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STATUS OF HIGH POWER TECHNOLOGY FOR EDUCATIONAL SATELLITES

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INTRODUCTION

The increasing desire to answer the educational needs of all segments of the population will necessitate a broader based communications system to allow the fullest distribution of our educational resources. This new communications system will require additional terminals, more interconnections, and more frequencies than are presently in use.

If a cost trade-off analysis is made of space communication systems involving many earth terminals the optimum point tends toward the use of higher transmission power. More frequencies means the need for better frequency utilization and the extension of technology to still higher frequencies. To extend the useful life of such high power systems requires the development of new spacecraft technologies and new technologies on the ground.

New space communication technologies have been demonstrated by NASA before using Syncom, and the ATS series of satellites. In the future the technology necessary for the new communications will be demonstrated by ATS-F and G, and future Applications Technology Satellites.

The future operational high power satellites will be of a different form than the present spin stabilized communication satellites. They will be actively stabilized and have an earth pointing body containing the high power transmitter, its supporting subsystems and the earth pointing antennas. Deployed from this body and "rotating" once a day to face the sun will be the high power solar array "wings" (figure 1).

LOW COST RECEIVERS

The first concern of anyone wishing to initiate widespread or broad-cast systems for education is to estimate the characteristics and costs of the receiver systems, as this in turn may determine to a large extent the feasibility of the system. NASA Lewis Research Center is at present supporting studies to determine these factors and to fabricate several receivers. The studies consider a low cost receiver system as shown in figure 2. The incoming rf signal is mixed down to an IF frequency, amplified, and demodulated to a baseband television signal. This signal in turn is mixed up to the frequency of a television VHF channel and sent to the television set. Systems having low noise pre-amplification using tunnel diodes are also being considered in the studies. One design developed at Stanford University has all the electronics packaged in the feed of the antenna. This particular receiver was developed for FM television reception at 2.62 GHz.

Another approach studied for NASA by General Electric divides the receiver into antenna and indoor units, as shown by the dashed lines in figure 2. In this study units are being designed and fabricated for 2.25 and 12.0 GHz FM and 2.25 GHz AM television reception.

In addition to these two studies, studies of receivers at 800 MHz have taken place at other NASA centers and in private industry. Using all these studies as a basis, the manufacturing costs given in Table I have been estimated. Also shown in the table are the typical ranges of estimated satellite EIRP per channel. These EIRP levels are dependent upon receiver antenna size and picture quality. It should be emphasized that these are manufacturing costs. The cost to the consumer will be two to four times higher than shown:

Table I

Estimated Receiver Manufacturing Costs and Transmitter Power Requirements

	Cost/ Receiver for Quantity Manufactured		Estimated EIRP, dBW
	10^3/Year	10^5/Year	
700 MHz-FM, Mixer	$40	$25	55-60
2.5 GHz-FM, Mixer	$45	$25	54-60
12.0 GHz-FM, Mixer	$85	$40	62-68
Added TDA Preamp	$75	$40	1/2 - 1/3 of above
Receiving Antenna	$10\text{-}15D^2$	$7\text{-}10D^2$, where D (diameter) is in meters	

In the basic receiver costs shown about 1/5 is for labor and about 4/5 is for parts. One item, the local oscillator diode, accounts for about 1/6 of the basic receiver cost.

The costs can only be considered as approximate, as solid state component costs are very sensitive to the demands of the total market, for example: the 1972 manufacturing costs which were estimated in the fall of 1969 were met in the fall of 1970, due to the lowered costs of solid state components.

By 1975 the receiver costs for volumes of 10^5 are expected to be 1/2 to 3/4 of the costs in Table I, depending upon the starting date of production.

NARROW AND SHAPED TRANSMISSION BEAMS

The EIRP levels given in Table I will be obtained using a combination of high power transmitters and spot or shaped beams.

The demands for more satellite communications channels and more power may place unbearable burdens upon the solar power requirements and the requirements for orbit sharing unless more directive antennas are used to beam the radio frequency power to the areas of interest.

At low frequencies the antenna type contemplated is best exemplified by the 9 meter parabola of ATS-F and G (figure 3). This antenna will be used in an experimental transmission of FM television programming for educational program distribution and community reception in India. At the frequency of operation of the India experiment (850 MHz) the beam at the half power contour covers most of the country. At 2.5 GHz used for experimentation in this country the beam will cover a multistate area. Because of the very large size of this antenna it must be folded to fit the launch shroud. In this case it is done by wrapping the mesh supporting ribs around the center hub.

