# ELECTROMAGNETIC SPECTRUM UTILIZATION—
# THE SILENT CRISIS

**A Report on**
**Telecommunication Science and the Federal Government**

*by the*

Telecommunication Science Panel

*of the*

Commerce Technical Advisory Board

*with the cooperation of*

Office of Director of Telecommunications Management
Federal Communications Commission
Department of Defense
Department of Commerce

October 18, 1966

**U.S. DEPARTMENT OF COMMERCE**

JOHN T. CONNOR, Secretary

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# FOREWORD

Most people know that radio, television, long distance telephone, radar, police radio, etc., play important roles in their daily lives. Many of the more thoughtful are aware that telecommunication services are important, indeed essential, participants in all facets of the growth of our nation and even of our civilization. Relatively few, the technically inclined, know that telecommunications depend on a national resource -- the electromagnetic frequency spectrum; a technical concept which put the word "wireless" into our vocabulary.

The electromagnetic spectrum has become a silent partner vital to all our national enterprises. If it were suddenly to disappear we would have calamitous confusion and would have to retrogress many aspects of our society by as much as half a century before we could begin to function as a nation again. It is doubtful if anyone fully comprehends either the full impact on modern society or the interactions of all the technical, economic, social, and political complexities of our silent partner. The select groups who have attempted, during the past forty years, to achieve some level of understanding, have repeatedly warned us that our silent partner is ailing. In recent years the warnings have become more urgent and the symptoms have become more numerous and even obvious to those sectors of our industrial life which need to extend the use of this silent partner for the benefit of their business.

Take these news items:

-- A house burns to the ground in Los Angeles because crowding of a radio channel prevents fire-fighting equipment from being properly dispatched.

-- Our scientists and engineers develop a sophisticated communications satellite for which there are no suitable unallocated frequencies available--the problem is only partly solved by the sharing of frequencies already used by ground microwave services.

-- The operator of a delivery service in New York cannot improve his efficiency because he cannot obtain a mobile radio frequency. If, after long delays, he is fortunate enough to obtain one he finds he is sharing a party line with as many as fifty other active enterprises.

Indeed, our silent partner is suffering from a disease which we can identify as "accelerating paralysis". At present, there is no known cure and very little effort to find one. It is a malignant disease and costly. It is already having a slowing effect on the growth of our economy, slight at present, but inevitably increasing in the future.

Obviously, we must take some action -- now!

The electromagnetic spectrum usable for telecommunications is an extremely valuable, in fact essential, but also limited resource, which must be shared nationally and internationally. It is an unusual resource in that it is not depleted by use. However, its value at any specific time can be drastically reduced by misuse. It is unusual in another sense in that it is currently allocated without a use charge and with no quantitative measure of its value to the national welfare. It is a resource which can be increased in value to some limit (as yet indeterminate) by creative research and development and by skillful management.

Telecommunications, and hence the demands on the frequency spectrum will continue to grow indefinitely until limited by saturation of all or portions of that spectrum. Only effective planning, based on more knowledge that is now available, will ensure that the nation makes optimum use of this resource. The recognition of the potential threat to the continued growth of the nation led the Chairman of the Commerce Technical Advisory Board, Dr. J. Herbert Hollomon, to establish ad hoc the Telecommunication Science Panel. The study was initiated with the concurrence of the Secretary of Commerce, with the cooperation of and also for the benefit of the Director of Telecommunications Management (Executive Office of the President), the Federal Communications Commission, and the Department of Defense. The Panel sought to study the status and trends in the technology and use of the electromagnetic spectrum and to examine various methods of increasing the telecommunication capabilities of the nation through more effective use of the electromagnetic spectrum. The Panel members, who provided a variety of backgrounds, are leaders in the field; several had devoted many years to the development of methods for more effective spectrum utilization.

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The study was supported by liaison and staff from the cooperating agencies.

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# I. INTRODUCTION

> "After three thousand years of explosion, by means of fragmentary and mechanical technologies, the Western World is imploding. During the mechanical ages we had extended our bodies in space. Today, after more than a century of electric technology, we have extended our central nervous system itself in a global embrace, abolishing both space and time as far as our planet is concerned. Rapidly, we approach the final phase of the extensions of man -- the technological simulation of consciousness, when the creative process of knowing will be collectively and corporately extended to the whole of human society, much as we have already extended our senses and nerves by the various media. . . .
>
> . . . The tendency of electric media is to create a kind of organic interdependence among all the institutions of society, emphasizing de Chardin's view that the discovery of electromagnetism is to be regarded as a 'prodigious biological event'. . . ."
>
> Marshall McLuhan
> Understanding Media
> McGraw-Hill, N.Y. 1965

## TELECOMMUNICATION SINCE WORLD WAR II

There is no escaping that the vitality of the American economy, the agility of our defense, and indeed the level of our civilization, depend organically and profoundly upon electromagnetic means to obtain and convey information. The dependence is growing, and rapidly becoming critical.

The telegraph introduced the new technology of electromagnetic telecommunication to advance the speed and efficiency of transportation and information media. Radio brought the era of instant global communication, and the means for navigation which empower modern sea and air commerce. Most of the technology in use in telecommunications today we did not possess before World War II. The past two decades have brought immense growth of the numbers and kinds of telecommunication technology and applications now vital to the commercial, industrial and cultural life of the nation, as well as to national objectives in defense and space. Radar and television, and a variety of measurement and control applications in industry and science, are only a few of the applications.

The United States has the most advanced and widely available telecommunications in the world. We use half the world's telephones and more than 7 million transmitters licensed by the FCC or operated by the Government. The number of broadcasting and television stations has increased sixty percent, to nearly 8,800, in the seven years since 1958. Radio in industrial, land transportation and citizen's services--and other safety and special services such as fire and law enforcement--have grown more than three times in the same period, to more than 5.3 million licensed transmitters. Manufactures of transmitting and receiver equipment for communication, radar, navigation, etc., (not including broadcasting and television receivers or telephone/telegraph equipment) increased two and one-half times in this period, to over \$6 billion per year. The growth rate is several times that of the Gross National Product.

Telecommunication has a strong research base. The National Science Foundation Survey of 1964[1] showed about \$1½ billion research and development in components (more than half federally supported). Among the most significant developments have been: <u>wideband transmission and relay methods</u>, including new cable technology, communication satellites, lasers and millimeter wave technology; <u>solid state electronics</u>, especially recent microelectronics and integrated circuitry, reduce power requirements, cheapen complex circuits, and enable sophistication of a variety of telecommunication functions; and, <u>electronic computers</u>, for which much future significance to telecommunication has come into view quite abruptly during the past few years.

## THE ELECTROMAGNETIC FREQUENCY SPECTRUM

In view of the apparent vitality of telecommunication services, research and technology in the United States, why a question about "telecommunication science and the Federal Government"?

About one half of telecommunications between fixed points, and all broadcasting, mobile communication, radar and radionavigation services transmit through the atmosphere, radiating in various regions of the electromagnetic frequency spectrum. A $20 billion annual portion of telecommunications in the United States is estimated[2] to be comprised of manufactures and services involved in transmission through the atmosphere, that is, excluding the wire and cable applications.

The electromagnetic frequency spectrum is, from the point of view of administration and utilization, a natural resource enabling telecommunication. Interference among radiations of various users can impair or disable effective use; the resource must be allocated and shared nationally and internationally. There are limited regions of the spectrum technically suitable for various applications. It is a unique resource in that it is not depleted or depreciated by use. However, its value at any time may be drastically reduced by overuse or misue. The resource is given a degree of tangibility by allocation, agreements, assignments and licensing of rights to use. For such assignments, radiation in the spectrum has the dimensions of frequency bandwidth, time and space, as well as intensity (power flux density).

More than 80 percent of today's spectrum uses have come into being in the short period since World War II. Limited availability of prime frequency-regions of the spectrum already constrains the introduction or growth of important services. Some critical areas have already developed. In 1964, the Joint Technical Advisory Committee Report[3] observed:

> "We now have all areas of the usable radio spectrum allocated and, to varying degrees, in service.
>
> We have observed the potential of various segments of the spectrum to perform different and specialized tasks.
>
> We have been overwhelmed by the popularity and need for the 'product' obtained from radio spectrum utilization.
>
> We find far reaching changes of allocation of spectrum difficult to make because of fixed investments not fully amortized. . . ."

A prime example of growing pressure for new kinds or increasing capacities of telecommunication services is the urgent need for increased mobile radio communication to serve land transportation, distribution and construction industries, utilities, mining and forestry, and many other industries as well as to facilitate the increasing speed and volume of air traffic, marine communications, and growing safety and law enforcement requirements. In major metropolitan areas, the havoc and interference from congestion of mobile radio limits present usefulness and prevents expansion.

Arguments used against expansion or introduction of business owned, private or cooperative radio systems include limited availability of frequency spectrum and questions of efficient frequency utilization; the issue is in sharp focus today as a result of business interest in private microwave systems, and new proposals for domestic satellite communications.

The full promise of data transmission and information processing networks calls for communication capabilities not now in general existence, including satellites. Other advancing national objectives as in defense, high speed ground transportation, highway safety, oceanography, and law enforcement are generating new telecommunication technology with vastly increasing demands for use of frequency spectrum.

The electromagnetic frequency spectrum has been called the "6th natural resource." Just as land, water, minerals, forests and energy sources are husbanded as essential resources for a nation's development, use of the electromagnetic frequency spectrum must be "conserved", "developed", and allocated for the greatest value and yield to the nation's economy, welfare and defense.

The present utilization of the electromagnetic spectrum is intimately related to the accepted practices for the allocation and assignment of frequencies for various telecommunication services, and to the systems standards established for these services. The complex allocations and assignment procedures occur at three levels. There is, first, a subdivision of the spectrum by international agreement into bands for particular services. This action is guided by the desire to communicate between countries and to minimize harmful interference beyond national boundaries. A finer allocation of the spectrum is made on a national basis for domestic as well as international services. Finally, there is an assignment procedure which designates the precise channels to be used by specific systems within the bands allocated to the services provided by the systems.

Frequency allocation and assignment in the United States, and the establishment of policies and regulations for use of the spectrum are the responsibility of the Federal Communications Commission for non-government uses, and of the Director of

Telecommunications Management, Executive Office of the President, for Federal Government uses. The need for technical coordination and management of uses of the spectrum was recognized in the United States in 1922, when the Secretary of Commerce convened the first of the National Radio Conferences, which led to new allocations of frequencies, and to establishment of a Federal Radio Commission. Later, the Communications Act of 1934 created the Federal Communications Commission (FCC) "to regulate interstate and foreign commerce in communication by wire and radio." Also resulting from the first conference was the Interdepartment Radio Advisory Committee (IRAC), for Executive Branch coordination and technical standards for frequency utilization by Federal Agencies. The Communications Act formally established the dual system of control of the frequency spectrum. The work of IRAC continues today advisory to the Director of Telecommunications Management. The Department of State is responsible for the international negotiations, mainly through the International Telecommunications Union (ITU), concerning frequency allocations and radio regulation, and is advised primarily by the FCC and the DTM. Government-industry committees also advise, especially in technical matters such as considered by the International Radio Consultative Committee (CCIR) of the ITU.

While there are optimum frequency ranges for various telecommunications services, with few exceptions these tend to be broad ranges. Thus, there is usually considerable flexibility in the initial choice of a frequency for a given service. Once a band is allocated and its frequencies assigned, however, the capital investment involved in its subsequent exploitation is often of such magnitude that future flexibility in the use of the assigned frequency is greatly restricted.

## THE PRESENT STUDY

The present study was initiated to identify national needs and federal responsibilities for telecommunication science, on the premise that it is of essential government concern to increase the telecommunication capabilities of the nation by fostering technical means for more effective utilization of the electromagnetic frequency spectrum.

The scope of telecommunication science considered includes research and technical services concerning electromagnetic wave propagation, transmission media, antennas, information transmission and noise, as well as the operational and economic analysis, engineering data and methods needed for efficient frequency utilization and sharing. The study was intended to assess the extent to which present programs and organizational relationships are meeting the needs, and to identify possibilities for significant improvement.

The specific questions set out for study were:

"1. What research and technical service programs directed toward more efficient utilization of the electromagnetic frequency spectrum for telecommunications are needed:

(a) on behalf of telecommunications policy and management executed by the Federal Communications Commission and/or the Director of Telecommunications Management, and

(b) to facilitate growth and development of telecommunication services vital to the government, the national economy and public welfare?

2. What are the present research and technical service programs and what opportunities or responsibilities are not being fully met?

3. What recommendations are required for new or continuing programs, emphasis, organizational relations, legislation and budget?"

The technical problem, in its broadest sense, is to facilitate increase of capacity of the spectrum, by technical means for more intensive utilization, as well as by extending the usable regions. Technology may be advanced to accomplish desired telecommunication services using minimum frequency bandwidth, time, radiated power and spatial distribution of the emission. Frequency bands may be shared increasingly intensively by measures which reduce the necessary signal-to-interference protection ratios, by use of improved propagation predictions for estimating transmission parameters and interference probability, and by careful optimization of radiated power, bandwidth, directivity, and geographical separation of services. Exploitation of unused higher regions of the spectrum may be stimulated by increasing understanding of the propagation characteristics as well as by research leading to devices and systems capable of effective use of the new regions.

The Panel invited reviews from the cooperating agencies and from a number of experts in telecommunications research, planning and operations from government, industry and universities, to provide an up-to-date overview of the status, trends and problems of telecommunication services and the research and technology in the various frequency ranges. The technical programs and recommendations of the cooperating agencies were reviewed by means of briefings and discussions of the Panel, with the liaison representatives. Additional survey reports and documents were reviewed. Listening and discussion sessions were devoted by the Panel to the telecommunication services, research and technology in the frequency regions of the spectrum (a) below 30 MHz,* (b) 30 MHz to 15GHz, and finally, (c) above 15GHz to optical regions. At the conclusion of these sessions, the Panel set aside two meetings for deliberations leading to recommendations. Appendix 1 lists the oral presentations contributed to Panel meetings.

## RELATED STUDIES

Appendix 2 gives a summary of other study activities in this field which were reviewed by the Panel. Over the years many studies have been made and several are currently in progress concerning both technical and policy aspects of spectrum utilization. Though primarily related to allocations and management, they necessarily covered much of the same information as the present study, and their considerations or conclusions usually had some relevance to the present study. Most closely related to the present study are the work of the Joint Technical Advisory Committee (EIA/IEEE) and the continuing intergovernmental study programs of the International Radio Consultative Committee (CCIR). The JTAC Report Radio Spectrum Conservation (1952),[4] reviewed technical factors involved in radio frequency allocations, gave a critique of allocations at that time, and posed some technically ideal allocations and principles of spectrum conservation. The subsequent JTAC Report,[3] Radio Spectrum Utilization (1964) updated the review of the technical factors and made a number of recommendations of a technical-administrative nature for revised allocations and improved standards. Current JTAC studies[5] are considering the technical problems and approaches to "electromagnetic compatibility", i.e., increased spectrum sharing through technical measures to reduce mutual interference. While the JTAC study is a current one, the Panel has had the benefit of its progress through reports, and the active participation of the chairman of this JTAC study, Mr. Richard P. Gifford, as a Panel member. This study has been one of the most valuable sources of guidance in the technical complexity of the problems and to perspectives on solutions.

The Panel also reviewed the scope of the study of the FCC Advisory Committee for Land Mobile Radio Services. Though the final conclusions were not available during the course of the Panel's study, the Advisory Committee's characterization of the land mobile communication problems and identification of important topics for study were considered.

The Recommendations of the ITU Panel of Experts (1963)[6] on "ways and means of relieving the pressure on the bands between 4 and 27 Mc/s" were noted, as were the current extensive CCIR recommendations, reports, questions and study programs bearing on efficiency of spectrum utilization (Geneva, 1963). These questions and study programs provide a major and intricately developed framework for technical studies in telecommunications.

Also of interest was the activity of the Frequency Management Advisory Council of the Director of Telecommunications Management, which is studying the methods and bases for formulation of telecommunications policy for the Executive Branch of the Government. The Council has noted the need for technical and economic studies in support of frequency management activities of the Government, made known by the Director of Telecommunications Management and reflected in recent budget requests. Two members of the Advisory Council, Dr. C. M. Crain and Mr. Richard P. Gifford, are also members of the Telecommunication Science Panel, and additional liaison was provided by DTM and Commerce staff. Of special interest, particularly in light of the conclusions that this Panel finally reached, was the draft proposal of the Office of the Director of Telecommunications Management for long-range planning for allocation and use of the radio spectrum. The material proposing this function "to provide a feasible and continually available guide for the orderly development and exploitation of the radio spectrum" had been submitted by the Director for review by the Frequency Management Advisory Council. In this proposal there was further evidence that specific recommendations and action on spectrum allocation cannot be undertaken

* Hz, abbreviation for Hertz, the unit of frequency (cycles per second); with prefixes: KHz, Kilohertz (thousands), MHz, Megahertz (millions), and GHz, (billions).

without a continual input of technical and socio-economic data, analyses and planning alternatives.

A report of the Interdepartmental Committee for Atmospheric Sciences, on "Atmospheric Science Required to Facilitate Electromagnetic Telecommunication" was a useful source of summary data on the economic significance of telecommunications using the electromagnetic spectrum.

# II. SPECTRUM UTILIZATION—STATUS AND TRENDS

A striking index of the growth of telecommunications is given by the Census of Manufactures[7] of radio and TV communication equipment. The 1965 manufactures were in excess of $6 billion compared to $2.38 billion in 1958--two and one-half times growth in seven years. These values are essentially for equipment using the electromagnetic frequency spectrum, except for broadcast and television receivers; neither are regular telephone and telegraph equipment included.

The Interdepartmental Committee for Atmospheric Sciences, of the Federal Council on Science and Technology, published[2] in 1965 a survey of the economic significance of the portion of telecommunications which uses atmospheric transmission and involves radiation in the electromagnetic frequency spectrum. This analysis showed a 1962 "annual expenditure" of $17 billion which, projected to 1965 is estimated to be considerably in excess of $20 billion. Table I from the ICAS Report shows a breakdown of such expenditures as sales, revenue (or operating costs in the case of non-revenue services), and other expenditures for electromagnetic telecommunication equipment, operations or services. Table II estimates $26 billion as the 1963 depreciated U. S. investment in systems, equipment, and research and development facilities, related to the use of electromagnetic frequency spectrum for telecommunication. Table III shows the estimated employment in these activities.

The FCC Annual Report[8] for 1965 reports 5.3 million transmitters for the uses of radio for industrial, land transportation, aviation, citizens, and other safety and special services. This represents more than a <u>fourfold growth</u> from 1.3 million in 1958. Broadcasting authorization grew from 5,405 to 8,771 in the same period and produce an annual revenue of $2.8 billion (1965). At the end of 1965 there were more than half a million radio frequency assignments of record to U.S. radio services. FCC assignments as of August 1966 totalled over 392,000, representing a growth of more than 40,000 during the year.

The nation's airways simply could not function without radio means for communication, navigation, and control. It is estimated that 35,000 employees and $750 million of the annual budget of the Federal Aviation Agency directly provide these facilities and services. The airlines themselves devote an substantial portion of their budgets and operations to telecommunications; the ground communications network alone is massive and the requirement is growing--the airlines recently obtained proposals for a nationwide private microwave system which would tie together about 260 locations in the United States, over 23,000 route miles. The system would provide about 3 million channel miles of voice circuits, and 2 million channel miles of teletypewriter and data circuits. Besides the 260 microwave terminal sites, there would be 640 repeater stations.[9]

The transportation and public utilities industries,[10] as well as the petroleum industry, now have major investments in extensive and intricate radio services, for information and control vital to the services and economic life of these activities. Both point-to-point systems and 150,000 mobile radios comprise the nerve systems of power companies ranging from the the giant Bonnevilles and TVA's to statewide private networks, to the smallest REA cooperatives. The petroleum industry relies on point-to-point radio for linking refining and pipeline distribution operations, and another 100,000 two-way radios in all phases of operations from exploration and drilling to production, refining, and distribution by barge, ship or truck. Railroads use extensive private radio systems. Southern Railway is developing its own internal communications net using microwave links for an information processing network for its operational and management needs. This is said to be the largest privately owned microwave communication system outside the communications industry, involving $30 million acquisition of communications equipment and computers. Trucking lines also propose major new private or cooperative microwave facilities, and even use of satellite communications. All facets of the transportation industry, rail, bus, taxis, trucks and planes use more than 350,000 two-way mobile radios. Personal telephone paging units, a substitute for personal portable telephones, are growing in use; there are 2,000 units in the Washington area alone.

Use of radio has tripled in the past five years in local government agencies. From large highway maintenance departments to small rural school districts, local governments are using radio to improve service and reduce expense. Especially in

**I. Estimated annual sales, revenue, or expenditures for electromagnetic telecommunication equipment, operations, or services, 1962**

| | Millions |
|---|---|
| Manufacturing (value of shipments at manufacturers' prices) | $ 5 600 |
| Wholesale and retail trade in electromagnetic telecommunication equipment and components (estimated markup or net revenue) | 850 |
| Installation and repair services | 1 400 |
| Electromagnetic telecommunication operations and maintenance expenditures or revenues | 8 350 |
| Research and development expenditures not included in other categories (industry, government laboratories, universities, and other nonprofit organizations) | 800 |
| Total | $17 000 |

**II. Estimated U.S. investment in electromagnetic telecommunication systems, equipment, and R&D facilities, 1963**

| | Depreciated Value, millions |
|---|---|
| **U.S. Government** | |
| Department of Defense and other National Security Agencies | $ 9 000 |
| Federal Aviation Agency | 635 |
| National Aeronautics and Space Administration | 250 |
| Treasury (Coast Guard) | 450 |
| Commerce (Maritime Administration, Weather Bureau, National Bureau of Standards, etc.) | 70 |
| U.S. Information Agency | 90 |
| Others, including Atomic Energy Commission, Agriculture, Interior, Justice, Tennessee Valley Authority, Veterans Administration, St. Lawrence Seaway, etc. | 75 |
| **Manufacturing, net fixed assets** | 1 000 |
| **Non-U.S. Government communications services, facilities, and equipment** | |
| Broadcasting | |
| Television | 370 |
| Radio | 260 |
| Common carrier | 1 700 |
| Safety and special services, including state and local government | 1 500 |
| **Research and development, equipment and facilities not reported elsewhere** | |
| Government, industry, and educational and other nonprofit institutions | 350 |
| **Repair and installation services, and test and measuring equipment and facilities** | 300 |
| **Wholesale and retail trade** | 450 |
| **Consumer electromagnetic telecommunication equipment** | |
| Television receivers | 5 500 |
| Radio receivers | 4 000 |
| Total | $26 000 |

**III. Estimated employment in electromagnetic telecommunication activities, 1963**

| | Thousands of Employees |
|---|---|
| **Manufacturing** | |
| Government and commercial telecommunication equipment | 270 |
| Television and radio receivers | 115 |
| Electronic components | 160 |
| **Operations and maintenance** | |
| Government | |
| Department of Defense, including Armed Forces and civilian personnel | 400 |
| Other federal agencies | 60 |
| Nongovernment | |
| Broadcasting | 100 |
| Safety and special services | 140 |
| Common carrier | 40 |
| Government facilities operated by private contractors | 30 |
| **Research and development** | |
| Government, industrial, educational, and nonprofit R&D laboratories, not included elsewhere | 40 |
| **Wholesale and retail electromagnetic telecommunication equipment distribution** | |
| Television and radio receiver distribution | 70 |
| Other: commercial equipment and parts distribution | 15 |
| **Repair and installation services** | |
| Television and radio repair shops | 80 |
| Other: commercial equipment repair and installation services | 20 |
| Total | 1500 |

Booker, H. G. and C. G. Little (1965), Atmospheric research and electromagnetic telecommunication--part I, IEEE Spectrum, Vol. 2, No. 8, 44-52.

fire departments and law enforcement, the use is growing, having doubled in the past five years. Traffic safety studies have shown that an important contributor to fatality statistics is inadequate post-crash communications for summoning and coordinating aid; new concepts in highway communication and vehicle control are being considered for widespread use, many involving uses of spectrum.

Federal government uses of telecommunications are led by military uses for command, control and guidance of forces and weapons, for detection, surveillance, deception and destruction of hostile weapons and forces. There is almost $8 billion "electronics" content in the 1967 budget of the Department of Defense. Approximately 70 percent of electronics is estimated to be comprised of the telecommunication activities and equipment using the frequency spectrum. The requirement for increasing sophistication and capabilities of defense telecommunications is best illustrated by the programs for development of satellites for electromagnetic applications. Satellites are to be exploited for heavy communication routes to Europe, Africa and the Western Pacific, as well as for tactical-mobile field communications. Satellites also provide for measurement of radiation background and operation of nuclear test detection sensors for surface, high altitude and deep space nuclear tests, as well as navigation capability and geodetic observations. In addition, advanced ground-based radar provides for surveillance of space objects and diagnostic information on our own satellites in orbit--new radars capable of high resolution and using much greater power and frequency bandwidth are under development and coming into use. A family of Over-the-Horizon radars capable of detecting aircraft and missiles far beyond the radar or line-of-sight horizon has been developed. These new systems will bounce radar signals off the ionosphere and send them to the surface of the earth several thousand miles beyond the horizon, overcoming earlier limitations of radar capabilities to detection of objects within line of sight. To obtain more efficient use of high frequency transmission, extensive "oblique sounder" networks are being developed in a common user configuration for Defense Communication, and pilot studies of "short term prediction" of usable frequencies have been undertaken.

