 500 MHz, the MPE may be exceeded if the radiated power is 1.4(450/*f*) W or less where *f* is the frequency in MHz.

This exclusion does not apply to devices with the radiating structure maintained within 2.5 cm of the body.

4.3 Measurements

(1) For both pulsed and non-pulsed fields at frequencies below 300 MHz, the power density, the square of the field strengths and the SARs, as applicable, are averaged over any 6-min or 30-min period. The time-averaged values should not exceed those given in Table 1, Part A and Table 2, Part A, or the exclusions in 4.2. Note that the averaging time is a function of frequency above 15 GHz for a controlled environment and is a function of frequency between 1.34 and 3.0 MHz, and above 3 GHz for an uncontrolled environment. (The averaging time is also a function of frequency between 30 and 300 MHz for exposure to magnetic fields.)

In the case of induced currents, where RF shock or burn may be possible because of access to conductive structures, a 6-min or 30-min averaging time is no longer valid, and, for purposes of determining compliance with the recommended limits discussed in 4.1(a), the currents should be measured with an instrument having an averaging time no greater than 1 s. Induced body currents should be measured by determining the RF current flowing to ground through the feet of the individual. Contact currents should be measured by determining the RF current through the hand in contact with the ungrounded surface. The use of instrumentation which can simulate the impedance of the human body at the frequency of the current may be used to assess the maximum expected current that would flow if a person were to come into contact with an energized object. [B10] (See Fig A6.)

(2) Generally, for frequencies less than 300 MHz, both the electric and magnetic field strengths shall be determined. For frequencies equal to or less than 30 MHz, this can *only* be accomplished by independent measurement of both the electric and magnetic field strengths; for frequencies between 30 and 300 MHz, it may be possible through analysis to show that measurement of only one of the two fields, not both, is sufficient for determining compliance with the MPE. For frequencies above 300 MHz, only one field component need be measured (generally E).

(3) Measurements to determine adherence to the recommended MPE shall be made (with appropriate instruments) at distances 20 cm or greater from any object. See IEEE C95.3-1991 [1].

(4) Evaluation of induced RF currents will generally require a measurement, unless the exposure situation is very simple. Most exposure conditions are complex and induced currents are not amenable to analysis.

Induced currents may be measured by one or more of the following three methods:

(a) RF thermocouple-type ammeter measurements—These devices, employing thermocouple elements for the measurement of RF currents, offer true rms detection and may be inserted directly in series with the conduction path for the current flow into the body, or exiting the body. While simple in design and use, thermocouple type ammeters have very limited tolerance for overload currents that can destroy the thermocouple element.

(b) Voltage measurements—The induced current may also be determined by measuring the RF voltage developed across a noninductive resistor that is connected in series with the current path, as in (a). Either a broadband type of voltmeter, suitable for the frequency of the current, or a narrowband, tunable voltmeter in the form of a tuned receiver may be used to determine the voltage. The current is determined from the relation:

$I=V/R$

where

I=induced RF current (A)
V=RF voltage drop across the resistor (V)
R= impedance of the resistor (Ω)

Various forms of circuits making use of this basic method may be used for purposes of measuring the magnitude of the RF current flowing from the body to ground, including the use of parallel plate electrodes connected with a resistive element upon which an individual may stand. Commercial instruments with a flat frequency response between 3 kHz and 100 MHz are beginning to become available for this purpose, as are instruments with shoe-insertable sensors for personnel mobility.

(c) RF current transformer (current probe) measurements—RF current transformers are of the clamp-on type or the fixed window type. Either type may be used to measure the RF current flowing in a conductor. The current transformer consists of a toroidally wound transformer in which the current carrying conductor is typically placed in the window of the device and acts as the primary for the transformer. Current transformers may be used to determine the current flowing in a parallel plate electrode arrangement, as described in (b), or in conjunction with a conductive rod probe assembly to determine contact currents that might be experienced by a person touching an object exposed to RF fields. Generally, the current transformer requires some form of instrument to detect the output voltage from the transformer and subsequently, the current that flows through the window of the transformer.

In each of the three methods, it may be possible to insert an impedance equivalent to the human body at the frequency of interest that would permit a measurement of the induced current, without the current actually flowing in the body until after the evaluation of its magnitude.

In any of these methods, caution shall be exercised in the selection of the exact device for the measurement, since its frequency dependence will affect the measurement result. For example, thermocouple detectors used in some RF ammeters exhibit variations in their response to different frequencies (commonly becoming less efficient at higher frequencies), and current transformer performance characteristics are a compromise between sensitivity and bandwidth.

The meters, associated circuitry and methodology shall be appropriate for the particular frequency and the meters shall have an averaging time no greater than 1 second. When it is desired to make an indirect measurement of the current that might actually flow in a human, use of an antenna or phantom model may prove helpful. In this case, the phantom dipole moment, surface area, and contact impedance should be equivalent to those of the simulated subject.

4.4 Relaxation of Power Density Limits for Partial Body Exposures. The following relaxation of power density limits is allowed for exposure of all parts of the body *except* the eyes and the testes.

Compliance with the MPE of Tables 1 and 2 is determined from spatial averages of power density or the mean squared electric and magnetic field strengths over an area equivalent to the vertical cross-section of the human body (projected area) at a distance no closer than 20 cm from any object. For exposures in controlled environments, the peak value of the mean squared field strength should not exceed 20 times the square of the allowed spatially averaged values (Table 1) at frequencies below 300 MHz, and should not exceed the equivalent power density of 20 mW/cm^2 at frequencies between 300 MHz and 6 GHz, 20 $(f/6)^{1/4}$ mW/cm^2 at frequencies between 6 and 96 GHz (f is in GHz), and 40 mW/cm^2 at frequencies above 96 GHz. Similarly, for exposures in uncontrolled environments, the peak value of the mean squared field strengths should not exceed 20 times the square of the allowed spatially averaged values (Table 2) at frequencies below 300 MHz, or the equivalent power density of 4 mW/cm^2 for f between 300 MHz and 6 GHz, $(f/1.5)$ mW/cm^2 for frequencies between 6 GHz and 30 GHz (f is in GHz), and 20 mW/cm^2 at frequencies above 30 GHz. At frequencies below 300 MHz, the equivalent maximum rms field strengths should not exceed 4.47[4] times the maximum allowed spatially averaged values of E and H shown in Tables 1 and 2 (see 6.10). The relaxation for partial-body exposure is summarized in Table 3.

Table 3
Relaxations for Partial Body Exposures

	Frequency in GHz	Peak Value of Mean Squared Field	Equivalent Power Density in mW/cm^2
Controlled Environment	$0.0001 \leq f < 0.3$	$<20\overline{E}^2$ or $20\overline{H}^2$[*]	
	$0.3 < f \leq 6$		<20
	$6 < f \leq 96$		$< 20\ (f/6)^{1/4}$[‡]
	$96 < f \leq 300$		40
Uncontrolled Environment	$0.0001 \leq f < 0.3$	$<20\overline{E}^2$ or $20\overline{H}^2$[†]	
	$0.3 < f \leq 6$		4
	$6 < f \leq 30$		$f/1.5$[‡]
	$30 < f \leq 300$		20

[*] $\overline{E}$ and $\overline{H}$ are the spatially averaged values from Table 1.

[†] $\overline{E}$ and $\overline{H}$ are the spatially averaged values from Table 2.

[‡] f in GHz

5. Explanation

Exposure to electromagnetic fields in the resonance frequency range under consideration is but one of several sources of energy input to the human body. The MPE in a controlled environment results in energy deposition, averaged over the entire body mass for

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[4] $(\sqrt{20})$

any 6-min period of about 144 J/kg or less. This is equivalent to an SAR of about 0.40 W/kg or less, as spatially and temporally averaged over the entire body mass.

Biological effects data that are applicable to humans for all possible combinations of frequency and modulation do not exist. Therefore, this standard has been based on the best available interpretations of the extant literature and is intended to prevent adverse effects on the functioning of the human body.

At low frequencies, the magnetic field limits have been relaxed relative to ANSI C95.1-1982 [B1]. An anatomically realistic model [B26] of a human being has been used to show that the new limits will ensure SARs less than one twentieth of those specified (i.e., 0.4 and 0.08 W/kg). This is still very conservative, but more realistic than the H-field limits in ANSI C95.1-1982 [B1].

The electric field limits at low frequencies in Table 1 are primarily dictated by the following two objectives:

(1) limiting induced currents in the ankles during free-field exposure, and
(2) lowering the probability of inducing large body currents when conducting objects are touched.

The limits on induced RF currents are based on two different considerations.

First, *in any environment*, currents are limited to a level that prevents RF burns due to excessively high current densities in small areas of tissue while the subject is free standing in high-strength fields and has contact with conductive objects in which induced currents are flowing. This level, taken from [B10, B49, B54] is 100 mA, if measured through one foot, and 200 mA if measured through both feet. A value of 100 mA is applicable to contact situations, similar to a grasping contact with the hand. These currents will not result in localized SARs in the extremities (e.g., ankles or wrists) that exceed 20 W/kg, but may be perceived if protective clothing, such as insulated gloves, is not worn.

In controlled environments, various mitigative measures can be taken to reduce the probability of hazardous conditions. Such measures may include the following:

(1) protective gloves or clothing,
(2) awareness programs so that individuals are alerted to the possible presence of induced currents in conductive objects, and
(3) specific work practices that lessen the probability of exposure.

Second, for frequencies between 0.003 and 0.1 MHz, the induced current in controlled environments is limited to reduce the probability of reactions caused by induced currents that exceed the perception threshold for grasping contact with energized objects [B10]. The perception threshold is frequency dependent below 0.1 MHz and the limiting current is given by

$$I = 1000f \text{ mA for } (0.003 < f \le 0.1 \text{ MHz})$$

In uncontrolled environments, individuals will, in general, not be aware of the presence of induced currents in various objects illuminated with RF fields. Inadvertent contact by an individual with such objects could lead to burns or startle reactions that, while not hazardous per se, could lead to an accident. To reduce the probability of such startle reactions[5], the contact current limit is based on laboratory data on perception of currents at different frequencies in humans [B10, B14]. These data indicate that perception thresholds, at any given frequency, depend on the type of contact made with the conducting object; touching contact generally results in lower current perception thresholds than grasping contact by a factor as great as ten times. Accordingly, the current limits in Table 2 are based on

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[5] This does not include the startle reaction associated with spark discharges.

but is below that in Table 1. Other exposure conditions include that of the radio amateur who voluntarily and knowledgeably operates in a controlled RF environment.

At frequencies below 3 MHz, the MPEs, in terms of magnetic fields, have been relaxed to more reasonably correspond to whole-body SAR limits. On the other hand, the MPEs, in terms of E field, continue to be capped below 3 MHz in order to limit the possibility of reactions (shocks or burns) at the surface of the body that might occur in E fields of high strength, especially under conditions of spatial and temporal field concentration.

In this standard, there are extensive modifications of the averaging time for determining permissible exposure. At the upper frequencies, these rules agree with soundly-based averaging times derived from optical considerations. At the lower frequencies, new rules on induced currents have been introduced to prevent RF shock or burn upon grasping contact with an object in an RF environment. These rules supplement the limits on E and H field exposure.

This standard is thus an extension of ANSI C95.1-1982 [B1], and incorporates many refinements that will serve to make the MPEs more useful in a greater variety of exposure situations. There remain areas, however, which the standard does not cover, e.g., the possible exposure of the body to transient spark-discharge phenomena upon touching a large conducting object in an RF environment. Future research may provide the data base from which quantitative rules for preventing adverse effects from such discharges can be derived.

Research on the effects of chronic exposure and speculations on the biological significance of nonthermal interactions have not yet resulted in any meaningful basis for alteration of the standard. It remains to be seen what future research may produce for consideration at the time of the next revision of this standard.