At transmission frequencies above 6 GHz it is possible to have multiple narrow beam antennas without folding the package for launch. This allows the transmission of many widely dispersed narrow beams from the same spacecraft.

With a simple narrow beam circular parabolic antenna only 40 to 60 percent of the power radiated may reach the area where it is needed. This is due to irregular shapes of areas (figure 4a) and the power contained in the antenna beam beyond the 1/2 power contour, which is the normal method for defining beam size (figure 4b). It would appear logical to use array antennas which can theoretically control the pattern with exactitude. Unfortunately at the present time array antennas of any complexity are comparatively heavy and lossy, especially at the higher frequencies.

An array such as the mechanically steerable S-band planar array used on Surveyor, had an aperture 38 inches square and a beamwidth of 7-1/2 degrees and was designed for maximum aperture efficiency. Unfortunately maximum aperture efficiency also means high side lobes and the possibility of interference with other systems.

At frequencies below 2 GHz the use of a deployable array of solid state transmitters supported by a foldable truss structure looks promising. For higher frequencies, at this time, a considerable sacrifice in power and weight must be made to obtain the operational flexibility that goes with an electronically steerable array concept.

Another beam shaping technique is to use auxiliary low power radiators on the back of the feed and on the parabola edge to cancel out lobes adjacent to the main beam caused by aperture blockage and edge diffraction. This technique has been demonstrated and has lowered the adjacent side lobe levels some 40 dB below the level of the main beam center.

A very promising beam shaping approach is to use an aperture feed which is a matrix of horns whose phase and amplitudes can be adjusted to obtain a more desirable pattern. This type of feed is relatively large and can significantly block a parabolic antenna aperture. To avoid blocking the aperture the feed may be used with a lens or an offset fed parabola is used. An example of using a lens is the LES-7 antenna which would consist of a 19 horn cluster feeding a waveguide lens of 75 cm diameter. The antenna pattern size can be varied from 3 degrees to hemisphere coverage by using a combiner switch. The offset fed parabola approach, similar to the antenna used on the ANIK satellite, is now under study by NASA as part of the AAFE program for possible use in future applications satellites. The advantages of the use of such a matrix of small beams are two fold. When covering an irregular area such as the Eastern Time Zone or Alaska up to 5 dB in power savings can be obtained using such approaches instead of a simple circular beam (figure 5). In addition one spot beam in the matrix can be raised to a higher power level to overcome momentary outage in a region due to rain, to relay the program to some intermediate ground station at a higher signal to noise ratio, or to receive signals from small uplink terminals. Unfortunately at this time both the lens and the offset fed parabola exhibit slightly higher side lobes than can be obtained using a simple single center fed parabola. There will of course also be added losses due to switching, splitting, and phasing of the various feeds.

What is apparent is that to obtain flexibility in communications some sacrifice will have to be made in the efficiency of power delivery. True system efficiency is a combination of both.

HIGH EFFICIENCY TRANSMITTERS

Today present space qualified devices for transmitters are limited to power levels below 100 watts and efficiencies below 30 percent. Not only must future operating power be considerably higher but the older low efficiency levels will be unacceptable for high power space use as these low efficiencies would make many proposed space system difficult to justify technically or economically.

In most of the tube types considered for high power space applications, cross field amplifiers (CFA), traveling wave tubes (TWT), and klystrons, only a part (30 to 50 percent) of the energy in the electron beam is converted to radio frequency energy. The rest of the energy is converted into heat when the high velocity electrons strike the collector end of the tube. When the electrons are accelerated from the cathode they are almost of one velocity, but at the exit, or collector end, they are of many velocities due to the interaction between the radio frequency power and the electron beam. If the various velocity classes of electrons present in the spent beam are sorted out and each class slowed down and caught at zero velocity, this beam energy is not lost to the system as heat but would become potential electrical energy. The efficiency of the tube is greatly increased as this spent beam power is used to energize the beam as it leaves the cathode. NASA is developing the "multistage depressed collector" which does just this (Figure 6). Experimental measurements taken with the collector shown in figure 7, which was developed at the NASA Lewis Research Center, indicate that this type of collector will result in 60 to 80 percent of the spent beam power being collected as useful electrical energy. This high collector efficiency will result in tubes with overall efficiencies in excess of 70 percent at kilowatts of output power. This collection method not only means a higher maximum efficiency but a greater flexibility in operation.

