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ABSTRACT

Community antenna television (CATV) is particularly important because of its potential for economically supplying a large number of channels, for providing viewer feedback, and for at least partially shifting the basis of programing support from the advertiser to the viewer. This study examines these aspects of CATV in order to accomplish the following: (1) assess current and future technology, (2) determine feasible directions of network growth, and (3) indicate the planning and regulation required to obtain maximum social benefit. CATV has the potential for providing (1) a vast number of television channels; (2) a signal quality for the most poorly located viewer far superior to that currently available to the most favored viewer of broadcast television; and (3) such new services as truly local origination and viewer feedback, or interactive programming. These features offer the possibility for drastic changes in both commercial television and formal and informal instruction. Whether CATV is merely one more profitable business or whether it becomes a major tool for revolutionizing society's ability to cope with its problems depends on our willingness to support broad technology and policy studies, and to devise and evaluate meaningful experiments delineating the medium's problems and possibilities. (Author/SJ)

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THE POTENTIAL ROLE OF CABLE TELEVISION IN WIDEBAND DISTRIBUTION SYSTEMS

N. E. Feldman

A WORKING NOTE
prepared for the

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This Note was prepared to facilitate communication of preliminary research results. Views or conclusions expressed herein may be tentative and do not represent the official opinion of the sponsoring agency.

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PREFACE

On August 3, 1968, Public Law 90-456 established the Lister Hill National Center for Biomedical Communications under the National Library of Medicine. The Center's task was described as follows:

> The Center will serve as the focal point within the Department for the development and coordination, where needed, of communication networks and systems to improve health education, medical research and the delivery of health services.
>
> The primary functions of the Lister Hill National Center for Biomedical Communications are:
>
> 1. The design, development, implementation and technical management of a Biomedical Communications Network. Substantive materials and information to be transmitted will remain the responsibility of the program missions involved.
> 2. The application of existing and advanced technology to the improvement of biomedical communications.
> 3. To serve as the focal point in DHEW for biomedical communications systems and network projects, and represent the DHEW in these areas as appropriate.

This Working Note is oriented toward the second function, the application of existing and advanced technology to the improvement of biomedical communications. It attempts to describe the status and technology of community antenna television (CATV) systems, to discuss their potential in relation to competing technologies, and to establish a framework for future examination of the application of CATV to problems of medical education.

Although specific applications of CATV to medical education are not discussed at any length, the report is intended as a basis for such conceptualization. Toward this end, it examines the future viability and pervasiveness of CATV. The reader interested in particular applications is directed to J. A. Farquhar, R. Bretz, A. S. Ginsberg, T. L. Lincoln, R. J. Melone, and G. F. Mills, *Applications of Advanced Technology to Undergraduate Medical Education*, The RAND

Corporation, RM-6180-NLM, April 1970. The present study covers comparisons of competing technologies and long-range estimates of technological change; such a broad scope makes the report quite subjective in places.

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I. INTRODUCTION

Commercial television broadcasting began in the United States on July 1, 1941, and by 1969, nearly 95 percent of all American homes boasted at least one television set. (The Appendix offers a detailed picture of television growth, capital investment, and a comparison with cable systems.)

Currently, television reaches most of these homes directly via broadcast, that is, over-the-air transmission; only about seven percent of television households subscribe to community antenna television (CATV). CATV operators have functioned almost solely as distributors of broadcast programming; they have not altered the menu available to the television viewer. This situation is currently being changed, and CATV operators are being encouraged to originate programming. However, the change is too recent to have yet had significant impact.

CATV is particularly important because of its potential for economically supplying a large number of channels, for providing viewer feedback, and for at least partially shifting the basis of programming support from the advertiser to the viewer [74].

This study examines these (and other) aspects of CATV in order to:

- Assess current and future technology,
- Determine feasible directions of network growth,
- Indicate the planning and regulation required to obtain maximum social benefit.

The conclusions and opinions contained herein represent the opinion of the author, and do not necessarily reflect the official opinion of The RAND Corporation or the National Library of Medicine.

II. SUMMARY AND CONCLUSIONS

Community antenna television (CATV) may prove to be the decade's most important communications development. It uses frequency division multiplexing to distribute many television signals on a single, coaxial cable to homes and offices. Although many alternatives to the present CATV system have been proposed, none appears likely to supplant it. Home video playback machines will likely become prevalent in time, but they will complement CATV rather than compete with it. Although technologically feasible, videophone and switched and digital variants of the present CATV system do not appear to be economically competitive with the current approach for the distribution of commercial television signals. If they prove viable at all, it will be because they economically provide some other service in substantial demand.

CATV has the potential for providing 1) a vast number of television channels; 2) a signal quality for the most poorly located viewer far superior to that currently available to the most favored viewer of broadcast television; and 3) such new services as truly local origination and viewer feedback, or interactive programming. These features offer the possibility for drastic changes in both commercial television and formal and informal instruction.

CATV is solely a medium for distributing electronic signals. Whether it is merely one more profitable business or whether it becomes a major tool for revolutionizing society's ability to cope with its problems depends on our willingness to support broad technology and policy studies, and to devise and evaluate meaningful experiments delineating the medium's problems and possibilities. Many of the conclusions below are tentative and aim at stimulating further study rather than providing definite answers.

1. The increasing number of households with television sets suggests the importance of experimentation with CATV

now. At present, CATV reaches seven percent of U.S. homes. In Canada, 20 percent of all households are on CATV. When 20 to 30 percent of all U.S. households are on CATV--which could occur in as little as one decade--the hardware investment will be substantial. One can afford to experiment with technology when the total investment is low; wide experimentation with new services is essential now because these reflect back in requirements on the technology. Key decisions, which tend to be relatively irrevocable, must be settled early, i.e., before the investment reaches 5 to 11 billion dollars. There is greater flexibility when the investment is low. Thus, the next few years are critical for making technological decisions and for settling standards. Not enough experimentation has been tried, and inadequate data are available to permit good decisions to be made now. If CATV were to experience anything comparable to the rate of growth of television penetration, the results could be unfortunate as the country would become locked-in to the current technology. CATV would become a captive of the existing investment. The time to experiment with new services and technology is now, when CATV reaches only seven percent of homes. In ten years it may be too late.

2. Television's importance to the general public is indicated by the 11.8 million television sets manufactured in the U.S. in 1968, the $3.818 billion retail value of this production, and the fact that television has penetrated 95 percent of U.S. households. The rapid growth of television set production from 1947 to 1950 makes clear that U.S. production capability in electronics will not limit CATV's growth.

3. The domestic market has consumed almost all U.S. production. Since 1955, the U.S. has exported only 1 to 2 percent of each year's production. In 1968, compared to U.S. production, imports represented only about 5.3 percent of the retail value, but amounted to 23 percent of the number

of sets. Imports are now an appreciable fraction of the total number of television sets sold in the United States. There is a growing demand for all kinds of television sets, and for more television sets per home. Over 20 years of production have resulted not only in a television set in over 95 percent of homes, but also in color sets in 33 percent of U.S. households. Thirty-five percent of households now have two or more sets. The multiple-set household will probably be typical by the late 1970s. Already, the television audience is being fragmented within every household; CATV will only hasten this trend. It will facilitate the individual viewing essential for much educational and instructional television programming. Every home will contain a potential audience for more specialized programs.

4. Despite spectrum limitations and interference problems, the number of television broadcast stations continues to grow. However, 6 of the 100 largest market areas do not contain an affiliate of all 3 networks; 65 do not contain a single independent station; 73 do not have a single educational station. CATV offers a means for drastically changing this situation.

5. The $23 billion consumer investment in television reception and the approximately $6 billion recurring cost for maintaining that investment dwarf the $558 million invested by commercial and educational broadcasters in transmission and interconnection and the $59 million in associated recurring costs.

Broadcasting may therefore be considered a high-leverage activity as the broadcast industry exercises considerable consumer influence, although the industry's investment for transmission and interconnection is only one to two percent of total consumer investment. This imbalance argues for greater governmental concern for the consumer investment in television reception.

6. The low capital investment in equipment for distributing television broadcast signals to the viewer is indicative of the efficiency of VHF broadcasting. A single station can reach viewers distributed over a relatively large geographic area. This necessitates only a modest investment in the transmitter, transmitter building, and site; and in the antenna, antenna tower, and site. Neither cable, satellites, or any other means now foreseeable can compete with television broadcasting on this basis.

7. Broadcasting is not the primary concern of the television broadcasting industry. The broadcasting industry's primary concern is the generation, packaging, and presentation of highly professional programming, characterized by mass audience appeal. Such mass-appeal programming is likely to remain expensive and, therefore, scarce. Program competition on large numbers of channels is not likely to have the impact feared by the broadcasters. However, to the extent that some audience fragmentation does occur, it is likely to lead to a more rational use of television, and thus, to benefit the consumer.

8. CATV should lead to considerable audience fragmentation. A multitude of channels may improve the effectiveness and quality of television more than regulating such quality by law or arbitrary censorship.

9. The most important short-term factor in the growth of CATV is resolving the distant signal limitation-copyright issue. Everyone recognizes the benefits to CATV of unrestricted importation of distant signals. Excepting roughly the 6 largest market areas where such importation may add little, importation in the remaining 94 of the 100 largest market areas would ensure both rapid growth and high penetration of CATV. Settling the distant signal-copyright issue might remove such regulations as the ban on leapfrogging and the non-duplication requirement. All other

services CATV might offer represent some risk as they require experimentation, capital investment, and time to develop the market.

There are approximately 162 CATV systems having over 5000 subscribers each. Such systems probably represent the channel capacity likely to characterize most CATV systems over the next few years. The average subscriber receives approximately 9.3 channels, although almost all these systems have 12-channel equipment. The difference is probably due to the Federal Communications Commission's (FCC) distant signal limitation or to the unavailability of several VHF channels at the set because of strong through-the-air signals. The latter problem could be cured by using a set-top converter or a special television set with a carefully shielded tuner. In some cases, the high cost of microwave links for importing distant signals may be the primary limitation. The split among these needs to be studied. It is not apparent why there are so many large systems--i.e., systems with over 5000 subscribers--providing only 4, 5, or 6 channels. In many cases, these systems may be using old equipment that is highly limited in channel capacity. It could represent a captive market in which the franchise holder is not compelled to exert himself by the franchise agreement. This area deserves study.

10. In 1968, the average consumer investment for television reception was $410 per household. Such a high average suggests that comparably large investments in cable distribution systems on a per household basis may be justified. However, if the consumer is to bear the costs, such investments must provide each household with substantial improvements in the quantity and quality of signals, in the variety of programming, and in a variety of new services.

11. The difference between the price of a color television set and a black and white set is a measure of the value the consumer places on color. If CATV is to justify

an average investment of $300 to $400 or more per household, it must offer new and improved services whose value to the consumer roughly equals the benefit obtained in purchasing a color television receiver.

Although the average CATV investment per subscriber is on the order of $160, average penetration is perhaps only one-quarter or one-third of the households. Thus, a more representative value of the current cost of CATV per household (assuming 100-percent penetration in present areas) is probably about $60 to $75.

12. Regulation in the absence of adequate data can only be arbitrary. Any possible long-term Federal and state regulation of CATV operations must be based on a full disclosure of all capital investment, operating costs, and all details of services rendered. In particular, detailed information is needed on changes in plant, on profit and loss on each phase of the operation, and on customer complaints. Details for projections are needed on the franchise area; on the number of households and street miles within that area; and on the number of miles of trunk and feeder or strand installed and estimated necessary to cover all inhabitants. Information-gathering, rather than premature regulation, is important in the 1970 to 1980 time period.

13. Canadian experience suggests that CATV penetration can grow to as much as 20 to 60 percent over an interval of 10 years, while VHF television broadcasting concurrently flourishes. (Canada had no UHF stations as of 1969.) If there are any adverse effects only a careful analysis of the available statistics is likely to make them apparent. Canadian experience should be valuable in evaluating the interaction of CATV and broadcasting; such studies should be undertaken as soon as possible.

14. Lack of standardization is the largest single drawback to the advance of CATV technology. Major electronic manufacturers have not entered the field, and a plethora of

small component producers cater to the designers of marginal systems. Standards for providing high channel capacity are needed. Uniform high standards on signal quality across the entire frequency band as measured at the subscriber's set are needed, as are standards for high continuity of service and standardization of tuner design to provide for up to 100 channels per cable. These standards are essential if cable systems are to provide even a fraction of the new services postulated.

15. A need exists for a carefully shielded television set with a built-in standardized tuner specifically for CATV. Given the present lifetime of television sets, it can take 10 to 15 years to complete the changeover to such sets. In strong signals area, as many as three or four VHF channels are unusable due to the ghosts caused by through-the-air signals. A carefully shielded front end would permit use of all VHF channels. A tuner for CATV use needs low adjacent channel interference in addition to low crossmodulation. Good values for both must be simultaneously achievable. Today there are half a dozen methods for adding extra channels--and no standard one. If CATV standards were to change after the adoption of interim standards, a mechanically interchangeable tuner chassis could facilitate conversion to the new standard.

16. In order for cable systems to provide a high-quality signal adequate for long intervals of instruction on all channels, the imposition of Federal standards on output signal quality should be considered. A minimum standard should be a picture quality that is good to the median observer at least 97 percent of the time for 97 percent of the receiving locations using a reference signal injected at the antenna site. This exceeds the FCC's definition of principal city service, which requires only satisfactory quality at only 90 percent or more of the receiving locations. The CATV operator cannot be held responsible for the quality of

the broadcast signals or the vagaries of through-the-air propagation.

17. Because of the higher susceptibility of aerial installations to interference, to degradation due to ambient air temperature changes, and to deterioration due to weathering, imposition of a Federal standard requiring underground installation of all trunk, feeder, and drop cables should be considered for all new and improved installations. Exceptions for cases of unusual hardship may be necessary.

18. Because there are strong economies of scale in installing two or more cables at one time, imposition of a Federal standard requiring the installation of a minimum of dual trunk and feeder cables on all new construction should be considered. Excess capacity is essential if CATV is to offer new services. Large economies are possible with multiple coaxial cable installed in one operation. The L-4 and L-5 cables each consist of 20 3/8-inch diameter coaxial cables within a single sheath.

19. Although CATV cable is swept-tested for discontinuities or irregularities up to 300 MHz, the coaxial cable may prove useful up to 600 or even 1000 MHz. Study and measurement of the characteristics of 75-ohm CATV cable for trunk and feeder use and, in particular, the measurement of return loss, should be carried out at once. A study of the manufacturing methods required to produce cable useful up to 600 to 1000 MHz should be carried out and enough cable manufactured under these conditions to evaluate its yield and cost.

Although 300 MHz cable may prove adequate for 30 to 50 television channels, and although many cannot see the need for more channels, it would be unwise not to install cable good for 600 to 1000 MHz if the marginal cost proves small. Such large-bandwidth cable would be capable of carrying on the order of 100 or more television channels.

About one-quarter to one-third of the total investment in a CATV system is in the coaxial cable. When the total investment reaches 5 to 11 billion dollars (about 50 percent of all households served by CATV), it may be more difficult to gain acceptance for broader-bandwidth cable. Because cable installed underground can have a useful life of 30 years or more, replacement of obsolete cable in these areas would take some time.

20. In order to limit the intermodulation and cross-modulation in large-bandwidth systems, it may be desirable to use larger diameter trunk cable or lower-loss air core cable to limit the total number of amplifiers in cascade. Problems of water penetration, fracturing of the outer aluminum sheath, extrusion of the outer aluminum conductor from fittings due to cold flow, and differential expansion between the inner core and the outer sheath are just some of the cable problems requiring further study.

21. Viewer response, or feedback, is one of the most important new services that CATV can offer. Although many schemes are possible, none has been implemented. Both the FCC and franchising authorities should encourage CATV systems to provide feedback. Such feedback channels should 1) provide coverage to all subscribers; 2) identify the channel to which the set is tuned; 3) provide individual identification of each responder; 4) provide a multilevel rather than a single response, i.e., eight to ten multiple choices rather than merely "yes" or "no"; and 5) provide a minimum response rate of one response every 60 seconds (a rate as high as one response every 5 seconds may be desirable for some applications).

22. The widest range of experimentation on the uses of the response channels should be encouraged. At this point it is not desirable to specify how they should or should not be used but rather to observe the range of different uses to which they can be put. It is important that

such experimentation begin as soon as possible in order to influence the design of future systems.

23. One area requiring a decision is the technology for viewer response. Certain approaches may affect the kind of amplifiers or cable used. Therefore, early experimental results are important.

24. Experimentation on modulation techniques specifically for CATV is urgently needed. It has been suggested that a single side-band system offers substantial advantages for a cable distribution system. Evaluation of, and eventual standards for, an optimal modulation scheme for CATV is urgently needed.

25. The development of lower-cost solid-state amplifiers, e.g., integrated circuit versions offering lower imput noise figure, larger dynamic range, wider bandwidth, and lower crossmodulation are obviously desirable. Less obvious is the need for centralized computer control of signal level and tilt throughout the system.

26. Arrangements should be supported that facilitate direct connections, by cable or microwave link, between cable head ends and broadcast studios. This would lead toward the elimination of all off-the-air pickup.

27. With 2300 systems today, and only 7 percent of the population subscribing to cable systems, a growth to over 10,000 systems as coverage approaches 100 percent is easy to visualize. Large numbers of centrally located studios, preferably colocated with head ends and forming an intimate, single, small CATV system appear essential to ensure concern for local issues. Local origination depends on such involvement. Both local programming and picture quality are better served by a reduction in the length of cable between the head end and the farthest subscriber in the system. Systems should be limited to perhaps a 5-mile radius about the head end rather than the 10 to 20 miles from head end to furthest subscriber sometimes found now.

On the basis of the distinct neighborhood approach to determining the number of head ends, the optimum number might be as many as 50,000.

28. The consolidation of CATV systems or the development of regional and national networks may prove to be essential to CATV's growth. In any case, such developments are likely to offer substantial economies of scale and, thus, to thrive. They can either supplement the program fare or replace and destroy "localism." The directions in which cable systems grow must be guided to build and preserve an inherent involvement in local issues.

29. If CATV is to meaningfully provide for local origination, it may be necessary to assure that a large number of excess channels are readily available 1) in all systems, 2) in prime time, 3) on some form of common carrier basis, and 4) for a nominal fee.

30. Direct satellite broadcasting to the home is likely to be severely constrained in both number of channels and signal quality. Both economic limitations on ground station costs and spectrum limitations suggest that such a system will suffer from some of the problems of current terrestrial broadcasting. In view of the large research and development (R&D) investment required for such a system, and the government's difficulty in recovering this investment, it appears unlikely that such development will be undertaken. Only modest investments in R&D are needed for cable technology. CATV's economic structure readily facilitates charging viewers directly and thus amortizing the system's entire cost.

31. Picturephone® links, both analog and digital, are nowhere near adequate for commercial television. Low-cost signal processing providing adequate information compression to permit transmission of commercial color television signals over Picturephone® circuits cannot be foreseen at this time. Thus, Picturephone® will grow as a separate service inherently incompatible with CATV. If Picturephone®

service expands to perhaps a million sets in service by 1980, it will represent an investment of six to ten billion dollars. In 30 years, the investment may be on the order of 50 billion dollars, or comparable to the investment in cable television, and on the order of the total investment in telephone plant.

32. Electronic Video Recording (EVR), SelectraVision, and such cassette video tape players as Sony Corporation's Color Video Player and a magnetic tape player being developed by Matsushita (Panasonic) are designed for the home market. It is not clear at this time whether they possess the reliability and picture quality suitable for CATV head-end use.

33. The cost of a good signal-quality video tape operation, including both reliable equipment and staffing, is not as inexpensive as the price of the home equipment suggests. Reliance on the mails results in delays of days or weeks. This limits the topicality of public affairs programs, and forestalls national promotion of programs. Thus, there is considerable interest in real-time interconnection. Trade-off studies for a nationwide cable head-end interconnection system having growth potential, i.e., for 100 to 400 television channels, should be undertaken.

34. The availability of an inexpensive nationwide real-time cable head-end interconnection system could lead to the formation of a number of new networks. Whether supported by advertisers or CATV operators, a number of such networks could well flourish if the interconnection costs were low.

35. If the distant signal-copyright issue were resolved tomorrow, microwave link regional interconnection of CATV head ends would immediately flourish. A 200-mile multihop link can provide one or more signals to a dozen CATV systems along the way, each of which shares in the cost of the link.

36. Neither present nor near-term laser technology is likely to permit economically competitive terrestrial laser communications. It seems certain that lasers will not be commercially exploited as a terrestrial long-haul, large-capacity communications medium for many years to come.

37. At present, millimeter waveguide systems are more economic for long-haul transmissions than laser links, and offer more capacity than laser links for less initial cost. By the late 1970s, an operational millimeter waveguide transmission system is expected to be economically competitive with other available high-capacity systems. The system would cover the band from 40 to 110 GHz and use digital, regenerative repeaters. A single waveguide could carry 240 digitally-encoded color television signals and, with data processing to reduce the redundancy, as many as 840 color television signals.

38. A satellite interconnection system offering as many as 6 to 12 channels appears feasible in the near future. Fifty to one hundred channels per satellite in ten to fifteen years appear feasible given sufficient R&D investment on higher power, higher frequency communication satellites.

A modified Intelsat IV is an example of an initial television distribution satellite that could provide about 12 channels. The Intelsat IV in orbit is expected to cost about $33 million, including prorated R&D and launch activities. The true satellite in orbit cost rises to about $50 million if booster and orbital injection failures and the probability of achieving a 5-year life are taken into account. If satellite interconnection covers only 5 million subscribers, the direct cost of the satellite alone is only 16.5 cents per month (assuming a 5-year life).

39. A satellite ground station costing $25,000 can be utilized by 95 percent of CATV subscribers for a maximum capital investment per subscriber of only $60. A $50,000

ground station could be utilized by 99 percent of CATV subscribers for a maximum investment of $250 per subscriber. Although initial ground stations for CATV interconnection use are likely to cost $100,000 to $200,000 for the first 20 units, improvements in technology and economies of scale can be expected to reduce these costs to $25,000 to $50,000. The maximum allowable investment per subscriber is likely to lie between $60 and $250. Such ground station investments can provide the benefits of satellite interconnection to 95 to 99 percent of all CATV subscribers. The maintenance and annual operating costs of these stations are substantial. If such annual costs are held to only ten percent of the capital investment, they represent charges of fifty cents to two dollars per month per subscriber. Although the lower figure may appear a reasonable fraction of the five dollar typical monthly subscriber charge for many systems, it may represent an unreasonably large proportion of net profit.

40. In 1968, the average consumer investment for television reception was about $410, and the total investment was about $20 billion. This figure provides a scale for judging CATV investment. Assuming an average investment of only $500 per household in the year 2000, and assuming 100 million households, represents a $50 billion investment for television reception. With multiple color sets in each home, the investment may be even greater. A roughly equal investment in CATV spread over 30 years and reaching over 95 percent of all households may not be unreasonable.

41. Although the "wired-city" concept has received much attention, the "wired-nation" concept should perhaps supplant and encompass it. The costs of a wired nation are not as formidable as they first appeared. The cost of providing coverage to 75 percent of the 100 million households in the year 2000 is estimated to lie between $7.5 and $26 billion. The cost for 95 percent coverage is estimated to lie between $27.5 and $46 billion.