6.1 Recognition of Whole-Body Resonance. As is true of ANSI C95.1-1982 [B1], the MPE in this standard is based on recommendations of field strengths or of plane-wave-equivalent power densities of incident fields, but these limits are based on well established findings that the body, as a whole, exhibits frequency-dependent rates of absorbing electromagnetic energy [B6, B20, B21, B25]. Whole-body-averaged SARs approach maximal values when the long axis of a body is parallel to the E-field vector and is four tenths of a wavelength of the incident field. Maximal absorption occurs at a frequency near 70 MHz for Standard Man (height = 175 cm) and results in an approximate seven-fold increase of absorption relative to that in a 2450 MHz field [B22, B27]. In consideration of this dependency, recommended MPEs of field strength have been reduced across the range of frequencies in which human bodies from infants to large adults exhibit whole-body resonance. Above 6 GHz, the absorption is quasi-optical and body resonance considerations do not apply.

6.2 Incorporation of Dosimetry. Dosimetry is the fundamental process of measuring physical quantities of energy or substances that are imparted to an absorbing body [B40, B41]. In 1972, The National Council on Radiation Protection and Measurements (NCRP) convened Scientific Committee 39 to deliberate and recommend dosimetric quantities and units applicable to electromagnetic fields [B51]. In keeping with the NCRP recommendations, in 1982 the ANSI C95 Subcommittee IV adopted the unit-mass, time-averaged rate of electromagnetic energy absorption, as specified in units of watts per kilogram (W/kg). The quantity expressed by these units is termed the specific absorption rate (SAR).

Formally defined, the SAR is the time rate at which radio-frequency electromagnetic energy is imparted to an element of mass of a biological body. The SAR is applicable to any tissue or organ of interest (that is, can be applied to any macroscopic element of mass) or, as utilized in ANSI C95.1-1982 [B1], is expressed as a whole-body average. Ideally, anatomical distributions of SARs would be used explicitly to formulate a guide in recognition that absorption of electromagnetic energy from even the most uniform field can result in highly variable anatomical depositions of energy. It has been established [B31, B34, B35] through thermographic analyses of models of rats and man, and cadavers of rabbits, that spatial peak SAR values can exceed a whole-body average value by more than a factor of 20. Comparable findings have been reported [B27]. However, several factors preclude explicit use of peak SAR, such as the following:

(1) The availability of data on distributive SARs is limited, and
(2) SAR distributions are highly variable, since they depend on wavelength, polarization, and zone of the incident field, as well as on the mass and momentary geometry of the biological body.

The number of the possible SAR distributions approaches infinity. It is recognized, however, that a whole-body averaged SAR is the mean of a distribution, the high side of which is an envelope of electrical hotspots. These range from the mean value to the peak value, and when integrated with localized SARs of less than the mean value, are equal to the whole-body average. Moreover, for any given orientation of a given species in a given field, the correlation between the magnitude of a whole-body-averaged SAR and that of any lower or higher part-body SAR approaches unity. That is, if the power density of an incident electromagnetic field is increased, then the relative increase of the whole-body SAR will be directly proportional to the increase of any part-body SAR. Because of the invariable presence of electrical hotspots in the irradiated body and the inherent correlation between magnitudes of whole-body and part-body SARs, a biological effect induced by a localized SAR that is well above the whole-body average will be reflected to some extent by that average. The predictive utility of the correlation between part and whole has long served clinical and experimental medicine in which a whole-body, unit-mass dosimetry underlies therapeutic administration of pharmacological agents.

There are situations, however, where the implicit use of peak SAR provides a practical means for determining compliance with the MPEs. These situations correspond to exposure to nonuniform fields and partial body exposures. For example, the MPEs in Tables 1 and 2 are based on uniform field exposure and limit the whole-body averaged SAR, over the frequency range where SAR is meaningful (from approximately 3 MHz to 6 GHz for E-field exposure), to 0.4 W/kg for exposures in controlled environments and 0.08 W/kg for exposures in uncontrolled environments. As indicated above, implicit in these MPEs is the assumption that the spatial peak SARs may exceed the whole-body averaged values by a factor of more than 20 times. Since most exposures are not to uniform fields, a method has been derived, based on the demonstrated peak to whole-body averaged SAR ratio of 20, for equating nonuniform field exposure and partial body exposure to an equivalent uniform field exposure. This is used in this standard to allow relaxation of power density limits for partial body exposure, except in the case of the eyes and the testes.

The equivalent uniform field is obtained from a spatial average of the actual exposure field over a projected area equal to or greater than that of the exposed human. Measurements of the spatial average can be made using standard off-the-shelf instruments and devices such as data loggers. However, some situations may exist where the spatially-averaged value of a nonuniform field complies with Tables 1 or 2, but the peak value of the field corresponds to a partial-body exposure that could produce peak SARs exceeding 20 times the maximum whole-body average value. Simple, partial-body exposure analyses have indicated that peak SARs may be kept within desired limits if the peak mean squared field strengths do not exceed 20 times the maximum allowed spatial average values (Table 1) at frequencies below 300 MHz or the equivalent power density of 20 mW/cm^2 at frequencies between 300 MHz and 6 GHz, 20 $(f/6)^{1/4}$ mW/cm^2 for frequencies between 6 GHz and 96 GHz (f is in GHz) and 40 mW/cm^2 at frequencies above 96 GHz for exposures in controlled environments. Similarly, for exposures in uncontrolled environments, the peak value of the mean squared field strengths should not exceed 20 times the allowed spatial average values (Table 2) at frequencies below 300 MHz, nor the equivalent power density of 4 mW/cm^2 at frequencies between 300 MHz and 6 GHz, $(f/1.5)$ mW/cm^2 at frequencies between 6 and 30 GHz (f is in GHz), and 20 mW/cm^2 for frequencies above 30 GHz (see Table 3). These analyses are based on the following two models:

(1) exposure of a planar layer of tissue where the average SAR is calculated in 1 g of tissue in the shape of a cube below the surface;

(2) exposure of a triple layered (fat-muscle-bone) cylindrical arm model with the E field both perpendicular and parallel to the axis of the cylinder. (The results of the analyses where the E field is parallel to the axis of the cylinder are valid only where the arm model is equal or greater than one half wavelength.) The overall results of these analyses support the recommended peak exposure values as worst-case levels.

The planar model was based on an analysis described in [B42], and the cylindrical models were derived and discussed [B38, B41].

The rules for relaxation of exposure limits for partial-body exposure do not apply for exposure of the eyes and testes, but the SAR exclusion rules (see 4.2.1 and 4.2.2) can still be used to show conformance to the standard, despite localized power density limits above the specified whole-body average.

6.3 Data Base. The literature on RF bioeffects comprises many thousands of papers on all aspects of the subject presented in various scientific journals, reports, and symposia. From that large data base, the Literature Surveillance Working Group selected the initial list of 321 papers shown in Appendix A (listed in alphabetical order by first author) as representative of the current state of knowledge on the many RF bioeffects topics.

A prime criterion governing this first selection was peer review before publication. Presentations at recent scientific symposia or abstracts thereof were excluded from consideration (with few exceptions) under the assumption that either more complete, peer-reviewed accounts of such studies will appear subsequently or will not be published at all (perhaps because the study was flawed or the investigators were not able to reproduce their results). Other selection criteria were publication date, with greater emphasis given to more recent publications on each topic; possible significance of findings (positive or negative) to human health; and relevance to concerns expressed by citizen groups. Although many of the selections were published after the issuance of ANSI C95.1-1982 [B1], earlier papers regarded as seminal or of current interest were also included. The list was based on a cut-off publication date of December, 1985, with the proviso that later papers would be added if their findings could significantly affect the MPEs. Several papers published after 1985 on shock and burn from electromagnetic fields and on peak power, per se, were added to the list.

The Subcommittee IV Working Groups on Engineering Validation and Biological Validation then used the criteria described in 6.4 and 6.5 to assess the papers on the list. Those that fulfilled the acceptance criteria of these two working groups were further evaluated by the Risk Assessment Working Group. (See Fig A7 for a flow chart of the literature review process.) Appendix B is the final list of 120 papers comprising the data base for IEEE C95.1-1991.

6.4 Assessment Criteria. The absorption and distribution of electromagnetic energy in the body are very complex phenomena that depend on the mass, shape, and size of the body, the orientation of the body with respect to the field vectors, and the electrical properties of both the body and the environment. Other variables that may play a substantial role in possible biological effects are those that characterize the environment (e.g., ambient temperature, air velocity, relative humidity, and body insulation) and those that characterize the individual (e.g., age, gender, activity level, debilitation, or disease). Because innumerable factors may interact to determine the specific biological outcome of an exposure to electromagnetic fields, any protection guide shall consider maximal amplification of biological effects as a result of field-body interactions, environmental conditions, and physiological variables.

To assess positive reports of the biological effects of exposure to electromagnetic fields, Subcommittee IV emphasized studies that had generated evidence of debilitation or morbidity during both chronic and acute exposure. While it is generally agreed that measurements of the responses of human beings are the most pertinent to the establishment of guidelines for exposure to any noxious environment, few data of this type exist; most human studies are epidemiological or clinical in nature. As was the case for ANSI C95.1-1982 [B1], IEEE Subcommittee IV has had to turn to data collected on subhuman species, fully realizing that the small mass, limited physiological capacity, and unusual body dimensions of most furred laboratory animals strongly influence not only the SAR at any given frequency but also the character and magnitude of biological response. It is important to realize that not only is there an uncertainty inherent in measurements of the responses of animals, but extrapolation of these measurements to human beings may be difficult.

Despite the greatly expanded database since ANSI C95.1-1982 [B1], most reports of biological effects have embodied acute exposures at relatively few frequencies. An extensive review of the literature revealed once again that the most sensitive measures of potentially harmful biological effects were based on the disruption of ongoing behavior associated with an increase of body temperature in the presence of electromagnetic fields [B16, B17, B18, B19]. Because of the paucity of reliable data on chronic exposures, IEEE Subcommittee IV focused on evidence of behavioral disruption under acute exposures, even disruption of a transient and fully reversible nature. The disruption of a highly demanding operant task *is a statistically reliable endpoint that is associated with whole-body SARs in a narrow* range between 3.2 and 8.4 W/kg, despite considerable differences in carrier frequency (400 MHz to 5.8 GHz), species (rodents to rhesus monkeys), and exposure parameters (near- and far-field, multipath and planewave, CW- and pulse-modulated). In contrast, the time-averaged power densities associated with these thresholds of disruption ranged (by calculation or measurement) from 8 to 140 mW/cm^2.

During the assessment procedure, classifications of findings were made without prejudgment of mechanisms of effects. Studies such as those indicating effects, in vitro, on cell function were considered transient and reversible with no detrimental health effects. IEEE Subcommittee IV's intent was to protect exposed human beings from harm by any mechanism, including those arising from excessive elevations of body temperature. After the list of relevant peer-reviewed papers had been compiled by the Literature Surveillance Working Group (see 6.3), each report was evaluated in detail by the Engineering Validation and Biological Validation Working Groups. Three subgroups constituted the Engineering Validation Working Group. These were divided according to frequency as follows:

(1) Below 3 MHz,
(2) 3 to 300 MHz, and
(3) 300 MHz and above.

Fourteen subgroups constituted the Biological Validation Working Group, comprising scientists and experts in the following disciplines:

(1) Behavior, (2) Biorhythms, (3) Cardiovasculature, (4) Central Nervous System, (5) Development and Teratology, (6) Endocrinology, (7) Visual Systems, (8) Genetics, (9) Modulation (RF), (10) Hematology-Immunology, (11) Metabolism-Thermoregulation, (12) Oncology, (13) Combined Effects, and (14) Physiology.

Only those reports with adequate dosimetry were judged acceptable. The relevance of each of these reports to standards setting was evaluated, as were the scientific quality and originality of the data, reliability, and evidence of adverse effects. The evaluation stressed thresholds of adverse effects and the extent to which the findings had been verified in independent investigations. Reports embodying questionable statistical methods were evaluated further by a Statistical Evaluation Working Group. The acceptable reports were then funnelled to the Risk Assessment Working Group for an evaluation of the implied risk for human beings.