A high efficiency amplifier tube using the multistage depressed collector concept will be the heart of the 12 GHz transmitter experiment on the joint Canadian-United States Communication Technology Satellite to be launched in 1974. This tube will have the capability for 200 watts of rf power at saturation at an efficiency greater than 50 percent.

Following upon the development of this transmitter demonstration and with the presently projected development, it is estimated that a very high efficiency tube of a power level of 1 kilowatt or greater at a frequency of 12 GHz can be demonstrated in space by 1977. In future years, as work on better cathodes bears fruit, the collector concept will be applied to higher powers and high frequencies. Then 100 watts at 40 GHz and 50 percent efficiency may be attained.

HIGH POWER SOLAR ARRAYS

The large quantities of electrical power necessary to operate the high power transmitters will be supplied by solar cells until such time in the distant future when nuclear power supplies become competitive in cost, weight, reliability and safety. There has been a considerable amount of study devoted to the problem of reducing the weight of large solar arrays. The solar arrays developed under NASA and Air Force support consist of standard solar cells mounted on a thin flexible sheet which is supported by extendable booms. Prior to deployment the array is folded or rolled up on a drum. The FUSRA 2.5 kw array of this type developed for the Air Force will be demonstrated in space in 1972. A more advanced form will be used to power the CTS satellite in 1974.

INFORMATION STORAGE AND RETRIEVAL

The techniques of information storage and retrieval have in the past year or so at NASA come to be referred to as "information networking", a catch-all phrase which includes the system optimization and the tecniques of getting information from one place to another, or, simply, communication.

One area of concern to NASA and the Department of Health, Education and Welfare (HEW) is to make available to doctors everywhere in the United States the medical information at the medical libraries and the information in particular fields which is now available only to physicians in the larger teaching hospitals in metropolitan areas.

In the field of education similar needs have also been investigated. Some segments of the educational community have proposed a number of schemes which use modern communication techniques including the extensive use of television programming and computer aided instruction. To use either of these techniques to their fullest capacity requires extensive storage and retrieval systems.

Methods have been developed for high speed contact duplication of video tapes which can produce five simultaneous copies resulting in about 30 copies per hour from one machine. This is done by contact duplication from a master in the presence of a magnetic field. Methods have been developed for recording color programming on thin film by electro-optical methods. The system uses a high resolution film with side-by-side frames. The master is produced using electron beam recording. The copies are produced by high speed optical contact printing. It has been estimated that a half-hour color program, on a cartridge the size of an 8 mm movie film reel, will cost less than ten dollars. Systems such as these can make the local television program library an economic reality.

In rural areas or in remote regions where extensive equipment is unavailable the teacher could use scheduled programs broadcast to her via satellite or use demand access communication systems. The scheduled programs would also be received and recorded in the metropolitan areas having library systems. A satellite would thus act as a broadcaster and as a distributor.

FREQUENCIES AND SHARING

The political-technological decisions reached at the World Administrative Radio Conference in June and July of this year have done much to bring the thinking of satellite broadcast to some extent down to earth. Although the full potent of these decisions is not yet determined we do know that satellite broadcasting or high power satellite transmission will have to operate under severe flux density limitations at 620-790 MHz and at 2500 to 2690 MHz and share with terrestrial communications systems at these frequencies. Also at 2500-2690 MHz and 11.7 to 12.2 GHz the high power systems must share the orbit frequency bands wholly or in part with much lower powered Fixed Service satellites.

At 620-790 MHz FM television from space to community receivers in most tropical areas will not interfere with AM-VSB television broadcasting in Europe, Japan or the United States if directive transmission antennas are used and the side lobes are kept at a low level. High power terrestrial television broadcasting can interfere with space broadcast reception as much as 500 km from the terrestrial station unless precautions are taken to shield the community receiver. Discussion concerning the use of this frequency band may be considered somewhat academic as it has been made fairly clear that these frequencies will not be used in the United States for the purpose of broadcasting from space.