42. CATV can make it possible for anyone who can procure programming and sell advertising to obtain a channel at a nominal cost. No expenses need be incurred for a broadcast transmitter or antenna. The originator of such programming need only possess a videotape recorder and a video bandwidth line to the head end; not even a broadcast license is necessary. Access to the transmission medium can be assured to all programming sources. Surplus capacity can permit equality of access.

43. The technology and components required to provide competitive switched services, such as telephone and videophone, over current CATV systems have not been demonstrated. It is not apparent that current CATV systems will have any advantage in attempting to provide such services. The unique advantage of cable distribution systems lies in narrowcasting, that is, in efficient distribution from one source to large, selected, localized groups of receivers.

44. Voting; banking; electronic, first-class mail delivery; computing services; and such information retrieval as the facsimile reproduction of business or personal status data, transactions, and documents are often suggested as future CATV services. The switched telephone plant readily provides such point-to-point services. The requirement for privacy and some degree of security suggests that these services may be better provided as a modification of the current switched telephone plant. The dedicated local loop inherently provides a degree of privacy. The technology to provide comparable privacy in a CATV system at an acceptable price appears remote.

45. Because facsimile is currently unsatisfactory for interlibrary use, postulating its widespread use in the home in the near future seems unreasonable. Hard copy facsimile cannot begin to match such newspaper advantages as low cost per page and ease of scanning.

46. It is argued that subscription television (STV) on a per-program charge basis is essential to obtain popular, current programming both because program suppliers of box-office product prefer to participate in the gross receipts on the basis of percentage arrangements and because the public objects to paying a flat fee to purchase blocks of entertainment. The case for STV on a long-term subscription basis is based on the following arguments: 1) consumers will resist paying on a per-program basis; 2) the elimination of scrambling and unscrambling equipment reduces the costs of STV by over 30 percent; and 3) the additional signal processing required for scrambling and unscrambling is desirable to avoid degradation of the signal quality.

47. There might be considerable interest in bringing in a dozen or more European channels to the United States on a routine daily basis, and making these available to CATV operators for distribution on a long-term subscription basis. Programming costs could be small compared to U.S. television broadcasting costs for generating an equal number of programming hours.

48. Although the average household receives about 6 channels of television, some areas provide 10 to 12 channels. The fare offered in these areas does not differ noticeably from that in areas having half as many channels. From this it appears that if CATV were to make available only 20 channels to every home in the 48 states, it would not significantly change programming. Unless CATV can offer at least 30 to 50 channels, it is not likely to result in dramatic programming changes.

49. An excess of channels, e.g., as many as 100 for commercial programming, would permit repetition of existing programming perhaps 10 times in a single month. This could be used to reduce competition for the audience. The advertiser could look to the cumulative audience rather than the one-shot audience; the return to the copyright owner could be somewhat greater under these conditions.

50. For the television viewer who watches an average of five or six hours a day, program repetition so that he can see formerly competing programs cannot result in even doubling his viewing time. Discretionary time is probably so limited that an increase of an hour would be appreciable. For the discriminating viewer--one who watches an average of an hour a day or less--the availability of reviews and comments may also lead to a one- or two-hour increase in average viewing.

51. Programming that looks to the cumulative audience rather than to a one-shot audience should significantly reduce costs. Both the advertiser and the copyright owner may benefit from the change.

52. CATV's most important use may be in instructional television for schools, businesses, and homes. It may possibly revolutionize instruction--particularly for the university and for continuing education. Such developments are not likely to occur under the economic forces of the market. Studies, planning, and regulatory action will be required to nurture CATV's potential as an instructional medium.

53. The 100 most popular lecture classes on the university campuses each hour could be made available to a larger audience. Students who preferred could listen to the lectures at home, as some now do in dormitories. Colleges and universities could become primarily places for small discussion groups and laboratory work. Ubiquitous educational programming on the scale suggested can reduce some of the costs of student experimentation. The necessary requirements could evolve through individual testing, experimentation, and search, and thus be more uniquely suited to fulfilling the needs of the individual student. University education has functioned as a filter through which only the hardiest, most highly motivated, and best equipped pass through. In an industrialized society where education

is essential, such a filtering technique serves neither the individual nor society well. CATV can make it possible for the poorly prepared to hear each lecture and repeat each course as many times as necessary.

54. If professionals are to make full use of these courses, the programs must be acceptable for credit. Feedback from each participant is necessary to maintain interest, to verify participation, and to permit testing and scoring. The programs must be reviewed by outstanding specialists in the field, and their reviews widely disseminated in the technical literature. The programs must be repeated 10 to 20 times at widely varying hours and days over an interval of 30 days in order to make the cost of that time low relative to alternatives.

55. High-capacity CATV constitutes a promising technique for fulfilling 1) the need for education to begin much earlier in life than was formerly accepted, i.e., well before kindergarten age, 2) the need for continuing education due to rapid technological change and the trend toward several careers during a lifetime, and 3) the need for education to occupy the elderly. Its prospects are intimately associated with its potentially vast channel capacity. CATV has a unique potential for contributing to and revolutionizing the U.S. educational (instructional) system.

III. PROBLEM AREAS IN TERRESTRIAL TELEVISION BROADCASTING

In their concern for beautification, some communities are eliminating aerial utilities and rooftop antennas, and converting to underground utilities and an underground community antenna television (CATV) distribution system. This is a growing trend in recently planned communities. However, unsightliness of the rooftop antenna is not the primary complaint against television broadcasting. The issues treated in critical reviews of television tend to fall into two major areas: 1) lack of programming variety, and 2) high cost of both time and programming. This high cost prevents effective use of television in non-entertainment areas. An area less often mentioned is the problem of poor signal quality.

PROGRAMMING VARIETY

The increase of both VHF and UHF stations will probably continue because the number of authorized stations is substantially more than the number now on the air. There is room for few more VHF stations; thus, most growth is occurring in UHF stations.

Under present television standards, interference permits only every sixth UHF channel to be assigned if there is to be acceptable picture quality. If every possible UHF assignment were made, the total number of UHF channels within a particular community would be only 12. In adjacent communities, only a fraction of these channels could be assigned to each community. Thus, the effect of creating a large number of UHF stations for most of America's population would be at most to double the number of stations receivable. The average number of stations received might go from 5.6 (see Table 25 in the Appendix) to 10 or 12. In areas where there are now that many signals available, the variety of programming is not particularly different. Therefore, something other than a small factor increase in the number of broadcast stations is needed to obtain variety.

What effect would more networks have on programming variety? The profitability of ABC is so far below that of NBC and CBS that further consideration of a fourth commercial television network (to provide a broad spectrum of programming) is likely to be postponed for some time. Furthermore, there do not seem to be enough independent stations to comprise a network of equal magnitude to NBC or CBS. Because the major thrust of advertiser-supported commercial programming must be toward the mass audience, a fourth network could not afford to deviate substantially from the pattern of the currently profitable networks.

Both expansion of Educational Television (ETV) as proposed by the Carnegie Commission [8] and implementation of over-the-air subscription television (STV) are some of the remedies available to counter what has been called the mass-audience syndrome. Each of these may eventually provide a few channels of distinctive programming. There are a variety of public subsidy schemes that could provide more ETV programming, and a variety of possible regulations, e.g., the FCC proposal to cut back on network programming in prime time, that could provide a few hours of diversity.

TIME AND PROGRAMMING COSTS

No means are apparent for broadcasting highly specialized video programming (such as instructional material) on a large scale and with frequent repetition. Neither ETV nor STV broadcasting significantly alters this problem. The cost of an hour's time over a network station in the major markets is in the $1000 to $10,000 range. For spot announcements, the equivalent hourly rates are 10 to 100 times these figures.

The cost of a season's new programs acquired by the national commercial networks indicates an average cost per hour for each of about $120,000 [8]; the estimated cost of all types of contract programming for ETV national distribution varies from $29 thousand to $105 thousand per hour; national programs produced at key ETV stations run from $22.5 to $45 thousand, and local and exchange programs produced at key stations run from $3020 to $7097 per hour.[†] Although costs for local programming are low compared to programming costs for a national audience, they are still too high to permit more than an hour or two per week of local programming per station.

A large increase in the number of channels available to the home is needed if the time and programming costs are to be low. This is infeasible using terrestrial broadcasting without either reallocating frequency spectrum at the expense of many competing services, or drastically redrawing television receiver standards, which would make obsolete a consumer investment of over 20 billion dollars.

SIGNAL QUALITY

The problem of broadcast signal quality is increasing slowly but steadily due to the increase in high-rise construction in the cities, and increasing more rapidly with the penetration of color television receivers (see Table 13 in the Appendix).

Color television requires a higher-quality signal than black-and-white television because multiple images or ghosts become more disturbing. The viewer is not concerned with the reasons for the problem: multipath distortion due to propagation anomalies, a weak signal due to physical barriers such as mountains, the erection of a tall new building between the receiving antenna and the broadcast antenna site, or some kind of interference due to the arrival of multiple carriers at the set. The viewer does want a better, less variable picture.

[†] See Tables 20, 21, and 22 of Ref. 8.

Eliminating a single ghost requires two antennas and appropriate phasing of the two signals. But the phase adjustment that cancels the major ghost on one channel generally does not help the situation on the other channels. There are often two or more dominant ghosts on a single channel. Furthermore, only ghosts that are separated in azimuth can actually be eliminated by this means; the ghost originating behind but directly in line with the broadcast antenna, which is the problem in some major metropolitan areas, cannot be eliminated. Even if one were to invest ten times as much as is now spent in a home television antenna, one could not be assured of adequately solving this problem. Modulation changes and the associated major redesign of television sets, if feasible, could substantially improve the situation, but only at a high cost.

A grade B service contour is defined by the FCC as one in which the picture quality is expected to be satisfactory to the median observer at least 90 percent of the time for at least 50 percent of the receiving locations within the contour, in the absence of interferring co-channel and adjacent-channel signals. A grade A service contour is one in which satisfactory service is expected at least 90 percent of the time for at least 70 percent of the receiving locations. A principal city service contour is one in which satisfactory service is expected at least 90 percent of the time for at least 90 percent of the receiving locations. The quality of signal acceptable to many viewers for entertainment programming is likely to prove unacceptable for both extensive and intensive educational and instructional programming.

Thus, the potential of current terrestrial broadcast television is severely limited by two factors: lack of available channels and impaired signal quality. If television remains primarily an entertainment medium, these limitations will have little consequence.

Extensive use of television in instructional and community service activities might dramatically increase the demand for channel capacity, thus demanding a supplement--or an alternative--to broadcast television. Section IV sketches what capacity might be required with increased demand, and assesses the implications of such requirements.

IV. POSSIBLE FUTURE DEMANDS

Within the past few years, many have pointed out the potential of broadband communications to the home [11-33,62]. Table 1 lists various categories of future demands and provides crude subjective estimates of the range of bandwidth likely to be required for each category. The list is intended to be fairly inclusive and does not reflect the probability that the demand will materialize by any specific time period. For a detailed discussion of these services, the reader should consult Refs. 11-13.

SERVICES EXCLUDED FROM DEMAND PROJECTION

Telephone services and videophone services equivalent to AT&T's Picturephone® have been omitted from the list because these are switched services. The technology and components required to provide such switched services competitively over current community antenna television (CATV) cable systems have not been demonstrated, and it is not apparent that current CATV-type systems will have any advantage in attempting to provide such service. It is assumed that the unique advantage of current CATV cable distribution systems lies in their ability to provide efficient distribution from one source to selected groups of many receivers (i.e., a wired analogue of broadcasting sometimes described by the term "narrow-casting"), or perhaps in their ability in the converse mode to provide collection from many preselected groups of sensors and delivery of the output to a single terminal (data collection that could be described by the term "narrow-gathering").[†] Although variants of current cable distribution systems are possible, and although some of these

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[†] Satellites can be used both for broadcasting and for "broad-gathering," because their antenna beams cover large areas on the ground.

Table 1

POSSIBLE FUTURE DEMANDS ON CATV DISTRIBUTION SYSTEMS[a]

Service	Equivalent Bandwidth[b]
1. Commercial television (entertainment, sports, foreign language, news)	12-100 TV channels
2. Cultural television (ETV, STV)	3-10 TV channels
3. Instructional television	
Elementary	4-10 TV channels
Grammar, Jr. H.S., H.S.	8-20 TV channels
Undergraduate University	10-100 TV channels
Graduate University	4-10 TV channels
4. Continuing education	10-100 TV channels
5. Local origination	0.1-10 TV channels
6. Weather, stock market	0.1-2 TV channels
7. FM radio	20-100 MHz
8. Polling, instructional feedback	3 kHz-1 MHz
9. Surveillance and traffic control	0.5-4 TV channels
10. Shopping, meter reading, alarms	100 kHz
11. Public safety	1-10 TV channels
12. Remote pickup[c] back to head end	5-50 TV channels

[a] All are one-way services; for items 8-12, the direction is reversed from the normal one.

[b] Television channel is assumed to correspond to a 6-MHz bandwidth.

[c] These channels are for programming originating within the system and intended for distribution under categories 1 through 5.

variants can readily offer two-way switched services, there are not sufficient experimental data available to indicate that they are likely to supplant the present system.

Voting, banking, electronic first-class mail delivery, computing services, and such information retrieval as the facsimile reproduction of business or personal status data, transactions, and documents were not included as CATV services although they are often so listed. The requirement for privacy and security in these relatively personal services suggests that these services may be better provided as a modification of the current switched telephone plant. With the introduction of the solid-state electronic switching centers and touch-tone® telephones, these features may be more easily provided by the telephone system. The technology to provide privacy--much less security--in a CATV system at an acceptable price appears remote today. It is not at all clear at this time that there is any justification for proposing the inclusion of these services in a CATV system.

Document transmission by facsimile is currently costly [51-55]. Current facsimile equipment costs are approximately 50 cents per page. When telephone and staff costs are included, the costs vary from 68 cents to $6.20 per page, depending on the distance across the United States, the volume of transactions, and the type of facsimile equipment used. When substituted for mail in interlibrary use, the difference in time for a 10-page article is the difference between 4 and 21 days for mail and 2 to 34 hours for facsimile. The manner in which librarians handle interlibrary loan requests can create a situation in which facsimile makes little sense because the actual transmission time via U.S. mail may be only a fraction of the total delay.

Improvements in clarity of transmission, i.e., legibility of journal typography of six-point size type face and less, footnotes, and italicized material, and development of the capability for continuous tone illustrations is needed. The development of equipment for the direct scanning and transmission of material from bound volumes, preferably face up, is particularly necessary for library use.

If facsimile services are improved and widely adopted for interlibrary use in the next decade, then it may prove reasonable to postulate their extension to the home via CATV in the 1980 to 1990 time period as a one-way service to all subscribers. Costs per page will have to drop to one-tenth to one-one hundredth of present costs.

When two-way computing and facsimile services do spread to the home, they are more likely to do so via telephone lines, and only because there is a student in the house. The few recipes the housewife wishes to retrieve or copy, and the few documents the homeowner wishes to record or store, can be copied on a neighborhood machine without the investment in, and the clutter of, seldom-used home equipment, and can be more cheaply stored in the safedeposit box of the nearby branch bank. Thus, Table 1 makes no allowance for CATV channels for home computing or facsimile services on an individual basis.

SOME ASSUMPTIONS IN ESTIMATING NUMBER OF CHANNELS

The minimum number of 12 commercial television channels in item 1 of Table 1 is based on the fact that some households now receive 12 channels of television (see Tables 25 and 29 of the Appendix). If CATV were to provide 95 percent of all U.S. households with the 3 commercial networks, 2 ETV networks, 1 STV channel [72] and 9 regional independents, it would produce a significant increase over broadcasting's current capability for the majority of viewers. This lower-bound estimate allows for the usual duplication of programming among stations, but not for extensive repetition of programming.

STV is listed only under item 2 of Table 1, but many of the other services listed could be supported by special subscriber charges. A distinction can be made between paying on a per-program basis versus paying on a long-term subscription basis, e.g., for a series of programs or for a special-service channel. The case for STV on a per-program basis has been presented by Zenith Radio Corporation [34]. It is argued that per-program charges are essential to obtain popular, current programming because program suppliers of box-office product prefer to participate in the gross receipts on the basis of percentage arrangements, and that the public objects to paying a flat fee to purchase blocks of entertainment [35]. The case for STV on a long-term subscription basis is supported by a segment of the CATV operators, e.g., Gridtronics, Inc., a subsidiary of Television Communications Corporation, Inc., is exploiting this approach. It is argued that consumers will resist paying on a per-program basis, that the elimination of scrambling and unscrambling equipment reduces the costs of STV by over 30 percent, and that the additional signal processing required for scrambling and unscrambling is desirable to avoid degradation of the signal quality.

CATV systems facilitate charging on a per-channel basis because only inexpensive, passive filters are required to deny the special-service channel to non-subscribers. In the case of over-the-air or broadcast STV, it is technically feasible to install a decoder at the head end of a CATV system that would unscramble broadcast STV signals and transmit them over the cable to particular subscribers. The costs are reduced compared to broadcast STV because every subscriber no longer requires unscrambling equipment, but the ability to charge on a per-program basis is sacrificed.

Figure 1 shows the relationship between STV charges on a cumulative monthly basis and on a per-hour of programming basis. Current national advertiser-supported television

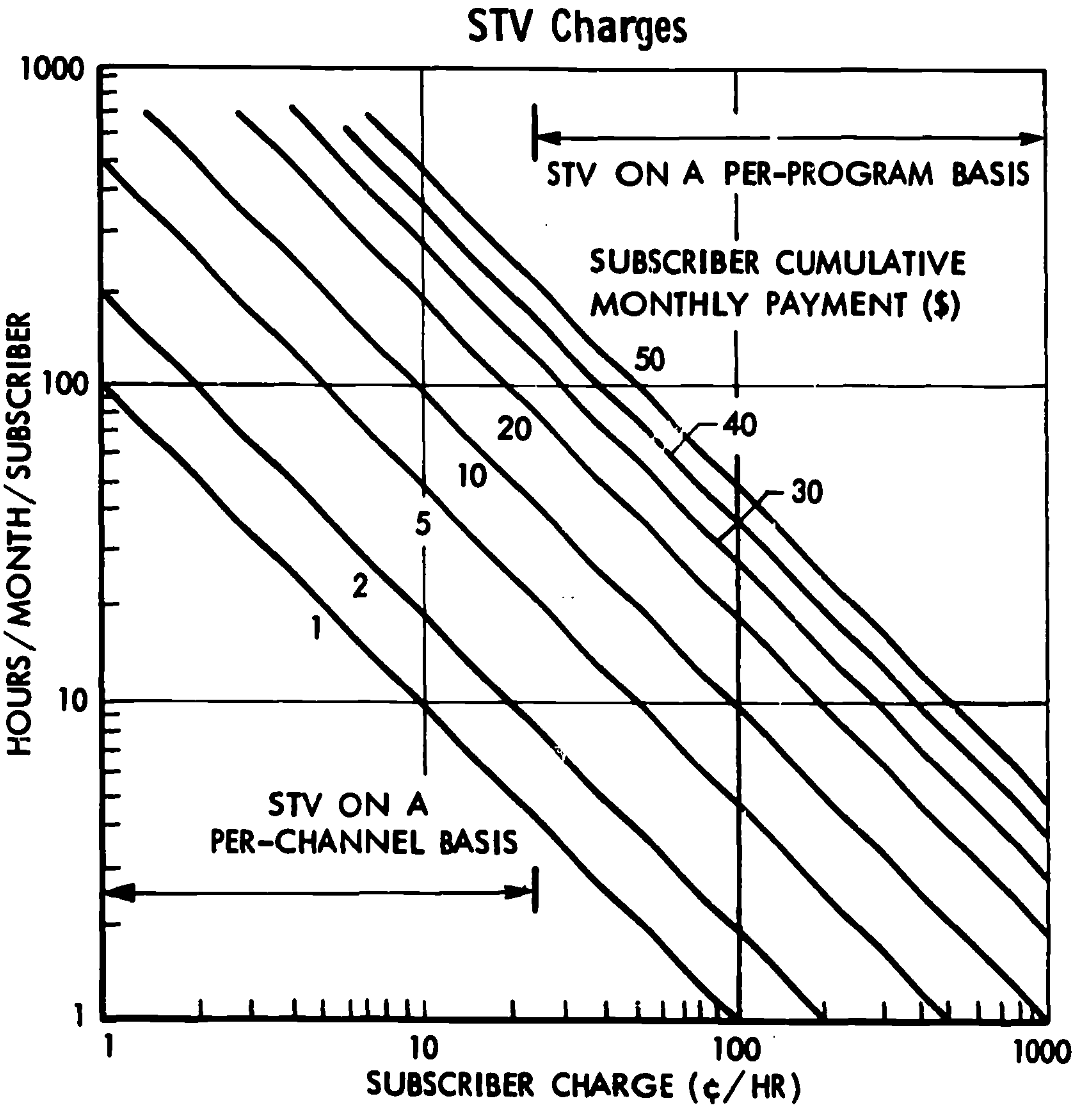

Fig. 1--STV Charges

programming represents an hourly investment of around one cent per household viewing the program; i.e., a range of one-sixth cent to two cents per household probably covers most network programming. Thus, the extreme left-hand side of the abcissa characterizes current television. Although using STV to present box-office material on a per-program basis suggests charges in excess of $1 per hour, it is likely that if such a system were in operation it would explore the potential of material as low as 25 to 50 cents per hour. Thus, roughly, the right half of the graph corresponds to charges on a per-program basis. The entire left half of the graph corresponds to charges on a per-channel basis.

Although an exceptional community may incur average STV charges in excess of $10 per month, the average subscriber is more likely to pay between $1 and $10 per month. The number of hours of programming the subscriber buys per month can be read from Fig. 1.

Although some box-office product may be shown only once, other material may be repeated up to ten times (at different times of the day throughout the week) to achieve saturation of the potential audience. Figure 2 shows the effect of such repetition on the number of hours of programming transmitted. Figure 3 shows the conversion to channel requirements. The minimum bandwidth of one channel for STV in Table 1 assumes a charge to the subscriber of 11 cents per hour, based on a channel subscription charge of $2 per month and 18 hours of program viewing per subscriber per month, 10 percent average penetration of the potential audience per showing and 10 showings, and use of the channel for only 6 hours per day and 30 days per month.