Meteorological satellites of NASA and ESSA are introducing automatic picture transmission systems for global and local weather surveillance. International "World Weather Watch" and "Natural Disaster Warning" are essentially telecommunication concepts in advanced environmental science and services, requiring extensive networks and a variety of sensors and communication capability.

International broadcasting by the Voice of America is a $30 million annual activity, with a plant investment of approximately $110 million. Over the next three years, an additional $50 million plant investment has been authorized. Some 120 radio transmitters throughout the world, primarily in the high frequency band, beam to all continents information on United States and world events. The Voice of America's keen interest in new technology and increased capabilities is reflected in a technical research program of several hundred thousand dollars annually, most of which is concerned with improving effectiveness of broadcasting utilization of the high frequency spectrum. There is a trend toward an immense increase in radiated power (transmitters of 1 to 5 million watts), as well as consideration of use of satellites.

The ICAS Report[2] listed present uses of the spectrum in (approximately) descending order of annual expenditure or revenue as follows:

1. Military uses for the command, control, and guidance of friendly forces and weapons, for the detection, surveillance, deception, and (if necessary) destruction of hostile weapons, activities, and forces.
2. Television broadcast
3. Mobile communication to and from aircraft, ships, and land vehicles.
4. Navigation
5. Long-distance radio relay of telephone calls
6. AM and FM broadcast
7. Public safety by law enforcement agencies, fire services, civil defense, etc.
8. Space telecommunication
9. Geodesy
10. Atmospheric research by remote electromagnetic probing
11. Voice of America broadcasts

12. Citizens' band

13. Amateur radio

14. Dissemination of time and frequency standards

One of the main features of changing technology and growth of telecommunications has been the trend to higher frequencies in the spectrum. As radio telecommunication usage has increased, the International Telecommunications Union has found it necessary to extend specific regulatory control to higher and higher frequencies. The upper limits of the ITU coverage are given in Table IV below:

TABLE IV

Upper Limits of International Telecommunications Union Allocations of Frequencies

| Year | Maximum Frequency of Allocations Cycles Per Second |
|---|---|
| 1927 | $6 \times 10^7$ |
| 1938 | $2 \times 10^8$ |
| 1947 | $1.05 \times 10^{10}$ |
| 1959 | $4 \times 10^{10}$ |

Some of the more important specific growth areas and problems of spectrum utilization and frequency mangement are discussed in this chapter. The rapid evolution of technology itself creates potentials and affects the character of growth. Finally, some of the major areas of latent demand which have come to the attention of the Panel are noted briefly.

SERVICES AND APPLICATIONS

## Satellites

The clearly dominant consideration for future spectrum utilization is the advent of the communication satellite. Reliable transmission or relay is possible over areas of the globe within "line of sight" of the satellite, using the vast regions of the frequency spectrum above about 100 MHz. Before satellites, only the region of the spectrum below about 25 MHz was useful for transoceanic, intercontinental transmission--less than one percent of the portion of the spectrum technically usable via satellites, and transmission was variable. Satellite use of frequencies to about 15 GHz is feasible with present technology, and the range is potentially extendable by order of magnitude. Intercontinental television became practical by satellite relay, along with reliable high-capacity trunks for telephone, telegraph and data. Satellite transmission appears to be more economical than present cable transmission for great distances, besides offering flexibility and potential connection to many ground locations.

The great distance range over which satellites are useful poses the corollary problem of interference to and from ground services. Most technically usable regions of the spectrum had been allocated to short-range ground services prior to the advent of satellites. The International Telecommunications Union in 1963 reallocated some bands for satellite and space applications, both exclusive and shared. It is clear, however, that imaginative and economic possibilities for satellite telecommunication applications vastly exceed the allocated frequency bands.

The Director of Telecommunications Management has said[11] "if we are going to use satellites for all of the things being advanced, if we are going to fully exploit this new technology, then we are going to have to do some long range planning," as far as the frequency spectrum in concerned. He has suggested that unless "a lot of thought is devoted to this subject, the frequency limitations will ultimately deter the use of this capability." He foresaw a serious problem as early as 1970, and the need for an "all out research and development effort to enable us to make better use of the spectrum."

The Communication Satellite Act of 1962 laid down objectives and Federal responsibilites for satellite communication activities in the United States. The Communications Satellite Corporation was established as a regulated private-enterprise monopoly to excercise United States participation in a "single global commercial satellite system." The International Telecommunication Satellite Consortium (INTELSAT) was created in August 1964, and now includes more than 50 countries. During 1965, commercial service began via Early Bird, the world's first commercial communication satellite. Ground stations used in experiments with TELSTAR, the AT&T experimental satellite, were converted for commercial service with the Early Bird satellite. The Federal Communications Commission has responsibility for authorization and domestic regulation of commercial satellite communication service, rates, and frequency allocations.

The Report of the Director of Telecommunications Management to the Communication Subcommittee, Committee on Commerce, U.S. Senate, in August 1966, stated with respect to commercial satellite services:

> "There is increasing reliability in the launch and emplacement of communication satellites in precise orbits and geographic positions. The maintenance of stability and the precise positioning of space satellites over extended periods is proving possible. The channel capacity and life of the satellites has been steadily increasing...
>
> For the first commercial communications satellite launched (INTELSAT I) the estimated life in terms of circuit years was 240 x 1.5 or 360 circuit years. . . The satellites being launched this year (INTELSAT II) are designed for 240 x 3 circuit years, or 720 circuit years. . . The Satellites for launch in 1968 (INTELSAT III) are being designed to accommodate 1,200 x 5 circuit years, or 6,000 circuit years.
>
> Multi-purpose satellites are now in conceptual development to meet the needs of the aeronautical, maritime, point to point, and distribution communication services, including television, voice and data. Multiple access techniques permitting many earth stations to operate with single satellites on a concurrent basis are proving feasible.
>
> The recent experiment in gravity gradient stabilization indicates that at synchronous altitudes. . . this technique is usable. . . This will clear the way for higher antenna gains, increased effective radiated power, and more effective control of the geographic area covered by the satellite radiated signals."

Two U. S. Government programs initially to lease major communication satellite service have been the NASA-APOLLO Program, for voice and data circuits between the U.S. and NASA tracking stations throughout the world, and the Department of Defense for trans-Pacific circuits from Hawaii to Japan, the Philippines, and Southeast Asia.

In May 1966, the United States sponsored, under the auspices of the International Telecommunication Union an international seminar to stimulate interest in international satellite communications and acquaint representatives from foreign nations with current capabilities in earth station technology for use of commercial satellites.

Besides the international communication satellite activities, a number of proposals have been made to the FCC for domestic private systems. Among the parties so far urging the FCC to authorize non-common carrier satellite communication facilities are the broadcasting networks, the American Trucking Association, the American Petroleum Industries, National Association of Manufacturers Communications Committee, and educational broadcasting interests. Perhaps the most intriguing of the proposals has been made by the Ford Foundation, which would propose a non-profit satellite television distribution system. The system would carry commercial television network broadcasting at a cost estimated by the proponents to be lower than present revenue carriers now provide, and would apply the earnings to subsidize nationwide educational television programming and distribution. There are a variety of other proposals, including some for direct television broadcasting.

Available frequency space, and interference from proliferation of systems and ground stations, are among the arguments cited by opponents of such authorizations.

Besides commercial satellite communication systems, there are extensive developments[12] and initial applications for government use, though it is "the policy of the Federal Government to make maximum practicable use of the commercial facilities of the INTELSAT Global Communications Satellite System."

The Initial Defense Communications Satellite Project (IDCSP) is regarded as developmental, but will be increasingly employed to pass high priority operational traffic. The IDCSP will consist of about 15 satellites randomly spaced in near synchronous equatorial orbits, spin stabilized, with lifetime of one and one-half to two years. The 7 and 8 GHz bands will be used, and surface terminals will be located on the East and West Coasts of the United States, in Europe, Africa, Hawaii, the Philippines, Okinawa and on Navy ships. At present there are two fixed ground terminals and four transportable terminals deployed and ready for operation. During 1967, 18 additional earth terminals will be deployed. An advanced Defense Communication Satellite Project (ADCSP) is planned as the operational system which will replace the IDCSP in the 1970's. A DOD Tactical Satellite Communications Program anticipates the feasibility of satellite relays to meet tactical mobile communication needs even where high mobility is required--in field echelons, and with ships and aircraft. The VELA Satellite Program is designed to provide a satellite-based nuclear detection capability for events occurring on the earth's surface to the outer reaches of space. A Navy Navigation Satellite System, operational since 1964, has led to installation of receivers aboard attack aircraft carriers operating in Southeast Asia. Various efforts are underway related to future uses of such systems; long-term ephermeral predictions for ship board use are being prepared, and development of receivers is underway for differential positioning in aircraft and smaller ships.

Other major government applications include aeronautical communications and meteorological surveillance. The FAA participated in a joint government-industry experiment using SYNCOM III which demonstrated the feasibility of satellite relay stations for long-range aeronuatical communications; FAA is also exploring the possible use of such stations for navigation and data-acquisition functions in the air traffic control system. The first ESSA operational meteorological satellite system was launched in 1966, to be followed by satellites equipped with automatic picture transmission system cameras. Some 30 nations of the World Meteorological Organization are equipping to receive transmission from this system, as a phase of the World Weather Watch.

The potential demands for space and satellite communications warrant serious concern for the possibilities for accommodating them in the frequency spectrum. The Director of Telecommunications Management has initiated a study of the requirements of government agencies and industry anticipated for use of satellite telecommunication, called the "Space Service Spectrum Saturation Study!" The results of this study are expected in late 1966.

It is inevitable that much of the spectrum required for satellite communication must be obtained by sharing with already crowded ground microwave (point-to-point) services. Technical standards for this sharing are complex and controversial, each service striving for margin to provide for future expansion. Microwave services alone are already congested in approaches to major metropolitan centers as New York and Los Angeles, where access requires several extra hops or "dog legs."

## Mobile Radio

The FCC Chairman's year-end statement of December 28, 1965, makes the observation that, "The growing need for more frequency space to relieve congestion in these (the land mobile). . . services is one of the Commission's most pressing problems." The FCC Annual Report for 1965 states that, "The ever increasing use of radio in the land mobile services and the need for frequency space to accommodate this growth have been under intensive study by the Commission as well as by the Industry. The overall problem is being considered by the Advisory Committee for Land Mobile Radio Services established by the Commission more than a year ago. The committee is composed of over 200 representatives of industry, commerce, state and local government, and user groups througout the country...."

The land mobile services comprise four basic categories: public safety, land transportation, industrial, and common carrier. The public safety usage includes not only police dispatching, but fire vehicles as well as portable use in directing fire-fighting, use by foresters, highway departments in construction, maintenance, and rescue operations, and many other applications. Land transportation uses include two-way radios in railroads, taxis, buses and trucks. Industrial uses range from direction of material-handling vehicles to the control of missile testing; from the repair of broken power cables and the coordination of pipeline operations to small businessmen's dispatch of delivery and repair trucks. The common carrier mobile telephone system provides service for individuals on the move, such as doctors.

The FCC Annual Report, after summarizing the present studies of the means to provide for this service, observes that, "Meanwhile, more requests for additional frequency space have been filed by land mobile users, many for new uses of radio. For example, the Automobile Manufacturer's Association has requested that a new service be established, a highway emergency location plan radio service (HELP), to provide emergency radio communication for the motorist. Also, the Forest Industries Radio Communications Association has requested a number of additional frequencies. . . ."

From 86,000 licensed transmitters in 1948, the number of Land Mobile Radio equipments have grown to 2.3 million in 1965. This growth was possible largely through successive improvement of technical standards, including "channel splitting." Channels which began with 120 KHz spacing, are now, after several steps, operating with 15 KHz separation and coordinated geographic location. Other technical improvements facilitated this increased intensity of frequency sharing.

Today, in almost all the major metropolitan areas, there is considerable interference. In Los Angeles, for example, frequencies may be shared by as many as 50 to 60 users, operating 500 or 600 mobile units. all in the same geographical area. A recent FCC inspection trip to New York City confirmed intense congestion there. The manufacturers contend that "the channel splitting process is just about finished . . . we think we are at the end of the line."

Projected demand for Land Mobile transmitters shows a growth from the present 2.3 million to 3.7 million in 1970, and 5 million in 1977. The FCC review of this subject for the Panel said,

> "There is no doubt that pressures by the land mobile services . . . will increase. Despite the efforts of the Advisory Committee for the Land Mobile Radio Services, the insatiable demands for mobile radio probably will rapidly out-distance their efforts, technically, operationally, and administratively. As can be seen . . . the growth of the land mobile services has been far greater than the population growth of the country, averaging about 12 percent per year since 1961, though it is expected to level off during the next two years, probably because of saturation of the frequency bands.
>
> "What are some of the measures being taken to provide some degree of relief? . . . Under consideration is the sharing of frequencies by services other than those to whom the frequencies are allocated . . . The reduction of channel spacing is still another possibility. The common carriers are making increased use of paging techniques using tone signalling where the individual, on receipt of a signal, calls a prearranged number by wire-line . . . the demand for such service is illustrated by the 2,000 customers of the still developmental service in Washington, D. C. . . . The use of a computer to make better geographical allocations might produce a few more usable channels in crowded areas . . . These measures can be considered short-term relief at best. Long term relief must continue to be sought not only from within the Commission, but from the Federal Government, the industry and the scientific community in general. An overall review of the use of the spectrum between 25-960 Mc/s has been suggested . . . Another step, theoretically, would be a review of the technical standards for television systems, with a view to making them more rigid . . . to free spectrum for reallocation to mobile services. However, any change which would obsolete existing receivers in the hands of the public probably should be regarded as a practical impossibility . . ."

The JTAC Report[3] of 1964 is rather pessimistic about the possibility of further technological aid to the needs of mobile service:

> "In order to meet these needs, either additional allocations must be made or new operational techniques, or both. Tests conducted by various engineering organizations confirm that 1000 Mc/s is a practical high limit for land mobile systems. The increasing inefficiency of practical omnidirectional mobile antennas at high frequencies, coupled with increased propagation losses . . . make this limit one that is likely to stand for some time. Finding additional frequencies below 1000 Mc/s will of course be a great challenge . . . . As for the possibility of developing new operational techniques . . . much has already been achieved in going to very narrow band FM, with large dynamic range capability in receivers. Further improvements via single sideband or suppressed carrier double sideband have been carefully studied and found to hold no promise for improvement in spectrum utilization. There is, however, a good chance that the use of computers in making better geographical allocations could produce a few more channels in crowded areas. Also, where the service to be rendered permits, it might be possible to make use of multichannel coordinated base stations systems and multiple receiver pickup with a resulting saving in frequency spectrum. Both of these possibilities should continue to be investigated."

Studies have been made of concepts for efficient queuing of calls, i.e. trunking with computer-allocated time sharing, as well as "cell" concept of use of multiple weak transmitters each covering a small area of a grid. The indication for the cell concept is that there is excessive signal fluctuation within the cells caused by irregular terrain and building obstacles.

## Broadcasting

Television and radio are the most pervasive media of present day American lives for entertainment, information on events, and cultural influence. Broadcasting also accounts for about 82% of the non-government allocations of the spectrum below 1000 MHz. The direct economic values of broadcasting exceed $10 billion. Station revenues in 1965 were approximately $2.8 billion; growth has been about 10% per year for the last ten years. Manufacture (value of shipments) of radio and TV receiving sets is estimated at $3.6 billion in 1966, compared to $1.5 billion in 1958 (even accompanied by reduction in the wholesale price index). Retail and installation would multiply these figures by 1.4. Annual servicing expenditures are estimated at $3 billion for 1965.

It was noted earlier that authorized stations have grown more than 60% during the past seven years, to a total of 8771, distributed as follows:

| | |
|---|---|
| Commercial AM | 4097 |
| Commercial TV | 689 |
| TV translators | 2023 |
| Educational TV | 125 |
| Commercial FM | 1565 |
| Educational FM | 272 |

Commercial AM broadcasting stations continue to increase, though at a slower rate during the past two years. The JTAC[3] has recommended enlarging the standard broadcasting band by extending to frequencies below 540 KHz. Many local and regional stations would like to extend hours of operation beyond present sunrise-sunset limits, but because of potential interference cannot obtain authorization. A number of "clear channel" stations would propose increasing power from present 50 kilowatts to 500 or 750 kilowatts, improving service and extending coverage to vast rural areas which do not have adequate night time radio or television service. There are both technical questions of the extent of coverage and interference, and unknown potential economic effects on smaller stations. If listeners were appreciably drawn away from smaller local and regional stations, some localities might ultimately be deprived of local radio service.

The growth of commercial FM stations is increasing markedly, from 1092 stations in 1961 to 1564 in 1965. There are now 7-1/2 million receivers in the U.S. Over half the homes in New York City have FM receivers, and similar proportions down to a low of 1/3 are found in nine other major cities. Important factors are the nighttime service given by FM (the only satisfactory nighttime service in many localities), the advent of stereophonic broadcasting, the decreasing cost of FM receivers, and increasing uses in automobiles. About a third of FM broadcasting stations are authorized to furnish additional multiplexed communication service, such as background music for commercial establishments.

Growth rate of TV stations has been smaller than that for radio stations in the past five years. Increase must be provided for largely by UHF channels. In localities where VHF stations exist, UHF competition may be uneconomic because of poor transmission characteristics. It is an objective and expectation of the FCC to provide for full development of "all channel" broadcasting. If the proliferation which characterizes AM broadcasting were to be realized, the TV channels would, using present standards, be fully utilized. Pay TV, and "CATV" could drastically affect the picture. Interest in noncommercial educational TV continues to increase, with 15 new stations authorized in 1965. Nearly every major city in the U.S. now has at least one educational TV station. The FCC has reserved 621 VHF and UHF channel assignments throughout the nation for non-commercial educational operation. An airborne educational ETV operation has been conducted from a plane circling over Indiana by the Midwest Program for Airborne Television Instruction. The operation has been the subject of controversy; because of the high altitude of the transmitter, the transmission precludes the use of same and certain other channels for ground-based UHF TV assignments over a wide area. While the FCC has recognized the quality of these programs and a valuable service to small schools in rural areas, which could not otherwise afford ecuational TV, the present judgment is that the operation on a regular basis would deprive communities of the opportunity for regular UHF stations, both commercial and educational. This controversy is a precursor of the problem posed for direct satellite broadcasting.

Pay television concepts are also under consideration; the FCC has permitted limited and trial operations to aid ultimate decisions as to any regular pay-TV service. Only one such operation is presently being conducted. Another significant development of TV services is the "community antenna television" (CATV); CATV systems may be highly important not only in the present concept of retransmitting broadcast programs, but also as potential forerunners of all-cable television (including programming) for metropolitan areas. CATV systems presently pick up programs of TV broadcasting stations by means of an antenna, or bring them in by cable and microwave radio relay. The signals are distributed to the homes of subscribers by a coaxial cable system which can carry up to a dozen or more channels. There are competitive effects on broadcasting stations, especially local TV stations.

It is interesting to compare the present dollar yield of spectrum utilization of the various broadcasting services, using only the index of total station revenues per MHz bandwidth of spectrum allocated. These striking contrasts are not altered appreciably even allowing for manufacturing, servicing, and other expenditures related broadcasting services. AM broadcasting revenues in 1965 were $0.8 billion for a 1.07 MHz bandwidth. The FM band produced $23 million for 20

MHz bandwidth. The television bands, allocated 492 MHz bandwidth, produced $2.0 billion. The comparison, revenue per unit bandwidth, is:

| | $Million per One MHz Bandwidth |
|---|---|
| AM | 750 |
| FM | 1.1 |
| TV | 4.0 |

TV revenues are growing several times more rapidly than radio revenues, and from a base now 2½ times larger. Present use of the VHF television portion of the spectrum yields about $50 million per MHz bandwidth, allowing for sales and services along with revenue.

There have been recommendations, including those of JTAC[3], that growth of TV might be provided for by more efficient utilization of the spectrum.

> ". . .In the U.S., . . . there are three separate TV bands with a total frequency ratio of almost 20 to 1 from the highest to the lowest channel. Differences in propagation, antenna effectiveness and receiver performance between the various bands--particularly between the VHF and UHF bands--have led to relatively heavy use of the lower frequency channels with little use of the higher channels.
>
> "There is no doubt that a single relatively compact TV allocation would lead to more even distribution of utilization and economies in equipment construction that could then be 'reinvested' in improved technical performance. Hardly any changes have been made over the past 15 years in the spectrum utilization standards of TV systems.* Studies of what improved receiver performance, or improved antenna systems might offer toward providing the required potential number of TV stations within a more limited total allocation should also be thoroughly explored in the laboratory and field.
>
> Work on evaluation of the need and toward improving utilization efficiency should go on even though at the outset it would appear that existing investments in stations and receivers might dictate perpetual maintenance of the status quo. The situation in the 30-1000 Mc/s band is definitely too far out of balance to freeze earlier decisions without continual investigations and field trials of many different technical approaches. . ."

In Panel discussions of this problem, it was suggested that improved receiver standards alone would not appreciably increase accommodation of TV assignments, as most interference problems are co-channel. The adjacent-or-other channel "taboos" limit only close spacings or co-locations, and the usual distribution of assignments is claimed to remove this factor as a limit to overall utilization of the TV band.

Analysis presented to the Panel by ITSA gave an example alternative assignment plan for VHF which would reduce geographical spacings by taking into account antenna directivity, alternating vertical and horizontal polarization for adjacent assignments, precise frequency offset, and acceptance of interference-limited coverage rather than noise limited. It is estimated that the plan would, for example, provide an increase from 19% to 41% of the percentage of communities ("market areas") which can have 3 or more VHF television services, and from 9% to 36% the communities which have 4 or more services, and so on. The FCC observes, however, that the effectiveness of some of the elements of such a plan are not yet proven, as, for example, the advantage of cross-polarization discrimination. Furthermore, the plan, while increasing the number of services available to the public, would reduce the coverage of some stations with probable consequent revenue losses.

Other possibilities for increased accommodation of television within limited allocations might also lie in major changes of transmission technical standards, perhaps involving (as yet impractical) bandwidth reductions. Without marketable advances in performance of equipment, there would be little incentive for industry to expend efforts on such standards.

Aeronautical and Marine Telecommunications, Radar, Navigation, Guidance, and Radio Measurement Systems

A broad, and probably the most rapidly intensifying, aspect of spectrum utilization for commerce and defense concerns aeronautical and marine communication and control, radar and radio navigation applications, the launching and tracking of space vehicles, and radio measurements used in geophysical or environmental probes, such as meteorological sounding, with their telemetering and control functions. Equipment manufactures for these applications, excluding the air/ground and ship/shore communications, rose from values of $1.4 billion in 1958 to $4.5 billion in 1963, a compound growth rate of 25% per year.

Such systems provide the surveillance, control and response functions for the

*This statement does disregard the provision for color television within the original assigned bandwidth for black and white transmission. The color television provision is a remarkable example, along with stereophonic FM multiplex broadcasting, of improved technical efficiency of spectrum utilization where industrial incentive exists. Not much incentive is apparent to reduce the total bandwidth of television transmission for the purpose of accommodating more stations within the allocation; indeed, for the broadcasting industry itself, the consequence would be increased competition.

defense of the nation, and the maintenance of safety and order of commerce. Second to television broadcasting, they utilize the next largest proportion of the prime regions of the frequency spectrum below about 1000 MHz. Aviation and marine uses of radio require intricate coordination among government agencies and industry, as well as with a number of technical and policy-making groups, and with other countries. The Radio Technical Commission for Aeronautics (RTCA) has a number of technical committees and studies concerned with the problems and radio services for aviation in the United States, and the International Civil Aviation Organization (ICAO) devotes extensive efforts to planning and coordination of uses of radio for international aviation.

Overocean aircraft communication, relying on densely used high-frequency channels, has been called the weakest link in transoceanic aviation. A survey of the use of regional and domestic air route high frequencies was made in 1964 preparatory to revision of the high frequency allotment plan for aeronautical mobile radio services at the 1966 ITU Extraordinary Administrative Radio Conference concerning aeronautical radio frequencies. The Communication Satellite Corporation plans to provide soon an "Aerocom" satellite, intended to provide by 1968 an increase in reliable air/ground communication capacity over the North Atlantic; the service must use for aircraft/satellite connections the already allocated VHF aeronautical bands.

The coexistence of satellite signals and ordinary VHF aeronautical communications in the same bands may present some problems. Studies are being made to determine possible methods for sharing bands with normal VHF communications which use amplitude modulation; frequency modulation will be used via satellite, with channel spacings of 50 KHz as planned by FAA and the ICAO. Communication is only one of the functions that satellites may eventually perform in air traffic control systems. Overocean traffic surveillance by synchronous satellites, as well as navigation aids, and meteorological surveillance for air routes are also developing.

About 60,000 civil aircraft use the 75 MHz marker beacons located throughout the U.S., and 100,000 use the air traffic control services. Some 30,000 are estimated to use the "glide-slope" service, and 15,000 the VORTAC/DME (a positioning system) service. The FAA has reported that its traffic control towers in 1965, using radio and radar, handled nearly 38 million aircraft operations. These operations account for 17% of all U.S. government radio frequency assignments. While the ultimate value of the services is not known, an example is provided by the estimate of $400,000 cost to airlines of a single radar maintenance shutdown in Chicago.

The review of aeronautical communication and navigation for the Panel stressed that accommodation of operational requirements was being increasingly limited by the level of use of the crowded bands. Close spacing of frequencies has been improved by making receivers more stable and selective; however, this trend is now being limited by the functional requirements of the emission and bandwidth needed to obtain the necessary system resolution. It was noted that "further spectrum advantage is obtainable by the form of time sharing possible in pulsed systems using repetitious code combinations for coherent response."