A majority of the Risk Assessment Working Group agreed that the literature is still supportive of the 4 W/kg criterion and that whole-body SARs below 4 W/kg were not associated with effects that demonstrably constitute a hazard for humans. Because the threshold for disruption of ongoing behavior in nonhuman primates always exceeded a whole-body SAR of 3.2 to 4 W/kg [B15, B17, B18, B19], the latter value has again been adopted as the working threshold for unfavorable biological effects in human beings in the frequency range from 100 kHz to 300 GHz. In terms of human metabolic heat production, 4 W/kg represents a moderate activity level (e.g., housecleaning or driving a truck) and falls well within the normal range of human thermoregulation.

At frequencies between 3 kHz and 100 kHz other mechanisms, such as electro-stimulation of excitable cells, become important. Since the SAR corresponding to thresholds for excitable cell stimulation decreases almost directly as the square of frequency (from above 8 W/kg at 100 kHz to approximately 0.01 W/kg at 3 kHz), a constant SAR cannot be used as a basis for the guidelines below 100 kHz. The thresholds for these biological effects have been quantified in terms of current density in [B8]. A peak current density of $35.0f$ mA/cm^2 (where f is in MHz), is below the reported thresholds for cell stimulation. This limit is used as the basis for the magnetic field guidelines and exclusions for controlled environments, described in Section 5, for the 3 kHz to 100 kHz frequency range. Exclusions for the uncontrolled environment require a lower peak current density limit of $15.7f$ for consistency with the larger safety factor employed for exposures in that group.

6.5 Safety Factors. The concept of a "safety factor" may be intuitively evident to all; yet, it deserves a closer examination. Considered literally, the expression "safety" (condition of being safe; freedom from danger or hazard) "factor" (agent, contributor to effect, element when multiplied by another form a product) means the agent or multiplier producing freedom from hazard. The development of a safety factor presupposes the following:

(1) the identification of the hazard, and
(2) the selection of the multiplier needed to produce freedom from the hazard.

In practice, the better the hazards involved are understood, the better the process. If, as in engineering practice, the phenomenon is catastrophic failure of a material or system under specified stress, and the failures follow a defined distribution about an average value, then it is possible to define a factor applied to the mean for which the probability of catastrophe is known with a specified degree of confidence. Biological hazards commonly pose special difficulties to the formulation of safety factors. For some phenomena, such as ionizing radiation carcinogenesis, the majority view is that the proper form of the dose response curve is linear or linear-quadratic through zero; hence, there is no safety factor at all. For some phenomena the threshold concept may be accepted, but the distribution of responses is inadequately known to formulate a moderately precise factor or margin of safety. The interested reader is referred to [B13] for a review that is both scholarly and pragmatic on the nature and use of inference guidelines for risk management. Particularly noteworthy is the explicit recognition of the need to distinguish between "science" and "science policy" in the formulation of guidelines.

One effect of lack of knowledge is to foster "conservative" assumptions. Not uncommonly, there may be layers, often unidentified, of such assumptions with each layer contributing to the approach to "safety." This is true for ANSI C.95.1-1982 [B1]. The previous standard explicitly invoked a safety factor of 10 on the threshold of 4 W/kg whole-body average SAR, but incorporated numerous "conservative assumptions" or implicit contributions toward "safety." The list (not comprehensive) includes:

(1) the threshold selected itself (evidence of behavioral disruption) is not a defined hazard; rather it was assumed that chronic exposure under such conditions constitutes a health hazard;

(2) the direct extrapolation from animal to man, arguably, is a conservative assumption given the demonstrably superb thermoregulation of man compared to the reference species;
(3) the selection of the far-field, E-polarized "worst case" exposure as the reference condition (the SAR decreases markedly for other polarizations); and
(4) the incorporation in one contour of the resonance frequencies for all size humans (the SAR falls off markedly for frequencies below resonance).

The collective impact of these "conservative" assumptions is to provide a degree of safety or freedom from hazard for a given human over time and space much greater than is implied by the explicit safety factor of ten. In the context of human thermoregulation, the impact of exposure to 0.4 W/kg is practically indistinguishable from the impact of normal ambient temperature variation, exposure to the sun, exercise, etc. The effect of (3) and (4) above greatly reduces the likelihood that the exposure of a given human to the fields permitted under the standard will produce a whole body average SAR of 0.4 W/kg, except at that individual's resonant frequency, oriented for E-polarization in the far-field.

For this present revision, IEEE Subcommittee IV concluded that an additional safety factor is justified only in an uncontrolled environment and then only for exposures that are penetrating or associated with complicating factors like effects from contacting metal objects. At high frequencies where exposure is quasi-optical or for exposure to low-frequency magnetic fields, where the safety factor is already very conservative, there is no need for an extra safety factor, even in an uncontrolled environment.

In summary, the use of a safety factor presupposes the selection of a threshold for a hazard. The existing MPEs are based on the threshold for behavioral disruption with acute (short-term) exposures of experimental animals. The threshold selected was 4 W/kg and the explicit safety factor of 10 or more was applied to obtain a maximum permitted SAR (whole body average) of 0.4 W/kg. In addition to this explicit safety factor, the MPE contains multiple conservative assumptions that constitute implicit or hidden contributions to a less precise but much greater margin of safety. An extra safety factor is justified only for some exposures in an uncontrolled environment.

It is true that safety factor has a clear meaning only if the bioeffects of electromagnetic energy exhibit thresholds. There is no scientific evidence that contradicts this basic assumption.

6.6 Measurement Procedures. Exposure to RF radiation below 3 MHz, and particularly below 100 kHz, requires special consideration and treatment. Practical experience has shown that prevention of electrical shock can be a significant safety consideration. The principal concern arises from the induction of RF currents in conductive objects that are immersed in ambient RF fields. These induced currents may flow through the body of an individual who contacts them. The amount of current that will flow through the body of a person depends on how well the individual is electrically grounded and the impedance between the current source and the individual [B28, B30]. Low-frequency fields can cause potentially hazardous electric currents to flow in capacitive objects such as vehicles, fencing, metal roofing and other supporting metallic cables like guy wires and other ungrounded conducting objects, including the human body, when these objects become adequately grounded [B24, B28]. RF exposures at low frequencies, even at very low field strengths, can cause high values of electrically induced current to flow from large conducting objects to a grounded individual. But, because of the very wide variety of conducting objects in the environment and the diverse opportunities for humans to contact these objects, it is impractical to specify numerical electromagnetic field strength limits that prevent all possible shock and RF burn effects.

The values of electric field strength given in Table 1 could produce a value of about 550-610 mA to flow to ground in a standing adult at 3 MHz. Such a current is significantly above the level of 100 mA normally taken as the threshold for RF burns for small contact (current conduction) areas. Thus, while this standard specifies maximum exposure field strengths, it is recommended that in those cases where such shock and RF-burn conditions may exist, action be taken to prevent their occurrence.

In particular, in conditions where the potential for RF burns exists, mitigation measures should be taken to reduce the induced currents through each foot to below 100 mA for $f > 0.1$ MHz and below $1000f$ mA for $0.003 < f \leq 0.1$ MHz. Possible methods for reducing currents include restricting area access and reduction in source power, shielding and other engineering methods.

Generally, the requirement to measure both electric and magnetic fields below 300 MHz derives from a consideration of the spatial variation in electric and magnetic field strengths commonly found in reflective environments that produce standing-wave exposure fields. In reflective field environments, the two fields are typically out of phase with one another; i.e., the electric and magnetic field strengths will not exhibit maxima at the same point in space relative to the reflective surface. Where the electric field strength is at a peak value, the magnetic field strength may be at a relative minimum value, and vice versa. If the maximum value of a given field parameter determined over the volume of space occupied by the body is used in determining compliance with the MPE, it is important to verify that a true maximum in the given field parameter has been measured. For example, at very-high-frequencies, with wavelengths of approximately a meter and the fields originating from an elevated antenna, the ground reflected fields will oscillate through successive maxima and minima (spaced apart by one-half wavelength) as a function of height above ground.

In this case, it will be found that the plane-wave equivalent power densities, based on the peak electric and magnetic fields, are comparable to one another, even though they occur at different points above the ground plane [B24]. Where measurements of only one of the field parameters are to be made, for example the electric field strength, *because of the relatively short wavelength compared with the size of the human body*, this single measurement would be sufficient to assure that both fields are within the recommended limits over the space that might normally be accessible. As the frequency of the exposure field decreases and the wavelength increases, the distance between the standing wave field maxima will correspondingly increase. At some point, this distance will exceed the range accessible to an individual performing the RF field measurement. Consequently, verifying that one has measured a peak in one of the reflected field distributions will become impossible under normal conditions; i.e., the peak in the field will occur at a height above ground or a distance away from the exposure area that cannot be readily reached. When this is the case, it is possible that while one field component may have relatively low field strength, the other component may possess a relatively high field strength. Should measurements be made of only one of the field components, and this component was of lower strength and within the MPE limits, and its spatial peak could not be verified because of its unreachable location, it is possible that the unmeasured field component might, in fact, be in excess of the MPE. Clearly, at low frequencies, below approximately 30 MHz (wavelength of 10 m), measurement of only one field component could lead to erroneous conclusions as to compliance with the MPE. Accordingly, below 30 MHz, both electric and magnetic fields shall be determined to evaluate compliance of exposure fields with the MPE. Between 30 and 300 MHz it may be possible through analyses to show that measurement of only one of the two fields is sufficient to determine compliance with the MPEs.

In exposure situations where the distribution of field strengths or plane-wave equivalent power densities is substantially non-uniform over the body (partial-body exposure), for frequencies less than 300 MHz, determination of compliance with the MPE field limits may be determined by a spatial average of the exposure fields over the plane occupied by the body but in the absence of the body, where feasible. Nonuniform fields are commonly encountered in reflective conditions such as standing wave fields produced by reflection of fields from the earth or other reflective surfaces. Averaging may be accomplished through the use of real-time data-logging equipment [B58], or via manually obtained point measurements.

For practical measures of compliance with the standard, the average of a series of ten field strength measurements performed in a vertical line with uniform spacing starting at ground level up to a height of 2 m shall be deemed sufficient. In practice, this means that field strength measurements shall be made at heights above ground separated by 20 cm. Additional field strength data, for example, as obtained through the use of data-logging or spatial averaging equipment, obtained at smaller spacings than 20 cm is acceptable and will provide more detail on the spatial distribution of the fields.

The concept of spatial averaging of field strengths is based on the finding that whole-body SARs are related more to the average field strength over the body dimensions than to the peak value at one specific point [B9]. Although it is recognized that additional research is needed to more accurately relate nonuniform field exposures to SARs, the assumption that the whole-body SAR in an individual exposed to nonuniform RF fields is related to the peak value of fields is unnecessarily conservative.

When the wavelength becomes sufficiently small, it is possible that electromagnetic fields can become relatively focused over areas that are small compared to the body dimensions. This is obvious for microwave frequencies above perhaps a few GHz. In this case, limited areas of the body could be exposed to very high power densities, resulting in inadvisable temperature elevations, while the average exposure for the body as a whole might be well within the MPE limits (see 6.2).

Measurements to determine adherence to the recommended MPEs should take into account the fact that several factors influence the response of measurement probes to the field which exists at any given point in space. These factors include the following:

(1) variation of probe impedance with proximity to nearby reflective surfaces,
(2) capacitive coupling between the probe and the field source, and
(3) nonuniform illumination of the sensing elements that make up the probe (for example, the three orthogonal elements that comprise an isotropic, broadband electric field probe) [B39, B55, B56, B57].

The influence of each of these factors, which can result in erroneous measurements of field strengths, can be eliminated by maintaining an adequate separation distance between the probe elements and the field source. Accordingly, measurements should be made at a distance equal to three-probe dimensions between the surface of the nearest probe element and any object or 20 cm, whichever is greater.

