THE EFFECTS OF SATELLITES ON CATV

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Since the world's first commercial communications satellite was placed in service in 1965, space system technology has made tremendous advances. Indeed, the technological advance has been so rapid that a number of CATV operators are concerned that CATV systems may soon be rendered obsolete by the delivery of video signals directly into the home via satellite.

This paper examines the potential of future satellites by considering the major technical and economic factors that influence system design. Consideration is given to the choice of launch vehicle, frequency, spacecraft communications subsystem, propagation, and earth station capacility.

The conclusion is that direct to the home satellite broadcasting systems are not likely to be introduced in the U. S. in the near future. Satellite systems can, however, provide economical video signal distribution to CATV head-ends.

INTRODUCTION

There appears to be considerable interest on the part of some CATV operators in the possibility that CATV systems may become technologically obsolete in the near future. These operators hear that satellites may be able to beam video signals directly to home receivers and thereby obviate cable signal delivery. This paper examines this possibility and investigates certain technical and economic factors which relate to the choice among alternative satellite systems for CATV signal distribution.

The first part of the paper is devoted to providing background information on the development of the existing International Telecommunications Satellite Organization (INTELSAT) system, the Canadian domestic system and the proposed United States domestic satellite systems. The proposed ATS-F/Rocky Mountain States experiment is then briefly described and the next part is devoted to technological factors involved in system design. This is followed by an economic analysis and, finally, concluding remarks.

The INTELSAT System

Early Bird, the first INTELSAT spacecraft, was launched in 1965 and was capable of providing 240 voice circuits between one earth station in the United States and one in Western Europe. Alternatively, a single, one-way television channel could be transmitted which introduced live transoceanic television on a commercial basis. The latest INTELSAT spacecraft, INTELSAT IV, can provide up to twelve television channels to all earth stations in the coverage area.

Pertinent characteristics of the four generations of satellites are given in Table 1.

TABLE 1.

SUMMARY OF INTELSAT SPACECRAFT CHARACTERISTICS

	INTELSAT I	INTELSAT II	INTELSAT III	INTELSAT IV
Nominal Weight in synchronous orbit (pounds)	85	190	334	1610
Launch Vehicle	Thrust-Augmented Delta (DSV - 3D)	Improved Delta (DSV-3E)	Long-Tank Delta (DSV-3M)	Atlas/ Centaur
Nominal Capacity (4kHz circuits)	240	240	1200	5000
Design Lifetime (years)	1.5	3	5	7
Number of Transponders	2	1	2	12
Multiple Access Capability	No	Yes	Yes	Yes
Transponder Bandwidth (MHz)	25	126	225	36
Spacecraft e.i.r.p. (dBw per transponder)	11.5	15.5	23	22.5 (global) 34.2 (spot)
Earth Coverage Pattern	North-Atlantic	Quasi-Global	Global (17^{o})	Global (17^{o}) (plus 2 steerable spot beams) (4.5^{o} each)
Year Placed in Service	1965	1967	1969	1971

Standard earth stations operating with INTELSAT satellites have also changed significantly with time, although the figure of merit, i.e., the effective antenna gain divided by the effective system noise temperature (G/T), has remained constant. The first U. S. earth station used a radome enclosed, folded-horn antenna and a narrow-band super-cooled MASER as the first amplifier. It was located at Andover, Maine, hundreds of miles from the circuit termination point in the New York City area, to avoid any possibility of radio frequency interference (RFI).

Subsequent U. S. earth stations have used unenclosed paraboloidal antennas with diameters of 90-100 feet. Cost factors, increased bandwidth requirements and improved performance capabilities have dictated the replacement of MASERS with cooled parametric amplifiers. In addition, the use of "stationary" orbits for the satellites greatly simplifies the RFI problem and, as a result, earth stations can be located closer to the desired circuit termination point.

The TELESAT System

The TELESAT System provides a complete telecommunication service to communities throughout Canada. Each satellite has twelve transponders, although only ten are usable during eclipse. Each transponder will relay one color video channel, two audio channels and one cue channel between properly equipped earth stations.

