NASA TECHNICAL MEMORANDUM

NASA TM X-52911

NASA TM X-52911

DIRECTIONS AND IMPLICATIONS OF COMMUNICATION TECHNOLOGY

by Perry W. Kuhns
Lewis Research Center
Cleveland, Ohio

TECHNICAL PAPER proposed for presentation at
Symposium on the New Communications Technology
and its Social Implications sponsored by the
International Broadcast Institute
Ditchley Park, Oxfordshire, England, November 2-7, 1970

E-6008

DIRECTIONS AND IMPLICATIONS OF COMMUNICATION TECHNOLOGY

Perry W. Kuhns

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio

Abstract

Aspects of the development of communication technology are discussed and related to National Aeronautics and Space Administration (NASA) technology development programs. The specific technology areas discussed include: low cost receivers for space broadcasting, high efficiency microwave tubes, solid state transmitters, shaped antenna beams, laser communications, information storage and retrieval, and orbit and frequency sharing.

Introduction

The development of new technology gains support and direction from a desire or need. The direction seems to be to supply more information to more people. This direction is engendered and sustained in many ways, from a crucial need to educate and lessen the burdens of life of millions of people in underdeveloped and developing nations down to the craving of a minor official to obtain a multitude of copies of everything spewn forth by the ubiquitous Xerox machine. Whether for good or bad this is the main driving force behind communications technology.

In space and terrestrial communication systems the need and desire to supply more information to more people requires more terminals, more interconnections, more frequencies, and greater system reliability. Economic trade-offs involving more terminals point toward small low cost terminals and resultant high transmission power. More frequencies means an urgent necessity for better frequency utilization and the extension of technology to higher frequencies. Greater system reliability and flexibility means greater automation and higher powers.

For satellite communications the direction is away from the earlier noise limited systems of inherent low utilization and toward interference limited systems, more similar in characteristics to terrestrial systems. The trend is toward larger satellites with higher channel capacity (figure 1). The future higher power satellites may be of a different form using solar cells mounted on flexible substrates which roll or fold up for packaging during launch. To extend the useful life and increase the reliability of such expensive satellites many new spacecraft technologies will have to be applied.

In considering the following examples of space or terrestrial communication technology we should always consider their impact upon all communication systems, for as the terrestrial and space systems become more similar, the technology developed by one becomes more applicable to the other.

Low Cost Receivers

Usually the first concern of administrations wishing to initiate widespread or broadcast 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 is at present supporting development studies to determine these two factors and to fabricate several receivers. The development 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 if necessary, demodulated to an AM-VSB signal. This signal in turn is mixed up to the frequency of a television UHF channel and sent to the television set. Systems having low noise pre-amplification using tunnel diodes will be considered in the studies at a later date. One design developed at Stanford University and which is shown in figure 3 has all the electronics packaged in the feed of the antenna. This particular receiver was developed for FM television reception at 2620 MHz.

Another approach developed 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, development of receivers at 800 MHz is taking place at 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 transmission power per channel. These power levels are dependent upon coverage area, receiver antenna size and picture quality.

Table I

Estimated Receiver Manufacturing Costs and Transmitter Power Requirements

	Cost/Receiver for Quantity Manufactured 10^3/Year	10^5/Year	Estimated Transmitter Power Range, Watts
800 MHz-FM, Mixer	\$40	\$25	100-400
2.5 GHz-FM, Mixer	\$45	\$25	100-400
12.0 GHz-FM, Mixer	\$85	\$40	500-2200
Added TDA Preamp	\$75	\$40	1/2 - 1/3 of above
Receiving Antenna	\$20 D^2	\$10 D^2, where D (diameter) is in meters	

In the basic receiver cost 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 can now be met in the fall of 1970, due to the lowered costs of solid state devices.

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.

High Efficiency Transmitters

The power levels given in Table I give an indication of the power requirements of future transmitters. Today present space qualified devices for transmitters are limited to power levels below 100 watts and efficiencies below 30 percent. The advanced space tube may have to operate in the kilowatt range for multichannel operation. Not only must the 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 systems 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 supporting the development of the "multistage depressed collector" which does just this (Figure 4). Experimental measurements taken with the collector shown in figure 5, which was developed at the NASA Lewis Research Center, indicate that from 50 to 70 percent of the spent beam power can be collected as useful electrical energy. This can result in tubes with efficiencies in excess of 70 percent. This collection method not only means a higher maximum efficiency but a greater flexibility in operation. Shown in figure 6 is the efficiency of a typical linear beam tube with and without multistage collection. As can be seen, the dependence of the efficiency upon output power is much less with multistage collection. This wide operating range will allow efficient multichannel operation.

With the present projected development schedule, it is felt that a very high efficiency tube of a power level of 1 kilowatt at frequencies up to 12 GHz can be demonstrated in space by 1976. In future years, as work on better cathodes bears fruit, the collector concept will be applied to higher powers and high frequencies: 100 watts at 40 GHz and 50 percent efficiency may be attained.

This technology development should also have great impact upon the economics of terrestrial VSB television operation since these systems are operated with an average efficiency of only 10 to 15 percent. Use of such a collector with a klystron at UHF frequencies would probably cut the transmitter electrical power consumption by more than 50 percent.

Solid State Transmitters

Today there are experiemental solid state modules in the 800 MHz range with power output of 50 watts and efficiencies of 40 percent. Indications of the power levels and efficiencies to be expected in the near future as a function of frequency are shown in figures 7a and 7b. The very sharp drop-off in power and efficiencies at the higher frequencies should be noted. Unless there is a conceptual and/or materials breakthrough the prospect of using solid state devices of high power and efficiency at frequencies about 10 GHz is rather dim.

Although the efficiency is low these modules do have many advantages. They can be joined together in a matrix or array form to obtain optimum phase and amplitude patterns. Use of a modular construction increases reliability and also provides dispersion of the source of heat. In addition the low voltage requirements of these devices when compared with the kilovolt sources for tubes makes them attractive.

