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Space-Based Broadcasting

The Future of Worldwide Audio Broadcasting

A Working Paper
by
Thomas F. Rogers

Submitted to
The Technical Operations Study Committee
for the Voice of America

Board on Telecommunications and Computer Applications
Commission on Engineering and Technical Systems
National Research Council

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PREFACE

This paper was prepared for submission as a source document to the study being conducted by the National Research Council's Technical Operations Study Committee for the Voice of America.

The Committee was appointed in April 1984 to advise and guide the VOA on its technical planning to renovate, modernize, and expand its transmission capabilities and facilities.

Although the author is a member of the Committee, this paper has not been reviewed by the Committee or the National Research Council Report Review Committee and reflects only the views of the author.

Writing and publication took about one year. Much of the time was devoted to the informal but pointed analysis of a series of drafts by a substantial number of thoughtful professionals. Much time was also spent in an effort to obtain as wide a consensus as possible in the context of the observations and judgments expressed by these professionals.

As the process concluded, it appeared that there was substantial general agreement as to both the paper's substance and form on today's (and tomorrow's likely) shortwave broadcasting circumstances; on the desirability of approaching the use of space for audio broadcasting via a common-user system-service; and on estimations of service characteristics, initial system concepts, and related technological risks, schedules, and acquisition costs.

In addition to the common-user concept, the paper advances other novel institutional suggestions for serious consideration: a worldwide audio broadcasting system-service provided, financed, and operated by the private sector rather than directly by governments; the broadcasting entity having some responsibility for the design and provision of the basic elements of the system's surface segment and its space segment; the private sector using the service to advertise goods and services worldwide, over a medium now essentially confined to the advertising of political views by governments; and the use of such a worldwide system-service to provide national, domestic services as well.

Time did not permit a coalescence of views on these latter concepts. They are so novel as to require more analyses and judgements than the circumstances surrounding the issuance of the paper have allowed, even though the present formulations of all of the concepts are probably acceptable to many, perhaps to most, for further debate. The last concept--the possibility of a system providing services to meet national-domestic needs--presented the most difficulty. The difficulty is not one of substance but rather involves the form in which the paper is presented.

Much of the feedback from colleagues, particularly those with greater and more recent experience than that of the author in the international political arenas that deal with telecommunications policy, pointed out that worldwide broadcasting is much more politically sensitive than national-domestic broadcasting. This sensitivity springs primarily from the basic fact that today many governments are much more comfortable with their own broadcasting to the people of other countries than with their own people receiving broadcasts by other governments. Many governments apparently prefer to talk rather than listen.

The feedback emphasized that the paper would elicit a more sympathetic and favorable reading abroad if it focused on the potential of using orbiting transmitters to provide national-domestic services. This approach also engages roughly as many countries and utilizes roughly the same amount of radiowave spectrum as does worldwide shortwave broadcasting.

In the end, the paper's discussion of the impressive potential value of a national-domestic service was enlarged while the original presentation thrust was retained. The resulting paper focuses specifically on the national interest that created the National Research Council's Technical Operations Study Committee for the Voice of America: concern for the future broadcasting posture of the United States Information Agency/Voice of America. Other times, other circumstances, and other authors can emphasize the national-domestic area. This paper therefore should be considered essentially as creative and instructive, not as comprehensive and detailed.

As noted, this paper was not reviewed by the NRC Technical Operations Study Committee for the VOA and did not go through the NRC review process. It has greatly profited, however, from the informal comments of Edward Bedrosian, the Rand Corporation; Bert Cowlan, Consultant; Douglass D. Crombie, until recently with the National Telecommunications and Information Administration; Keith Edwards, M.B.E., until recently with the British Broadcasting Corporation; Dr. Robert B. Fenwick, BR Communications; Dr. John E. Keigler, RCA--Astro-Electronics; and Robert P. Pahmeier, GE--Space Systems, all members of the Committee. This paper also benefitted from the comments of Richard B. Marsten and Jerome D. Rosenberg of the Committee staff. Ivan Bekey, NASA Headquarters; Dr. Sidney Metzger, formerly of the Communications Satellite Corporation; and Dr. Wilbur Pritchard, Satellite Systems Engineering also provided helpful insights.

The author extends particular thanks to Bert Cowlan for bringing to his attention the recent, important, Soviet paper noted here in footnote 25, and to Jerome D. Rosenberg for a great deal of professional assistance.

Thomas F. Rogers

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All states should proclaim policies under which the free flow of information within countries and across frontiers will be protected. The right to seek and transmit information should be insured in order to enable the public to ascertain facts and appraise events....

"The United Nations Declaration on Freedom of Information," Resolution 59 (I), The U.N. General Assembly (1946)

Everyone has the right to freedom of opinion and expression; this right includes freedom to hold opinions...and to seek, receive and import information and ideas through any media and regardless of frontiers.

"The United Nations Universal Declaration of Human Rights," Article 19, The U.N. General Assembly (1948)

It is our conviction that the most effective way to reduce the current [communications] imbalance is not by inhibiting the communications capacity of some, but by increasing the communications capacity of all....

Statement of U.S. Ambassador John Reinhardt to the UNESCO General Conference, Nairobi, 1976;
Quoted in "The United States and the Debate on the 'World Information Order,'" Academy for International Development, Inc., Washington, D.C., page 6

As the world's leading technological innovator, [the United States of] America has a special responsibility to strive for equitable international...arrangements for new communications technology.

"The United States and the Debate on the 'World Information Order,'" page 119

Section 102 (a) The Congress hereby declares that it is the policy of the United States that activities in space should be devoted to peaceful purposes for the benefit of all mankind.

Section 102 (c) The...space activities of the United States shall be conducted so as to contribute materially to....

> (5) The preservation of the role of the United States as a leader in...space...technology and in the application thereof to the conduct of peaceful activities within and outside the atmosphere....
>
> (7) Cooperation by the United States [in such activities] with other nations and groups of nations....

National Aeronautics and Space Act of 1958, as amended

The member states [of the United Nations] shall use spacecraft in...the interests of maintaining peace...and for the development of international cooperation and mutual understanding.

From a new space treaty draft proposed by the U.S.S.R. and transmitted to the U.N. in mid-1981,
quoted in "Nature," 292,
August 20, 1981; page 262

...Americans cannot realize the impact of...radio broadcasts [throughout the world] since they never lack multiple sources of news [and] few Americans realize that radio, not television or the printed media, is the main means of communications abroad. [For instance] Despite the gap in standards of living, there are ten times more shortwave radio sets in the U.S.S.R. than in the United States....

"Speaking of America:
Public Policy In Our Times," Kenneth L. Adelman,
Foreign Affairs, Spring, 1981;
pages 913-936, esp. page 914

Extensive, timely and candid information is an indication of trust in people and of respect for their intelligence, feelings and ability to comprehend various events on their own.

Mikhail S. Gorbachev
General Secretary of the Central Committee of the Communist Party of the Soviet Union,
quoted from a December 10, 1984, speech as reported in the New York Times, March 13, 1985; page D-2

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ABSTRACT

There are powerful economic, operational, political and cultural reasons for pursuing the establishment of a high-quality, high-capacity, DBS-A, common-user worldwide system-service.

Surface-based shortwave broadcasting is beset with serious and growing problems of limited coverage, capacity, reliability and quality; exceedingly complex global frequency assignment and monitoring; and ever-increasing signal interference. The world community of audio broadcasters should explore the possibility of using orbiting transmitters to provide worldwide audio broadcasting services to eliminate these problems.

Two conceptual common-user, common-carrier, system designs are described in this paper that would allow Direct to the receiver Broadcast from Space-Audio (DBS-A) services to be provided throughout the world with excellent quality, reliability, and at low cost. One service uses a frequency band in the upper part of the high frequency (HF) portion of the radiowave spectrum, the other uses a frequency band in the high ultra high frequency (UHF) region. The paper compares the relative advantages and limitations of each.

Although either could serve all countries of the world on an equitable basis, the UHF band offers important cost and service advantages. A worldwide system of this character could be installed region-by-region and could provide a standard service of as many as 1,000 5-kHz audio channels for each of as many as 1,000 individual surface areas. Each area would be 10,000 square miles (25,000 square kilometers) at the Earth's surface.

The acquisition cost of a technologically sophisticated space segment, installed and serviced in space using the Space Station, of a global system with a large capacity could approximate $500 million (U.S. 1985), and the ongoing cost of ownership and operation would approximate, roughly, $100 million (U.S. 1985) per year. This cost would be much lower than the total now being paid by the world's shortwave broadcasters for a service with much less coverage, and lower quality and reliability. The surface segment would be made up of new fixed and portable spacewave receivers, each costing tens of dollars, would cost $10 billion on a worldwide basis.

Although governments could finance the space segments of such a system, the private sector could reasonably be expected to finance and acquire the system and offer its services to government broadcasters throughout the world.

Such a system-service could be in operation by the end of the century. Smaller channel capacity or coverage area services could be provided in less than a decade and at lower space segment cost. Regional system-services could be installed initially and expanded to provide worldwide coverage.

The space technology used to provide such worldwide audio broadcasting could be employed for national, domestic, low-cost broadcasting as well; it could do so at a low marginal cost. Reliability, quality, and cost also suggest that the private sector, as well as governments, would be interested in using the system.

INTRODUCTION

Most governments broadcast audio programs outside their sovereign borders. In the United States the Voice of America (VOA) of the United States Information Agency (USIA) is the Federal government agency charged with broadcasting over-the-air radio programs related to U.S. interests and activities.[1] The U.S. Board for International Broadcasting (BIB) oversees Radio Liberty (RL) and Radio Free Europe (RFE), which act as surrogate radio broadcasters for people who reside in the Soviet Union and the Eastern Bloc countries, respectively. VOA transmits audio programs to audiences throughout most of the world. The transmissions originate in the United States and are picked up by people using fixed and portable receivers.

VOA audio programs include talk and music presentations. Some programs are broadcast by radio transmitters that operate in the medium frequency (MF) portion of the radiowave spectrum at frequencies of 0.3-3.0 MHz. The bulk of VOA programs are broadcast in the high-frequency (HF) shortwave portion at frequencies generally confined to 3.0-30.0 MHz.

VOA audio programs broadcast at HF are directed to listeners located great distances from the VOA broadcasting transmitter sites. With the exception of the lowest part of the MF band and even lower frequencies, the range of radio signals transmitted via the Earth's atmosphere and surface or ground-wave propagation that can be easily and usefully received is limited to a few hundred miles from the transmitter. If properly directed upward and forward by the transmitter's antenna, a much greater range may be obtained by using HF shortwave signals. This increase in range is caused by sky-wave propagation--the HF shortwave signals usually are reflected or refracted downward toward the Earth's surface from one or more layers of ionized gas normally present in the upper atmosphere.

The quality of the HF shortwave signal received and the ease and reliability of that reception depend upon

1. The amount of radio-frequency power radiated by the broadcasting transmitter; several transmitters may be used to broadcast the same program simultaneously.

2. The effective absolute gain of the transmitting antenna in the direction of the intended audience.

3. The surface distance from the transmitter to the listening audience.

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1. Other USIA offices are responsible for additional methods of disseminating information, including the distribution of books and television programs, and the sponsoring of international visitor and lecturer exchanges.

4. The electromagnetic characteristics of those portions of the ionosphere and the Earth's surface involved in the propagation of the transmitted signal at the transmitter's radio frequency during the broadcasting interval.

5. The character and intensity of natural and commercial-industrial electrical noise generated external to the listener's receiver.

6. The character and intensity of any other signals radiated simultaneously on, or very close to, the desired signal's frequency, and the electromagnetic characteristics of those portions of the ionosphere and the Earth's surface involved in the propagation of those other signals toward the receiver.

7. The characteristics of the listener's receiver, including the absolute gain of the antenna at the received frequency in the direction of the desired arriving signal, and the antenna's relative gain in the direction of arriving commercial-industrial electrical noise, and any other natural or manmade signals.

In light of these operating circumstances and the limited number of frequencies that by international agreement are available to the more than 100 countries conducting HF shortwave broadcasting, broadcasters must now use sophisticated and costly transmitter plants and operating procedures to provide service that will attract and retain listeners.

During the past two decades, many governments have placed greater importance on their worldwide audio broadcasting activities. There has also been a large increase in the number of countries engaging in HF shortwave broadcasting. These developments have fostered a trend toward the use of greater transmitter effective radiated power[2] (EIRP), a growing practice of broadcasting the same program simultaneously on more than one frequency, and a more sophisticated, more dynamic movement among transmitting frequencies and the directions that signals are radiated throughout the preferred listening hours of the day. Average EIRPs now exceed 100 million watts and the same program may be broadcast on as many as six frequencies at the same time.

These efforts are made to accommodate to solar-related diurnal, seasonal, annual, and 11-year cycles of change in the ionosphere's radiowave propagation characteristics. Efforts are also made to retain audience share in the face of growing competition by other broadcasters and other media.

These trends burden many broadcasters, who face increased financial costs, increased need for more effective transmitting sites, increased professional engineering and operating demands, and increased interference to their signals by the signals of other broadcasters that arrive

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2. Radio frequency power X antenna gain relative to an isotropic radiator.

simultaneously in their desired audience areas on essentially the same or closely nearby frequencies.

Two unfortunate results of this large, growing overpopulation within the HF shortwave broadcasting bands agreed upon by the countries using the International Telecommunications Union "offices" are the use of frequencies within these bands by countries that are not part of such agreements, and the use of frequencies outside of these bands. There are now an average of two to three broadcasting transmitters competing for each useful signal channel during the more popular listening hours.

This situation is further exacerbated by a few governments that routinely contrive to deny some or all of their citizens the ability to receive signals broadcast to them by other countries. They do so by radiating intentionally harmful interference (jamming signals) on the frequencies used by other broadcasters. The radiowave propagation characteristics of the ionosphere often allow jamming signals to interfere with the reception of programs broadcast on these frequencies within countries located far from the areas being jammed.

These circumstances and trends have caused a sharp increase in the level of nonnatural interference to HF shortwave signals broadcast over much of the world, and growing problems in allocating and using available frequencies. The increased use of satellite communications circuits and networks to provide long-haul fixed and marine mobile communications services has reduced the use of the HF portion of the radio spectrum for these other purposes. Yet there is a large demand for these vacated frequencies for national, domestic broadcasting and other services. There is also little immediate likelihood that these strong basic shortwave trends can be arrested, let alone reversed.

This situation has become so serious that the utility of some services provided by the largest and most sophisticated broadcasters is being questioned. Many countries with more modest financial resources and/or without long-established broadcasting spectrum occupancy positions are increasingly frustrated and resentful about their apparent inability to obtain what they judge as their fair share of a valuable and increasingly limited global commodity. Their inability to obtain clear and affordable HF broadcasting air space adds to existing international political strains.

Today, and in this context, VOA and RFE/RL HF shortwave broadcasting operations are triply disadvantaged:

1. Other HF shortwave broadcasters are growing in numbers and sophistication, competing for the attention of listeners that VOA and RFE/RL are expected to serve.

2. Limited broadcasting plants have not allowed VOA and RFE/RL to keep up with increased foreign capabilities, despite the fact that national security considerations require VOA and RFE/RL to reach larger and additional audiences.

3. Until recently the VOA and RFE/RL have not had the funds to conduct appropriate research and development (R&D) activities. These activities could allow modifications in plant and operations designed to allow VOA and RFE/RL to keep up with and perhaps outpace other countries.

The VOA and RFE/RL clearly need a major increase in their broadcasting capabilities.

The recognition of this need began to gain credence a few years ago. During the past two years VOA has begun a $2 billion broadcasting plant and operations modernization and expansion program and the consideration of appropriate R&D activities. Adequately staffed, funded, and administered, and carried out with imagination, determination, and political sensitivity, these efforts should provide an enhanced U.S. audio shortwave signal broadcasting capability the end of this decade.

Indeed if all countries adopted some of the promising technological and operational methods and means that the VOA is now planning to study experimentally, the overall operating climate for HF audio broadcasting would be significantly improved.

But even when VOA and RFE/RL meet their new goals, the serious inherent limitations in the surface-based HF ionospheric mode of shortwave broadcasting audio signals in real time over long distances will remain with them, and all other shortwave broadcasters. These limitations are so fundamental and so severe that, given any sensible alternative, the United States should not depend upon the current mode any longer than necessary. Indeed neither should any other country. In addition to acquiring the best possible HF shortwave capabilities, we should urge and assist other countries in working with us to pursue an acceptable and sensible alternative.

The serious limitations of surface-based HF shortwave are generally well known throughout the community of broadcasters. Important limitations include

1. <u>Inherent complexity in identifying truly useful operating frequencies, and in reaching acceptable multicountry agreements to their specific allocation and proper use</u>

2. <u>Limits on the range of signal distance created by the geometry of the Earth's surface and its ionospheric layers</u>

   When audiences to be served are located beyond the approximately 2,000-mile maximum one-hop signal distance from a shortwave transmitter, repeater transmitters must be located in other countries sufficiently close to the audiences. The use of remote transmitters involves important political, financial, and operational costs, including substantial payments to the host countries. There is also always the possibility that repeater transmitters will not continue to be available in circumstances where their availability would be particularly valuable.

3. Potential interference by shortwave signals reflected and scattered by the ionosphere

Shortwave signals broadcast to an audience area one hop away from a transmitter are reflected and scattered upward and outward from this surface area and are propagated back down toward the Earth via the ionosphere, perhaps several times. This phenomenon creates the potential for interference over great surface areas. Signals transmitted to serve listening areas two or more hops away may present potential interference to audiences in the intermediate hop area or areas. Signals radiated in directions other than the direction of the intended audience area (i.e., signals that are also always radiated from the broadcasting transmitter antenna's sidelobes and backlobes, even though of lesser intensity than those radiated from its main lobe) also may cause interference to additional audiences distributed over great areas. Indeed HF shortwave transmitters and their antennas, the Earth's surface, and the ionosphere are dull and fuzzy tools for focusing audio broadcasting signals efficiently onto specific listening audiences.

4. Poor, distorted, reduced, or lost signal

Often the received signal quality is poor because natural variations in ionospheric radiowave propagation conditions cause rapid and intense variations or fading in received signal power. Multiple overlapping signals, arriving at the receiver may be delayed in time one from another because components of the originally transmitted signal have travelled along markedly different Earth-ionospheric paths. These signals often fade rapidly and are often distorted when they reach the listener. Intense electrical noise bursts generated during electrical storms or thunderstorms in the general vicinity of the receiver can also reduce listening quality or completely overcome reception of the desired signal. Loss of signals altogether can occur when the ionosphere is sufficiently disturbed. A powerful burst of solar energy, for example, can change the ionosphere's electrical characteristics suddenly and profoundly when that energy reaches and interacts with the ionosphere.

5. Commercial-industrial noise

Signal quality can be degraded by the electrical noise accompanying the expansion of commercial and industrial activities.