Several earth station designs are used in the TELESAT System but perhaps the most interesting to this audience is the "remote television" class of station. This station uses a manually steerable, paraboloidal antenna with a diameter of 26 feet, an uncooled parametric pre-amplifier and the G/T is 26 dB/°K or better. The stations are equipped to receive one or two video channels initially and the output video S/N is 55 dB.* Transmission capability is not provided.

Another type of earth station in the TELESAT System of interest to this audience is the "Network Television" class. This station uses an antenna with a diameter of 33 feet, an uncooled parametric pre-amplifier, has a minimum G/T of 28 dB/°K and provides an output video S/N of 57 dB. These stations transmit, as well as receive, video programs.

United States Domestic Satellite System Proposals

Listed below are the six active proposals for domestic satellite systems currently being processed by the Federal Communications Commission.

- American Satellite Corporation
- American Telephone & Telegraph/Comsat General Corp.
- CML Satellite Corporation
- GTE Satellite/National Satellite Services
- Radio Corporation of America
- Western Union

American Satellite Corporation (ASC)

ASC is 80% owned by Fairchild Industries and 20% owned by Western Union International. It plans to obtain three, 12 transponder, 4/6 GHz satellites based on the TELESAT design and to establish two of these in orbit using Thor-Delta rockets in the third quarter of 1974. Four to eight earth stations equipped with single antennas, 33-feet in diameter, are planned for the initial system. ASC has leased space segment capacity in the Canadian system to offer an earlier service capability.

American Telephone & Telegraph/Comsat General Corp. (AT&T/COMSAT)

AT&T plans to lease the entire capacity of three in-orbit satellites to be owned and operated by COMSAT GENERAL Corporation, a wholly owned subsidiary of the Communications Satellite Corporation. Each satellite is to contain 24 transponders, in the 4/6 GHz frequency band, and is to be launched by an Atlas/Centaur rocket. Each of the five initial earth stations is to have at least two 100-foot diameter antennas. Under FCC rules, AT&T may not use these facilities for the normal provision of commercial video services for the first three years.

CML Satellite Corporation

CML is equally and jointly owned by COMSAT GENERAL, MCI and Lockheed Corporations. At the present time, it has not announced its system plans.

*The signal/noise (S/N) is defined as the ratio of the peak to peak signal (including sync.) to weighted RMS noise.

GTE Satellite Corporation/National Satellite Services (NSS)

GTE is a wholly owned subsidiary of General Telephone and Electronics and plans to lease capacity in satellites owned by the National Satellite Services Corporation, a wholly owned subsidiary of Hughes Aircraft Company. The satellites are based on the TELESAT design, contain 12 transponders at 4/6 GHz and are to be launched by Thor-Delta rockets. GTE would utilize ten transponders and would have service continuity priority in the event of transponder and/or satellite failures. The GTE earth stations would be equipped with at least two antennas, each one 100-feet in diameter. NSS plans to use any capacity available in excess of GTE requirements, including the spare in-orbit satellite, to provide video distribution services primarily for CATV.

RCA

RCA plans to lease space segment capacity initially from the Canadian Satellite System. RCA has applied for the future provision of its own space segment capacity along with the alternative of leasing capacity in another system. It has applied for a number of earth stations with various antenna sizes.

Western Union (WU)

WU plans to orbit two, 12 transponder, 4/6 GHz satellites based on the TELESAT design. It also plans five earth stations, each with one antenna 50 feet in diameter. WU is scheduled to launch its first satellite in the spring of 1974.

The ATS/F-Rocky Mountain State Experiment

In 1974/5, the National Aeronautics and Space Administration (NASA) and the Health, Education and Welfare Department (HEW) plan to conduct experiments involving video transmission via satellite to schools and institutions in the Rocky Mountain region (1). NASA is to provide the satellite (ATS/F) and HEW is to furnish both the programming material and the small earth stations.