The upper bound of ten channels for item 2 of Table 1 assumes two ETV channels and eight STV channels. In this case, the 8 channels are assumed to be used as average of 12 hours per day per channel over the 30 days per month,

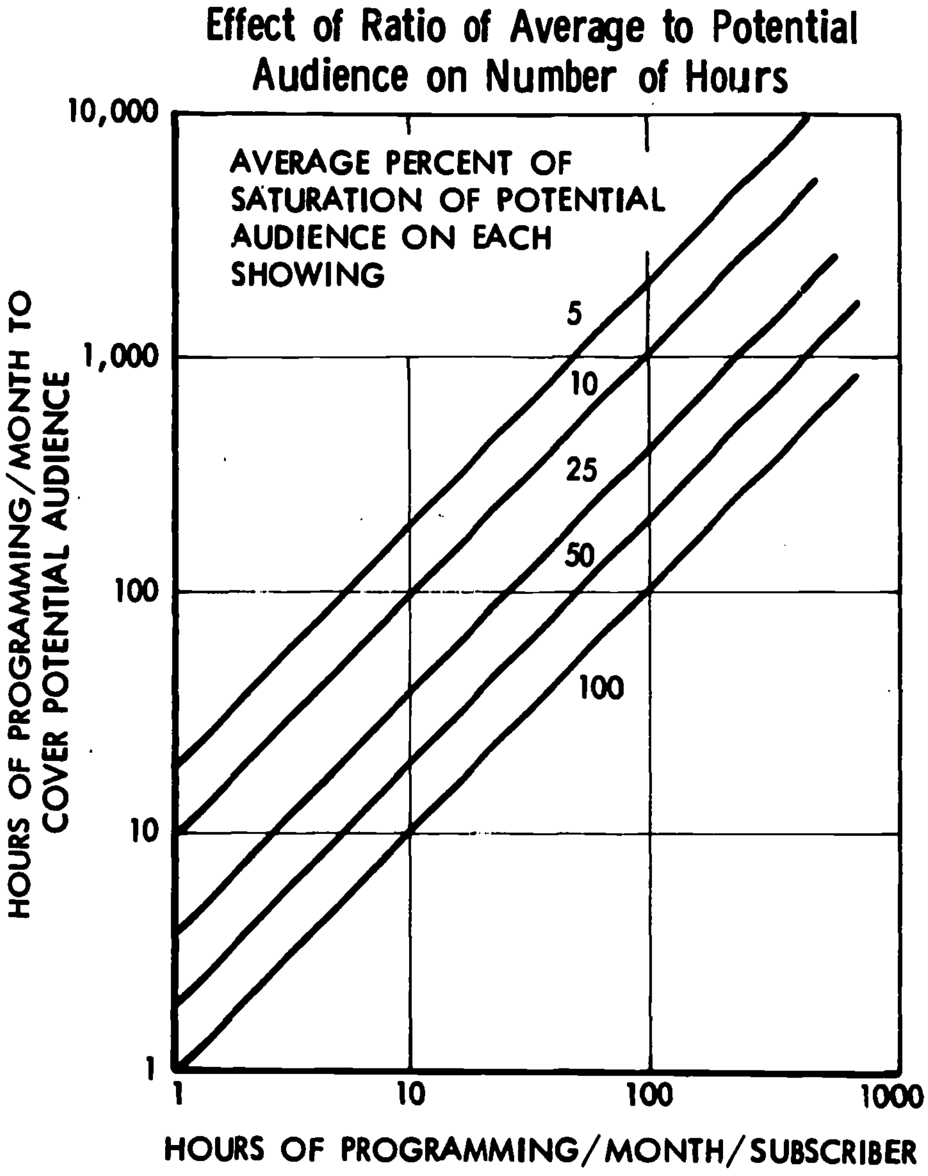

Fig. 2--Hours of Programming Required to Reach 100 Percent of Potential Audience

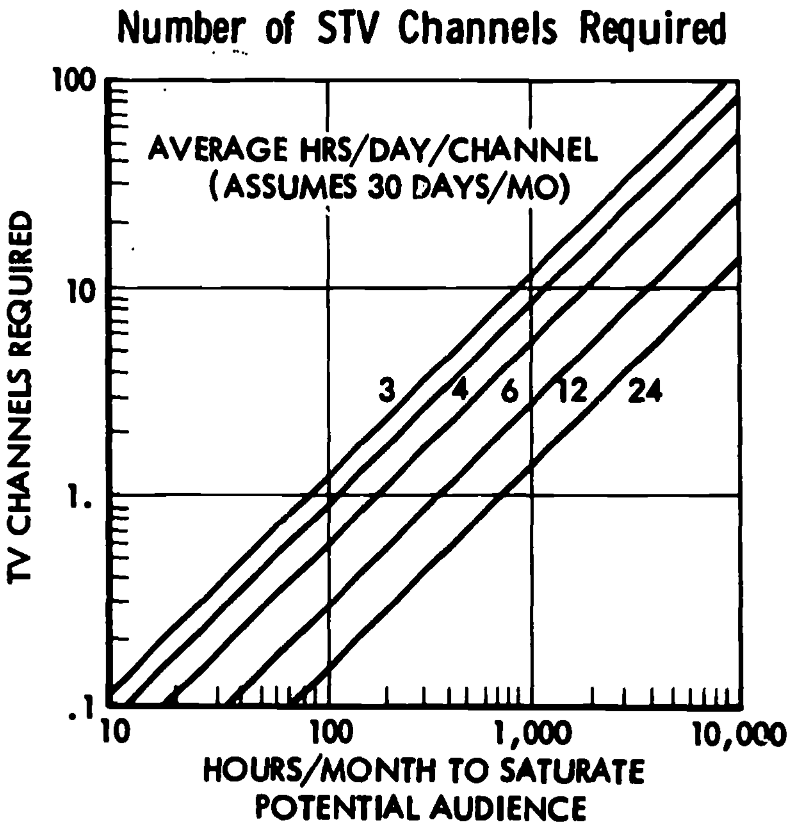

Fig. 3--Number of STV Channels Required to Reach 100 Percent of Potential Audience

or for 2880 hours; 10-percent saturation of the potential audience is assumed so that the average subscriber household watches 288 hours per month. For a typical household of four persons, this means 71 hours per month of STV viewing per person. A $20 total monthly payment per subscriber corresponds to $2.50 per month per channel and an average charge to the subscriber of 7 cents per hour of programming.

The minimum estimates (items 3 and 4) are based on existing Instructional Television (ITV) systems, either closed-circuit systems, microwave link interconnected systems, or broadcast using ITFS (the Instructional Television Fixed Service band around 2500 MHz).

The lower limit on local origination, item 5, is based on the one example of a middle-class tract (Dale City, Virginia) that generates an average of a few hours of programming per week over its own channel, using volunteers [61]. The upper bound is suggested by a review of Ref. 26. The minimum value for item 6 is set by a typical time-shared weather channel similar to that in current cable system usage. The upper bound assumes plots of rain, wind, and other data shown continuously with analysis on a channel dedicated to weather information. The FM radio band of item 7 provides between 50 and 100 FM stations per cable and allows for some radio channels to be dedicated to emergency services. The upper bound allows for between 125 and 250 FM music programs. Even a small cable system could afford to distribute large numbers of canned FM channels because a single tape player could be built to provide 25 FM channels for 24 hours on a single spool of wide magnetic tape. Such a system could be used to supplement the books-for-the-blind program.

It is assumed that all instructional channels would use the audio return channels of item 9 for audience participation. The minimum 3kHz bandwidth allows for a single time-shared response channel. The upper bound of 1 MHz assumes that every television channel has an associated response channel available for use if desired.

Items 9 through 13 are listed as one-way services. The direction, however, is reversed from the normal one. It is assumed that either a separate portion of the frequency band is used to separate these return direction signals from those being sent out from the head end, or separate cables are used in each direction. In the first case, filters are used to separate the signals in each direction. The signals can either be amplified independently in split-band amplifiers, or passed through a common wide-band amplifier and separated again by filters so they can be routed in opposite directions. Such equipment is already on the market. The technique is used in some cable systems to send local-origination signals from a cable system studio to a distant head end, or to bring an off-the-air broadcast signal from an antenna site to the head end. If the volume of narrow-gathering traffic is large enough, a separate cable could carry the signals back to the head end.

The public safety channels, item 12, can be used for such emergency purposes as medical links and fire and police services. The degree of privacy possible on these channels is primarily determined by the amount spent on special scrambling equipment. Privacy here is common or shared, and thus more practical than the personal or individual privacy required by banking, electronic mail, etc.

DOMINANT UPPER BOUNDS

The upper bounds of 100 television channels set for item 1, for undergraduate instruction under item 3, and for item 4 tend to completely dominate the total bandwidth requirements. Although these figures are designed to set the scale rather than the precise number of channels required, a discussion of how such large values were arrived at seems desirable.

How should so many channels be used? How could programming costs be paid for? One of the first uses for additional channels would be to repeat existing programming so that the viewer can choose when to see a given program. Because some areas of the United States now receive 8 to 13 channels of television, mere repetition of this material on other days and at other hours could consume 40 to 100 channels. Television watching, like moviegoing, could become more discriminating. Note that such extensive repetition of commercial television would involve no additional costs for programming preparation. Thus, commercial television could fill many more channels of television with a slight increase in origination and transmission costs.

One of the new services provided by Intelsat satellites is intercontinental television. If a dozen or more European television channels were brought to the United States on a routine daily basis, and if these channels were made available to CATV operators for distribution, there might be considerable interest in such a service by the public on a long-term subscription basis. Even if payments for the programming were required of all cable operators offering this service, the costs per subscriber could be expected to be small compared to U.S. television broadcasting costs for generating an equal number of programming hours.

It may be necessary to supply as many as 100 channels for entertainment, sports events, and foreign language programs so that adequate numbers of channels are left over for the other uses mentioned in Table 1.

The 100 most popular lecture classes on the university campuses each hour could be made available to a larger audience if a large number of channels were available; students who preferred could listen to the lectures at home, as some now do in dormitories. Lectures also could be repeated at several hours of the day to make them more readily available, and to help those who want to hear the material a second or third time. Colleges and universities could become primarily places for small discussion groups, section meetings, and laboratory work. The money spent on large auditoriums and lecture halls could be made available for other needs. This approach might alleviate the inexorable rise in costs per student for education, compounded by the increasing number of students applying for admission each year.

University education functions as a filter. In an industrialized society where education is considered essential, such a filtering technique may serve neither the individual nor society well [50]. If CATV can eliminate the economic necessity for such filtering, the poorly prepared could hear each lecture, and repeat each course, as many times as necessary.

Recent British discussions on establishing an open university by broadcasting lectures over the BBC during prime time in order to 1) reduce the cost of a university education, 2) make it more readily available to all, and 3) make it a more pervasive component of life at all ages indicate an awareness of the potential value of such an approach to education.

During evenings and on weekends, channels could be used for continuing education at home for a variety of professionals: doctors and paramedical personnel, dentists, lawyers, scientists, engineers, etc. The costs of these programs could perhaps be recovered on a pay-television basis: a charge per course or lecture series in addition to the monthly cable charges. The number of hours offered for a particular specialty need not be arbitrarily set. It can be determined by those who need and use the service. In fact, to maximize the quality, relevancy, suitability, and variety of programming material offered for continuing education, pay television is perhaps both the simplest and the best solution.

Many requirements must be met if professionals are to make full use of these channels. The programs must be acceptable for credit, e.g., they must satisfy the state medical society requirements for continuing education or be acceptable for undergraduate or graduate university degrees. Feedback from each participant is necessary to verify participation and to permit testing and scoring. The programs must be reviewed by outstanding specialists in the field, and these reviews widely disseminated in the technical literature 30 to 60 days before the showing. To be readily available, the programs must be repeated often, e.g., 10 to 20 times over approximately 30 days.

Every automobile mechanic and home appliance repairman faces the same problem as the professional in trying to keep up with his field. If he is to be helped in maintaining and refreshing his competence, courses must be relevant, convenient, and timely.

Some of these channels could also be used for televised conferences. Whereas pay television has been suggested for supporting the programming costs of instruction for professionals, industrial support can be anticipated for channeling people into activities suffering from a shortage of personnel, and government support may be available for enriched and remedial education for school children.

Perhaps instructional television should be committed to the simple goal of effective self-improvement; such a non-elite principle best serves the objective of enlisting television in the service of diversity. Between formal and informal education, vocational training and continuing education for professionals, and avocations or hobbies, instructional television can make a contribution to everyone. To the extent that instructional television provides some professional-vocational enrichment or remedial programming for everyone, or to the extent that local programming or specialized fare can at some time appeal to each viewer, it transforms television into a rich menu of usages. The problem of audience capture for an evening by a single channel may be eliminated; in time, a more active and critical use of the medium by the general public should emerge.

V. POSSIBLE SYSTEM DEVELOPMENTS

The limited frequency spectrum, the characteristics of electromagnetic wave propagation parallel to the earth's surface, and economic considerations argue against anticipating radical developments that would permit the volume of over-the-air terrestrial broadcasting services discussed in Sec. IV. However, present coaxial cable distribution facilities and special terminal equipment could provide every service listed in Table 1 to a customer indifferent to price. The discussion in this section focuses first on competing technological developments and then on those developments in current community antenna television (CATV) technology that are most likely to provide these services at reasonable prices.

COMPETITIVE SYSTEMS

Satellite Broadcast Direct to the Home

An exciting alternative to CATV distribution is the use of direct-to-the-home broadcast satellites. The potential of satellites for providing services to the home has been extrapolated far beyond the usual proposals of the aerospace industry [31-33]. Such satellites face problems in limited spectrum, limited capacity, degradation of signal quality due to atmospheric and multipath effects, and high cost. In principle, spectrum and capacity limitations can be overcome by re-using the same frequency spectrum among large numbers of highly directional beams on a single satellite. The signal quality of such a space broadcasting system can be superior to current broadcasting due to the lower sensitivity to terrain contour than the near-horizon signals generated by terrestrial broadcast stations. Therefore, signals should be subject to less fading and multipath degradation.

It is impossible to accurately evaluate the investment in research and development (R&D), the corresponding time required, or the in-orbit cost of the subsequent operational capability described in Refs. 31-33. The relevance of any examples to the vast extrapolations to be evaluated remains open to question.

By mid-1963, U.S. federal agencies and private corporations had spent half a billion dollars on just the R&D phase of communication satellites [36]. At present, more than a billion dollars have been spent on U.S. procurements in communication satellites. The technology advance in the past decade has been less than anticipated in many areas [37].

The R&D cost of a program to build a synchronous 10-year satellite capable of 1) reliably providing one million two-way voice-equivalent circuits to inexpensive consumer-owned earth stations; or 2) reliably providing 500 independent television programs to portable, inexpensive receivers in 150-mile-diameter areas is estimated as 2 to 20 billion dollars. This is far larger than the R&D support planned for communication satellites for the next decade. Based on the current rate of communication satellite research, 20 to 40 years might be required to achieve such a capability. Such developments as the re-usable space shuttle are not likely to significantly reduce either the development time or cost of such a communication satellite. However, a decision to make satellite communications a high-priority national goal could cut this time to ten years.

In the absence of such a national commitment, the development will not be undertaken. It will not evolve out of other programs. Neither COMSAT, AT&T, or any segment of industry can afford the combination of investment and risk.[†] Despite any wishful thinking that the vast profits from satellite communications would rapidly advance the state-of-the-art, progress has been slow. COMSAT's efforts have been largely derivative, perturbations of technology pioneered by

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[†] See p. 21 of Ref. 31.

NASA and DoD. Limited funding of these agencies' communication satellite programs has forced cautious approach of limited, specific objectives. There is no indication that the pace of this evolutionary program will be modified in the next decade. Applications of present technology (with minor modifications) might well consume most of the funding available.

This does not eliminate, however, all direct-broadcast satellite systems. A direct-broadcast satellite system offering up to ten channels of television can be a useful capability for isolated seashore, mountain, and desert regions, as well as for mobile users. Such a capability would be adequate to cover the three existing television networks, several independent stations, and one or two ETV and STV stations. In general, good quality television signals are not currently available to these remote locations, and it does not appear economically feasible to supply these isolated and mobile users by other techniques.

Domestic satellites may have a more important role. For very large numbers of channels, satellite interconnection for real-time networking to head ends, and subsequent cable distribution appears to have two advantages over direct-to-the-home broadcast satellites: 1) the cost of the earth station can be spread over 100 to 25,000 subscribers; and 2) the frequency spectrum per satellite can be utilized more efficiently. A low-cost terminal receiving 100 high-quality television signals from a single satellite must rely on significant signal-to-noise improvement by wideband deviation, i.e., by using large index modulation. The more expensive terminal at the head end of a cable distribution network can use less bandwidth per channel. Higher frequencies would be necessary for a system providing 100 channels of television direct to the home, which also would raise the costs of terminal equipment.

Advances in CATV technology do not require large capital investments. Market forces can be used to produce the technology required for the services listed in Table 1 without government subsidy of the development. Cable systems can be built and modified on an incremental basis. CATV has an economic structure that readily facilitates charging viewers directly, and thus amortizing the entire cost of the system. The investment in a communication satellite system would be more difficult to recoup directly from the viewers and is therefore more likely to require advertiser support or government subsidies.[†]

Switched Video-Bandwidth Systems

A switched system is one in which the subscriber signals his choice of program to a switching center. Current cable characteristics limit the useful bandwidth of a single cable to 300 MHz, roughly adequate for 50 frequency-division-multiplexed channels. Improvements in cable characteristics may permit extending this to 100 channels. Therefore, to provide the almost 400-channel capacity of Table 1 would require 4 of these improved 100-channel cables. Amplifier and converter characteristics have limited capacity to under 20 channels. Many alternatives are possible, although the technology appears most likely to evolve in the direction set by the present system, i.e., frequency-division-multiplexed AM signals.

There are, for example, four video distribution schemes that have stimulated wide interest: 1) AT&T's Picturephone® [7,38-43,56-59], 2) Rediffusion's submission to the FCC [44], 3) the DISCADE (Discrete Cable Data Distribution Equipment) system proposed by Ameco, Inc. [60], and 4) the digital loop concept [24]. All of these should be classified as switched video-bandwidth systems.

[†] See p. 70 of Ref. 22.

AT&T's Picturephone ®

In selecting the parameters for Picturephone ®, the cost of transmission bandwidth had to be balanced against such parameters as resolution, frame rate, and picture size. The compromise decided on was about 250 active lines per frame (two interlaced fields per frame), 30 frames per second, and a 5.5 by 5-inch screen size, resulting in a black and white 1-MHz bandwidth analogue signal transmitted digitally for long hauls at a rate of 6.312 Mbit/second. The analogue video signals are transmitted at baseband between a few Hertz and 1 MHz, over twisted-pair wire, between the subscriber and the local central office. Two pairs are used, one for each direction. The limitation on the frequency band that can be distributed over a pair of twisted wires is an economic one. It is set by the closer spacing and higher cost of the amplifiers and equalizers with increasing frequency. Altogether, including the voice pair, there are three two-wire loops to the central office for each Picturephone ® installation. The loop distance is currently limited to about 3 miles (one way) for No. 22-gauge wire and 1 mile for No. 26-gauge wire in underground installations due to lack of temperature compensation in the amplifiers and to equalizer distortion. The transistor amplifiers on the video twisted pairs are spaced at two-third to one-mile intervals, depending on whether the gauge of the wire is No. 26 or No. 22.

Because the costs of 1) analogue to digital conversion, and 2) digital multiplexing were considered high, the design decision was made to carry the signals in analogue form between central offices, and to digitize only where the signal enters a digital trunk for long-distance transmission. Digital transmission over long distances is desirable to minimize signal degradation [45]. Because signal degradation is inevitable with digital encoding or decoding, the conversion is done no more than once between a pair of subscribers. Either digital (i.e., regenerative) or analogue amplifiers, or a mixture of both, may be used in digital long-haul transmission [46,68]. The planned high-speed rate for data transmission over Picturephone ® facilities (0.4608 Mbits/sec) will provide 10 times the 50-kbit data rate of DATA-PHONE-50 ® for about double the charge [71].

The Picturephone ® system is not compatible with current commercial television standards, which require at least 3-MHz bandwidth for analogue black and white transmission and about 5 MHz for color. Some time after 1980 it may be economically practical to go digital all the way to the customer at the 6.3-Mbit/sec rate. Analogue or digital, Picturephone ® links are far below the requirements for commercial television. High-quality digital encoding of the commercial black and white television signal results in a 80-Mbit/sec data rate, but simple processing can reduce this to 40 Mbit/sec [66], with subjective evaluations indicating negligible degradation of picture quality. A similar 40-Mbit/sec rate may be achievable with color television pictures [67]. Such a color picture still represents about five to seven times the bandwidth or the information rate planned for Picturephone ®. Low-cost signal-processing providing adequate information compression [64,69] to permit the transmission of commercial color television signals over Picturephone ® circuits cannot be foreseen at this time.

The capital investment per Picturephone ® subscriber has been estimated at around $6,000 to $10,000 [62], and many within AT&T believe the service will expand to perhaps a million sets in service by 1980 [58]. Thus, in the next decade, the investment in Picturephone ® facilities and equipment should be on the order of $5 billion; and in 30 years, the investment may be on the order of $50 billion. This latter figure would make the total investment in

Picturephone® comparable to the total investment in telephone plant.

Present and projected costs for Picturephone® service are so high as to make it utterly impractical for other than business use within the next ten years, except for perhaps the few percent of the population at the highest income level [71]. Picturephone® transmission will require 100 to 400 times the bandwidth of a telephone call, yet will probably cost in the range of 10 to 20 times as much for equal long-distance, equal-time calls. With widespread business and industrial use in the period between 1980 and 1990, it is possible that costs per call may fall to four to eight times that of the equivalent telephone call. Between the lack of compatibility in bandwidth with commercial television[†] and estimated fixed monthly charges of $50 to $100 (two video circuits to a central office),[‡] Picturephone® does not appear to constitute a viable alternative to CATV distribution in the foreseeable future.

Rediffusion's Submission to the FCC[††]

Rediffusion International Limited of London, England, currently supplies television over pairs of twisted copper wires, i.e., multipair telephone lines, to as many as

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[†] In urban areas with underground plant and short subscriber loops, an analogue Picturephone® bandwidth of 6 MHz or a digital information rate of 40 Mbits/sec may prove economically feasible over the existing twisted-pair plant in a decade or so. Such a broader bandwidth modification of the current Picturephone® system is not likely to evolve in a shorter time because of the formidable problems posed by the initiation of a new system and by its incompatibility with the suburban aerial plant, which is particularly sensitive to changes in ambient temperature, radio frequency interference (e.g., from AM broadcast stations) and 60 Hz longitudinal signals (i.e., pickup from power lines).

[‡] See Ref. 7, Exhibit 6, "Additional Costs for Picturephone® Service."

[††] See Ref. 44.

600,000 subscriber homes in the United Kingdom. In Hong Kong, 83,000 subscribers receive an average of 13 hours of television daily over Redifussion's 2 video channels combined. Each video signal is carried over its own pair of twisted wires. Thus, this system may be viewed as a wideband (more than 6 MHz), unswitched, one-way version of the Picturephone® local loop distribution, as Picturephone® service is also predicated on the transmission of video as an analogue signal between central offices and subscribers over twisted-pair telephone plant.

It is clear that long before the number of channels to be supplied to each subscriber reaches 100 to 400, a single coaxial cable has an advantage over 100 to 400 twisted pairs. In order to allow for growth to a large number of channels and for the host of new services predicted, Rediffusion proposed a modification of their existing system in their submission to the FCC. Their submission involves the use of only two dedicated, twisted, balanced-pairs to each subscriber rather than one twisted-pair per video signal. One of the two twisted balanced-pairs is for a video signal and one is for a control signal. The control signal is dialed. The subscriber dials a special video central office, called a program exchange center, to remotely operate automatic switches. The switches select the desired program and route it to the subscriber over his single, video, twisted-pair, balanced-wire line. If there are several television sets in the household, each must be provided with its own dial unit and its own set of two twisted-pairs back to the program exchange center. Thus, the costs per set rise linearly--both for capital investment and for operation.

Since the video signal is transmitted at HF, i.e., from 3.2 to 9.2 MHz, conventional television sets must use a converter to shift the frequencies to the broadcast television band. The savings in using a special set without a tuner, i.e., one designed to accept the HF signal and without audio amplifiers (assuming a high level audio signal is also transmitted over the same twisted-pair), would result in a significant savings in small-size television sets. For large picture-tube color sets and for all console models, the savings would be a small percentage of the total cost.