An example of the use of solid state transmitters is the communication package in ATS F and G. The transmitters at 850, 1550 and 1800 MHz will be solid state. A schematic diagram of the proposed transmitter at 850 MHz is shown in figure 8.

Narrow and Shaped Transmission Beams

The ever increasing demands for more satellite communications channels will place an unbearable burden 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. The same is true of higher power satellites used for broadcasting, with an additional impetus coming from the need for frequency sharing with terrestrial systems.

The type of antennas contemplated for use in the immediate future are primarily circular parabolic reflectors. At low frequencies this type is best exemplified by the 9 meter parabola of ATS-F and G (figure 9). This antenna will be used in an experimental transmission of FM television programming for 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. In addition to the India experiment the antenna will be used to transmit frequencies as high as 7.3 GHz where the beam pattern would cover an area as small as Ireland. 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 type of system, shown in figure 10 and 12 GHz antennas, allows the transmission of many widely dispersed narrow beams from the same spacecraft. The beam pattern from the 60 cm antennas will be about the same size as the beam pattern at 850 MHz from the 9 meter parabola.

With these narrow beam circular parabolic antennas only 40 to 60 percent of the power radiated reaches the areas where it is needed This is due to irregular shapes of areas (figure 11a) and the power contained in the antenna beam beyond the 1/2 power contour, which is the normal method for defining beam size (figure 11b). It appears that after all the effort to convserve power on the spacecraft we have wasted it on the ground. 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, expecially at the higher frequencies.

Typical of the arrays now being used is the mechanically steerable S-band planer array used on Surveyor. This antenna 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.

Some steps are being made to make the transmission from space more efficient and less objectionable to terrestrial services. Parabolas will be developed for space which are eliptical in shape so that the resultant pattern better fits areas whose view from the satellite is distorted by location at high latitudes, such as Alaska.

Another technique is to use auxiliary low power radiators on the back of the feed and on the parabola edge to "clean up" the pattern and lower the side lobes adjacent to the main beam which might cause interference to terrestrial or other space services (figure 12). 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 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 (figure 13a), or a cornucopia horn (figure 13b). An example of using a lens to avoid blockage is the LES-7 antenna which consists 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.

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

Laser Communications

Two properties of the laser beam, spatial coherence and potential wide bandwidth, make a laser system particularly useful for long distance future communications. The intrinsic high gain and small size of laser antennas provide for communication systems that are light in weight and low in power, thus attractive for space communications. However because of the lack of efficient external modulators and the poor time response of light sources that are directly modulated, the potential of large bandwidth has not been fully realized at this time. Typical of the present start of art is the Gallium Arsinide laser with a bandwidth of less than 50 MHz and a power output of 1 watt at 40 percent efficiency, at liquid Nitrogen temperatures. The application of lasers to communications systems has also been hampered because of low efficiency and poor sensitivity of the presently available detectors.

Degradation of the signal on passage through the atmosphere places another limitation upon the use of laser communications. The atmospheric effects include, attenuation, scintallation and scattering. To overcome this limitation closed systems using fiber optics or dry gas filled optical pipes can be used in terrestrial communication systems. Where an atmospheric transmission path is not present, such as in applications to deep space probes and satellite-to-satellite communications, the laser systems are very attractive.

A CO_2 gas laser communication system experiment will be used on ATS-F to: establish the technology required for wide band clear weather data channels between the satellite and earth, provide direct comparison between laser and millimeter wave communication systems, and measure the effects of the atmosphere on propagation. This experiment will be similar to a CO_2 optical hetrodyne communication system that has operated terrestrially over a 30 km path. Television signals (FM with 3 MHz deviation) have been transmitted with this system using internal electro-optical modulation. On a clear day the demodulated signal-to-noise ratio has averaged 50 dB.

A drawing of a more advanced proposed experimental package proposed by Hughes Aircraft is shown in figure 14. The package employs a CO_2 laser of 2 watts output power. The terminal telescopes are 5 inches in diameter. The modulation, with approximately 30 MHz bandwidth, is achieved through the use of an external cadmium-telluride modulator. Many future laser experiments will use solid state (GaAs, Nd - YAG) lasers for greater efficiency and bandwidth.

The limits placed upon the data rate by narrow bandwidth can be circumvented by using multiplexing techniques and pulse code modulation. Since the optical pulses are generally very narrow relative to their period, a number of independent channels can be interleaved in time. Presently this is done using a device which varies the polarization of a series of pulses. The next step is to use frequency division multiplexing in which laser beams of different carrier frequencies are combined into a single beam. Finally a multimode waveguide can be used to obtain spatial multiplexing. The combination of all three multiplexing techniques in a closed system with developed lasers could theoretically result in an optical communication system with a capacity of 10^{14} bits/sec, or about one million television channels.

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 techniques of getting information from one place to another, or, simply, communicating.

One area of immediate 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, such as tropical diseases, which is now available only physicians in the larger teaching hospitals in metropolitan areas.

Ideally the satellite would operate as the complete switchboard and transmitter. The satellite however would not have sufficient storage capacity to do the whole job efficiently. Instead, the information request would be sent to a computer on the ground (at the medical library) where the proper address would be determined. The information requested would then be forwarded through the satellite to the requesting party (figure 15). In addition the satellite would act as a transmitter to hospitals and medical groups to provide medical instruction television programs. In metropolitan areas the medical groups and hospitals would also be tied in by closed circuit television, as many are already today.

In the field of education similar techniques have also been investigated. Some segments of the educational community have proposed a number of schemes which use modern communication techniques, contain a considerable amount of electronics, use considerable bandwidth, and minimize the humanizing role of the teacher.