These stations are to use antennas 10-feet in diameter, tunnel diode preamplifiers, and the output video S/N at the earth station is expected to be 47 dB. Perhaps the most exciting aspect of these earth stations is that the "front end" (i.e., the antenna and pre-amplifier) is expected to cost on the order of $2,000 each. Since the remote television earth station in the TELESAT System is about two orders of magnitude more costly, it might seem to some that this experiment is likely to usher in the age of truly inexpensive satellite telecommunications.

The technical and economic factors that bear on cost-effective satellite system designs will be developed subsequently, but it might be useful to look now at one of these factors in the ATS/F-Rocky Mountain States experiment. It should be kept in mind that no satellite system can be designed to provide maximum flexibility and capacity with minimum complexity and cost although any system can be optimized with respect to these criteria. Any satellite system which emerges from the design process is the result of a great many compromises, or trade-offs, between existing component performance capability; the confidence of achieving improvements in performance, the degree of added complexity required to achieve the added performance, the cost of the increased performance and the value of this increased performance in terms either of an improved system or of relaxed performance requirements in other components.

In the ATS/F experiment, for example, the concentration of spacecraft power into a relatively small area, permits high effective radiated power levels and, in turn, allows the use of low performance/low cost earth stations. An ATS/F beam covers approximately 170,000 square miles and a simple calculation shows that more than 20 such beams would be required to cover the United States. If we assume that a domestic satellite system must serve all of the continental United States, then it is entirely possible that lower total system costs could result from the use of a larger coverage area in the spacecraft beam and higher performance earth stations.

II. TECHNOLOGICAL FACTORS

Useable Frequency Bands

At the 1971 World Administrative Radio Conference (WARC), several new frequency bands were allocated to the Fixed Satellite Service. This is defined as a radio communications service between earth stations at specified fixed points; the INTELSAT satellites operating with a global network of earth stations is a good example of this service.

For the first time, allocations were made to the Broadcasting Satellite Service, defined as one where transmissions from the satellite are intended for direct reception by the general public. Two types of reception are recognized. For individual reception, simple domestic installations with small antennas are used; for community reception, the satellite transmissions are received by installations having larger antennas and are intended for use by groups of the general public at one location or through a distribution system covering a limited area.

A summary of WARC frequency allocations of interest for the fixed and broadcasting satellite services is given in Table 2. The 4 and 6 GHz frequency bands are used extensively today for international communications and all announced U. S. domestic satellite systems plan to use these bands initially.*

TABLE 2

FREQUENCY ALLOCATIONS OF INTEREST

FREQUENCY BAND GHz	SERVICE	FLUX DENSITY LIMITS	REMARKS ON BAND USE
2.5-2.69	Broadcast Satellite (Community)	-152 dBW/m^2/4kHz $0° < \theta \leq 5°$ $-152 + \frac{3(\theta - 5)}{4}$ dBW/m^2/4kHz $5° < \theta \leq 25°$ -137 dBW/m^2/4kHz $25° < \theta \leq 90°$	Use of this band is limited to domestic and regional systems for community reception, subject to agreement between the administrations concerned and those having services which may be affected
3.7-4.2	Fixed Satellite	-152 dBW/m^2/4kHz $0° < \theta \leq 5°$ $-152 + \left(\frac{\theta - 5}{2}\right)$ dBW/m^2/4kHz $5° < \theta \leq 25°$ -142 dBW/m^2/4kHz $25° < \theta \leq 90°$	Shared with terrestrial common carrier radio relay
11.7-12.2	Broadcast Satellite Fixed Satellite		1. Terrestrial use in this band introduced after space services to insure compatibility 2. Use of this band for satellite service is limited to domestic systems subject to agreement between the administrations concerned and those having services which may be affected
10.95-11.2 11.45-11.7	Fixed Satellite	-150 dBW/m^2/4kHz $0° < \theta \leq 5°$ $-150 + \left(\frac{\theta - 5}{2}\right)$ dBW/m^2/4kHz $5° < \theta \leq 25°$ -140 dBW/m^2/4kHz $25° < \theta \leq 90°$	Shared with terrestrial common carrier radio relay

θ = Angle of arrival (in degrees) above horizontal plane

Two frequency bands in the broadcasting satellite service are of some interest for U. S. applications. The 2.5 to 2.69 GHz band has limited interest due to its limited bandwidth and the fact that it is restricted to educational television use in the United States. The ATS/F experiment described earlier will use frequencies in this band. The 11.7 to 12.2 GHz band which is also allocated to the Fixed Satellite Service has considerable interest for the following reasons:

1. The band is not shared with terrestrial facilities so that the earth station can be located at the CATV head-end where site geometry and local zoning permit.