Besides the congestion of these services in their allocated bands, there are external sources of interference to air navigation. The FCC Annual Report[8] notes: "In the Far West, garage door openers produced interfering signals that invaded vital aviation and navigation frequencies. . . 285 offending units had to be located and removed from the air . . . in the Southeast, three instances of interference to air navigation frequencies were traced to radiation from malfunctioning intruder alarms. Such signals are difficult to hear on the ground because of their rapid attenuation, but are audible in aircraft up to 15 miles from the source. Several hundred alarms are already in the hands of the public and proposals to relax further the manufacturing requirements promise a bigger problem in the future."

Future requirements involving increased airspeed and numbers of aircraft will focus sharply on spectrum limitations. Height finder radars are an important element not yet incorporated in the air traffic control system. Study and tests are in progress on collision avoidance systems as well as comprehensive airborne transponder systems connected to traffic control for automatic exchange of flight data on position, altitude, fuel, speeds, and ground control signals.

A large volume of marine communication is now handled in the high frequency bands, well suited to the longer range operations, but accruing a great deal of congestion from use also for short ranges in coastal and inland waterways. The ITU

Panel of Experts[6] has recommended complete conversion to single-sideband operation, and the JTAC[3] has recommended transfer of short-range operations to the VHF bands. Newly developing prospects for data transmission in commercial shipping, and for automated operations on shipboard, will increase communication requirements on the seas and in harbors. The use of satellites, again, may meet some of these needs. Electronic replacement or supplement of the "bow lookout," and bridge-to-bridge communication for navigation in congested waters, are areas of active development for the maritime services.

Long-range navigation systems account for much of the use world-wide of the low frequency portion of the spectrum, say from 10 to 130 KHz, because of the uniquely stable, low loss transmission. This use is expanding greatly, with the introduction during the past decade of new systems such as Loran C, Decca and Omega.

A wide variety of radar applications is one of the most important factors in future spectrum utilization. Radars are used not only for defense surveillance and air traffic control, but aboard ship and aircraft for weather and traffic surveillance, for police control of traffic, and for precise geodetic and seismological applications. There are potential applications in commercial security.

Present radars occupy about 30% of the spectrum between 1 and 10 GHz and many use wide frequency bandwidth to achieve target resolution. Information reviewed by the Panel suggested that increasing applications and advancing technology will require greater concentration in allocated bands, and probably additional frequency space. Some important developments for future radars appear to be increasing the bandwidth requirement. The trends appear to include high power, say 10 megawatts average power, pulse duty factors of 1% or greater, greater resolution capabilities (a foot or less) using bandwidths of possibly 500 MHz, and great agility of the radiated beam, either using multiple beams or beam switching rates of a few microseconds. From these parameters, the output power density of such a high resolution radar might reach 20,000 watts per MHz bandwidth. Though the number of such super-power systems may be necessarily small there would appear to be an impending concentration near 5 GHz. Frequency utilization of radars is closely related to effects of the atmosphere and response to "clutter." Weather-surveillance radars and clear-air turbulence detectors must operate at frequencies effectively coupled to atmospheric scattering or absorption; target-detection radars must avoid these effects as far as practicable.

Even at an 8 percent growth per year, the equipments in this overall class of navigation, search and detection, and radio measurement, would increase 15 fold in the next 35 years. Perhaps this cannot be realized; will aircraft navigation and control equipment really increase 15 times? Can an orderly environment exist which would require such an increase to be feasible, reduction in airspace separation is a necessity, as would be a tremendous increase in the traffic handling capabilities of air terminals. These requirements would in turn demand corresponding increase in resolution capabilities of the navigation, surveillance, communication and control facilities.

The evolution of transport serves to illustrate also the telecommunication coupling of environmental measurements and observations with the operations of commerce. Planning is underway for the supersonic transport. Efficient and economical operation of the supersonic transport is achieved only by direct flight from departure to destination. Complete flight details along the entire route must be known pre-takeoff. A landing slot must be reserved in advance, taking into account all other traffic. The calculation of a pre-takeoff flight plan may include meteorological conditions over half the distance around the earth. These must be accurate, timely, and in sufficient detail for interpretation and use. Data collection and dissemination for weather and oceanography are examples of the growth in use of the spectrum that would appear to lie ahead in this class of services.

## Latent Demand

There are other potential demands not really represented in discussion of existing telecommunication services.

Commercial information processing networks may be one of the most important such examples. A Report[13] prepared for the National Commission on Technology, Automation, and Economic Progress (1966) observes that:

> "The electronic computer is gradually becoming a common and major ingredient of all our traditional communication and information systems. Rapid developments during the past two decades have yielded a computing technology with present

capabilities that would have staggered the imagination of the early pioneers in this field only 20 years ago . . .

"A current development that promises to be of great importance and one that represents a dramatic advance over the past 20 years is the rapidly increasing worldwide capability to give ready and economical access to many computers . . ."

According to a report published by the American Federation of Information Processing Societies, today's U.S. investment of $8 billion in 35,200 working computers will rise by 1975 to more than $30 billion and 85,000 computers. One of the most important concepts in the future schemes for computers is the commercial information processing network for high capacity storage, processing and transmission. Project MAC (Multiples Access Computer) at MIT typifies the state of the art and present thinking regarding such a "computer utility." Good discussions have been published[14,15] on the concept of such networks and their applications in business, engineering, medicine, education, and research. These capabilities will depend on <u>vastly increased communication capabilities, not now in general existence</u>. Whether all-out development is undertaken early remains to be seen. However, the potential demand and trend for extensive wide-band interconnection of computers seems clear. The requirement for spectrum vs. cables is an economic question in many applications.

An ocean data system[16] has been proposed which might provide consolidated acquisition and transmission of data for worldwide oceanographic and ocean meteorological programs. The system has involved extensive planning for efficient frequency utilization, (primarily HF so far), and is being considered cooperatively by the Intergovernmental Oceanographic Commission, the World Meteorological Organization, and World Weather Watch. The proponents suggest sharing international maritime frequency bands, and present maritime users are concerned with increasing congestion. Very high utilization of small bandwidths are planned for the ocean data for this service. R&D is also proposed to increase further the effectiveness of frequency utilization.

The experimental High-Speed Ground Transportation program has encountered difficulty in providing adequate telecommunications, i.e., communications and control, for the high speed train studies, due to limited available landmobile frequencies. A project is being initiated to study feasibility of guided transmission along trackside which can be effectively coupled into a moving train. Similar investigations are underway in Japan and England. The concept of guided transmission, using surface transmission lines or leaky wave guides, may also be important to future highway applications. Communication and control has been cited as a significant factor in highway traffic safety.

The role in law enforcement of new telecommunication technology and increased capacities is being studied intensively by the President's Commission on Law Enforcement and Administration of Justice. The growing crime rate, as well as court decisions upholding rights of individuals, have increased the need for rapid access to crime information. Identification of individuals and property must be accomplished quickly because of their high mobility. Means for public communication with appropriate agencies in emergencies, tactical and administrative communications between elements of a law enforcement agency, and regional or national channels interconnecting law enforcement agencies and central data sources, are examples of the expanding communication needs.

Some public notice has been given to "picture phone" experiments, and demonstration service has been set up in three major cities. It was indicated to the Panel that "for the telephone system to provide one percent of its subscribers with picture phone service would require doubling present plant facilities!"

Less costly and possibly more imminent is the concept of the "home communication center," for financial transactions, ordering of goods and services, document transmission, and many record communications provided today by mail.

Not all new telecommunication services, or even these few examples, will entirely employ transmission through the atmosphere using the frequency spectrum. Most must certainly be realized through cable or wave-guide transmission. But the technical and economic exchangeability of wire and radio media, and the occurrence of many situations in which use of the spectrum is a more economical approach, may be expected to increase future pressures for spectrum utilization.

FREQUENCY MANAGEMENT

It was noted earlier that the Communications Act of 1934 gives the Federal Communications Commission responsibility for regulation of non-(Federal) Government* interstate and foreign telecommunication, including frequency utilization. The Act provides that radio services belonging to and operated by the U.S. Government shall be assigned and regulated under the authority of the President; this authority is delegated[17] to the Director of Telecommunications Management, who also coordinates policies and standards for telecommunication of Government Agencies. Apart from the question of balance of allocations between government and non-government users, there appear to be strong bases advanced for this separation. The separation is rooted mainly in the direct responsibility of the President for national defense and the missions of the Federal Agencies. The administration of non-government telecommunications in the national interest requires processes which provide adequate public representation of economic and political forces.

In any case, the Panel was not charged to consider the regulatory and policy structure for telecommunication management, except as research and engineering may be effectively related. Indeed whatever may be said** of the United State's unique and traditional dual frequency management, the benefits derived by the U.S. from spectrum utilization appear to exceed, by any meaningful index, those of any of the most advanced nations. Growth toward saturation, however, brings into focus problems of basic technical, operational and economic nature, many common to or affecting both government and non-government spectrum utilization.

Frequency assignments of record in the United States were approaching the number 500,000 at the end of 1965. (Some 104,000 of these were government assignments). The growth of FCC assignments was noted earlier at 10% per year. Forty-seven percent of the spectrum below 40 GHz is allocated for government use, *34% for non-government, and the 19% balance is shared. At frequencies below 1 GHz, the government has 28%, non-government 61%, and the 11% balance is shared.

The most apparent trend is to the use of higher frequencies, illustrated by progressive extension of international allocations to 40 GHz (shown earlier in Table IV)--there are a few operations at higher frequencies, mainly of an experimental nature. The trend is being intensified by demands for satellite applications and microwave trunks. A statement to the Panel from the ODTM, that, "judging by the activity in frequency assignments, 68% of the growth is above 25 MHz" suggests, however, that continued concern is justified for the region below 25 MHz, if indeed this saturated portion of the spectrum is absorbing the 32% balance of growth! A special IRAC discussion[21] of the future of HF utilization reported to the Panel, emphasizes that, while point-to-point trunk and some mobile uses of HF will decline in favor of cable and satellite transmission, marine and HF broadcasting requirements are expected to continue to increase, and new applications such as Over-the-Horizon Radar are also to be reckoned with.

Non-Government Frequencies

Reviews for the Panel, and the FCC Annual Report, identify major issues in future non-government spectrum utilization as the need to provide for satellite communication, mobile radio, microwave systems for both common carrier and private uses, to develop UHF television, and to optimize the emerging role of CATV operations. Specific discussion of most of these problems has been given earlier in this Section.

Attention of the Panel was drawn to a number of questions of technical standards and other technical information which is becoming increasingly desirable in the regulatory and planning activities of the FCC. A tabulation of these topics is included in Appendix 3. Some of the more important questions concern land mobile radio, as optimum modulation and channel width, intermodulation and transmitter noise problems,

*"non-Government" used in the text means non-Federal Government.

**Much has been said. See, for example References 18, 19, and 20

*Direct correlation is not evident between allocated bandwidth and numbers of frequency assignments, probably because a preponderance of wideband radar assignments are for government use.

multiple access systems, techniques for "flutter" reduction and the general problems of utilization of higher frequencies, background electromagnetic noise limitations, and methods for multiplexing and compressing information transmission. A more general need is expressed for advisory standards for complete systems for all services, which might be used as a reference in FCC rules, or as assumed standards for a service. Characteristics of transmitters, receivers, antennas, etc., would be included. Additional emphasis is placed on the need for electromagnetic noise information, data and methods of measurement for such interference or "radio smog" from electrical equipment in industry, homes, and vehicles. There are questions of resolving and reconciling various standards and methods of measurement of noise nationally and internationally. Measurement and analysis of the level and growth of such noise as a limitation to radio uses are needed. Monitoring and analyzing uses of the spectrum and sources of interference are becoming enormously complex. While some mass survey techniques are employed, each case of interference has its own peculiarities, and actions required must be carefully and individually evaluated. Moreover, existing law does not permit the control of manufacture and sale of interference producing devices except for functionally radiating equipment; interference from electrical equipment must be located and dealt with as individual occurrences.

The FCC Annual Report notes that:

> "The plethora of non-licensed radio frequency devices continues to pose major problems. The numbers and types of such devices grow at an explosive rate. Typical are radio controls, wireless microphones, radio and TV receivers, electronic intruder alarms, gadgets and toys, appliances, industrial heaters, medical equipment, and ultrasonic devices used in industry and home . . . an estimated 500,000 residential garage door openers are in use today, and 90 to 100 thousand are being manufactured annually."

The FCC at present has no authority over the manufacture of most electrical equipment capable of causing such interference; legislation has been proposed.

Of the FCC's 1,500 employees and $17 million current annual budget, about 25 engineers and approximately $280,000 of the budget are engaged in the technical research and development area. The Commission relies for technical guidance largely on advisory committees, research of other agencies, industry research, technical publications, and data developed through the public inquiries and rule-making proceedings. Current FCC study programs include: (1) the experimental UHF TV transmission and analysis in New York City, (2) studies of noise related to the Land Mobile Advisory Committee work, (3) occurrence of off-path microwave interference from scattering, (4) automated retrieval of terrain data for use in computation of frequency sharing, (5) study of trans-equatorial field strength in the standard AM broadcasting band, related to regional sharing of channels, and (6) automated spectrum monitoring. Laboratory programs have been set up for studying the characteristics of receivers, transmitters, as well as interference and its suppression. For example, recent studies have been made on a proposal for audio filters to permit increase in AM broadcast station powers without increased interference to adjacent channels, the characteristics of FM receivers currently manufactured, and various devices proposed for selective ringing of shipboard radio-telephone installations. The laboratory also tests radiating equipment for "type approval," as transmitters, diathermy, industrial ultrasonic equipment, etc.

The FCC frequency assignment records are maintained on punched cards which facilitate analysis and printing. The proposal for a new frequency use is made by the prospective user, and examined by the FCC, considering existing station operations to avoid causing or receiving interference. Some work has been done in the computer generation of frequency assignment plans for broadcast services; there is interest in these possibilities for other services such as land mobile and microwave.

U. S. Government

The ODTM identified for the Panel also the major issue of future provision for "space services." The intra-government Study of Space Service Spectrum Saturation was outlined to determine the needs of the Space Services between now and 1980, and the means of their satisfaction in the light of "potential spectrum saturation." Results of this study are expected in late 1966.

Technical support indicated needed for frequency management included: (1) automated frequency assignment and sharing procedures, and (2) development of technical standards for frequency management features of government transmitting and receiving equipment and antennas. The examples of urgent current technical questions cited by the ODTM were: (1) Can there be more current frequency assignments in the HF portion of the spectrum? Currently, processing time is about 17 weeks for routine frequency assignments. Is it reasonable to look forward to "real time" propagation information and assignments? (2) What are effective standards for earth-station siting and interference protection for the space services?

Technical standards are developed largely as a cooperative voluntary effort of the using agencies, in the IRAC's Technical Subcommittee, in which the FCC also participates. Effective rules have been developed for government operation of low power devices and ISM* equipment which are compatible with long-standing FCC rules in this area. In more complex and costly areas, such as radar design, and HF transmitters and receivers, progress has been slow and partial in achieving standards which contribute meaningfully to efficient spectrum utilization. The ODTM has developed and issued recently the first codification of regulations and procedures for frequency management by government agencies. ODTM studies support developments for computer processing in frequency administration. The current ODTM staff comprises approximately 60 people; the Fiscal Year 1967 budget of $1.6 million includes $425 thousand for research.

## INTERNATIONAL PROBLEMS

Important, often controlling, international aspects of spectrum utilization relate to frequency allocation, radio regulation, system standards, operating procedures and tariffs.

The International Telecommunication Union (ITU), a treaty organization, periodically holds Administrative Radio Conferences which revise the Table of Allocations in accordance with negotiations based on needs expressed by governments for radio services and frequencies throughout the world (See Appendix 2). Each country as well as regional groups establish subdivisions of the allocation table as needed. An intricate framework of radio regulations is necessary to avoid harmful interference and achieve effective international communication. Allocation by service provides a degree of international compatibility, and permits efficiencies in frequency sharing among fairly homogeneous classes of service.

It was the ITU Administrative Radio Conference in Geneva in 1959 which adopted regulations extending the allocated frequency spectrum to 40 GHz. A new Master International Frequency Register was established; the International Frequency Registration Board (IFRB) now maintains a fully computerized file of international registration and for new notifications, reviews circumstances indicating interference with existing uses. For high frequency broadcasting, countries now provide seasonal broadcast schedules to the IFRB in advance of their implementation. The Board is responsible for suggesting time and frequency adjustments needed to improve reception and reduce interference. The 1959 Conference also set up the ITU Panel of Experts to study means of reducing congestion in the high frequency band; a report containing 38 recommendations was issued in 1963. Appendix 3 contains three of the recommendations pertaining to technical studies.

An Extraordinary Radio Conference in 1963 made allocations of bands for space (including satellite) communication and Radio Astronomy. A further World Administrative Radio Conference on Space Communications can be recommended by the ITU Administrative Council when developments and demands warrant. The 1963 Conference used technical information prepared by the CCIR for establishing feasibility and conditions for sharing of microwave bands with space services. It is clear that the applications of satellite technology and the needed frequency allocation will dominate issues in international telecommunications for some time in the future. Potentially critical issues lie in the possibilities for internationally competitive proliferation of satellite communications systems, as well as international satellite broadcasting.

The CCIR role in studying technical and operating questions is well illustrated by the space-services sharing recommendations. The CCIR comprises fourteen international study groups, organized corresponding to various classes of services, plus transmitters, receivers, and propagation. CCIR recommendations, while not obligatory, carry great weight. The Radio Regulations provide that choice of apparatus, techniques and measurements shall be in accordance with CCIR recommendations. Developing countries, an increasing factor in international frequency utilization, often specify CCIR recommendations as the basis for equipment to be procured for such new systems. The

* Industrial/Scientific/Medical.

international system standards which are implicit in CCIR recommendations can affect both spectrum utilization and international marketability of equipment manufactured.

Some of the more important CCIR programs related to spectrum utilization are reproduced in Appendix 3. A resolution adopted at Geneva in 1963 exhorted studies of "optimum spectrum utilization;" improved information is sought on tolerable wanted-to-unwanted signal ratios, as well as statistical methods for assessing the probability of interference and for maximizing the effective sharing of frequency bands. Another recent action has been the drafting of an international handbook on antennas, to give design guidance which fosters improved antenna directivity for reduction on interference.

The CCIR provides the most effective medium for technical guidance and advancement of international telecommunications, and potentially for achieving increased efficiency of spectrum utilization. In the U.S., participation in the work is largely voluntary by industry and government organizations, with coordination by the Department of State. There is a natural emphasis on topics and positions of interest to the participants, their mission and competence, or products and services. The strength of the system is seen in many original, sophisticated, and practical technical contributions. But there are major gaps in contributions, for example, on bandwidth compression, signal-to-interference ratios, and broad questions of overall efficient utilization of the spectrum. The ITSA and FCC among the government agencies are most active in CCIR work.

The International Scientific Radio Union (URSI) is an effective forum for international discussion of the scientific basis of radio communication. Its activities in information theory, antennas, tropospheric propagation, solar control of ionospheric propagation, and natural noise sources over the entire frequency spectrum are pertinent to questions of efficient frequency utilization.

# III. SCIENCE AND ENGINEERING

The Panel has reviewed broadly the status of technology, and projections for research, in major fields of telecommunication science related to utilization of the various regions of the frequency spectrum.

Certain "common denominator" kinds of research can be identified which lead to increased capabilities throughout the spectrum. These concern information theory, propagation, and noise, some fundamental problems in networks, filters, and frequency stability, and studies of alternative media such as waveguides and cables. This section discusses some of the more important of these research topics considered by the Panel, as well as topics in engineering methods, technical standards, and operations analysis related to frequency management.

## INFORMATION TRANSMISSION TECHNOLOGY

An intrinsic requirement for bandwidth is the width of the signal spectrum which must be preserved in order to render the sampled signal waveform reproducible sufficiently undistorted. In addition, because of the response characteristics of physical networks, and frequency instability, additional frequency range or guard space is also required. Total frequency space assigned to a channel includes the entire band, the intrinsic bandwidth plus guard space. For the past thirty years there has been considerable development and increasing application of new systems of modulation such as frequency modulation and pulse code modulation. These have the interesting property that it is possible to exchange bandwidth for signal-to-noise ratio. This means, in effect, that we can transmit the same information in the same time with less signal power, provided we are willing to use more bandwidth. If the signals are quantized, as in pulse-code modulation, the converse is true, that is, we use less bandwidth at the expense of more signal power. The notion of conserving bandwidth alone is inadequate to optimize spectrum use; it is just as meaningful to conserve energy density radiated, even though extra bandwidth may be required.

In a very practical sense, the performance of information transmission techniques is judged by the criteria of bandwidth and signal-to-noise ratio required to transmit information at a given capacity (bits/sec.). Obviously, the smaller the bandwidth and the signal-to-noise ratio to transmit a given capacity, the smaller the demand on the spectrum. Effective transmission in this sense can be achieved by (1) maximizing the capacity of the link for given bandwidth and signal-to-noise ratio, and by (2) compressing the information to be transmitted.

Insight to "channel capacity" has grown profoundly since Shannon's introduction in 1948 of the concept and basic theorem of bounds on information capacity for transmission related to limiting noise. Many practical applications have been stimulated, and are showing capabilities of several-fold increase of capacity and/or accuracy of transmission in given channel widths as compared to present day radio operating practices. Further progress in these techniques is especially important to uses in the prime portions of the spectrum below 15 GHz which are already becoming congested, and may be of critical importance to mobile radio applications which, for reasons of physical limitations, may be required to continue development at frequencies below 1 GHz.

An article by J. R. Pierce[22] illustrates the orders of magnitude of transmission capacity which might be gained...

> "... Shannon's equations demonstrated for the first time just how wasteful most communication channels are. He showed for example, that a letter of English text contains only about one bit of information, if due allowance is made for letter frequencies in English words and the predictable constraints that exist in all written languages. In other words, with an efficient coding scheme, one should be able to transmit ordinary English text with an expenditure of one bit per letter. Thus the information contained in a typical 300-word page of typewritten text is only some 1,800 bits. To transmit 300 words with ordinary data encoding techniques, however, requires the expenditure of about 12,600 bits (a seven bit code group for each letter). To transmit a page of text by facsimile requires about a million bits. In this case, of course, the entire page is transmitted as a picture, which is mostly white space. If the page were read aloud over a pulse-code modulation telephone channel one would need more than 11 million bits to transmit it. Finally if the same page were transmitted by television for the time needed to read it aloud, say three minutes, more than 10 billion bits would be required. An obvious way to reduce the number of bits transmitted in this case would be to send the picture once, which would take only a thirtieth of a second, and then send a few bits of information containing the message, 'Hold picture on screen for three minutes'....."

Compare these information rates, also, with estimates[23, 24] of the human capacity of less than 50 bits/sec to assimilate visual or oral information.

## Channel Modulation and Coding

In studies of channel modulation and coding, a widely used measure of "efficiency", and the objective of much research, is in terms only of the required ratio of signal energy to noise power per Hz of bandwidth ($E/N_0$) to derive one bit of information. The more efficient the system is in terms of $E/N_0$, however, the greater bandwidth required. Contemporary coding and modulation techniques operate over a wide range of $E/N_0$ values. For example, for an error rate of one per $10^5$ bits, a 16-level SSB transmission, using a bandwidth of about ¼ Hz per bit/sec information rate, may require about 500 times the theoretical minimum $E/N_0$. Other effective modulation/coding schemes, using bandwidths of 5 to 10 Hz per bit/sec information rate, reduce the required $E/N_0$ to 2 to 5 times the theoretical minimum.

While minimum signal-to-noise ratio is not an adequate criterion of efficiency when the spectrum is shared with other services, neither is minimum bandwidth. Rejection of interference may be increased by use of wider bandwidth, and the increased rejection allows closer geographical spacing of services. For example, the 200 KHz bandwidth assigned to FM broadcasting channels could be reduced, without loss of fidelity or service, at the expense of increased transmitter power and greater geographical separation of stations in crowded areas. Newer "spread spectrum" systems are effective from the point of view of contributing reduced detectable interference per unit bandwidth, and with proper coding and sufficient bandwidth they can work well in strong interference.

Current research reflects adequate awareness of the problems of maximizing the capacity of a system for limited signal power without critical constraints on bandwidth--the power limitations of space probes, surveillance radars, and scatter communication links have emphasized this need. On the other hand, the problem of overall optimization of bandwidth and signal powers for a number of services sharing a band appears to have had less if any serious attention. This is much more complex, requiring some valuation of the bandwidth in the exchange for signal-to-noise ratio, and posing difficult definitions of optimization where an aggregate of services is involved. Emphasis on bandwidth compression alone, by frequency management authorities and CCIR, largely reflects traditional assignment patterns.

Further, much of the work so far has used highly idealized characterization of the transmission channels. Increased capacity of channels is most critically needed in the lower frequency portions of the spectrum, which depend upon ionospheric and tropospheric transmission media. Unfortunately, the propagation and noise characteristics of these channels do not correspond to the usual "mathematically convenient" models. Reviews for the Panel stressed the need for emphasis on time-varying dispersive channel models truly characteristic of ionospheric and tropospheric transmission media. Specific recommendations were noted for:

(1) Channel measurements aimed at testing and quantifying channel disturbances in terms of the kinds of mathematical models used in system theory, representing both convolutional ("multiplicative" or time-varying dispersive disturbances) and "additive" noise.

(2) Laboratory simulators of physical channels, capable of representing real channel behavior and disturbances.

(3) Signal design (modulation and coding) for maximizing the efficiency and reliability of using the spectrum in the presence of real channel disturbances, for effective diversity and combining techniques, and multi-level (M'ary coding) to determine their tradeoffs in spectrum utilization.