6. Interference by other signals

Signal quality can be degraded by inadvertent interference by signals arriving simultaneously from other broadcasting transmitters that utilize the same or nearly the same transmitted frequency. These interfering signals may be propagated directly or reflected via the ionosphere toward the receiver.

7. Jamming

Signal quality can be degraded and useful signal reception can be prevented by jamming transmitters. Jamming affects the listeners the jammer focuses on and often also affects listeners in other countries who cannot escape the jammer's signals.

8. Changes in transmitter frequency

Many listening audiences are required to readjust their receivers several times throughout the day, sometimes hour-to-hour or more often, to receive signals from a given broadcaster. These frequent changes are necessary as the broadcaster changes transmitter frequency to accommodate changing radiowave propagation conditions and/or unintentional and intentional interference.

9. Operating complexity and high cost

The complexity and cost of the capital and operations and maintenance (O&M) required to maintain an acceptable broadcasting service encompass increasing a broadcasting system's effective radiated power, the number of simultaneous transmissions on different radio frequencies, and extra-country repeater transmitter sites. These requirements continue in the face of a seemingly inexorable increase in signal interference as many countries adopt the same methods to retain or enhance their own competitive position as they cope with limited natural resources--in brief, the problem of the global commons.

Similar concerns face the VOA and RFE/RL as they begin to plan for modernization and expansion of their broadcasting plants. Their concerns include the following:

1. A sharp increase in the number of distant repeater sites located within other countries.

2. An increase in overall system effective radiated power at great capital (probably $2 billion) and ongoing O&M (probably $300 million per year) cost.

3. Dependence upon the availability of many satisfactory frequencies.

4. Dependence upon an audience willing to track VOA and RFE/RL broadcasts by retuning receivers as broadcast frequencies change.

The VOA and RFE/RL engineers now accept service limitations such as audience areas of secondary as well as primary service quality, and--even in the primary listening areas--being able to serve only 90 percent of the desired locations and for only 90 percent of the time. Even this level of service can be maintained only if the signals are degraded by no more than modest levels of manmade noise and unintentional interference.

Such service levels are two orders of magnitude (expressed in powers of 10) poorer in quality and reliability than those delivered by U.S. commercial AM, FM, and TV over-the-air broadcasters. Although some of the lower-power local AM stations may be confronted with skywave propagated interference outside of their primary service areas, the latter two are generally interference free.

Over the longer term, other countries will follow the same course to regain their broadcasting effectiveness and match increased U.S. effectiveness and this trend could neutralize the relative advantage the United States has purchased at such great cost.

Perhaps the greatest longterm threat to the effectiveness of any surface-based shortwave audio broadcasting service is the gradual loss of audience share. Several factors make this threat a real possibility, including continued efforts by many countries to increase their use of great effective radiated power and multiple simultaneous frequency broadcasting, raising the general susceptibility of received signals to degradation. The proliferation of other electronic communications products such as audio and video tape players, recorder-players, and high quality stereo receivers, and radio and TV services also adds to the competition for today's HF shortwave listening audiences. The fundamental and grave deficiencies of this particular broadcasting mode place it at growing disadvantage when compared with other electrical communication modes available in a world of growing electronic communications and sophistication.[3]

Yet listening to audio broadcasting generally appeals to the general public if broadcast quality, reliability, price, and program content are acceptable, even when the broadcast competes with other activities. In the relatively financially and culturally rich and sophisticated area as Washington, D.C., with its diverse mix of over-the-air and cable television, newspapers, magazines, motion picture houses, orchestras, theatres, museums, sports activities, 23 over-the-air AM and FM broadcasting stations thrive. The United States has more than 9,000 local over-the-air AM and FM broadcasting stations. Ninety-nine percent of U.S. households have at least one radio; the average number per household is 5.5 sets.

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3. The VOA recognizes the gravity of this competition: "[VOA broadcasting] would have difficulty attracting significant audiences in countries that already have an abundance of sophisticated technologically advanced radio, television and print media [and] VOA sources...looking into the technical question of how to deliver the product [in Europe] say that [already] the old short-wave transmissions can no longer attract listeners." (The Washington Post, June 13, 1985, page A-6.)

Fortunately, an audio broadcasting option should be available to the worldwide broadcasting community within the next decade that will offer all countries the prospect of obviating the deficiencies inherent in surface-based broadcasting. Transmitters placed in orbit high above the Earth could receive broadcasting programs directed toward them from the Earth and then rebroadcast the programs directly to audiences living in most areas of the world. These space rebroadcast transmitters would operate on fixed frequencies high enough to avoid all important ionospheric influences. They could deliver a broadcasting service with great surface coverage and high quality. And they could do so at the lowest per channel cost, with the greatest value to the world, if the broadcasting service were of large capacity and were offered in the common user-common carrier form.

In recent years the executive branch of the U.S. Federal government has given growing attention to the practical possibility of using space broadcasting to meet the needs of the VOA, RFE/RL, and the Armed Forces Radio Network. Congressional hearings have been held on the issue. NASA, working with the VOA, has conducted early, related systems studies and may conduct experiments in space. There is now a general hope, bordering on trust, that satellite communication will soon find its place in global broadcasting.[4]

This paper outlines the fundamental technological and operational characteristics of two similar, direct audio satellite broadcast, very-high-capacity, common carrier-common user, system-services. Initial estimates are made of their acquisition and ongoing financial costs, and observations are made regarding how these costs could be met.

Although many radiowave bands may be used for broadcasting and/or for space-related communications, at present there are no bands set aside by international agreement to be used specifically for broadcasting audio signals from space directly to individual, not community, surface receivers. To date discussions of ways to provide regional DBS-A system-services have focused upon two quite different portions of the electromagnetic spectrum. One band is in HF (25.67-26.10 MHz) and is already set aside for direct audio broadcasting but with no explicit recognition that broadcasting transmitters could be located in orbit above the Earth as well as on its surface. The other band is in UHF (2500-2690 MHz), where broadcasting from orbit for community reception at the surface would be allowed to take place, but where the power flux density at the surface is so limited as to discourage a broadcasting service that would allow reception by the general public. Such space broadcasting would have

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4. "Through the explosion of satellite communications, a technological 'genie' has been unleashed which will change forever the way that governments communicate ideas and information abroad," Charles Z. Wick, director of the United States Information Agency, in a speech delivered at the George Washington University, Washington, D.C., May 5, 1985.

to be shared with fixed- and mobile-surface services.[5] This paper's exploration of the two conceptual DBS-A system-services assumes that appropriate frequency allocations could be made in either of the HF or UHF bands and compares their general characteristics.

This paper does not explore the intriguing possibility of employing very-high-altitude powered platforms (HAPP's) now under study by the Department of Energy and NASA. These platforms are to be crewless, lighter- or heavier-than-air craft that could be kept high in the air but not in orbit at altitudes of 10 to 20 miles (16 to 32 kilometers), hovering over a selected surface area for a year or more or forever. They would receive power to drive their electric engines and support their payloads via a collimated microwave beam of electrical energy directed upward to them from the Earth. Powerful HF band signals could be broadcast directly from such platforms. If a HAPP were stationed at an altitude of 20 miles, the signals broadcast from it could be received at distances of as much as 400 miles (620 kilometers). The signals would avoid most ionospheric influences and, therefore, would deliver reliable, steady, and clear audio programs. They could be used in some circumstances to complement the worldwide, space-related, system-service outlined here.

5. Footnotes 757 and 2561, ITU Radio Regulations

SECTION 1

GENERAL SERVICE AND SYSTEM CONSIDERATIONS

Since the Soviet Union launched its Sputnik satellite, there has been an impressive growth in the use of space to improve the range, quality, and reliability of radio communications. This use of space for communications has been confined to long-haul trunk and mobile services and indirect broadcasting through the wedding of long-haul satellite communication circuits to local, over-the-air, and community cable television and radio services. A few analytical studies of space-based direct audio broadcasting possibilities were conducted in the 1960's and 1970's, and, the United States and other nations have pursued the use of nations satellites to provide video broadcasting direct to individual surface receivers. Yet DBS-TV has not been realized.

Several times during the first 20 years of the space age, engineering consideration was given to the design of a DBS-A system for use by the U.S. government only. Early attempts made it clear that the technological demands involved in the design of such a system, especially development costs, were too high. Later, after potentially useful technological development had progressed for other purposes, new engineering studies looked more promising. Operations, cost, and financing were considered only briefly because communications engineers were discouraged by the obstacles posed by these factors.

Space technology has continued to advance and further developments relevant to DBS-A are now expected. Operational (and perhaps, in a creative sense, financial) circumstances have also changed. A growing number of persons concerned with improving the prospects of international audio broadcasting now believe that the correlation of forces at last appear to favor the use of space soon.

Experts in the field, especially space and communications engineers, must now appreciate the fact that the use of space for international audio broadcasting will occur only if

1. A politically sensitive and operationally useful broadcasting service can be developed and accepted as available to all interested government broadcasters on an equal basis.

2. A sufficiently innovative and practical system can be designed to provide such a service.

3. Novel means of financing are found to meet large acquisition and ongoing O&M costs so as to allow the acquisition and use of the service at an acceptable price.

Any serious discussion of the practical possibility of replacing the world's present surface-based, HF, ionospheric, shortwave methods and means with space-based direct audio broadcasting must begin with the realization that all countries may not immediately embrace the new service. There can be no assurance, therefore, that all HF shortwave radio receivers throughout the world would be replaced by receivers designed to receive high-quality signals broadcast by space-based transmitters.

If the geostationary orbit assumed here is to be used by space-based broadcasting transmitters, international or at least regional agreement must be sought and obtained regarding the orbital slots to be employed. And agreement must be reached regarding the radiowave spectrum to be used and the signal transmission and reception standards to be maintained. Such agreements require that a large number of countries believe that their audio broadcasting interests would be better served by a space-based system-service than they are by systems available today or the individual-nation surface-based HF systems projected for tomorrow. A nation's decision to go with space broadcasting will be shaped by political, operational, cultural, financial and economic factors affecting that nation. Therefore, those giving serious thought to the acquisition of any space-based systems for the delivery of any broadcasting services using such systems, must be prepared to use space for audio broadcasting in a particularly sensitive, equitable, innovative, and sophisticated fashion to accommodate the factors that can be expected to shape the nation's decision to broadcast via space. To do otherwise could easily delay the acquisition of the system-service and jeopardize the likelihood that the service will become reality in the predictable future. Many--quite possibly all--of the world's governments expect that planning the use of space broadcasting will mirror the International Telecommunications Union Convention planning agreement that states: "...the planning of...bands allocated to the broadcasting service shall be based on the principle of equal rights of all countries, large or small, to equitable access to these bands...."[6]

Widespread international support for a space-based system-service would also

1. Involve a large number of active broadcasters, increasing the likelihood of spreading the costs more efficiently over a large number of system users and substantially reducing the unit cost to each.

2. Allow people throughout the world to learn much more about the interests, values, and activities of other people in other countries.

The greater the coverage area, the lower the cost of its use, the greater its listening acceptability compared to other competitive services,

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6. World Administrative Radio Conference for the planning of the HF bands allocated to the broadcasting service, First Session, Geneva, 1984 Report to the Second Session of the Conference, General Secretariat of the International Telecommunications Union, Geneva, 1984; page 75, paragraph 4.1.1.

and the more equitably the service is made available to all countries, the more likely it is that broadcasters throughout the world will use it, and the greater its value to the people of the world.

The audio broadcasting community should plan from the beginning to use space to provide a high-quality service that can be delivered to people anywhere who are interested in access to the service. That would likely include perhaps 99 percent of the world's population. The community should be prepared to proceed without the active participation of some countries. Those countries can continue to be served with HF broadcasting from surface-based transmitters. Such leadership could contribute to what Ian M. Ross calls the use of "telecommunications...to improve the quality of human existence."[7]

Service Requirements

The service requirements of a space-based broadcasting system include the following:

1. The system should be capable of providing acceptable service to essentially the entire world's population.

2. Some countries may not initially wish to utilize the service, but the system should be designed so the service would be available to all countries for broadcast to all other countries on an equitable access and price basis.

3. The system should be reliable.

4. The system should be of generally high quality, with higher quality available on demand for some areas and/or times at a price premium.

5. The system should place no more demand upon the listening audiences than what is expected of listeners to today's local over-the-air AM and FM audio broadcasting stations, including ease of moving receivers about; locating, pointing, or adjusting antennas; using house electrical current or batteries; and tuning from one station to another.

6. The system should be easily and effectively accessible through the use of low-cost receivers that require little power to operate, use small antennas, are easily tuned, can be used indoors and out, are readily transported, and can be used while in motion.

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7. "Telecommunications," Ian M. Ross, Technological Frontiers and Foreign Relations, National Academy Press, National Academy of Sciences, National Academy of Engineering, Council on Foreign Relations, Washington, D.C., 1985; pages 22-45.

7. The system should be able to be used economically by broadcasters who wish to direct one or a few programs toward relatively small audiences located essentially anywhere on the globe. Broadcasters also should be able to use the service to address relatively large audiences with multiple programs, with the price of such service related to the audience area, the number and duration of broadcasts, and their level of quality.

8. The system should have an acceptably low annual price for a standard quality broadcasting channel.

9. The system should be installed and operated region-by-region as dictated by political and financial circumstances.

10. The system should use the electromagnetic spectrum efficiently and without precluding the continued use of HF shortwave surface-based broadcasting by countries wishing to do so.

General engineering-operational requirements for an initial space-spaced audio broadcasting system can be inferred from these basic broadcasting service characteristics.

The word initial should be stressed. Some system engineering parameters cannot be defined until the following factors are clarified:

1. The number of programs to be broadcast simultaneously, their times and durations, and the geographical size and location of the audiences.

2. The quality of service desired.

3. Any influence the ionosphere may have on coverage of specific areas and signal fading and attenuation in others.

4. Foliage, building wall, and terrain roughness that can increase radiowave path loss.

5. The influence of electrical noise generated external to the receiver, including commercial, industrial, and naturally occurring noise.

Judgments about the character and pace of related space and communications technology developments must also be made. Such judgments may need to be revised later. Large space-segment costs and financing must be addressed, and perhaps an installation staging process may need to be planned.

Finally, the prospect of space-based broadcasting--and the accompanying financial costs--offers innovative engineering concepts to meet development challenges within the constraints created by the financial means of many of the system's potential users, both broadcasters and listeners.

Engineering-Operational Characteristics

The basic engineering-operational system characteristics follow:

1. Direct broadcasting coverage should be provided to most of the world's population. Excluded are the areas within the Arctic and Antarctic circles; the ocean, heavy jungle, extreme desert, and extremely high altitude regions; and particularly difficult terrains where mountains would shield a receiver from direct and diffracted field strengths radiated from space.

The remaining 15 percent of the Earth's surface area of 200 million square miles (30 million square miles or 80 million square kilometers), should be served. This area contains at least 99.9 percent of the world's population. Particular provision could be made to serve such individual locations as Point Barrow, Alaska; Gothab, Greenland; Tromso, Norway; Murmansk, U.S.S.R.; La Paz, Bolivia; Brasilia, Brazil; Alice Springs, Australia; and one or more locations in the Artic and Antarctica that lie outside these general boundaries.

Even areas well within the Arctic and Antarctic circles could be served if desired; a small Canadian government group now receives television via geostationary satellite at 76^{o} north latitude, only 900 miles from the North Pole. Special provisions also could be made to serve surface ships and aircraft making long transoceanic trips.

2. It should be a common user system.[8] Without particular reference to their specific organizational forms, it could be a system of the general character as those provided by Intelsat, Inmarsat, Eutelsat, etc. (The VOA has long accepted the practice of making some of its broadcasting facilities available for use by other countries.)

3. While coverage of most of the globe should be the fundamental goal, regional coverage would be quite acceptable, even perhaps preferable initially. Provision could be made for region-to-region linkage, probably via direct satellite-to-satellite optical or millimeter wave circuits in the overall system design.

4. All locations within a large region should be served by broadcasts by any country during the primary evening and morning listening hours; eventually, all locations throughout the world should be able to be so served.

5. Transmitters in geostationary orbits should be employed to ease receiver use where antenna directivity is employed in reception.

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8. In the United States, called common carrier.

6. Virtually 100 percent (99.9 percent +) overall, hour-to-hour reliability should be maintained throughout the year. All factors that could cause signal degradation below the minimum acceptable service standards should be considered: the entire broadcasting plant, the receivers in normal condition and sensible operating use, and all signal transmission vagaries.

7. Three levels of service would be available for receivers meeting minimal acceptance standards:

a. Basic service: 35 db signal-to-noise ratio (S/N) in a post-detection bandwidth of 5 kHz, available in all broadcast channels and to all receivers in all locations.

b. Standard service: 45 db S/N in a post-detection bandwidth of 5 kHz, available in nearly all locations.

c. Superior service: 50 db S/N in a post-detection bandwidth of 15 kHz, with provision for stereo operation, available in as many as 10 percent of the channels simultaneously.

8. The lowest reasonable overall broadcasting plant acquisition and O&M cost should be sought. A single channel should ideally be supplied to a broadcaster at the same unit price (or less) as an over-the-air local service AM (MF) broadcasting channel, when normalized for comparable coverage, duration, and quality of broadcasting service.

9. The lowest reasonable retail prices should be sought for fixed and transportable Basic and Standard service spacewave receivers. A unit price of a very few tens of dollars, at most, is preferred and should be obtainable in large-scale production;[9] mobile receiver prices could be somewhat greater.

10. The system should be installed and operated on a large regional basis. It should also have sufficient flexibility to easily accommodate increases in use and the interconnections of large regional systems.

11. Frequency modulation or digital modulation should be employed to minimize the need for in-orbit transmitter peak power, while providing the large S/N and small interference levels required for high-quality service and the most efficient use of the radiowave spectrum.

12. Techniques should be employed to minimize the overall bandwidth and spectrum allocation required to meet the system capacity, reliability, and quality requirements.

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9. The potential market size would be hundreds of millions of receivers.

SECTION 2

SPECIFIC CONSIDERATION OF A UHF DBS-A SYSTEM-SERVICE

Ultrahigh frequency could be chosen as a DBS-A system's operating frequency region. Ultrahigh rather than high frequency will be discussed first to reflect the committee's greater apparent interest in the former.[10] Two recent papers speak to the use of VHF and FM for national and/or regional systems for the provision of DBS-A services.[11,12] Several of the observations and judgements contained therein are of equal value when applied to UHF system-service considerations.

Simply for illustrative purposes here, a relatively narrow band near 2.5 GHz, one that could be located within the 155 MHz-wide 2.500-2.655 GHz band, is chosen for study. This band is designated by international agreement for shared use between broadcasting satellite and fixed services. In general, the kinds of system parameters and their performance discussed here are representative of those designed specifically for operation in any very high VHF, or UHF, or very low SHF band.