2. It is expected that high flux density levels will be permitted thereby allowing the use of small, low cost receiving stations.

*The CML Corporation has not announced its system plans at this time. It is possible that CML will incorporate the use of the 12/14 GHz bands in its initial system.

For the reasons discussed above, the use of the 4 and 6 GHz bands and the 11.7-12.2 band will be considered.

System Configurations and Frequency Factors

Two satellite system configurations are examined in this paper. In one the satellite interfaces with CATV systems through an earth station which can be located at a head-end or remote from it. For the second configuration, transmissions are direct from the satellite to the home.

In the United States, satellites used for CATV applications would transmit in either the 3.7-4.2 GHz or 11.7-12.2 GHz frequency bands; the broadcasting satellite service would use the 11.7-12.2 GHz band. Transmissions to the satellite would be in the 5.925 - 6.425 GHz or 14.0 - 14.5 GHz bands.

For the satellite/CATV configuration, each frequency band has advantages and disadvantages as shown in Table 3 and described below.

Earth Station Siting - At 4/6 GHz, operational regulations have been established to permit shared use of the band by satellites and an extensive network of established terrestrial microwave systems. The existence of microwave facilities in many areas (usually most dense in urban areas), necessitates careful earth station site selection and available sites are typically on the order of a microwave hop from the desired location. Thus, an interconnect facility is needed and may take the form of either microwave or cable. In the 12 GHz band on the other hand, terrestrial services are not allocated in the United States so that an earth station could be placed at any desired location (e.g. CATV head-end).

Propagation Factors - At 4 GHz, transmissions are affected very little by precipitation. During heavy rains the attenuation at these frequencies is less than one dB and is not a major consideration. At 12 GHz on the other hand, propagation conditions are a major factor in designing an overall satellite system. Figure 1 shows typical results of precipitation attenuation measurements for frequencies near 12 GHz during sunlight hours when the attenuation is the most pronounced. The effect of these propagation factors can be overcome by increasing the power radiated from the satellite or by using diversity stations separated sufficiently to ensure that high attenuation caused by precipitation is not suffered simultaneously at both stations. For CATV applications, it is conceivable to have dual earth stations which interface with the existing cable at widely separated points, thus avoiding the necessity for establishing a new terrestrial interconnect link between the earth stations.

TABLE 3

COMPARISON OF 4 AND 12 GHZ BANDS
FOR CATV APPLICATIONS

4 GHz — ADVANTAGES	12 GHz — ADVANTAGES
• Developed E.S. and satellite technology and equipment • Insignificant propagation effects • Uncooled paramps now with noise temps of 55-60°K.	• No site selection problems. E. S. can be located at CATV head-end • Frequency band is not shared with terrestrial facilities
4 GHz — DISADVANTAGES	**12 GHz — DISADVANTAGES**
• E. S. site selection could be difficult in certain locations thus requiring extensive interconnect facilities	• Components are being developed • Significant precipitation attenuation of signals-need either S/C power margin or diversity stations to overcome rain attenuation • If diversity is needed, interconnect advantage is lost