At 2500-2690 MHz, FM television from space for community reception in tropical areas will not interfere with troposcatter systems in Europe and North America unless the scatter system points almost directly at the satellite and no attempt is made to lower the satellite antenna side lobes. FM television from space for educational purposes will not interfere with the ITFS systems used in the United States, on the contrary the ITFS system will interfere with the satellite reception out to the terrestrial system horizon unless shielding precautions are taken. Using demonstrated techniques for near side lobe reduction the field strength beyond the main lobe can be reduced such that the levels will be within the flux density limits.

At 12 GHz, space FM television transmission for community reception will not interfere with single hop television systems commonly used at these frequencies except if both systems are operating at greater than about 60 degrees latitude. The terrestrial systems will not interfere with the space broadcast reception unless the space receiver is in line with and pointed right at the terrestrial transmitter and is less than about 10 miles away.

The necessary spacing between adjacent satellites operating at the same frequency, transmitting at the same power level and beaming to the same area is given in figure 8. The spacing depends upon antenna size, desired reception quality, and FM modulation index. As the frequency increases the receiving antenna directivity increases, allowing for closer satellite spacing. If satellites are deployed within the orbit segment which encompasses the North American continent, the beam width of antennas at 2500 MHz will be so wide for antennas less than 3 meters, that for fully operational systems transmitting to all areas of the continent only one half of the allocated frequencies may be used in each time zone coverage area. At 12 GHz the antenna beam width will be sufficiently small, even for moderately sized apertures, so all frequencies can be used in each coverage area.

Operating space communications systems of disparate power levels and receiver characteristics at the same frequencies and beaming to the same or adjacent coverage areas creates further difficulties. It has been shown that at 2500 MHz there can be no sharing, under these terms, between the Broadcasting Service satellites and the thin route Fixed Service satellites. However they may share the orbit segment if their coverage areas are sufficiently separated. The sharing of the band 11.7 - 12.2 GHz by Fixed and Broadcasting Service satellites can result in lower frequency-orbit utilization than if the two services had separate frequency allocations. The amount of sharing possible depends upon the allowable orbit segment size and the method and sequence of satellite deployment.

CONCLUSION

If the present direction of technology continues it will allow for a trend toward communication system implementation which is different in form from that which has traditionally happened. Present systems for the dissemination of information for education begin in the major cities and political capitals. The first recipients are a few people favored economically or politically. The system then expands outward and inward to the less advantaged.

Through the use of satellites the system growth trend can be different. As the educational systems are brought into operation, community reception can commence in wide spread rural and remote areas. Through the use of information storage and retrieval, education can be available 24 hours, 7 days a week. Thus the nation can be served by a system which was established equably among all segments of the population.

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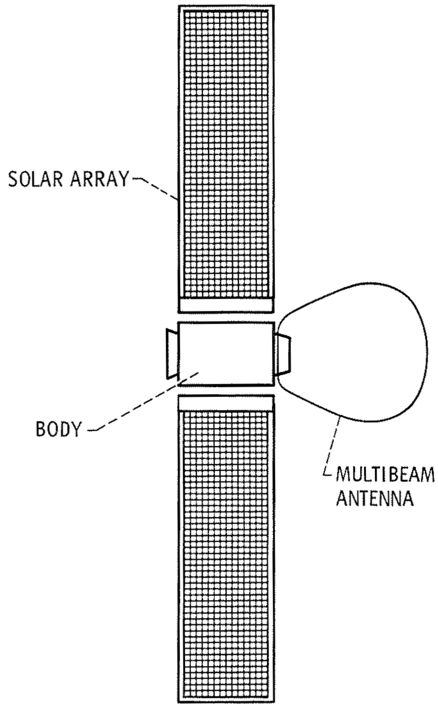

Figure 1. - Future high power satellite.

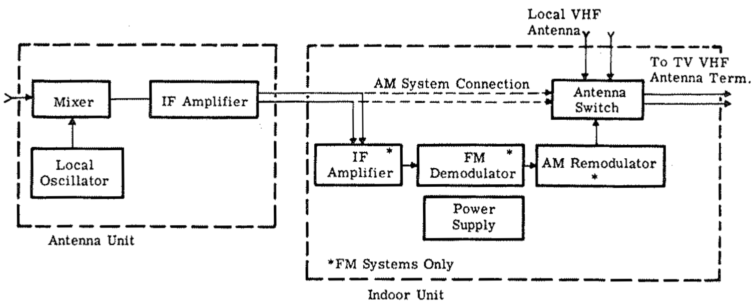

Figure 2. - Generic block diagram of converter systems.