The enlightened teacher in the lower schools in the United States while recognizing the primacy of personal contact is aware that good television can be a highly useful tool. She desires a television set in the classroom which she can turn on, at a convenient time, and receive a program she has chosen the day before from a large up-to-date library. In metropolitan areas this form of storage and retrieval is ideal for CCTV systems connected to alocal program library. Today there have been developed methods of reproducing large quantities of quality color television programs.

A technique has been developed by Ampex 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.

A technique has been developed by CBS Laboratories of recording color programming on thin film by electro-optical methods. The system uses a high resolution 9 mm film (developed by Ilford Ltd) with side-by-side frames; one for luminance, one for chrominance. 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 program library an economic reality.

In rural areas or in regions where this equipment is unavailable the teacher would use scheduled programs broadcast to her via satellite. These same programs would also be received and recorded in the metropolitan areas having the library system. The satellite would thus act as a broadcaster and as a distributor.

NASA is also investigating the use of Data Relay Satellites (DRS) which will relay information from spacecraft below the horizon to the proper receiving point. By this means satellites in low altitude or polar orbits, such as weather and earth resources satellites, will be able to relay data via the DRS to the ground terminals at a rate which is consistent with the capacities of the sensors instead of being limited by satellite storage systems. Experiments on ATS-F will demonstrate such a relay system. If operational, a burden will then probably be placed upon terrestrial systems to survey the vast amount of data which will be produced and forward what is needed to interested parties in form which is usable to them.

Automated Broadcasting

Experience with automated radio broadcasting has shown that it is more reliable, allows better program planning, and is more economical than standard broadcasting. For these reasons the radio broadcasting systems in the United States may soon become almost completely automated. It is only logical to expect many terrestrial television stations to be automated as the more advanced video program storage equipment becomes available.

A communication spacecraft is an entirely automated system; it is not a complete station. The spacecraft only translates programs, very rarely originates them (television pictures of the world being an exception). The technology developed for the space transmitter, which must have at least five years of unattended life, is directly applicalbe to the terrestrial transmitter. This is an area to which space technology can make a definite contribution to terrestrial communications.

Frequencies and Sharing

Some of the results of a number of analyses of space-to-earth television communication systems are summarized in the curves given in figure 16. In figure 16a the lower curve marked "Reception" indicates the relative required power flux density (or field strength) needed for reception as a function of frequency. The rise in power flux density at the lower frequencies is due to increased interference from man-made and solar noise and the limiting of FM bandwidth due to ionspheric distortion. The rise in flux density at the upper frequencies is due to increasing rain attenuation, increasing receiver noise levels, and decreasing antenna size due to beamwidth limitations.

The upper curve in 16a marked "Transmission" indicates the relative power flux density which can be transmitted. The decrease at lower frequencies is due to practical limits on the size of the transmitting antenna while the decrease at the upper frequencies is due to a decrease in amplifier efficiency. The width of the shaded area between the two curves is an indication of the possibilities of growth, flexibility, and reliability of the system.

In figure 16b are two of the system costs: the relative cost of the space segment including launch and the relative cost of the ground receiver (this is not the total ground segment costs). From these two sets of curves one may make the deduction that for a system with few channels and many receivers it is best to go to the lower end of the shaded area, while for fewer receivers the upper end is attractive. This, then indicates the interest in frequencies between 600 MHz and 15 GHz. Unfortunately terrestrial communications people went through this same exercise shortly after Lindbergh flew the Atlantic and came to the same conclusions.

Thus this region between 600 MHz and 15 GHz is a region which must be shared between terrestrial and space services to a high degree. After much work and discussion, the criteria for sharing between terrestrial services has been fairly well settled. Now, with the advent of space communications, the whole sharing problem must be re-examined. NASA over the past few years has become deeply involved in this problem. Work by NASA has included subjective measurements of interference between AM-VSB and FM television systems and the determination of the sharing feasibility between space and terrestrial systems and between space systems. It is difficult to reduce this rather complex subject to a few simple words or graphs. Generally, the ability to share is determined by the directivity of the receiving antennas, the required protection, and the relative power levels.

At 600-900 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 antennas are used and the side lobes are kept at a moderate level. High power terrestrial television broadcasting can interfere with space broadcast reception as much as 300 km from the terrestrial station unless precautions are taken such as shielding the community receiver with trees or buildings.

At 2000 to 3000 MHz FM television from space for community reception in tropical areas will not interfere with troposcater 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 interfer 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 present CCIR recommendations for power flux densities between 1 and 10 GHz.

Above 10 GHz space FM television transmission for community or individual 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. In general, space communication systems flux density levels for sharing can be considerably higher than now recommended for lower frequencies.

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 17. 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.

Operating space communication systems of disparate power levels and receiver characteristics, at the same frequency, and beaming to the same or adjacent regions, can result in reducing the total orbit utilization from what could be achieved by separate frequency allocations. To optimize such mixing necessitates agreements as to antenna patterns, protection ratios, modulation formats, and orbit locations. With satellite systems of greatly different characteristics this will require an orbit slot assignment plan.

Conclusion - Implementation of a Large Scale Broadcast System

If the present direction of technology continues it will allow for a trend communication system implementation which is different in form from that which has traditionally happened. Present systems for the dissemination of information to large segments of the population begin in the major cities and political capitals. The first recipients are a few people favored economically or politically. The system then expands outward by means of cable links and translator stations.

Through the use of satellites and automated stations the system growth trend can be different. As the major city transmitters are brought into operation, community reception can commence in a wide spread rural area. The growth is done by spreading and linking the reception outside the cities with terrestrial translators working from community receivers. In the end the nation is served by a system which was established equallably among all segments of the population.