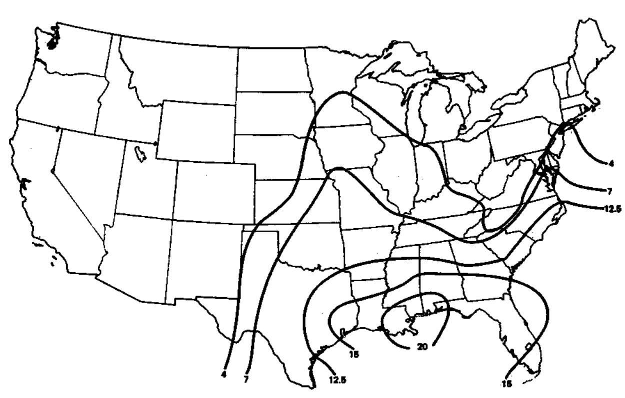

FIGURE 1 REGIONS WHERE INDICATED DB OF ATTENUATION AT 12 GHZ IS EXCEEDED FOR 0.05 PERCENT OF THE TIME PER YEAR

(TAKEN FROM REF. 2)

System Design

Typical parameters are shown in Table 4 for three cases of interest, CATV at 4 and 12 GHz and individual reception at 12 GHz. These values have been selected on the basis of both past studies and various trade-offs; in all cases frequency modulation is used (Ref. 3, 4, 5). For CATV at 4 GHz, the satellite eirp is taken to be essentially the same as that specified in several domestic satellite applications.* A signal-to-noise ratio of 53 dB would require an antenna having a diameter of about 22' and an uncooled parametric amplifier. For full United States coverage, a Thor Delta launched satellite could supply 12 television channels without frequency reuse.

TABLE 4

TYPICAL PARAMETERS

	CATV		INDIVIDUAL RECEPTION
Frequency (GHz)	4	12	12
S/N (dB) (1)	53	53	42
Eclipse Operation	Yes (2)	No	No
Path Margin (dB)	<1	4	1
Antenna Diameter (Ft.)	22	16	3.5
Beamwidth (Deg.)	.73	.35	2.1
Antenna Gain (dBi)	46.5	53.5	40.5
Pointing Loss (dB)	.25	1.3	.2
S/C Station Keeping (Deg.)	.1	.1	.1 (3)
Receive System Noise Temp. (°K)	100	200	1000
Satellite Beamedge eirp per TV Channel (dBW)	33	41.8	60

NOTES
1. Frequency modulated signal with S/N defined as the ratio of the peak-to-peak signal (including sync.) to weighted RMS noise
2. It is assumed that a CATV distribution service at 4 GHz would utilize one of the currently proposed domestic systems which provide for some eclipse operation.
3. Station keeping is not as critical in this application due to the relatively wide beamwidth of the earth receive antennas.

At 12 GHz, because of the propagation factors mentioned previously, a sizable margin is introduced. Even with a 4 dB margin, however, a relatively large portion of the country would require diversity earth stations in order to meet a video signal-to-noise ratio of 53 dB which is taken as the performance objective.

*Due to flux density limitations as shown in Table 2, very high satellite eirp's and very low performance earth stations are not feasible at 4 GHz.

This is particularly true in the southeastern part of the country where precipitation rates are the greatest, as indicated by the contours shown in Figure 1. At 12 GHz, a Thor Delta launched body stabilized satellite could provide 6 wideband television channels and an Atlas-Centaur satellite could provide 14 channels with no eclipse operation.

If a lower value of signal-to-noise were acceptable, or if the signal-to-noise ratio were allowed to fall below the assumed value of 53 dB for more than .05% of the time (the value used in this paper), then it would be possible to achieve a higher satellite capacity and/or the use of lower performance earth stations. This would change the equipment design requirement and could also change the relative economics.

For each of the two frequency bands, a relatively small diameter earth station antenna would be sufficient. The beamwidths of these antennas together with a constraint of allowable satellite movement of no more than ±0.1° in the east-west and north-south directions, allow the antenna to remain pointing in a fixed direction (i.e., no tracking is required). This is a governing factor in the design of simple unattended earth stations.

Satellite designs for CATV in this paper use a single spacecraft antenna beam for coverage of the contiguous 48 states which is similar to the designs now being implemented for domestic service. Future systems, however, may effectively utilize multiple spacecraft beams as a means of allowing different margins for precipitation at selected regions within the United States.