In the performance of measurements for determining compliance with the MPE, it is not uncommon to encounter RF hot spots. RF hot spots usually exhibit locally enhanced field conditions near to (within a few probe diameters of) RF sources, conductive surfaces, or objects that act as parasitic sources. The associated electric and/or magnetic fields vary extremely rapidly in radial directions away from the source over dimensions equal to a few probe diameters. Although these highly localized fields can often be extremely intense, their capacity to cause high SARs in tissue is usually significantly reduced when compared to plane waves having the same intensity [B3, B7]. One way of viewing this is to consider the total RF energy that is available in the incident fields if the reradiating object were not there. In general, the reradiated fields cannot contain more energy than was contained in the incident fields [B59]. Obviously, large focusing surfaces could conceivably collect sufficient amounts of incident energy to produce a concentration at a specific point, but this generally occurs only in the microwave frequency range.

SARs that are smaller than might be expected on the basis of the local field strength are partially a function of the field impedances normally associated with hot spots [B50]. For example, very high impedance fields (i.e., high values of E/H) cannot deliver RF energy to nearby absorptive tissues as effectively as lower field impedances. Thus, in these near-field situations involving RF fields with ratios of E to H that are significantly different from plane waves (E/H = 377 ohms), assessment of the resulting SARs in exposed tissues is complicated by the fact that our present state of knowledge does not permit accurately relating such fields to SAR. The determination of this SAR requires either internal field measurements in the tissue [B53] or a thermographic method, neither of which is currently practical for humans, or the measurement of induced tissue-currents that may be related to local SARs through knowledge of tissue geometries and electrical parameters.

Contact currents associated with individuals contacting objects that are exposed to ambient RF fields have been investigated [B54]. A common finding is that conductive objects, when immersed in relatively weak ambient RF fields with strengths less than the applicable MPE, can exhibit locally strong surface fields which may exceed the MPE in the immediate region of the surface of the object. While these surface fields might imply that the MPE is exceeded, measurements of the contact currents that result when touching the object can often be used to determine local SARs in the tissue that are less than the SAR limits inherent to the MPE. Thus, often high-strength surface fields common to reradiating objects do not imply that the MPE SAR limits are exceeded.

6.7 Shock and Burn Hazards. Shock and burn hazards from electric field exposures are mitigated by imposing limits on the magnitude of the rms current (averaged over a 1-second period) allowed to flow from an exposed subject to ground or a conducting object. Maximum current limits are preferable to electric field limits for preventing shocks and burns, since maximum induced current levels are a function of the size, shape, and impedance to ground of the contacted object, as well as the uniformity of the exposure field, presence of nearby objects, and type of footwear and clothing worn by the exposed subject.

The current limits specified in Table 1, Part B, and Table 2, Part B, and current density limits for the basis of the exclusions in 4.2, have been set below the threshold for shock perception and cell stimulation in the exposed subject. The current density limits for the uncontrolled environment are reduced to account for the increase in the safety factor adopted for those conditions. The specified limits are also below thresholds for the production of burns from direct contact with metal objects. It should be noted, however, that the specified levels of current provide protection from shock or burn *only* under conditions of direct contact and *do not* protect against spark discharge phenomena associated with making or breaking contact with conducting objects. The perception threshold of spark discharge is a complicated function of many variables. These include frequency, induced open-circuit voltage and capacitance between the conducting object and exposed person, temperature, speed of making or breaking contact, bodily location where contact is made, and other variables. Although much quantitative research has helped to solve this problem for 60-Hz electric field exposures, insufficient archival data exist to formulate MPEs for exposures at other frequencies.

6.8 Averaging Time. Averaging time is the appropriate time period over which exposure ($|E|^2$, $|H|^2$ or S) is averaged, for the purpose of determining compliance with the standard. Because the present revision of the standard introduces many refinements, it is necessary to permit averaging time, as well as the limits on E, H or S, to be frequency-dependent. This permits the transition from values of minutes for averaging time in the resonance range, to values of seconds for the averaging time suitable at infrared frequencies. This transition appropriately reflects the frequency-dependent change in thermal time constant that characterizes the heating of the whole or part of the human body by exposure to radiofrequency energy. At low frequencies, frequency-dependence in averaging time is used to permit a continuous transition between an MPE that is identical for controlled and uncontrolled environments (below 1.34 MHz), to the existence of two different MPEs in the resonance range. Here, the lower MPEs for the uncontrolled environment are tempered by a longer averaging time to allow for transient exposures. The rules always insure, however, that the SA in an uncontrolled environment will be less than or equal to the corresponding SA permitted in a controlled environment, even in the transition range where either or both of the field limits and averaging time are frequency-dependent.

The reduction of the averaging time with increasing frequency precludes high SARs for short periods (seconds) in decreasingly thin layers of skin and subcutaneous tissue that otherwise could result in skin burns. Since the penetration depth at frequencies above 30 GHz is similar to that at visible and near infrared wavelengths, the literature for skin burn thresholds for optical radiation is expected to be applicable. Thus, the averaging time (10 s) and MPE (10 mW/cm^2), at 300 GHz, are consistent with the averaging time and MPE, at a wavelength of 1 mm, specified in ANSI Z136.1-1986 [B2]. These MPEs are derived from the biological database for skin burns and apply to irradiation of large areas (greater than 1000 cm^2).

In uncontrolled environments, the appropriate averaging time for exposure to electric fields (Table 2) is 0.5 hr. (30 min) for frequencies between 3 MHz and 3 GHz. For frequencies between 15 GHz and 300 GHz, the appropriate averaging time is given by the formula $T_{avg} = 616\ 000/f^{1.2}$ where f is the frequency in MHz. Between 3 and 15 GHz the averaging time follows the function $T_{avg} = 90\ 000/f$. The increased averaging time addresses typical expected transient exposures to E fields in uncontrolled environments. Since the MPE in Table 2 is 1/5 of the MPE in Table 1, the maximum SA over the averaging time of each MPE is the same for E field exposures. For exposure times less than the averaging time in Table 1, the two MPEs are identical. Below 1.34 MHz, the averaging time is the same (6 minutes) for either a controlled or uncontrolled environment.

For exposures to low-frequency magnetic fields where the limits are the same for both controlled and uncontrolled environments, the averaging time is the same, i.e., 6 minutes. However, the averaging time changes to 30 min above the transition region 30-100 MHz. Above 100 MHz, power density becomes a meaningful exposure parameter and the associated E and H field limits must be consistent with plane-wave equivalence. Below 30 MHz, however, E and H field exposures can occur separately, and the respective MPEs follow different rules of frequency dependence because of the important difference in the nature of potential bioeffects. H fields heat biologic tissue and induce internal currents less effectively than E fields.

The application of the MPEs at low frequencies assures that induced currents are prevented or limited by measures other than imposition of field limits. Since the time averaging of induced currents is over a period of one second, the likelihood of permitted exposures to E or H fields greatly exceeding the long term limits is small and restricted to special situations.

6.9 Peak Power Exposure. Peak power limits are provided to prevent unintentionally high exposure and to preclude high SA for decreasingly short widths of RF pulses. For some time, it has been recognized that the lack of such consideration in the standard has allowed the peak power density to rise arbitrarily, as long as average power density met the standard.

Furthermore, under exposure to pulsed fields it is advisable to be conservative in view of some uncertainty about the value of spatial peak SAR, which could be over twenty times the spatially-averaged SAR. Under pulsed conditions (less than 100 ms pulses), the allowable MPE as averaged over any 100 ms is reduced by a factor of five times.

For a single pulse, this is equivalent to reducing the maximum permissible peak power density by a factor of five times below the value that normal time averaging would permit. A maximum of five such pulses are permitted during any period equal to the averaging time. If there are more than five pulses in any period equal to the averaging time, normal time-averaging will further reduce the permissible peak power density.

The limits on peak power are the values obtained by consideration of a well-established scientific base of data that includes the auditory effect in humans and radio-frequency energy-induced unconsciousness in rats [B11, B33, B36, B45, B46, B47, B48, B49]. The limit on SA associated with the reduced averaging time [4.1.1(g) and 4.1.2(g)] is conservative relative to RF-induced unconsciousness and is well above the threshold for auditory effect. The latter is clearly not deleterious. For example, in the microwave range for exposures to a single pulse, the SA over any six-minute period is limited to 28.8 J/kg (spatial average) and 576 J/kg (spatial peak), assuming a ratio of twenty to one between peak and average.

For low frequencies and short pulses, the more conservative limit of 100 kV/m [4.1.1(f)] takes precedence over the SA limit [4.1.1(g)]. For high frequencies and longer pulses, the SA limit [4.1.1(g)] is more conservative than the 100 kV/m limit [4.1.1(f)]. The recommendation for a peak E-field limit of 100 kV/m is based on the necessity to cap the allowable field below levels at which air breakdown or spark discharges occur. The level chosen is ultraconservative in this regard, and represents an absorbed energy which is also more conservative than the continuous-wave limit over pulse lengths for which it is intended. This conservatism is prudent in light of the relative sparseness of studies for very-short high-intensity exposures. Such studies as do exist are reassuring that this level is indeed far below the threshold for adverse effects.

6.10 Exclusions and Relaxation of Limits for Partial Body Exposure. Under certain conditions, the only practical way to cope with the problems of exposures to nonuniform fields and low-power devices is by means of exclusion clauses that allow the local incident field strengths (and the plane-wave equivalent power density, where applicable) to exceed the general MPE.

The exclusions are based on the following considerations:

(1) The general provisions of the standard should not be violated. The whole-body averaged SAR during localized exposure should be limited to 0.4 W/kg and 0.08 W/kg for, respectively, controlled and uncontrolled environments. Previous studies have shown that peak SARs in a biological body can be 10 to 20 times higher than the average SAR [B37]. If the peak value of the mean-squared field strengths and the equivalent power densities are in accordance with the provision of 4.4, then the general provisions of the MPE will not be violated under conditions of partial body exposure or exposure to non-uniform fields.

(2) Laboratory studies have shown that it is unlikely for devices such as low-power hand-held radios (where the radiating structure is not maintained 2.5 cm or less from the body) to expose the user in excess of the exclusion criterion for the controlled environment (4.2.1), or other persons in the immediate vicinity of the user in excess of the criterion for the uncontrolled environment (4.2.2), if the radiated power is 7 W or less at frequencies between 100 kHz and 450 MHz, and $7(450/f)$ W or less at frequencies between 450 and 1 500 MHz [B4, B5, B12]. Further, these studies have also shown that similar devices will not expose the user in excess of the exclusion criterion for the uncontrolled environment (4.2.2) if the radiated power is 1.4 W or less at frequencies between 100 kHz and 450 MHz, and $1.4(450/f)$ W or less at frequencies between 450 and 1 500 MHz.

Therefore, these exclusions have been included in this standard to allow the pertinent MPE to be exceeded if it can be shown that:

(i) the SAR averaged over the whole-body and over the appropriate averaging time does not exceed 0.4 W/kg and 0.08 W/kg for, respectively, exposure in controlled and uncontrolled environments and;

(ii) the spatial peak value of the SAR averaged over any 1 g of tissue (defined as a tissue volume in the shape of a cube) and over the appropriate averaging time does not exceed 8 W/kg (controlled environment) or 1.6 W/kg (uncontrolled environment) in the body,and over any 10 g of tissue (defined as a tissue volume in the shape of a cube) and over the appropriate averaging time does not exceed 20 W/kg (controlled environment) or 4 W/kg (uncontrolled environment) in wrists, ankles, hands and feet. The

20 W/kg limit for the wrists and ankles allows higher absorptions in the soft tissues produced by the induced currents specified in Table 1 flowing in these bony, narrow cross-sectional areas. Considerations that mitigate these higher permitted local SARs include relatively high surface-to-volume ratios for these parts of the body, the common experience of relatively large temperature excursions of these parts that normally occur without apparent adverse effects, and the lack of critical function when compared to vital organs.

It is also recognized that, in some cases, it may be difficult to determine whether a particular RF exposure would meet these absorption criteria, and, therefore, could be done only in a laboratory setting or by an appropriate scientific body. In many cases, however, the determination could be made with an appropriate source material, e.g., dosimetry handbooks [B22]. Detailed measurements of the field distribution over the volume of the human body and spatial averaging over the same volume could, in some instances, be used to verify compliance with the relaxation of limits for partial body exposure. In the case of the eyes and testes, direct relaxation of power density limits is not permitted. However, the SAR exclusion rules still apply.