E-6008

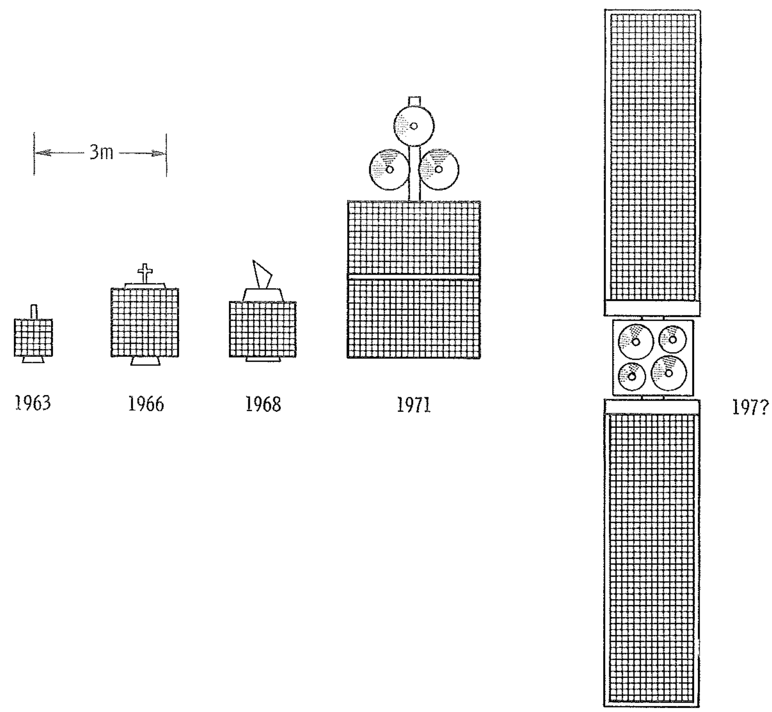


Figure 1. - Growth in communication satellites.

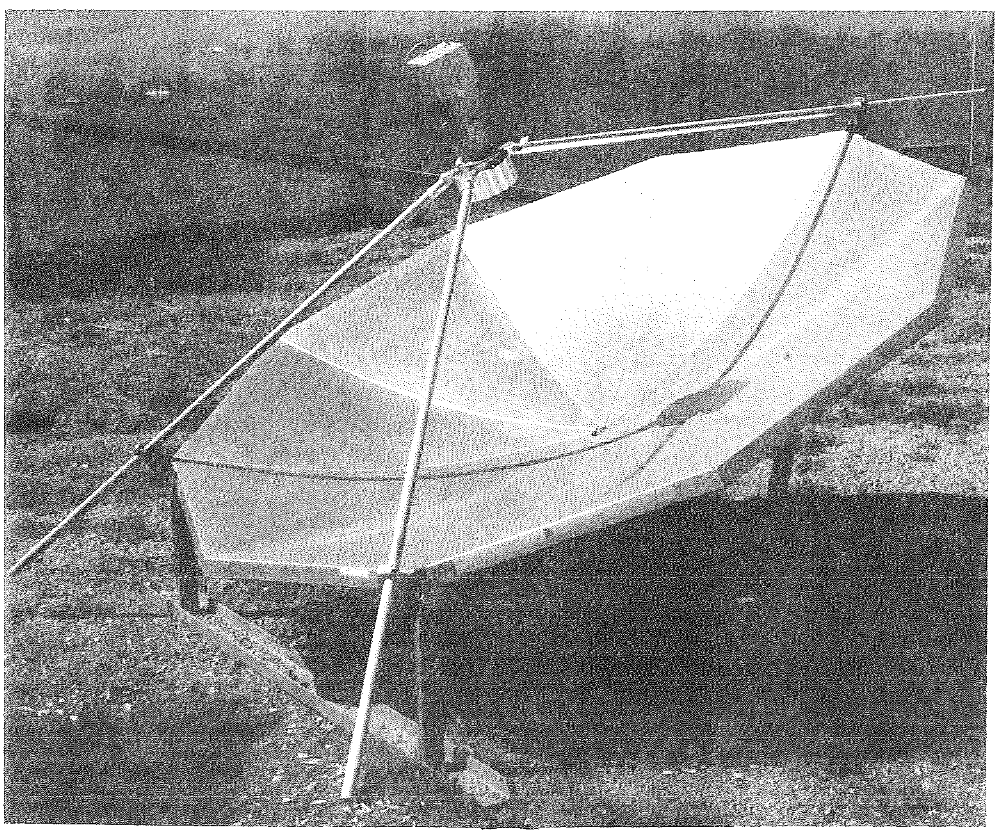


Figure 2. - 2620 MHz low cost receiver-antenna system.

E-6008

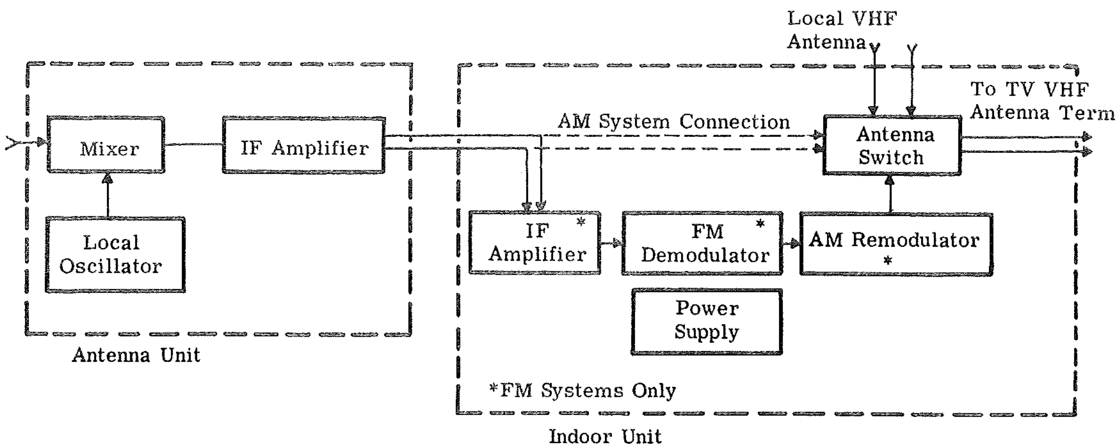


Figure 3. - Generic block diagram of converter systems.