For direct to the home transmissions, parameter values based on CCIR examples have been assumed. (Ref. 5) A signal-to-noise ratio of 42 dB would result in a good picture quality, but is 11 dB lower than that considered typical for CATV services. Also, the percentage of time that the quality would be less than 42 dB could be as high as 1%, a value considered unacceptable for CATV. To achieve higher service availability (i.e., to overcome precipitation attenuation), considerably more satellite power or larger home terminal antennas would be required, since diversity cannot be used with direct to the home broadcasting.

The terminal for a direct to the home system would consist of a small outdoor antenna, a pre-amplifier located at the antenna, a down-converter and a demodulator. The output would be fed directly to an existing television set. An antenna diameter of three and one-half feet is typical of a size which would pose no roof mounting problems. Considerable research of front-end devices for home receivers has been conducted recently leading to designs having a system noise temperature on the order of 6 dB. (Reference 6)

Even with lesser performance objectives, the broadcasting satellite radiated power at 12 GHz would be about 60-70 times as high as that required in the CATV example (per channel) for the values considered. For U. S. coverage, only one channel could be provided by a Titan IIIC launched satellite.

Technology Availability - Both spacecraft and earth station technology are well developed and widely available for applications at 4/6 GHz. Component refinements (e.g., lower noise uncooled paramps) are still in progress but major research and development for use of this band has already been accomplished. For operation at 12/14 GHz, research and development is underway. A significant step in accomplishing this is being provided by the Communications Technology Satellite Program, a joint undertaking by the Canadian Government and the National Aeronautics and Space Administration. The program objective is to advance the state of the art in spacecraft and earth terminal technology for operation at 12 GHz and the mission includes the development and flight test of a 200 watt transmitter tube.

III. Economics

All satellite telecommunication systems require significant investments to get started. A Thor-Delta launched satellite, for example, costs about 15 Million Dollars in-orbit and at least two satellites are required to provide service continuity in the event of satellite in-orbit failure. The possibility of launch failure adds to potential start-up costs. Thus, a minimum of $30 to $45 Million Dollars is needed to provide just the space segment of a satellite system.*

*The six proposed systems for U. S. domestic satellite services have start-up costs ranging from approximately 70 to 220 Million Dollars. The high figure is for the AT&T/Comsat system which provides the most capacity. ASC anticipates expenditures of 85 Million Dollars in the start-up of their system, while the equivalent figure for WU is 70 Million Dollars.

The ground stations needed for tracking, telemetry and command and those needed to transmit program signals to the satellite add at least $5,000,000 more to start-up costs. Earth stations to receive the satellite signals may cost as little as $70,000 each if they are located at a cable system head-end and, at these sites, the cost of connecting the cable system to the earth station is negligible.

The high costs of the space segment argue against a satellite system solely for CATV purposes unless there is a large number of receive-only stations in the system. A space system which costs $35 to $50 Million Dollars to bring signals to a few $70,000 receive earth stations is absurd. The number of stations would have to be in the hundreds to made economic sense.

The start-up costs of a moderate capacity satellite system are on the order of $75 Million Dollars. These are only the distribution costs and do not include the costs of programming material to fill the distribution channels.

Given the high start-up costs, it is much more likely that initial satellite system services for the CATV industry will be provided, at a minimum, via a shared space segment. This means that the CATV industry will most likely lease capacity in a satellite system owned by others.

All of the initial United States satellite systems are based solely on the use of the 4/6 GHz frequency bands.* Thus, it is also clear that services to the CATV industry provided in the next few years at least will be in these frequency bands. The question then becomes whether the 12/14 GHz frequency bands offer economic advantages that justify delaying the introduction of satellite distribution services for the CATV industry.

Tables 5 and 6 have been constructed to compare the annual costs of various system configurations in the two frequency bands. The number of receive earth stations is assumed to be in the 100 to 1500 range and the number of space segment channels varies from 1 to 64.

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*As previously stated, CML Corporation has not stated its system plans at the present time. It could be that CML may offer service at 12/14 GHz.