7. Bibliography

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Appendix A
Final List of Papers Comprising Data Base

(The following Appendixes are not a part of IEEE C95.1-1991, IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHZ to 300 GHz, but are included for information only.)

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Appendix B
Final List of Papers Reviewed for IEEE C95.1-1991

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Appendix C
Exposure Calculations for Multiple Sources

When a number of sources at different frequencies, and/or broadband sources contribute to the total exposure, it becomes necessary to weigh each contribution relative to the MPE in accordance with the provisions of 4.1.1 (e) and 4.1.2 (e). To comply with the MPE, the fraction of the MPE in terms of E^2, H^2 (or power density) incurred within each frequency interval should be determined and the sum of all such fractions should not exceed unity. The following example illustrates this:

Measurements were made in a controlled environment at a point near several induction heaters (IH) and dielectric heaters (DH). The values below present the electric and magnetic field strengths as averaged over an area equivalent to the vertical cross section of an adult.

Source	Frequency (MHz)	Electric Field Strength (V/m)	Magnetic Field Strength (A/m)	Duty Factor (%)
DH_1	27.5	90	0.1	20
DH_2	7.5	283	0.2	60
DH_3	3.5	592	0.4	45
IH_1	0.400	15	8	100
IH_2	0.900	21	4	100
IH_3	8.035	30	0.2	100

In order to ensure compliance with the MPE for a controlled environment, the sum of the ratios of the time averaged squares of the measured electric field strength to the corresponding squares of the MPE, and the sum of the ratios of the time averaged squares of the measured magnetic field strength to the corresponding squares of the MPE, should not exceed unity. That is:

$$\sum_{i=1}^{n} \frac{E_i^2}{MPE_i^2} \leq 1$$

and

$$\sum_{i=1}^{n} \frac{H_i^2}{MPE_i^2} \leq 1$$

Applying this to the data above yields

$$\sum_{i=1}^{n} \frac{E_i^2}{MPE_i^2} = \frac{0.2(90)^2}{67^2} + \frac{0.6(283)^2}{246^2} + \frac{0.45(592)^2}{526^2} + \frac{15^2}{614^2} + \frac{21^2}{614^2} + \frac{30^2}{230^2} = 1.74 > 1$$

$$\sum_{i=1}^{n} \frac{H_i^2}{MPE_i^2} = \frac{0.2(0.1)^2}{(0.6)^2} + \frac{0.6(0.2)^2}{(2.2)^2} + \frac{0.45(0.4)^2}{(4.7)^2} + \frac{8^2}{(40.8)^2} + \frac{4^2}{(18.1)^2} + \frac{0.2^2}{(2.0)^2} = 0.11 < 1$$

In order to comply with the provisions of the MPE, both summation must be less than unity. Although the summation in terms of magnetic field strength is less than unity, the summation in terms of electric field strength exceeds unity and, therefore, the MPE for controlled environment is exceeded.

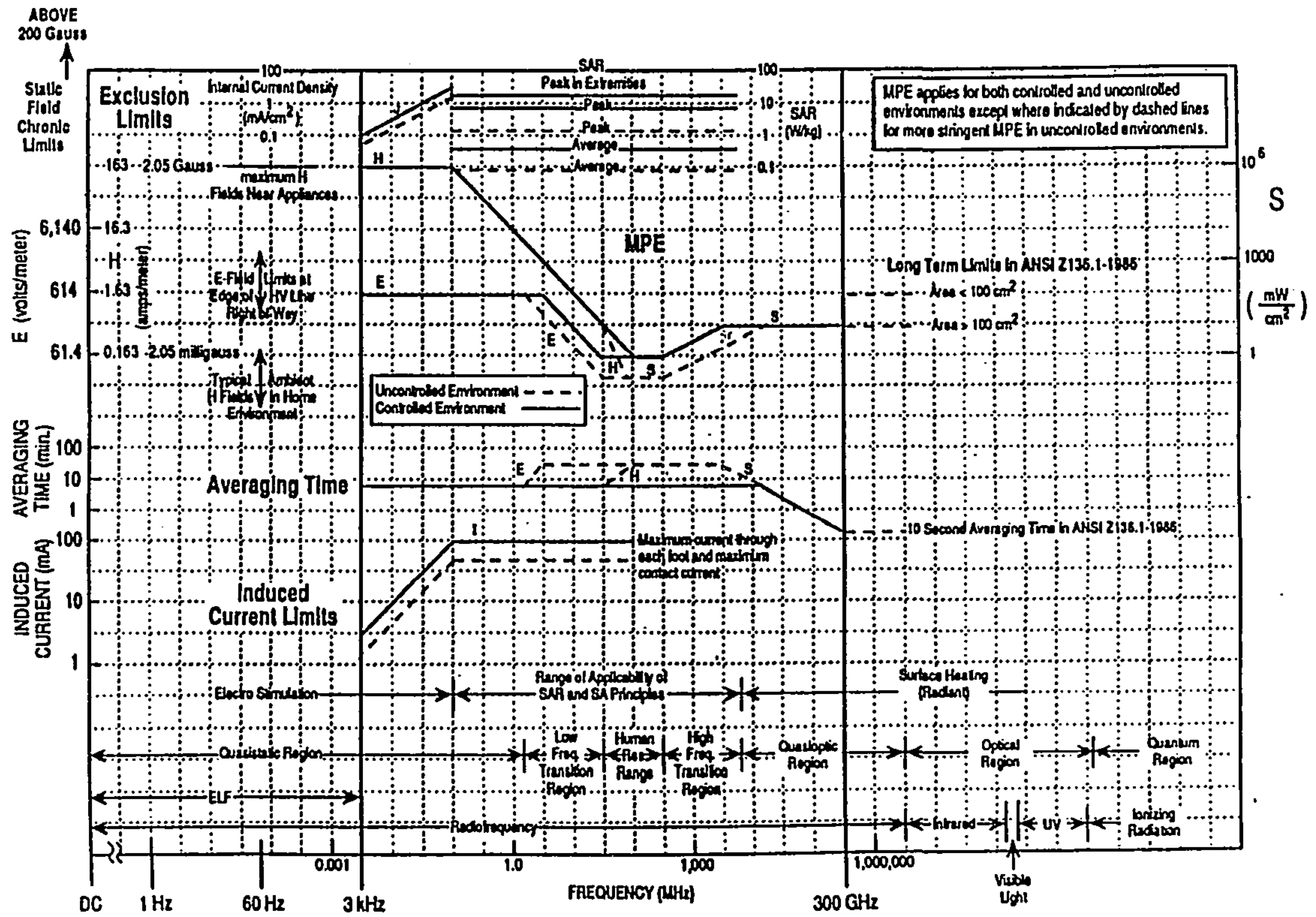

Fig A1
Capsule Guide to the Standard

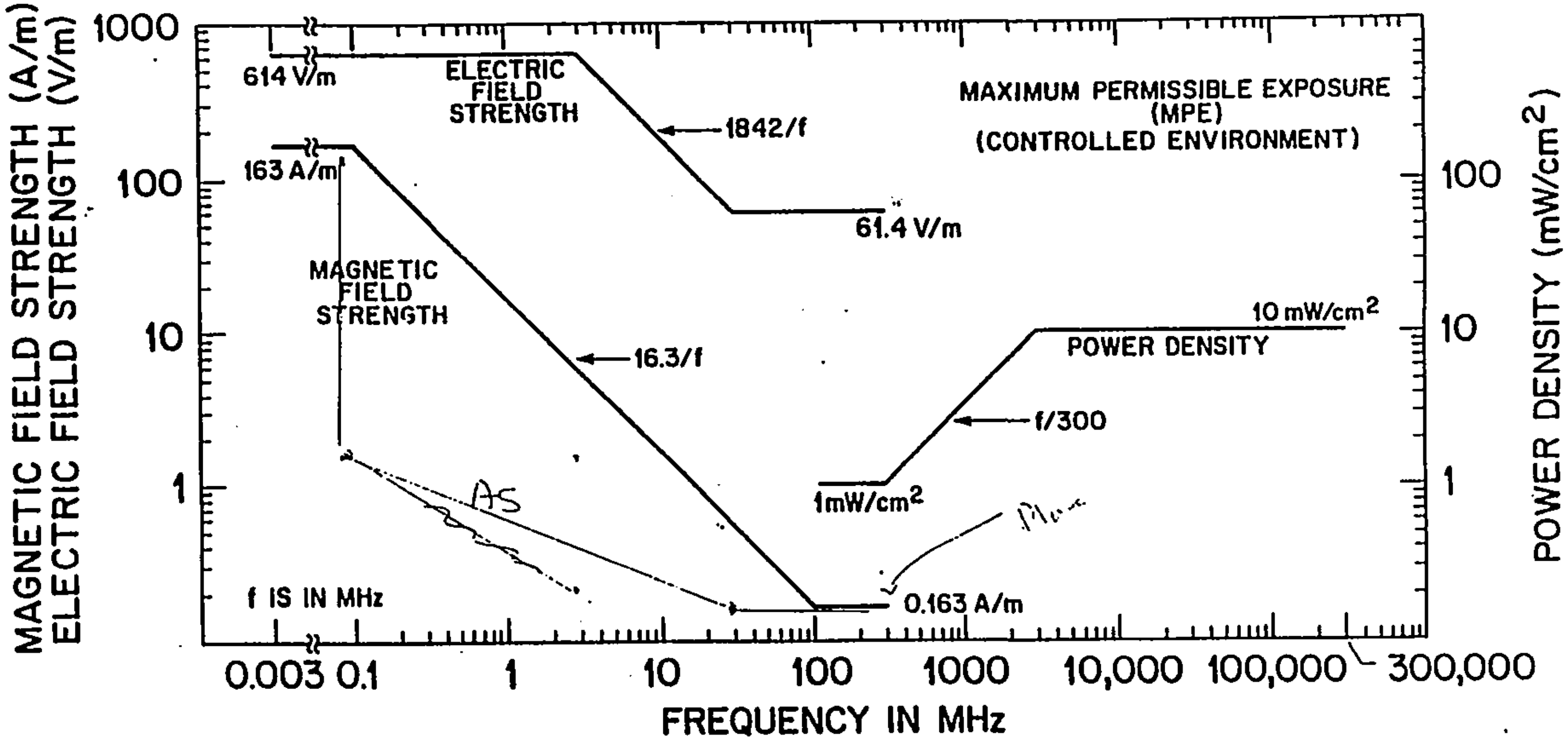

Fig A2
Graphic Representation of Maximum Permissible Exposure in Terms of Fields and Power Density for a Controlled Environment.