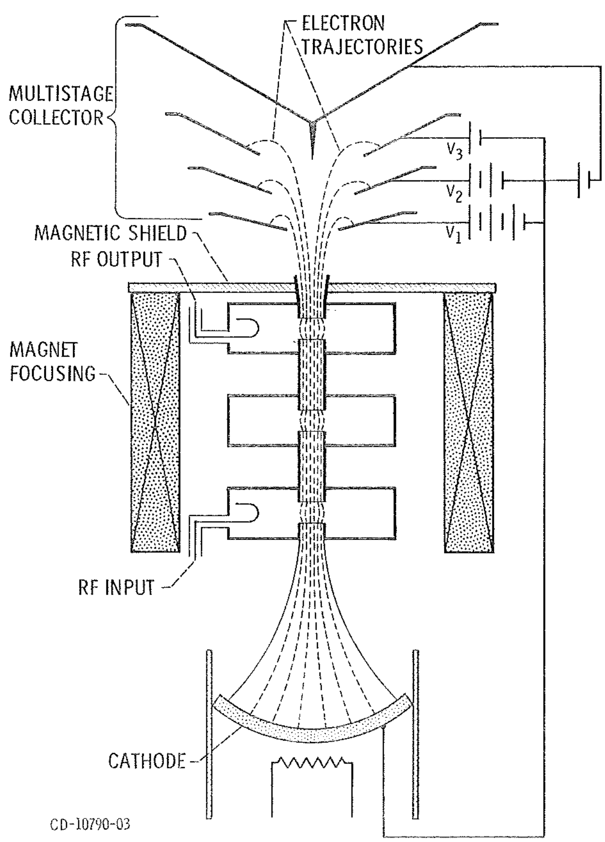


Figure 4. - Schematic of linear beam tube with multistage collector.

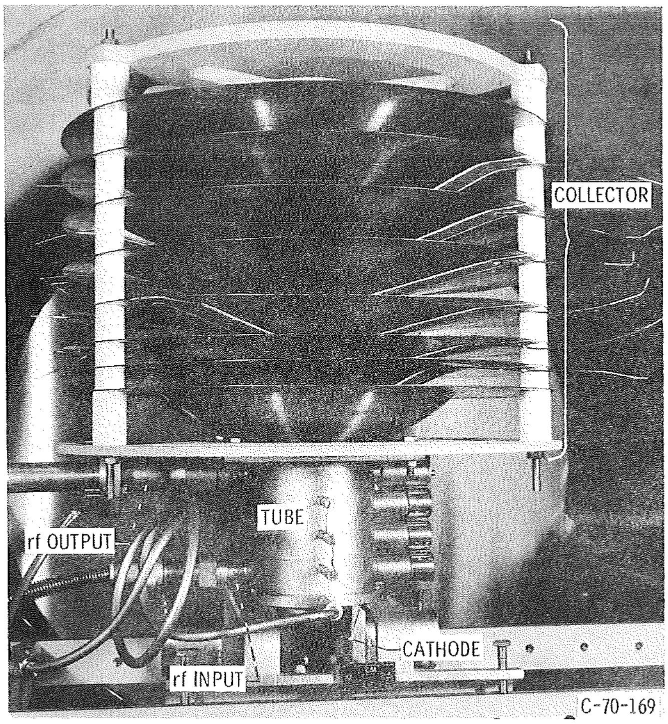


Figure 5. - Depressed collector tube with experimental multistage.

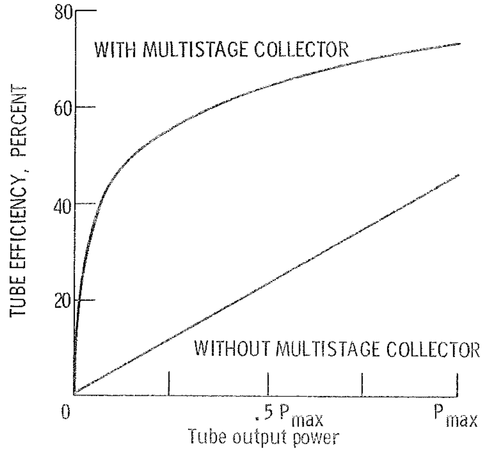
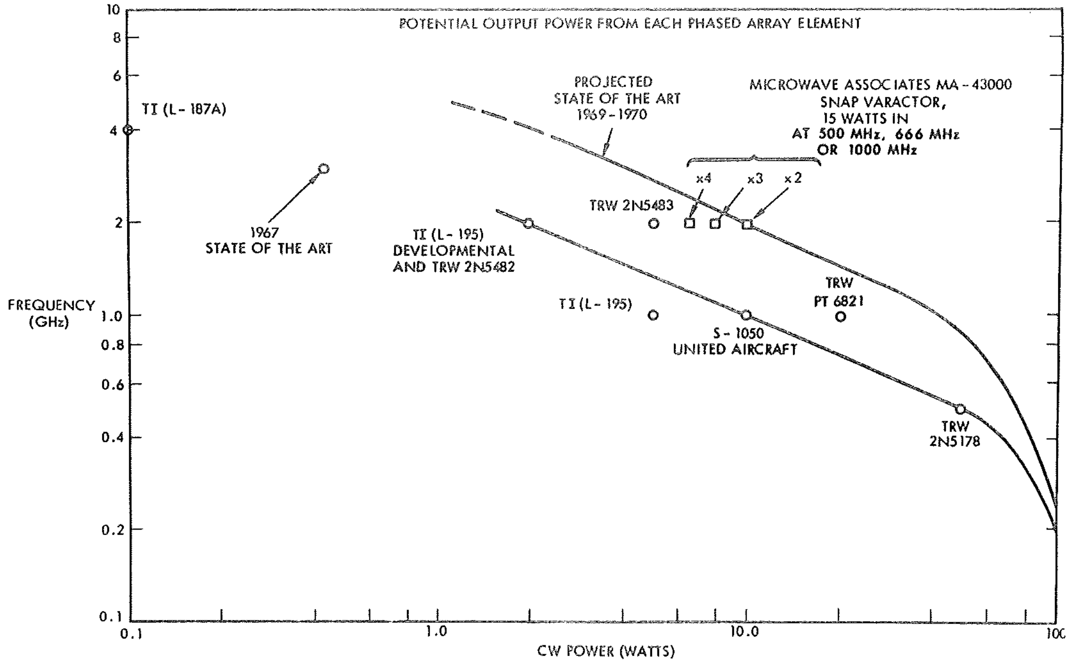


Figure 6. - Tube efficiency as a function of output power level, with and without multistage collector.