Inspection of the Tables indicates that the least cost alternative between frequency bands depends upon the system configuration.*

TABLE 5

ANNUAL COSTS - CATV SYSTEM @ 4/6 GHz

($000,000)

Number of Receive-Only Stations	Number of Channels Per Station	Number of Space Channels	Space Segment Cost	Receive-Only Station Cost	Terrestrial Link Cost	TOTAL System Cost
100	1	1	$ 1.8	$ 2.7	$ 1.8	$ 6.3
800	1	1	$ 1.8	$21.6	$14.4	$37.8
1500	1	1	$ 1.8	$40.5	$27.0	$69.3
100	2	3	$ 5.4	$ 2.9	$ 1.8	$10.1
200	2	3	$ 5.4	$ 5.9	$ 3.6	$14.9
300	2	3	$ 5.4	$ 8.8	$ 5.4	$19.6
400	2	3	$ 5.4	$11.8	$ 7.2	$24.4
500	2	3	$ 5.4	$14.7	$ 9.0	$29.1
100	4	8	$14.4	$ 3.4	$ 1.8	$19.6
800	4	36	$64.8	$27.4	$14.4	$106.6
1500	4	64	$115.2	$51.3	$27.0	$193.5

NOTES: 1. Western Union has announced estimated rates for satellite services. These rates are, in part, 1 to 1.2 Million Dollars per year for the annual use of one transponder on a pre-emptible service basis, and 1.7 to 1.9 Million Dollars per year for a non-interruptable service. The higher figure is used here since an on-going CATV distribution service would require a high service availability.

2. The investment cost of receive-only stations is $90,000 for a one-channel station. Each additional channel adds $8,000 per station. The annual cost is assumed to be 30% of the investment cost.

3. The investment cost of the terrestrial link is taken to be $60,000 for one to four channels. The annual cost is assumed to be 30% of the investment cost.

TABLE 6

ANNUAL COSTS - CATV SYSTEM @ 12/14 GHz

($000,000)

Number of Receive-Only Stations	Number of Channels Per Station	Number of Space Channels	Space Segment Cost	Receive-Only Station Cost	Terrestrial Link Cost	TOTAL System Cost
100	1	1	$ 3.6	$ 2.8	$ 0	$ 6.4
800	1	1	$ 3.6	$22.4	$ 0	$26.0
1500	1	1	$ 3.6	$42.0	$ 0	$45.6
100	2	3	$10.8	$ 3.1	$ 0	$13.9
200	2	3	$10.8	$ 6.2	$ 0	$17.0
300	2	3	$10.8	$ 9.3	$ 0	$20.1
400	2	3	$10.8	$12.4	$ 0	$23.2
500	2	3	$10.8	$15.5	$ 0	$26.3
100	4	8	$28.8	$ 3.8	$ 0	$32.6
800	4	36	$129.6	$30.1	$ 0	$159.7
1500	4	64	$230.4	$56.4	$ 0	$286.8

NOTES: 1. The space segment cost is based on the ratio of capacities as calculated in Section II. A Thor-Delta launched spacecraft is assumed and, while eclipse operation exists at 4 GHz, eclipse operation is not provided at 12 GHz.

2. The investment cost of receive-only stations is $70,000 for a one-channel station. Each additional channel costs $8,000 per station. The annual cost is assumed to be 30% of the investment cost. One-third of the locations are assumed to require dual installations, geographically separated, to meet service continuity criteria.

If the satellite distribution system for CATV is primarily a means of providing a single nationwide video channel to all receive earth stations, then the 12 GHz band is economically favored. The use of three space segment channels is an interesting case, as shown in the Tables. Here, the 4 GHz band is more economical if less than approximately 300 earth stations are involved, while

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*Similar calculations have been made for a system at 12/14 GHz using tunnel diode, rather than uncooled parametric, preamplifiers in the receive earth stations. This saves approximately $11,000 at each station but the loss in space segment capacity results in higher costs for all system configurations shown in Table 6.

the 12 GHz band is more economical with larger numbers of earth stations. When large numbers of space segment channels are utilized, the economic balance tips in favor of the 4 GHz band.