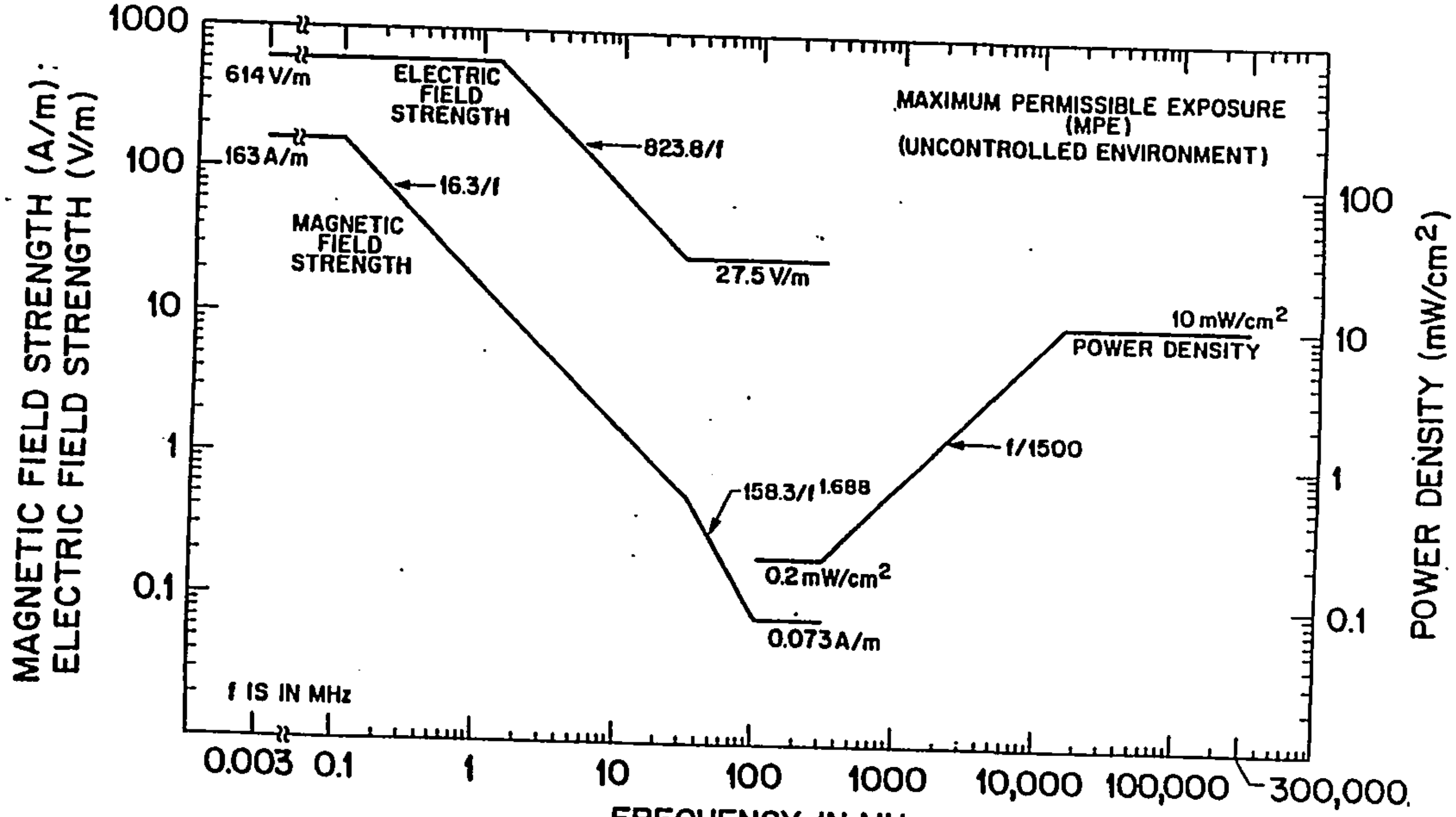

Fig A3
Graphic Representation of Maximum Permissible Exposure in Terms of Fields and Power Density for an Uncontrolled Environment.

Annex 3 : Safety Aspects of Radio-Frequency Radiation From
Space Research Earth Stations
International Radio Consultative Committee of the ITU (CCIR)
Report 543, 1974

REPORT 543 *

SAFETY ASPECTS OF RADIO-FREQUENCY RADIATION FROM SPACE RESEARCH EARTH STATIONS

Comparison between predicted and measured field strengths at 2 GHz

(Study Programme 15B/2)

(1974)

1. Introduction

This Report describes and compares calculations and actual system tests used to determine power flux-density in the vicinity of a large (64 m) diameter reflector antenna with an input of 400 kW in the vicinity of 2 GHz. In this analysis, power flux-densities greater than 10 mW/cm^2 are examined in the greatest detail since they may be considered as being potentially dangerous to human beings exposed to the radiation [USA Standard, 1966]. Intermediate densities, from 1 to 10 mW/cm^2, are covered in lesser detail, since this category is considered safe for occasional exposure. Densities less than 1 mW/cm^2 are examined, although radiation in this category is considered safe for indefinite exposure. The material in this Report is taken largely from a report recently published in the United States [Bathker, 1971].

High power radio-frequency radiation constitutes a biological hazard and also a hazard to volatile fuels and electro-explosive devices. This Report is concerned primarily with the levels of radiation which are considered biologically hazardous: applicability to fuels and electro-explosive devices is not discussed. Radio-frequency radiation effects in these areas are discussed elsewhere [Constant and Martin, 1963; IME, 1968, Wood, 1969].

2. System characteristics

The system discussed is the United States NASA, 64 m diameter, Cassegrain-fed, parabolic reflector antenna at Goldstone, California, operating at 2.12 GHz with 400 kW CW transmitter power input to the antenna. This system is a very carefully optimized transmit/receive arrangement wherein high beam efficiency (percentage of total radiated power delivered to the main beam) and low spillover and scatter (the percentage of the total energy that is wasted in the form of stray radiation) were sought after in design and achieved. This point is important; a poor selection of a feed system could invalidate the results of this study.

Figure 1 gives the far-field E-plane and H-plane radiation patterns of the hybrid mode, corrugated, waveguide feedhorn used at 2.12 GHz. It has been possible to achieve the highly symmetrical beam shown in this figure because the feedhorn aperture distributions in both planes are equal, and are of low intensity near the waveguide boundaries. Ninety-three per cent of the radiated power has been subtended at 14.7° from the feedhorn boresight, which is the edge of the Cassegrain sub-reflector. The feedhorn axial gain is +21.8 dB with respect to isotropic.

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* This Report is brought to the attention of Study Group 1 with respect to Question 52/1.

Figure 2 gives the far-field E-plane and H-plane radiation patterns of the complete feed system, i.e., the above feedhorn and the sub-reflector. The origin of these patterns is the focal point of the prime reflector. Fig. 2 shows that the feedhorn radiation has been primarily spread over a 60° zone, the edge of which represents the rim of the paraboloidal reflector. Fig. 2 also shows the reduced radiation in the 60° to 160° zone, and the feedhorn spillover past the edge of the sub-reflector in the 160° to 180° zone, as well as the back lobe due to feed system. Fig. 3 is helpful in visualizing the above zones.

At 61.4° from the feed system boresight, which is the edge of the paraboloid, 92.6% of the power has been subtended. From 61.4° to 90°, the rear spillover amounts to 0.4%. The forward spillover, from 90° to 180°, accounts for the remainder, 7%. Of this 7%, the bulk (5%) is contained within the 160° to 170° lobe. The total feed system axial gain is, for all practical purposes, +8.4 dB relative to isotropic *.

Three additional factors must be considered in accounting for the total power; scattering from the feed system supports (quadripod) and central blockage, leakage through the parabolic reflector, and the back lobe of the parabolic reflector. The total central power blockage due to the feedhorn cone is 3.0%. The area blocked by the quadripod is 6.3%. Accepting the quadripod blocking shadows on the 64 m aperture as having roughly the form of radial wedges, we obtain 6.3% power blocking. Recalling that we are blocking 6.3% of 93.0%, we finally obtain 5.9% loss for the quadripod and 8.9% total power scattered.

Excellent agreement between theory and experiment has been obtained for radio-frequency transmission through metal meshes such as are used for the outer 50% of the radius on the 64 m reflector. For the particular material used, the 2.1 GHz leakage for normal incidence is −42 dB. Non-normal incidence causes the leakage to tend towards −50 dB. An upper limit of 0.01% power leakage due to the mesh is reasonable. The front-to-back power ratio of the parabolic reflector has been estimated for the case of an isotropic feed as 58.5 dB [Kritikos, 1963]. In this case, the edge illumination is 6.4 dB below isotropic and the forward gain is about 4 dB better than produced by the isotropic feed; the front-to-back power ratio should be 60.9 dB. A reasonable estimate of the power lost due to the back lobe is approximately 10^{-4} %.

Table I summarizes the feed system and reflector in terms of the total power to be accounted for.

TABLE I – *Total power description, 64 m hybrid mode feed system and reflector*

Radiation type	Percentage of total
Forward spillover	7·0
Scattered	8·9
Rear spillover.	0·4
Reflector leakage	10^{-2}
Reflector back lobe	10^{-4}
Balance to main beam	83·7

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* An anomaly of scattering computations of importance here is the axial (0 deg) "bright spot", seen in Fig. 2 which would lead to an axial gain figure of 9.7 dB. Whether the spot physically exists or not is unknown, but in either event is not of any consequence, since precisely zero power is contained in such a point. It is therefore entirely correct to ignore the bright spot and adopt an axial gain of +8.4 dB relative to isotropic.