(4) Signal separation techniques and receiver design for multi-signal environments; real-time and quasi-real time pattern recognition techniques for improving signal separation capabilities.

(5) Adaptive source-data compression techniques.

## Source Encoding or Information Compression

In "source encoding," statistical characteristics or redundancy in picture and speech (or even teleprinter) transmission can be exploited to reduce the bandwidth or time required for transmission. Advantage can be taken of the "activity statistics" in multiplexing an ensemble of transmissions. "Vocoders" (speech bandwidth compressing techniques) have achieved some success; it seems likely that the

50,000 bits/sec capacities required for normal speech via pulse-code modulated systems could be reduced to perhaps 10,000 bits/sec by multiplexing large groups, and further, by the use of vocoder, to 1,000 to 2,000 bits/sec per voice channel. The compression coding of TV has not been so rewarding and the future is not clear. Techniques have been simulated on computers which permit rate reductions of two to three times over conventional transmission. In theory, reductions of several hundred times are suggested. Research on reduction of picture bandwidths appears to have diminished to very low activity. This is understandable, though nonetheless disappointing, in view of the large portions of the spectrum devoted to picture transmission, and probable increasing demands. Bandwidth occupancy is perhaps the one dimension of spectrum utilization in which a ten-fold or greater intensification of spectrum use may reasonably be sought. Studies of both channel capacity and source encoding should be fostered vigorously in relation to <u>overall</u> improvements in spectrum utilization. Independent progress in "integrated circuitry" and storage devices of large capacity is being achieved rapidly and will likely make economical in a few years signal processing applications for which the complexity now results in prohibitive cost. Development of signal separation (interference rejection) techniques related to anti-jam principles may also be an important modulation/coding topic for increased spectrum utilization.

Much of the emphasis on realistic channel characterization stresses the need for closer relation of research on information transmission to that on propagation.

The urgency with which the ITU regards the need for advances in bandwidth compression is expressed in a number of questions and study programs of the CCIR, and also by a recommendation of ITU Panel of Experts.

## PROPAGATION DESCRIPTION AND PREDICTION, NOISE AND ANTENNAS

The dependence of telecommunication on propagation of electromagnetic waves along the ground and through the atmosphere, and descriptions of the various mechanisms of propagation, have been developed extensively by the JTAC and ICAS Reports[3, 2]. Approximately two thirds of the JTAC text is devoted to propagation, noise and antenna factors in spectrum utilization, with descriptions and data for line-of-sight, ground-wave, ionospheric and tropospheric propagation. The ICAS Report discusses atmospheric research relevant to the various propagation mechanisms. The Panel considers it pointless to duplicate the contributions of these surveys, which are recent, assumed to be available, and are commended to the reader. Propagation prediction and description has been considered by the Panel in the perspective of overall science and engineering efforts related to efficient spectrum utilization.

A knowledge of transmission loss and dispersion characteristics of the transmission medium, with their time variation and relation to terrain and atmospheric conditions, is essential to effective system design and spectrum sharing.

In planning systems the designer is faced with crucial problems in selecting sites, choosing frequencies, and in determining the power and antennas required, the modulation, coding, and diversity systems to be employed, and the performance to be expected. Transmission loss for nearly all paths is variable, and the development of sound models for prediction is of fundamental importance. Besides transmission loss, the characterization of dispersion, and fading with its time, frequency and spatial relationships, is essential to design of modulation and diversity methods. In the absence of accurate knowledge of propagation capabilities and limitations, systems must be built by expensive cut-and-try or over-design. An important aspect of optimization is the avoidance of unnecessary interference. Historical examples of expensive retro-fit in spectrum utilization include the reallocation of FM and TV channels from the frequency range 42-50 MHz to much higher portions of the spectrum as the result of interference; the 1948-52 freeze of television assignments in the U.S. was precipitated by belated discovery of strong interference fields.

International negotiations for frequency allocations and sharing arrangements especially require a strong base of propagation understanding for rational agreements, protection of national interests, and maximizing the possibilities for exploitation of the spectrum as an international resource. Examples of some propagation-related questions pending before the ITU in the CCIR concern: (1) communication-satellite systems sharing the same frequency bands as microwave radio relay and other terrestrial radio systems, as well as frequency bands for re-entry communications, (2) atmospheric absorption and refraction effects for line-of-sight transmission at frequencies above about 10 GHz, (3) means for obtaining diversity for line-of-sight relay and tropospheric scatter systems (e.g., is frequency diversity necessary and justified on economic grounds, as compared to space diversity which does not involve redundant spectrum occupancy?), and (4) the capabilities of HF inospheric propagation for high-rate data transmission and error control with related questions for international system design.

The unique and essential role of propagation information in the international aspects of spectrum utilization commends continued vigorous support and direction of research in this field by the government.

An order of priority for propagation research by regions of the spectrum is problematical. Transmission at frequencies above 15 GHz, through millimeter to optical waves, is least known and stirs the greatest hopes for ultimate expansion of wide band telecommunications; however, atmospheric attenuation is a limiting factor, and physical limitations of components make technological development expensive and slow. Tropospheric and line-of-sight transmission from 30 MHz to 15 GHz are much better understood, but important improvements of engineering predictability are still needed. Challenging research questions remain. This portion of the spectrum is clearly absorbing the greatest present expansion of services, including satellite and mobile radio services. Finally, the long range capabilities of ionospheric transmission at frequencies below about 30 MHz have established the status of this region of the spectrum as a unique international resource; the most severe and growing congestion of this portion of the spectrum led to the special ITU Panel of Experts study in 1963. The U.S. investment <u>per MHz</u> of bandwidth is greater below 30 MHz than in any other region of the spectrum.

The possibilities over the next twenty years of expansion to higher and higher frequencies have led the Panel to consider the importance of effort in the following order:

## Region Above 15 GHz

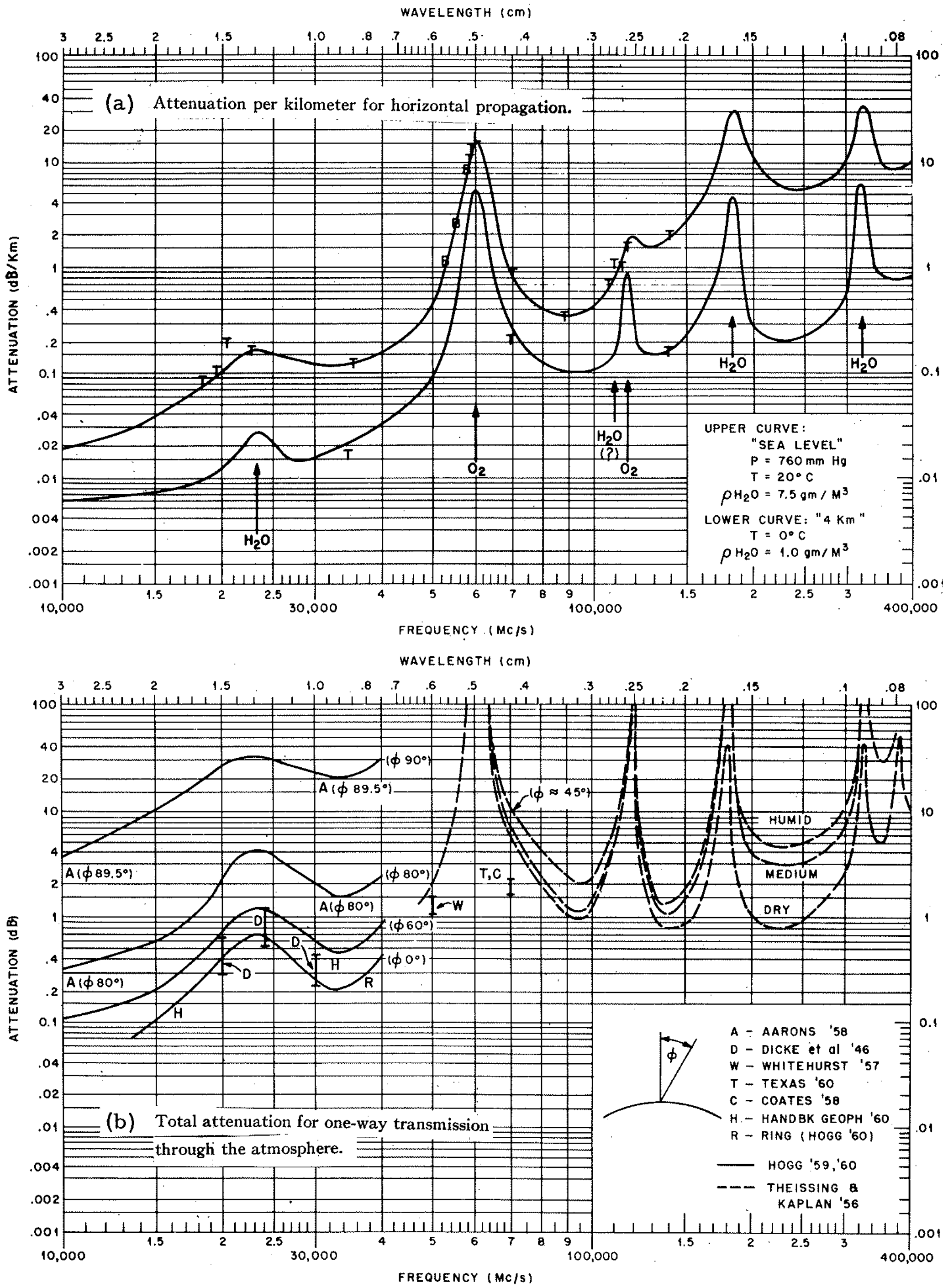
Constituents of the atmosphere, including water vapor, oxygen, rain and snow are known to attenuate electromagnetic waves, especially at frequencies above about 15 GHz, and also to result in noise radiation at these frequencies. In addition, the refractive index structure of the troposphere is known to affect the bending and coherence of the wave front. Present estimates of attenuation for one way transmission through the atmosphere[25] are given in Figure I. Examples of recent experimental[26] communication studies include transmission of television signals over a 19 Km path in California at about 94 GHz (3.2 millimeter), and show the scintillation and attenuation effects for various weather conditions. High quality television and voice transmission were reported obtainable even during moderate rainfall.

Reviews for the Panel suggested that the water vapor attenuation effect is not fully understood at millimeter wavelengths. It turns out that there is a stronger attenuation by water vapor in air than one would predict on the basis of laboratory measurements of pure water vapor. Attenuation is stronger near the oxygen resonance (5 mm) than away from it. As far as using the wide bands of frequencies near 18, 30, and 100 GHz is concerned, the major restriction is rainfall. Statistics on rainfall--the sizes of heavy showers and their occurrences, are inadequate for prediction of performance of propagation paths and planning of alternate routes. It appears that technological developments of sources and detectors is lagged by understanding of transmission. As far as optical wavelengths are concerned, attenuation and beam broadening (scintillation) effects in clear air are encountered, and rain, fog and snow can interrupt transmission. Optical transmission may be significant in studies of clear air turbulence.

A CCIR Study Program on Tropospheric Absorption and Refraction (Geneva, 1963) effectively summarizes the studies needed:

> "1. the measurement and development of methods of prediction of the attenuation of radio waves passing through the troposphere, as a function of frequency, angle of elevation, geographic location, time and constituents of the troposphere, including oxygen, water vapor, water droplets, the distribution of the sizes of the drops and rainfall rate, etc.,
> 2. the measurement and development of methods of prediction of the refraction, scintillation and coherence of the wave front of radio waves passing through the troposphere as a function of frequency, angle of elevation, geographic location and time.,
> 3. the measurement and development of methods of prediction of the noise radiation from atmospheric gases, clouds, and precipitation."

The ICAS Report summarizes related atmospheric science studies needed for optical and infrared telecommunication:




Meyer, James W. (1966), Radar astronomy at millimeter and submillimeter wavelengths*, Proc. IEEE, Vol. 54, No. 4, 484-492.

*Quoted from: Rosenblum, E. S. (1961), Atmospheric absorption of 10-400 kMcps radiation, Microwave J., Vol. 4, No. 3, 91.

**Figure I**

"1. The space-time variations of density and temperature of atmospheric constituents, and the consequent space-time variations of refractive index,

2. The telecommunication characteristics of electromagnetic signals propagating via the same region of space,

3. The relationship of the refractive index structure and consequent telecommunication capability to the much more widely available information on weather and climate,

4. The absorption of electromagnetic waves by atmospheric constituents,

5. The non-linear processes occurring at high power fluxes."

## Region From 30 MHz to 15 GHz

Most of the development of use of this portion of the spectrum has come since World War II; the rate of increase of use has been such that approximately 80% of the total national expenditure on spectrum usage is now concentrated here. Propagation is affected by the lower atmosphere (troposphere) and terrain. Climate, weather, atmospheric structure and turbulence, and terrain irregularities play important roles in determining the strength and fading properties of tropospheric signals. While absorption is not of major importance, refractive and scattering effects are. Estimates of the propagation loss, long and short-term variability, and structure of the signal, are essential to design of point-to-point relay, satellite, broadcasting, navigation and guidance systems. It is important to be able to predict the weakest signal levels, exceeded for large percentages of the time, to estimate probability of service and required power; on the other hand, strong signals, exceeded for small percentages of time, impose the interference limitations. At present, predictions of long term median values of transmission loss, derived empirically from many hours of measured data obtained under various conditions of climate and terrain, can be made with a standard error of about 4 decibels. This means, however, costly over- or underestimate of the median value by a factor of 10 times for a significant number of paths; much greater errors are involved in the estimate of weak and strong signal statistics.

Besides transmission loss data, refractive effects limit navigation and guidance systems, dispersion and fading effects affect design for bandwidth which can be transmitted, and "off-path" scattering by aircraft, hail, and precipitation can be a limiting factor in interference.

Another CCIR Study Program, on Tropospheric Propagation Factors Affecting the Sharing of the Radio Frequency Spectrum by line-of-sight radio relay systems, space communications, etc. specifies the need for the following studies:

"1. Measurements, for different path lengths and for at least as long as one year, of the cumulative distributions at hourly median transmission losses for each month of the year;

2. measurements for different path lengths of within-the-hour cumulative distributions of signal levels;

3. measurements for different path lengths of the cumulative time distributions of fading below specified amplitude levels above and below the hourly median level;

4. long term measurements, at appropriate frequencies above 100 Mc/s and up to at least 20 Gc/s of the cumulative amplitude and fade duration distributions of transmission loss over representative wanted and unwanted signal propagation paths, between highly directional antennas oriented at various angles in elevation and azimuth away from the directions of maximum path antenna gain;

5. the transmission loss measurements referred to in 4 above should be related to the location and size of aircraft, hail, or other reflecting object near the propagation path;

6....

7. measurement of correlation over long periods of time between hourly median transmission losses on wanted and unwanted propagation paths with a common terminal;

8. determination of the effects of the common terminal terrain and climate on the correlation of errors of prediction of the hourly median transmission losses exceeded for various percentages of the time for the wanted and unwanted signal propagation paths ......."

Similar study programs are urged by CCIR for use in international spectrum and system planning on the effects of tropospheric refraction, for prediction of tropospheric scattering beyond the horizon, and for investigation of multipath and fading characteristics of tropospheric transmission. One of the most urgent problems concerns the sharing of satellite systems with surface systems. Scattered interference from thunderstorm cells and other sources pose an, as yet, unevaluated limit to such sharing.

A most fundamental problem concerning tropospheric propagation prediction is the present poorly understood physics, not only of electromagnetic propagation through an irregularly stratified, turbulent, refractive medium, but of the structure of the atmosphere itself in terms of fluid mechanics. Hour-to-hour field strength variations are largely uncorrelated with any presently known and observed physical changes in the atmosphere--the long term "climatic" correlations are of the crudest sort.

In the long run, more than electromagnetic research needs to be done. Fluid mechanics research on the atmosphere is needed, on a dimensional scale that is only of secondary interest in weather forecasting and weather modification problems. Traditional radio studies have been concerned with the refractive index of the atmosphere. The refractive index depends upon both temperature and humidity, and these elements affect the dynamics of the atmosphere quite differently. Separate studies of the temperature and humidity variations are essential for understanding the cause of the fluctuations. Additional support for such fundamental research should probably be directed to competent fluid dynamics workers brought to close relationship to the radio studies.

Some newly identified electromagnetic problems may be expected to be of increasing importance as systems of increased sensitivity are employed, especially for space communications. One example is the attenuation and noise temperature of the clear earth atmosphere. The noise limitation is now observed to be other than discrete radio sources--there is an additional background radiation amounting to about 3.5 degrees K, believed related to expansion of an oscillating universe. Thus, wherever we point an antenna beam--toward a space probe or satellite--it sees this radiation in addition to our own atmosphere. There is also an observed unexplained attenuation, greater than theoretical, by the earth's atmosphere at frequencies about 2 GHz. It is not known if the losses are higher at lower frequencies, nor what is the explanation. The coherence limitations for a wavefront passing through the atmosphere from a source in space are not well known; this question affects how large an antenna array can effectively be used on the ground before suffering from atmospheric distortions.

Region Below 30 MHz

This is the most densely congested portion of the spectrum, the oldest from the point of view of usage, and the most favored for research in earlier years. Point-to-point heavy trunk circuits, and even some mobile applications, will transfer to satellite relay and cables. At the same time, increased broadcasting and maritime use is indicated, and even point-to-point applications where great flexibility is required. New technology is emerging to exploit this region of the spectrum, such as detection systems and "over-the-horizon radar" mentioned earlier. Effective new digital transmission systems are being introduced to provide good transmission quality for narrow band links or spurs connected to cable or satellite main trunks. Some requirements are uniquely well suited to HF, as a portion of the "ocean data" system. VLF transmission penetrates the sea surface for submarine communication, and provides for very long-range navigation systems and world-wide standard time and frequency services because of good phase stability; the LF region provides good ground wave coverage for broadcasting and for the most accurate radio navigation systems. The whole concern of the International Panel of Experts Study (1963) was for the frequency band between 4 and 27½ MHz; along with recommendations for transfer of some services to other portions of the spectrum, continuing increase of congestion was foreseen.

Regular long-term ionospheric predictions for frequency planning at present provide estimates of median values of usable frequencies on a world-wide basis, which appear to be good when transmission is by F2 layer, or E or F1 layers. Neither the variation about the median, nor effects of sporadic-E ionization nor the effective heights of reflection are well predicted. Sporadic-E and elevation angle predictions are of first order importance in planning of frequencies and antennas; there are a number of examples of costly transmitting and receiving installations which could obtain more effective performance, and cause less interference, if design of antennas and choice of frequencies could be based on improved predictions.

An interest is developing for short-term predictions to allow effective exploitation of a regional pool of frequencies under common control. The Defense Communication System employs "oblique sounders" in a common user configuration to provide current observations of usable frequencies on a few selected paths. Both the DCA and the Navy have sponsored studies at ITSA in short-term predictions which make use of pooled observations in a region, with correlation techniques and ionospheric indices used to predict conditions a few hours forward. These are far from operational systems; to provide reliable short-term predictions even for a limited region requires a significant development of prediction technique, indices and sensors. For high-frequency broadcasting applications techniques are being developed for current observation of coverage areas and usable frequencies. Their operational usefulness will depend on possibilities for flexibility and coordination internationally.

Perhaps the most important, and possibly most difficult, series of problems requiring study in the HF band are those of describing propagation of waves traveling through the dynamic, irregular ionosphere, and of determining the characteristic disturbances and perturbations imposed. Answers to these problems are especially important to the effective use of this portion of the spectrum for detection, direction finding, and radar systems, as well as for "signal design" for transmission.

An intriguing and potentially important phenomenon at HF concerns "low-angle" transmission. Where antenna design has been such as to radiate and/or receive effectively at low elevation angles, there have been observations of significantly increased reliability and strength of signals. Typical HF antennas do not respond effectively at low angles, except where high sites are involved, or vertical polarization is used over sea water (relevant to ship and buoy application). So far the phenomenon is not well enough understood to permit reliable estimate of the advantages obtainable in frequency utilization or system performance.

A number of these problems might be investigated using a large, highly directive, steerable antenna array, capable of operating in a bi-static or mono-static radar mode. Such an array, with the necessary instrumentation, has been suggested as a possible national facility for ionospheric telecommunication research; it would provide the experimental sensitivity and flexibility for investigation of many of the specific questions discussed above, such as the "low angle" and "irregularity" problems. The system would have to be capable of high resolution, steerable in azimuth and elevation, with sufficient transmitter power and receiver sophistication to achieve a new level of sensitivity and resolution in ionospheric propagation studies.

At frequencies below about 1 MHz there is continuing strong interest in propagation studies in relation to navigational systems employing pulses or phase comparison, as well as for communications and standard time/frequency transmission. Geophysical observation and exploration make use of frequencies all the way from fractional cycles per second through medium frequencies (above 1 MHz). The basic limitation on the performance of VLF navigation and frequency dissemination systems is the phase fluctuation imposed by irregularities in the lower ionosphere. Little is actually known about the properties of the fluctuations, or about the irregularities causing them. There is especially a need for descriptions of the correlation of the fluctuations in space, time, and frequency. At medium frequencies the behavior of the ionospheric wave is still not very well understood for some practical needs--for example, a good understanding of the reflection coefficient in the standard broadcasting band as a function of frequency and geometry is lacking. This lack prevents confident prediction of extended frequency sharing extended through sunrise-sunset hours for AM broadcasting.

Electromagnetic Noise Environment

The minimum signal level required for satisfactory reception in the absence of interfering signals is determined by the ambient electromagnetic noise. Throughout most of the usable radio spectrum, in built-up areas of population and industry where telecommunication services concentrate, man-made noise is usually the limiting factor, assuming good receiver design. In lower regions of the spectrum, natural noise limitations may prevail but are now well known. At frequencies below about 25 MHz, atmospheric noise usually limits; the atmospheric noise has been studied throughout the world for a number of years, and the CCIR has issued reports which serve adequately for most spectrum utilization considerations. An exception is the need for directional characteristics of the noise for new high-resolution systems at HF. At frequencies between about 25 and 150 MHz, galactic or solar noise is usually limiting in quiet receiving locations, but these levels are also adequately established for most telecommunication purposes.

Man-made noise originates in electrical equipment and lighting, transportation, industrial and power systems, auto ignitions, and many other sources including spurious emissions from radio receivers and transmitters. While some measurements are available, information on the level and effects of man-made noise is quite sketchy; at present, results obtained by different investigators are even difficult to compare because of differences in measurement techniques and conditions. An important deficiency in knowledge of electromagnetic noise as a limitation to telecommunications, and the main pollutant of the frequency spectrum, has been cited by other principal studies. The presence of such noise may require in cities a hundred to thousand times the transmitter power, in many applications such as mobile radio, compared to limitation by natural or receiver noise. The use of such higher transmitter power itself contributes additional interference through introduction of non-linear effects. Determination of the sources and levels of man-made electromagnetic noise, and prediction of the future increase with growth of population and industrialization, as well as of the effects of this noise on telecommunications systems, is needed to guide effective utilization of the spectrum and to consider counter-action, including the possible needs for legislation or regulation. The CCIR programs and FCC questions (Appendix 3) suggest specific technical data and methods of measurement needed.

## Antennas

Directional confinement of radiation and reception is another dimension and technique for spectrum conservation. In some regions of antenna design, however, where large structures are involved, it is often economical to invest in transmitter power rather than costly antenna directivity or advances of technology for obtaining antenna directivity economically. Important examples are at frequencies below 1 GHz, but especially below 100 MHz.

A great deal of antenna research in industry and government carried on toward specific system objectives is also highly relevant to efficient spectrum utilization. Research in antenna principles is also an attractive and natural field for academic work. A fostering of a portion of such studies on behalf of the broadest objectives of efficient spectrum utilization, as well as interpretation of the relevance of the results of many laboratories active in this field, should be an important feature of an adequate government program for spectrum conservation.

In the reviews presented to the Panel, it was indicated that large phased (including non-uniform) arrays and wire grid lens antennas offer promising characteristics for applications to many services in the lower frequency portion of the spectrum. Special attention to side lobe control is needed, which is often deemphasized in design of non-radar systems because of costs incommensurate with direct benefit to the using system. In the higher frequency portions of the spectrum, work on the focal region of large reflector antennas could lead to directional capabilities comparable to optical telescopes, with implications for reducing time and bandwidth in radar systems, and orders of magnitude improvements in information and range capacity of communication circuits. Other important possibilities exist in the adaptive or data processing antennas of both array and reflector types.

## NETWORKS AND NON-LINEAR EFFECTS

A really major technical constraint on density of utilization of the spectrum is the problem of avoiding interference to a weak signal received in the presence of strong signal, at a different frequency or even in a different band, emitted nearby geographically. Ideally, wave filters might prevent such interference, except for the cost of advancing the technology for adequate filters, the requirements of which are made severe by non-linear characteristics encountered in receivers. Spurious emission from transmitters, and its reduction by filtering and improvement of linearity of networks, is an analagous problem.

Advances in economical linear, narrow band filters, introduced in future equipments with commensurate improvement in frequency stability, could permit significantly greater density of utilization, especially at frequencies above 100 MHz.

## TECHNOLOGY FOR MILLIMETER WAVES AND BEYOND

The technology of sources, detectors, antennas and components for millimeter waves today corresponds roughly with that of microwave technology early in World War II. The potential utility of millimeter wave systems has long been hoped for, but research has not been really intensive. Progress is slow, and most serious applications are scientific. At frequencies much above 100 GHz, "breakthroughs" are awaited to advance both source and detector technology into really useful power and sensitivity ranges.