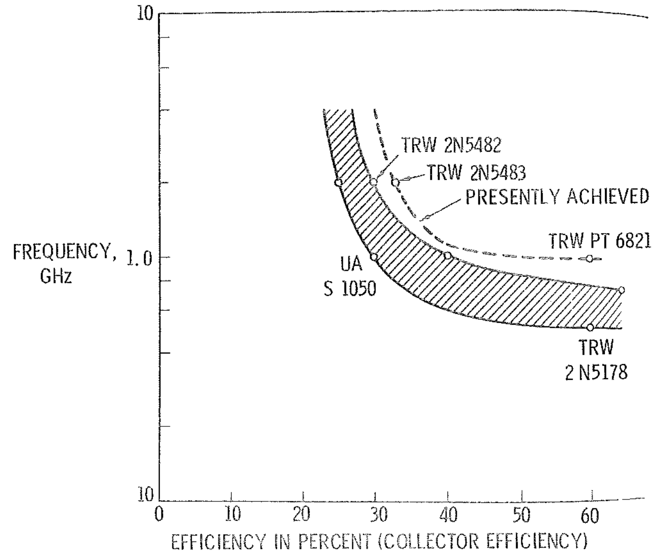
E-6008

E-6008



(A) POWER.

Figure 7. - Microwave power generation from single transistors and varactors and corresponding efficiency.



(B) EFFICIENCY.

Figure 7. - Concluded.

E-6008

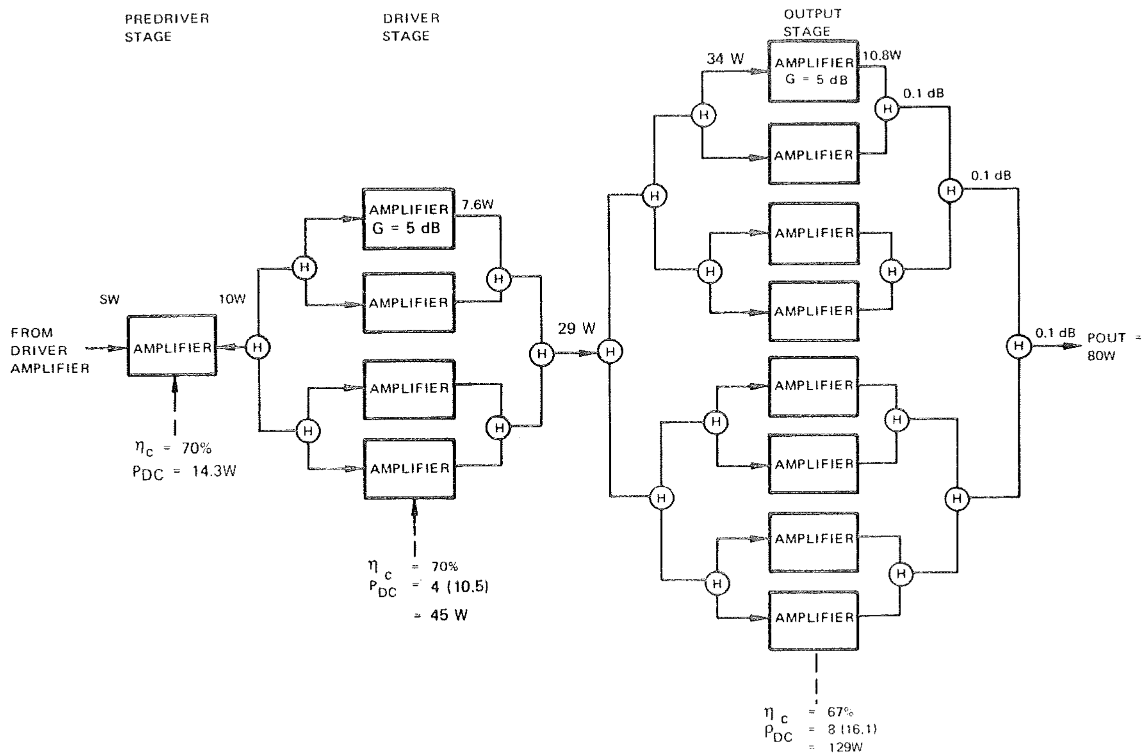


Figure 8. - UHF power amplifier configuration, ATS-F.

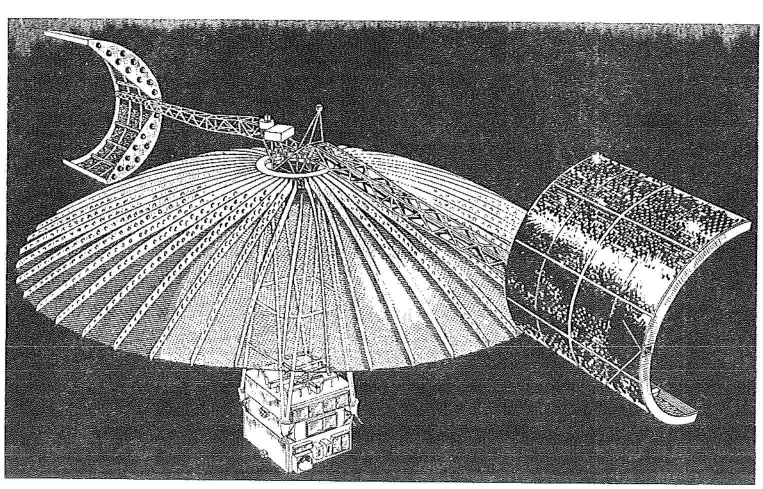


Figure 9. - Application Technology Satellite and 9 meter antenna.