In the UHF system-service design outlined here, very large channel capacity and very small unit surface coverage areas are assumed; they are inherently required by any eventual global system-service. Their actual dimensions could be achieved but only by using technology not now expected to become available in much less than a decade. The cost of this technology and its financing, although undoubtedly acceptable (see Sections 4 and 8), would be relatively high. If an earlier commencement of service were desired, and/or if financial considerations suggested a lower initial cost,

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10. Certain of the concepts described here for application at UHF have been considered earlier for application at high HF, and the professional reader therefore might now wish to note the references in Section 3.

11. "Sound broadcasting-satellite system for a national coverage in developing countries," O.P. Arora and K. Narayanan, Telecommunications Journal, Vol. 51-No.XII/1984; pages 645-649.

12. "Broadcasting [via VHF/FM] of Radio Programmes by Satellite Direct to Portable/Vehicle Receivers," J. Chaplin, H.-H. Fromm, and C. Rosetti, E.S.A. Bulletin, February 1984; pages 77-81. See also "Satellite/sound broadcasting to portable and vehicle receivers" by these authors in Telecommunications Journal, Vol. 52-No. I/1985.

    (This, the paper by Narayanan, and the studies they reference suggest somewhat different values for certain of the circuit parameters and somewhat different transmission methods than those used here. All should be carefully considered and compared in more detailed studies than this.)

the capacity could be scaled down and/or the surface coverage minimum unit area could be scaled up.

Space Repeater Segment

A large, say 200-foot (60 meter) diameter, sophisticated parabolic reflector would be employed. It would be provided with many feeds that would allow a large number of independent, surface-directed radiation patterns or beams to be generated as they are driven by multiple subtransmitters. At the frequency that would be employed, the radio wavelength is 0.4 foot (0.12 meter) so that the antenna's diameter/wavelength is 500. With an illumination efficiency of 0.6, the gain re isotropic at the center of each beam would be 62 db, and the 1/2 power beam width would be about 0.14 degree.[13] Each such beam would illuminate a surface area and provide a broadcasting footprint roughly 100 miles (160 kilometers) in diameter. One beam's total surface area would be about 7,500 (circular) square miles (about 20,000 square kilometers) in the subsatellite region and larger than this at higher latitudes. Away from the subsatellite region, the footprints would become larger in area, oval in shape, and the Earth's geometry would elongate the patterns. In the farthest regions to be served the surface area/beam would be several tens of thousands of square miles.

The basic unit of surface coverage (the standard coverage area) used here for illustrative purposes will be taken to be a footprint of 10,000 square miles (25,000 square kilometers). This is roughly the size of the U.S. states of Maryland, New Jersey, or Massachusetts; the countries of Belgium, Haiti, Israel or Albania; the island of Sicily in Italy; the Republic of Armenia in the Soviet Union; or the principality of Wales in the United Kingdom. Using such narrow beams would provide great flexibility to broadcasters and system operators in selecting audience locations, channels, and broadcasting times and durations. Using these beams, near real-time knowledge of the signal transmission and noise circumstances, and dynamic power control among the individual subtransmitters would allow a sophisticated statistical approach to minimizing space segment peak power in the face of large temporal variations in channel capacity demands; the influence of the ionosphere that can cause scintillation-type signal fading, physical structures, foliage and terrain roughness on radiowave path loss; and other variations in noise levels external to the surface receivers. In view of the narrowness of the beams and the need to assure that desired audience areas are properly illuminated, care would have to be taken in

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13. NASA now has aspirations to develop a series of UHF space antennas, the most sophisticated of which would have radiation characteristics quite similar to these. They would be used in an R&D program that, in the 1990s, would study the provision of mobile communications in rural areas. Optical astronomers, using controlled parabolic reflector segmenting techniques, are now planning to construct and use lenses with gains of over 150 db re isotropic.

designing the space segment to insure that satisfactory methods and means of beam steering and stabilization were employed, and that the illumination performance could be easily verified in near real time. This would have to be a truly sophisticated multiple subtransmitter, multiple-feed, space ensemble. Its satisfactory development calls for engineering imagination and skill.

Assuming that there would be four active geostationary satellites to provide adequate surface coverage (two each serving the Eastern and Western hemispheres) and with a total of some 30 million square surface miles (80 million square kilometers) to be served on a worldwide basis, on average each would have to deliver an adequate radiowave flux density to the surface over an area of some 7.5 million square miles (20 million square kilometers). Most of today's HF shortwave audio listening population listens during an average 2-hour period during the local dinner and breakfast time hours. Because their local times widely separate them from each other, these audiences around the world would be served simultaneously by separate satellite transmitters. Each satellite transmitter could serve an area as large as 6,000-miles long (Arctic Circle to Antarctic Circle) by 10,000-kilometer wide, measured at the Earth's equator. With the rotation of the Earth, this area corresponds to a total daily time duration of 6 hours in the A.M. and another in the P.M. It would serve three separate 2-hour (2,000-mile-wide, 3,200-kilometer-wide) areas one-at-a-time by switching the beams, as a group to each of three azimuthal positions in sequence as local times suggest. The number of 10,000-square-mile footprints, and consequently the number of beams required per space transmitter, would thus be (7.5-million/3)/10,000 = 250. Conservatively estimated about 300 subtransmitters would be required to accommodate the actual size and distribution of specific surface areas to be served in any region.

Each of the beams, and its associated subtransmitter, would be capable of carrying at least a single audio broadcasting channel, and two or more beams, usually adjacent, could be employed to serve areas larger than 10,000 square miles with the same program (channel) at the same time. Each beam could simultaneously carry, in the limit, as many channels as the system's full capacity, or 300 channels. Those beams serving low population areas would probably carry only a few channels while large metropolitan areas would be served by many. (This subject is discussed further in Section 3.)

The reference here to 300 audio channels is a rough initial estimate of the capacity required to serve a single large region by 100 broadcasting governments. Larger countries could well employ 10 or more channels simultaneously in a region, while smaller countries perhaps could meet their needs with a single channel.

To avoid interference, adjacent beams would radiate signals on different carrier frequencies (and perhaps orthogonal polarizations) when their channels carried different programs. The sharpness of the beams and the use of frequency modulation (and perhaps polarization orthogonality) would allow the maximum frequency re-use and thus minimize the number of channels and the amount of radiowave spectrum that would have to be allocated for a DBS-A service. Of course each of the four separate space segments also could re-use the same allocated spectrum. As a first estimate, the total worldwide DBS-A service allocation would require a few MHz of bandwidth.

A multibeam switch would be required in the space segment--one that would allow subtransmitters, beams, channels, and frequencies to be appropriately matched in terms of the areas to be served with various programs. The switching would be accomplished reliably and quickly under command from the surface feeder station. The feeder station would receive the information it needed to command the switch from both the individual organizations supplying the programs to be broadcast and from a network of surface signal monitoring sites.

The RF power delivered to each beam also would be controlled by the surface feeder station in order to provide a higher or lower than nominal flux density to some areas at some times. This control capability would preserve an appropriate quality of service in the face of changing program-channel-service quality demands and accommodate excess radiowave path loss associated with different areas served, season, weather, and ionospheric conditions. All of this activity would be accomplished in a manner that would keep the required space segment DC peak power demand as low as possible.

The space segment maximum DC power required would be some 5,000 watts (see the space segment-surface segment power budget estimation in Section 3). The system design should anticipate, in a statistical sense, all of the various likely demands for space segment electrical power in order to minimize the peak demand and to minimize the cost of meeting it in space.

Only one surface feeder station would probably be needed, since the programs could be routed space segment-to-space segment, as necessary, via wideband line-of-sight optical or millimeter wave distribution circuits.

If the present aspirations of the leaders of the U.S. Government's civilian space program are realized, a low-Earth-orbit (LEO) Space Station, one or more geostationary service platforms, and an economic LEO-geostationary orbit spacecraft servicing capability should be in place within a decade. Some space industry satellite communications engineers are not as close to these potential developments as are leaders of the U.S. public space program at NASA. They, too, must by necessity plan their costly and financially risky space activities in a conservative, paced, fashion. Some are therefore understandably reluctant at this early date to accept these aspirations as a basis for sound planning. But as such aspirations are translated into firm programs and schedules, the space segments could be designed to share basic support services with other assets used in nearby geostationary orbit. The space segments could also be designed to take full advantage of Space Station-based, externally provided, in-space, short-response-time maintenance services that would restore performance upon its degradation, and be able to accommodate, promptly, the large changes in broadcasting service requirements.

Surface Feeder Segment

The surface feeder site could be served by Intelsat circuits that would allow programs to originate essentially anywhere in the world and be carried to the site for transmission upward via a line-of-sight microwave circuit to the nearest geostationary space segment. It could also be served by Intelsat circuits that could carry information to the site from surface monitoring network locations.

The design of the surface feeder system segment should be straightforward. The maximum base bandwidth required to be transmitted would be 300 multiplexed audio channels each at least 5 kHz wide (as many as 10 percent of the channels could be 15 kHz wide) to be delivered to each of four space segments simultaneously, i.e., the rough equivalent of two standard television channels to be transmitted upward over a 23,000-mile, line-of-sight path.

A relatively less valuable portion of the spectrum could be employed, probably in the high SHF region or higher.

Surface Receiver Segment

The spacewave receivers should be designed to be small, rugged, long-lived, easily and precisely tunable by electronic (not mechanical) means; to have low self-generated input noise; and to have a small antenna, easily pointed toward the fixed, in-space broadcasting transmitter. Different receiver models could (1) be powered by local sources of electricity, batteries, or solar cells, (2) have various degrees of antenna directivity-gain, (3) produce various levels of S/N, dynamic range, and audio power output in various audio bandwidths, and (4) provide other electronic services such as reception of local AM and FM broadcasts, stereo, and audio tape recording and playback.

A retail price of a very few tens of dollars should be the objective for the Basic and Standard service, handheld, and "kitchen table," fixed and transportable, mass receiver markets. Extra attention would have to be given to the design of truly mobile receivers.

Two classes of antennas would be employed:

1. For Basic and Standard Service signal quality service reception, perhaps a single half-wave folded dipole with a reflector and 8-10 director elements arrayed in end-fire, Yagi, fashion. Such an antenna's outside dimensions (keeping in mind that the radio wavelength is less than 5 inches) would be about 2" x 1/2" x 8". It would have a wide half-power azimuthal beamwidth of about 40°, and a gain of some 13 db re isotropic, inclusive of a small cable loss. Use of circular polarization should be considered, and this would suggest a helix rather than a linear Yagi.

2. A high-efficiency parabolic antenna, perhaps 1-1/4 feet in diameter, would be used for Superior quality service reception and for reception in particularly high latitude or otherwise difficult reception areas. Such an antenna would have a half-power beamwidth of some 25° and a gain of some 18 db re isotropic, inclusive of a modest cable loss. In particularly difficult terrain or in the presence of urban building signal "shadowing" where there could be significant additional diffraction field propagation loss, reception would be improved by elevating the antenna.

The spacewave receivers should have noncooled, low-noise front ends, and exhibit a low noise figure under all usual operating conditions.

SECTION 3

THE SPACE SEGMENT (TRANSMITTER)-SURFACE SEGMENT (RECEIVER) POWER BUDGET FOR A UHF DBS-A SYSTEM-SERVICE

This section of the paper addresses the following question: What basic space segment engineering characteristics, especially RF and DC power and bandwidth, are required to provide the surface segment--the receivers of the listening audiences--with the availability, quality, and reliability of service necessary to capture and keep their attention?[14]

It should be appreciated that while the technological and operational characteristics suggested here are rational, reasonably well informed, and adequate for an initial paper addressed primarily to other communications engineers, these characteristics are neither comprehensive nor described in the detail required for space and communications system engineering. Correcting errors of facts and/or judgement and "putting flesh on the bones" must be the challenge to, and the responsibility of, others.

Individual Circuit Reliability

A fundamental assumption made here is that given the inherent dependability of UHF line-of-sight radiowave propagation along higher angle, unobstructed space-to-surface paths, the system engineering parameters should be chosen to see circuit reliability at the 99.9 percent performance level. This reliability should be limited only by any failure of the space segment or the surface equipments to provide the operating performance they were designed to exhibit. That they do so is a matter for communications and space engineers to ensure. Of course, the experts must balance performance--quality, ease, and flexibility of operation--against the cost of production, distribution, and use of both the space and surface segments of the system.

With some important exceptions, the circuit characteristics are all essentially constants. With the space signal arrival angles considered here, i.e., from the subsatellite point (90°) to the Arctic and Antarctic circle regions (15°-20°), there will be no fading of the kind experienced on surface-to-surface, line-of-sight circuits, where the arrival angle is usually well less than 1°. The exceptions, which must be dealt with statistically and about which present statistical data are inadequate, include the following:

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14. The provision of a broadcasting service that would meet sound engineering and operating standards is a necessary but not a sufficient condition of successfully gaining and retaining audience attention. The program content will determine "bottom line" broadcasting service success or failure.

1. The influence of structures that might intervene in the space transmitter-surface receiver radiowave propagation path.

2. The influence of foliage that might intervene.

3. The effect of tropospheric rainfall conditions.

4. Attenuation caused by the total of building structures plus foliage.

5. The influence of rough terrain.

6. The effect of scintillation fading.

7. Frequency selective fading.

The Influence of Structures

Some building wall structures will attenuate 2.5 GHz signals more than others. The attenuation exhibited can be influenced by intense incident precipitation when sheets of water can form on the structures. Some receivers will be effectively out in the open, some shielded by one wall, some by more than one. Some receivers will only receive signals directly from the transmitter; others will receive additional (in and/or out of phase) fields reflected from one or more nearby structures. The likelihood that received signals will be appreciably attenuated by building walls is greater the farther the receiver is from the equator, and may be greater in colder months. Other nearby buildings, especially in urban areas, can "shadow" a receiver from the incoming signal.

Only in situ measurements on or near the expected operational frequency, and for various signal arrival angles, over a sufficient length of time in various locations within the regions served will provide the statistical data base needed for satisfactory engineering and operational judgments.

As a first, somewhat arbitrary but reasonable, estimate the following building structure attenuation circumstances are assumed:

- On average, 25 percent of all receivers at all times will experience essentially no radiowave attenuation beyond the inverse distance-squared free space path loss.
- On average 25 percent will experience 3 db.
- 25 percent, 6 db.
- 15 percent, 9 db.
- 7 percent, 12 db.
- 3 percent, 15 db.

Thus, on average 25 percent of the space segment's transmitter beams would have to radiate twice as much RF power (and therefore would require twice as much space segment DC power) as those 25 percent of the beams that would have to radiate just enough power simply to overcome the free-space radiowave path loss in providing the required quality, reliability, and capacity of service. These assumptions suggest that on a statistically weighted average basis the space segment's overall RF power output would have to be 5 db greater than that predicted from consideration of free-space propagation conditions alone.

The Influence of Foliage

Increased density of foliage and, in some cases, the incidence of intense precipitation on foliage, can increase radiowave path loss.[15] It is generally more likely that foliage attenuation rates experienced will be higher for receivers located nearer the equator and during the warmer months. But the actual overall attenuation could be greater in areas far removed from the equator when low-elevation angle reception would see the radiowaves traverse greater foliage path lengths. The same somewhat arbitrary but reasonable statistical distribution of foliage attenuation levels is assumed as that previously described for building structure attentuation.

The Influence of Tropospheric Rainfall

Even at the 99.9%+ reliability level, it does not appear necessary to consider providing more than a fraction of a db to accommodate excess signal attenuation in tropospheric rainfall conditions.

Attenuation Caused by the Total of Building Structures Plus Foliage

Over the large broadcast area expected to be served by any one space segment (some 7.5 million square miles; some 20 million square kilometers), climate and weather circumstances can be expected to increase structure radiowave attenuation considerably but not to increase foliage attenuation simultaneously. Thus the increased power demands required of an alert and dynamic space segment that is informed about the climate, weather, and channel-beam use circumstances throughout its service area could be designed, and could dynamically comport itself, so as not to require nearly as much increased RF power output as the 2 X 5 db = 10 db of additional structure plus foliage attenuation might suggest. It is assumed here that a total of 7 db would be required.

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15. "An Analytical Study of Wave Propagation Through Foliage," G.S. Brown and W.J. Curry, RADC-TR-79-359, Rome Air Development Center AFSC, Griffis Air Force Base. N.Y. 13441, 1980.

    "An Initial Critical Summary of Models for Predicting the Attenuation of Radio Waves by Foliage," M.A. Weissberger, ECAC-CR-80-035, Electromagnetic Compatibility Analysis Center, Annapolis, MD 21402 (1980).

The Influence of Rough Terrain

In addition to structure- and foliage-related excess attenuation, an additional power budget margin must accommodate those spacewave receivers that may be partially shielded from the space-radiated signals by rough terrain. In the limit, some receivers will be found to be well within the diffraction, rather than the line-of-sight, radiowave propagation regime. Because the diffraction field attenuation rate at 2.5 GHz is great, receiver locations well within this regime can lose reception altogether. Clearly, the greater the system power margin provided, the greater the fraction of total diffraction field receiving locations that can be served satisfactorily, and the greater the space segment cost. Considering all demands for space segment power, the peak DC power level will probably have to be in the kilowatt range, and this margin-cost balance is a particularly important consideration.

Under many receiver location circumstances, considerable accommodation to such additional losses can be obtained through increased receiver antenna gain, at the cost of increased directivity restrictions; through increased receiving antenna heights, at the cost of reduced receiver transportability; and by accepting a lower receiver S/N, at the cost of reduced quality of reception.

It is beyond the scope of this paper to attempt to relate all of these circumstances and considerations and the physical characteristics of the actual regions to be served in a quantitative statistical manner. Rather, somewhat arbitrarily, an additional margin of 8 db is provided for service to these locations.

Scintillation Fading of Signals

Occasionally and in some areas, ionospheric conditions can cause rapid scintillation fading of signals received after they transverse the ionosphere. The rate of occurrence and duration of important fading levels at a radiowave frequency as high as 2.5 GHz, the surface areas over which such fading would be experienced at any one time, and the likely times of occurrence suggest that the system power margins and dynamic response characteristics employed to accommodate the anticipated structure-, foliage- and rough-terrain-related increased radiowave path losses should be sufficient to accommodate to scintillation fading as well. (See the more detailed discussion of this kind of fading in Section 6).

Thus the total system margin included to accommodate, statistically, all propagation-related excess path losses is 7 db + 8 db = 15 db. This margin would be in addition to a 7 db margin for ordinary system operating misalignments and degradation, for an overall total of 22 db--all at the S/N = 45 db level.

This total of 22 db for system operating margin may impress some satellite communications engineers as extremely high. They would be concerned, quite properly, about the additional design and cost burdens, and the need to confine surface flux densities to a sufficiently low level to obviate concern for meeting interference standards that providing such a margin would present to the system design engineer and the service user. But, for the most part, these engineers are accustomed to dealing with radiowave path losses between space transmitters and carefully sited surface receivers whose antennas are located external to buildings and have an unobstructed, high angle-of-arrival, radiowave view of the geostationary signal source. Of course, it may well be that better statistics and/or a different judgement concerning the acceptable trade-off between transmitter power on the one hand, and the number of spacewave receivers to be served and the quality of the service that is acceptable on the other, would allow the use of a lower system margin. All that can be said in today's circumstances is that the total of 22 db is the author's present judgement of what is required, but that 22 db is so large a number -- each additional DC kilowatt costs about $5 million in initial system acquisition cost -- that its verification should be a serious challenge to professionals in the radiowave propagation and communications systems analysis communities. Indeed, the matter of excess radiowave path loss is fundamental to any consideration of employing the electromagnetic spectrum for a UHF DBS-A system, and it requires careful and comprehensive experimental and statistical study.