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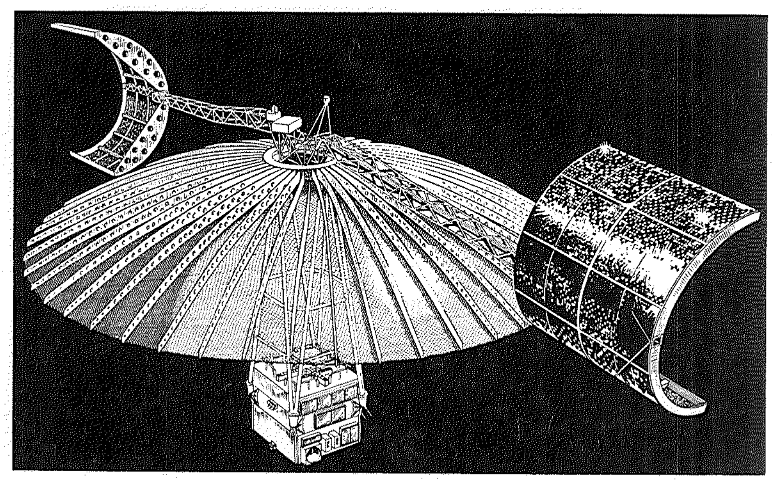

Figure 3. - Application Technology Satellite and 9 meter antenna.

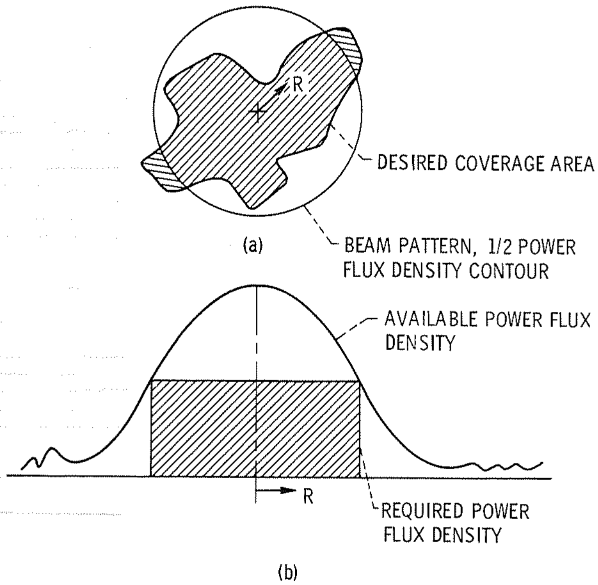

Figure 4. - Comparison of desired power flux density contours and actual power flux density contours.

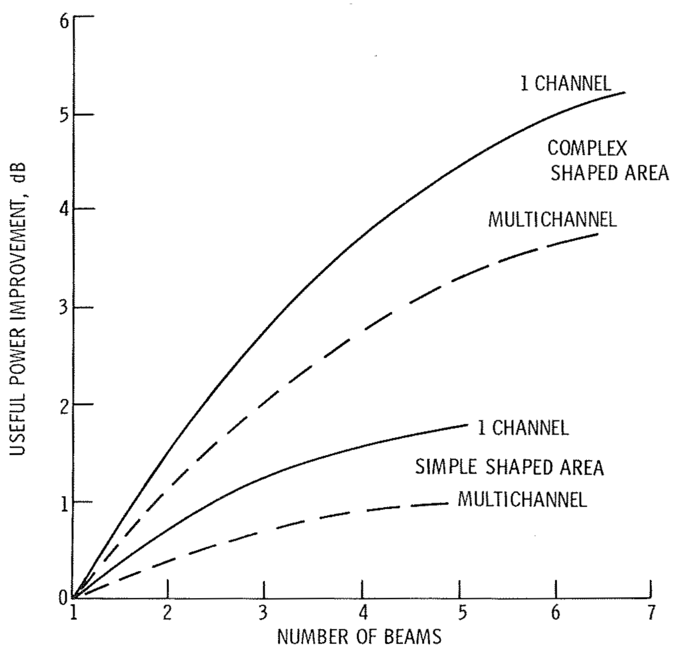

Figure 5. - Useful power improvement as a function of the number of equal sized beams in a matrix. Complex areas used: Alaska, Eastern time zone and Mexico.