At frequencies below 100 GHz, substantial increases in power levels and efficiency of sources have been realized since 1960, especially using electron tube sources. Powers of the order of 100 watts (CW) or more can be obtained at 100 GHz, decreasing to less than a tenth of that at 150 GHz. A sub-millimeter gas laser using water vapor excited by pulsed electrical discharge, and several other gases using either CW or pulse, produces powers of the order of a watt in the 100 to 1000 micron region. (300 GHz). Gas laser research in this frequency range is very young, with relatively few experiments done on a limited number of gases, with most of the effort so far to identify emission rather than optimize power. Gas lasers appear to represent a hope for useful generation of power at submillimeter waves. Power generation by transistor, varactor multipliers and chains, appears to be at about the 10 to perhaps 100 milliwatt level at 100 GHz.

Point-contact diodes familiar in early radio and microwave uses remain in various forms the principal millimeter detector, modulator, and parametric amplifier. Overall receiver noise figures of about 15-20 dB are attainable at 50 GHz. As frequency is increased, fundamental limitations are encountered due to the diode's inherent barrier capacitance, spreading resistance, and parasitic lead inductance. Thus the minimum dimensions reached lead to fragility, short life, and poor noise figure. Alternative possibilities which show some promise include use of the distributed structure of bulk semiconductor. Some maser experiments have been done, and theoretical work on "quantum detectors" using paramagnetic materials, to down-convert the high frequency energy to microwaves where sensitive detectors are available.

Millimeter wave antennas are primarily parabolic reflectors, Cassegrain systems, and lenses. While some surface tolerance problems arise because of the small physical dimensions, these antennas can have greater directivity and much larger gain per unit cost than lower frequency microwave antennas. Atmospheric absorption noise tends to reduce the criticality of antenna noise (losses and side lobes).

Reviews for the Panel stressed the need for greater attention to thermionics and power supplies for tubes, but suggested that solid state research was adequately supported. The importance of development of reliable solid-state repeaters to enable any extensive telecommunication use was indicated.

The Introduction to a Special Issue on Millimeter Waves and Above of the Proceedings, IEEE, April, 1966, noted that "The potential of millimeter waves for a variety of uses has long been recognized. However, repeated disappointments at the slow progress of technology have tended to inhibit a favorable evaluation of any single step forward. The attendant lack of interest has fostered a correspondingly small scale of effort."

It would appear that a major incentive for great strengthening of research and development for "millimeter waves and beyond" lies in the objective of fostering overall improvement of spectrum utilization.

## ALTERNATIVES: CABLE, WAVEGUIDES

Confined media, such as cable and waveguide, are technical alternatives to radiation in the spectrum. Point-to-point services already make extensive use of cables, with the choice determined on economic grounds which depend on the transmission circumstances. There are, technically, other potential applications for cable, as for broadcasting/television distribution in populous areas. "Leaky waveguides" or surface transmission lines are possibly feasible media for high capacity communication and control for trains, and motor vehicles along main routes.

## ENGINEERING METHODS, TECHNICAL STANDARDS, OPERATIONS ANALYSIS FOR SPECTRUM MANAGEMENT

The engineering methods and technical standards related to the allocation and assignment process are primarily concerned with the avoidance of interference--propagation, antennas, bandwidth, protection ratios, selectivity of receivers, frequency stability and spurious emissions from transmitters. These nowadays are topics in "electromagnetic compatibility." There are a number of technical possibilities for realizing increased utilization--the JTAC studies have endeavored to define this very complex problem, to identify important approaches, the need for careful dimensioning of spectrum utilization, and the need for a vast amount of data to describe actual usages in a useful way. Reviews presented to the Panel by the FCC, the DTM, Commerce ITSA, and the Defense ECAC all stressed the importance of sophisticated computation for frequency sharing, the need for advancing (in some cases just defining) technical standards, and the potential usefulness of operations analysis applied to administration of telecommunication utilization of the spectrum. The suggestions will be reviewed briefly. However, the Panel has considered carefully the question of the potential value of any or all of such technical measures, and is convinced that the assessment of such values would require extensive data and analyses of a cost-benefit character; the needed analyses have not been done, and were not feasible in the present study--much of the needed basic data is not readily available or has not been collected.

The JTAC has characterized the general engineering aspects of spectrum administration as involving:

-- assignment of frequencies

-- short-term compatibility planning

-- spectrum utilization policing

-- requirement of improved equipment specifications to reduce spectrum used

-- resolution of overloading problems experienced in the field

-- solution of interference problems experienced in the field

-- provision for additional equipment deployments

## Engineering Methods Including Computer Applications for Frequency Sharing

The DTM has outlined a program to apply computer techniques to frequency management; programming of an initial phase is scheduled for completion in the next few weeks, intended to support day-to-day frequency assignment activities, providing magnetic tape, file maintenance and information retrieval, and related printing and publication functions. An "engineering model" proposed for later incorporation into the system would provide central engineering review of frequency assignment requests for HF point-to-point services.

The FCC maintains a computer file of non-government frequency assignments, providing data on punched cards. The International Frequency Registration Board maintains magnetic tape records of frequency uses notified by various countries. The ECAC of the Department of Defense represents the present most detailed and comprehensive effort to establish a data base and analytic capability for assessing frequency sharing, including environmental files (present utilization), equipment characteristics filed (nominal characteristics and spectrum signatures from measured data) and terrain data filed.

The JTAC[5] has identified present dimensioning of spectrum utilization as completely inadequate for really effective analutical efforts toward frequency sharing. Dimensioning is primarily in terms of frequency, and that provides only a small segment of the total picture. Usually, only an inference of the geographical space utilized is obtainable from the power, antennas, and geographical data supplied. R. P. Gifford[27] has observed the need for a standard unit of spectrum space utilization that is based on a specified level of radiated energy density over a specified bandwidth over a specified geographical area; the allocation of a natural resource seems difficult to administer without careful attention to meaningful standard units of measure.

These approaches are potentially of enormous complexity and cost (consider ECAC, for example) and suggest the need for vast amounts of data, highly sophisticated analytical methods, and large, intricate computing programs. Progress has been slow and to date barely penetrates the potential technical depth and breadth of the problem.

## Technical Standards

Both the FCC and the DTM have cited the need for better defining and further advancing standards of performance and methods of measurement for systems using the spectrum. Included are topics such as optimum channel width for particular service; possible adjacent carrier interleaving; performance characteristics of receivers, transmitters, and antennas; radio frequency interference from non-telecommunications devices; monitoring and measuring of emissions. At present, FCC must rely on industry guidance and limited laboratory evaluations for technical standards. DTM interest in technical standards for government utilization give some emphasis here to radar engineering design objectives; other important topics concern spurious emissions, basic characteristics of single sideband equipments, narrow band FM transmission standards, and minimum performance requirements for transmitters, receivers and antennas operating in the various classes of service. The DTM information on technical standards is obtained largely from the user-agency members of IRAC.

## Operations Analysis

The Panel has observed that many of the problems of frequency utilization are administrative, or administrative-technical, rather than purely technical. Scientific assistance in these areas is also available; it is likely that systems analysis and operations research would be as useful to the administering of the utilization of the electromagnetic spectrum as they have been found to be in industrial and military administration.

It would require study, of course, to determine how useful these tools could be in providing guidance to the allocating and regulatory authorities, and to develop more appropriate techniques if needed. There is a qualified group in existence at the National Bureau of Standards, which could carry out some of this study and could contract out other portions as deemed necessary. The investigations should, of course, be carried on in close collaboration with the allocation and regulatory authorities, with one or more of their staff as a part of the team carrying out the analyses.

By bringing to bear the techniques of communication theory, probability, and operations research, such questions as measures of value of various parts of the spectrum, and measures of effectiveness of utilization could be investigated, and procedures to share efficiently the spectrum in time, space, and frequency. These studies might also suggest ways in which modern computers could assist in data gathering and analysis, and could assist decision making by using computer simulation to try out the consequences of various possible sharing and allocation schemes.

# IV. FINDINGS AND RECOMMENDATIONS

## IMPROVING EFFECTIVENESS OF SPECTRUM UTILIZATION

The Panel recognized early in its study that there were several ways by which additional research might lead to the overall effectiveness of utilization of the electromagnetic frequency spectrum. The most obvious examples of these are listed below--the first four are evolutionary technical steps:

(1) The extension of the usable regions of the spectrum. This involves doing the research and development necessary to make new regions of the spectrum available to new or existing services.

(2) Increasing the "technical" capacity of given telecommunications channels. This involves research in the fields of propagation, telecommunication systems, and information theory in order to obtain the transmission of the maximum number of bits of information in a given time through a given channel used by an aggregate of systems.

(3) Increasing the efficiency of operation of a given telecommunication function. This involves the objective analysis of the telecommunication function to be performed in order to minimize the amount of transmitted information needed to accomplish the function.

(4) Vacating the spectrum by transferring the telecommunication function to a non-atmospheric form of transmission.

(5) Optimizing the use of the total complex of telecommunications capabilities on the basis of the overall value to the nation.

The presentations made to the Panel during its study made it clear that there is a variety of natural incentives to provide continuing progress on the first four of these examples. Defense and other agencies of the Federal Government and the scientific and business communities of the nation are all expending considerable effort which will ensure that this progress will continue into the future. Furthermore, it is possible to establish some quantitative evaluation of that progress in technical or economic terms if the evaluation is restricted to a sufficiently specific situation. It is also to be noted that while the approaches indicated in the first four examples are important components of the overall optimization of the use of the spectrum, they have tended to be executed independently of it.

In contrast, however, under example (5) there is a clear lack of adequate natural incentives to provide an "evolutionary" optimization and an almost complete absence of the quantitative means needed to provide a logically determined optimization.

## ECONOMIC ASPECTS OF OPTIMUM SPECTRUM UTILIZATION AND RELATED RESEARCH

The first charge to the Telecommunication Science Panel was to answer the question:

> "1. What research and technical service programs directed toward more efficient utilization of the electromagnetic frequency spectrum for telecommunications are needed . . .?"

The key word in that question is "efficient." Clearly some cost benefit relationship must ultimately be the decisive factor in choosing alternatives for advancement of system technology, intensification of frequency sharing, or exploitation of new regions of the spectrum. The relevance of technical advances, and the incentive for fostering them, are mainly economic. In order to specify what research and technical service programs will result in more efficient utilization of the frequency spectrum, one must have a criterion or criteria for distinguishing more efficient configurations from less efficient ones. Early in its deliberations, the Panel found itself struggling with that question in a variety of forms.

Perhaps the most apparent of these is the problem of competing uses for frequencies. Although reallocation was not a subject for consideration by the Panel, a number of briefings contained explicit or implicit suggestions that the need for research and more stringent technical measures could be partly alleviated by providing certain services more spectrum space at the expense of others. Such suggestions run squarely into the criterion problem. How does one decide whether it is more "efficient" to allocate fewer frequencies to broadcast TV, and more to land mobile service, or vice versa?

More subtle, but also more relevant to the Panel's deliberations is the question of whether, or to what extent accommodating more users through research and development is equivalent to more effective use of the spectrum. Research and development is not a free good. It always entails a cost, and the spectrum is being used more effectively only if in some meaningful sense the value of the rights created exceeds the R&D costs.

Even if the R&D costs are ignored, many suggestions for more intensive use of the spectrum impose costs on current users either in a form of modifications to existing equipment, or in increased levels of interference, and some criterion is required if one is to say whether the additional use compensates for these costs imposed.

Frequently, criteria are explicitly suggested with little appreciation for what their acceptance implies. One rule often advocated, for example, is that no service should use the frequency spectrum if it is possible to provide that service without utilizing it. If this rule were taken seriously, many current uses of the spectrum would be forbidden. For example, it is physically possible to supply broadcasting services to homes and buildings entirely through wire systems, and similarly telephone could be provided entirely through wire and cable systems.

Two other unworkable criteria that are sometimes suggested deserve mention. One of these is "maximizing the use of the spectrum;" another is "minimizing interference." An ultimate minimum of interference is achieved when there is absolutely none, and it is difficult to defend that situation as optimal. (Indeed the heart of the problem of criteria is in a sense trying to specify what is the optimal amount of interference.)

Maximum utilization of the spectrum is an equally empty concept, since it also gives no hint as to what level of interference is acceptable. A more sophisticated criterion, often proposed in suboptimization of systems, is that of maximizing the flow of information through a channel in a given period. Taking that dictum seriously implies that costs are irrelevant, since at some cost one can almost always increase the amount of information put through a channel per unit time.

All of these examples of the difficulties encountered in considering the criterion problem are simply a reflection of the fact that the right to radiate energy, i.e., use of the frequency spectrum, represents use of a scarce economic resource. In recent years there has been a growing recognition of this fact, and more and more attention has been focused on efficient or optimal use of the spectrum. The 1964 JTAC report states ". . . today we find ourselves faced more than ever before with the problem of how to use the spectrum efficiently and effectively for the greatest possible good." Unfortunately, such statements have generally not been accompanied by clear declaration how one decides what is optimal, i.e., what is more or less efficient.

Recognition that frequency spectrum is an economic resource immediately raises the question of what criterion is applied in deciding how other economic resources will be used. For example, what criterion is applied in deciding whether a particular parcel of land is used for production of corn or wheat, or whether a particular hour of labor will be used to produce automobiles or refrigerators. The answer to this question has been the subject of intensive study by economists at least since the days of Adam Smith. They have developed a criterion that is widely accepted not only among economists but as an integral part of the organization of our economic system. This is not the place for detailed discussion of how the economic system operates, but a general statement about how means of production are allocated among competing uses is central to the criterion discussion.

Generally speaking, individuals and firms have rights in resources like land, labor and capital--rights that are transferable. Gains or losses resulting from the way these resources are used accrue to or are imposed on the individuals and firms to whom the rights belong. Because individuals and firms bear the consequences of their actions, they have an incentive to use the resources at their command in a way that will maximize their value. Moreover, since rights are transferable, individuals and firms can make exchanges if such exchanges are deemed to be advisable by both parties to the exchange. The result is a tendency for resources to be employed where their value is a maximum. If a parcel of land is more valuable in the production of corn than in the production of wheat, some corn grower will acquire the right to use the land and will employ it in growing corn. The same statement holds for other means of production. In general, resources tend to be attracted into the production of those commodities in which the value of the resources is a maximum.

Thus, for most of the nation's resources, the criterion that is used to discriminate less efficient configurations from more efficient ones is the value of the resource in the particular use in question. More efficient use coincides with higher value and less efficient use with lower value.

Of course, the extent to which the economic system achieves optimal utilization of resources, i.e., utilization that maximizes the value of resources available, is a question of fact, but we are not concerned here with how closely that objective is approximated, we are only concerned with what criterion is employed in deciding how other resources will be used in our economy.

Frequency spectrum regarded as an economic resource is in no important respect different from most other economic resources. What is different is the way individual rights to radiate energy are defined. It is important to recognize that individuals and firms do acquire rights in frequencies just as they do in other resources. The primary distinction is that rights to radiate usually are not transferable. The major exception is broadcast rights which are defacto transferable as a part of the sale of stations. Because of the limitation on transferability, it is difficult or impossible in most instances to determine the value of any particular piece of the spectrum. For other resources, the transfer of rights from one firm to another or from one individual to another reveals the value thereof. A measure of the value of any particular parcel of land, or a barrel of oil, or a ton of steel, is generated in the process of selling these resources. No comparable measure of value is available in the case of frequency spectrum.28 It is this deficiency that lies at the heart of the problem faced by the Panel, and has been largely responsible for the Panel's recommendation that an organization be established which would include economic studies in its program. One of its primary assignments would be to elicit ways for assessing the value of individual units of frequency spectrum, i.e., of specific rights in radiation.

It is important to emphasize that it is the marginal value of frequency rights that is relevant in making decisions about utilization, rather than aggregate value of the spectrum. The aggregate value of water to our society is no doubt very large. If water were so scarce that it was used only for drinking, the price of a gallon of water would be very high. In truth, however, while water is a scarce resource it is nonetheless plentiful enough to be used not only for drinking but for bathing, laundry, maintaining lawns, etc. The value of a gallon of water is thus determined by what people would pay for an additional unit in any one of these uses. The water example parallels the case of the frequency spectrum. The relevant criterion in deciding the frequency utilization or efficiency question is the marginal value of spectrum in various potential uses, not the aggregate value of spectrum.

If the Panel had had at its disposal information regarding the marginal value of spectrum in various uses, it would have been in a much better position to make recommendations about alternative R&D programs. When the inherent uncertainty about how particular R&D programs will turn out is compounded with the lack of a measure of value of the spectrum, the task of intelligently evaluating alternative programs is beyond the bounds of reason.

In summary, the Panel's study led to certain observations with regard to the allocation and assignment procedures.

(1) While economic and social considerations, as well as matters of national interest and security are undoubtedly part of individual specific frequency assignment deliberations, normal economic processes cannot operate in this situation to achieve a natural optimization of the overall use of the spectrum. The resource is dispensed essentially without charge for its use. Filing fees do no more than cover some of the administrative costs of issuing and recording the licenses and do not reflect the economic value of the use of the resource. The domestic organizations which have the responsibility for the allocation and assignment of frequencies also have the responsibility for optimizing the overall use of the spectrum on the basis of the value to the nation. Unfortunately, in addition to having inadequate natural forces tending to bring about an optimum distribution of use, they lack the tools needed to develop the objective analyses which must precede any logical and deliberative determination of the optimum.

(2) Science and engineering play important roles in the allocation and assignment procedure. They make newly-usable regions of the spectrum available for allocation, but also develop new

services which make additional demands on the already allocated parts of the spectrum. They establish the technical standards which the allocation and assignment processes must respect if a telecommunication service is to operate at tolerable levels of harmful interference. However, while science and engineering originate the possible alternatives for allocation and establish the technical constraints which must be satisfied, they have relatively little leverage in the final choice among alternatives and therefore exercise minor influence on the optimization of the overall utilization of the spectrum. At the same time, the allocation and assignment process with its attendant establishment of technical standards and of investment generated inflexibilities, tends to remove any incentives for making technological contributions which would lead to more effective overall spectrum utilization. In fact, the total amount of research activity in technology seeking primarily to increase the overall effectiveness of spectrum use is exceedingly small relative to its potential national significance.

(3) Procedurally the allocation and assignment process appears to be quite adequate for the purpose of improving the overall effectiveness of the spectrum. In fact, if the regulatory agencies could be provided with appropriate information and analysis their procedures can provide considerable incentives for specific technological developments for improvements in spectrum utilization.

The Panel's hope is that the organization recommended here will not only lead to a balanced research program but will provide interested agencies estimates of the value of spectrum that can be employed in making policy decisions.

## TECHNOLOGY AND SPECTRUM UTILIZATION

There are many and varied scientific and technological programs in progress in the nation which have some impact on the utilization of the electromagnetic spectrum. The Federal Government, industry, and the universities, all participate in this activity. The objectives of the work are extremely diverse and range over such fields as satisfaction of a large military mission requirement to the generation of additional commercial business and to the desire to acquire greater scientific understanding.

The impact on the overall utilization of the spectrum can vary widely. For instance, it can result in the provision of additional service within a specific assigned channel as in the case of the various multiplexing schemes being applied in FM broadcasting, or it can require the exclusive use of enormous regions of the spectrum as in the case of some special high definition radars.

While appreciable scientific and technical effort is directed to improving the effectiveness of a specific service within specific frequency channels, a very small part of the total technical effort is directed to the problem of improving the overall use of the spectrum.

The Panel had little difficulty in identifying a number of projects, reviewed in Section III, which might be component parts of a research program to correct this situation. However, all its attempts to develop a recommendation for a rational and balanced program (or even a very rough approximation to one) ended in complete frustration. A program could have been developed which might very well have been accepted on the strength of the recommendation of the Panel. In truth, it would have been no more than an unsubstantiated group opinion. The difficulty here, as in the allocation and assignment procedures, lies in the dearth of quantitative data necessary to make value judgments as to the total magnitude of the required program or as to the relative emphasis and therefore, support to be given the component projects.

## CONCLUSIONS

On the basis of the data accumulated, and of the relevant discussions, the Panel reached certain basic conclusions:

(1) Means of improving the overall efficiency of utilization of the electromagnetic spectrum are urgently needed--in fact, the situation is critical. This confirms similar conclusions reached by other study groups.

(2) It is inevitable that further portions, if not all, of the electromagnetic spectrum will become saturated. Better organized and more informed judgments as to the relative values of the various telecommunications services to the nation will be required for the spectrum allocation process and for the organization of research

projects directed primarily to more effective overall spectrum utilization.

(3) It is essential that planning and research be organized now in economics and sociology, and be expanded in science and technology, if the nation is to have the tools it will need to make intelligent decisions with regard to spectrum utilization in the future.

(4) The absolute value of the electromagnetic frequency spectrum to the national welfare is enormous. For instance, the part of the GNP produced directly by the manufacture and operation of just those telecommunications systems which use the atmosphere for transmission is estimated to be approximately $20 billion per year. The total significance of telecommunications to our society, economy, and national security is obviously much greater than this basic figure would indicate. Air transport is a typical example among the several industries in which the present operations and future development are critically dependent on the use of the electromagnetic spectrum.

(5) The development of the electromagnetic spectrum as a national resource has many facets and there are many incentives in government, industry, and universities to continue its development. But the total research and engineering expenditure on the specific problem of increasing the overall effectiveness of the spectrum, particularly of the already exploited frequency ranges, is remarkably small, being only a few hundredths of one percent of the value of the dependent industry.

(6) The inflexibilities resulting from the allocation procedures operating in an environment from which important natural economic processes are absent, the many dimensions involved in the basic judgments affecting the situation and the absence or unavailability of many data necessary to the formulation of intelligent recommendations, give this problem a magnitude and complexity which take it beyond the possibility of resolution by the Panel or any other ad hoc group.

PANEL RECOMMENDATION

The preceding summary of the Panel's deliberations and the supporting information contained in the full report show that the Panel identified and focused on two very basic shortcomings in the present situation:

(1) Completely inadequate quantitative measures of the relative value to the nation of existing and future telecommunications services.

(2) Grossly inadequate technical programs aimed specifically at improvement of the overall effectiveness of the utilization of the spectrum.

On the basis of these findings, the Panel makes the following recommendation:

That the Federal Government develop a research organization which has as its primary objective the improvement of the overall effectiveness of utilization of the electromagnetic spectrum; that the recommended organization be operated and financed at levels commensurate with its potential value in the national interest; and that the recommended organization will:

(1) Provide the Director of Telecommunications Management, the Federal Communications Commission, the Department of State, and all the other government, industrial, and academic institutions having interest in telecommunications, with the economic, social, and technical information and analyses necessary to provide a valid basis for judgments which affect the overall effectiveness of use of the spectrum.

(2) Identify and stimulate those technical research programs which are essential to the improvement in the overall effectiveness of the use of the spectrum and execute or sponsor those which, for any reason, are not likely to be included in the related scientific and technological research programs of the nation.

FURTHER RELEVANT DISCUSSION CONCERNING THE PROPOSED ORGANIZATION

General

The Panel envisions a research organization highly motivated to perform its mission of developing the tools which are indispensable to the deliberative determination of the optimum use of the spectrum, but which do not presently exist. The organization will perform its mission in cooperation with, and as a service to, its "customers," viz:

(1) Government policy-making and regulatory agencies.

(2) The telecommunication industry.

(3) The "telecommunication user" organizations in government and industry.

(4) The research and development community in government, industry, and academic institutions.

This organization must be differentiated from the large number of other organizations with related missions by its dedication (a) to research on the overall problem of spectrum utilization--not on any specific segment of it, and (b) to the development of the necessary tools--not to their application.

## Proposed Program

The Panel's concept of the nature of the proposed organization can probably be communicated most easily by describing, in quite general terms, the program which the Panel considers appropriate for it:

(1) Identify the specific activities in the nation in which telecommunications play a role and develop an understanding of the role played. The list should be complete and include all activities related to the nation's economy, society, culture, and security, etc.

(2) Develop quantitative measures of the relative values to the nation, at present and in the future, of each of the identified activities.

(3) Develop quantitative measures of the dependence of each of these activities and their respective rates of growth on telecommunications.

(4) Develop, from the above efforts, relative quantitative values to the nation of each type of telecommunication service and more specifically, the value of each type of service to each activity in which it plays a role.

(5) Develop appropriate methods by which the information and conclusions generated by the above efforts can be disseminated to, and be accepted by the organization's "customers."

(6) Identify the technical opportunities in the future development of telecommunications, determine the degree to which they may be dependent upon the availability of frequencies, and develop measures of their relative importance in enhancing the growth of the nation.

(7) Stimulate and execute or sponsor research and development programs which will supplement already existing programs to the extent needed to bring the nation's total effort on each of the technical opportunities into balance with its measure of importance.

The Panel is very aware of the magnitude of the difficulties and complexities inherent in this program. In fact, there is no implied guarantee of success. Nevertheless, the Panel has the conviction that given a few individuals of sufficient intellectual brilliance, adequately motivated towards making important contributions to the program, the probability of success is sufficiently high to justify making a start on it. The alternative is to accept the fact that at some time in the future, the lack of telecommunications must be a major factor in limiting the rate of growth of the nation.

## Some Criteria for Establishing Proposed Organization

The Panel members who, in aggregate, represent a great many years of experience in the establishment and administration of research and development programs of similar complexity believe that a reasonable probability of success can be assured only if certain criteria are satisfied in choosing a "home" for the organization.

(1) The program is of such complexity and difficulty that successful execution requires a single-minded dedication which must not be diluted by day-to-day operating responsibilities, nor by uncertainties as to the degree of loyalty required by the traditions or the other responsibilities of the parent organization within which the program is developed.