Frequency Selective Fading

There is little reason to imagine that any of the signal fading circumstances previously outlined would result in important frequency selective fading across the bandwidth of interest in this suggested system design.

Other Considerations

The use of sophisticated compandor-expandor techniques will provide an effective increase in the signal-to-voice ratio of some 16 db, and certainly should be employed. Advantage also should be taken of individual channel use statistics when a large number of channels are available: when any channel would not be in use, it is assumed that its subtransmitter RF power output would be turned off, or at least reduced by 10 db or more. Under these circumstances statistical advantage can be taken of the fact that, on a second-to-second basis, all in-use audio channels are not in continuous use. When a large number of audio channels are being used, the total RF (and, therefore, DC) power required would be at least 5 db less than the amount calculated on the basis of multiplying the required power per channel by the number of channels. Caution should be exercised, however, in adding this 16 db and 5 db; it may be that the realizable total is closer to 18 db than to 21 db.

The number of independent channels that the space segments of any regional system would be designed to accommodate is assumed here to be 300. This number would allow each of about 100 countries to have access to one Standard service channel that could be broadcast to one or more standard surface area(s) simultaneously, and to provide a further capacity of 200 channels that would allow more than one simultaneous broadcast by many countries to any one space segment's service region.

The maximum number of independent radiation beams provided by each such space segment would also be 300, allowing any broadcast to serve more than the one standard 10,000-square-mile area provided by each radiated beam. Without confident "service market" knowledge based upon study of the geographic, demographic, listening, and other characteristics of any region's potential listening audiences, it is not possible to estimate the maximum expected channel X beam product (i.e., the number of combinations and permutations of beams and channels) that could be in use simultaneously. It is assumed here--somewhat arbitrarily--that any regional system-service's maximum usage product would be one-third to one-quarter the total number of such combinations and permutations of 300 channels X 300 beams = 90,000 channels X beams, i.e., 23,000 channels X beams. The total RF and therefore DC power required thus would be 5-6 db less than the amount calculated on the basis of multiplying the required power/channel by the total number of channels that, in principle, would be available for use. Again, as in the case of required system margin, this assumption must be given careful study by communications systems analysis professionals.

Circuit Quality

Given the near complete absence of frequency selective fading (for other than mobile reception), co- and adjacent-channel signal interference, and the influence of atmospheric and external commercial-industrial electrical noise, the circuit communications quality is defined here as the product of the spacewave receiver's post-detection signal-to-noise ratio (S/N) and its audio bandwidth. The circuit performance required to provide the three different service qualities are Basic Service, Standard Service, and Superior Service.

Basic Service. For Basic Service the circuit performance would be 35 db in 5 kHz. This would be the minimum, systemwide performance expected with the minimum suggested receiver audio bandwidth, antenna and cost. Basic Service would provide a performance that should be acceptable in those relatively few, remote, low-population density areas that are served by few, if any, other attention-commanding electronic communications media. These areas probably would contain less than 0.1 percent of the total population expected to be able to listen to DBS-A broadcasts.

Standard Service. For Standard Service the circuit performance would be 45 db S/N in 5 kHz. This would be the performance expected in nearly all locations served by the system's space segments that should be achieved with the minimum receiver characteristics. Considering the 45 db S/N and the absence of electrical storm impulse noise, impulse noise from automobile ignition and other commercial and industrial sources, and skywave interference caused by distant, high-powered, co-channel and adjacent channel broadcasting transmitters, this quality of service would be at least equivalent to that obtainable by using a fine, modern receiver operated within the primary service area of a local, AM (MF) over-the-air broadcasting station. The quality would closely approach that available in over-the-air FM (VHF) broadcasting.

In considering these Standard Service characteristics, it should be noted for comparison purposes that a fundamental design goal of the VOA's HF modernization and expansion program is to "...provide a 73 db [post-detection] signal-to-noise density in a 1 Hz bandwidth at 90 percent reliability for 90 percent of the locations and hours...."[16] A 73 db S/N in 1 Hz is the equivalent of 36 db in a 5 kHz bandwidth, i.e., 1 db more than is adopted here for a Basic Service quality and 9 db less than that for a Standard Service quality. The comparable service goals for the reliability of a DBS-A system-service would be 99.9 percent for both locations and hours. For all practical purposes, however, it is impossible to design a surface-based HF real-time audio broadcasting system-service that would approach 99.9 percent/99.9 percent. The cost in effective radiated power, spectrum and number of transmitters and transmitter sites required would be enormous and prohibitive, even for a country with the resources of the United States. And probably no system could deal effectively with sudden ionospheric disturbances (SID's).

In addition, the received S/N required for satisfactory use of audio broadcasting signals need not be as high as those for signals used in a long-haul trunk service. These broadcasting signals are used directly at the individual receiver's location and do not have to be retransmitted for use elsewhere and therefore they do not have to be designed to guard against the signal degradation associated with such subsequent retransmission.

Superior Service. For Superior Service the circuit performance would be 50 db in 15 kHz. This quality of service would be available (at a user price higher than the Standard Service price) to any broadcaster who wished to reach an audience served by other, competing, high-quality electronic communications media. This quality would be equivalent to that expected to be obtained by using a fine receiver within the primary service area of a U.S. local FM (VHF) broadcasting station. This service would be available on about 10 percent of the system's channels at any one time.

Fundamental Circuit Characteristics Related to the Power Budget

The other more important illustrative circuit characteristics are as follows:

1. Frequency = 2.5 GHz.

2. Gain of the space segment transmitting antenna G_T = 62 db in the center of each beam, assuming a reflector illumination efficiency factor of 60 percent.

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16. Voice of America Engineering Standards, VOA Standard - 16775.01, High Frequency (Shortwave) Broadcast System Design, Chapter 1: Requirements Definition, January 7, 1985, page 2.

3. KT F = 204 dbw/Hz.

4. Receiver noise figure (NF) = 5 db.[17]

5. Receiver gain figure (G_R) = 13 db.

6. Frequency modulation (FM).[18]

7. Required FM receiver threshold carrier-to-noise ratio referred to 25 kHz, (C/N) = 10 db.

8. Free space loss, i.e., the inverse distance squared radiowave path loss between small doublet transmitting and receiving antennas that are very short relative to the radio wavelength, is 191 db along a vertical, subsatellite, path.

9. Ordinary system design and operating margin to accommodate receiver locations away from a beam center, and/or away from the subsatellite region [19] (for which the propagation path loss will be greater and, because the receiving antenna beam sees more of the Earth's surface, the noise temperature will be higher); less than maximum gain for beams formed by feeds offset far from the reflector axis; and longer-term equipment degradation = 7 db.

10. Loss in converting the space segment's DC power to transmitter RF power output, assuming solid state final stages, and including line losses from the final power amplifiers to the antenna feeds; power required for the power amplifiers' driver stages; power for the receiver to receive signals from the surface feeder station; power consumed by the switch; and general spacecraft housekeeping demands = 5 db.

Space Segment Power Requirements

Basic Service. Basic Service is defined as 35 db S/N in 5 kHz, post-detection. The individual RF channel width assumed is about 25 kHz.

The space segment power requirements for the Basic Service, per channel, per standard coverage area, follow:

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17. It is assumed that in mass production this low figure could be obtained at an acceptably low financial cost; some communications engineers argue for a much lower figure, perhaps as low as 2 db.

18. The alternative use of digital modulation certainly should also be considered.

19. The overall antenna pattern should be designed to favor higher latitude reception to some extent.

	+		-
G_T	= 62 db	DC-to-RF conversion, etc.	= 5 db
G_R	= 13 db	Ordinary system margin	= 7 db
KT F referred to 1 Watt/Hz	=204 dbw	Free space path loss	=191 db
Channel use statistics	= 5 db	NF	= 5 db
		Structure, foliage, rough terrain and ionosphere excess attenuation	= 15 db
		25 kHz referred to 1 Hz	= 44 db
FM Pre-emphasis effective S/N increase	= 3 db	C/N (in 25 kHz)	= 10 db
Total:	+287 db	Total:	-277 db

The S/N = 10 db [C/N] + 16 db [compandor-expandor][20] + 9db [10 $\log_{10}$ (3) $(1.6)^2$] = 35 db.

Therefore, the DC power required is 277 db - 287 db = - 10 db referred to 1 watt = 0.1 watt DC/5 kHz channel/ standard unit surface area.

The total DC power required for Basic Service for an entire regional system--one employing a single space segment with the maximum product of channels X the number of beams expected to be in use at any one time = 23,000--is (0.1) (23,000) = 2,300 watts.

Because a large frequency re-use factor would accompany the use of the type of space segment multiple-beam antenna suggested here, a total spectrum allocation of a few hundred kHz, perhaps as much as a MHz, would be required.

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20. It is quite possible that (at long last) sophisticated speech processing techniques may begin to move out of the R&D laboratories in the next few years and be realized in low-cost receivers employing solid state integrated circuitry. If so, significant transmitter power reduction and system cost reductions could eventually occur.

It should be noted that the requirement for a spectrum allocation of some 25 kHz/channel would be the total spectrum requirement/5 kHz post-detection audio channel serving any given area. In principle, HF broadcasters, employing double sideband AM, should require an allocation of 10 kHz, i.e., less than half this amount. In practice, however, several transmitters are often employed simultaneously in order to maintain a desired S/N in the face of propagation and/or external noise vagaries. The absolute amount of spectrum use/program broadcast can exceed 10 kHz by a significant amount. Indeed some broadcasters plan to broadcast a single program designed to reach an audience distributed throughout four time zones by using as many as six transmitters broadcasting simultaneously on different frequencies when circumstances warrant doing so. In that case, 60 kHz of spectrum would be used rather than 10 kHz.

Standard Service. Standard Service is defined as 45 db S/N in 5 kHz, post-detection. The individual R.F. channel width assumed is 60 kHz.

The power requirements for Standard Service, per channel, per standard coverage area follow:

The channel width of 60 kHz = 48 db referred to 1 Hz (i.e., there would be 4 db more receiver input noise power than for the Basic Service).

The S/N = 10 db [C/N] + 16 db [compandor-expandor][20] + 19db [10 $\log_{10}$ (3) $(5.2)^2$] = 45 db.

Therefore, the power required in the average space-segment = (0.1) (2.5) = 0.25 watt DC/5 kHz channel/standard unit surface area.

For a 23,000 maximum in-use channel X beam product, the total DC power required to provide Standard Service is: (0.25) (23,000) = 5,800 watts.

Some 2.5X the total spectrum allocation required for a Basic Service would be required for a Standard Service.

The use of narrow radiation beams would result in small surface footprints and, with the use of FM and perhaps orthogonal polarization on adjacent beams, would allow an extraordinary amount of interference-free re-use. It would not be surprising if a UHF DBS-A system could provide services throughout the world with a total spectrum occupancy of no more than 2.5 MHz (see Superior Service quality following), compared to the total of some 3.0 MHz now placed at the disposal of HF international audio broadcasting, if 60 kHz/channel were used to deliver a Standard quality of Service.

Superior Service. Superior Service is defined as 50 db S/N in 15 kHz post-detection. The RF channel width assumed is 300 kHz.

The power requirements, per channel, per standard coverage area, follow:

The channel width of 300 kHz = 55 db referred to 1 Hz (i.e., there would be 11 db more receiver input noise power than for the Basic Service). Provision for stereo also might be included. Recalling that G_R = 18 db (i.e., 5 db more than that assumed for the Basic and Standard Services) the net power increase required = + 11 db - 5 db = + 6 db referred to the Basic Service.

But only 10 percent of the system channels are to have this additional capability and not all of these channels would be expected to be in use simultaneously. The system power increase referred to the Basic Service is therefore probably less than (0.1)(4), or perhaps less than 1 db. Thus the power required to provide a region with a Superior Service on 10 percent of its channels, with the remaining 90 percent providing a Standard Service, is some 7,000 DC space segment watts.

In view of all of the judgements, approximations and roundings that must be accepted at this time, the peak space segment DC power level will be taken as 5 kilowatts DC.

All three of these Services--Basic, Standard, and Superior--assume some modest receiver antenna gain. Although the antenna sizes would be small and the receivers could be light-weight and easily transported, they would have to be employed so that the antenna directivity remained essentially fixed in space while in use. If it were decided to provide a truly mobile service for all beams and channels at the space segment 5,000 DC watt level, the Basic Service could be provided with a receiving antenna gain of 9 db, i.e., over a received acceptance half-power beamwidth of about 80° with an efficiency factor of 100 percent. If it were required, instead, to operate a Basic quality mobile service (again, at the space segment power level of 5,000 DC watts, i.e., without increasing the space segment power) with a receiver antenna gain of -2 db, this service could be offered if the use were confined to 10 percent of the system's channels.

Given all the assumptions, the space segment DC power level estimate of 5 kilowatts should not be expected to be more accurate than an order of magnitude ($\pm$ 5 db). It is interesting to note that while this is a respectable satellite DC power level today it is about the DC power level required in a commercial, multibeam, geostationary satellite that would provide a microwave DBS-video (DBS-TV), i.e., direct television, service to a large (over a million square mile) surface area. NASA recently tested a satisfactory solar cell array in space on the Shuttle that, if it had included all of the solar cells it is capable of mounting, would have provided 12 kilowatts, i.e., the amount expected by Space Industries, Inc., to be in use by the end of 1989 at the first of its "space factories." And 5 kilowatts is only 5 percent of the initial power level of 100 kilowatts now planned for the Space Station a decade or so from now.

International agreement now limits the RF power flux density generated by the transmitter of a space segment of any DBS system operating in the 2.5 GHz band. For radiation arriving over angles from the vertical (the subsatellite point) down to 25° above the horizon, no more than -137 dbw/square meter/4 kHz band is allowed.[21] The allowance is less for angles closer to the horizon. The average RF power expected here to be radiated by a UHF DBS-A FM system-service designed to provide a Standard Service in any 60 kHz channel over a 10,000 square mile area would be 5 db below the space segment's DC power of 0.1 watt, i.e., 0.03 watt. This would be the equivalent of (0.03)(4)/(60) = 0.002 watt in 4 kHz. Because the standard service area considered here is 10,000 square miles (i.e., 2.6 x 10^{10} square meters), this would be a power flux density of (0.002)/(2.6 x 10^{10}) = 8 x 10^{-14} = -132 dbw, i.e., 5 db more than is presently allowed.

There should be some modest concern about meeting the specified surface power flux density if the maximum space transmitter RF power output, per channel, per beam, suggested here as a reasonable initial estimate is eventually seen to be the amount required. But because the required RF power output is not estimated here more accurately than an order of magnitude, a judgement that the power flux density limitation is sufficiently close to being able to be met is acceptable for the purposes of this paper.

In any event, radio engineers concerned with the introduction of a new service understand that the identification of a surface flux density limitation is simply sound initial guidance arrived at by other engineers who were concerned with the introduction of an earlier service. The basic goal of the former is to see that any radio interference caused by one radio service to another is kept within acceptable limits. A number of engineering steps could be taken to see that this interference goal would be attained even though today's 2.5 GHz flux density limitations might be exceeded somewhat by a DBS-A system in some areas. Communications system analysis professionals should look into the actual present and planned UHF band occupancy by surface fixed services throughout the world in order to begin to make useful judgements about such power flux density matters.

If the total RF spectrum devoted to a DBS-A system-service providing $(23,000)^{1/2}(4)$ = 600 channels, worldwide, were to be 80% of that now devoted to surface-based HF shortwave (i.e. (0.8)(3.1MHz) = some 2.5 MHz) then, with 60 kHz used per channel to provide a Standard Service and 5 different 60 kHz allowances made to avoid mutual interference between adjacent beams or footprints, each footprint area could be served by as many as eight channels (i.e., (60 kHz)(5)(8) = 2.5 MHz). If some metropolitan areas were served by more than eight channels, however, either more spectrum would need to be allocated or for these areas less spectrum than 60 kHz/channel could be used and increased space segment radiated power employed in order to maintain the Standard Service S/N (again, keeping maximum allowable surface flux density limits in mind).

Because such circumstances would be realized in only a small fraction of the footprints, and because the peak DC power required/channel/beam is only

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21. Footnote 2561, ITU Radio Regulations.

0.25 watt for Standard Service, a relatively small overall increase in space segment power (a 1 db increase in peak space segment power would be somewhat more than 1000 watts) could allow a large increase in the number of channels in those relatively few areas where they would be needed.

Once the DBS-A service was in sufficiently broad use, consideration could be given by shortwave broadcasters to vacating some of the 3.1 MHz now used at HF so it could be allocated for other purposes.

Finally, the 2.5 MHz suggested here as the approximate amount of spectrum required for a UHF DBS-A worldwide broadcasting system-service might be compared with the total of over 21 MHz allocated in the United States for all local over-the-air AM and FM broadcasting.

SECTION 4

THE ACQUISITION COST OF A UHF DBS-A SYSTEM-SERVICE

Estimating the financial and economic future is at least as difficult and tentative an undertaking as predicting the future of technological development and the listening interests of radio broadcasting audiences. But it seems reasonable to predict that the cost of providing the services described here, in the manner outlined, can be rationally estimated to within a factor of 2X or so, and that is sufficiently instructive to serve the purposes of this paper.

The Surface Segment

The potential market is enormous. Several hundreds of millions of spacewave receivers eventually could be expected to be purchased to replace those now in use to receive shortwave programs. Purchases also should be induced not only by the increased reliability, quality, and clarity of signal reception compared with today's shortwave services, but also by the ability to listen to many more program channels broadcast by the governments of countries all over the world, and perhaps by the prospect of listening to commercial broadcasting--altogether, a global initial purchase market of $10-billion.

Thus, were the communications industry to believe that deployment of one or more space segment(s) was in the offing, the industry could be expected to meet the development, production, marketing, distribution, and sales costs of the required new receivers. The purchase price of a Standard Service spacewave receiver need be no more than a few tens of dollars, i.e., the retail price of today's handheld and kitchen table AM and FM receivers. The only novel features would be accurate and stable channel tuning, a low-noise front end and a different looking small antenna. So, even though the cost to produce, install, and use the surface segment of the overall system would be greater than the space segment by at least an order of magnitude, there would be good reasons to expect that its users would be able to, and would, make such a large overall investment; that providing the receivers would require little that would be novel to the communications industry; and, indeed, that there would be a great economic incentive for the industry to do so rapidly.