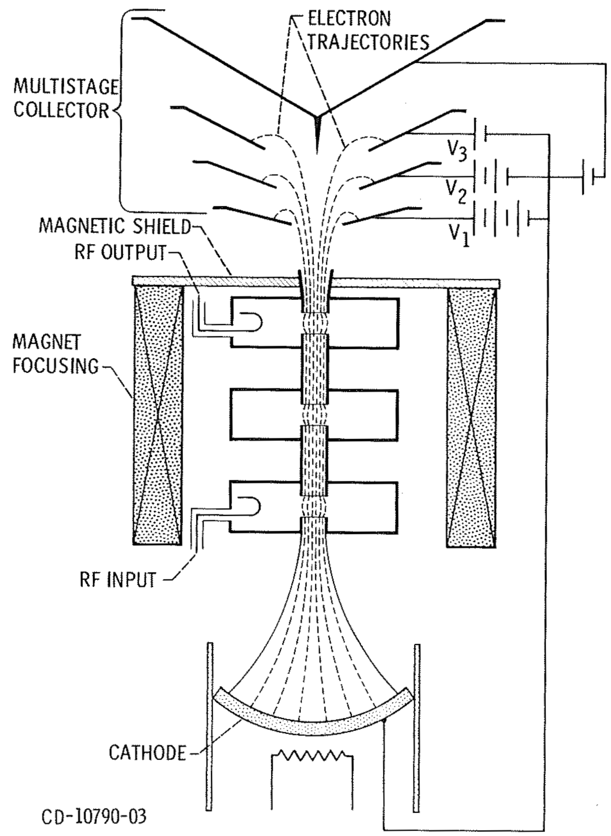

Figure 6. - Schematic of linear beam tube with multistage collector.

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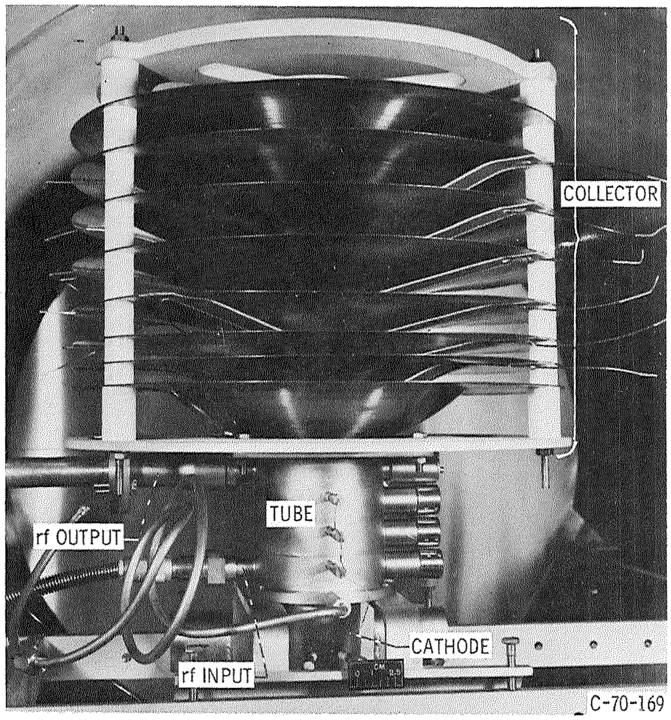

Figure 7. - Depressed collector tube with experimental multistage.

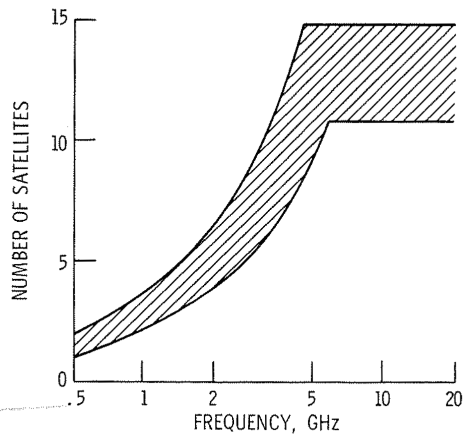

Figure 8. - Number of Broadcast Service Satellites using the same frequency which can be deployed in a 100 degree longitudinal segment.