(2) The success of the program is critically dependent on the quality of the individuals executing it, on their motivation, and on their dedication to the attainment of its objectives. The attraction, selection, and utilization of such individuals must avoid any limitations which might be imposed by the "image" or traditions of the parent organization.

(3) Success in developing tools for its "customers" is of no value unless the "customers" find the tools acceptable and actually use them. This requires that the organization providing the tools develop an <u>accepted</u> reputation for a high level of competence in its specialized

field and for complete objectivity in that field.

(4) The success of the program will also be dependent on the organization having access to all of the information it needs. This requires that the organization develop an accepted reputation for independence as well as for competence and objectivity.

(5) The organization must be free to work in complete cooperation with all of its "customers."

## Reporting Relationship

We well realize that discussion of location for any new organization is always a "touchy" subject. In making the following suggestion, the Panel was torn between its desire to be helpful and a risk of distraction from the basic content of its recommendations.

These thoughts, therefore, are offered on the premise that attention will be given to this reporting relationship matter only after adequate discussion has confirmed the need for the recommended type of work.

After considerable, but not exhaustive discussion, the Panel concluded that if the organization were developed by the Secretary of Commerce and operated at a high level within the Department of Commerce, it could satisfy the above criteria. There are several other factors which give strong support to considering the Department of Commerce as the "home" for the proposed organization.

(1) The main mission of the Department relates to the overall economy of the nation.

(2) Much of the raw economic data and many of the processes for obtaining the new data required by the organization already exist in the Department.

(3) The Department can be objective since it is not primarily a using agency and since it has no direct allocating or regulatory responsibilities with respect to telecommunications.

(4) The nuclei for some of the basic technologies and research activities already exist within the Environmental Science Services Administration and National Bureau of Standards with are parts of the Department of Commerce.

## The Organization's Life Cycle

It should be recognized that the proposed organization will have two major phases in its life history. The initial phase, which can be expected to last between five and ten years, will be largely a research effort in which methods of data collection, processing, and analysis will be developed and tested in a dedicated effort to provide some new and badly needed tools. If the organization is successful in developing some useful and accepted tools, its mode of operation will evolve into a second phase in which the information will be collected, analyzed, and disseminated routinely and the further development of the methods will become a slower process of refinement. Obviously, the transition from the initial to second phases will take place slowly.

Nevertheless, it should be recognized from the beginning that the types of management and staff required in these two phases are quite different. For instance, temporary (three to five years) appointments of experienced and recognized leaders in the field could be used initially to fill the key positions in both the management and the staff. Similarly, the Panel concluded that the organization should not attempt, in the beginning, to carry out all of its functions primarily in-house. In addition to its own activities, the staff would take the responsibility for promoting programs in appropriate organizations, for coordinating the results, and for developing supplementary efforts carried out under direct contracts in industry, universities, and in other government agencies. This total approach would guarantee good communications with industry, the government, and with the universities and have the by-product of developing a supply of individuals with training and interest in the field of spectrum utilization. Many of the staff of the proposed organization in its later phase might come from this supply.

## Budget

The Panel found it impossible to determine the "correct" budget for the initial operation of the proposed organization. To do this requires the same tools which the organization is being established to develop. This did not disturb the members since it was a familiar problem to many of them. It was recognized that, initially, expenditures would be limited by the difficulties of attracting personnel of appropriately high quality and of establishing a valid program. At this point the magnitude of the intended support is important primarily as an indicator of the importance which the Government attaches to the program. The Panel proposes initial annual investments supporting growth to the $10 million level.

Appropriate growth beyond this initial level will be determined by careful appraisal of the data generated by the early studies. The final level of support (and indeed, the continuation of the activity as proposed) should be determined by demonstrable positive impact on the telecommunication services of the nation. It should be pointed out that, assuming that the organization is successful, an annual budget of $50 million would not necessarily be excessive since that sum is a modest ¼ of one percent of the part of the GNP generated by atmospheric telecommunications.

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# APPENDIX 1

## CONTRIBUTORS TO TELECOMMUNICATION SCIENCE PANEL MEETINGS

January 26 - 27 Meetings

| Subject | Contributor | Organization |
|---|---|---|
| Study of Telecommunication Sience and the Federal Government | R. C. Kirby | Department of Commerce |
| Summary of Federal Communications Commissions Activities and Needs | R. J. Renton | Federal Communications Commission |
| ITSA and the Telecommunication Science Study | Dr. C. G. Little | Department of Commerce |
| Descriptive Functions of the Director of Telecommunications Management | F. W. Morris | Office of the Director of Telecommunication Management |
| Review of the Department of Defense Organization for Telecommunications | Col. E.J. Quashnock | Department of Defense |

March 8 - 9 Meetings

| Subject | Contributor | Organization |
|---|---|---|
| EM Wave Propagation at Frequencies Below 30 MHz | W. F. Utlaut | Department of Commerce |
| Status of Research in Modulation, Detection, Coding and Noise Below 30 MHz | Dr. E. J. Baghdady | ADCOM, Inc. |
| Antenna Research for Improved Utilization of the Electromagnetic Spectrum Below 30 MHz | Dr. R. L. Tanner | TRG, Inc. |
| Character of Present Operations and Trends in Telecommunications at Frequencies Below 30MHz | W. H. Watkins | Federal Communications Commission |
| New HF Communications Systems and Applications | R. A. Kulinyi | United States Army Electronic Laboratory |
| Broadcast Services | G. Jacobs | United States Information Agency |
| HF Radars | A. VanEvery | Department of Defense |
| Systems at Frequencies Below 500 KHz | A. D. Watt | DECO Electronics, Inc. |
| Ocean Data Service | J. M. Snodgrass | Scripps Institution of Oceanography |
| JTAC Committee 65.1 Prospective Uses of the Spectrum | D. Hull | Electronics Industries Association |

April 6 - 7 Meetings

| Subject | Contributor | Organization |
| --- | --- | --- |
| Electromagnetic Wave Propagation and Prediction at Frequencies 30 MHz to 10 GHz | J. W. Herbstreit | Department of Commerce Environmental Science Services Administration, Institute for Telecommunication Sciences and Aeronomy |
| Information Transmission | W. E. Morrow | Massachusetts Institute of Technology, Lincoln Laboratories |
| Antennas at Frequencies Above 30 MHz | C. J. Sletten | Air Force Cambridge Research Laboratory |
| Survey of Telecommunications and Trends at Frequencies Above 30 MHz | W. E. Plummer and R. Cutts | Office of the Director of Telecommunications Management; Federal Communications Commission |
| Defense Satellite Communications | T. F. Rogers | Department of Defense |
| Satellite Communications | S. Reiger | Communication Satellite Corporation |
| Satellite Communication Technology | J. J. Kelleher | National Aeronautics and Space Administration |
| Radar Systems | R. D. Mitchell | Radio Corporation of America, Missile and Surface Radar Division |
| Air Navigation and Communications | G. M. Kanen | Federal Aviation Agency |
| Land Mobile Communications | W. J. Weisz | Motorola, Inc. |
| Telecommunications Study of the President's Commission on Law Enforcement and the Administration of Justice | R. S. Kirby | Department of Commerce Environmental Science Service Administration, Institute for Telecommunication Sciences and Aeronomy |

May 3 - 4 Meetings

| Subject | Contributor | Organization |
| --- | --- | --- |
| Electromagnetic Wave Propagation at Frequencies from About 10 GHz to Optical | Dr. D. C. Hogg | Bell Telephone Laboratories |
| Technology Above 10 GHz | W. J. Edwards | Air Force Avionics Laboratory |
| Cable and Waveguide Technology | L. G. Abraham | Bell Telephone Laboratories |
| Operations Research; Some Telecommunications Applications | W. H. MacWilliams | Bell Telephone Laboratories |
| Operations Research; Some Fundamental Aspects and Relation to Spectrum Utilization | Dr. R. S. Machol | University of Illinois |
| Department of Defense Electromagnetic Compatability Program | J. P. Georgi | Electromagnetic Compatability Analysis Center Naval Experiment Station |

# APPENDIX 2

# RELATED STUDIES

## A. JTAC STUDIES

Spectrum Utilization has been the subject of comprehensive publications and continuing studies of The Joint Technical Advisory Committee (JTAC) of the Institute of Electrical and Electronic Engineers (IEEE) and of the Electronic Industries Association (EIA). JTAC has published two books "Radio Spectrum Utilization (1964)" which is a successor to "Radio Spectrum Conservation" (McGraw-Hill Book Co., 1952). These books were prepared to present a current view of our knowledge of the electromagnetic spectrum as a natural resource and to present also the problems which JTAC felt must be solved by the world community in order to attain continued growth and utilization of the spectrum.

General recommendations presented in "Radio Spectrum Utilization" include aspects of: continuous review of usage, research and development, flexibility required, system standards, non-radio communication uses, noise, and technical basis for allocations. Specific recommendations are made in three frequency bands: Below 3 MHz, 3-30 MHz and above 30 MHz. These recommendations deal with relocation of presently allocated services, research and development and allocation objectives.

The Progress Report on "Electromagnetic Compatibility", of the JTAC Subcommittee 63.1, provides a summary of objectives of their work for DTM. The report has the clarifying subtitle "A Challenge in Natural Resource Utilization Requiring Technical Guidance and Direction." The committee was established at the request of Dr. Jerome B. Wiesner and addressed itself to three distinct objectives: to identify EMC problems and existing control techniques; to establish potential technical approaches toward solving compatibility problems and developing greater efficiency of use; to recommend technically-based procedures to increase effective and efficient use of the radio spectrum. The first two of these objectives are now being pursued through group and subgroup activities of the committee. Government agencies represented include: the FAA, GSA, NASA, Treasury Department, Department of Commerce, and the FCC.

With respect to the first objective, identification of EMC, the subcommittee is examining:

- Electromagnetic Compatibility (EMC) in operations of Government Agencies
- EMC in the operations of non-Government users
- Data files for EMC use
- Monitoring and frequency coordination in the field
- New concepts in R&D which will affect the need for spectrum space

Field analyses will be conducted in several specific geographic areas considered representative of large urban areas to obtain an appraisal of electromagnetic compatibility and usage in operating situations. Included will be common-carrier microwave, private microwave, educational microwave, TV, land mobile, special industrial radio, taxicab radio, manufacturers' radio service and public safety services. Radio noise environment studies are to be undertaken.

In the task on Identification of Technical approaches, the objectives are to review and evaluate various procedures that could be developed to:

- Provide for maximum effective use of the spectrum consistent with relative needs for protection from interference
- Meet problems uncovered by the Survey group in developing technical approaches by developing
  - Data File (receiver characteristics and location)
  - System Modeling and Interference Prediction Techniques
  - Optimum Frequency Assignment Model
  - Frequency Band Optimization for service to be rendered
  - Spectrum Utilization efficiency criteria
  - Technical System Optimization
  - Operational System Optimization
  - Equipment Design Specification Standards
  - Monitoring

Another JTAC group (65.1) is currently examining "New Uses of the Radio Spectrum" in conjunction with the JTAC Electromagnetic Study (63.1). The work was undertaken on the basis that knowledge of potential future uses, both as to nature and quantity, would be an important foundation for suggestion on possible technical policy that could guide radio spectrum management.

B. FCC ADVISORY COMMITTEE FOR THE LAND MOBILE RADIO SERVICES

In order to resolve the serious congestion problems confronting the Mobile Services, the FCC, in 1964, established the "Advisory Committee for the Land Mobile Radio Services." This Committee, composed of about 175 people, knowledgeable in two-way radio, has representation from the major user groups in Public Safety, Industrial and Land transportation services, such as Police, Fire, Forest Conservation Petroleum, Public Utilities, Taxicabs, Railroads and many others. Also represented are members of universities, engineering societies, manufacturers, government and FCC staff personnel. Short of reallocation of the spectrum space, the Committee is to explore all possibilities for resolving congestion problems by collecting and analyzing information pertinent to land mobile radio communications and to recommend actions to be taken to alleviate the situation.

Although not limited to the following, some of the prescribed areas of study are:

- Current usage of land mobile service channels
- Service growth predictions
- Extent of harmful interference in land mobile services on various frequencies and various locations
- Technical and operational measures that could reduce harmful interference or increase spectrum utilization efficiency
- Possible use of frequencies above 890 MHZ for land mobile services
- Ways the Commission might improve the administrative and frequency assignment procedures in the land mobile service, both common carrier and private
- Use of computers to assist in frequency assignments

The Committee is composed of three standing committees: Operational Standing Committee, Technical Standing Committee and a Frequency Utilization and Administration Standing Committee, each composed of 8 to 9 working groups. Under each are the following areas of study:

Operational Standing Committee - To study various base-mobile radio systems from an operational point of view and to examine known operating techniques toward more efficient spectrum utilization. Study areas are:

- Operational aspects of multiple access, digital and broadband systems
- Advantages and disadvantages of increased use of channels restricted to low power operation
- Operational aspects of better frequency utilization through one-way, base to mobile systems
- Operational aspects of cooperative use of base stations by more than one licensee
- Operational advantage or disadvantage of increased use of multiplexed transmitting facilities
- Operational aspects of broader use of mobile relay techniques
- Possibilities of improved operational techniques
- Value of land mobile radio service to the overall national economy
- Service growth predictions

Technical Standing Committee - To examine the latest technical developments and recommend those adaptable to land mobile communications and to investigate and recommend possible improvements in present systems. Study areas are:

- Select suitable service frequency bands; study use of frequencies above 890 MHz and examine possibilities of cross-band operation
- Study bandwidth requirements and merits of various modulation systems such as narrow band AM or SSB
- Ambient noise limits
- Feasibility of more precise specification of power, antenna height, location and gain, new signal strength selective devices
- Transmitter power, interference and service limits
- Use of advanced technical developments such as digital systems, compressed information systems, broad-band, etc.
- Use of multiplex channels on FM broadcast stations for land mobile base stations
- Technical standards for reduced channel spacing in the 450 MHz band

Frequency Utilization and Administration Standing Committee - To examine present method of frequency assignment and recommend improvements toward a more practical and efficient spectrum usage. Study areas are:

- FCC techniques, rules, procedures
  - Frequency coordination procedures
  - Examine FCC techniques, rules, procedures (other than frequency coordination and computer techniques)
  - Review application of computer techniques to assignment of frequencies
- Study geographical sharing and allocation
  - Analyze "block" or "service" allocation plans, history and advantage
  - Study alternative allocation plans for land mobile service
  - Analyze EIA card study
  - Compile statements of users about existing land mobile services

To date there has been some useful output in the areas of improved operational techniques and better handling of applications, and licensing procedures, and on the use of multiplex channels on FM broadcast stations for land mobile base stations. However, these and many other areas need more extensive and thorough study.

C. OFFICE OF DIRECTOR OF TELECOMMUNICATIONS MANAGEMENT

(1) Proposal for Long-Range Planning for Allocation and Use of the Radio Spectrum

The DTM has in draft form a proposal for a long-range planning function that will "provide a feasible and continually available guide for the orderly development and exploitation of the radio spectrum." This proposal contains plans for special studies required to support this function. At the time of the convening of this Panel, the material was being reviewed in the Frequency Management Advisory Council.

(2) The Frequency Management Advisory Council

The Frequency Management Advisory Council was formed by the Director of Telecommunications Management to advise on measures to increase the effectiveness of frequency management throughout the Executive Branch of the Government.

The members of the Council are appointed by the Director of Telecommunications Management and represent a cross section of talent and experience from outside the Government to provide objective judgment on frequency management problems and concepts. The present members of the Council are:

Dr. Cullen Crain
Commander T. A. M. Craven
Mr. Richard P. Gifford
Dr. John P. Hagen
Mr. Philip F. Siling
Mr. Ray Vincent
Commodore E. M. Webster

Mr. James D. O'Connell, Director of Telecommunications Management, is Chairman of the Council and Mr. Philip F. Siling serves as Secretary. Mr. Richard C. Kirby, Department of Commerce, is an observer. The Council has been functioning since July 1965.

(3) Study of the Radio Spectrum Requirements for the Space Service Between Now and 1980

A contract was recently made with Jansky & Bailey to determine the frequency needs between now and 1980 for the various space services and how these needs might be met if portions of the required radio spectrum were saturated. The study is to assume the most efficient practicable spectrum utilization to provide a great variety of Government and non-Government satellite services. A report is expected late in 1966.

D. INTERNATIONAL TELECOMMUNICATION UNION

(1) International Radio Consultative Committee (CCIR)

The International Radio Consultative Committee (CCIR) has developed a large number of technical programs relating to spectrum utilization studies. See Appendix 3. Results of studies and recommendations, together with current Questions and Study Programs, have been published in the latest

Documents of the $X^{th}$ Plenary Assembly of Geneva, 1963.* Subjects covered in five Volumes include:

| | |
|---|---|
| Volume I. | Emission, Reception |
| Volume II. | Propagation |
| Volume III. | Fixed and Mobile Services, Monitoring of Emissions |
| Volume IV. | Radio Relay Systems, Space Systems, Radioastronomy |
| Volume V. | Sound Broadcasting, TV |

(2) <u>Recommendations of the ITU Panel of Experts</u>

The Panel of Experts was established by the ITU's Administrative Council in 1959 in order to devise ways and means of relieving the pressure on the bands between 4 and 27.5 MHz. After two sessions, held in 1961 and 1963, it adopted 38 recommendations covering the following general matters:

- Discontinuance of double sideband in fixed, maritime mobile and aeronautical mobile services
- Grouping, where practical, of single channel radiotelegraph and radio-telephone circuits into multichannel SSB or ISB circuits
- Siting of stations, choice and maintenance of equipment
- Employment of minimum power and bandwidth
- More stringent tolerances on transmitter stability and spurious emissions
- Use of directional antennas in fixed and broadcast services
- Discontinuance of short-range broadcasting in the HF band
- Use of vertical incidence antennas for broadcasting in tropical zones
- Fixed circuit reductions through groupings on common frequencies
- Reduction in number of frequencies simultaneously used for HF broadcasting
- Need for centralized frequency and telecommunications management
- Use of radio other than HF radio where feasible
- Use of other means of telecommunications where feasible
- Notification of only those frequency assignments which represent actual usage
- Provision of economic and technical assistance to new and developing countries

*Revised at Oslo, Norway, July 1966. To be published in 1967.

- Preparation by IFRB of handbook on recommended techniques for better utilization and reduction of congestion in HF spectrum
- Preparation by CCIR Secretariat of handbook on the performance and application of preferred types of HF directionsl antennas
- Study by CCIR of
  - Arrangements for adoption for SSB systems of the HF maritime mobile service, with suppressed carrier, to control the receiver gain in absence of speech
  - Most suitable methods for automatically controlling output power of HF transmitters
  - Use of HF directional antennas to limit radiation outside of direction necessary for service
- Acceleration of CCIR bandwidth compression studies, taking into account, Panel's recommendations

The DTM has requested each Federal Department and establishment to comply where practical with the actions proposed by IRAC with respect to the Panel's recommendations, particularly in the procurement of new equipment in the bands between 4 and 27.5 MHz, where SSB equipment should be obtained instead of DSB. The impact of the recommendation is expected to become industry-wide.

(3) Conferences

(a) Aeronautical Mobile

An Extraordinary Administrative Radio Conference (EARC) in two sessions revised the allotment plan for the Aeronautical Mobile (R). Service now contained in Appendix 26 to the Radio Regulations. In a first meeting, certain criteria were adopted for the new allocation plan, and members submitted data relating to current HF Aeronautical Mobile (R) Service. The second session (14 March to 6 May 1966) was held to prepare the new allotment plan and to make any necessary amendments to the Radio Regulations.

(b) Maritime Mobile WARC

The Maritime Mobile Service Radio Regulations are to be reviewed and revised in a World Administrative Radio Conference to be held in Geneva in 1967. Objectives include conversion from double to single side band in the medium and high frequency bands, and considerations of accomodating HF requirements for oceanography in the HF maritime and mobile bands.

(c) WARC on Space Radio Communications

The Administrative Council of the ITU reviews annually the progress in space radio communications made by Member Countries of the Union. When appropriate, the Council recommends a WARC to work out further agreements for international regulation of frequency bands allocated for space. However, there is no evidence that the Council sees a need to convene such a conference during 1966.

(d) World Administrative Radio Conference

While no need has yet been expressed for holding an additional world administrative radio conference, a sum has been set aside for an 8 weeks conference to be held within 1968-1971.

(e) XII$^{th}$ Plenary Assembly of the CCIR

The XII$^{th}$ Plenary Assembly of the CCIR is expected to be held in 1969 or 1970.

(f) Next ITU Plenipotentiary Conference

The next Plenipotentiary Conference of the ITU is expected to be held in 1971.

# APPENDIX 3

# SELECTED RELATED QUESTIONS AND STUDY PROGRAMS OF THE CCIR, A RECOMMENDATION OF THE ITU PANEL OF EXPERTS (1963), AND FCC TECHNICAL TOPICS

## QUESTION 219(I)

### COMPRESSION OF THE RADIOTELEPHONE SIGNAL SPECTRUM IN THE HF BANDS

THE INTERNATIONAL FREQUENCY REGISTRATION BOARD,

IN VIEW OF

the request of the PANEL OF EXPERTS in Section II of Part D of its Interim Report, **after** considering;

*(a)* the congestion in the bands between 4 and 27·5 Mc/s;

*(b)* the need to adopt new methods for the solution of the frequency problems with which Administrations are confronted in the use of those bands;

*(c)* the work accomplished in the field of Communication Theory;

*(d)* the need to know what practical experience has been acquired in the matter of compressing the spectrum occupied by HF radiotelephone signals for the Panel's second session;

AND IN VIEW OF

No. 180 of the International Telecommunication Convention, Geneva, 1959;

DECIDES

to submit the following urgent question to the C.C.I.R.:

1. what, in practice, can be done to reduce the spectrum space occupied by HF radiotelephone signals;

2. what experience has been acquired in so doing, for example, what degradation of intelligibility or ability to converse accompanies the use of spectrum reducing techniques?

## QUESTION 220(I)

## COMPRESSION OF THE RADIOTELEGRAPH SIGNAL SPECTRUM IN THE HF BANDS

THE INTERNATIONAL FREQUENCY REGISTRATION BOARD,

IN VIEW OF

the request of the PANEL OF EXPERTS in Section II of Part D of its Interim Report, after considering;

*(a)* the congestion in the bands between 4 and 27·5 Mc/s;

*(b)* the need to adopt new methods for the solution of the frequency problems with which Administrations are confronted in the use of those bands;

*(c)* the work accomplished in the field of Communication Theory;

*(d)* the need to know what practical experience has been acquired in the matter of compressing the time-bandwidth product of HF radiotelegraph (or other digital) signals for the Panel's second session;

AND IN VIEW OF

No. 180 of the International Telecommunication Convention, Geneva, 1959;

DECIDES

to submit the following urgent question to the C.C.I.R.:

what are the advantages, limitations and practical experience with:

1. phase-change signalling systems;
2. digital signalling systems which employ three or more states of amplitude, frequency-shift or phase change;
3. coding techniques which provide either message compression or error reduction, or both?

# QUESTION 227(I) *

## LIMITATION OF RADIATION FROM INDUSTRIAL, SCIENTIFIC AND MEDICAL INSTALLATIONS AND OTHER KINDS OF ELECTRICAL EQUIPMENT

The C.C.I.R., (London, 1953 – Geneva, 1963)

CONSIDERING

*(a)* that Resolution No. 5, annexed to the International Telecommunication Convention, Buenos Aires, 1952, required the study of the influence of intentional or parasitic oscillations on radio services, especially broadcasting and mobile services, with a view to the possible establishment of standards permitting a harmonious co-existence of radio services with industrial installations producing radio oscillations;

*(b)* that the harmonious co-existence of radio services with industrial installations, producing radio oscillations, involves close collaboration between organizations representing the manufacturers and users of these installations on the one hand, and the radio services on the other, for which the existing collaboration between the C.C.I.R. and the Special International Committee on Radio Interference (C.I.S.P.R.) provides;

*(c)* that the C.I.S.P.R. has already studied extensively, and continues to study, the permissible signal-to-interference ratios for sound and television broadcasting, but has not yet made equivalent studies for other radio services;

UNANIMOUSLY DECIDES that the following question should be studied:

1. what is the maximum level of interference, caused by radiations from industrial, scientific and medical installations and other kinds of electrical equipment, that can be tolerated in various frequency ranges by the types of equipment employed by radio services, especially by the mobile services;
2. what are the most appropriate means of determining the level of intentional or parasitic radiations produced by industrial, scientific or medical installations and other kind of electrical equipment;
3. to what levels is it practicable to reduce such radiations?

*Note 1.* – Some examples of electrical equipment liable to cause disturbance are given in Opinion 2; radio transmitters are excluded.

*Note 2.* – In this study, the C.C.I.R. should, to avoid duplication of work, keep itself informed of the results of the studies of the C.I.S.P.R. on the same subject.

* This Question replaces Question 75.