The Space Segment

The present U.S. Federal Government Advanced Communications Technology Satellite (ACTS) and its anticipated rural mobile, satellite-to-satellite optical, surface-to-12-mile-high aerostat powered platform (HAPP), Milstar and Strategic Defense Initiative (SDI) R&D programs, and commercial DBS-TV development programs, should inferentially underwrite the bulk of the basic technological developments needed for space segment transmitters, switches, and space power sources, and the exploration of the operational characteristics of dynamically programmable, multichannel, multibeam, geostationary, UHF, SHF, and EHF transmitters.[22]

The U.S. civilian Space Station, inclusive of both lower orbit Orbital Maneuvering Vehicles (OMV's) and higher, even encompassing geostationary orbit (GEO), Reuseable Orbital Transfer Vehicles--ROTV's, the Hubble space telescope, the Space Industries, Inc., "space factories," and the SDI R&D programs (and, quite possibly a new surface-LEO booster, a geostationary space "platform," and Lunar and/or Mars exploration program(s)), in conjunction with use of the Shuttle fleet, and European Space Agency programs such as Columbus, would inferentially underwrite the development of in-space infrastructure. This support would allow large and sophisticated space structures to be assembled and tested in low-Earth-orbit (LEO), the development of economical satellite servicing assets and operations, and significant reduction in the unit cost of surface-to-LEO and surface-to-GEO space transportation. The existence and use of such permanent, sophisticated, in-space infrastructure, including technicians, will speed the introduction of advanced space communications technology and lower its unit costs generally by easing the conduct of in-space development programs and allow for the repair and updating of operating in-space assets.

The assumption is made that four separate space segments would be required to provide adequate surface coverage on a worldwide basis (two for North, Central, and South America, and the eastern Pacific Ocean; two for Europe, Africa and Asia, the Indian Ocean, and the western Pacific Ocean). It is important to appreciate that this number would constitute a quasi-production run of essentially identical spacecraft (although the number of beams and their pointing directions would vary satellite-to-satellite as would the pointing direction of the satellite-to-satellite optical or millimeter wave program transfer circuits, etc.). This would allow significant production learning curve efficiencies to be obtained and allow the total acquisition program engineering financial costs to be spread over a multiple satellite procurement.

Another assumption is that the space segments would be designed and constructed to be able to have their parts packed for surface-to-LEO shipment aboard several Orbiters of the Shuttle fleet in a most compact and efficient fashion so as to obtain the lowest price for the overall shipment. Delivered to LEO over time, the parts would be off-loaded from the Orbiters and temporarily stored on the Space Station. One-by-one they

22. See "Satellites and mobile phones: planning a marriage," Alex Hills, IEEE Spectrum, pages 62-67; August, 1985. This article reviews NASA's aspirations for an R&D program that would involve a large and sophisticated space segment and small surface receivers to provide two-way audio communications in low population density areas. The space segment would have a large parabolic antenna, multiple spot beams, a high DC power and would operate in the UHF spectrum region. The receiver would have a low-noise front end and a modest antenna gain.

would be assembled there by appropriate Space Station technicians, tested in LEO, and then sent on their way outward to their intended final geostationary orbital locations.[23]

Finally, each space segment might be able to take up its position on or near a geostationary space focal point, or "platform," where they would share basic services such as orbit adjustment engines, fuel, telemetry, electrical power, basic stabilized structural framework, and visiting maintenance crew quarters with other space platform occupants. Other such occupants could be transceivers used for long-haul trunk, mobile, teleconferencing and DBS-TV communications; navigation and position-fixing transceivers; increasingly sophisticated passive and active radiowave and optical Earth-directed remote sensing instruments; and sophisticated astronomy instruments. Whether or not this possibility occurs cannot be clearly predicted now because NASA's geostationary space "platform" aspirations are still in the study stage, not the commitment-to-develop stage.

Within the context of these assumptions, a system's space segment would cost roughly less than $200 million, as detailed below.

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23. Perhaps it could go without saying that space-related economic competitive drives in other countries as well as the U.S. could modify such assumptions and lower the costs estimated here.

Space Segment Cost Estimates--Major Components

Item	Cost (millions of U.S. dollars 1985)
1. Components	
Antenna	20
DC power	30*
Switch	10
Upper Stage	10
"Bus"	10*
Power amplifiers, drivers, etc.	20
2. Insurance, per satellite	10
3. Launch to LEO	40+
4. In-orbit parts storage, assembly, and test	10
5. Space segment surface feeder station	10
6. Surface signal monitoring network	10
TOTAL	$180

* Both the cost of the DC power and the bus could be reduced by a factor of 2 or more for any DBS-A space segment that shared a geostationary space "platform" with other space assets and services. For instance, a geostationary DBS-A space segment would need a maximum of electrical energy during the pre-workday AM hours and the post-workday PM hours, while a long-haul trunk space segment needs the most electrical energy during the work day.

\+ The equivalent of half of a full shuttle flight at $80 million each.

Each subsequent space segment would cost $160 million on this same basis. Therefore, the total acquisition cost of the space segments of a global system-service would be: $180 + (3)($160) = $660 million. Considering both the judgements and approximations that had to be made in the circuit power budget, expected learning curve savings, and the possible cost savings that sharing geostationary services at space "platforms" would allow, it seems reasonable to round off the total cost to $500 million.

It should be reemphasized that the UHF space segment outlined here is a truly sophisticated one that would challenge communications and space engineers. While anticipated space-related technological developments offer a clear promise that its operational and cost goals could be attained, a relatively early regional system-service implementation could be initiated with greater confidence with a less sophisticated space segment. If the space segment antenna were scaled down from the 200-foot diameter suggested to 60 feet, or a frequency in the upper UHF TV region employed rather than the illustrative 2.5 GHz, then a system-service channel capacity reduction of some 10X would ensue. This arrangement would still provide a very respectable capacity for an initial service to be established within the next decade; it would not present the technical challenge and risk posed by a transmitter with 10X the antenna aperture area and 10X the number of subtransmitters; and it would result in an initial financial cost estimate of $30 to 50 million less for each satellite. Such a lower capacity initial regional system-service could be acquired at a cost estimated to be $130 to 150 million, rather than the $180 million estimated for a large capacity system-service. An initial worldwide network of four such regional systems for an estimated gross cost of $100 to 200 million less than that estimated for the higher capacity system service.

Again, it should be noted that such early cost estimates, made before detailed studies of service standards, system operating margins, overall system-service sizing, actual development of sophisticated in-space antenna, sub-transmitter and switch technology, and the actual installation and test of in-space spacecraft assembly and service infrastructure (i.e., a civilian Space Station), must be considered as preliminary and not accurate to more than a factor of two.

SECTION 5

THE UHF SPACE SEGMENT AND SURFACE FEEDER OWNERSHIP AND OPERATION AND MAINTENANCE COSTS

Assume that in-space support services become an operational and economic reality within a decade or so. Then assume that the space segments would be designed to have an overall useful (amortized) lifetime of 20 to 30 years or more, with a service call every 5 years. Assume that the cost to the system-service would be approximately $50 million for each service call, i.e., an average of $10 million per year, or 5 percent per year of the space segment's acquisition cost.

Assume that the space segments are acquired and paid for by the private sector.[24] Assume, further, that the cost of capitalizing the system-service would require that two-thirds of the investment involved would be debt costing 15 percent per year, and one-third equity that would expect a 30 percent per year return. The total financing cost, averaged over the 20 to 30 years, would then be 20 percent per year before taxes. With allowance made for depreciation tax deductions, investment tax credits, etc., the cost after taxes would be approximately 15 percent per year.

Assume that the annual operating cost of the surface feeder site, including Intelsat audio channel charges for channels from the individual government broadcasters and surface monitoring sites, would be $10 million.

Thus the yearly cost of amortizing and operating the system's entire space segment would be ($500 million) (0.15) + $20 million or, roughly, $100 million per year. (All of the regional space segments need not be installed at the same time. If they were phased-in over time, the initial financial cost impact would be considerably less.)

If the assumptions made about the space segments' acquisition underestimated their cost by as much as 50 percent, and if the Shuttle pricing policy for this kind of launch service required a $90 million per full-flight charge, the operating cost would then be approximately $130 million per year. Or if the assumptions about financing rates were too low by one-third, for example, the annual cost would, again, be approximately $130 million per year. Of course eventually the cost assumptions could just as well be found to have been too high.

Recall that each channel could serve an area averaging approximately 10,000 square miles (25,000 square kilometers). Recall, also, that each regional space segment could serve as many as 300 of these standard areas at a time, or provide as many as 300 Standard Service channels at a time, or a lesser number of each simultaneously. The maximum number of beams X

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24. The estimates that follow reflect the author's U.S. experience and judgement re U.S. financial markets. Other persons especially in other countries, could make different estimates based on their experiences.

channels that could be served simultaneously would be approximately 23,000. Recall, also, that by reorienting the radiated package of beams in step with local surface time, each regional space segment could serve as many as three times this number of beams X channels/day, for intervals of 2 hours each in both the morning and evening hours, and that there could be four regional space segments. Thus the maximum regional daily capacity would be (3)(23,000) = some 70,000 beams X channels, to be used for both morning and evening service. The worldwide capacity would be four times this number, or approximately 300,000.

If only one standard area of approximately 10,000 square miles were served under these circumstances, then the per-channel cost of doing so would be \$100,000,000/(300,000) i.e., \$400 per year for 4 hours per day. This suggests that programs could be broadcast throughout France's 200,000-square-mile area for 2 hours each morning and evening, every day of the year, for (\$400)(200,000/10,000) = about \$8,000 per year, and that programs in three different languages could be broadcast simultaneously throughout Switzerland during both the morning and evening hours for (\$400)(16,000)/(10,000)(3) = about \$2,000 per year.

This estimated cost is quite low for the kind of broadcasting service provided. An area of 10,000 square miles is, roughly, three to 10 times (depending upon the terrain features) the primary service area of a fine AM (MF) or FM (VHF) over-the-air audio broadcasting service. The latter, however, would be available about 20/4 = 5X as many hours/day as the former. Thus, on a normalized square miles X broadcasting hours basis, they each provide roughly the same service. But the local stations' annual financial cost of ownership and operation can be one or two orders of magnitude (or more in difficult terrain) greater than the cost of the DBS-A service.[12, 25]

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25. A paper entitled "Concerning Satellite Broadcasting (Sound) In The Band 0.5 - 2.00 GHz," August 20, 1985, was submitted by the U.S.S.R. to Committee 4, Working Group 4A, at the first session of the International Telecommunication Union World Administrative Radio Conference in Geneva. In this paper "...a comparison is drawn between the cost of satellite broadcasting (sound) systems and conventional methods of high-quality sound broadcasting." The paper's Annex 2 gives the cost estimate for providing two audio programs via a terrestrial VHF-FM network to the Ukrainian Soviet Socialist Republic, and Annex 1 estimates the provision of such a Ukrainian service were it to be provided by a space segment. A comparison of the two methods "...shows that the establishment of terrestrial sound broadcasting systems is 5-40 times cheaper...." The paper's main conclusion is: "In view of the fact that sound broadcasting-satellite systems are not economically justified, the U.S.S.R. Administration considers it inappropriate to allot frequency bands for satellite broadcasting (sound) in the 0.5 - 2 GHz range."

(Continued on following page)

Of course, cost is one thing, price is another. If the total price charged to the individual government broadcasters were to be expected to

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(footnote continued from preceding page)

This broad conclusion cannot be reached on the basis of such a narrow comparison and is incorrect.

A common-user, common-carrier system of the character outlined in this paper takes advantage of the fact that, using sophisticated space technology and operating methods, enormous areas can be appropriately served and a very large number of sound channels can be made available to the large number of broadcasting users of the service offered. This can be accomplished for only a modest increase in the cost of a space segment designed to provide a low-capacity, small coverage area service of the kind outlined in the U.S.S.R. paper, making the unit cost per sound channel per desired coverage area quite small.

The U.S.S.R. paper, for example, suggests that the acquisition cost of a space segment designed to allow two voice channels to be broadcast throughout the Ukraine's 230,000 square miles from a geostationary transmitter would be $144 million. The space segment cost estimated here would be approximately $170 million for each of the four required to provide a worldwide service. Such a segment would be capable of serving 7.5 million square miles (i.e., 33X the area of the Ukraine) and providing 300 sound channels (i.e., 150X the number used in the U.S.S.R. paper's Ukrainian example), an (area X capacity)/cost advantage of some (33) (150) (144/170) = 4,200X. And the Ukraine is not representative of many areas in the world where the terrain is not flat and where, consequently, a greater surface density of transmitters would be required.

This is a particularly graphic and useful example of the economic power of the common-user, common-carrier, sophisticated technology approach to providing telecommunications services. Long appreciated by the terrestrial and space long-haul trunk telecommunications engineering community, it can now be be applied to the sound broadcasting area as well and with great economic advantage.

While the official conclusions of the WARC-ORB '85 are not available at this writing (early October 1985), the text of that portion of its proceedings which relate to satellite sound broadcasting systems that was submitted to the Editorial Committee on September 10, 1985, "recommends" that further service, technology, systems and cost studies be carried out--studies involving "multiple user satellites." The text observes that: "Investigation is required into the ... use of the same satellite by more than one administration to satisfy their individual requirements."

defray the entire DBS-A system-service cost, then averaged over time the price charged to them for a channel would have to approximate the ratio of the system's annual cost to the number of channels used. But if, for example, only 10 percent of the system's available capacity were utilized over the year, then the price that a broadcaster would expect to pay would have to be 10X greater. Considerable thought, therefore, needs to be given to sizing the system's service capacity so that its annual cost is reasonably well matched to its use and, consequently, to the revenues this use could be expected to command.

Another way of looking at the service's cost distribution is to observe that, if it were shared equally among all of today's HF broadcasting countries, on average it would cost each of them somewhat less than $1 million per year. Inasmuch as some countries could easily use 10 percent or more of the service's capacity at an annual cost to each of them of some $10 million per year, then other countries could have their comparatively modest broadcasting needs met for $10,000 to $100,000 per year.

(At the present time, of the $160 million per year the VOA spends for other than the acquisition of equipment and facilities, it spends approximately $50 million to broadcast to the Soviet Union and Eastern Europe and, approximately $110 million to broadcast to the rest of the world. If the VOA could use 10 percent of a DBS-A service to broadcast to countries other than the Soviet Union and Eastern Europe at a cost of $10 to 20 million per year, it could then reduce its ongoing broadcasting costs by about $100 million per year.)

As was pointed out in Section 4, an initial system-service could be installed earlier and with greater confidence in the technology development schedule and cost if its capacity were scaled down by a factor of 10 from the large capacity example given here. In such circumstances its acquisition cost and therefore its ongoing financial cost would be significantly less. The order-of-magnitude annual cost estimate of $100 million per year for a large capacity system is sufficiently accurate, however, for the purposes of this paper.

SECTION 6

THE SPACE SEGMENT (TRANSMITTER)-SURFACE SEGMENT (RECEIVER) POWER BUDGET FOR AN HF DBS-A SYSTEM-SERVICE

In an earlier paper, the author outlined an approach to the design of a DBS-A common user system that could provide the world with reliable, high-quality audio broadcasting in the HF portion of the electromagnetic spectrum, specifically in the 26 MHz band.[26] Because the ionosphere supports onward radiowave propagation in this high frequency portion of the HF region for only a relatively small fraction of the time, this band is only marginally useful for long-distance, surface-based shortwave audio broadcasting.[27] For this very reason, however, this band could be used effectively by space-based transmitters because essentially all of the time signals transmitted downward along line-of-sight propagation paths toward receivers on the Earth's surface would not experience important ionospheric influences throughout large subsatellite surface areas.

The first time that the possibility of using this portion of the radiowave spectrum in such a fashion was discussed professionally in the public literature was in a paper by two British Broadcasting Corporation (BBC) engineers in 1978.[28] U.S. professionals at the National Telecommunications and Information Administration (NTIA) recently have explored the influence of the ionosphere on such a use in great detail.[29]

In the author's earlier report,[26] the basic circuit estimations made by Phillips and Knight[28] were used as the basis for a more detailed consideration of this possibility in overall system design terms.

In one circuit example, Phillips and Knight[28] assumed a 26-MHz, double-sideband AM transmitter to be located in geostationary orbit that would broadcast downward to state-of-the-art spacewave receivers having a

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26. "Modernizing And Expanding International High-Frequency Broadcasting," T. F. Rogers (unpublished) January 1982. See also: "The Use of Satellites in Modernizing and Expanding International HF Broadcasting," T. F. Rogers, <u>Report of the International Broadcasting Convention</u>, Brighton, U.K., September 16-25, 1982; pages 155-157.

27. The 1979 World Administrative Radio Conference reduced the 26 MHz region spectrum for broadcasting from 500 to 430 KHz.

28. "Use of the 26-MHz band for satellite broadcasting," G. J. Phillips and P. Knight, <u>E.B.U. Review-Technical Part</u>, August, 1978; pages 173-178.

29. "Study of Factors Affecting an HF/VHF Direct Broadcasting Satellite Service," C. Rush, J. Aarons, F. Stewart, J. Klobuchar, P. Doherty, M. PoKempner, and R. Reasoner, <u>N.T.I.A. Report 84-158</u>, September, 1984.

simple half-wave dipole wire antenna with 5 db gain, or for easily transported or even mobile purposes a 5 db gain ferrite rod antenna incorporating improved components then becoming available. A post-detection audio bandwidth of 5 kHz also was assumed. Phillips and Knight then estimated the size and character of the in-orbit transmitter required to provide reliable, high-quality signal reception over a surface area that would escape almost all ionospheric influences except for the Faraday rotation effect.

The author assumed that each regional satellite transmitter would incorporate a large, multisegmented[30] or multifeed antenna with an approximate 1,000-foot overall diameter[31] that, driven by an array of individual subtransmitters, could generate several Earth-directed spot-coverage beams. The selection, frequency, and power output of each subtransmitter would be controlled by the space segment's surface feeder station. Each surface footprint would have an area of approximately 2 million square miles.

In that paper the author concluded that with such a geostationary transmitter and adequate statistical system allowance for natural and commercial-industrial electrical noise and ionospheric attenuation (a system allowance that, in total, is 11 db greater than that used by Phillips and Knight [28] in their single circuit power budget calculation), a 40-db,

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30. See "On the Feasibility of Direct Emergency Spot Broadcast from Satellite to Ordinary Ground Receivers," R. M. Lerner, M.I.T. Lincoln Laboratory Technical Report 546, 29 December, 1980; see, especially, pages 13-15.