Crosstalk between balanced twisted-pairs in a multipair cable limits the maximum cable length to 500 yards from the program exchange center. Thereafter, the pairs must be separated. Thus, a city would have to be split up into zones of about 0.1 square miles, with a program exchange center centrally located within each zone. Rediffusion bases its cost comparison on 88 subscribers per mile, or about 770 households per square mile. Only 1 of the 323 standard metropolitan statistical areas (SMSA) used by the Bureau of the Census, has a density higher than this. The 24 most dense SMSAs, containing over 27 percent of households, have an average density of only 350 households per square mile. The average density over the 323 SMSAs is only 81.9 households per square mile. They contain 66 percent of all households in the conterminous United States. Thus, Rediffusion's approach appears focused on the dense city cores.

Examination of the cost comparison[†] between Rediffusion's HF Remote Selection approach and the typical U.S. coaxial CATV distribution system shows a small advantage in favor of the Rediffusion approach, based solely on comparative material costs--$49.60 versus $53.50 per subscriber. Most of the typical coaxial cable system approach cost is in a converter on top of the television set. If a special television set for coaxial CATV is used that has a built-in converter, the material cost drops from $53.50 to $23.50. In the United Kingdom, a special 19-inch screen-size monochrome receiver, designed for use with the present Rediffusion wire distribution system (no tuner and no audio

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[†] See Ref. 44, p. 32.

amplifiers), saves over $50 per subscriber. These differences are not decisive. However, the ratio of trunking costs for the two approaches does appear to be a decisive factor. Trunk cable cost per subscriber is higher in the Rediffusion approach by a factor of 2.3. This limits the Rediffusion approach to the most dense areas, and necessitates that two types of distribution systems exist: 1) that suggested by Rediffusion in the most dense areas, and 2) a conventional frequency-multiplexed coaxial cable system in the less dense areas.

The fact that AT&T started Picturephone® as a .5-MHz bandwidth system and only moved up to a 1-MHz bandwidth after careful evaluation and technical review suggests the severe problems in video transmission over twisted-pair. AT&T has the advantage that its twisted-pair multipair cable plant is already installed. AT&T could presumably see the advantage of developing Picturephone® as a 5- to 6-MHz bandwidth system compatible with commercial television signals if the economic penalties were not excessive. It thus appears unlikely that the development and evaluation of the Rediffusion approach will be undertaken in the United States. Without such an experiment in a typical U.S. city, a more definitive evaluation is difficult.

DISCADE: Ameco's Approach

Ameco, Inc. of Phoenix, Arizona has proposed a variant of the Rediffusion approach. Signals are distributed over small-diameter coaxial cables. Each television signal is on a separate cable, and the trunk consists of a bundle of such cables. Mainline or trunk amplifiers can be a mile apart. Assuming 25 amplifiers can be operated in cascade without excessive picture quality degradation, the 1-mile separation would permit serving customers up to 25 miles from the head end. The remote-controlled switching occurs at an area distribution center (ADC) that services about

24 or 25 television sets. Ameco does not propose to change-over to twisted-pair at the switching centers. The switching centers cover only up to 24 subscribers or television sets, rather than Rediffusion's 700 to several thousand. Typically, customers can be served who are 2000 feet from an ADC, and up to 3800 feet may prove possible.

This approach suffers from the same major flaws as Rediffusion's proposal. However, its use of shielded co-axial rather than bundles of twisted-pairs gives it some economic advantages in reaching subscribers in less dense areas. If for some reason conventional frequency-division multiplexed CATV distribution were not to prove practical for at least 20 to 30 channels per cable, this scheme might constitute a viable alternative. Not enough information is available on the Ameco approach to accurately assess its potential.

Digital Loop Concept

If many different signals are on the same cable in digital form, e.g., time-division multiplexed together, and if each signal is coded for a different destination, it is possible to separate the digital pulse-code modulated [65] streams by appropriate gating at each destination [24]. Such time-domain gating is an alternative form of switching. Although it has been suggested that such a system may evolve independently within about five years for home services [24], the suggestion appears to be unwarranted. The costs are likely to remain too high for some time [63].

However, another approach to a digital system is to install a separate coaxial cable and digital amplifiers from a central exchange to each subscriber. The creation of such a new digital network, independent of the existing plant, does not appear likely at this time. Instead, wide use is likely to be made of the 0.4608-Mbit/sec capability of

Picturephone ® circuits. By 1980, it may prove economically feasible to use regenerative amplifiers on the twisted-pair telephone plant, and to up the Picturephone ® data rate to 6.3 Mbit/sec. In underground, short, local loops, i.e., in urban areas, 40 Mbits/sec may be feasible. These modifications are likely to evolve after 1980 as part of Picturephone ® service where versatility and interchangeability in the types of information handled is required, where low error rate transmission is required [70], and where privacy or security is required. These are not the characteristics of home services in general, but rather of special industrial and business services.

Actual growth of digital communications has lagged decades behind its potential; the period from 1970 to 1990 is likely to see a redressing of this situation for the business world. Between digital telephone links and digital applications of Picturephone ® circuits, this period is likely to see a vast expansion of digital communications for business. At this time, it seems that only toward 1990 are the costs of wideband digital links likely to drop sufficiently to make worthwhile careful study of their role for non-business use.

CATV TECHNOLOGY

Number of Head Ends

The most important feature of local origination is that it characterizes a particular place. Large numbers of studios, each intimately a part of a single small CATV system, appear essential to ensure this concern for local issues. Economic and technological forces press toward the consolidation of small cable systems into a number of large, interconnected systems. For example, one effect of requiring origination may be to lead toward the consolidation or sharing of facilities, with its associated economies.

Such a development can only weaken the involvement in local issues. The problem cannot be viewed solely in terms of an implied definition of local programming, or in terms of setting a fixed number of hours for "local programming," as is indicated by broadcast industry experience. Explicit definitions and demonstrated involvement in community issues are essential. The direction in which cable systems grow must be guided to build and preserve an inherent involvement in local issues. (As a minimum, a number of channels in prime time, on a common-carrier basis and for a nominal fee must be readily available.)

If community desire for local programming is as great as community desire for local school boards or local government, then it seems desirable that the point at which programming is inserted into the system be located in the community, and perhaps centrally located in the larger communities. With existing CATV equipment, the limit on the radial distance covered from a single head end is about 15 miles. A distribution system can thus cover an area of over 200 square miles from a single head end with good reception of up to 12 channels. On the basis of this 200-square mile figure, the 3 million square miles in the 48 states could be served by less than 15,000 head ends. But any such number, based purely on technological limitations, should be viewed solely as a lower bound. Other considerations should determine the number of head ends or input points to the local cable distribution network. For example, if the basis were identifiable and distinct local school districts or political units, a more desirable number of head ends for emphasizing local programming would perhaps be about 22,000 (the number of school districts) or even 35,000 (in January 1967 there were 18,048 municipalities and 17,105 towns and townships in the United States). Under these conditions, related public service programming is likely to be more fully exploited.

But another, perhaps more desirable, basis would be distinguishable neighborhoods. Despite evidence that even in a major city a distinct neighborhood may consist of at most about 25,000 households, the planned number of households per head end in one major city is over 100,000. If local programming is to realize its full potential, the number of head ends in the cities should relate directly to distinct neighborhoods. It should not relate to an entity as large as the congressional district. Both local programming and picture quality are better served by a reduction in the length of cable between the head end and the farthest subscriber. Both are thus better served by a centrally colocated studio and head end. On the basis of the distinct neighborhood approach to determining the number of head ends, the optimum number might be as many as 50,000, rather than the 35,000 based on the number of municipalities, towns, and townships.

Compare this number with the present number. As of February 1969, there were about 2300 CATV systems, and about 2500 head ends. These served some 3702 communities. In addition, there were 1898 franchises not yet operating, and 2296 applications pending. The proposed increase from 2300 CATV systems to 50,000 is at most a factor of 22. If one were to reach this number of head ends between the years 1990 and 2000, when the number of U.S. households will have increased from the present 60 million to about 100 million, the average number of households per head end would be about 2000--roughly the same as the present average number of subscribers per CATV system. This small a number of subscribers per head end would have to support the local programming.

Number of Channels

The future growth of CATV strongly depends on the success of the present approach of frequency-multiplexed channels. Until about 1965, the average operating CATV system had a nominal capacity of 5 channels; between 1965 and 1968, most systems were built to have a nominal capacity of 12 channels on a single cable. Since then, systems have installed equipment capable of providing up to 20 channels when used with a converter. A few systems are now being built with dual cables and thus will have a nominal capacity of 24 channels without a converter (a switch is used instead at each subscriber's set).

Since 1968, systems are being built with amplifiers nominally capable of handling 20 channels. Although there are problems with picture quality in many existing 12-channel cable systems--and the problems become worse as the number of channels increase--improved cables and solid-state amplifiers are likely to solve these problems.

About 40 channels could be carried on a single cable by broadband, low-distortion amplification from the low end of the television band to the highest frequency for which cable manufacturers currently sweep-test their CATV cables. Impedance mismatches cause signal reflections from the discontinuity. These reflections appear as ghosts in the picture. The substitution of low-modulation index FM signals for the typical AM signals would not significantly reduce this sensitivity to reflected ~~signals~~. Although wideband FM would result in a substantial improvement, the increase in bandwidth per signal would also be substantial. Although the current return loss of cables over the 300 MHz is 26 to 30 dB, improvements in cable manufacturing techniques is likely to raise this frequency limit to 600 MHz over the next decade. If larger diameter cable is used, the attenuation at 600 MHz need be no greater than at 300 MHz. The same amplifier spacing can be used. Thus, the coaxial cable itself will not impose a limit of less than 100 television channels.

Careful suppression of harmonics and of third order intermodulation products in the amplifiers is essential.

Greater linearity is required at each stage of the broadband amplifier [60] to keep the crossmodulation products to an acceptable level. In principle, split-band amplifiers and filtering can solve the problem, but this brute force solution is expensive at this time. The problem of spurious outputs, both harmonic and third order intermodulation, are greatly aggravated by the dynamic environment of an actual installation (e.g., temperature changes, and the cascading of large numbers of amplifiers). Some experts claim a noticeable degradation in even black and white picture quality after going through only 15 to 25 amplifiers.

Within the next few years, even 40-channel amplifiers will probably be available at little extra cost if there is such a demand. Solid-state amplifiers with flat bandwidths of 1000 MHz are currently available for use in sophisticated microwave equipment, although they are exceedingly expensive. The use of CATV amplifiers with such broad bandwidths would permit sending more than 100 channels over a single cable.

To carry more channels, amplifiers require not only more bandwidth but also closer spacing to offset the higher cable losses at the higher frequencies. Developments in the semiconductor industry ensure that the cost per amplifier stage will continue to drop drastically every year for some time. Perhaps only 10 years from now the cost per mile of cable of the solid-state amplifiers suitable for amplifying 100 CATV channels may be only a little more than the cost per mile of cable of present amplifiers suitable for amplifying 12 channels.

This large improvement factor is inherent in the semiconductor industry. In this industry, manufacturing costs tend to be dominated by the investment in technology and capital equipment rather than by direct labor and material costs. Thus, prices may fall substantially given drastic increases in quantity. For example, the selling price of an integrated-circuit amplifier fell from between $300 and

$600 to $2.50 over a period of about 9 years. Thus, yearly price reductions averaging 40 to 50 percent per year for a period of 9 years are not unknown, given sufficient volume to justify the capital investment.

If 4 of the present 12-channel cables were installed in a single duct in one operation, along with 4 sets of 12-channel amplifiers, one could have a 48-channel television distribution system. Due to some economies of scale and some learning effects, the cost per mile of the operation is likely to be only 2 to 2.5 times as much as a single cable for the cheapest system, and much less than this for the most expensive systems, e.g., systems where trenching and duct installation costs are high. In 10 to 20 years, a 4-cable system could provide 400 channels of television.

Some of those involved with CATV feel that a tunable converter, designed to convert 8 or more nonstandard channels and the 12 standard VHF channels to 1 frequency cannot be obtained at an acceptable price. However, this seems to represent unwarranted pessimism if interpreted to cover not only the present but also the next decade. The absence of operational single cable systems with over 20 channels can be accounted for by 1) the lack of a universal industry standard for the converter, 2) consumer resistance to an extraneous gadget on top of the console, 3) the vulnerability of the set-top converter to physical damage, 4) the competitive cost of a second cable in new systems, 5) the distant signal limitation of the FCC, and 6) the high cost of multi-channel microwave links. Adoption of a standard tuner for CATV use and the production of television sets with such a tuner built-in will eliminate these problems. Based on the increasing longevity of television sets (see Fig. 15 in the Appendix), widespread usage of such a set may require 10 to 15 years after adoption of the standard.

VI. DIRECTIONS OF FEASIBLE CATV GROWTH

INTERCONNECTION

The interconnection problem exists on many levels. One of the most important is the interconnection of city blocks where duct space is not available and where the costs of street cutting are high. Microwave links can be used in place of running cable trunks. One such approach is called the Amplitude Modulated Link (AML) [75]. Versions of this equipment have been built at 18 GHz using a single, highly-linear output amplifier and, more recently, at 12 GHz using separate output amplifiers for each channel and multiplexing the signals into a common antenna. In the original concept, the antenna was to radiate a sector or horizontal fan to serve many receivers; more recently, the design has been constrained to use a pencil beam. The system is limited in capacity by spectrum availability. Equipment costs may be high for high signal quality. If the channel capacity of cable systems grows, microwave trunking will be forced to the millimeter wave band where its economic advantage (compared to cable trunking) is questionable at present.

Regional and national real-time networking is generally suggested by the concept of CATV interconnection. Some of the arguments for such interconnection have already been made. Instructional programming aimed at the continuing education of professionals must be timely (except for basic instruction). The routing of film or magnetic tapes among thousands of cable systems on a sequential basis can thus be unsatisfactory; routing on a parallel basis is inordinately costly. Basic instruction is on roughly the same schedule everywhere, and thus also requires a parallel operation. To store 10 hours of video programming per day for 100 channels at each of 50,000 cable head ends for simultaneous transmission (at a cost of $40 per hour of videotape) results in a total cost of $2000 million just for one day's tape. The problems of handling 100 videotapes each hour and the personnel required to operate 100 videotape playback units are vastly out of scale for the average cable system's 2000 subscribers. Instructional programming on the scale suggested could perhaps be best carried out by interconnection of cable head ends via a wideband transmission system. In this case, the signals are simply poured into and through the head ends with little attention required by operating personnel. Alternatives for such interconnection are cables, wave guides, microwave, millimeter wave, laser links, and satellites.

Figure 4 shows the general trend in long-haul interconnection costs. The ordinate is the approximate actual cost per mile in dollars rather than some normalized value [107]. The wire, cable, and microwave links all seem to show the same general trend, which is expected to continue to be valid for even higher capacity. The L-4 cable extends the abcissa to 32,400 two-way voice circuits, and the L-5 cable extends it to 97,200 two-way voice circuits. The L-4 cable consists of a bundle of 20 coaxial cables within a single sheath. Each of these coaxial cables consists of a 0.1-inch diameter copper wire center conductor supported by polyethylene spacers about 1 inch apart within a 0.375-inch diameter copper outer tube. Each coaxial pair carries about 3600 voice channels in the frequency range from about 500 kHz to about 18 MHz. Half of the 20 cables transmit signals in one direction, while the other half transmit them in the opposite direction. Since 2 coaxial cables are used for spares and 18 for regular service, the capacity of the L-4 cable is 9 by 3600, or 32,400 two-way voice circuits [107]. Systems capable of transmitting as many as 10,800 voice channels per 3/8-inch coaxial cable, or 97,200 two-way voice circuits over a

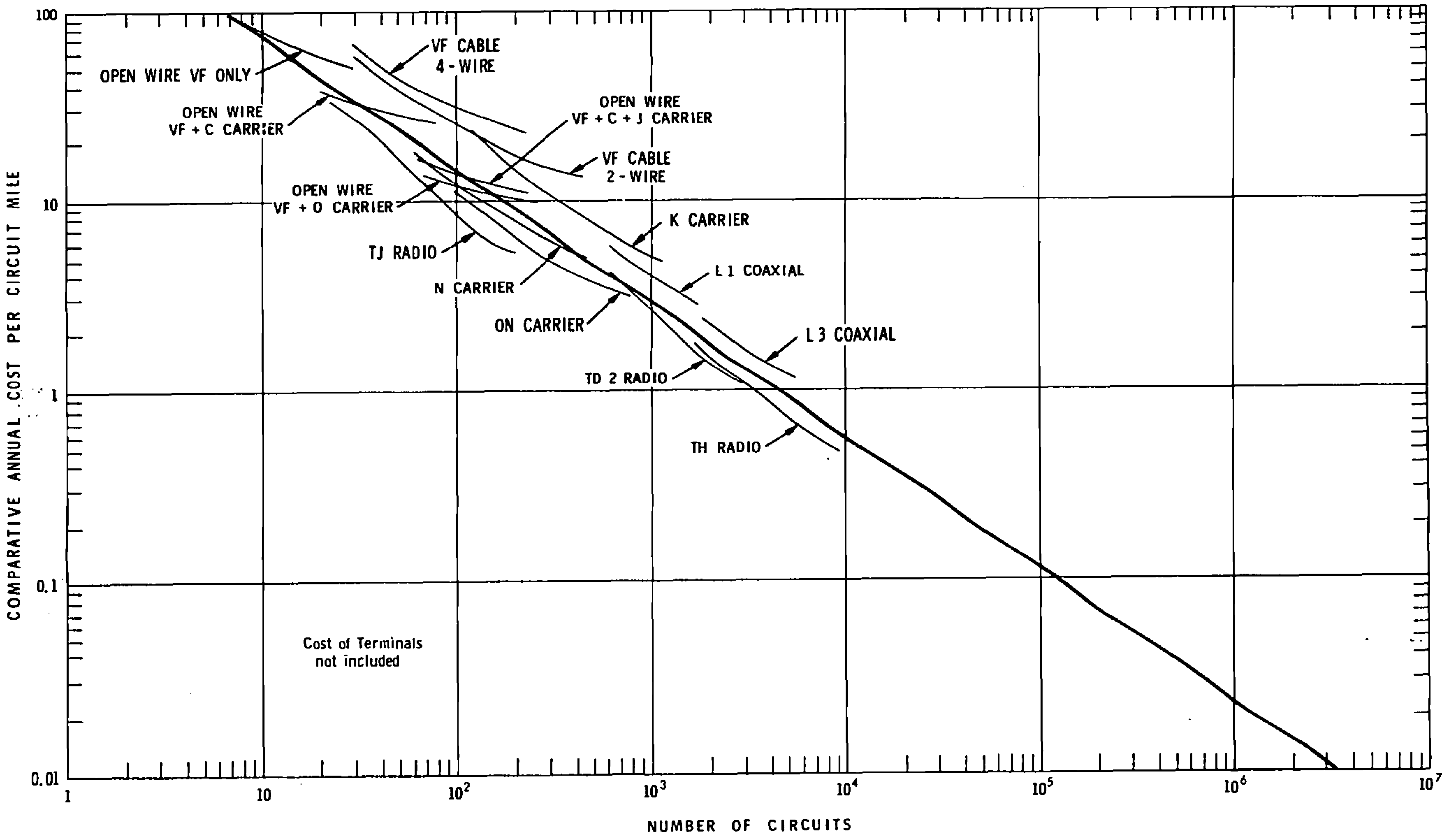

Fig. 4--Circuit Cost as a Function of Number of Telephone Circuits

bundle of 20 coaxial cables (after allowing for a spare in each direction); are being developed in many countries. Such cables, as well as wave guide, laser links, and satellite links are expected to follow the same cost trends of Fig. 4.

No real-time high-capacity interconnection of head ends within each of the 4 time zones of the 48 states is likely to be in operation before 1980. Regional interconnection for a limited number of channels is likely to be in use via microwave links. For business and industrial use, competition is developing for AT&T's long-haul transmission service. New common carriers are seeking to create a series of regionally-owned, nationally-interconnected, point-to-point microwave communication systems that will offer wider options on usage in terms of bandwidth, time-sharing, and terminal equipment at rates estimated at about one-half those offered by existing carriers [77]. Such facilities may prove attractive for CATV head end regional interconnection in addition to the community antenna relay service (CARS) band equipment. Several developments are being pressed to relieve the saturation of microwave link, common-carrier bands in and around major cities. Modulation parameters and equipment are being changed to use the existing allocations more efficiently and to reduce interference levels. The bulk of new long-haul investment is now in cable rather than microwave link; microwave has represented a decreasing share of new investment for some years now. Higher microwave frequencies, particularly the region between 18 and 50 GHz, are becoming attractive--aided by the rapid evolution of solid-state components in these bands.

Laser links for optical communications in the earth's atmosphere have received considerable attention in recent years [78-82]. Both studies and working hardware for optical transmission are available. Nevertheless, neither present nor near-term technology is likely to permit economically competitive terrestrial laser communications. The gulf between laboratory laser R&D and practical applications for terrestrial communications seems great, and lasers as a terrestrial long-haul, large-capacity communications medium will not be commercially exploited for many years. The use of lasers depends on an application that can fully utilize their tremendous information-carrying capacity, i.e., an application where no alternative technology is available. Such an application will exist only when the demand for communications has grown considerably. At present, millimeter wave guide systems are more economical for long-haul transmissions; they offer more capacity than optical links, and their initial cost is less.

Research on long-haul, circular, electric-mode wave guide transmission for communications has been carried on for 35 years [83-105], but recent developments radically differ from early concepts. A few of the most important changes are 1) the change from ordinary, hollow, cylindrical wave guide to 2-inch diameter, dielectric-lined, copper-plated, circular wave guide interspersed with occasional sections of helical wave guide (a hollow steel pipe containing a copper wire helix imbedded in plastic) for the suppression of spurious modes; 2) the change from an analogue, linear amplifier to a digital, regenerative repeater handling 282 Mb/s PCM; 3) the increase in the single-guide transmission bandwidth from 40 GHz (35 to 75 GHz) to 70 GHz (40 GHz to 110 GHz); and 4) the change from a 10 GHz bandwidth, 30 dB gain, 500 mW output traveling wave tube to an all solid-state repeater spaced at 20-mile intervals.

A single 282-Mb/s channel occupies a bandwidth of about 500 MHz and is capable of carrying 4032 digitally-derived telephone channels (one way). The per-channel performance objective is for an error of less than one bit in 10^6 for a transcontinental system, i.e., after a cascade of over 100 repeaters. The total band from 40 to 110 GHz frequency is divided into 120 channels, 60 for each direction. Assuming 58 working and 2 protection channels in each direction, the total wave guide capacity is 233,858 two-way telephone conversations. With a change in modulation from a two-level signal to a four-level signal, the waveguide capacity can be doubled to about 500,000 circuits. Forecasts of traffic growth in the United States indicate a need for a transmission medium with the capacity of a waveguide system by the late 1970s. Furthermore, the cost of such a system can be expected to be competitive with other high-capacity systems available in that time period, and the technology is well advanced for establishing such a system. Therefore, a field trial is tentatively scheduled for 1974. Following a period of design optimization and tooling up for production, service could start in 1978. The growth of Picturephone® service, high-speed data traffic, and CATV demand for interconnection could be key factors in determining the starting date of a long-haul waveguide transmission service. If color television signals are digitally encoded, a single channel on the guide could carry at least 2 television signals, or as many as 7, with data processing to reduce the redundancy. Thus, the 60 channels in each direction could carry 120 to 420 television signals, or a single such waveguide could carry 240 to 840 color television signals.