E-6008

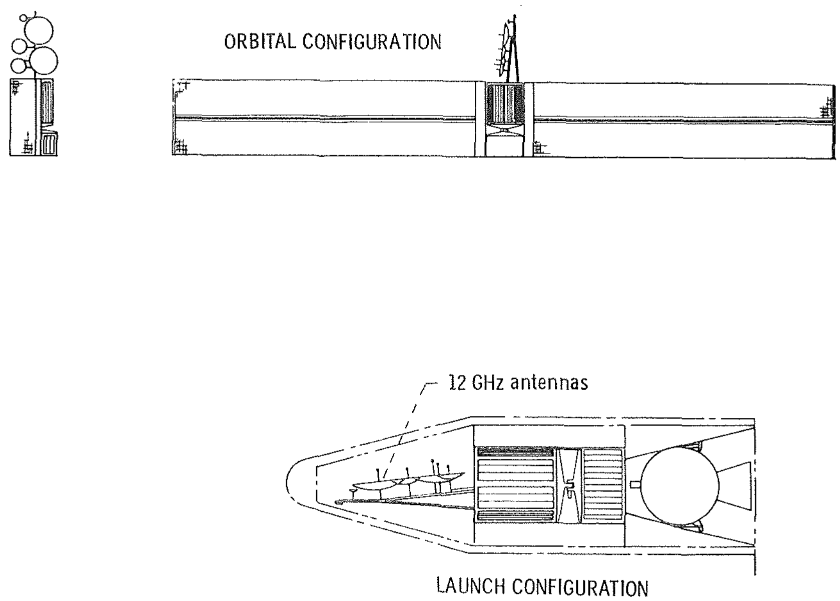


Figure 10. - Satellite configuration using multiple 12 GHz antennas.

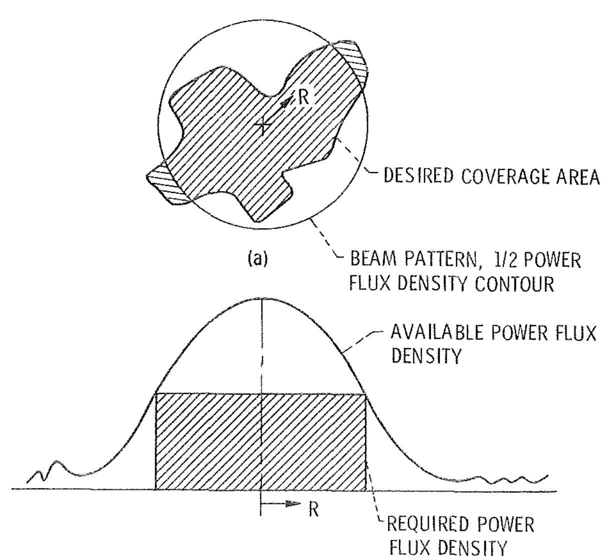


Figure 11. - Comparison of desired power flux density contours and actual power flux density contours.

E-6008

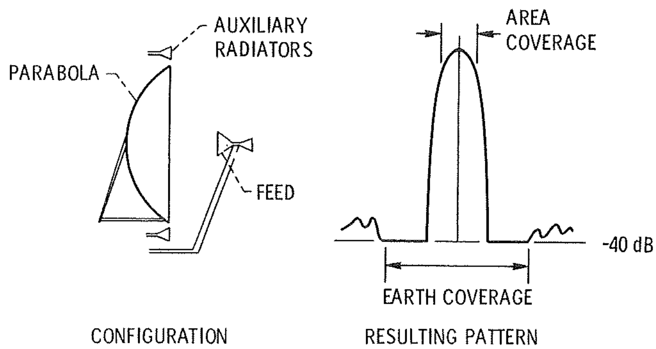


Figure 12. - Lowering of side lobes using auxiliary radiators.

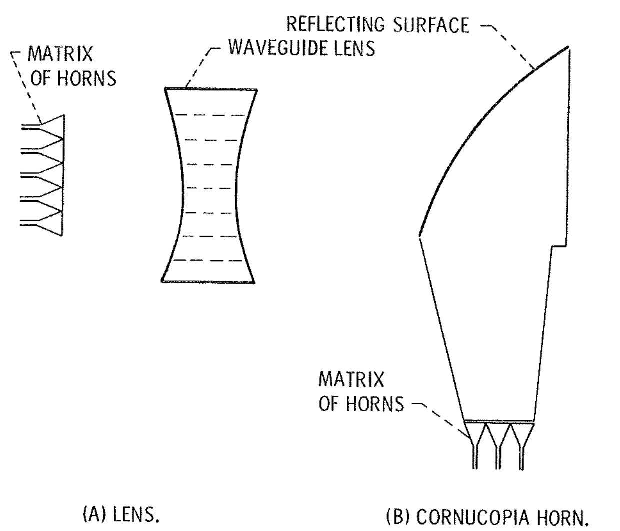


Figure 13. - Use of matrix feed system.