31. While the physical size of such an antenna would be large, its electrical size, i.e., the ratio of its area to the radio wavelength used, and therefore its inherent directivity and gain, would be about the same as that of the UHF antenna employed on the U.S.-NASA ATS-6 R&D communications satellite that was placed in orbit over a decade ago. Space antenna technology has advanced to the stage where an aerospace firm is now working under U.S. government contract on an antenna reflector which, when unfurled in space, would be "nearly twice the size of a football field" (i.e., almost 20 percent of the area suggested here). Because of its accuracy and stability of construction, it could be satisfactorily employed at wavelengths much shorter than the near 40 feet of 26 MHz radiation. The Soviet Union reports that it is working on the construction of a parabolic reflector for use in space that has a diameter of 300 to 350 meters, i.e., at least the size suggested here. And the possibility of employing very long end-fire arrays made up of tether elements should not be overlooked. A fundamental justification advanced by NASA for a civilian Space Station is that it, including its crew of technicians, could be used to assemble and test large structures such as this in low-Earth-orbit.

post-detection S/N (corresponding to a C/N = 38 db in a pre-detection bandwidth of 10 kHz) could be expected in 99.9 percent of the surface areas covered, 99.9 percent of the time, with a radiated RF continuous wave power of 1,300 watts.

The report by Rush, et. al., [29] (see its Section 3) suggests that the influence of the ionosphere on the ability of 26-MHz signals to penetrate to the Earth's surface, especially in the most northern latitudes and/or during intervals of maximum sun spot activity, may be more important than Phillips and Knight and this author realized. This might raise a question concerning the ability of any 26-MHz space-based system to provide an overall 99.9 percent service reliability. As in the 2.5 GHz conceptual system-service studied here earlier, however, by excluding areas north of the Arctic and south of the Antarctic circles from service considerations, excluding even a few additional regions at latitudes closer to the Equator where the population density is as small as in the Arctic and Antarctic regions, and insuring that geostationary space segments are optimumly located in orbit to favor coverage of the more northern regions. But, because of the ionosphere's influence on surface coverage, the use of more space segments in an HF DBS-A system-service would be required than in a UHF DBS-A system-service to ensure that the reliability of service would be excellent at all times for the vast bulk of the world's population.[32] In the limit, if it were judged necessary to provide a higher reliability of service to some northern regions not easily possible with the use of geostationary satellites, one or more additional space segments, placed into appropriate "Molniya"-like orbit(s) could be employed. Of course, almost any desired reliability of service for almost any surface location could be obtained in this fashion at increased system cost.

The report by Rush, et. al.,[29] (see its Section 7) emphasizes that the ionosphere would cause short-term fading of 26-MHz signals received after they had traversed it. In some surface regions (the more intense fading affecting heavily populated regions would be confined to some 10° north and south of the geomagnetic equator) and at certain times, particularly during the local late evening hours at times of high sun spot activity. This fading would be more important than was judged to be the case by Phillips and Knight[28] and the author.[26] But the conclusion reached by Rush, et. al.,[29] (see their page 123) that "It is not reasonable to try to overcome the nighttime (1900-2400 hrs. local standard time) levels of scintillation activity...with more power" is too pessimistic.

The author's 26-MHz DBS-A conceptual system design characteristics[26] incorporate power budget margins (see its Appendix No. 3) that provide received signal strengths 18 db above rural quiet, 11 db above rural, and 4 db above residential area electrical noise levels external to the receiver.

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32. More detailed northern region statistical coverage calculations are required than necessary for the purposes of this paper.

Except for some high-noise metropolitan areas (i.e., Bogota, Colombia; Santiago, Chile; Buenos Aires, Argentina; Rio de Janeiro-Sao Paulo, Brazil; and Calcutta, India) nearly all of the inhabited surface areas that are likely to experience intense scintillation fading could thus accommodate it by using various portions of this 4 to 18 db range of system power margin.

An additional margin of 9 db to accommodate the peak hours of commercial-industrial activity, and thus the electrical noise that it creates, is also contained in the power budget estimates[26] and, since the peak noise level that occurs late in the business day is over, or nearly over, by the time any intense scintillation fading is expected to occur, this margin also could be drawn upon.

Finally, the system's total power could be "taxed," dynamically, to provide power to the beam covering the region affected during such intense fading. Recall that a S/N of 45 db would be provided as a Standard Service in all of the system's radiated beams for most of the time (see Section 3). Were an HF DBS-A system to have, for example, six beams that could be used simultaneously, then a short-term power "tax" of 1 db could be levied upon each of five beams, increasing the power of the one beam serving the affected region by 5 db. All regions not affected by the scintillation fading would then have a S/N of 44 db, rather than 45 db, i.e., a nominal decrease during the relatively rare interval of short-term scintillation fading in the one region. A short-term power tax that reduced the S/N in regions not affected by fading to 43 db would provide 10 db to combat the scintillation fading; etc. (If FM were employed in the DBS-A system, then expectation of this kind of fading would strongly suggest that the surface receivers be provided with a means of "FM threshold extension.")

Thus because of the large power margins that would be built into an HF DBS-A system-service, and the way it could be designed to operate dynamically (it would be able to respond quickly to reports of such fading from a surface monitoring network), a great and effective power reservoir could be available to accommodate scintillation fading. More comprehensive statistical analyses are indicated--analyses that would inquire carefully into exactly how often 26-MHz scintillation fading could be expected to occur, where, when, and with what hour-to-hour and short-term intensity. These statistics would have to be related with analogous statistics concerning commercial-industrial and naturally occurring electrical noise.[33] But the situation need not be as pessimistic in overall service reliability and quality as the Rush, et. al., report[29] suggests, and perhaps no further system power margin need be required.

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33. It may be that the data now available--as in the building structure, foliage, and rough terrain attenuation circumstances of comparable interest at UHF--are not sufficient to allow temporal and spatial engineering studies to be made satisfactorily on a worldwide, decades-long basis. If that data are needed, they would have to be gathered.

Finally, for any listener who found the received signals unsatisfactory because of severe scintillation fading, even after the system's entire power margin had been drawn upon, there would still be the option of employing increased receiver antenna gain. A fixed, half-wave folded dipole employed in a five-element Yagi (or helix) array, and having outside area dimensions of about 20 feet x 40 feet, would provide 5 to 8 db more gain than the assumed half-wave (wire) antenna.

Although a large allowance must be made at HF for the influence of external electrical noise and ionospheric influences, no allowance is needed for building structure or foliage attenuation. HF reception in circumstances of difficult terrain would also generally be superior to that at UHF because the diffraction field propagation loss rate is much less. And although the assumed gains of both the space transmitter and surface receiver antennas are much lower at HF than at UHF, so is the free-space path loss. There need be essentially no concern for the influence of receiver antenna directivity. Moreover, the DC-to-RF efficiency of HF transmitters is higher today. Unlike FM, provision for peak modulation power must be made for AM. To compare the performance of an HF DBS-A system-service with that of the UHF system-service outlined in Sections 2 and 3, adjustments must be made to the power budget analysis made in Section 3.

Three HF service cases are considered:

1. A Baseline Service that would continue to use the world's present 26-MHz receivers designed to receive double-sideband AM signals.

2. A Standard Service that would require either the use of a much higher power in the space segments than for the Basic Service, or use of FM by the 26-MHz band system. In the latter circumstance new receivers would be required. In each case, delivery of a 45 db S/N in a 5 kHz post-detection band would be expected.

3. A Superior Service that assumes the 26-MHz band would be used for wide-band FM, and 50 db S/N in 15 kHz, post-detection, would be delivered by using new receivers.

The author's earlier study included a power budget estimate [26] that concluded that a space segment power of 1,300 continuous wave RF watts would be required. General adjustments to that estimate are as follows:

1. An ordinary system design and operating margin to accommodate less than optimum overall systems performance: + 5 db.

2. For the conversion of DC to RF and for other space segment power needs: + 3 db.

3. Although it is not clear what influence the use of the compandor-expandor technique would have on the allowance for accommodating

to AM modulating peaks, the peak-to-average power ratio adjustment to be made, probably conservatively, is: + 6 db.

4. Use of the compandor-expandor technique: - 16 db.

5. Allowance for multi-channel use statistics: - 5 db.

Total: - 7 db.

Therefore, the basic, adjusted, power budget now suggests that the initial space segment power estimate is 1,300/5 = about 260 DC watts/channel/beam.

Baseline Service

As did Phillips and Knight,[28] it is assumed here that either a horizontal dipole receiving antenna is used or that more efficient components are used in a newly purchased, low-cost, ferrite rod antenna. Thus the approximate DC power required in a space segment in order to provide one reliable 5 kHz channel of double sideband AM service to receivers in a surface area of 2 million square miles at various levels of received S/N is as follows:

Received S/N	Space DC Power
45 db	820 watts
40 db	260 watts
35 db	80 watts
30 db	26 watts
25 db	8 watts

If one channel were provided to a maximum of six such surface areas simultaneously--areas extending over approximately 1,500 miles in latitude in the subsatellite area, and approximately 9,000 miles in longitude for one, 1-1/2 hour, interval of three such intervals in the morning and in the evening each day (six in-orbit space segments are assumed to be required at 26-MHz re 4 at 2.5 GHz to eliminate any important ionospheric influence on surface coverage), the total space segment DC power required would be:

Received S/N	Space DC Power
45 db	5,000 watts
40 db	1,600 watts
35 db	500 watts
30 db	160 watts
25 db	50 watts

Thus if, for comparative purposes, the DC power available in the space segment were taken as the same 5,000 watts necessary to provide the quality and reliability of service desired at 2.5 GHz, then only one channel could be provided at a Baseline (and Standard) Service quality, i.e., 45 db S/N in 5 kHz, if this channel were delivered throughout the entire surface area served by one space segment. The maximum number of channels that could be provided at various lower S/N levels in covering this total area would be:

Received S/N	Number of Channels
45 db	1
40 db	3
35 db	10
30 db	30
25 db	100

As observed in the 2.5 GHz case, it is not possible to judge what maximum number of channels would be expected to serve what maximum number of surface areas simultaneously. It is also more difficult to judge the acceptance of a lower than Standard Service S/N level by an HF AM listening audience. A 25 db S/N might seem unacceptably low to a person who, accustomed to listening to radio only under circumstances where high-quality signals are broadcast over local over-the-air AM and FM stations, would be faced with deciding to purchase a new receiver to listen to programs broadcast from space. But for a shortwave broadcasting listening audience able to receive a steady, fixed-frequency, undistorted signal--one not marred by interference--a 25 db S/N might be quite acceptable. (It should be noted that HF shortwave broadcasters are now seriously discussing the acceptability of signal-to-interference ratios of only 27 db or even less.) If the latter is the case, then 100 channels, i.e., a number of channels commensurate with those that could be delivered by a 2.5 GHz system-service, albeit with Standard Service quality in the latter case, could be delivered at 26-MHz. The capacity of a 26-MHz AM system-service that would otherwise utilize today's receivers would be much less than that of a 2.5 GHz system-service unless the power of its space segment were increased to well above 5,000 DC watts and/or unless the comparative capacity required of a 2.5 GHz system-service were scaled down considerably.

Of course, because of the sharply lower number of beams at 26-MHz, the use of AM, and no possibility of using polarization discrimination because of the Faraday effect, particular care would be required to guard against channel-to-channel interference when using a large number of channels.

Standard Service

AM If a Standard Service were provided with a 26-MHz AM signal, much more power would have to be provided in the space segment. Because one Standard Service channel serving all areas of a given region simultaneously would require 5,000 DC watts, 100 channels or more could require hundreds of thousands of DC watts, depending upon the maximum simultaneous number of channels required to serve the maximum number of any region's 2 million-square-mile footprint.

Until recently, many might have viewed this amount of space power to be unreasonable. But it is important to recall that Skylab's solar cell-battery space power supply provided over 12 kw a dozen years ago and NASA has just tested a modern array on the Shuttle that is designed to produce 12 kw. The civilian Space Station also expects to be operating with 100 kw within a decade. A U.S. multi-Federal department program is exploring space nuclear power supply options ranging from 50 kw to a megawatt or more, the SDI program is reportedly actively considering the generation of 10 megawatts of electromagnetic radiation and its transmission across thousands of miles in space, and NASA demonstrated many years ago that 50 kw average could be transmitted through the atmosphere with high reliability and efficiency using a collimated microwave beam--thus emphasizing that large amounts of electricity could be obtained at, or shipped to, geostationary orbit from the surface. And NASA, with the Department of Energy, is readying a program to conduct an early experiment-demonstration that could see an unattended, long-flight, perpetual aerostat platform (HAPP) and its payload stationed at 70,000 feet, powered from the ground via a beam of microwave electricity. So, there is no doubt that hundreds of kilowatts, or more, could be employed by DBS-A space segments a decade from now if the involved organizations considered such activity important. The question is not one of fundamental technological feasibility, but one of the relative newness of the concept of using such high in-space power in the satellite communications field and, perhaps, its high initial development cost.

It should be noted that the use of extremely high effective radiated powers in space to provide a large capacity, high-quality DBS-A service does not raise the same hazard of unwelcome surface flux densities at HF that it might at UHF, there is no expressed concern in international agreements about space-generated high surface flux densities in the 26 MHz band.

FM As in the 2.5 GHz conceptual system design outline, 60 kHz of RF bandwidth could be used per channel to allow FM to produce a S/N of 45 db. With a deviation ratio of 5X, a C/N of 23 db would be required (i.e., 45 db (S/N) - 10 $\log_{10}$ (3) $(M)^2$ - 3 db (pre-emphasis) = 45 db - 19 db - 3 db = 23 db), since the 16 db of effective S/N improvement provided by compandor-expandor use is already allowed for here in the basic adjusted power budget estimate. The Baseline Service 26-MHz space segment DC power estimate of 260 watts/channel/unit surface area assumes a S/N = 38 db delivered in a 10 kHz RF bandwidth. This FM case requires a C/N of 23 db in 60 kHz and therefore 260 watts would be too high by 38 db - 8 db - 23 db = 7 db. Also, the 6 db allowance made earlier for peak AM power is not needed. Thus employment of FM rather than AM, 60 kHz of spectrum/channel rather than 10 kHz, and new receivers would allow the delivery of a highly reliable channel for 260/20 = 13 watts of space segment DC power/channel/per beam at a Standard Service quality.

Given a maximum of six beams to be served simultaneously, the maximum number of simultaneous channels that could be provided with the 5,000 DC watts required for the UHF DBS-A system outlined earlier would be (5,000)/(6)(13) = about 60. In the basic AM case, however, only one channel could be provided at Standard Service quality. Even so, this would be a lesser Standard Service system capacity, by a factor of about three, than would be available in a 2.5 GHz service in which the system's space segment power and RF bandwidth were the same. In order to provide the same capacity arrived at in studying the 2.5-GHz conceptual system-service, 10 to 15 kw of space segment DC power would be required. Given the great difference in the surface footprint area, however, 200X greater at HF than at UHF (2 million/10,000), the minimum number of receivers served per channel would be much greater at HF.

While the surface area-to-area self-interference situation would be sharply improved with the use of FM, it might still be difficult to accommodate 100 channels in the 430 kHz now used for shortwave broadcasting in the 26-MHz band. This would be the case unless a considerable re-use of frequencies in each region is found to be feasible even with the simultaneous use of only six beams and, more importantly, unless much or all of the other 2.7 MHz used for such broadcasting in the other, lower frequency, HF bands, also were allocated to a 26-MHz DBS-A system-service. If 1/2 of the 2.7 MHz were to be so used, for instance, and a frequency re-use factor of 3X were achievable, then about 75 Standard Service channels could be accommodated/space segment; if all were so used, 140 channels could be accommodated. If not, and if a large number of channels were nonetheless required, then a smaller FM deviation ratio would have to be used and the lower resulting S/N compensated for with even more space segment DC power.

Superior Service

A Superior Service, one providing 50 db S/N in 15 kHz in each reliable channel would require an additional space segment power of 10 db. Unlike the 2.5 GHz situation, however, the employment of greater receiver antenna gain at 26-MHz generally does not appear to be a practical course because the radio wavelength is nearly 40 feet. If the RF bandwidth were not increased, one channel could be provided to one beam for (13)(10) = 130 watts of space segment DC power, and to all six beams for 800 DC watts. Of course, this would leave less capacity for the provision of many Standard Service channels; 10 Standard Service channels/beam would have to be sacrificed for each Superior Service channel/beam. If the bandwidth were increased and a larger deviation ratio employed, the DC power and, consequently, the number of Standard Service channels sacrificed would be reduced. The prospects of such a move are not now particularly encouraging. Considering the space power and 26-MHz spectrum required, it might well be that a Superior Service could only be delivered economically at times outside the prime dinner and breakfast Standard Service delivery intervals.

SECTION 7

THE ACQUISITION COST OF AN HF DBS-A SYSTEM-SERVICE

There does not appear to be any significant cost difference between a fine HF and a fine UHF receiver, if there is a sufficiently large market.

It is somewhat more difficult to estimate the acquisition cost, and therefore the related financial cost of ownership and operation, of an HF DBS-A system-service than it is for a UHF service at this time.[34] The individual space segment cost would be somewhat greater because of the larger antenna required and the increased demand that its size would put upon transporting it to orbit and assembling it there. Greater RF power would be required to overcome the external electrical noise at 26-MHz--particularly greater at the absolute DC power level to be associated with a high-capacity, high-quality system-service where the in-space cost of providing the service would be very great. And because of the influence of the ionosphere on limiting reliable coverage areas, more space segments would be required.

The following cost-related changes appear to be indicated for the space segment of an HF DBS-A system-service, as compared with the costs outlined in Section 4 for UHF:

1. Perhaps six (or more) active satellites would be required instead of four in order to obtain adequate coverage.

2. The cost of the much larger HF space segment antenna would be greater.

3. Fewer subtransmitters would be employed, but their required power-handling capability would be greater.

4. Much greater DC power would be required--hundreds of kilowatts for a full capacity AM system-service and at least 10 kW for one employing FM.

5. The complexity of in-space assembly of the antennas would be greater.

6. Perhaps two additional Shuttle flights would be required to transport and deploy the larger antenna and the greater number of satellites required.

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34. Our present statistical (time and location) knowledge of the influence of some ionospheric characteristics upon system engineering considerations is incomplete, and the cost of much greater in-space DC power levels that would be required at HF is not yet known with high confidence.

Setting aside, momentarily, the matter of greater space segment DC power, it appears that the cost of an individual AM HF space segment, including its insurance, would be about $10 million greater and, with the larger number of HF space segments and their Shuttle launches required, the total space segment initial acquisition cost would approximate $900 million, i.e., it would approximate 1.5X to 2X the total cost of the space segments of a worldwide UHF system-service. But such an HF AM space segment would provide only one channel of Standard Service for each of all beams in all regions with a space segment DC power of 5,000 watts. Each such additional channel, requiring 5,000 DC watts/space segment to serve six beams/region simultaneously, would therefore cost ($5,000) (5,000) (6) = $150 million. Unless the technique of providing large amounts of power from the surface is perfected, a worldwide, high-quality, high-capacity AM system-service will be extremely expensive.

A worldwide 26-MHz FM system-service could provide 60 channels with each of six space segments having 5,000 DC watts of power. The acquisition cost of this power would be ($5,000)(5,000 watts)(6 space segments) = $150 million. Thus the cost of the space segment power required to provide a commensurate number of channels, about 150, at 26-MHz as at 2.5 GHz would be (150/60) = 2.5X as great, or an additional $200 million. Finally the total worldwide system-service space segment cost would be $900 million + $200 million = $1.1 billion. While this cost would be much less than that of an equivalent 26-MHz AM system-service, it is much more, 2X as much, as that of a 2.5 GHz FM system-service of roughly the same maximum system capacity and surface coverage.