To be compatible with the present scenario, a communication satellite system would have to be capable of providing between 100 and 400 channels of television to on the order of 50,000 cable head ends. All head ends in the same time zone would receive the same programming. It appears that the commercial networks (based on present practice) would be satisfied with only providing two rather than four sets of programming, i.e., splitting the country into two parts rather than providing separate programming for each of the four time zones. If CATV were to evolve in the directions suggested, any system providing networking among the head ends, i.e., real-time interconnection, should be capable of evolving in the same direction.

The cost per subscriber of the ground terminal is a critical parameter in determining the minimum-size system that can afford satellite interconnection. Table 2 indicates the cumulative percent of subscribers in CATV systems above a given size, and Fig. 5 shows the results graphically. Assuming ground terminal costs of 10,000 to 100,000 dollars, Fig. 6 shows the relationship between the allowable investment per subscriber and the percent of subscribers covered by such systems.

If 95-percent coverage of CATV subscribers is considered adequate and the maximum allowable investment per subscriber is $240, the total ground terminal cost can be $100,000. On the other hand, if 99 percent coverage of CATV subscribers is considered essential and the maximum allowable investment per subscriber remains about $250, the total ground terminal cost can be only $50,000.

The system size distribution on which Fig. 6 is based is taken from the current data of Table 22 in the Appendix. In the absence of regulations restraining system size in the interests of local origination or signal quality, CATV systems are bound to become larger as they become more numerous. Economic forces tend to pressure toward larger, consolidated systems. They also lead to higher penetration as consumer income rises and color television sets become more pervasive. With more subscribers per system, the percentage of CATV subscribers covered by a given ground terminal cost will rise.

Although initial per-subscriber investments of about $240 to $250 just for the ground terminal seem high, economies of scale and improvements in technology are likely to reduce terminal costs by factors of 2 to 5 over a period of 20 years. The problems of providing 12 television channels

Table 2

CUMULATIVE NUMBER OF SUBSCRIBERS BY SYSTEM SIZE

Size of System[a] Number of Subscribers	Number of Subscribers in Category	Number of Subscribers (Percent)	Cumulative Number of Subscribers in Systems of this Size or Larger
10,000 or more	634,210[b]	17.33	17.33
5,000 - 9,999	767,253[c]	20.97	38.30
2,500 - 4,999	888,750	24.29	62.59
1,000 - 2,499	885,500	24.20	86.79
500 - 999	300,000	8.20	94.99
250 - 499	126,750	3.46	98.45
100 - 249	49,175	1.34	99.79
50 - 99	5,925	0.16	99.95
0 - 50	1,075	0.03	99.98[d]

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[a] See Table 22 in the Appendix.

[b] Includes the 44 largest systems plus the systems ranked as number 63 and number 88.

[c] This total covers all items not included in the preceding category.

[d] Discrepancy is caused by round-off.

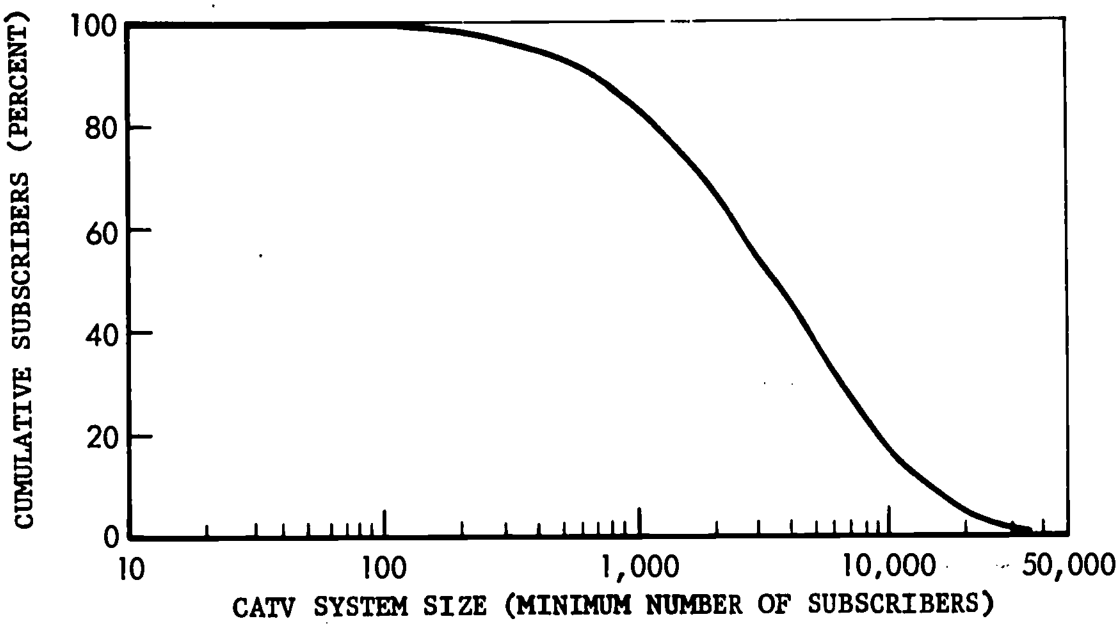
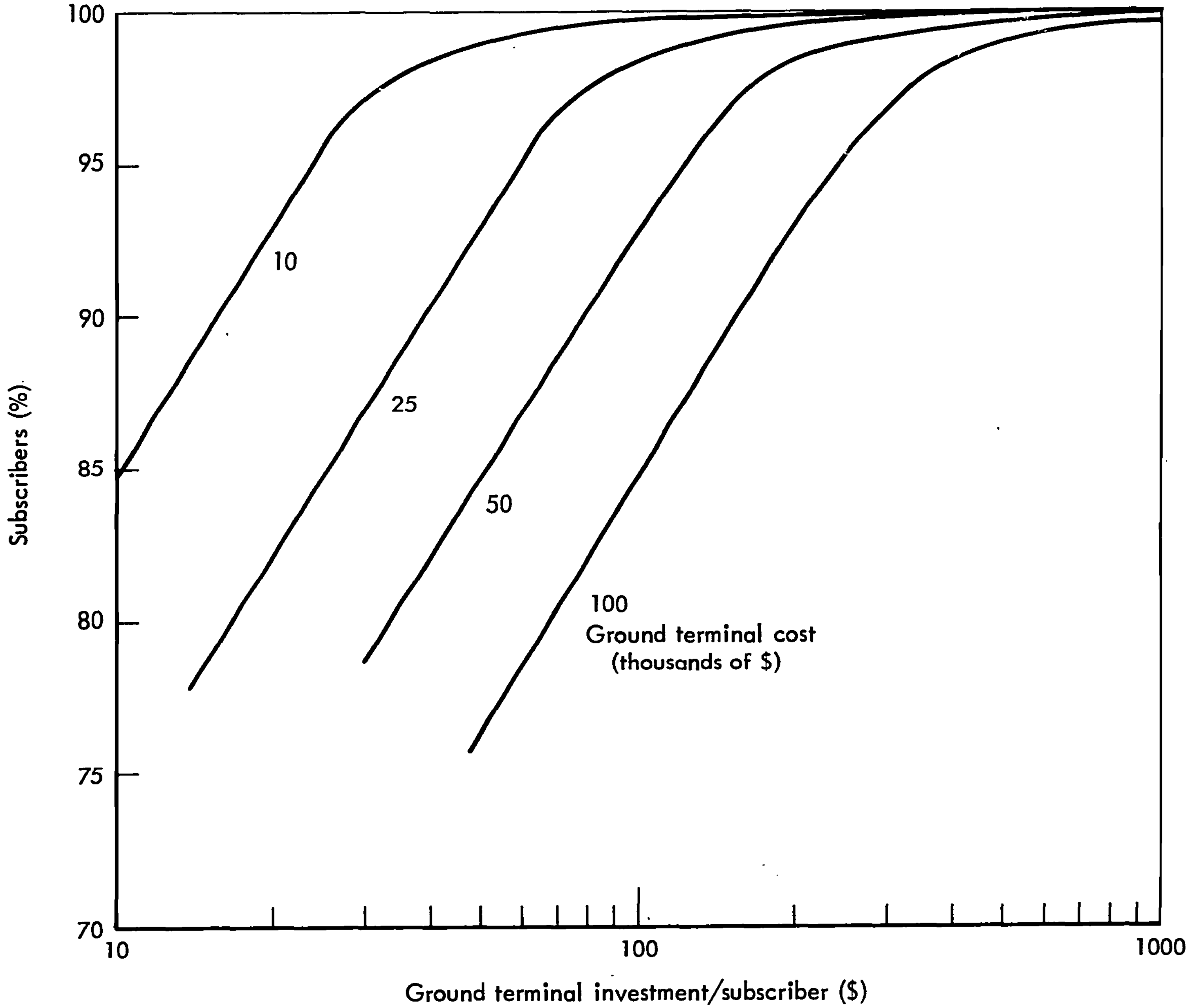


Fig. 5--Percent of Subscribers in Systems above a Given Size



Satellite Ground Terminal Investment

to a ground terminal costing between $50,000 and $100,000, based on current satellite technology, are severe.

The FCC submissions of Comsat Corp. [108-114], AT&T, and the Ford Foundation [115] in connection with a domestic satellite system first highlighted the potential benefits of communication satellites for television distribution.[†] Comsat proposed 4 satellites, each capable of transmitting 12 channels of color television. The 161 earth stations were to use 25- to 32-foot diameter receiving antennas. AT&T proposed 3 satellites, each capable of transmitting 12 channels of color television, and 73 earth stations using 25-foot antennas. The Broadcasters' non-profit Satellite System proposed by the Ford Foundation for the early 1970s, the BNS-3, utilized 2 satellites, each with a capacity of 24 color television channels. The 219 secondary earth stations used 25-foot antennas.

Comsat presented no estimate of savings from satellite operations in its August and December 1966 submissions to the FCC. AT&T estimated the total annual savings in 1969 for television distribution as $19 million. The Ford Foundation comments of December 12, 1966, estimated AT&T charges for television networking in 1970 as $60 millions, and satellite system costs as $28.8 million, for a total saving of $31.2 million. The potential savings for CATV interconnection should be even greater as a few satellites can be used to reach a larger number of ground stations, e.g., 10,000 to 50,000, and as the number of channels may eventually be greater than originally proposed.

Table 3 presents the current state-of-the-art for a commercial communication satellite [116-117]. The increasing costs for Intelsat communication satellites are

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[†] Docket No. 16495, "In the Matter of the Establishment of domestic non-common carrier communication-satellite facilities by non-governmental entities."

Table 3

INTELSAT IV PARAMETERS (1968)

Parameters	
Satellite manufacturer	Hughes Space Systems Division
Manufacturer's designation	HS 312
Weight at payload separation or ground weight (includes the apogee kick motor), lb	2,450
Orbital weight of satellite after apogee motor burnout, therefore includes apogee motor case and stationkeeping fuel, lb	1,250
Weight of hydrazine fuel for stationkeeping to 1 deg in longitude, lb	225
Diameter, in.	93.5
Height (with solar panels), in.	108
Overall height (including antennas), in.	180
Launch vehicle	Titan IIIb-Agena or Atlas Centaur
Contract start date	Oct. 1968
Delivery of first flight article	Aug. 1970
First launch	early 1971
Satellite receive frequencies, MHz	5932 - 6418
Satellite transmit frequencies, MHz	3707 - 4193
RF and IF channel bandwidths, MHz	36
Total number of channels	12
Stabilization	Spin, with antennas mechanically despun
Pointing accuracy, deg	± 0.35
3-dB beamwidth of two earth coverage satellite antennas, deg	17
3-dB beamwidth of two spot beams (pointing is set by a beam steering command to ± 0.1 deg accuracy in both east-west and north-south), deg	4.5
Gain of earth coverage antennas at edge of earth (subtract 1 dB to allow for losses), dB	16.5

Table 3--Continued

Gain of narrow beam antennas at 3-dB points (subtract 1 dB to allow for losses), dB	28.5
Total number of TWTs	24
Maximum number of TWTs operating at one time	12
Power output per TWT, min to max, W	6.5 to 8.0
ERP, global antenna, dBW/TWT	23 to 24.3
ERP, 12 TWTs in global coverage, dBW	33.8
ERP, spot beam antenna, dBW/channel	34.7 to 36
Total ERP (for 6 TWTs in global coverage antenna and 6 TWTs transmitting via the two 4.5 deg spot beams)	44
Earth station antenna diameter (typical), ft	85 to 106
G/T characteristic at 3-dB edge of beam, dB/deg Kelvin	40.7
Capacity in two-way voice-grade circuits	5000 to 6000
Capacity in TV channels	12
Nominal satellite contractual cost, R&D, flight models, and spare parts, $ million	72
Number of flight models	4
Cost per launch vehicle, plus related launch services, $ million	14 to 20
Specified life (with 0.70 probability of 10 out of 12 repeater channels operating), years	7
Prime power at beginning of life, summer solstice, W	565
Prime power at end of life, i.e., 7 years, summer solstice, W	435

not only due to the greater weight and complexity of each generation of satellites and to inflationary effects in the aerospace industry, but also to the fact that Comsat is beginning to carry a greater share of the R&D burden rather than merely procuring modifications of NASA and DoD hardware.

The parameters given in Table 3 were selected early in 1968. Thus, they represent early design values. When the equipment is built and tested during 1970, the new parameters that emerge will represent a laboratory state-of-the-art. Some three to seven years after launch, performance data will establish the state-of-the-art for operational hardware. The objectives of Table 3 do not advance the state-of-the-art as much as was proposed in the August 1966 submissions to the FCC on the domestic satellite. Instead, the parameters represent the balance a responsible manager must seek between aggressive development (and its associated large risks) and the risk of failure (and the subsequent charge of irresponsible stewardship).

A few studies have specifically looked at satellites for interconnecting CATV head ends [118-121]. The state-of-the-art assumed is essentially that of Table 3 for the near term. Table 4 summarizes some of the parameters for the interconnection satellite systems.

It is assumed [118,120] that the satellite power will depend on solar radiation and that it is not advisable to provide batteries to maintain the high primary power required during eclipses. Thus, it is desirable to select the satellite position in orbit so that the eclipse period falls about zero to two hours after local midnight. These eclipses occur on 88 days a year during the equinoctial periods, and vary up to 70 minutes maximum duration. To achieve an early morning eclipse requires that the satellite be situated at a more westerly longitude than the area to be covered.

Table 4

CATV INTERCONNECTION SATELLITE SYSTEMS

	Jefferis(118)	Early(119) (1970 model)	McClannon(120)
Satellite weight, lb	--	2400	--
Satellite receive frequency band, GHz	12	5.925-6.425	12
Satellite transmit frequency band, GHz	12	3.7-4.2	12
Peak-to-peak deviation of color television signal, MHz	4 to 16	--	--
Occupied RF bandwidth, MHz	14 to 26	35-40	--
Typical protection ratio required for just perceptible interference, dB (order corresponds to order of preceding values)	36 to 24	--	--
System margin allowance on protection ratio, dB	6	--	--
Allowance for a number of interfering signals, dB	4	--	--
Allowance for reduction in level of the wanted signal at the edge of the beam, dB	3	--	--
Allowance for pointing error of the earth station antenna and for satellite drift, dB	2	--	--
Attitude stabilization, deg	--	± 0.2	--
Stationkeeping, deg	--	± 0.1	--
Satellite transmit antenna beamwidth (neglecting satellite libration), deg	0.5-4	--	--

Table 4--Continued

Diameter, m (Sequence corresponds to previous beamwidths)	3.5-0.45	--	--
Diameter of coverage area at the sub-satellite point, km	315-2500	--	--
Satellite antenna gain, dB	32-51	--	33
Satellite RF transmitter power/TV channel, W	2.5-160	--	500
ERP/TV Channel, dBW	--	38	55-60
Community receiving antenna, diameter, ft	9.84	25 to 32	6-10
Gain, peak of main beam, dB	49.7	--	--
Beamwidth, half-power, deg	0.6	--	--
Receiver noise temperature, deg K	700	--	--
G/T characteristic at 3-dB edge of beam, dB/deg Kelvin	18.2	24.5 to 25.6	15 to 20
Color Television standards, number of lines	625	--	--
Number of fields/scan	50	--	--
Luminance-channel-weighted signal/noise in 5 MHz bandwidth, dB	46	--	--
Clear weather carrier/noise ratio in RF bandwidth, dB	14	--	--
Allowance for sound channel, dB	1	--	--
Loss in satellite feed, diplexer, etc., dB	3	--	--
Capacity in TV channels	4	12	6
Satellite lifetime, years	--	5 to 7	--
Cost of the ground station, $ thousands	--	200	100 20 @ 1000 level

Figure 7 indicates the effect of direct satellite cost on subscriber charges. Although satellites have demonstrated lifetimes in orbit in excess of five years, the pace of technological change tends to make satellites in orbit obsolete in two to five years. This pace of technological change may well continue for another two decades, and satellite technology may take this long to reach maturity and a degree of stability. Based on increased satellite complexity and rapid obsolescence, a useful satellite lifetime of five years has been assumed as reasonable in Fig. 7. Prorated direct satellite costs for Intelsat IV are $18 million for R&D and approximately $15 million for an Atlas-Centaur launch, or a $33 million direct cost per satellite. Allowing for booster and apogee engine failures and 5-year reliability brings the true cost to about $50 million. Satellites for CATV interconnection use are not likely to cost significantly less than this if they provide on the order of 6 to 12 channels. Higher capacity satellites are likely to cost significantly more. If 5 million subscribers are covered by satellite interconnection, the direct cost of a $50-million satellite would be 16.5 cents per month. The growth in number of subscribers is likely to offset the growth in direct satellite costs.

A more important cost is the maintenance and operating cost of the ground station. If recurring costs are as high as microwave relay station operating costs, e.g., 20 to 30 percent of investment, satellite interconnection could prove impractical for providing large numbers of channels. Fully automated, all solid-state ground stations with periodic maintenance might permit a recurring cost that is ten percent of investment to be achieved. The two encircled reference points of Fig. 8 are for a $25,000 ground station that can be utilized by 95 percent of subscribers for a maximum investment of $60 per subscriber, and a $50,000

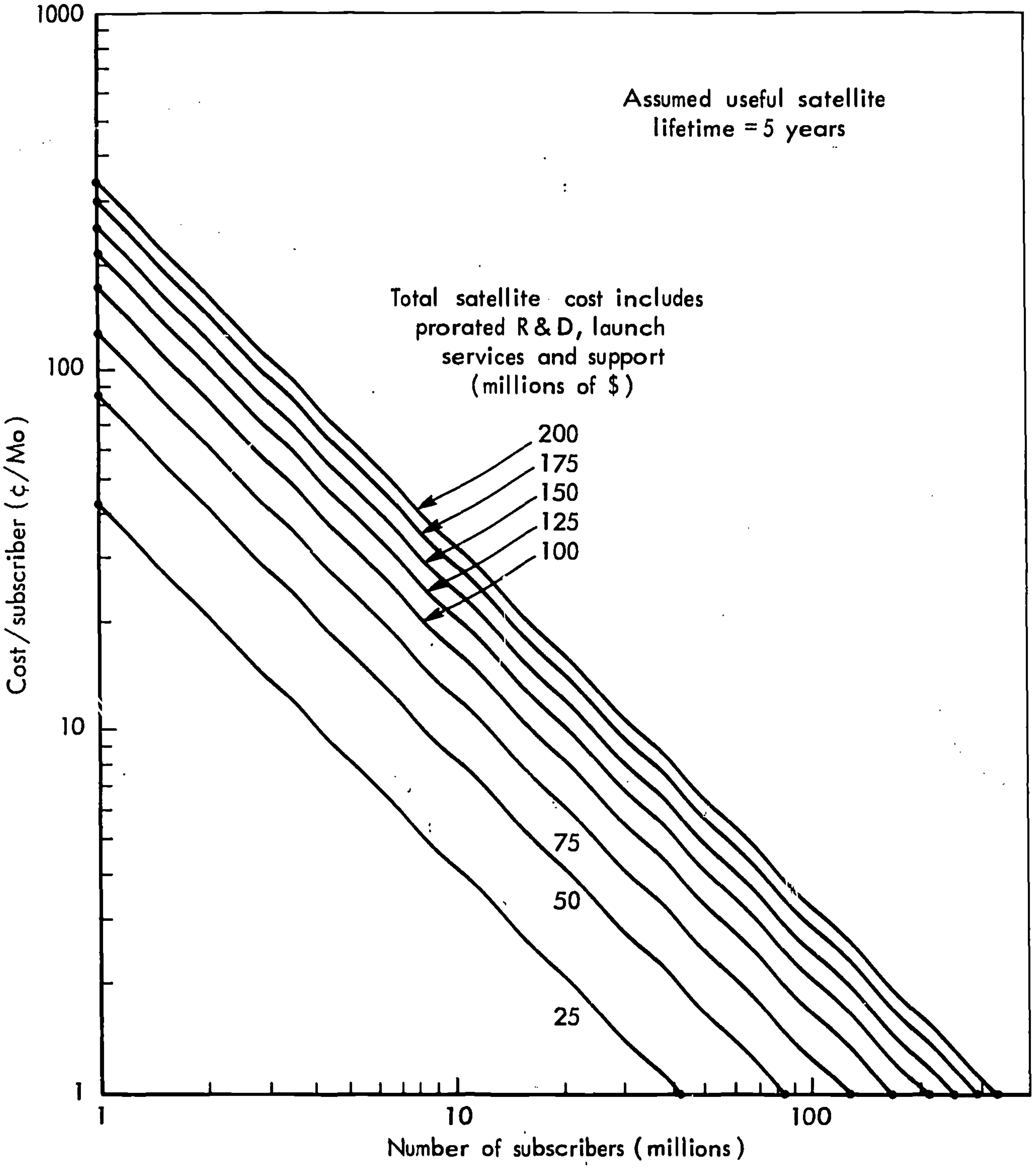


Fig. 7--Direct Satellite Cost

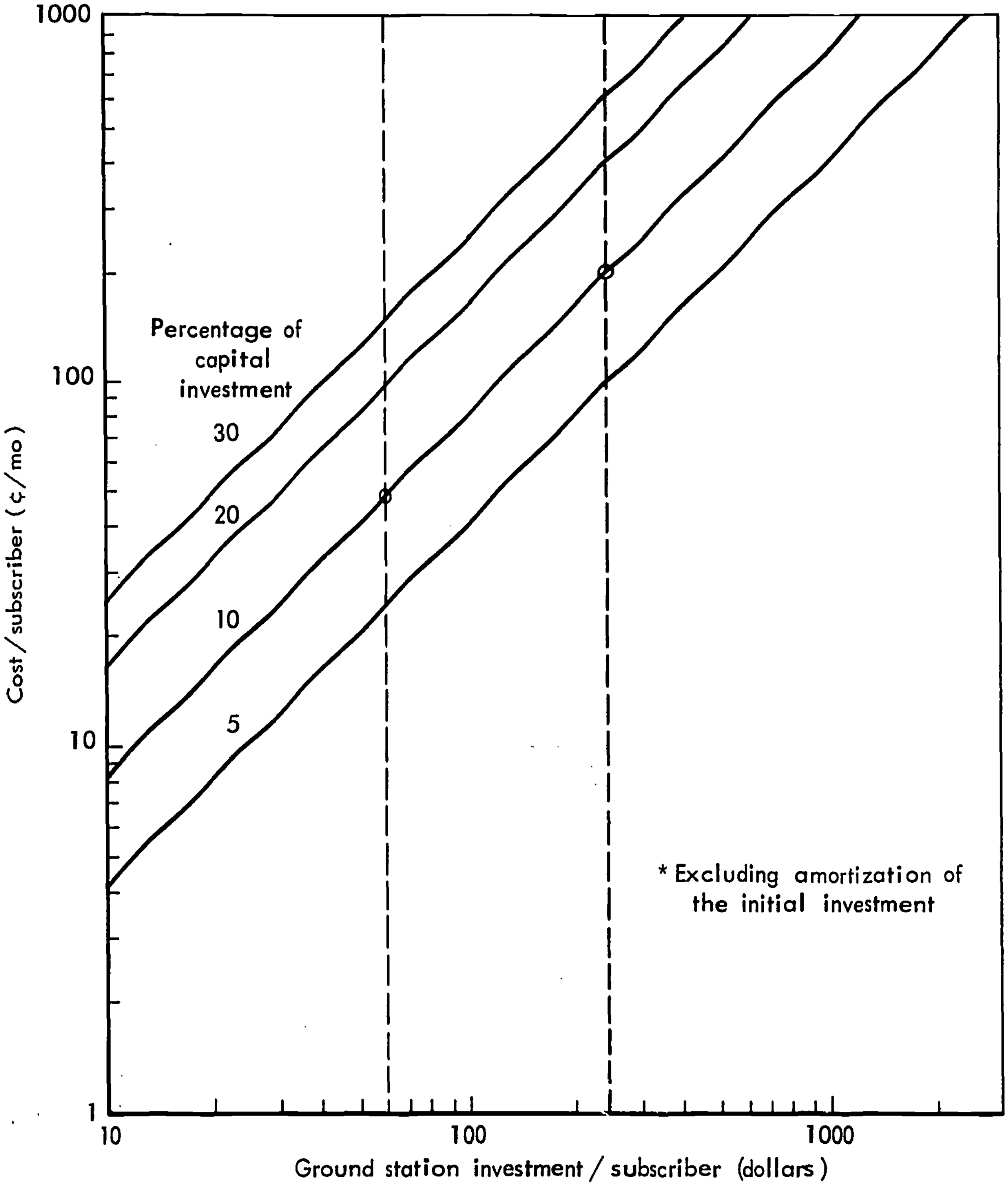


Fig. 8--CATV Satellite Ground Station Maintenance and Annual Operating Cost*

ground station that can be utilized by 99 percent of subscribers for a maximum investment of $250 per subscriber.