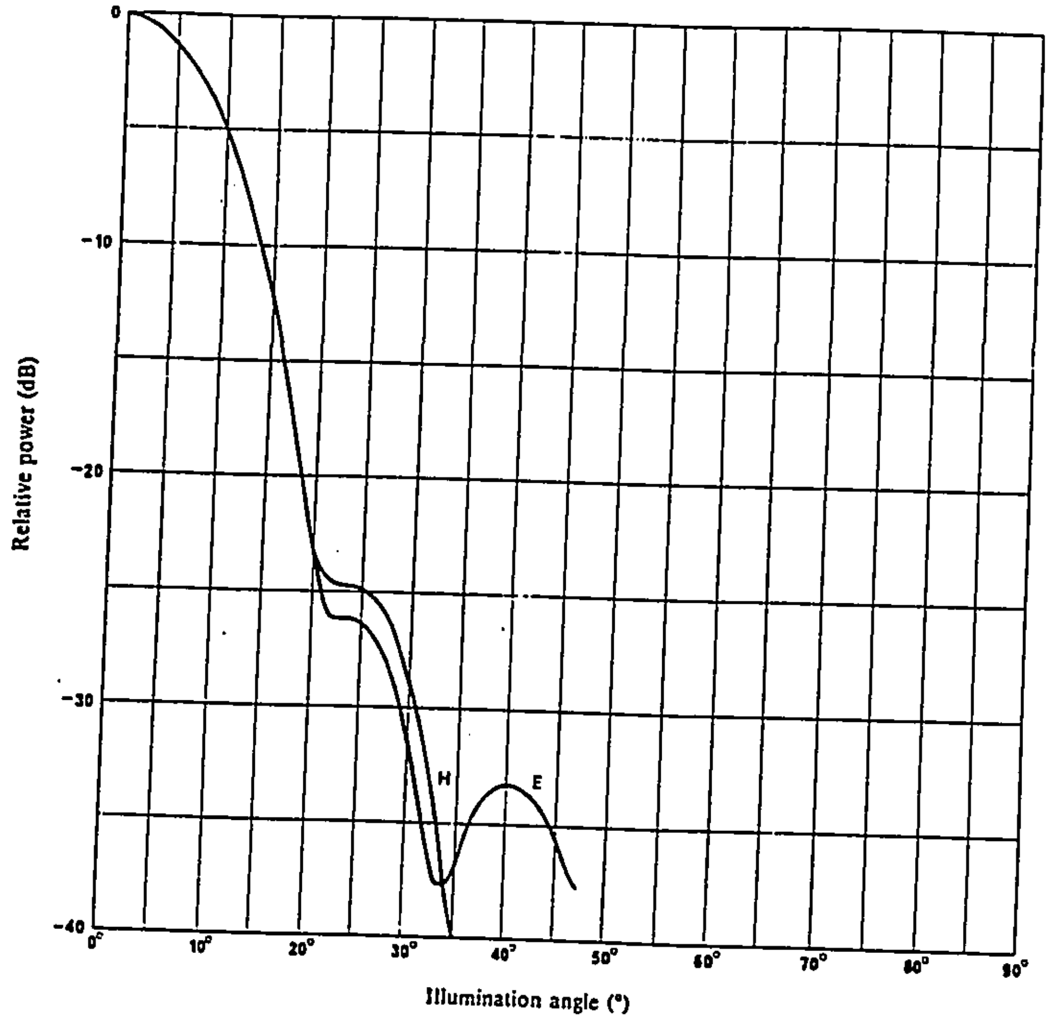

FIGURE 1 - *2120 MHz corrugated hybrid mode horn*

E: far-field in E-plane
H: far-field in H-plane

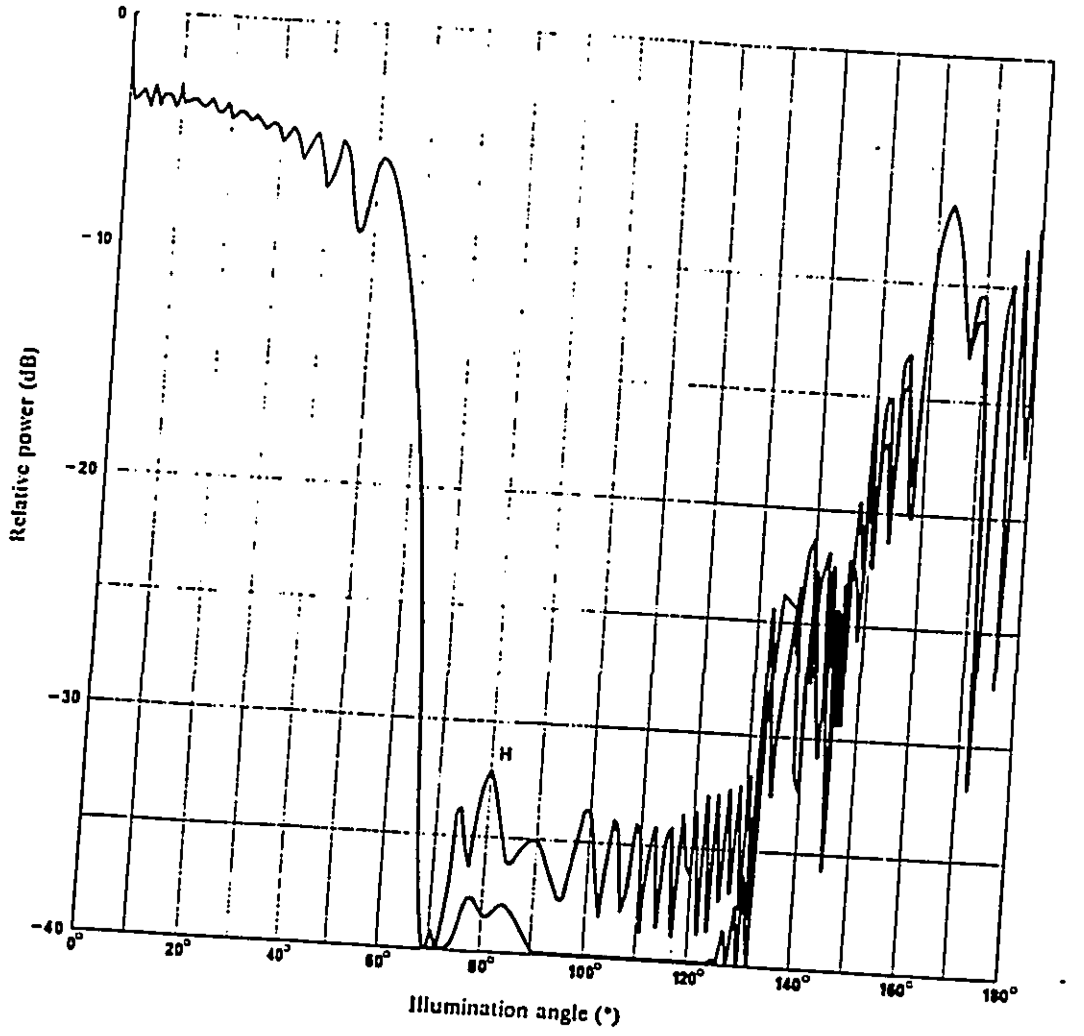

FIGURE 2 - *Scatter pattern*

H: far-field in H-plane

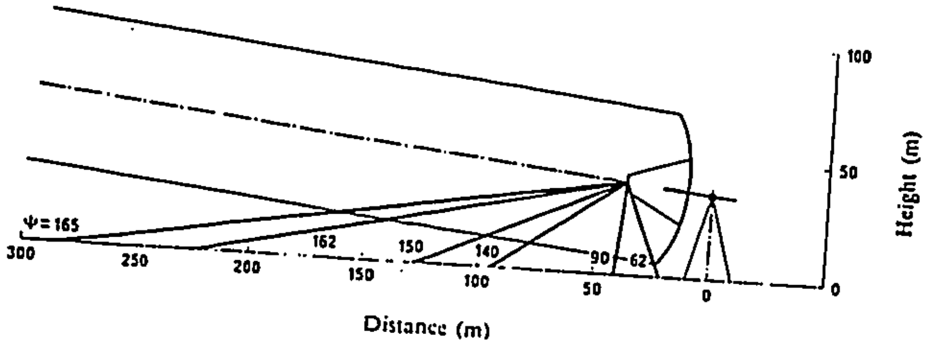

FIGURE 3 - *64 m antenna system power flux-density study (see Table IV)*

Elevation angle: 6.0°

3. Power flux-density calculations

The power flux-density is

$$PG/4\pi r^2$$

where

P: is the power,

G: is the gain relative to isotropic,

and $(4\pi r^2)^{-1}$: is the inverse square law.

It is implied in the use of this equation that we remain in the far zone (divergent rays) of the radiation considered. For example, the use of the above equation to predict power densities at distances less than $2D^2/\lambda$ from a constant phased aperture, where D is the aperture diameter, is incorrect. But, for the prediction of aperture illuminations (either of the sub-reflector by the feedhorn or of the paraboloid by the total feed system), or for the prediction of stray fields known to be divergent, the above applies.

The condition selected for calculation is shown in Fig. 3. With the system pointing at the lowest operational elevation angle of 6.0°, the main beam is in closest proximity to the ground and the forward and rear spillovers as well as the scattered power are intercepted by the ground. From the H-plane pattern is Fig. 2 and taking the ranges from Fig. 3, we can obtain Table II, a straightforward series of singular field calculations. By the expression "singular field" it is meant that we postpone considerations of possible power additions due to multiple sources, and possible reflections. Further, Table II does not take into consideration the scattered, leakage and back lobe components.

Table II shows that on the basis of singular fields, power flux-densities greater than 1 mW/cm² exist only on the aperture.

TABLE II *Calculated singular power flux-densities**
64 m reflector, 6.0° elevation angle, 400 kW

Angle Ψ (deg)	Gain, G, relative to isotropic (dB)	Range, r, to intercept (m)	Type of intercept	$PG/4\pi r^2$ (mW/cm²)	Notes
0	+ 8·4	27·0	Paraboloid	30	27 m is the focal length of paraboloid
10	+ 8·4	27·2		29·5	
19	+ 7·9	27·6		25·7	
29	+ 7·1	28·9		19·5	
38	+ 6·7	30·3		16·2	
46	+ 3·5	31·9		7·1	Mesh reflector portion
54	+ 4·9	34·0		8·5	
61	− 5·8	36·4		0·63	
61·4	− 6·4	36·5		0·55	Edge of reflector
61·4	− 6·4	41·5	Ground	0·41	First ray to ground
62	− 7·5	41·3		0·32	
64	−13·1	40·8		0·09	
66	−19·3	40·4		0·02	
68	−25·6	39·9		0 005	
75	−22·1	38·9		0·001	
80	−20·6	38·6		0·018	Shortest ray to ground
90	−23·6	38·8		0·009	
100	−22·1	40·1		0·012	
120	−24·6	47·6		0·012	
140	− 9·7	69·0		0·071	
150	− 3·8	94·8		0·15	
160	+ 2·3	157		0·22	
162	+ 4·9	184		0·29	Forward spillover peak
163	+ 5·2	201		0·26	
164	+ 4·4	218		0·18	
165	+ 3·0	241		0·11	
175	+ 1·8	∞	Sky	—	
180	+11·6	∞		—	

* Aperture distribution, forward and rear spillovers only.

[illegible]

Figure 4 is an example of the 64 m system far-field pattern at 2.3 GHz, showing the half-power beamwidth of 0.14° that is normally considered for such an aperture. At ranges which are less than $2D^2/\lambda$ (58 km), but greater than $D^2/2\lambda$ (14.5 km), the observed patterns are in a transition zone between the far-field pattern and the aperture distribution. At ranges of less than $D^2/2\lambda$, a parallel or tubular beam exists which exhibits no divergence and therefore no "space loss". The significance of the tubular beam is that, for practical purposes, one should imagine the aperture distribution being repeated in space, beginning at the aperture and extending to about $D^2/2\lambda$. Of course, neither range mentioned above represents a sharp demarcation in beam type, but here we may assume that this is so for simplicity. In so doing, useful and consistent results will be achieved.

The peak power flux-density at 14.5 km is approximately 32 mW/cm^2, and at 58 km, 1 mW/cm^2. It must be emphasized that the 32 mW/cm^2 density in fact exists, beginning at the aperture and extending outward to 14.5 km. This tubular beam is 64 m in diameter with approximately 0.5 mW/cm^2 density at the edges, and an estimated 12 dB/radius decay beyond the beam edge as listed in Table III.

It is worthwhile noting that a second order tubular beam theory predicts a power flux-density increase of 2 dB at a range of one half of the 14.5 km value above mentioned [Bickmore and Hansen, 1959]. The most intense power flux-density for the system considered here would thus be 48 mW/cm^2 at a range of 7 km.

It is noteworthy that for a given power output, the smaller systems produce higher power flux-densities in the tubular beam.

Tubular beaming has been observed with the 64 m system, albeit at short (0.05 $D^2/2\lambda$) range, as shown in Fig. 5. The observed angular width of the beam ($\approx 5°$) is that of a 64 m arc at a distance of 0.7 km.

Energy transport by means of tubular beam transmission has been studied and verified by experiment, where high efficiency ($\approx$ 0.8) transfer is realized up to the $D^2/2\lambda$ range. The 64 m/400 kW system is an efficient power transmission means, up to a range of 15 km, and its calculated power flux-densities are in the danger category (Table III).

TABLE III – *Calculated tubular beam power flux-densities 64 m reflector, 400 kW*

Radius (m)	Power flux-density (mW/cm^2)
0	30·2
4·7	29·5
9·1	25·7
14	19·5
19	16·2
23	7·1
28	8·5
31	0·63
32	0·55 (beam edge)
48	0·14
64	0·035 (−12 dB/radius)

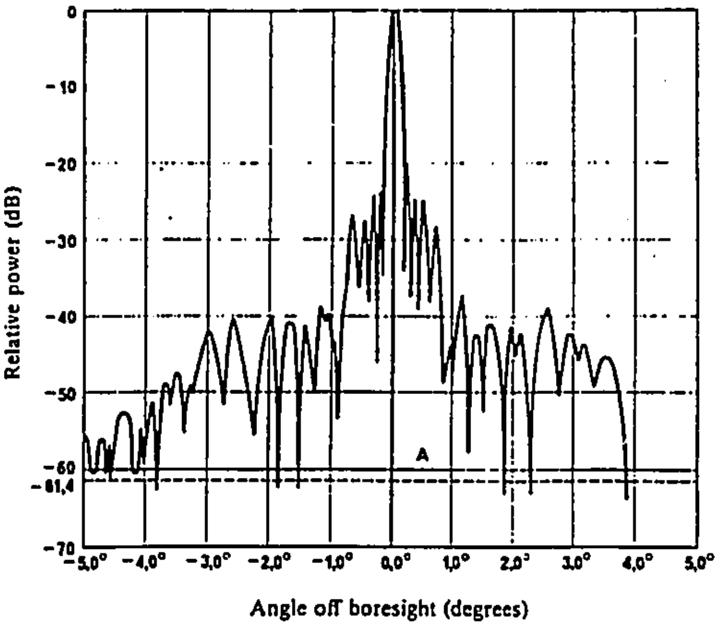

FIGURE 4 – *Measured azimuth pattern of the 64 m advanced antenna system at Goldstone, California 2295 MHz, 400 000 km range*