## STUDY PROGRAMME 227A(I) *

## LIMITATION OF UNWANTED RADIATION FROM INDUSTRIAL INSTALLATIONS

The C.C.I.R., (Warsaw, 1956)

CONSIDERING

*(a)* that no standard measuring method can yet be recommended for the measurement of unwanted radiation;

*(b)* that the effect of interference is dependent on the particular type of service and on the waveform of the unwanted radiation;

*(c)* that, it is desirable to compare measurements made at various test sites and possibly using different methods;

*(d)* that the effect of interference depends on the transmission coefficient between the source of interference and the receiver affected;

*(e)* that the C.I.S.P.R. has already studied, and continues to study, extensively the measuring methods for determining the level of interference from industrial, scientific and medical apparatus to sound and television broadcasting;

*(f)* that due regard should be given to the special requirements of radiocommunication services other than broadcasting;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. determination of which parameters of the interfering field should be measured. The polarization and the relation between the magnetic and electric field should be considered;
2. the effects of the relative positions of the industrial, scientific and medical equipment, or groups of equipments, and the measuring set, the number of measurements at different distances and the number of directions in which measurements should be made;
3. the effect of different open sites on the measured field;
4. the methods that can be used to measure the radiation from industrial, scientific and medical equipment which is situated indoors and the relationship between measurements made indoors and those made on outside sites;
5. the importance of interference due to the presence of radio-frequency voltages in the mains leads of the industrial, scientific and medical equipment and the methods of measurement;
6. the effect of the working conditions of the apparatus to be measured during the measurements;
7. the wave collectors to be used for measurements in the different frequency bands;
8. the characteristics of the equipment to be used for the measurements, particularly its bandwidth;
9. the way in which interference with various radio services depends upon the waveform of the disturbing field;
10. the statistical distribution and the representative values for the transmission coefficient between the interference sources and the receiving antenna in the service concerned.

*Note.* – In this study the C.C.I.R. should, to avoid duplication of work, keep itself informed of the results of the studies of the C.I.S.P.R. on the same subject.

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* This Study Programme was formerly designated Study Programme 84 (I).

## STUDY PROGRAMME 3A(III) *

## FACTORS AFFECTING THE QUALITY OF PERFORMANCE OF COMPLETE SYSTEMS OF THE FIXED SERVICES

### Signal-to-noise and signal-to-interference protection ratios for fading signals, bandwidth and adjacent channel spacing

The C.C.I.R., (Los Angeles, 1959)

CONSIDERING

*(a)* that Question 3(III) establishes a permanent study of questions relating to the desired conditions of performance to be fulfilled by the fixed services;

*(b)* that the conditions for satisfactory performance of a system must take account of the need to receive signals propagated via the ionosphere, which are subject to fading and multipath effects and are accompanied by radio noise and interference;

*(c)* that studies requiring signal-to-noise and signal-to-interference protection ratios are closely related, and that determination of necessary adjacent channel spacings requires, in addition, consideration of frequency stability and bandwidth of the systems;

*(d)* that there are a number of different techniques and systems in use in the radiotelegraph and radiotelephone services and, while it is essential to consider the most advanced state of the radio art, it is also necessary to give special study to conventional systems, either affecting integration of land-line and radio services, or of concern to the I.F.R.B.;

UNANIMOUSLY DECIDES to carry out the following studies:

**1. Classes of service**

The studies concern the following classes of service in regular use in the fixed services, but should also give due regard to new techniques and systems, including those under development, for application to the fixed services:

1.1 *Radiotelephony*

1.1.1 Types of emission: A3, A3A, A3B, F3 **;

1.2 *Radiotelegraphy*

1.2.1 Types of emission: A1, A2, A7, F1;

1.2.2 Telegraph speeds:

- A1, A2, hand speed 8 and 24 bauds, machine speed 50 and 120 bauds;
- A7, multichannel VF telegraphy, 50 to 200 bauds per channel;
- F1, 50 to 600 bauds;

1.2.3 Codes:

- 5-unit start-stop;
- 5-unit synchronous;
- synchronous error-detecting and correcting systems using two-condition signalling codes other than the International Alphabet No. 2;
- other systems using more than two signalling conditions;

1.3 *Facsimile, phototelegraphy; Hellschreiber*

1.3.1 Types of emission: A4, F4.

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* This Study Programme, which replaces Study Programmes 44, 45, 49 and 50 and Questions 82, 129 and 131, was previously designated Study Programme 128(III).

** F3 above 30 Mc/s only, with reference to ionospheric-scatter applications.

## 2. Minimum conditions required for satisfactory service

2.1 Acceptable criteria and values for:

2.1.1 *intelligibility* over radiotelephone circuits *;

2.1.2 *error rate* for characters and elements over radiotelegraph circuits (*efficiency factor* for ARQ circuits);

2.1.3 *legibility* of copy over facsimile (phototelegraphy) and Hellschreiber circuits;

- what is the maximum duration and percentage of the time during which performance inferior to the standard values can be tolerated;

2.2 Performance of the system as a function of:

- signal-to-noise and signal-to-interference (co-channel) ratios;
- required signal-to-noise and signal-to-interference (co-channel) protection ratios for the acceptable standard values of intelligibility, error rate (efficiency factor on ARQ circuits), or legibility, for the various services **, considering:

2.2.1 Signal fading, taking account not only of the amplitude distribution, but also of the autocorrelation function and the distribution of duration of the fades;

2.2.2 Diversity (space, frequency, or time) techniques:

- noise reducers,
- coding including the use of error-correcting; codes or ARQ ***,
- use of more than two signalling conditions, and
- optimum modulation and detection techniques ****,

2.2.3 Multipath effects;

2.2.4 Interference effects of radio noise of various types, such as atmospheric, impulsive, or Gaussian noise, as described by the wave form and amplitude distribution of the instantaneous values of the noise,

- the resulting interference effects on actual reception, taking account of the method of detection, and of filtering prior to and following detection;

2.2.5 Interference effects of co-channel signals representing the various classes of emission, taking account of the spectral and statistical (fading) characteristics of the interfering signal;

2.2.6 Monthly mean signal-to-noise ratios and signal-to-interference ratios, required for circuits of various lengths and directions, for the acceptable standard values of circuit performance (§ 2.1), to be met during the specified percentage of the time, taking into account,

- the distribution within an hour of the mean values of the short-term (fading) distributions of signals and noise,
- the distribution, within a month or season, for a given hour of the hourly mean values of the signal strengths and atmospheric noise levels (Report 322) *****,

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* For the various grades – just usable, operator to operator (order wire);
– marginally commercial;
– good commercial.

** For radiotelephone services, the signal-to-noise ratio required in the audio band must be specified, and from this the signal-to-noise ratio required in the radio-frequency band is established.

*** It would be useful to compare the systems using the various telegraph codes, including those of § 1.2.3, in terms of undetected or uncorrected error rate for a given power and signalling speed, in words per minute, and operating under the same conditions. A 5-unit start-stop system may also be used as the reference system by regarding each mutilated character as an error only. It is provisionally suggested that the ratio of error rates should be expressed for two circuit conditions only, namely, when the system under test is subjected to an average of one undetected or uncorrected error per 1000 characters, and per 10 000 characters.

**** A special study is needed comparing the different systems used for voice-frequency telegraphy on radio circuits; this is dealt with in Study Programme 43A(III).

***** The monthly mean values of atmospheric noise for various time blocks, and information on the distribution of values within the month, is given in Report 322; with regard to monthly mean values of signal strength, and distribution of hourly values within the month, until such time as C.C.I.R. adopts information on this subject, other standard references may be used, such as U.S. National Bureau of Standards Circular No. 462.

this study is intended to lead to revisions or replacement of Recommendations **240**, 339 and 340.

2.3 Minimum bandwidth required for satisfactory transmission and reception of the intelligence, in a complete system (this is not the question of " bandwidth necessarily occupied ", involving the capability of the transmitting system to avoid radiation outside the band needed for communication, which is included in Study Programme 181(I)).

**3. Determination of adjacent channel signal-to-interference protection ratios, and frequency separations between various classes of service, considering**

3.1 the use of effective receiving band-pass filters no wider than necessary for satisfactory reception (§ 2.3 above, and Recommendations 237, 330 and 332);

3.2 the bandwidth occupied by the interfering transmission;

3.3 the frequency tolerance and stability of the wanted and unwanted signals;

3.4 the studies of § 2.2 above relating to co-channel signal-to-interference protection ratios.

*Note.* – The results of this study should be presented in the form indicated in the Annex. The results are intended to lead to revision of Recommendation 240.

## QUESTION 133(III) *

## COMMUNICATION THEORY

The C.C.I.R., (Geneva, 1951 – Warsaw, 1956)

CONSIDERING

*(a)* that for the transmission of a given volume of information through a given telecommunication channel with a given power, either in a given time using a minimum bandwidth, or with a given bandwidth in a minimum time, the theoretical formulae suggest the use of pulse-code modulation;

*(b)* that the theoretical coding method for improving on this involves a long delay;

*(c)* that the theoretical coding methods usually do not take into account the presence of a return channel, which in practice has led to efficient transmission systems with a low error rate;

*(d)* that the U.R.S.I. has suggested further study in Doc. 14 of Warsaw, 1956;

UNANIMOUSLY RECOMMENDS that the following question should be studied:

**1.** the relation between permissible delay and residual uncertainty and its dependence on bandwidth utilization;

**2.** the improvement practicably possible in existing systems, with regard to the transmission of information, in particular for those systems where a go and a return channel are available.

* This Study Programme replaces Study Programme 86.

## STUDY PROGRAMME 133A(III) **

## COMMUNICATION THEORY

The C.C.I.R., (Geneva, 1951 – London, 1953 – Warsaw, 1956 – Geneva, 1963)

CONSIDERING

*(a)* that, in view of the increasing congestion of the radio spectrum and telecommunication circuits, it would be advantageous to discover technical methods of decreasing the bandwidth, the transmission time of a given quantity of information, or the transmitted power;

*(b)* that present studies seek mainly to perfect established systems, whereas recent theories seem to show that these systems occupy several times the bandwidths strictly necessary for the transmission of the required information at the required speed;

*(c)* that, even with existing systems, it is not possible to reduce the bandwidth to that strictly necessary because of unpredictable noise, natural and man-made interference, and complex propagation conditions; a margin of bandwidth is necessary to decrease distortion and the frequency of errors due to these phenomena;

*(d)* that it is not certain that existing codes, some at least of which were not designed in the light of phenomena peculiar to radio propagation, are making the best use of the occupied bandwidth;

** This Question replaces Question 44.

*(e)* that, to assess the effectiveness of any error-detecting or error-correcting codes over radio circuits, it is essential that realistic error statistics be known for these radio circuits;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the review of the various codes in use and the study of new codes, leading to an economy of bandwidth or transmission time for a given quantity of information preserving a given quality of transmission, taking into account the phenomena peculiar to radio propagation and the comparison of the various existing systems of modulation from the point of view of the bandwidth occupied in relation to the amount of information transmitted in a given time for a given power; *

2. that experimental determination of error statistics be made for operating radio circuits. On the 3 out of 7 ARQ systems, this can conveniently be done by counting and printing out the errors on " idle alpha " characters, while the system is in full operation. The result of these experiments will be a table, showing the frequency of occurrence of $m$ errors in a sequence of $n$ digits ($m = 0, 1, 2, 3 \ldots$ and $n = 7, 14, 21 \ldots$). Where this is possible, it may be useful to give information on the occurrence of the different types of error);

3. that experimental determination of the relative frequencies of occurrence of $m$ errors be extended to values of $n$ other than multiples of 7. This experiment may require a separate experimental channel. The suggested range of values for $n$ is between about 10 and 100, with particular emphasis put on 15, 31, 63 and 127;

4. the study, in conjunction with the U.R.S.I., of the methods of communication theory that are best suited for practical application.

*Note.* – The statistical information asked for under § 2 and 3 should, where possible, state the conditions of the channel: signal-to-noise ratio, fading characteristics, special noise or channel disturbances, interference from other stations, etc.

* Relative to this study, it is useful to consider for radiotelephony, the determination of the relationship between intelligibility and the shape and width of the passband of the receiver for signal-to-noise ratios consistent with:
- just usable quality, operator to operator,
- marginally commercial quality,
- good commercial quality,

taking into account that:
- in many cases, the noise power is distributed uniformly over the audio-frequency spectrum, while speech power is distributed unevenly over the spectrum;
- when high noise levels are present in the communication system, and the signal-to-noise ratio is constant, the intelligibility might show a maximum as a function of the bandwidth and the distribution of the power corresponding to the frequencies it contains. This distribution of the power may vary with fading.

# QUESTION 233(III)

## USE OF COMMON-FREQUENCY SYSTEMS ON INTERNATIONAL RADIOTELEPHONE CIRCUITS

The C.C.I.R., (Geneva, 1963)

CONSIDERING

*(a)* that relief of the present congestion of the HF (decametric) band is a matter of urgency;

*(b)* that, in certain cases, the use of the same frequency for both directions of transmission (in combination with the use of VODAS equipment), may result in important economies in spectrum utilization on international radiotelephone circuits;

UNANIMOUSLY DECIDES that the following question should be studied:

**1.** what are the characteristics to be specified for international radiotelephone systems using the principles of common-frequency operation;

**2.** what should be the minimum difference in level at the input to the receiver between the received signal from the distant station, and signals from the nearby transmitting station, to avoid interference between the wanted signal and that from the nearby transmitter operating on the same frequency;

**3.** to what extent will the use of transmitting and receiving antennae, with different transmission characteristics, reduce the possibilities of application of this technique;,

**4.** to what extent will the possibilities of application of this technique be reduced by the presence of different noise levels at the receiving locations;

**5.** what other factors should be taken into account when planning such systems, for example:
- non-linearities in the transmitting and receiving equipment,
- carrier-filter bandwidth,
- frequency stability of the equipment?

## QUESTION 280(III)

### USE OF DIRECTIONAL ANTENNAE IN THE BAND 4 TO 27·5 Mc/s

#### Limitation of radiation outside the direction necessary for the service

THE INTERNATIONAL FREQUENCY TEGISTRATION BOARD,

IN VIEW OF the request by the Panel of Experts in Recommendation No. 38 of its Final Report, Geneva, 1963, and AFTER CONSIDERING:

*(a)* that there is serious congestion in the frequency bands between 4 and 27·5 Mc/s;

*(b)* that there is a need to adopt methods and regulations for the solution of the frequency problems with which Administrations are confronted in the use of these bands;

*(c)* that occupation of the radio-frequency spectrum is represented, not only in time and bandwidth, but also in the spatial distribution of the radiated power;

*(d)* that this latter distribution can be effectively controlled by the use of directional antennae;

*(e)* that the intent of Articles 12 and 14 of the Radio Regulations, Geneva, 1959, would seem to justify further explicit requirements for the use of directional antennae in the bands between 4 and 27·5 Mc/s, as well as for quantitative limitation of the intensity of radiation in directions other than that required for the service;

AND IN VIEW OF No. 180 of the International Telecommunication Convention, Geneva, 1959;

DECIDES to submit the following urgent question to the C.C.I.R.:

what are reasonable standards for the directivity of antennae in the various types of radio services, and for various distances, in the bands between 4 and 27·5 Mc/s, including the width of the main beam and the allowable intensity of radiation (effective radiated power) in directions of azimuth outside the main beam (such standards should reflect due regard for practical considerations of construction and cost)?

## STUDY PROGRAMME 235 A (IV) *

## FEASIBILITY OF FREQUENCY SHARING BETWEEN COMMUNICATION-SATELLITE SYSTEMS AND TERRESTRIAL RADIO SERVICES

The C.C.I.R., (1961 — Geneva, 1963)

CONSIDERING

*(a)* that use of communication-satellite systems will require extensive use of the radio-frequency spectrum;

*(b)* that for communication-satellite systems, the spectrum should be shared with terrestrial services to the extent practicable, in the interest of spectrum conservation; and

*(c)* that the feasibility of sharing spectrum space with line-of-sight radio-relay systems should be investigated;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. what criteria affect the selection of sites for earth stations in the communication-satellite system, taking into account the various portions of the radio-frequency spectrum;
2. what are the preferred technical characteristics of transmitting and receiving antennae for earth stations at fixed locations, from the standpoint of spectrum sharing with other radio services;
3. what criteria affect the determination of the minimum angle of elevation, which should be employed at the locations of the earth stations;
4. to what degree will physical modification of terminal sites provide electromagnetic shielding between earth stations and stations in other radio services;
5. what criteria affect the selection of satellite power in frequency bands shared with other radio services;
6. what criteria affect the determination of the minimum practicable separation between the transmitting and receiving locations of line-of-sight radio-relay systems and the receiving and transmitting locations of earth stations in the communication-satellite systems?

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* This Study Programme replaces Study Programme 174.

## STUDY PROGRAMME 235 B (IV) *

# FREQUENCY SHARING BETWEEN COMMUNICATION-SATELLITE SYSTEMS AND TERRESTRIAL RADIO SERVICES

### Wanted-to-unwanted signal ratios

The C.C.I.R., (1962 — Geneva, 1963)

CONSIDERING

*(a)* that methods are described in Report 209 for determining the conditions under which frequency sharing is feasible between communication-satellite systems and terrestrial services;

*(b)* that a precise determination depends upon the availability of appropriate values for the acceptance ratios between wanted and unwanted signal powers at the receiver input for specified grades of service;

*(c)* that acceptance ratios are required between each type of wanted signal and each type of unwanted signal, for appropriate modulation and fading conditions, for which a test of the feasibility of sharing is desired;

UNANIMOUSLY DECIDES that the following studies should be carried out:

**1.** theoretical and experimental determinations of the acceptance ratios required for specified grades of service for various types of wanted and unwanted signal, for appropriate modulation conditions and for various kinds of fading;

**2.** investigation of those techniques of transmission, reception and modulation which will minimize the acceptance ratios required for a specified grade of service.

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## STUDY PROGRAMME 235 C (IV) **

# COMMUNICATION-SATELLITE SYSTEMS

### Feasibility of frequency sharing among communication-satellite systems

The C.C.I.R., (Geneva, 1963)

CONSIDERING

*(a)* that the use of communication-satellite systems will require extensive use of the radio spectrum;

*(b)* that the feasibility of frequency sharing among communication-satellites operating in the same system or operating in different systems should be investigated;

UNANIMOUSLY DECIDES that the following studies should be carried out:

**1.** what criteria affect interference among communication-satellites in a given system and between communication-satellite systems, taking into account the two directions of transmission, for:

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* This Study Programme replaces Study Programme 179.

** This Study Programme, together with Question 235 (IV), replaces Question 214.

1.1 systems using stationary satellites;

1.2 systems using station-keeping satellites;

1.3 systems using random satellites;

1.4 satellites operating in various orbits in the same system;

1.5 satellites operating in various orbits in different systems;

2. what are the preferred technical characteristics of transmitting and receiving antennae for earth stations, from the standpoint of frequency sharing within the same system and with other communication-satellite systems;

3. what criteria affect the determination of the minimum elevation angle which should be employed at the earth stations, from the standpoint of frequency sharing among communication-satellite systems;

4. is there an optimum range of powers to be employed by satellites and by earth-station transmitters, to facilitate frequency sharing among communication-satellite systems;

5. what are the effects of baseband and modulation characteristics on frequency sharing among communication-satellite systems;

6. would the selection of preferred reference frequencies facilitate frequency sharing among communication-satellite systems?

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## STUDY PROGRAMME 235 D(IV) *

## STUDY OF PREFERRED MODULATION CHARACTERISTICS FOR COMMUNICATION-SATELLITE SYSTEMS

The C.C.I.R., (1961 — Geneva, 1963)

CONSIDERING

*(a)* that earth satellites are expected to be used extensively for the relay of communication signals of various types;

*(b)* that substantial use of communication satellites will place substantial demands upon the radio spectrum;

*(c)* that, in the interest of conservation of the radio-frequency spectrum, effort should be exerted to use the minimum feasible amount of spectrum space to convey the maximum amount of information;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. determination of the preferred characteristics for transmission from earth to satellite to earth in passive communication-satellite systems;

2. determination of the preferred modulation characteristics for transmission from earth to satellite and from satellite to earth in active communication-satellite systems,

3. determination of the extent to which signal compression or signal processing techniques can usefully be employed to conserve radio-frequency bandwidth, and the preferred characteristics which should be employed when such techniques are used for satellite-communication systems.

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* This Study Programme replaces Study Programme 175.

# STUDY PROGRAMME 235 E (IV) *

## FACTORS AFFECTING FREEDOM OF ACCESS IN COMMUNICATION-SATELLITE SYSTEMS

(1962 — Geneva, 1963)

ᴀne C.C.I.R.,

CONSIDERING

*(a)* that communication-satellite systems may require simultaneous use by large numbers of earth stations at various locations, this being termed "freedom of access";

*(b)* that this freedom of access may be affected by the orbital design of the system;

*(c)* that this freedom of access may be affected by the choice of modulation techniques used;

*(d)* that this freedom of access may be affected by the interference characteristics of the system or systems used;

*(e)* that multiple access requirements may dictate a system design, different from that which may be optimum for limited access systems;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. what factors determine the accessibility of a communication-satellite system to a number of earth stations simultaneously or in random order;

2. to what extent does the choice of orbital parameters affect this freedom of access, and are there preferred orbits for such freedom of access;

3. to what extent does the type of modulation and channel arrangement employed affect freedom of access, and are there preferred types of modulation and channel arrangement for such freedom of access;

4. what are the effects of the preferred choices resulting from §§ 2 and 3 on the possibilities of sharing with terrestrial services and with other satellite systems of the same and of different type?

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* This Study Programme replaces Study Programme 178.

## QUESTION 236 (IV) **

## SHARING OF RADIO-FREQUENCY BANDS BY LINKS BETWEEN EARTH STATIONS AND SPACECRAFT

The C.C.I.R., (1961 — Geneva, 1963)

CONSIDERING

*(a)* that sharing of the radio spectrum by links between earth stations and spacecraft with all other radio services may be necessary, because of the limited spectrum space available to support the world's communication requirements: and

*(b)* that factors which determine the ability to share spectrum space are strongly interdependent;

UNANIMOUSLY DECIDES that the following question should be studied:

**1.** how do the following factors, among others, affect the practicability of sharing:

1.1 location of space and earth stations of a link and the resulting zones of mutual visibility;

1.2 time of use during period of mutual visibility;

1.3 probability of occupancy of the zones of mutual visibility of links between earth stations and spacecraft by other operating stations during the required times of use of the link and the resulting power levels at all earth stations, as a consequence of this combined occupancy;

1.4 other system parameters, such as modulation techniques, antenna directivity, etc.;

1.5 natural (non man-made) interference;

**2.** to what extent is spectrum sharing feasible for different links between earth stations and spacecraft; between these links and other space systems; and between these links and terrestrial radio services?

## QUESTION 237(IV) *

## TECHNICAL CHARACTERISTICS OF LINKS BETWEEN EARTH STATIONS AND SPACECRAFT

The C.C.I.R., (1961 — Geneva, 1963)

CONSIDERING

*(a)* that the value of spacecraft will, in the future, depend almost entirely on the ability to use radio-frequency electromagnetic energy for the transmission of all types of information over links between earth stations and spacecraft;

*(b)* that available bandwidth in useful regions of the radio-frequency spectrum will be limited;

UNANIMOUSLY DECIDES that the following question should be studied:

what are the preferred technical characteristics and system parameters commensurate with technical feasibility which will insure the maximum practical use of radio-frequency spectrum space for the following types of links between earth stations and spacecraft:

1. maintenance telemetering;
2. tracking;
3. telecommand;
4. communication and data transmission?

*Note 1.* — This Question relates both to space research and to developmental and operational systems.

*Note 2.* — The following factors should be taken into account in carrying out this study:

— information rate and duty-cycle as they affect bandwidth requirements;

— required signal-to-noise ratio;

* This Question replaces Question 211.

## STUDY PROGRAMME 185 A (V)

## PROPAGATION DATA REQUIRED FOR LINE-OF-SIGHT RADIO-RELAY SYSTEMS

(Geneva, 1963)

The C.C.I.R.,

CONSIDERING

*(a)* that, in planning a communication network, it is necessary to define the overall system performance achieved for given percentages of the time;

*(b)* that designers of radio systems in the VHF (metric), UHF (decimetric) and SHF (centimetric) bands require to know, from the viewpoint of sustained satisfactory operation, the tropospheric propagation characteristics and the resulting transmission loss (see Recommendation 341), that is not exceeded for a large percentage of the time for each particular frequency band over the working range, which may extend from several tens of kilometres up to more than 200 km for certain links between elevated sites;

*(c)* that the planning of systems requires a knowledge of the seasonal distribution curves as functions of time, of the transmission loss for the most unfavourable season or month;

*(d)* that, for interference studies, it is necessary to know the quasi-minimum value of the transmission loss;

*(e)* that the bandwidth of the system may be limited by the effects of multipath propagation;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. what is the distribution in time of the values, relative to free-space of the received power-level reached, in the VHF (metric), UHF (decimetric) and SHF (centimetric) bands, for each month of the year. The recording should be performed with an instrument having a time constant of less than or equal to one second;
2. what are the levels for given percentages of time corresponding to the most unfavourable month, the most favourable month and those corresponding to the whole year;
3. to what extent do the distributions found depend on the path length, the climate, the nature of the terrain over which the path passes and the clearances of the antennae;
4. to what extent can the distributions found be described by simple statistical laws;
5. what limitations are imposed on transmission by the effects of multipath propagation and how may these be overcome;
6. what limitations on the use of the system are imposed by solar noise and noise from other external sources?

*Note.* — To meet the needs of Study Group IX, priority should be given to measurements to establish the magnitude of interfering fields at 6 and 11 Gc/s, with antennae representative of practical systems, over representative paths and at longer distances.