Although 6 to 12 television channels are adequate for experimentation and evaluation for an initial satellite interconnection system, the system parameters should allow for eventual expansion to about 50 to 100 channels per satellite. The use of 20 MHz per channel, orthogonal polarizations, 1000 MHz of the microwave spectrum allocated to television distribution around 12 GHz, and 30-foot diameter non-steerable receiving antennas could form the basis of such a system. Satellite station keeping in both longitude and latitude to better than ±0.1 degree would be necessary, with satellite attitude control to better than ±0.2 degrees. Such communication satellite performance has not yet been demonstrated.

POPULATION COVERAGE

A key matter is estimating the fraction of the population that it is economically practical to serve by CATV. Based on 1960 census data and a 12-level population density model, Table 5 shows the total cost for cable, drops, and head ends for supplying 12 channels of television by cable to various percentages of U.S. households.

Table 5

COST OF PROVIDING CATV TO ALL HOUSEHOLDS IN THE 48 STATES

Percentage of all Households in the Conterminous States	Cost[a] ($ billion)
50	11
65	19
95	46
96.5	48
99.5	61
100	66

[a] Assumes 1970 dollars.

The model assumed in this study used an average cable cost per mile of $5000. However, costs in urban areas have run as high as $100 thousand to $1 million per mile; New York City, for example, is toward the upper bound. Thus, any such calculation must be viewed as little more than a ballpark estimate. Average underground costs, for example, can be relatively meaningless because they are highly variable. If work need not be halted to let traffic flow, it may be possible to considerably reduce the cost of a street-cutting underground installation. An underground installation made in a new area before sidewalks and streets are in can cost as little as $3900 to $4800 per mile for a 12-channel system--exactly the same as an overhead pole installation. These figures do not include the drop lines, which are figured on a per house rather than a per mile basis.

Cost Differential Due to the Increase in Households from 1960 to the Year 2000

The cost calculations later in this section were based on 1960 census data and thus on the 44,951,000 households in the conterminous United States. By about the year 2000, the number of households in the 48 states will be about 100 million. The difference in the number of households, i.e., between 100 million and 44,951,000, can result in a relatively small cost difference.

To the extent that additions to the population are colocated with or interspersed between existing populations already served by CATV, the cost for supplying CATV to additional households may involve only the cost of the drop to the house or apartment. Thus, the cost of supplying an additional 55 million households at $30 per drop is only $1.7 billion. Whether the cost is $1.7 billion, or even $3.4 billion, it is low compared to the lowest model estimates for 95-percent or higher coverage, i.e., compared to

$46 billion or more. On this basis, the total investment for the year 2000 would be approximately the same as for 1960 for the same percentage coverage.

Investment on a Per Household Basis

In Table 6, 100 percent of households in 1960 corresponds to 44,950,824 households; in the year 2000, 100 percent of households corresponds to 100 million households. It is assumed that the investment in cable head ends is $5 billion at 100-percent coverage and varies proportionately with the percent of households covered.

Table 6

INVESTMENT PER HOUSEHOLD FOR CATV

Percentage of all Households in the 48 States	Average Investment/Household ($) 1960	2000[a]	Incremental Investment/Household ($) 1960	2000
50	489	237	-	-
65	659	313	1,226	566
95	1,071	498	1,964	899
96.5	1,103	512	3,130	1,400
99.5	1,363	629	9,726	4,390
100	1,477	680	24,163	10,829

[a] Assumes $30 per drop per additional household.

Rural Electrification Administration (REA) Experience with Supplying Electric Utility Power [122] and Improving Telephone Service [123] to Farms

The distribution of electricity by wire to remote and isolated farms is analogous to CATV distribution to households in such areas. Only 4 states have less than 95 percent of their farms supplied with utility power (see Table 7).

Table 7

STATES HAVING LESS THAN 95 PERCENT OF FARMS SUPPLIED BY CENTRAL STATION ELECTRIC SERVICE

State	Percent Supplied
Alaska	93.8
Hawaii	88.3
Nevada	88.1
New Mexico	89.9

It has taken both REA assistance and roughly 35 years to raise the number of farms receiving central station power from 10.9 percent (in 1934) to 98.4 percent (as of June 1967). Little is known about those who are not receiving central station power. REA has not yet established the characteristics of this 1.6 percent, but it has been claimed that all those who want power distribution already have it, and that a primary factor for those who do not want it is religious principle. Congress has fixed the interest rate on REA loans at 2 percent per annum and the maximum repayment period at 35 years.

There are 3.6 consumers per mile of line built with REA funds, and the annual revenue is $571 per mile of line. The average consumer pays $13.20 per month. This is higher than typical CATV payments in the United States today, which range from $2 to $10, with an average of about $5 per month. This high figure for the average REA customer suggests that charges of $10 to $20 per month for CATV in rural areas may prove acceptable to most.

REA-financed systems serve slightly more than half of the 3.1 million U.S. farms that are electrified. REA loans approved as of July 1968 total almost $6.6 billion, and its borrowers serve 6.6 million consumers. Thus, the loan alone amounts to about $1000 per consumer.

The incremental cost per household does not exceed $1000 until the population density falls below 100 to 200 persons per square mile. The average cost per household within the 223 SMSAs never rises above $549. Note that this average cost is just slightly over half of the average REA loan per customer.

Data showing that 98.4 percent of all U.S. farms receive central station electric service and that the average loan per REA customer is about $1000 seem to support the idea that 95-percent coverage of conterminous U.S. households by CATV may be reasonable.

CATV capital investment per wired household could be as much as $300 based on the typical $5 monthly charge and could go as high as $1200 based on $20 per month for rural areas in the 1980 to 2000 time period.

In view of projections of increased income per capita between 1980 and 2000 (in constant dollars), charges of $20 per month in rural areas for CATV may prove acceptable.

In October 1948, REA was authorized to make loans for improving telephone service. In 1950, 38.2 percent of U.S. farms had some kind of telephone service. About 80 percent now have service, and 95 percent of this service is dial. The loan per customer is less than for electric power, and the percent of farms covered is far less. Thus, the aspect of the REA telephone program that has implications for CATV is the rapidity with which coverage was extended from 38 percent to 80 percent of farms, i.e., 17 years.

Alternative Costing Procedures

The cost of providing CATV to 75 percent of the 67 million television households in 1980 has been estimated at $5 to $10 billion [46]. This estimate assumed a cost of between $100 and $200 per household and coverage to 50 million households; it proposed to cover all television households located in areas having a density in excess of 900 households per square mile. Figure 9 (based on the data of Table 5) indicates the cost of wiring 75 percent of the 100 million households in the year 2000 to be $26 billion. If the lower bound of $100 (in 1970 dollars) per household were to prove correct for up to 75 percent of households, the value of 75-percent coverage in the year 2000 would be $7.5 billion. In this case, the figures for more than 75 percent of households would be high by as much as $18.5 billion even if they followed the same trend. The lower curve in Fig. 9 is based on the $100 per household figure up to 75 percent of the households, and on a downward translation of $18.5 billion from the upper curve for all higher percentages of households. These two curves form reasonable estimates of the upper and lower bounds for providing CATV to all households in the 48 states.

A Perspective

To place this initial capital investment in perspective, note that the 1968 total consumer investment in television receivers and antennas was estimated at about $20 to $23 billion. With the greater penetration of both color television and the small, personal television sets, consumer investment for television reception is likely to grow. Assuming an average investment of $500 per household (1970 dollars), and 100 million households in the year 2000, represents a consumer investment of $50 billion. This represents only a modest increase in the $410 investment per household in 1968, when less than 25 percent of households had color sets (see Tables 16 and 24 in the Appendix).

A roughly equal investment in CATV spread over about 30 years and reaching 97.5 to 100 percent of all households (see Fig. 9) may not be unreasonable. When viewed

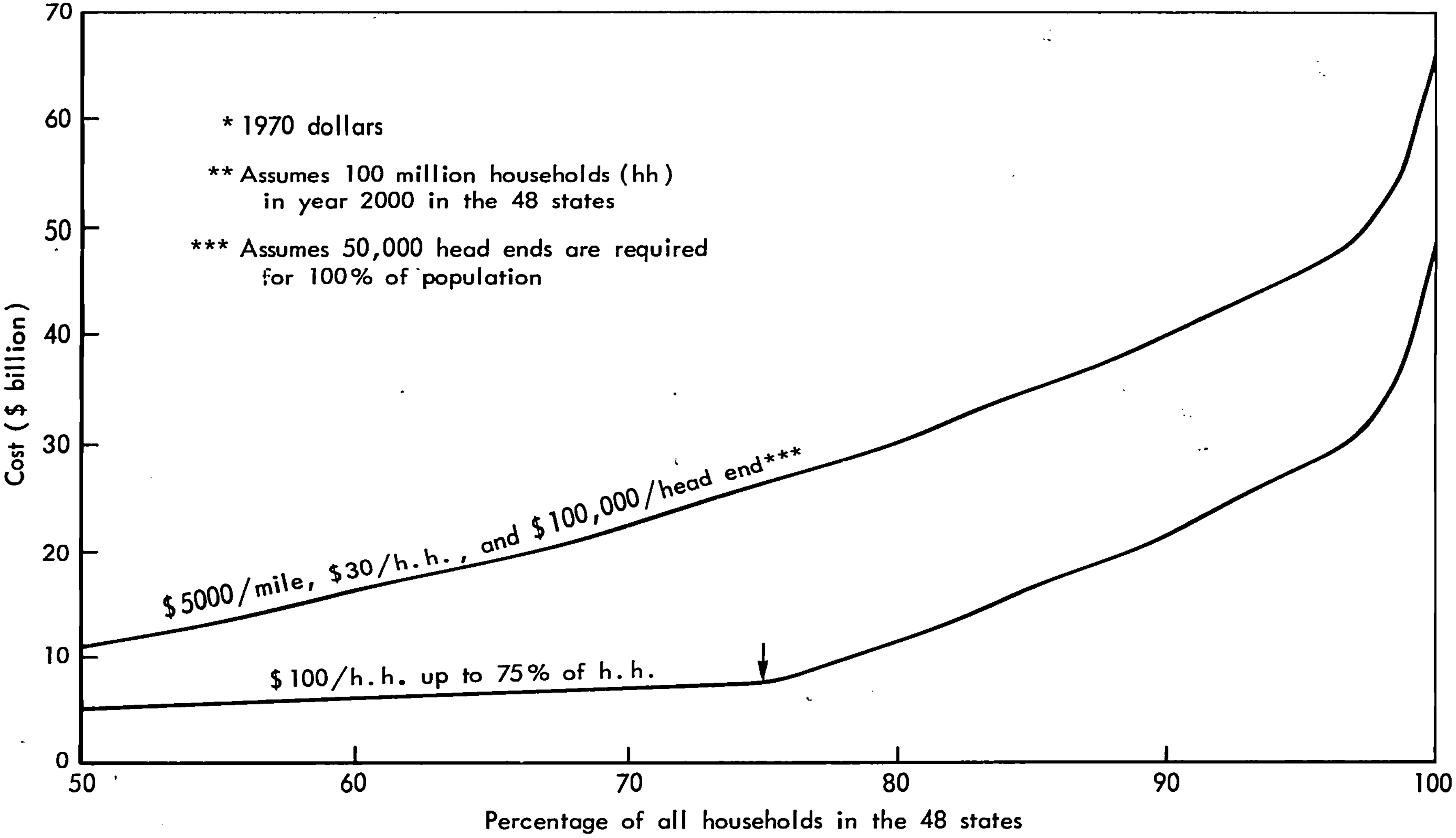


Fig. 9--Cost* of Providing CATV to All Households** in the 48 States

in relation to the growth of the economy over 30 years, even an investment of $46 billion to bring CATV to 95 percent of all households may not be unreasonable.

Although 95-percent coverage may seem high, it may be achievable at lower costs because of the large uncertainty in the figures provided by the upper bound cost models. Taking into account 1) that population is more dense and more clustered than the model allows (the model used 1960 density distribution data and average densities over large areas), 2) the large reduction in cost by not providing service to those most dispersed and remote areas, and 3) economies of scale and improvements in technology that may reduce costs, the cost should certainly be lower than the upper bound of Fig. 9 indicates.

COST OF PROVIDING CATV TO ALL HOUSEHOLDS IN THE 48 STATES

Data Base and Model

The data base is the 1960 U.S. census data for the conterminous United States. The data cover all 223 standard metropolitan statistical areas (SMSAs). All data are averaged over the SMSA. Thus, the analysis examines the distribution of the 223 averages. Only two-thirds of the population falls within the SMSAs. Finer detail on 100 percent of the population could be obtained by using the data available on the 3000 counties. Table 8 presents the population density distributions based on these 223 samples; Table 9 presents the household density distribution. The population outside the 223 SMSAs but within the conterminous United States are covered under item 2 in each table. The entire population of the conterminous United States is represented by item 3. The final line under item 1, i.e., inside the SMSAs, represents either the total of the column above the entry or the average for the column above the entry. For example, the average population density within

Table 8

POPULATION DENSITY DISTRIBUTION

Population density range (persons/mi^2)	Area (mi^2)	No. of SMSAs in Category	Population	Population (percent)
1. **INSIDE SMSA**				
		-	-	
> 20,000	0	0	0	
10,000 - 20,000	47	1	610,734	0.34
5,000 - 10,000	2,136	1	10,694,632	5.99
2,000 - 5,000	2,596	5	6,458,671	3.62
1,000 - 2,000	21,721	17	30,616,107	17.16
500 - 1,000	30,677	33	20,827,772	11.67
200 - 500	102,613	84	31,059,075	17.40
100 - 200	71,029	49	10,657,554	5.97
50 - 100	40,097	19	2,883,368	1.62
20 - 50	72,070	11	2,383,820	1.34
10 - 20	17,555	3	276,550	0.15
< 10	0	0		
Average 323	360,541	223	116,468,283	65.26
2. **OUTSIDE SMSAs**				
Average 23.8	2,607,684	0	61,995,953	34.74
3. **CONTERMINOUS U.S.**				
Average 60.1	2,968,225	223	178,464,236	100.00

Table 9

HOUSEHOLD DENSITY DISTRIBUTION

Population Density Range (persons/mi^2)	Persons/ Household	Households in Category	Household density (households/mi^2)	Households (percent)
1. **INSIDE SMSA**				
10,000 - 20,000	3.71	164,812	3,484	0.37
5,000 - 10,000	3.81	2,807,603	1,314	6.25
2,000 - 5,000	3.87	1,668,961	643	3.71
1,000 - 2,000	3.94	7,771,455	357	17.29
500 - 1,000	3.95	5,272,022	172	11.73
200 - 500	3.96	7,836,432	76.4	17.43
100 - 200	4.06	2,622,230	36.9	5.83
50 - 100	4.06	709,602	17.7	1.58
20 - 50	3.98	598,389	8.30	1.33
10 - 20	4.09	67,676	3.86	0.15
Average 323	3.94	29,519,182	81.87	65.67
2. **OUTSIDE SMSA**				
Average 23.8	4.02	15,431,642	5.918	34.33
3. **CONTERMINOUS U.S.**				
Average 60.1	3.97	44,950,824	15.14	100.00

the SMSAs is 323 persons per square mile, the average number of persons per household is 3.94, and the average household density is 81.87 households per square mile, while the total number of households within the SMSAs is 29,519,182.

A brief examination of the number of miles of cable required to connect a random distribution of households and a uniform distribution of the same average density indicates that over a large sample they are approximately equal. Thus, the number of miles of cable required per square mile at a given household density was calculated in Table 8 based on a relationship suitable for a uniform distribution. The relationship used assumes the miles of cable per square mile to be equal to one mile of cable plus the square root of the household density in households per square mile. The extra one mile is the maximum amount of cable to interconnect each square mile section. Such a calculation does not distinguish between main trunk and other feeder cables. Multiplying the number of "miles of cable per square mile" and the "area at that density" from Table 8 gives the number of miles of cable required.

The figure 10.05 in Table 10 for the average number of miles of cable per square mile within the SMSAs was calculated using the average density over the entire group of SMSAs, i.e., 81.87 in Table 9. It is not the average value of the figures above it in the same column. Note that using the same formula, i.e., miles of cable per square mile = $1 + \sqrt{\text{household density}}$, for the aggregated average density within the SMSAs results in 18.5 percent more miles of cable (3,622,896 versus the cumulative total of 3,058,560). Thus, for the assumed model, the effect of using 10 density levels versus a single average value is just 18.5 percent.

The cost of the system, i.e., cables plus drops, was calculated in Table 11 assuming \$5000 per mile of cable plus \$30 per household for the drop lines to each house.

Interpretation

Figure 10 shows that it would cost $8.5 billion dollars to provide 12 channels of CATV to the 50 percent of all U.S. households in the 223 SMSAs. About $100,000 per head end must be added to this cost for the cable and drops. Assuming 50,000 head ends correspond to 100-percent coverage, an additional $5 billion must be added to the $61.4 billion estimate for 100-percent coverage.

Tables 10 and 11 show that over 65 percent of the households in the 48 states can be wired for 12 channels of CATV for approximately $16 billion according to the model assumed. The cost of wiring 100 percent of the households in the 48 states with CATV was calculated to be about $61 billion.

Excluding the most dispersed and isolated 0.5 percent of households, i.e., areas of density below 1 person per square kilometer, lowers the initial investment by $5 billion according to the data in Table 12. Thus, 99.5 percent of households can be supplied with CATV for $56 billion.

Excluding the most dispersed and isolated 3.5 percent of households, i.e., areas of density below 5 persons per square kilometer, lowers the initial investment by over $18 billion. Thus, 96.5 percent of households can be supplied with CATV for less than $43 billion.

Excluding the two lowest density groups within the SMSAs, i.e., population densities between 10 and 50 persons per square mile, lowers the initial investment by $1.7 billion. Thus, 95 percent of households can be supplied with CATV for $41 billion.