A : Isotropic antenna

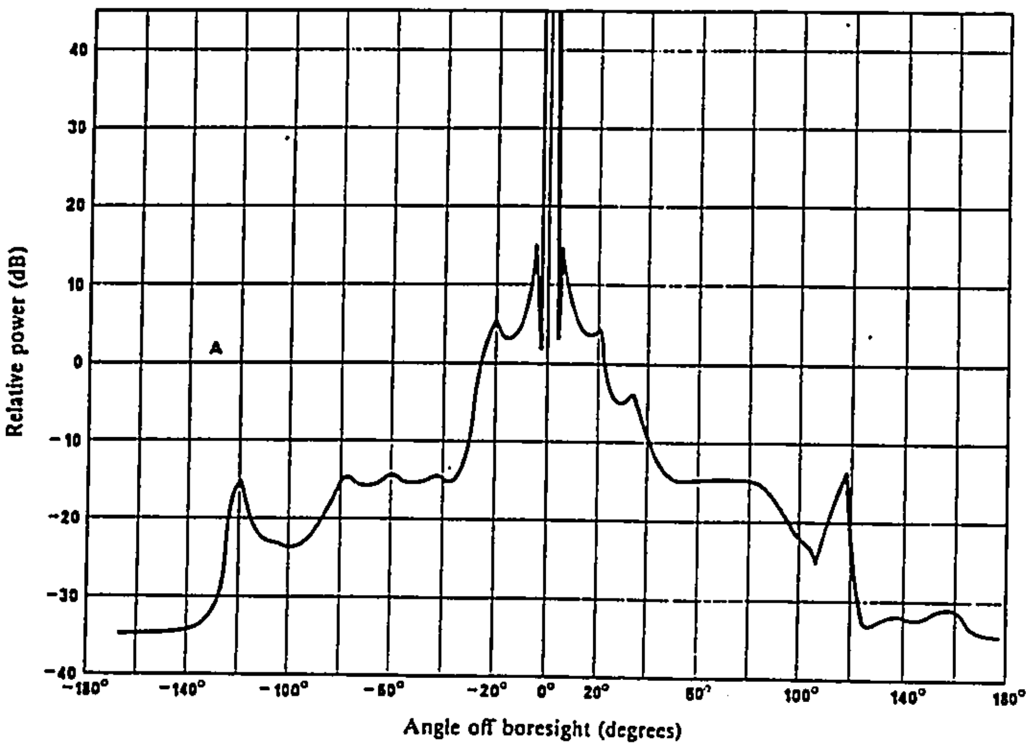

FIGURE 5 – *Measured azimuth pattern of the 64 m antenna system at Goldstone, California 2115 MHz, 700 m range*

A : Isotropic antenna

Table II gives the singular field power flux-densities along the boresight direction of the reflector, at ground level, arising from the forward and rear spillover components. We will next consider the scattered components and also discuss the possible multiple sources and reflections.

The model for quadripod scattering (5.9%) or −12.3 dB supposes the total power directed equally in all directions with the exception of the shielding provided by the 64 m reflector, leading to an average gain +1.3 dB relative to isotropic. The resultant radiation level (−11.0 dBi[*]) may be compared with the −15 dBi plateau seen in Fig. 5. This plateau is considered to extend from boresight ± 100° approximately, and crudely verifies the simple model. Accepting this radiation as arising from a complex line source along the reflector z axis, which is 35 m above ground, the power flux-density due to quadripod scatter is estimated as 0.2 mW/cm^2 on the ground, immediately below the quadripod.

In the model, the central blockage (scattering 3%, or −15.2 dB total power) is assumed to direct this energy fraction into the forward hemisphere with a gain of +3 dBi. The source is taken to be in the region of the feedhorn, again 35 m above ground. The resultant radiation level (−12.2 dBi) is similar to the quadripod level; the power flux-density due to central blockage scatter is estimated as 0.16 mW/cm^2 on the ground, immediately below the feedcones.

From Table II we have 0.4 mW/cm^2 due to direct spillover on the ground, immediately below the antenna, and from scattering we have 0.2 and 0.16 mW/cm^2. Adding the three nearly equal signals coherently, we obtain possible maxima of 2.2 mW/cm^2. An intensity maximum of this kind, due to multiple sources, will be found on a spot basis only. Minima will also be found due to destructive interference, again on a spot basis.

A second region of interest in the reflector boresight direction on the ground is the feedhorn forward spillover maximum of 0.29 mW/cm^2, roughly 200 m from the other sources. The scattered sources contribute 0.016 and 0.013 mW/cm^2 at 200 m on the ground. A fourth source, the decay of the tubular beam in this region, contributes 0.07 mW/cm^2. Again, taking the peak or spot maxima for this region on the ground we obtain 1.1 mW/cm^2.

Ground (or other) reflections can be relied upon for doubling the field amplitude or the 6 dB spot power maximum provided the angle of incidence is grazing. For normal incidence, the ground is taken as absorbing. Therefore, it appears that this region on the ground, in front of the 64 m reflector, and extending perhaps 250 m from the azimuth axis, contains the calculated spot maximum power flux-densities of the order of 2.5 to 4 mW/cm^2. Uniform power flux-densities in this category are considered safe for incidental or occasional exposure.

6. Stray radiation, rear zone

We have two indices of back radiation mentioned earlier: mesh leakage and the predicted front-to-back ratio. With a maximum power flux-density of 20 mW/cm^2 on the mesh (Table II) and a leakage of −42 dB, the maximum fields immediately behind the reflector will be 0.0013 mW/cm^2, due to mesh leakage.

It appears proper to treat the back lobe as another tubular (non-divergent) beam, insofar as within reasonable observing distances it has not yet formed in the far-field sense. The non-divergent beam exhibits no space loss, so we may consider the aperture power flux-density maximum (32 mW/cm^2) as being down in level to the order of 60 dB; the resultant 0.000032 mW/cm^2 due to the near field or tubular back lobe is indistinguishable in the presence of the mesh leakage above. Calculated power flux-densities in the rear zone are considered safe for indefinite exposure.

7. Comparison, predicted and measured power densities

A number of radiation surveys have been made in the station area around the 64 m Goldstone reflector. Radiation surveys are typically taken with probes having a rather large (500 cm^2) effective area and using a radio frequency thermal detector with a usable sensitivity in the 10^{-2} mW class. Such an arrangement responds to the average power flux-density over a few square wavelengths or several spot maxima and minima, if any exist. The minimum detectable average power density is 10^{-5} mW/cm^2, and larger fields are accurately managed by use of attenuators. Experience has shown one characteristic of the stray radiation is strong elliptical polarization, i.e., the polarization tends towards linear for each sample.

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[*] Decibels relative to isotropic.

Selected results from the various surveys are given in Table IV (the entries in Table IV indicating the points at which measurements were made; see Fig. 3). The primary purpose of Table IV is to show the measured high fields on the 64 m aperture, and in the tubular beam. The moderate fields expected on the ground in front of the reflector at 6° elevation are found. The back radiation is seen to be very small.

We consider the 64 m/400 kW system very adequately described for power flux-densities greater than 10 mW/cm². Totally independent studies of apertures with tapered illumination show a ratio of power flux-density at the aperture to the density at $2D^2/\lambda$ of 14.2 dB [Bickmore and Hansen, 1959]. The results obtained here yield 14.3 dB. We have the calculated tubular beam maximum agreeing with the measurement at 700 m within 0.3 dB. The limitations in handling the multiple and reflected fields near the ground both analytically and during the field surveys should be borne in mind, that is, the spot maxima and minima phenomenon (standing waves) and the averaging provided by the measuring process are important in interpreting the results *.

The first order tubular beam approach taken above is considered totally valid in the context of this study. Results of sufficient accuracy are quickly obtained and the interested reader is presented with a clear impression. A survey party using the hand-held equipment, mentioned in the measurement paragraphs above, would observe a received power of about 25 watts at 7 km; a 2 m diameter dish would receive nearly 1 kW **. Higher power flux-densities are possible in a mis-focused condition. An approximate density increase of 6 dB is available at 14.5 km; the reflector power flux should always remain focused at infinity when transmitting.

In the intermediate (1 to 10 mW/cm²) zone, which, necessarily, is likely to be more loosely controlled, mention of unlikely, but possible, effects should be made. Resonant or focusing devices, perhaps key-rings, metal eyeglass frames or wrenches are capable of exhibiting a reasonable absorption area at S-band. For example, a half-wave dipole (7.0 cm) in a 1 mW/cm² field will deliver 25 mW to a matched load.

Effects of this kind have been reported, but are considered little more than an improbable irritation. Normal tracking motion of the antenna will impose a time limit on the intermediate zone to some extent. In this intermediate zone, we have calculated spot power flux-densities, but measured average power flux-densities (the average over the aperture of the test horn) appear lower as might be expected. It is considered that the average value is important in terms of personnel exposure, while the spots are important in the event of resonant phenomena, if any. In either case, this zone, on the ground, is considered safe for incidental or occasional exposure, even at 6.0° elevation angle.

The greatest hazard is thus the tubular beam itself. Because acceptable siting of large microwave ground antennae generally places such installations in depressions, the primary restriction is to avoid interception of the tubular beam with the surrounding terrain. Surrounding terrain includes man-made objects such as towers, other antennae, power lines and possibly roofs of buildings near to the antenna. Generally, the NASA 64 m station sites are such that the transmitter will be inoperative at 6° elevation angles, due to the above primary restriction. This further helps to alleviate the power flux-density in the intermediate zone, as may be seen by inspection of Fig 3.

8. Conclusions

As a result of the adopted standards, the following restrictions on the movement of personnel when operating the described system are required:

- access to the reflection surfaces must be avoided;
- access to the tubular beam must be avoided;
- the time during which access into the zone described as intermediate is allowable must be limited (to 1 hour in 24 hours).

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* Recent information, based upon the use of a small aperture polarization-independent probe confirms that, in a complex field, measurements taken with such a probe are generally 6 to 10 dB greater than with a large aperture.

** A 2 m dish, 1.5 km from a 25 m/400 kW system operated at 2.39 GHz, has been inadvertently swept, during normal tracking, by the tubular beam. The power flux-density and range of the tubular beam in this case is 186 mW/cm² and 2.7 km, respectively. Further, the 2 dB increase at half range was evident here; the dish collected approximately 5 kW with resultant loss of feed and cabling due to thermal damage.

TABLE IV *Selected power flux-densities, 64 m/400 kW Goldstone system (see Fig. 3)*

Measurement point	Power flux-density		Remarks
	Measured values (mW/cm²)	Calculated values (mW/cm²)	
On 64 m reflector	43·5	29·5	Radius: 5 m
On 64 m reflector	22·0	19·0	Radius: 15 m
On tubular beam centre	28·0	30·0	Range: 700 m
Below beam, on ground (1)	0·02 to 2·0	4·0	Range: 100–300 m
Reflector edge, on ground (1)	0·32 to 0·8	2·5	Height: 1·7 m
Directly behind reflector	0·11	—	Leak near opening
Directly behind reflector	< 0·02	0·001	Continuous panel
Behind reflector, on ground	0·002	≈ 0·000032	Angle of elevation: ≈ 15°
Back lobe search, on ground (1)	< 0·001	≈ 0·000032	Plunge tests
Under hyperboloid, on ground	0·11	—	Height: 1·7 m

(1) At 6° elevation.

All operating personnel should be familiarized with the tubular beam characteristics (range and power density) and the unlikely, but possible, effects in the zone where time-limited access is applicable.

The following environmental restrictions are also important:

- restrictions are necessary as regards the masking of the site by obstacles;
- restrictions are necessary as regards the height of the station buildings;
- collimation and other towers are potentially dangerous.

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ATTACHMENT 5

CONSULTED PARTIES IN THE PREPARATION OF THE SUPPLEMENTAL ASSESSMENT

Federal Agencies
U.S. Department of Commerce - National Telecommunication and Information Administration - Information Technology and Science Division

State Agencies
University of Hawaii - Facilities Planning and Management Office
University of Hawaii - Environmental Health and Safety Office
University of Hawaii - Information Technology Service
University of Hawaii - Laboratory High School
University of Hawaii - Office of VP for Research and Graduate Education
Office of Environmental Quality Control
Hawaii Public Broadcasting Authority

City and County of Honolulu Agencies
Department of Land Utilization - Building Department

Other Organizations
Marine-Air Systems, Ltd.