There does not appear to be a significant difference in the cost of the surface feeder.

While the acquisition and ongoing cost of the space segments of an HF DBS-A system-service would be great in absolute terms, and greater relative to the cost of a comparable UHF DBS-A system-service, its cost would still be only 10 percent of the total global system-service cost because the bulk of the total cost would be concentrated in the surface segment.[35]

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35. In considering employment of a frequency band other than 26-MHz or 2.5 GHz, several important observations can be made. As the frequency increases above 26-MHz, the size of the space segment antenna, the receiver external noise, and the influence of the ionosphere on radiowave propagation decrease rapidly. At the same time the service area footprints become smaller so that system cost would decrease and service flexibility would increase. Eventually, however, excess radiowave attenuation caused by building structures, foliage, rough terrain, and surface flux density limitations begin to become important.

(Continued on following page)

It is important to appreciate that throughout this paper estimates of cost have considered only the financial cost, not the political cost, of either, and indeed any, DBS-A system-service. Of course the great economic, political, and cultural benefits that could be derived from all countries of the world having such a new, worldwide service, are most important to note.

(footnote continued from preceding page)

Careful analysis could lead to the conclusion that the most efficient use of the electromagnetic spectrum for DBS-A would result from use of a frequency band intermediate to the two studied here. Two other regions should be given particular attention. The VHF region presently used for FM broadcasting, among other services, offers many of the advantages of the UHF region: the influence of the ionosphere is no longer very important, diffraction field radiowave attenuation rates are much more modest than at UHF, building wall and foliage radiowave attenuation concerns are modest, and relatively sensitive receivers are in wide use throughout the world in various frequency bands. And the large UHF television band, which also is relatively attractive in many respects, also could be looked into: the amount of radiowave spectrum now used for one surface-based UHF television channel would be sufficient to accommodate thousands of audio channels throughout the world via a DBS-A system-service.

SECTION 8

PAYING FOR A DBS-A SYSTEM-SERVICE

If reliable, easily used, and sufficiently low-cost spacewave receivers were placed on the market and programs were sufficiently attractive, the listening public could be expected to acquire the surface segment in numbers large enough to defray all costs (engineering, production, distribution, and capital) of bringing them to market.

There now are 1.4 billion radio receivers in the world; about one-fourth can receive shortwave programs. In the United States alone more than one billion radios were sold over the past 37 years; more than 50 million radios were sold in 1983. If the private sector were confident that large numbers of today's government shortwave audio broadcasters and their listeners would want a DBS-A service, if reasonable political assurances that the frequency assignments and orbital slots required to allow sensible system operation would be available were foreseen, and if the political and financial assurances given by government broadcasting entities concerning use of the service were sufficiently encouraging, there is little reason to doubt that it could command the capital, talents, energies, and facilities required to provide an adequate service within a decade.

If the regional space segments of the DBS-A service were acquired by some or all of the governments themselves, and if they were to provide the required investment capital, the annual cost of this capital should be lower since government borrowing interest rates tend to be lower than private sector rates. There also would be no need for relatively more costly equity capital. The total system cost and the per-channel cost therefore, might be lower. But such apparently lower financing costs would be offset, at least to some important extent, by the absence of taxes otherwise paid by the private sector on net revenues and the seemingly inherently higher costs paid by governments in the acquisition of high-technology assets, especially space technology assets--at least in the U.S.

In considering how the space segments might be financed, it is useful to reflect upon their presumed absolute cost in a broader relative context. The figures used here will be those associated with a very high capacity UHF, FM, Standard Service, i.e., \$500 million for initial acquisition, and \$100 million per year for the total of annual amortization, profit and O&M charges; these should be understood to be within a factor of two of the eventual real ones.

Setting aside any consideration of the BIB-RFE/RL, the acquisition cost of the VOA's HF (and MF) surface-based broadcasting modernization and expansion program presently underway is expected to be \$1.8 billion, and this is for the U.S. alone. The equivalent 30-year amortization charge at the U.S. government's present average borrowing cost to finance the national debt, 10 to 11 percent per annum, would be \$200 million per year. Along with the VOA O&M charges (including the cost of fuel to provide electricity) for operating its U.S. and overseas broadcasting plants, probably approaching $200 million per year after its modernization and expansion program is completed, the actual total annual U.S. cost of ownership thus would probably exceed $400 million. Again, these would be U.S. costs alone, not worldwide costs that, in total, are probably 10X as great.

The replacement cost of the surface-based HF plants owned by the over 120 countries now engaged in shortwave audio broadcasting is probably more than $10 billion (i.e., a cost commensurate with that of the world's estimated 400 million HF receiver population). If annual amortization and O&M charges amount to 20 percent of this cost, the world's total cost of ownership today approximates $2 billion per year.

All of these numbers are so much higher than the DBS-A system-service acquisition and ongoing costs estimated here that with a decade's sensible planning, sensible regional strategies for system-service acquisition, and sensible cost-sharing arrangements, these costs should not burden the government broadcasters, the system-service developers and producers, or the listening public. Indeed they suggest that over the longer term it should be much less expensive to use the Earth's space than its surface and ionosphere for worldwide audio broadcasting.

It could also be noted that the revenue received by Intelsat (with 109 countries as members) in 1984 for maintaining and operating its international, long-haul, space-based communications system-service was over $400 million--an amount commensurate with, but greater than, that expected to be derived from a global DBS-A service. From this additional perspective, the absolute level of annual space-related costs and revenues should not create concern.

All of the cost of financing the initial acquisition of a DBS-A system-services's space segments, of course, need not be borne by the governments using them. Indeed, conceptually, they need not be burdened with paying for them at all. In principle the cost of the space segments, inasmuch as they can be expected to cost only five percent of the cost of the associated initial surface segments, could be financed with a charge of only $1 to $2 to be included in the price of each individual DBS-A UHF skywave receiver, i.e., five percent of the average retail price of the receivers. Setting aside consideration of the funds that could be generated by a cost add-on to the initial replacement of the receiver stock, the add-on included in annual receiver sales could be an ongoing source of funds that could help meet the annual cost of space segment ownership. If the world's stock of receivers designed for listening to broadcasting, worldwide, were continually replaced at a 5 to 10 percent per year rate (i.e., if they had an average useful lifetime of 10 to 20 years) and if the world's population growth, longevity, and personal income growth increases on average at a total rate of 2 to 4 percent, then average annual receiver sales, worldwide, could approximate ($10 billion)(7-14%) = approximately $1 billion per year, i.e., about 10X the total estimated annual DBS-A system-service cost. This estimate gives no consideration to any additional sales induced by the greater quality and reliability of reception and the increased variety of programming made possible by the global introduction of such a new system-service.

Perhaps there could be an intermediate arrangement, i.e., cost-sharing between the broadcasters and the listening public. Such an arrangement could encompass the common-user broadcasting service entity (or entities), developing and testing especially low-cost Basic and Standard Service spacewave receiver models, and assisting in their local production in countries interested in doing so--especially in countries with modest financial resources for the purchase of foreign goods.

It is also important to appreciate that over 40 percent of the total global need for HF broadcasting supports national, i.e., domestic services in approximately 100 countries and, of course, a high-capacity, flexible, DBS-A system-service could also easily be used to provide such national audio broadcasting. Brazil, for instance, will employ two "Brasilsat" satellites in geostationary orbit to provide itself with national voice and television transmission services; and 22 Arab countries will use their "Arabsat" satellites to interconnect themselves with voice, data, and television channels.

The importance and value of using space-based transmitters to provide national direct broadcasting services is described usefully and persuasively in a recent United Nations study.[36] This study notes that space technology could be employed by the world's educational community "...not only to educate the young, but also to provide a continuing source of information knowledge and know-how to the adult population," would be "...particularly [valuable] in remote rural areas," and "...could fulfill many needs in diverse fields, including school education, health, family planning, nutrition, agriculture, teacher training [,] and agriculture [and] health extension worker training." It also could be used for "...continuing education for already trained workers, such as doctors and nurses, to keep their skills and knowledge up to date."

While the bulk of the United Nations study is focused upon the use of television, it speaks specifically to "...the role of broadcast radio..." and notes that for "...educational purposes, audio services may be cheaper than television services, particularly when program costs are considered in addition to the cost of hardware." The U.N. report also observes that "television has proven less effective than radio for some subjects and purposes and even counter-productive on occasion" and concludes that "because of the high cost of television services or because television may not the best medium for a particular education objective, audio services warrant consideration." (This video-audio cost differential can be two

36. "The Feasibility of Using Direct Broadcasting Satellites for Educational Purposes and of Internationally or Regionally Owned Space Segments," United Nations General Assembly, Committee on the Peaceful Uses of Outer Space (COPUOS), A/AC. 105/341; November 16, 1984.

orders of magnitude. "... your entire [advertising] campaign of five fabulous 60-second radio commercials will cost less to produce than one second of some TV commercials."[37]

The low marginal cost of employing the kind of system-service outlined here--one designed to meet global audio broadcasting needs and expected to be paid for by the governments using it for this purpose--should allow, and indeed prompt, very low-cost experimentation, demonstration, and on-going use for national-domestic educational and other purposes. Note, particularly, that the peak demand for the capacity of the worldwide system-service outlined here would occur during the early morning and evening listening hours, where news and entertainment programs predominate. Therefore much, perhaps most, of the capacity would thus be available for educational and other purposes during the day's "working" hours and could be provided at a low marginal cost. The small, low-cost, easily used and transported spacewave audio receivers also should obviate concern for their initial acquisition and continuing O&M costs, and eliminate the necessity for employing sophisticated community receivers with their attendant scheduling and O&M costs, and problems. Program redistribution, for example, simply would not be needed. And the additional revenues generated from this additional service could offset system costs.

A recent European Space Agency study, considering the provision of domestic direct audio broadcasting services via space transmitters within African countries[12] that have low and average Gross National Products (GNP) per capita, noted that these countries spend 0.1 to 0.5 percent of their GNP on broadcasting.[38] Because the GNP for all of the countries of Africa recently totalled $400 billion, this suggests that this continent alone could support domestic (national) DBS-A services within an annual revenue stream of $400 million to $2 billion dollars per year. And, if the same broadcasting expenditure rule of thumb were to apply to Central and South America's GNP of $700 billion, the annual revenue stream envelope there would be $700 million to $3.5 billion.

An essentially new and potentially quite important element also could be introduced into worldwide audio broadcasting through the provision of DBS-A interconnected regional system services: that of its widespread use by the private sector in addition to traditional use by the government sector. Today there is little private use of HF shortwave audio broadcasting. Such shortwave broadcasting is for the most part seen as a way for governments to conduct public diplomacy, i.e., "government advertising." There is reason to imagine that with the availability of a fine DBS-A service,

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37. "Creativity--Effectiveness, Aesthetics and Morality," Edward A. McCabe, Vital Speeches of the Day; August 1, 1985: pages 228-232.

38. It is not clear to the author whether these figures encompasses television as well as radio broadcasting.

government-sponsored public "advertising" could be joined by private commercial advertising.

Recall, for instance, the earlier example of broadcasting to France: 4 hours of audio broadcasting could be delivered daily throughout France's 260,000 square miles at a charge for a Standard Service channel of $8,000 per year. The French population is somewhat over 50 million. Therefore, during these hours the French population could be served for ($8,000)/(365)(4)(60) = less than 10¢ per minute. If 0.1 percent of the population listens to a one-minute advertising message, the service cost for reaching these 50,000 listeners would be about ($0.1)/(50,000) = 0.0002 cent each. The broadcast area throughout the world could be as great as 30 million square miles with a listening population of hundreds of millions, or as small as 10,000 square miles, located essentially anywhere in the world, thus allowing a new and flexible focus to the commercial advertising business. Also, keeping in mind that the service cost estimate assumes that the system's space segments would not be used by governments, on average, for more than half of the hours per day, the potential for use by additional, nongovernment interests could be great.

Indeed the DBS-A service would offer an opportunity for a new worldwide commercial advertising medium to develop, one whose character and dimension simply cannot now be imagined. If such a use occurs to any great extent, the additional gross revenue provided could be brought down directly to net income since the initial worldwide service pricing structure would be set to offset all system-service costs; this additional income could be applied against the basic system-service cost.

It might be noted that private firms in the U.S. alone currently spend $20 billion/year for advertising, and that the 35 firms with the largest advertising budget, as a group, allocate over four percent of their budgets to radio broadcasting services. Thus there is the potential for attracting private revenues of truly significant amounts. If only one percent of today's U.S. private radio advertising revenues were spent using a DBS-A service, these revenues would approximate 10 percent of the system-service's total annual financial cost. Provision of global paging and data broadcasting services, and the rapid relaying of newspaper master sheets by facsimile to many local printers (particularly during late-night "off hours") would become possible, and a narrow-band data distribution channel also could be included for national purposes. Broadcasting of sophisticated "compressed video" signals over the system-service's high quality audio channels also could occur in time. (And it should not escape notice that employment of a 3-foot diameter parabolic reflector surface receiving antenna, with a gain of 15 db, in principle could allow a video channel to be broadcast using the space segment capacity normally provided for 60 of its 1,000 audio channels.)

That such private interest in using space for commercial broadcasting is far from conjectural is attested to by the beginning of satellite broadcasting in conjunction with surface commercial cable television systems in Europe. There a TV channel, called Sky Channel, uses a transponder on an in-space communications satellite to broadcast TV programs which carry advertising. The channel already is being received by 3 million of the 100 million European television households now on cable. And a leading U.S. advertising agency estimates that European advertisers alone would spend at least $1 billion per year televising there if current government restrictions were removed.

However, consideration of how the self-interest of many countries, organizations, and institutions could be sorted out to allow such possible private use is well beyond the purposes of this paper and the competence of its author. For any introduction of private advertising into an arena so far exploited by government "advertising" alone would require the solution of a new array of problems on a nation-to-nation basis, and could be attended by complex economic, political, and cultural concerns.

Public services could be expanded, also. Emergency storm and other warnings, for example, could be broadcast to small, specific areas or to an entire nation without requiring the listeners to have special receivers of the type now employed in the U.S. to receive weather information. Agriculture information could be provided directly to individual farmers in developing countries (such as that generated by the Developing Countries Farm Radio Network in Canada) and could be disseminated with sharp audience/location focus and great efficiency.

Historically, the space technology/space applications area often has been burdened by scientists and engineers devising solutions to presumed problems and then being unable to see such solutions satisfactorily demonstrated in a real world context.[39] In contrast, this is one societal area where there are clearly important objective problems seeking solutions, and important opportunities to be grasped, that now appear amenable to technological solutions.

All-in-all, the possibilities for developing, acquiring, and financing regional and worldwide DBS-A system-services now appear quite encouraging--indeed, even intriguing--always assuming that they are envisioned by persons with sufficient imagination to consider the creation not only of new technology but of innovative institutional arrangements for so doing.

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39. See, for instance "Growing the next Silicon Valley," Roger Miller and Marcel Côte', Harvard Business Review, July - August, 1985; pages 114-123. The authors observe that "...most government laboratories and universities are poor incubators of ...high-tech products. Usually [they do not] have any significant contact with the marketplace...its needs, its organizations, or its people...."

SECTION 9

IMPLICATIONS OF A DBS-A SYSTEM-SERVICE FOR THE UNITED STATES AND THE UNITED STATES INFORMATION AGENCY-VOICE OF AMERICA

This section addresses the more important political, cultural, operational, financial, and economic implications of U.S. and VOA support for a worldwide DBS-A common-user system-service to be provided and used by the world's audio broadcasting community.

Political

The United States could work with other countries and various multinational radio communications entities (i.e., Intelsat, Inmarsat, Eutelsat, and Arabsat) to rationalize and improve the whole field of worldwide audio broadcasting and to see it made available on a low-cost, equitable basis to all countries regardless of their political persuasion, financial circumstances, or geographical location.

Such an undertaking would be a particularly benign and generally useful exploitation of U.S. civilian space technological know-how. It would also exhibit U.S. leadership in space so that all the world could benefit.

It would essentially eliminate an international political problem area, the dimensions and intensity of which otherwise will continue to grow: the congestion of the HF shortwave bands used for worldwide audio broadcasting and the consequent disruption of this broadcasting.

It would make conservative use of the electromagnetic spectrum. It would be designed so it would not cause interference to other services, including any ongoing HF shortwave audio broadcasting. And it could share geostationary orbit locations with other communications and other space-related services and activities, thereby conserving this unusual natural resource.

It would reduce the cost, and increase the operational effectiveness, of audio broadcasting for more than 100 countries throughout the world.

Proceeding to help with the organization and development of a DBS-A system-service would be a truly useful objective response to any international criticism directed toward the United States as it employs higher radiated power, and more frequencies and sites, in the VOA and BIB-RFE/RL HF modernization and expansion programs. This is a response that could also be made by any other country engaged in expanding its shortwave system.

Initially some countries might not wish to avail themselves of a worldwide ensemble of regional DBS-A services. This should not hinder a move by the bulk of the world's countries to see the services come into being, for the following reasons:

1. All countries would retain their ability to conduct shortwave broadcasting.

2. No government would be required to employ the DBS-A service.

3. All general populations need not have receivers that would enable them to receive signals broadcast by the DBS-A system-service.

The fact that the DBS-A system-service would have broad appeal and support and would be used by scores of countries should provide its assets and operations with a great deal of physical, political, and financial security.

Even if agreement cannot be reached initially on a system to serve the entire world, a few, large, regional systems could be established. One might serve all of the countries of North, Central, and South America, for instance.

Encouragement for the creation of a DBS-A system-service would allow the U.S. government to demonstrate, further, its support for the exploitation of the civilian space area "for the betterment of all mankind" (and in a way that could be of personal interest to the present President, i.e., audio broadcasting--an activity with which he continues to be personally and publicly associated). The use of geostationary satellites in a common-user common-carrier, type of system-service also should ease the concern of all countries, perhaps especially developing countries, that they might not have useful access to geostationary "slots."

Political/Cultural

Public Law 95-426 calls upon the USIA to "...enhance understanding on the part of the [U.S.] government ...of the history, culture, attitudes, perceptions, and aspirations of others." A global DBS-A service would allow every government in the world, on an equitable and low-cost basis, to broadcast directly to the United States. Such broadcasts would increase the likelihood that our elected and appointed government officials and other national leaders would become more aware of, and better informed about, the interests of these governments. At a minimum, they would learn what these governments want them to know and appreciate.

The U.S. general public would also have a broadened, inexpensive, and easy opportunity to learn more about the interests and activities of other countries, and to be stimulated and entertained by audio programs originating from all over the world. Other countries, in turn, could profit by learning of the response by the U.S. general public to their programs. In general, opportunities for maintaining the cultural diversity of the world would be enhanced to the enrichment of all of us.