The cost for coverage of 95 percent of households is divided as follows:

Within the SMSAs	$14.5 billion
Outside the SMSAs	26.7 billion
Total cost	$41.2 billion

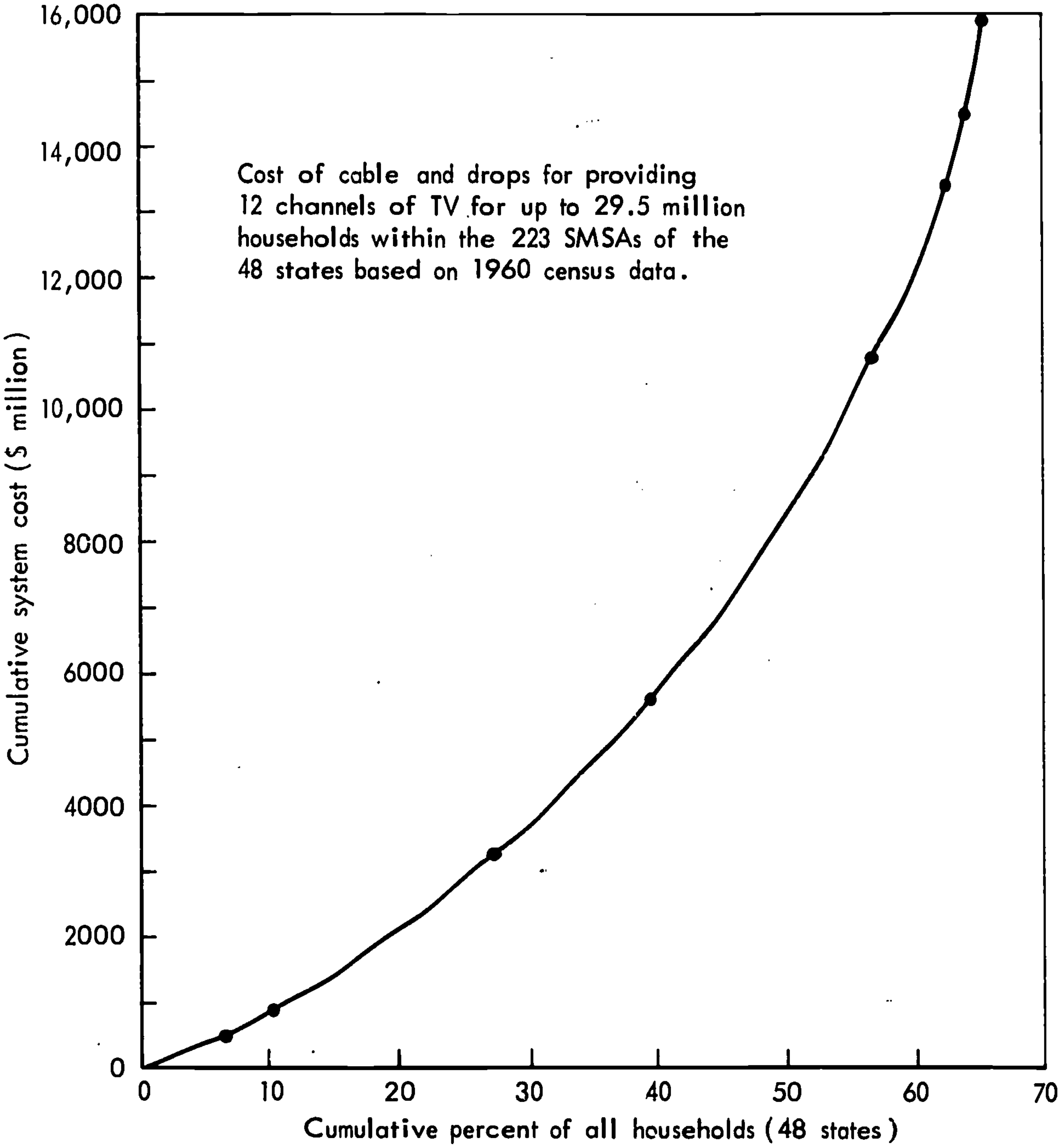


Fig. 10--Cumulative System Cost Within SMSAs

Table 10

MILES OF CABLE REQUIRED

Population Density Range (persons mi^2)	Cumulative No. of Households	Cumulative Households (percent)	$1 + \sqrt{\text{Household Density}}$ (miles of cable/mi^2)	Miles of Cable	Cumulative Miles of Cable
1. **INSIDE SMSAs**					
10,000 - 20,000	164,812	0.37	60.0	2,820	2,820
5,000 - 10,000	2,972,415	6.62	37.2	79,460	82,280
2,000 - 5,000	4,641,376	10.33	26.4	68,530	150,810
1,000 - 2,000	12,412,831	27.62	19.9	432,250	583,060
500 - 1000	17,684,853	39.35	14.1	432,500	1,015,560
200 - 500	25,521,285	56.78	9.74	1,000,000	2,015,560
100 - 200	28,143,515	62.61	7.07	502,000	2,517,560
50 - 100	28,853,117	64.19	5.21	209,000	2,726,560
20 - 50	29,451,506	65.52	3.88	280,000	3,006,560
10 - 20	29,519,182	65.67	2.96	52,000	3,058,560
323 (avg.)	29,519,182	65.67	-	3,058,560	3,058,560
			(10.05 avg.)	(3,622,896)	
2. **OUTSIDE SMSAs**					
23.8 (avg)	15,431,642	34.33	3.433	8,951,400	8,951,400
3. **CONTERMINOUS U.S.**					
60.1 (avg)	44,950,824	100.00	-	12,009,960	12,009,960

Table 11

TOTAL AND INCREMENTAL COSTS

Population Density Range (persons/mi^2)	Cost of Cable Plus Drops[a] ($ million)	Cumulative System Cost (million)	Cumulative system cost/household	Incremental Cost/ Household
1. **INSIDE SMSAs**				
10,000 - 20,000	19.0	19.0	115.3	115.3
5,000 - 10,000	481.5	500.5	168.4	171.5
2,000 - 5,000	392.7	893.2	192.4	235.3
1,000 - 2,000	2,394	3,287	264.8	308.1
500 - 1,000	2,321	5,608	317.1	440.2
200 - 500	5,235	10,843	424.9	668.0
100 - 200	2,589	13,432	477.3	987.3
50 - 100	1,066	14,498	502.5	1,502
20 - 50	1,418	15,916	540.4	2,370
10 - 20	262	16,178	548.1	3,871
323 (avg)	16,178	16,178	548.1	548.1
2. **OUTSIDE SMSAs**				
23.8 (avg)	45,220	45,220	2,930	2,930
3. **CONTERMINOUS U.S.**				
60.1 (avg)	61,398	61,398	1,366 (avg)	1,366 (avg)

[a] $5000 per mile plus $30 per household.

Table 12

LOWEST DENSITY AREAS

Population Density Range (persons/mi^2)	Area of Conterminous States[a] (percent)	Area (mi^2)	Average Population Within Area	Average Number of Households Within Area[b]	Cumulative Households (percent)
0 to 2.6	21.4	635,200	825,800	205,400	0.46
2.6 to 13	23.9	709,400	5,533,000	1,376,000	3.52

Population Density Range (persons/mi^2)	Household Density (households/mi^2)	Households in Category (percent)	$1 + \sqrt{\text{Household Density}}$ (miles of cable/mi^2)	Miles of Cable	Cumulative Miles of Cable
0 to 2.6	0.323	0.46	1.568	996,000	996,000
2.6 to 13	1.940	3.06	2.393	1,698,000	2,694,000

Population Density Range (persons/mi^2)	Cost of Cable plus drops[c] ($ million)	Cumulative System Cost ($ million)	Cumulative System Cost/Household ($)	Incremental Cost/ Household ($)
0 to 2.6	4,986	4,986	24,270	24,270
2.6 to 13	13,511	18,497	11,700	9,819

[a] The area data were obtained by planimeter from a shaded map of population density in the Pergamon World Atlas, published by Panstwowe Wydawnictwo Naukowe, Poland, 1968, p. 307, and are based on 1960 U.S. Bureau of the Census data.

[b] Assumes 4.02 persons per household.

[c] Assumes $5000 per mile plus $30 per household.

If it is assumed that the density distribution outside the SMSAs is weighted just as the distribution within the SMSAs, then the aggregated calculation may result in a cost that is inflated by 18.5 percent. Applying this factor, the costs are:

Within the SMSAs	$14.5 billion
Outside the SMSAs	21.8 billion
Total cost	$36.3 billion

Thus, cable distribution to 95 percent of households may require an investment as low as $36 billion, using the assumed model.

APPENDIX

CURRENT STATUS OF BROADCAST TELEVISION

Should it continue to thrive, cable television (CATV) may affect many aspects of the television industry. An examination of statistics in such areas as television set production and demand; consumer, broadcaster, and cable operator investment; and service in terms of quantity of channels available provides a picture of some aspects of the television industry and of the relative characteristics of both broadcast transmission and CATV distribution.

TELEVISION SET PRODUCTION

Commercial television broadcasting was authorized by the FCC on July 1, 1941, and began in the United States on that day over WNBT in New York. Television set production, however, remained negligible until 1946.

Table 13 presents U.S. television set production figures. The black and white television set figures include table, portable, and console models, and also include all phonograph and radio combinations. These figures represent U.S. production, and thus include exports but not imports. Total yearly production, i.e., black and white plus color, is shown in Fig. 11.

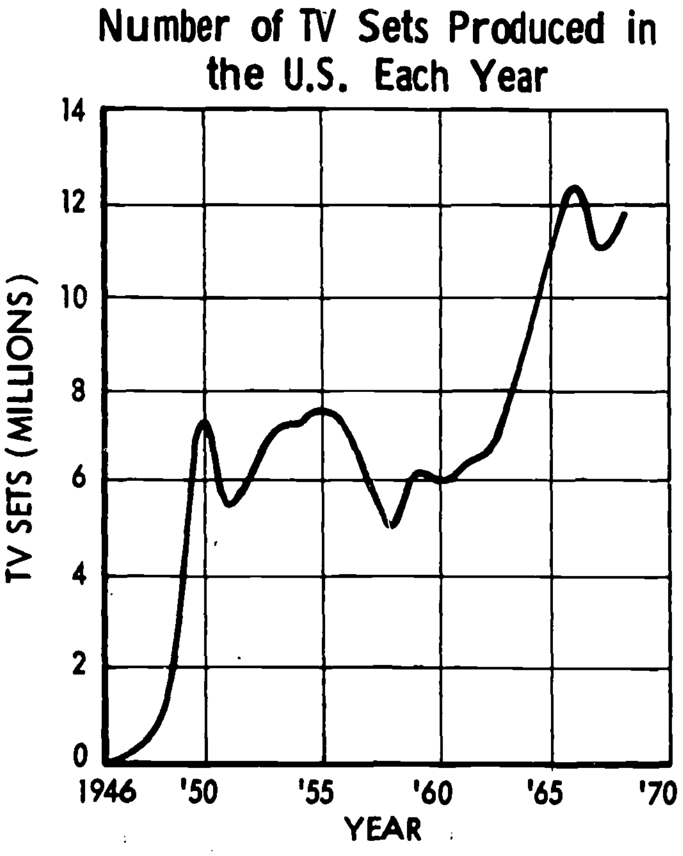
Table 14 indicates the relatively small fraction of U.S. television set production that is exported; Table 15 indicates the substantial number of sets imported to supplement the large domestic production reflected in Table 13. The large scale of television manufacturing is indicated by the total (for one year, 1966) of 13.73 million sets, with a retail value of 3.8 billion dollars. This total is made up of U.S. production, plus imports, minus exports.

Table 13

U.S. TELEVISION SET PRODUCTION[a]

	Black and White		Color	
Year	Number of Units (Millions of units)	Retail Value (Millions of $)	Number of Units (Millions of units)	Retail Value (Millions of $)
1946	.007			
1947	.179			
1948	.975			
1949	3.000			
1950	7.464	2,235		
1951	5.385			
1952	6.096			
1953	7.216	2,020		
1954	7.347	1,690		
1955	7.757	1,745		
1956	7.387	1,404		
1957	6.399	1,216		
1958	4.920	1,009		
1959	6.350	1,353		
1960	5.708	1,269	0.120	
1961	6.178	1,293		
1962	6.471	1,245		
1963	7.130	1,265	0.747	415
1964	8.107	1,311	1.463	806
1965	8.382	1,336	2.646	1,482
1966	7.288	1,024	5.092	2,724
1967	5.104	681	5.777	3,033
1968	5.816	767	5.982	3,051

[a] Figures include exports. All data are from Ref. 1. However, Ref. 1 contains no data on color production before 1960.



Data from Ref. 1

Fig. 11--Number of Television Sets Produced in the United States Each Year

Table 14

U.S. TELEVISION SET EXPORTS[a]

Year	Number of Units (Millions of Units)	Units as a Percentage of Total U.S. Production[b] (Percent)	Retail Value (Millions of $)
1955[c]	0.077	1.0	10.0
1960	0.106	1.9	14.7
1965[c]	0.181	1.6	21.3
1966[c]	0.168	1.4	26.3
1967[d]	0.139	1.3	23.6
1968[d]	0.144	1.2	27.8

[a] Television broadcast receivers including those combined with radio or phonograph. Does not include television receiver chassis without cabinets.

[b] Relative to the sum of black and white and color sales of Table 13.

[c] See Ref. 2.

[d] See Ref. 3.

Table 15

TELEVISION SETS IMPORTED INTO THE UNITED STATES[a]

Year	Total Number of Units (Millions of Units)	Units as a Percentage of Total U.S. Production (Percent)	Retail Value (Millions of $)
1955	--	--	0.14
1960	--	--	1.946
1965	1.048	9.5	59.6
1966	1.524	12.3	115
1967	1.608	14.8	124
1968	2.708	23.0	203

[a] See Ref. 4. Includes all combinations with radio and phonograph.

1967 TV Imports[b]		Number of Units	Value
B&W	< 10"	421,535	$ 23,132,113
B&W	> 10"	868,252	47,511,995
	Total B&W	1,289,787	$ 70,644,108
Color	< 10"	9,758	943,205
Color	> 10"	308,046	52,269,707
	Total Color	317,804	$ 53,212,912

1968 TV Imports		Number of Units	Value
B&W	< 10"	655,231	$ 31,744,825
B&W	> 10"	1,387,455	65,273,256
	Total B&W	2,042,686	$ 97,018,081
Color	< 10"	15,945	1,854,157
Color	> 10"	649,758	104,178,811
	Total Color	665,703	$ 106,032,968
	Total Imports	2,708,389	$ 203,051,049

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[b] Private communication, U.S. Department of Commerce.

TELEVISION SET DEMAND

Figure 12 shows the cumulative effect of production. By 1968, over 150 million television sets had been produced. Figure 12 also shows the estimated number of television sets in use, by year. About half of all sets produced are still in use. The effect of the sustained high level of production has been to place one or more television sets in almost every home in the United States (95 percent of households). Table 16 and Fig. 13 indicate the growth in the penetration of television into U.S. homes, based on sampling. The number of homes with two or more sets is both substantial (35 percent) and growing rapidly.

Based on the data in the preceding tables, it is possible to determine the average selling price of a television set, and to estimate the number of years sets remain in use. Figure 14 indicates the steady and substantial decrease in the average selling price of black and white receivers, the slow decrease in the price of color receivers (the price decreases occurred despite inflationary effects), and the large disparity in cost between black and white and color sets. This latter effect would be even more apparent if the comparison were made with the generally small-size black and white imports. By adding up the number of years of production[†] required to equal the number of sets in use, Fig. 15 indicates that sets as old as 10 to 11 years must still be in use.

CONSUMER AND BROADCASTER INVESTMENT

One result of 23 years of television production has been that by early 1968 consumers had accumulated about 76 million television receivers, at an investment in sets

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[†] Until recently, imports have been a small percentage of sales compared to U.S. production and therefore have a small effect on this calculation.

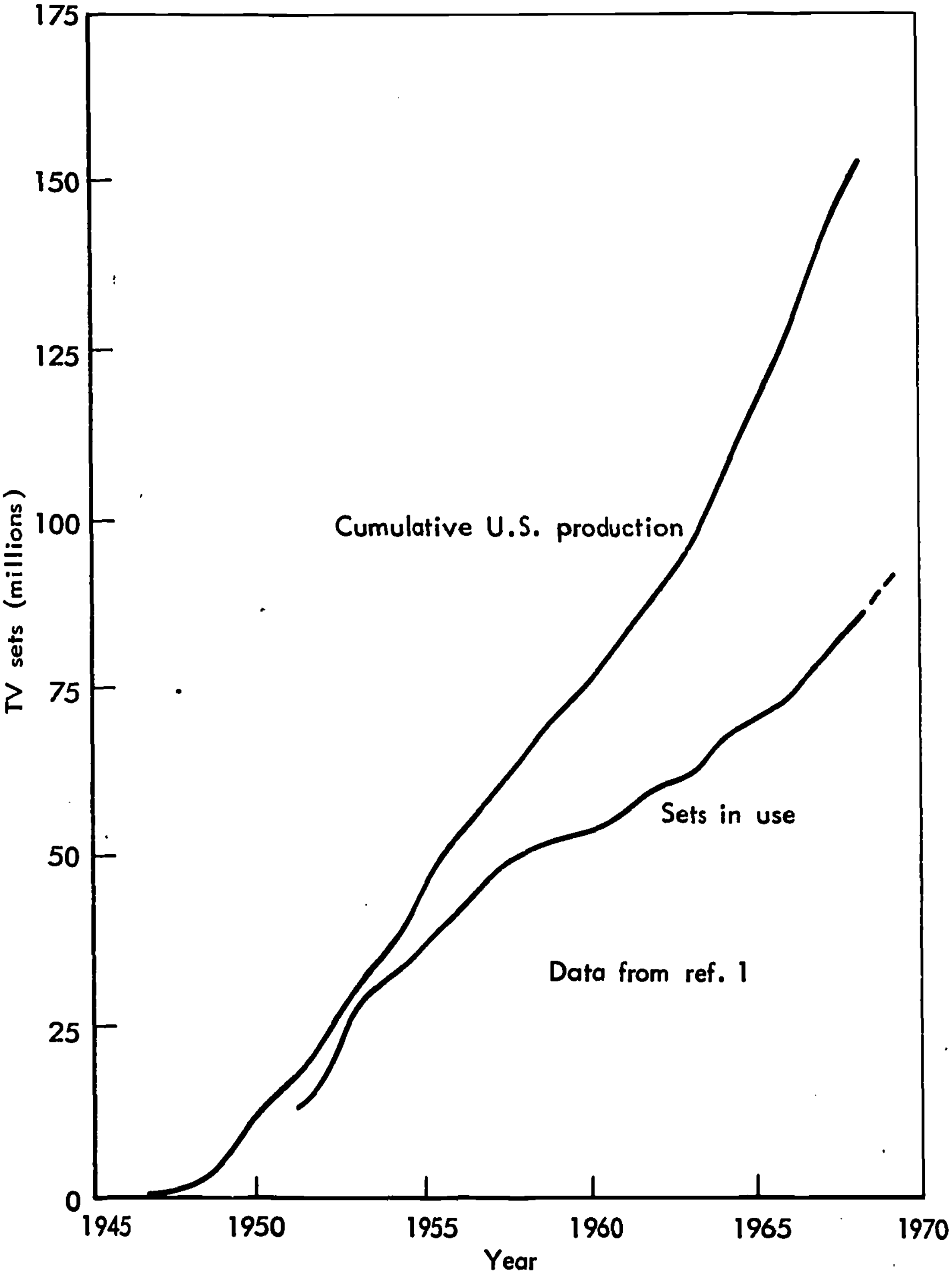


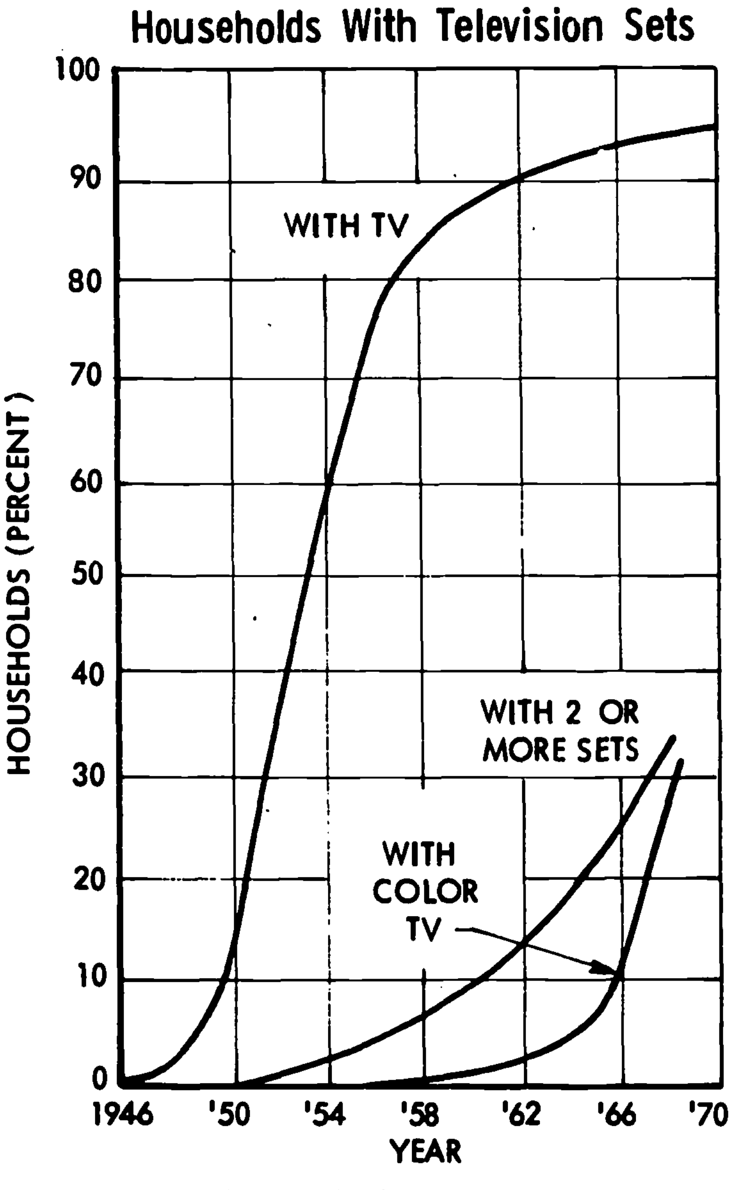
Fig. 12--Cumulative Production and Number of Television Sets in Use

Table 16

TELEVISION PENETRATION INTO U.S. HOUSEHOLDS[a]

Year	No. of Households Millions	Percent with TV	Percent with 1 TV set	Percent with 2 or more sets	Percentage of homes with color TV[e]
1946	37.8[e]	0.02[e]			
1947	38.6[e]	0.04[e]			
1948	40.0[e]	0.4[e]	0.4[e]	0.0025[e]	
1949	41.5[e]	2.3[e]	2.3[e]	0.024[e]	
1950	43.6[b]	9.0[e]	8.9[e]	.12[e]	
1951	43.9[e]	23.5[e]	23.1[e]	.38[e]	
1952	44.8[e]	34.2[e]	33.5[e]	.70[e]	
1953	46.3[b]	44.7[e]	43.6[e]	1.1[e]	
1954	46.9[b]	55.7[e]	54.0[e]	1.7[e]	
1955	47.8[b]	67	65	2	0.02
1956	48.8[b]	76	72	4	0.05
1957	49.5[b]	78.6[e]	74[e]	5[e]	0.2
1958	50.4[c]	83	76	7	0.4
1959	51.3[c]	86	78	8	0.6
1960	52.6[c]	88[d]	77[d]	11[d]	0.7
1961	53.3[c]	89	77	12	0.9
1962	54.6[c]	90	77	13	1.2
1963	55.2	91.3[e]	76[e]	16[e]	1.9
1964	56.0	93	76	17	3.1
1965	57.2	92	73	20	5.3
1966	58.1	93	71	23	9.7
1967	58.8	94	69	25	16.7
1968	60.4	94.6[e]	63[e]	31[e]	24.9
1969	60.9[e]	94.8[e]	60[e]	35[e]	33.3

[a] All data from Ref. 1 except as noted.
[b] See Ref. 5.
[c] See Ref. 6.
[d] Beginning with 1960, these figures include Alaska and Hawaii.
[e] See Ref. 10, p. 72-a.



Data from Ref. 1

Fig. 13--Percent of Households with Television Sets

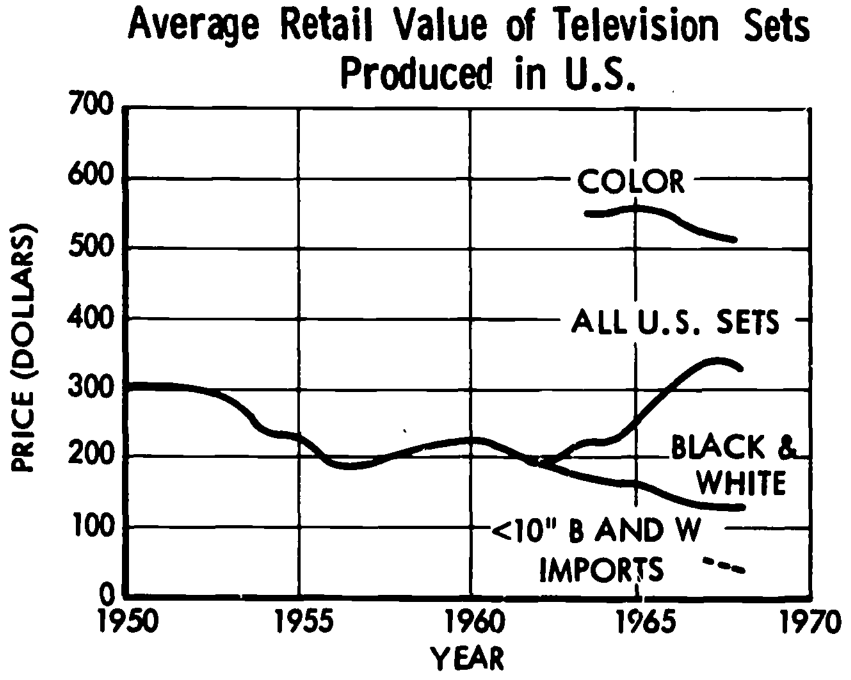


Fig. 14--Average Retail Value of Television Sets Produced in the United States

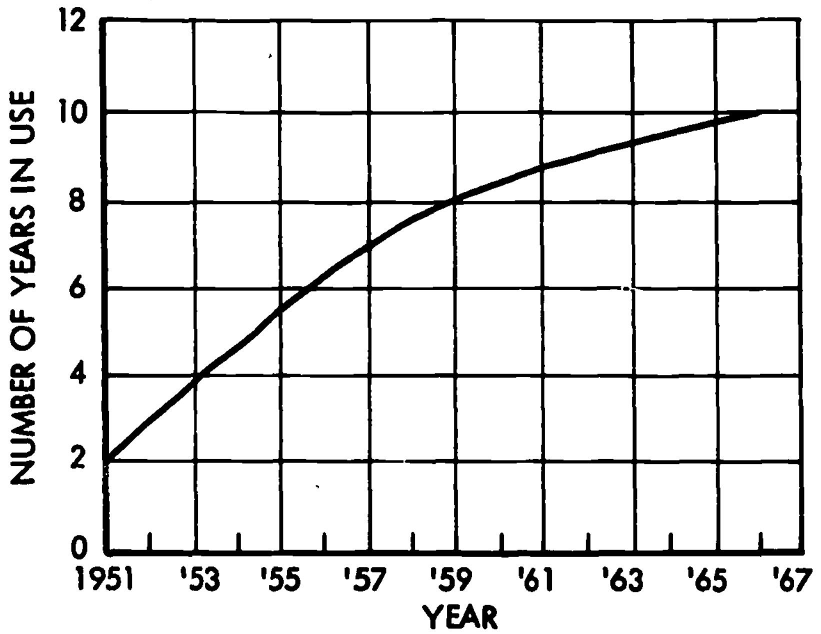


Fig. 15--Number of Years of U.S. Production Required to Equal the Number of Television Sets in Use

and antennas of over 20 billion dollars [7]. Table 17 gives a breakdown of these figures.