E-6008

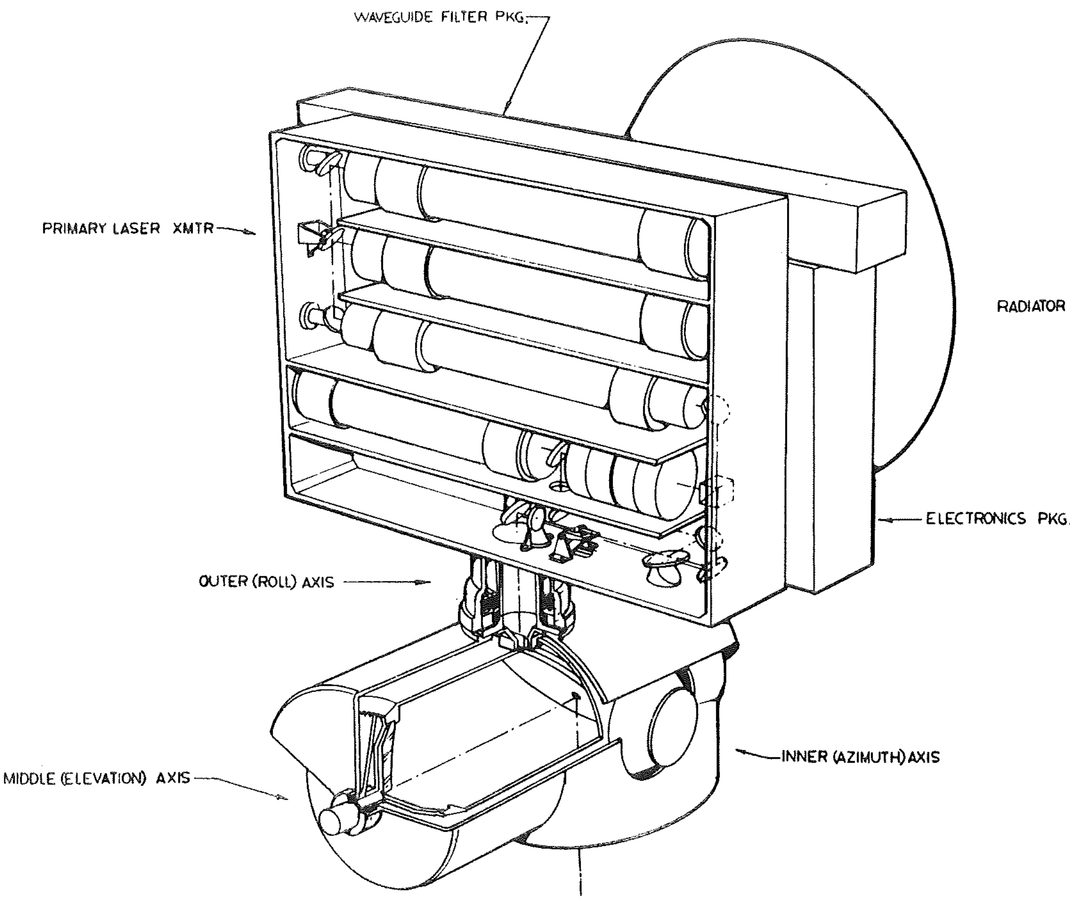


Figure 14. - Laser experiment flight package.

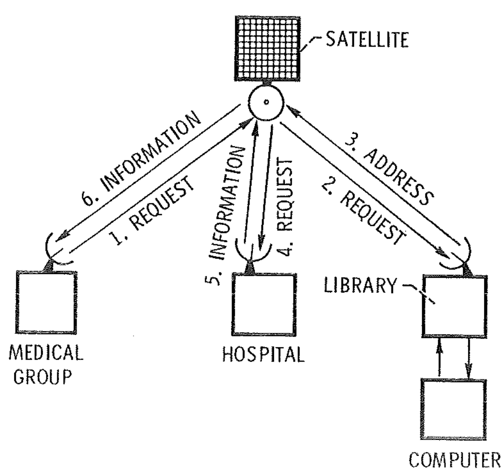


Figure 15. - Possible information transfer of medical information using a satellite.

E-6008

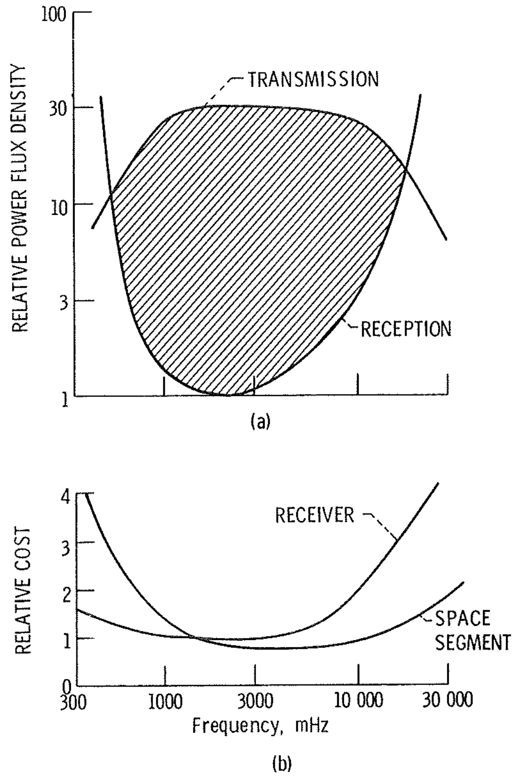


Figure 16. - Relative power flux densities (a) and costs (b).

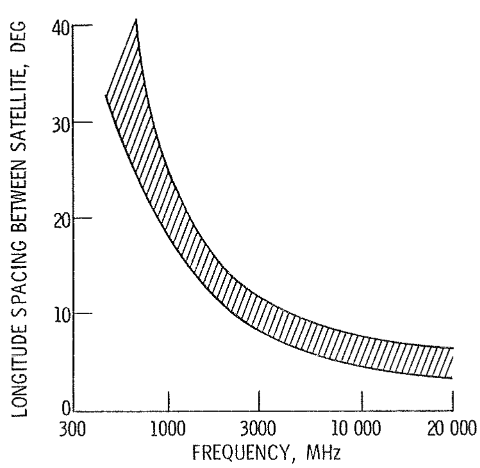


Figure 17. - Estimated required spacing between broadcast satellites as a function of frequency.