Operational

The reliability, quality, and clarity of signals broadcast by a DBS-A system would be unexceptionable--certainly as fine as local AM and FM over-the-air broadcasting signals--and the service could be designed to reach at least 99.9 percent of the world's population in a flexible and selective manner.

The characteristics of the DBS-A service and its cost would allow the VOA and any other nation's broadcasting entity to reach out to new geographical regions and to national, religious, cultural, and ethnic groups beyond its ability to reach, satisfactorily, by using a surface-based, HF, shortwave audio capability alone.

The VOA, the State Department, and their analogues in more than 100 countries would be relieved of the increasingly onerous burden of dealing with shortwave broadcasting frequency allocation and interference problems.

Beginning perhaps a decade from now, the VOA may no longer have to be concerned with providing technical and administrative personnel, facilities, power sources, etc., and physical protection for a large overseas broadcasting operation--perhaps none of it or only that part of it needed to broadcast at HF and MF to countries that decide not to receive DBS-A service broadcasts.

In the meantime, considering all of the complexities and uncertainties facing the creation of a global DBS-A system-service and the additional years required to gain listener acceptance and to effect a change-over of the world's receiver stock, the VOA and RFE/RL must continue to concentrate on their HF shortwave modernization and expansion programs, the results of which are long and sorely needed.

The Armed Forces Radio and Television Network could be another important U.S. user of a DBS-A service.

Financial

It appears that the VOA could broadcast to audiences via a DBS-A system-service at a cost 10 times less than it costs to broadcast via surfaced-based, HF shortwave--and with greatly increased audience coverage, and sharply increased signal reliability and quality.

The financial burden of providing audio broadcasting also would be similarly lessened for any other country using DBS-A services.

The amortization and O&M costs incurred by the VOA after its modernization and expansion plans are completed could approximate $200 million per year. Beginning a decade from now, for example, that fraction of a worldwide DBS-A service that the VOA would need to lease could be priced at $10 to 20 million per year, and could be phased in as worldwide DBS-A receiver populations grow. The net reduction in cost to the VOA (and perhaps RFE/RL) would depend upon how much surface-based HF shortwave audio broadcasting effort would have to be continued, but it should well exceed $100 million per year.

The VOA budget could then begin to focus upon funds for leased services. In general, it is somewhat less difficult to gain acceptance by the OMB and the Congress for annual leased service charges than it is for long-term capital investment funds.

Economic

If an agreement were reached that made interconnected regional DBS-A services available, wholly new space-related, high-technology, commercial-industrial businesses would be created.

The entire system-service could be financed, acquired, and operated by private interests.

U.S. industry would be in a good position to compete to provide the space-segments of the system (as much as a $500 million global market) and to compete to provide a large portion of the surface segment (an initial receiver replacement market of $10 billion, and $1 billion/year thereafter). This space-related market could begin to develop when the use of wideband, fibre optic, surface cable offers serious competition to the use of space for long-haul trunk communications services.

Once space is seen to be useful for providing excellent audio broadcasting services directly to individually retained spacewave receivers, there could be interest in the provision of national (domestic) audio DBS-A services as well to a market commensurate with the size of the worldwide market.

There is also the prospect that there would be substantial private commercial, as well as government, use of a DBS-A service.

Over the long term the prospect of seeing DBS-video services made available on a global basis could also be encouraged by the acceptance and success of DBS-audio services.

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N.B. While this section views the prospects for DBS-A specifically from the the U.S. perspective, it should be appreciated that worldwide audio broadcasting, by its very nature, is of important interest to the entire world. Therefore, the world's community of audio broadcasters should be encouraged to give careful consideration to the great potential offered by this use of space, a use that promises important political, economic, social, and cultural benefits to all people.

CONCLUSIONS

The world's space and communications engineering, commercial, and industrial communities could provide the natural and human resources required to establish a global, multiregional, common-user, direct-to-surface receiver space audio broadcasting (DBS-A) system-service within the next decade. The service could have unexceptionable coverage, reliability and quality, and could be flexibly and easily used by the world's listening public.

This could be done in such a fashion as to allow the system-service's widespread, equitable use by all of the countries of the world relatively soon and at a cost quite low relative to that of today's shortwave broadcasting.

Such a service would sharply improve worldwide audio broadcasting; most of the political and operational problems inherent in today's shortwave direct broadcasting would be eliminated.

While able to be established in the high HF, VHF, UHF or low SHF portions of the electromagnetic spectrum, location at VHF or UHF appears preferable.

The private sector should be able to provide such system-services using its own resources, given related ongoing and anticipated technological developments, especially those by the U.S. government, and the character and magnitude of the broadcaster and listener markets. The public purse need not be burdened for either its acquisition or ongoing provision.

For the next several years, most of the VOA's planning and engineering attention must be devoted to its surface-based HF and MF modernization and expansion program. But, at the same time and in close concert with other Federal agencies (NSC, Departments of State and Commerce, NTIA, NASA, FEMA, and FCC) it would protect its own, and the country's, longer term interests if it supported the research and associated national and international activity required to develop worldwide DBS-A services at the earliest reasonable moment.

Different assumptions could be made about the quality, reliability and capacity of service, service coverage areas, operational circumstances, technological characteristics of the electronic components, and communications methods required and the cost of space-related technology and its use. Such different assumptions would result in somewhat different conclusions about the kind of space segment and the DC power it would require, the amount and location of radiowave spectrum that would be occupied, and the cost of providing regional and worldwide DBS-A system-services. But the assumptions, estimates, and conclusions presented here appear to be adequate for the purposes of this paper and this Committee's charge.

SUMMARY

For decades governments have made rapidly increasing use of the high frequency (HF) portion of the electromagnetic spectrum and the Earth's ionosphere and surface to conduct public diplomacy by broadcasting speech and music throughout the world. These shortwave broadcasts are made directly to an enormous number of fixed and portable radio receivers used by individuals in nearly every country in the world.[40]

This increasing use in the context of the limited number of frequencies available, and the limitations inherent in using the ionosphere and the Earth's surface for long-distance radiowave transmission of real-time audio programs, has resulted in broadcasters employing such practices as great transmitter power, simultaneous use of several frequencies for broadcasting the same program, and broadcasting on nonallocated, out-of-band frequencies. This has led to considerable overuse, congestion of the spectrum, and serious interference among signals.

This situation has deprived many countries of the opportunity to meet their broadcasting needs at an acceptable financial cost and often results in a seriously reduced quality of reception over large areas. These trends will likely continue indefinitely as countries compete with each other for audience attention. Unfortunately, shortwave transmitters, the Earth's surface, and the ionosphere are dull and fuzzy tools for focusing broadcasting signals to specific distant listening audiences.

Important technological advance has taken place in the civilian space area, however, and further specific advances are reasonably, confidently expected. Therefore, attention now can be given to the use of orbiting satellites to supplement, and eventually to supplant, today's surface-based HF shortwave broadcasting plants and operations. The use of orbiting satellites could begin well within a decade.

Technological, operational, cost, and financing considerations suggest that well before the end of this century space-based audio broadcasting transmitters could replace surface-based audio broadcasting transmitters, just as they have replaced surface-based, HF, long-haul trunk communications plant and operations. Regional system-services, utilizing interconnected, in-space direct broadcast transmitters, could essentially replicate this long-haul trunk communications experience and provide all of the governments of the world with the opportunity to continue their audio broadcasting, directly and easily, to individual spacewave receivers located essentially

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40. The Voice of America (VOA) of the United States Information Agency and the Board for International Broadcasting (BIB), Radio Free Europe/Radio Liberty (RFE/RL), are now engaged in a multibillion-dollar modernization and expansion of their shortwave broadcasting plants and operations.

anywhere in the world. They could do this with enlarged and more focused coverage, with unexceptionable reliability, quality, and clarity, with little if any operating concern, and at a much lower cost than is the case today.

This report has discussed the service requirements for broadcasting audio programs from space directly to surface receivers (DBS-A), and two conceptual space-related systems and the means of providing them. The two conceptual systems could operate in either of two quite different portions of the electromagnetic spectrum: the upper ends of both the ultra-high frequency (UHF) (0.3-3.0 GHz) and the high frequency (HF) (3.0-30.0 MHz) bands. The more important design and operating features of both surface segments (the individual receivers) and the space segments (the satellites, including their surface feeders) and their expected performance have been presented, along with their estimated costs for global, high-capacity, small individual surface coverage area operations.

Such a space-related system-service would provide a received signal reliability and quality easily the equal of today's popular, local, over-the-air AM and FM audio surface broadcasting stations.

The surface segment "spacewave" receivers would be small, employ precise and repeatable electronic (not mechanical) tuning, have quite modest antenna directivity, and be easily transportable and used both outdoors and indoors. In mass production they should cost little if any more than today's local AM (MF) (300 kHz-3 MHz) and FM (VHF) (30 MHz-300 MHz) broadcasting receivers, i.e., a few 10s of dollars at most.[41]

Beyond the basic housekeeping in-orbit space-craft services (power, telemetry, orbit adjustment, etc.) each space segment would consist of an array of subtransmitters, each coupled to one or more large antenna(s) capable of radiating a large number of shaped, earthward-pointing beams. The selection of beams, the allocation of program channels to individual and/or groups of beams, and the setting of radio frequency (RF) power output levels for each beam would be accomplished by means of sophisticated and dynamic electronic switching in the satellite. This switching would be under the control of the space segment's surface feeder station. The switching would respond both to the broadcasters' changing needs for serving individual service areas, the quantity and quality of service for each, and the vagaries of both radiowave propagation and/or natural and commercial-industrial electrical noise in the regions being served by each beam.

Each space segment would be designed to operate as part of a regional system and each segment could be interconnected with the others via optical or millimeter space links. They would be designed so that, in total, they could provide a fine level of service throughout the populated areas of the

41. All dollars in this paper are U.S. 1985.

world. They would have sufficient capacity so that they could be operated in a common user[42] manner, as are, for instance, long lines system-services operated by AT&T, GTE, MCI, SBS, etc., and the space communications system-services operated by Intelsat and Inmarsat.

This new space-related, common user, direct audio broadcasting service would be made available to every country of the world in an equitable fashion.

In each case the space segment design, the character of the technology used, the method of operation, and the large capacity and large presumed use of the service, could see such a service provided at an acceptable, indeed a relatively quite low, cost per channel/surface square mile/year. Full advantage of Space Station infrastructure (physical assets and technicians) to assemble the space segments in orbit and, later, to service them there, thereby containing their acquisition and ongoing costs.

The UHF conceptual system would provide approximately 1,000 full-time audio channels on a global basis, and serve 99.9 percent + of the world's population residing throughout 30 million square miles (80 million square kilometers). The HF conceptual system would have a much lower capacity unless quite advanced technological steps were taken to provide extremely large space segment power.

A government might not wish to make use of such a common user service to broadcast its programs and might not wish to have its population receive the other programs that such a service could provide. If this is the case, it need not send its programs to the system-service for broadcast and its population need not be supplied with the new kind of receiver requested for listening. Other governments that wish to broadcast directly to the people of such countries could do so by employing surface-based HF plants, as they do today by international agreement.

A decade from now, the space segments of one or more regional DBS-A system-services of satisfactory reliability, quality, coverage, and great operating flexibility could be in operation. By the end of this century, a high-capacity, worldwide space segment coverage could be acquired at UHF for a cost of roughly $500 million and a total ongoing cost of roughly $100 million per year. Interconnected regional systems could be designed to operate in either a high HF band or, by inference, a very high frequency (VHF) band or, preferably, a UHF band.

Significant advantages in cost and service area would lie with a UHF design, and perhaps some advantage in service quality as well, particularly if a truly superior service were desired. It would be more difficult and costly to obtain a large system capacity at HF. There are no flux density limitations at HF; this might be somewhat of a problem at UHF. Reception

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42. In the United States, called common carrier.

could be more easily provided at HF in difficult terrain. A case could be made for concluding that the most efficient spectrum use for a DBS-A system-service would be obtained if a frequency band intermediate to the 26 MHz and 2.5 GHz bands (taken as illustrative examples here) were employed. It is not clear at this time which frequency region would be more acceptable, but particular attention should be given to the regions used for VHF FM audio and UHF television broadcasting.

Over time the surface segment of an overall DBS-A system could be installed at a cost of $10 billion for the hundreds of millions of spacewave receivers that would be involved. The world's radio-listening general public (and not just those who now make up the worldwide shortwave broadcasting listening audience) would be prompted to make the relatively modest investment on an individual basis because, relative to today's shortwave broadcasting circumstances, DBS-A signals could then be received in areas not now reached by shortwave signals, and could be received easily (i.e., without periodic and vexing mechanical retuning of receivers) and with unparalleled reliability, clarity, and quality. In addition, expanded and more diverse programming could be offered.

Perhaps the same entity that provides the space segment also could see to the provision of some or all of the surface segments. In this fashion a continuing balance of the cost allocation between them could be effected, much as it is in the long-haul trunk satellite communications and telephone plant areas today, and the availability (and perhaps indigenous manufacturing) of truly low cost receiver models thereby assured, particularly in lesser developed countries.

If the cost of acquiring, maintaining, and operating the space segments were to be borne by the broadcasting governments alone, the cost could be apportioned to each to reflect that fraction of the service's capability (i.e., the product of its capacity, quality, coverage area, and time) that the government would use. For instance, some countries (i.e., the United States, the Soviet Union, the United Kingdom, the Federal Republic of Germany, the Netherlands) might wish to avail themselves of up to 10 percent of the total available (at a cost to each of approximately $10 million per year); others might wish to purchase as little as a few tenths of a percent (at a cost to each of a few tens of thousands of dollars per year).

The governments using the service should be able to do so for a fraction of the financial cost they now incur on an individual nation basis, and they would have access to a service of much greater and selective coverage and much higher quality and reliability. (If it becomes available within a decade, the VOA alone could expect to save $100 million per year.)

Essentially all present frequency allocation and operating problems would be solved, and almost all governments could avoid most of the electromagnetic and political fallout associated with the conduct of electronic warfare, i.e., jamming, by a few countries.

As an alternative, the space segments' cost could be shared with or borne by the surface segment. Given the large potential market, the addition of only $1 to 2 to the retail price of each receiver (i.e., a few percent of the expected average price) that would be used to pay for the acquisition of the space segments, would meet or nearly meet its cost.

The clear and important advantages of having such a worldwide common-user audio broadcasting service available should appeal to almost all countries of the world, developed and lesser developed alike.

Such DBS-A services also could be used to meet national, i.e., domestic, broadcasting needs in many places throughout the world with cost and operating advantages over not only surface-based HF, but surface-based VHF as well. The availability of such services could be particularly important to many of the lesser developed countries and in low population density areas generally. With the cost of the basic worldwide system-service met by payments from governments for its use in nondomestic broadcasting, the marginal cost of providing domestic services as well, especially during the "working" hours of the day, should be quite low. And any net revenues generated by use of the system for domestic broadcasting could be used to lower the cost of the worldwide broadcasting service even further.

Finally, the availability of a new DBS-A service such as that outlined here, one that provides the same service characteristics as today's local AM and FM audio broadcasting but on a wide-area, low-cost basis, could prompt private interests to reach listening audiences in this new way, thereby providing additional private revenues to the system-service.

Listening to local AM and FM is extremely popular; there are now 1.4 billion radios throughout the world. It remains very popular in the United States in spite of the great number and diversity of other media and activities that compete for listener's attention. Over 99 percent of the U.S. population has at least one radio; the average is 5.5 per household. A billion radios were sold in the U.S. over the last 37 years (over 50 million in 1983 alone), and the country supports 9,000 audio broadcasting stations. There is reason to expect that this medium would be further vitalized, both nationally and globally, and in both the public and private sectors, by the availability of a high-quality, high-capacity, space-related audio broadcasting system-service.

The imaginative and sensible use of space technology should brook large in the future of worldwide audio broadcasting direct to the world's general public. The outlines of solutions to technological, operational, political, and financial problems that have long precluded its use are now clearly in sight. This is one societal area in which there are important needs clearly seeking, and now amenable to, space-related technological solutions. These solutions are in sharp contrast to some others where, unfortunately, space engineers have tended to evolve "solutions" that failed when tested in the real world.

POSTSCRIPT

By using "...direct broadcast satellites...perfect reception will be possible all over the world, and the horrid cracklings of the shortwaves will be a thing of the past."

Arthur C. Clark
"New Telecommunications for the
Developing World"
Interdisciplinary Science Reviews
June 1982

PROFESSIONAL BIOGRAPHY

Thomas F. Rogers is a physicist, an electronics-communications engineer, a private investor, and the president of his family's private operating foundation: The Sophron Foundation. He holds B.Sc. and M.A. degrees in Physics, has held professional positions with university, industrial, government, and not-for-profit organizations, and has held senior federal administrative positions. He did basic, applied research and development work at the Radio Research Laboratory of Harvard University, the Bell and Howell Co., and the Air Force Cambridge Research Center. While at the Air Force Center, he organized a Laboratory on Radiowave Propagation, and later, one on Communications, and he worked on our first intercontinental ballistic missile, the Atlas. At the Massachusetts Institute of Technology's Lincoln Laboratory he organized its Communications Division and was a member of the Laboratory's steering committee, and he headed the group that was the first to accomplish transmission of television signals via an orbiting spacecraft. Later, as a Deputy Director of Defense Research and Engineering in the Office of the Secretary of Defense, he was responsible for advances in the command and control of our strategic nuclear forces, for the general design, development, and deployment of the first global satellite communications system, and for the beginning of work on satellite navigation-position fixing and very high energy lasers.

He was the first Director of Research in the Office of the Secretary of the Department of Housing and Urban Development where he inaugurated federal urban research and development, and helped found the Urban Institute. Later, he was a Vice President of the Mitre Corporation. He was a member of a group of the President's Science Advisory Committee and a member of the Federal Council on Science and Technology. For the past dozen years he has been an advisor to several federal executive and legislative branch offices, several major foundations, both the National Academy of Sciences and the National Research Council, and the Institute of Medicine. He was a member of the National Academy of Sciences/Institute of Medicine/Robert Wood Johnson Foundation group that inaugurated emergency medical system services in over forty locations throughout the country. He has been a member-at-large on nearly all of those professional groups that advise the National Aeronautics and Space Administration on space applications, and is now a member of both the Space Applications Board and the Voice of America Study Committee of the National Research Council. He played a leading role in prompting the recent federal decision to explore the use of satellites for international direct audio broadcasting.

Most recently, he directed a study of civilian space stations and the U.S. future in space for the United States Congress as a consultant to its Office of Technology Assessment. His family's Foundation has established programs in Northern Virginia for housing the elderly in crises, and a children's dental program, and is exploring some novel civilian space activities. He has published over fifty professional papers and book chapters, has lectured widely, and has testified, oftentimes, before the U.S. Congress. He is a Fellow of the Institute of Electrical and

Electronics Engineers and a member of the Cosmos Club. His professional biography appears in American Men and Women of Science and Who's Who in America.