## STUDY PROGRAMME 185 B(V)

## PROPAGATION DATA REQUIRED FOR BEYOND-THE-HORIZON RADIO-RELAY SYSTEMS

(Geneva, 1963)

The C.C.I.R.,

CONSIDERING

*(a)* that in the planning of a communication network it is necessary to define the overall system performance achieved for a given percentage of the time;

*(b)* that designers of radio systems in the VHF (metric), UHF (decimetric) and SHF (centimetric) bands require to know, from the viewpoint of sustained satisfactory operation, the tropospheric propagation characteristics and the resulting transmission loss, that is not exceeded for a large percentage of the time for each particular frequency band, over the distance corresponding to the service range, which may extend from about 200 km to more than 500 km;

*(c)* that the planning of systems requires a knowledge of the distribution curves, as functions of time, of the transmission loss for the most unfavourable month of the climatic zone under consideration;

*(d)* that, for interference studies, it is necessary to know the quasi-minimum value of the transmission loss;

*(e)* that the bandwidth of the system may be limited by the nature of the mode of propagation employed;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. what is the distribution in time of the basic transmission loss (see Recommendation 341) in the VHF (metric), UHF (decimetric) and SHF (centimetric) bands, for each month of the year (the value of the path antenna gain being specified). The recording should be performed with an instrument having a time constant of one minute * and especial importance should be attached to the quasi-maximum and quasi-minimum values of the transmission loss or field-strength;

2. what are the levels for given percentage of time corresponding to the most unfavourable month, the most favourable month and those corresponding to the whole year;

3. which are the hours of the day for which the greatest transmission loss may usually be expected;

4. what is the distribution in time of the fluctuation of the level of the received signal about its hourly median value **, when the recording is made with a time constant as short as possible;

5. how do the distributions depend on the climatic zone in which the path under consideration is located, and which distinct climatic zones should be taken into consideration ***;

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* Other time constants may be used, should it appear desirable, but in all cases the time constant used should be specified.

** Other periods of time may be used to define the median value, but these periods should be stated.

*** In view of the paucity of data relating to propagation in climates other than temperate, Administrations are urged to give special attention to the collection of data relating to other types of climate.

6. how do the distributions found depend on the frequency, the distance between the stations, the angle of elevation of the antennae at each terminal and on the nature of the terrain over which the path passes;

7. to what extent can these distributions be described by simple statistical laws;

8. what limitations on the bandwidth of the system are imposed by the propagation process employed (diffraction, partial reflection, scattering, etc.);

9. what limitations on the use of the system are imposed by the effects of solar noise, and noise from other external sources?

*Note.* — The results of these studies should be presented in the form given in Administrative Circular AC/63.

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## STUDY PROGRAMME 139(V) *

## RADIO TRANSMISSION UTILIZING INHOMOGENEITIES IN THE TROPOSPHERE (COMMONLY TERMED "SCATTERING")

(Warsaw, 1956 — Los Angeles, 1959)

The C.C.I.R.,

CONSIDERING

*(a)* that, in various countries, recent experiments, characterized by the use of transmitting and receiving antennae directed towards the same part of the troposphere, have shown that radio signals in the VHF (metric), UHF (decimetric) and SHF (centimetric) bands can be propagated consistently through the troposphere over unexpectedly great distances, and that, beyond the line of sight, fields are found to be much greater than the diffraction theory for a standard radio atmosphere would predict;

*(b)* that useful signals can be obtained in this manner at distances greater than was formerly expected;

*(c)* that tropospheric inhomogeneities play an important role in this phenomenon;

*(d)* that little is known about geographical and topographical influences;

UNANIMOUSLY DECIDES that the following studies should be carried out:

investigation of this new tropospheric propagation phenomenon, in its widest sense, with a view to the extension of knowledge of:

1. the characterisitcs of the signal, in particular signal strength, signal distortion (time delays, bandwidth), fading rates and fading range and their dependence on frequency, range and geographical situation;

2. the influence of meteorological conditions, including water vapour, rain and snow on signal strength;

3. the efficiency of antennae in relation to size and design;

4. the use of space, frequency and polarization diversity for transmission and reception;

5. the application of such diversity techniques for co-channel transmission and reception.

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* This Study Programme, which replaces Study Programme 91, does not refer to any Question under study.

## STUDY PROGRAMME 194 (VI)

# IDENTIFICATION OF PRECURSORS INDICATIVE OF SHORT-TERM VARIATIONS OF IONOSPHERIC PROPAGATION CONDITIONS AND METHODS FOR DESCRIBING IONOSPHERIC DISTURBANCES AND THE PERFORMANCE OF RADIO CIRCUITS

(London, 1953 — Warsaw, 1956 — Geneva, 1963)

The C.C.I.R.,

CONSIDERING

*(a)* that it is desirable to have an index, or indices, suitable for short-term forecasts of ionospheric disturbances;

*(b)* that long-term indices for ionospheric propagation are not satisfactory for indicating short-term variations in the ionosphere;

*(c)* that ionospheric propagation disturbances may result from either corpuscular or photon radiation from the sun;

*(d)* that a correlation has been found between short-term variations of ionospheric propagation conditions and certain indices of magnetic phenomena and solar eruptions;

*(e)* that it is desirable to have forecasts of ionospheric disturbances, expressed in terms which are at the same time meaningful to operators of ionospheric communications systems, and appropriate for use in the subsequent evaluation of the reliability of the forecasts;

*(f)* that the application of ionospheric disturbance forecasts varies widely with the type of radio circuit in question;

*(g)* that it is desirable that the forecasts issued by different agencies should be expressed in a way which facilitate comparison between them;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the possibility of selecting particular kinds of solar observations or observations of other phenomena, such as geomagnetic activity, cosmic rays, whistlers, etc., which can be made objectively, and which may be usefully employed for short-term predictions of ionospheric propagation conditions;

2. the possibility of describing ionospheric disturbances in terms comparable with the forecasts;

3. the possibility of establishing a common method for the description of ionospheric disturbances, for use in forecasting and verification, taking account of such factors of the disturbance as: starting time, areas affected, movement, change of size, duration and magnitude;

4. the possibility of defining indices, which describe the intensity of ionospheric disturbance for each of a series of equal short intervals and which might be combined into an estimate of the importance of the disturbance for the whole period;

5. the relationship between the characteristics of the disturbance, as described by the common method (see § 3), and the expected performance of radio circuits of various kinds;

6. the possibility of defining a more objective scale of the importance of sudden ionospheric disturbances, for example, by studying changes in the mean field-strength of atmospherics in the frequency band 20 to 40 kc/s.

## STUDY PROGRAMME 195 (VI)

# PROPAGATION BY WAY OF SPORADIC-E AND OTHER ANOMALOUS IONIZATION IN THE E- AND F-REGIONS OF THE IONOSPHERE

(Los Angeles, 1959 — Geneva, 1963)

The C.C.I.R.,

CONSIDERING

*(a)* that sporadic-E propagation may play an important role in HF communications out to great distances and, frequently, in the lower part of the VHF band, up to distances of about 2300 km;

*(b)* that sporadic-E data from ionosondes do not provide adequate statistics for the prediction, for oblique paths, of the field strength of the received signal or of the transmission loss;

*(c)* that data on propagation by sporadic-E and other abnormal ionization obtained from continuous-wave recordings, and from fixed frequency pulse measurements at oblique incidence, provide statistical data of the type needed by engineers;

*(d)* that with continuous-wave observations, it is frequently very difficult to separate sporadic-E from other anomalous ionization in the E- and F-regions and from tropospheric propagation effects;

*(e)* that the path configuration plays an important part in those modes of propagation, where reflections from field-aligned ionization seem to occur, as for example, auroral-type phenomena;

*(f)* that, whilst it may be possible to exploit these anomalous modes, they are also a potential source of interference;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. field-strength or transmission loss of signals propagated by abnormal modes in the E- and F-regions at frequencies in the upper part of the HF band and the lower part of the VHF band. In analyzing the measurements, attention should be paid to:
   - separation of the effects of the different modes of propagation;
   - influence of frequency, distance, time of day, season and solar cycle;
   - the effects of field-aligned ionization;
   - the vertical and azimuthal angles of arrival of the different abnormal modes;
   - characteristics of the terminals, such as antenna gains and directivities, site configuration, receiver characteristics and calibration procedures, transmitter power, and transmission-line losses;

2. comparison, where possible, of the results so obtained with data obtained by means of ionosondes (for example, foEs);

3. preparation of simple world-wide and regional charts of received signal level relative to free-space, or of transmission loss, at suitable frequencies for those abnormal modes which are found to be significant.

## STUDY PROGRAMME 198 (VI)

### ESTIMATION OF SKY-WAVE FIELD-STRENGTH AND TRANSMISSION LOSS FOR FREQUENCIES BETWEEN THE APPROXIMATE LIMITS OF 1·5 AND 40 Mc/s

(Geneva, 1951 — London, 1953 — Warsaw, 1956 — Los Angeles, 1959 — Geneva, 1963)

The C.C.I.R.,

CONSIDERING

that present methods of estimating sky-wave field-strength and transmission loss are not always sufficiently accurate;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. detailed theoretical investigations of long distance ionospheric propagation;
2. improvements in methods of estimation, taking into account for example, off great-circle propagation, ground scatter and the influence, not only of the strength of the magnetic field of the earth, but also of its direction relative to the direction of propagation;
3. improvements in the estimation techniques for paths traversing the equatorial or the auroral zone, and for the short paths, up to 800 km, involved in tropical broadcasting;
4. improvements in the estimation of night-time attenuation;
5. statistical comparisons between the calculated and measured values of the field-strength or transmission loss, taking into account the values of the propagation parameters for the period of comparison, as well as the influence of the actual polar diagrams of the antennae;
6. measurements of absorption from both vertical and oblique incidence pulse transmissions on a number of frequencies especially in regions of high absorption;
7. application of the temporal variations of the absorption of extraterrestrial noise and of field strengths of signals received from spacecraft.

STUDY PROGRAMME 200 (VI) **

## BASIC PREDICTION INFORMATION FOR IONOSPHERIC PROPAGATION

(London, 1953 — Los Angeles, 1959 — Geneva, 1963)

The C.C.I.R.,

CONSIDERING

*(a)* that the production of basic predictions for ionospheric propagation involves problems which are not yet fully solved;

*(b)* that, nevertheless, extensive practical use is made of predictions by radio operating services and Administrations***;

*(c)* that the application of basic prediction information, as supplied to various Administrations and centres, to specific operational problems, has revealed occasional large discrepancies between predictions and operational results, even though the solar activity may have been correctly forecast. These discrepancies may be attributed to such causes as:

— different interpretations placed upon the basic ionospheric observations;

— different methods of converting basic ionospheric observational data into predictions;

— inadequate understanding and lack of research concerning the role played by the E-, Es-and Fl-layers, for the actual modes of propagation and for the effects of ground and ionospheric scatter;

— the need for suitable methods of interpolation in the preparation of basic world prediction's especially for regions from which no ionosonde data are available;

— differences in the statistical significance of the ionospheric and operational data sampled, and in the methods of assessing the circuit performance of the various classes of service;

*(d)* that the distinction between operational, standard and classical MUF* is not yet familiar to many users.

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the suitability of present methods for predicting oblique-incidence MUF from vertical data for both short and long paths;

2. the ratio of operational MUF to standard MUF so that a correction factor dependent on system parameters such as power, type of service, and information rate could be introduced into predictions wherever it is needed;

3. the extent to which basic prediction data could be improved by different methods of interpolation;

4. the role played by ionization in the layers of the E-region for both short and long paths;

5. practical methods of introducing into predictions such subjects as propagation modes, the related angles of arrival and departure, and the effects of ionospheric-layer tilts;

6. propagation off the great-circle path;

7. a statistical determination in terms of season, solar cycle, location, etc. of the day-to-day variation of both standard and operational MUF so that practical methods may be devised whereby this factor can be introduced into monthly predictions.

## STUDY PROGRAMME 153 (VI) *

## MEASUREMENT OF MAN-MADE RADIO-NOISE

(Los Angeles, 1959)

The C.C.I.R.,

CONSIDERING

*(a)* that man-made radio-noise is frequently the limiting factor in the reception of radio signals over a wide frequency range, particularly during daylight hours, when atmospheric noise is low;

*(b)* that the dynamic characteristics, as well as the geographical, time and frequency dependence of man-made radio-noise are entirely different from those of atmospheric noise;

*(c)* that information on the relative importance of atmospheric and man-made radio noise is needed for future revisions of Report 322;

*(d)* that previous measurements of man-made noise have largely been concentrated on the individual sources, the principal objective being the reduction in noise rather than a determination of the composite effect throughout given areas;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the investigation of the level of composite man-made radio-noise, as a function of geographic location, frequency, and time of day;
2. the investigation of the statistical characteristics of composite man-made radio-noise, as a function of the above variables, during short-time intervals as well as for day-to-day variation;
3. the determination of the correlation of man-made radio-noise levels with population density, industrial activity, electric power consumption, and other factors;
4. the determination of the types of measurement most significant for the evaluation of the interference potential of man-made radio-noise for different types of service, for example, peak, quasi-peak, r.m.s. voltage, average envelope voltage, average logarithm, and probability distribution of the amplitudes.

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## STUDY PROGRAMME 205 (VI) *

## EFFECTS OF RADIO-NOISE IN SPACE ON COMMUNICATIONS WITH SPACECRAFT

(Geneva, 1963)

The C.C.I.R.,

CONSIDERING

*(a)* that radio noise is an important element in radiocommunications with spacecraft;

*(b)* that little is known of this noise in the ionosphere and in space;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. measurement of the noise in the ionosphere and in space from:
   - cosmic sources;
   - lightning discharges and other terrestrial sources;
2. development of methods of prediction of noise in the ionosphere and in space from:
   - cosmic sources
   - lightning discharges and other terrestrial sources.

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RECOMMENDATION OF THE PANEL OF EXPERTS
(GENEVA 1963)

## REDUCTION OF BANDWIDTH OF RADIO SYSTEMS IN THE 4 - 27.5 Mc/s BAND

The Panel,

considering

a) speech bandwidth compression schemes have been under development for a number of years. Experimental systems have given compression ratios of 6:1 and others proposed may achieve 10 or 20:1. Such systems have not been used in public correspondence networks because they degrade the telephone service and greatly increase the complexity of terminal equipment. Furthermore, the requirement in some systems for full compatibility within the network to transmit signals other than speech also limits the applicability of speech bandwidth compression. On the other hand reasonably simple terminal equipment has been demonstrated which gives 2:1 bandwidth compression with little degradation of transmission quality, and the application of such techniques may offer an increase of channel capacity under conditions of spectrum congestion;

b) multichannel radiotelegraph systems have been developed and placed in operation which make more efficient use of the bandwidth in ISB systems than previously obtained. Combining the advantages of frequency division multiplexing, time-division synchronous multiple-frequency keying, and ARQ such systems have achieved ratios of 1 bit/sec communication rate per 1.7 c/s bandwidth. High capacity data transmission systems have been developed using combined frequency division and time division synchronous multi-level phase keying, and are in operation to communicate 3000 bits/sec. per 3000 c/s bandwidth. Such systems also can accommodate a corresponding number of synchronous teleprinter channels at communication rates of 1 bit/sec. per 1 c/s bandwidth. Error detection coding and ARQ techniques are an important part of the effectiveness of these advanced telegraph systems.

c) recent developments have demonstrated reduced time facsimile transmission.

The Panel recommends

1. As regards radiotelephone systems, the study of the technical and economic feasibility of utilization of speech-bandwidth compression techniques to achieve compression ratios of at least 2:1.

2. As regards radiotelegraph systems,

a) the study of multichannel teleprinter systems so as to use minimum bandwidth for the composite transmission rate, achieving at least a ratio of 1 bit/sec. communication rate per 2 c/s bandwidth;

b) the study, for high capacity data transmission (corresponding for example to requirements approaching 3 kc/s bandwidth for several hours per day), of systems especially designed to minimize required bandwidth, rather than to rely entirely on minor adaptations of existing frequency-and-time division multiplexing systems which may be wasteful of bandwidth. It should be expected to achieve a ratio of at least 1 bit/sec. communication rate per 1 c/s bandwidth in such systems.

3. As regards facsimile and phototelegraphy systems, the study of technical development showing promise of reduction of bandwidth or time required for transmission; in particular, for black and white transmission, as for business documents and meteorological charts, the study of systems designed for smaller bandwidth-time product than required for picture transmission.

# FCC TECHNICAL TOPICS

The following list consists of items suggested to the Panel on which technical information is desired by the Federal Communications Commission. Work is underway on many of the topics and the FCC is working on some of them. However, the FCC does not have what it considers to be adequate information on these subjects.

## LAND MOBILE

What is the optimum channel width?

Merits of low deviation FM vs SSB or other bandwidth reduction technique.

Use of minimum power to cover an area, automatic power reduction or other variable power concept.

How can intermodulation effects be reduced, in receivers, in transmitters, and externally generated?

Can transmitter noise output be reduced by practical means below the presently accepted level of 80 to 100 dB below the carrier level?

Broadband multiple access systems-Are they efficient from a frequency utilization point of view?

Antennas for flutter reduction (especially at the higher radio freqs.) Some sort of diversity necessary?

Noise, measurement, reduction, best methods of combatting?

Merits of multiple low power stations vs single high power stations for base station use.

Different methods of handling information such as teletypewriters, facsimile systems such as hellschreiber, etc.

One way systems.

What is the long range outlook on frequency utilization?

What are the possibilities of frequency usage above 1 Gc/s? Considerable difficulty with flutter in mobile unit expected due to multipath propagation along with vehicle motion.

Methods of designing equipment to make higher frequencies economically attractive to the user.

Complete study of merits of all base stations in a given area being at the same location and with equal power. Assume two frequency operation for each circuit with transmitting and receiving freq. widely spaced and all trans. freq. in one band and receiving in another (a technique for reduction of effects of intermodulation).

Multiplexing of land mobile of FM broadcast stations.

Multiplexing of several land mobile base stations on one station.

Merits of interleaving signals (i.e. bandwidth of emission wider than channel frequency separation).

Information of filtering at VHF and UHF to reduce intermodulation. Crystal filters can be built at 150 Mc/s, can they at 450?

## STANDARDS FOR COMMUNICATIONS SYSTEMS

Compile advisory standards for complete systems which can be used for reference in FCC rules as assumed standard for a given service, etc. Includes characteristics of transmitters, receivers, antennas, etc.

## CABLE DISTRIBUTION IN LIEU OF RADIO (feasibility and economics of)

Television
Aural program
Land mobile services (e.g. at some submultiple of final frequency and radiated frequently at final freq.)

## SSB STUDIES

Freq. stability improvements at low cost
Merits of various amounts of carrier reduction
Use for land mobile, air-ground circuits, etc.
Reduction in equipment size

## CONTROL OF VEHICLES BY RADIO

Automatic control of automobiles on highways
Spectrum space requirements

FUTURE GROWTH PREDICTIONS FOR ALL SERVICES

Number of stations seem to be increasing exponentially but reason indicates that there must be a flattening off at some point in time.

RADIO SMOG-RADIO FREQUENCY INTERFERENCE

Man-made noise
- Automobile ignition
  - Transistorized ignition systems likely to be more troublesome than conventional systems.
- Dust precipitators (now becoming available for homes).
- RF cookers (becoming more reasonably priced for home use)
- SCR light dimmers (transient switching pulses may be a problem when SCR's are used for home illumination dimmers, etc.)

NATIONAL AND INTERNATIONAL AGREEMENT ON NOISE STANDARDS AND NOISE MEASUREMENTS

Are differences between ASA and CISPR noise meters necessary?
Is there a more general type of noise measurement that can be applied to new systems without remeasurement of levels?
Is the ITSA - CCIR (Report 322) measurement of atmospheric noise level applicable to man-made or impulsive noise? Over all frequency ranges and for all types of communication systems?

RADIATION MEASUREMENTS

Any correlation possible between 100 foot and 10 foot measurement ranges?
Can screen room measurements be used and correlated with interference effects?
How can meaningful measurements be performed in congested areas (e.g. downtown Manhattan, N.Y.)

RECEIVERS

Performance characteristics of all types of receivers.
- Sensitivity, noise figure, spurious responses, intermodulation effects, desensitization, selectivity, ease of tuning, frequency stability, temperature stability, etc.

RADIO WAVE PROPAGATION

More accurate methods for calculating field strength, esp. VHF and UHF

Propagation over irregular terrain, including effect of trees and buildings on the obstruction.

Comprehensive study of small area prediction techniques.

Depression factor (reduction of signal strength) for cities.

Measurement techniques
- Ht. of receiving antenna
- mobile vs cluster
- road speed
- methods of accounting for type of receiving antenna
- time constant of meter and recorder for mobile meas.

Weather front fades
- methods of combatting fades where diversity does not work
- especially for FM broadcast reception at long distances

Determine field strength levels of distant interfering sources for UHF and microwave

DIRECT BROADCASTING FROM SATELLITES

What frequencies can be used (international) and domestic complications)

Type receiver needed?

Receiving antennas to be used based on various assumptions of service

MEDIUM FREQUENCY PROPAGATION (AM Broadcast band)

Study long distance interference between stations over North-South paths, especially transequatorial, and for various portions of sunspot cycle

Revision of conductivity map

LOUDNESS METER

Method needed for quantitatively measuring loudness as an effect upon the human sensory mechanism. Should take into account the contrast between a preceding sound and the present sound. To be used in determining loudness of commercial announcements, vs adjacent program material.

STEREO TELEVISION - PICTURE AND SOUND

NEW METHODS OF TV TRANSMISSION

Spectrum conserving methods of transmission needed. Needs to be sufficient improvement from a conservation point of view to overcome economic problems with existing investment in equipment.

GROUND CONDUCTIVITY MEASUREMENTS

Would be desirable to be able to directly measure the equivalent ground conductivity for frequencies in the LF and MF range. Present method involves measurement of field strengths along a radial and matching the curve obtained with a theoretical curve.

COMPATIBLE SINGLE SIDEBAND FOR STANDARD BROADCAST STATIONS

Is it worthwhile and under what conditions?

IMPROVED TV RECEPTION FOR THE HOME

Better receivers and antennas

Reduce noise and reduce ghosting

NEW ANTENNA DEVELOPMENTS

Any suitable antenna having low angle radiation properties which is practical for the low frequency end of the standard broadcast band. Franklin antenna becomes unwieldy. A ring type of antenna may be suitable.

MEASUREMENT OF RADIATION FROM ANTENNA AS INSTALLED (VHF AND UHF BROADCASTING)

Method of determining that antenna is performing as designed. Some stations have found that antenna change caused phenomenal change in received signals indicating that original antenna was not connected properly.

ANTENNA DIRECTIVITY AS FUNCTION OF POLARIZATION

If cross polarization is used for broadcast service a detailed study of the actual rejection that can be expected for signals polarized orthogonally to that desired. How stable is the rejection ratio in actual practice? What are the maintenance problems and costs?

DISTORTION OF RADIATED PATTERN OF SIDE MOUNTED FM BROADCAST ANTENNAS

RADIO ASTRONOMY

Where is best compromise between frequencies desired and absolutely necessary?

Degree to which exclusivity is necessary. Can the frequencies be shared?

STUDY USES FOR FREQUENCIES ABOVE 10 GC/S

Have all the windows been found?

Methods for overcoming absorption.

WAVE PROPAGATION PREDICTION FROM WEATHER STATISTICS

If adequate correlation can be found better prediction should be possible since weather data has been taken at more places and for a longer time than radio data.

SITE SCREENING

What amount of site screening can be obtained for space communications sharing with terrestrial services? Best methods?

AUTOMATED MONITORING AND MEASURING

IMPROVED MODULATION MONITORS

Present monitors not adequate for peak measurements. Correlation of frequency of peaks vs interfering effects. Should spec. be changed to quasi-peak that can be read by monitors?

BRANDWIDTH OF EMISSION MEASUREMENTS AND STUDIES

CCIR bandwidth specs. not practical to measure at a distance from the station. CR Spectroscope useful at a distance but does not measure total power to correlate with CCIR specs.

STANDARDIZE TV TESTLINE TRANSMISSION

Testlines transmitted by networks at top of TV picture may be more useful if all stations transmitted same information. Could be used for setting of levels, checking bandwidth of device, color adjustments, etc.

BEST FREQUENCY FOR AIRBORNE EDUCATIONAL TV

Study practicality of frequencies from 2.5 Gc/s and up

INFORMATION RETRIEVAL

Best method of searching for information on devices or ideas that may be useful for telecommunications or cause interferemce. Looking for unknown devices with unknown characteristics. Need to know of the plans for devices prior to existence so guidance can be provided in frequency selection.

COMPUTER APPLICATIONS

Systems engineering computation

Land mobile coordination methods

Modification or adaptation of ECAC methods

AUTOMATIC TERRAIN INFORMATION SYSTEM FROM COMPUTER IMPUT

Need cheap method of obtaining data for or for drawing radials, present studies involve huge amounts of stored data (e.g., several hundred reels of magnetic tape for U.S.)

GENERATION OF FREQUENCY ASSIGNMENT PLANS BY COMPUTERS

Presently being done for broadcast services, is it practical to do for land mobile and microwave?

DATA TRANSMISSION

High speed computers need wide band channels for handling of data from one location to another in a centralized computer operation. What are possible demands on frequencies and where in spectrum?

RADIO MONITORING SURVEILLANCE SATELLITE

Is this a practical method of obtaining the desired information on the higher frequencies?

Can antennas be made directive enough to avoid getting a hodgepodge of signals?

Need storage devices to store signals to be retransmitted on microwave when over receiving location.

Can bandwidth, frequency, signal strength and location of station be determined?

Measurement of noise levels?

RECAPITULATION

Studies or further studies are needed on the following general areas of interest:

(1) Methods for good frequency utilization

(2) Methods to solve the land mobile problem

(3) Methods to solve the intermodulation problem

(4) Methods of reducing undesired emissions (radio smog)

(5) Sharing between the space and terrestrial services

(6) Automated monitoring

(7) Radio astronomy requirements

(8) Uses for frequencies above 10 Gc/s up to and beyond the visible range

(9) Computer applications

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