If three space segment channels and 100 to 500 earth stations is a reasonable CATV system assumption, then the system is more likely to evolve at 4 GHz than at 12 GHz. This is so for a number of reasons.

First, the assumption in Table 6 is that terrestrial link costs are zero in the 12 GHz band. Clearly, this is an optimistic assumption since problems of size, space, line of sight geometry and local zoning will prevent the location of all 12 GHz receive stations at the head end. This is particularly true where space diversity earth stations are required.

Secondly, the CATV satellite distribution ststem will have started at 4 GHz. Some number of earth stations will have been installed and operating and change-over costs will be involved in the switch to 12 GHz.

Thirdly, there will exist, in many communities, a 4 GHz earth station providing services to users other than the local CATV operator. Thus, it will be possible for some operators to effectively share the costs of the 4 GHz station which could be less costly than the alternative of an independent 12 GHz station.

Tables 5 and 6 indicate that the distribution costs of a three channel space segment, 300 receive earth station system, are approximately 20 Million Dollars per year, either at 4 GHz or at 12 GHz. Assuming each receive earth station serves one CATV system, and that each system serves an average of 4,000 subscribers, the distribution costs amount to $1.39 per subscriber-month ($0.70 per subscriber-channel-month). A single space segment channel, with 50 receive earth stations, would cost $1.69 per subscriber-month for distribution at 4/6 GHz and $2.08 at 12/14 GHz.

These cost levels are a significant increase over present subscriber fee levels which could suggest a relatively slow introduction of widespread satellite distribution services into CATV operations. If this is so, then it might be possible to design a viable satellite system to permit the reception of video signals directly at the home receiver.

There are approximately 62 Million TV households in the United States (7). This is a current upper limit on the number of earth stations needed but clearly, the actual number would be less than that. It would seem, for example, that all apartments in a single structure would be served by a single earth station and a master distribution system.

The installed cost of a 3.5 foot antenna, a 12 GHz pre-amplifier and a frequency/modulation converter is probably in the range of $100-200 when production quantities in the millions are assumed. Keep in mind, however, that each one million earth stations means a total investment of $100-200 Million Dollars.

The cost of a Titan IIIC launched satellite is probably around 25 Million Dollars and the launch vehicle cost is around 28 Million Dollars*. The launch of two satellites is a minimum of 106 Million Dollars and, with a launch failure, would be 159 Million Dollars. This provides one video channel in the continental United States.

A one million earth station, two satellite, one channel broadcasting satellite system would require start-up costs of 206 to 359 Million Dollars. A system based on reaching one million TV households via earth stations serving 250 CATV systems at 4/6 GHz would cost about 44 Million Dollars for the earth stations and interconnect facilities. In addition, about 1.8 Million Dollars per year would be required for the space segment channel.

Concluding Remarks

Domestic satellite systems are certain to aid in the development of CATV operations in the United States. This is due to the ability of the satellite system to interconnect all earth stations in the United States through a single space channel. It is also due to the great flexibility available in a satellite system, which permits the almost instantaneous reconfiguration of existing networks.

The satellite system facilities which must be provided to meet future CATV requirements cannot be accurately predicted at this time. An optimum system design requires knowledge of the number of earth

*Research and development costs of around 30 to 50 Million Dollars would be required in addition to the costs mentioned.

stations and the number of space channels to be furnished as well as the service quality requirements. This information is not currently available and is likely to be gathered from embryonic satellite system operations.

The high start-up costs associated with any satellite distribution system suggest that its introduction into CATV operations will be gradual. This paper has addressed only the physical facilities and it could well be that the larger problems will be connected with the economics of obtaining the programming material to fill the distribution channels.

The direct-to-the-home broadcasting satellite system would be based on the use of 12 GHz. While technically feasible, the enormous start-up costs, and the limited capacity of the system, discourage its introduction. The implementation of such a system on a commercial basis is highly unlikely in the foreseeable future.

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