An examination of the average selling prices shown in Fig. 14, for black and white sets over the 9.5- to 11-year age of sets in use and for color sets in the more recent years, tends roughly to check the consumer capital investments of $150 for black and white and $500 for color used in Table 17. The comparison suggests, however, that these figures are low by about 10 to 15 percent even when imports are included. Thus, about $23 billion appears to be a better figure for the total consumer capital investment on an original cost basis (unless the average set was purchased at a discount of 10 to 15 percent from the manufacturer's suggested list price).

On the other hand, the investment by broadcasters, i.e., by those engaged in providing over-the-air transmission to the consumer, has been estimated as only 1.6 billion dollars [7]. Table 18 gives a breakdown of these costs for 649 commercial stations and 147 educational stations. Figure 16 shows the growth in the number of commercial stations on the air starting in 1945; Table 19 shows the growth for all stations.

Using a figure of $23 billion for the consumer investment and $1.6 billion for the broadcaster investment gives a consumer capital investment 14 times greater than the broadcaster investment. Because the capital investment of Table 18 includes studio facilities, it involves costs associated with programming; such costs are not included in Table 17.

Table 20 shows a detailed breakdown of the capital assets for educational television (ETV) stations. The figures for commercial stations are assumed to be similar. Because the capital assets of a repeater station are $549 thousand, only this amount should be attributable directly to the broadcaster investment for transmission

Table 17

CONSUMER RECEIVING COSTS[a]

		Unit Costs		Total Costs	
	Units	Capital (Millions of $)	Annual	Capital (Millions of $)	Annual
TV Sets					
Monochrome	61M	$150	$ 45[b]	$ 9,150	$2,745
Color	15M	500	150[b]	7,500	2,250
TV Antennae	56M	60	10	3,360	560
Total Receiver				$20,010[c]	$5,555

[a] Data are taken from Ref. 7, and are for the first part of 1968.

[b] Note ratio of recurring costs to capital expenditure is 30 percent--a relatively high ratio for consumer-electrical equipment. This figure includes both maintenance and amortization.

[c] Using Complan's figure of 56 million television households results in an average of $360 per household.

Table 18

BROADCASTING COSTS[a]

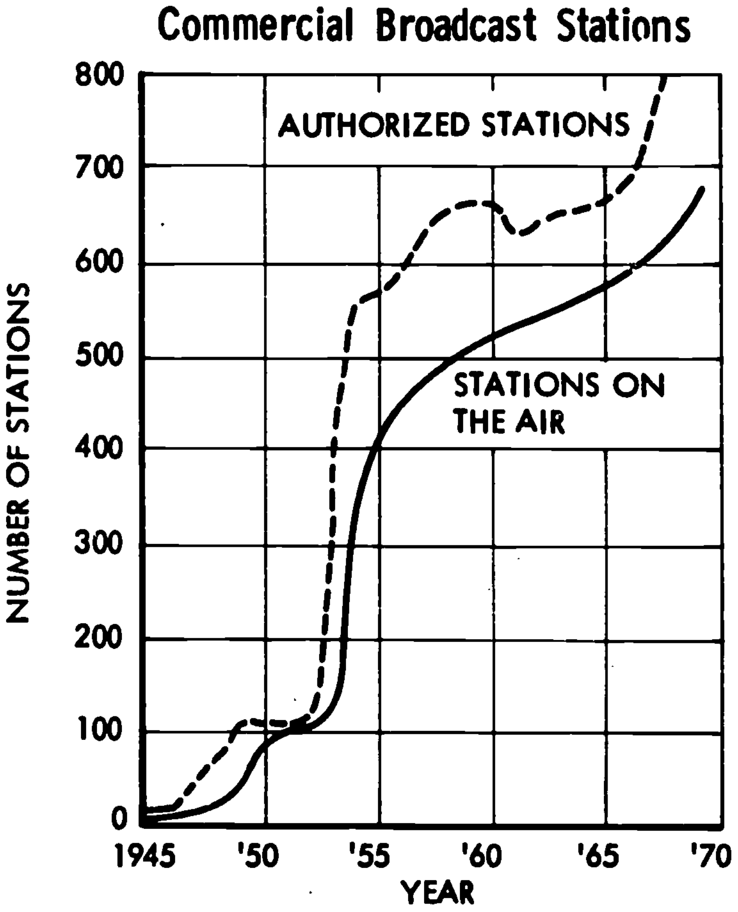
(Millions of $)

	Units (Millions)	Unit Costs		Total Costs	
		Capital	Annual[b]	Capital	Annual[b]
Commercial Networks	3	$61	$310	$ 183	$ 930
VHF Commercial Stations	504	1.5	1.5	756	756
UHF Commercial Stations	145	.7	.7	102	102
VHF Educational Stations	72	4.3	2.46	320	177
UHF Educational Stations	75	1.	.33	75	25
Interstate Circuits[c]	3			97	20
Intrastate Circuits[c]	796			24	5
Total Broadcast				$1557	$2062

[a] Same as Ref. 7.

[b] Costs do not include equity capital or income taxes.

[c] Circuits obtained from the common carriers. The interstate portion is for the three major networks plus the Sports Network plus a small Educational Network. The intrastate circuits consist of links from the television station or studio to the transmitter to remote program sources and to the Television Operating Center of the common carrier. It is estimated that there are 1.5 such links for each television station.



Data from Ref. 1

Fig. 16--Number of Commercial Broadcast Stations, by Year

Table 19

TELEVISION STATIONS ON THE AIR, 1946-1969[a]

(As of Jan. 1 for Each Year)

Year	VHF Coml.	VHF ETV	Total VHF	UHF Coml.	UHF ETV	Total UHF	Total Coml.	Total ETV	Grand Total
1946			6			--			6
1947			12			--			12
1948			16			--			16
1949			51			--			51
1950			98			--			98
1951			107			--			107
1952			108			--			108
1953			120			6			126
1954	233	1	234	121	1	122	354	2	356
1955	297	8	305	114	3	117	411	11	422
1956	344	13	357	97	5	102	441	18	459
1957	381	17	398	90	6	96	471	23	494
1958	411	22	433	84	6	90	495	28	523
1959	433	28	461	77	7	84	510	35	545
1960	440	34	474	75	10	85	515	44	559
1961	451	37	488	76	15	91	527	52	579
1962	458	43	501	83	19	102	541	62	603
1963	466	46	512	91	22	113	557	68	625
1964	476	53	529	88	32	120	564	85	649
1965	481	58	539	88	41	129	569	99	668
1966	486	65	551	99	49	148	585	114	699
1967	492	71	563	118	56	174	610	127	737
1968	499	75	574	136	75	211	635	150	785
1969	499	78	577	163	97	260	662	175	837

[a] From Ref. 10, p. 72-a.

Table 20

LONG-RANGE CAPITAL ASSETS OF EDUCATIONAL TELEVISION STATIONS[a]

	Land		Structures		Equipment at Studio and Mobile		Equipment at Transmitter		Total Capital
Type of Station	Value per Station (thousands of dollars)	% of Total	Value per Station (thousands of dollars)	% of Total	Value per Station[b] (thousands of dollars)	% of Total	Value per Station (thousands of dollars)	% of Total	Total per Station (thousands of dollars)
Key	578	9.3	1,675	26.9	3,608	58.0	359	5.8	6,220
Flag	208	6.3	1,232	37.4	1,473	44.7	381	11.6	3,294
Standard	70	4.1	487	28.8	730	43.2	403	23.8	1,690
Basic	26	2.1	252	20.0	575	45.6	409	32.4	1,262
Repeater	1	0.2	117	21.3	-	-	431	78.5	549
Years of Life	∞		30		7		10		

[a] Data drawn from Table 10 of Ref. 8

[b] Excluding $0.7 million for videotape replacement, expensed annually.

On this basis, the 796 stations (commercial plus educational) represent a capital investment for transmission of $437 million. Adding the interstate and intrastate circuits makes the total investment associated with transmission and interconnection about $558 million. On this basis, the consumer capital investment for reception is 41 times the broadcaster investment for transmission plus interconnection. This enormous imbalance in relative investment is a salient feature of the current television system.

Another view of the relative cost of transmission and interconnection is obtained by looking at the annual station operating expenditures for this purpose relative to total expenses. Table 21 shows a breakdown of the annual costs of operating a television transmitter. Although intended for application to ETV station operation, the data are also assumed to apply to commercial television stations. The total recurring broadcast transmission costs are at most $93 thousand per station. For the 504 VHF commercial stations and the 145 UHF commercial stations of Table 18, transmission costs total $59 million annually. The 1966 revenues for ABC, CBS, and NBC, including owned and operated stations, were roughly $1160 million, and the 1966 expenses were roughly $970 million. (This latter figure checks fairly well with the $930 million shown for the total annual costs for the three commercial networks in Table 18.) The $59 million spent annually on transmission is thus about 6.3 percent of annual network expenses.

Because not all of the commercial stations are network affiliated, the calculated 6.3 percent is too high. Net broadcast revenues from time sales in 1966 were $1521 million, and the gross (which includes commissions) was $1835 million. In addition to this, there are additional revenues, principally from the sale of talent and programs. In 1966, these amounted to $683 million. Thus, gross overall broadcaster revenues in 1966 were $2518 million. Assuming overall

Table 21

INCREMENTAL ANNUAL COST TO THE SYSTEM OF ONE MORE TELEVISION TRANSMITTER[a]

	VHF	UHF	Weighted[b] Average
	(thousands	of dollars	annually)
Operating Expenses			
Engineering attendance[c]	29	0[b]	4.4
Engineering maintenance	10	10	10.0
Electricity	6	11	10.4
Replacement parts	13	13	13
Total	58	34	38
Capital Amortization			
Tower and Building	4	4	4
Equipment	31	45	43
Total	35	49	47
Total Transmission	93	83	85
Interconnection	30	30	30
Total	123	113	115

[a] Data from Ref. 8.

[b] Weights: VHF 26, UHF 144, relative frequencies among repeater stations.

[c] UHF transmitters may run unattended; VHF may not.

annual expenses were about $2110 million, the $59 million transmission costs are about 2.8 percent of total expenses.

In 1968 there were about 100 thousand television channel miles of intercity video facilities for connecting more than 400 commercial television broadcast stations in 217 cities. Bell System charges for distribution of video programs for the major television networks have represented a constantly decreasing percentage of network expenses over a 13-year period, going from 8.8 percent in 1954 to 3.9 percent in 1966 [9]. Thus, the 1966 video interconnection charges of about $38 million† are a small part of the total cost of network operations. (The reasons for the large discrepancy between this $38 million AT&T figure from Ref. 9 and the annual circuit interconnection costs of $25 million in Table 18, which is based on Ref. 7, are not clear.) The combined recurring costs of transmission and distribution of commercial television represents about 6.7 percent of annual expenses. Thus, the bulk of the commercial television broadcasting business is associated with the generation of programming, not with the distribution or transmission of that programming.

An important conclusion to be drawn from these figures is that even if the cost of broadcast transmission and interconnection were to be zero, the increase in funds available for programming would be only about ten percent more than at present. Thus, the cost of broadcast transmission and interconnection do not inhibit the creation of new networks. One of the primary problems handicapping the creation of more commercial stations or of a fourth network is the limited availability and high cost of generating programming that appeals to a mass audience.

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†As of November 1, 1969, AT&T increased its annual charges for network television interconnection by $20 million, bringing its total yearly charges to the three nationwide television networks to $65 million.

CATV GROWTH

Figures 17 and 18 show the growth of CATV both in number of systems and number of subscribers.

The 50 largest operators have 2,173,256 subscribers, or 60 percent of the total. The situation is far more chaotic than these figures suggest. The holdings of these large operators are often quite spread out and, generally, recently acquired. Thus, they represent disparate equipment, investment, and operating procedures even among the systems owned by a single operator.

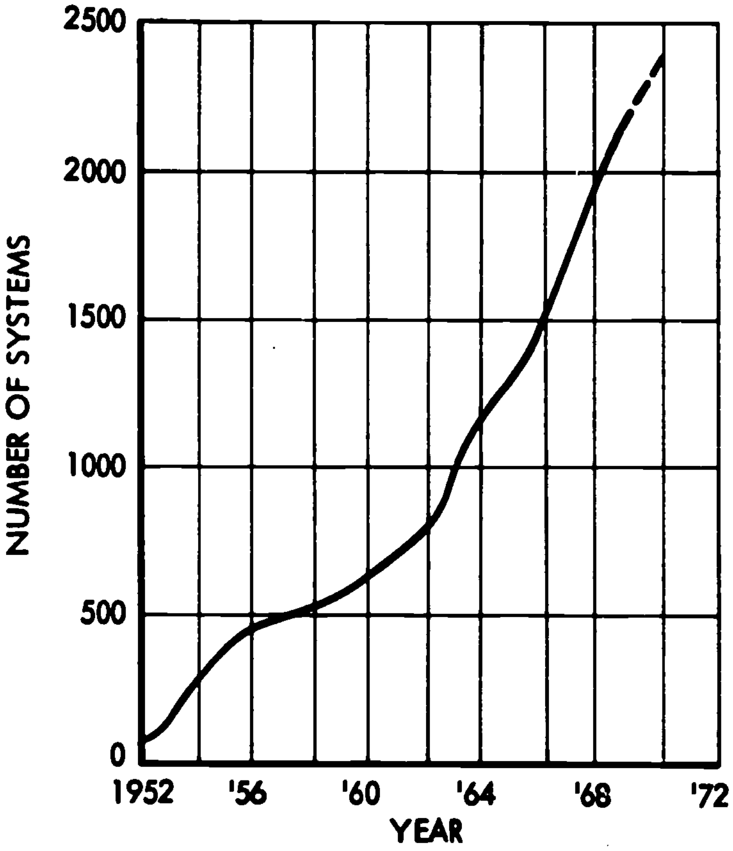
Table 22 shows the complete spread in number of subscribers for the 2300 CATV systems, and Fig. 19 presents the cumulative number of subscribers for the N largest systems (all systems of 5000 or more subscribers).

CATV INVESTMENT

Table 23 indicates the total capital investment and annual costs for CATV for the first part of 1968. The $75,000 for the head end equipment for each of the 2000 head ends is a typical value since most industry estimates lie between $50,000 and $100,000. Thus, about 38 percent of the CATV investment is indicated to be in head end equipment.

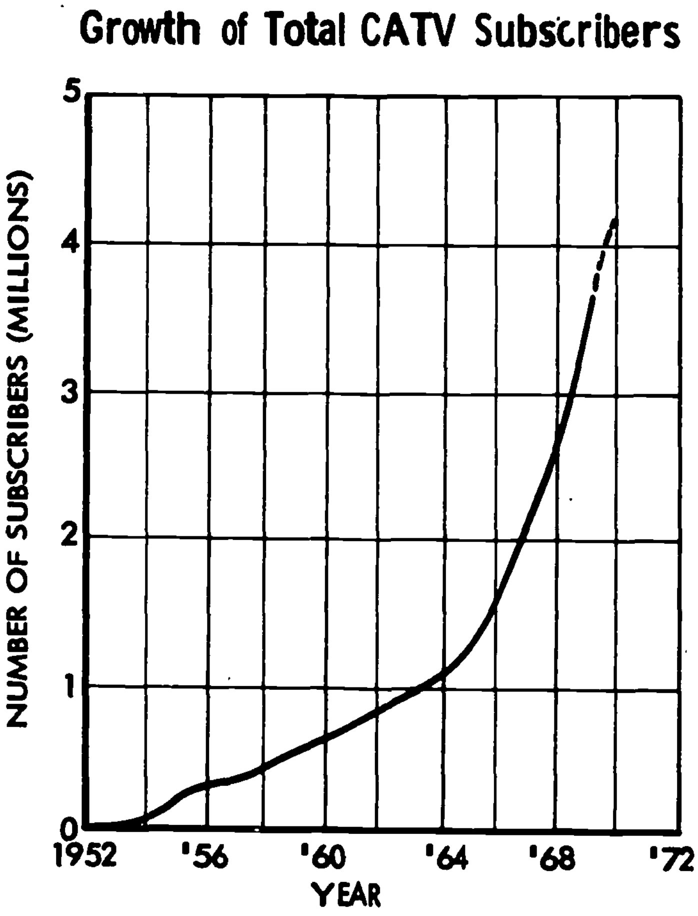
If the $23 billion consumer investment in television receiving equipment is prorated over the 56 million television households (Table 17), the investment per household is $410. The average capital investment per CATV subscriber, based on 2.4 million subscribers (Table 21), is about $160. Thus, the ratio of cable operator capital investment for distribution to consumer investment for reception on a per-household basis in early 1968 was about a factor of 0.4. This ratio would be less if penetration were 100 percent; that is, if all homes passed by the cable were to subscribe to the service.

Growth of Operating CATV Systems



As of January 1 of each year

Fig. 17--Growth of Operating CATV Systems



As of January 1 of each year

Fig. 18--Growth of Total CATV Subscribers

Table 22

U.S. CATV SYSTEMS BY SUBSCRIBER SIZE[a]

(As of Feb. 7, 1969)

Size by Subscribers	Systems	No. of Systems in Category
10,000 and more	46	2.0
5,000-9,999	111	4.8
2,500-4,999	237	10.3
1,000-2,499	506	22.0
500-999	400	17.4
250-499	338	14.7
100-249	281	12.2
50-99	79	3.4
sub-50	43	1.9
Not available	259	11.3
Total	2,300	

[a] From Ref. 10.

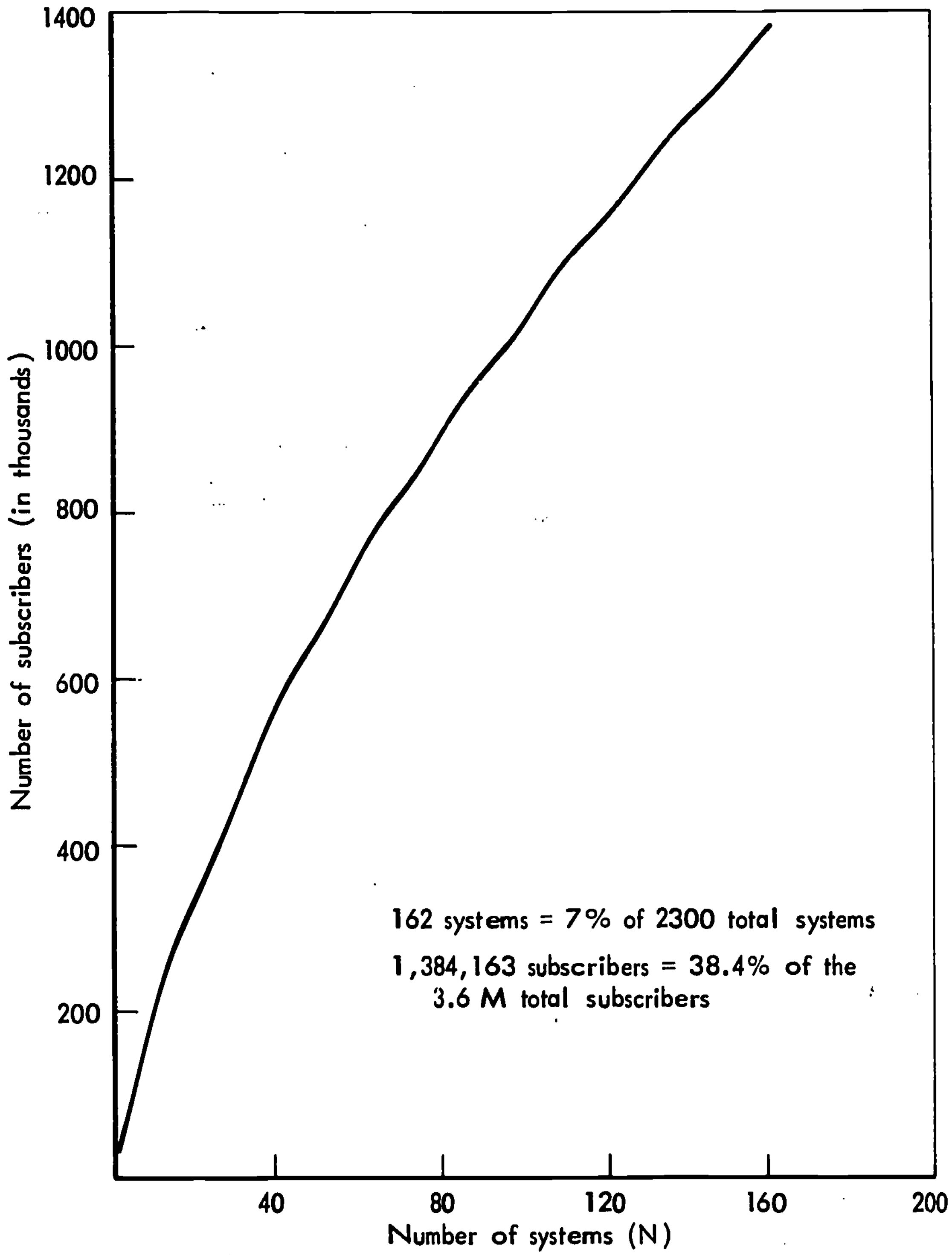


Fig. 19--Cumulative Number of Subscribers for the N Largest CATV Systems

Table 23

INVESTMENT IN CATV DISTRIBUTION[a]

		Unit Costs		Total Costs	
	Units	Capital	Annual	Capital	Annual[a]
Head end equipment	2,000[d]	$75,000[b]		$150M	
Cable and repeater	2.4M[e]	75[c]		180M	
Drop connection	2.4M	25[c]		60M	
Annual costs	2.4M		$40[c]	—	$96M
Grand Total				$390M	$96M

[a] Data based on Ref. 7, Appendix I, p. 17.

[b] This includes an allowance of $2500-3000 per channel for electronics. The remainder is for antenna tower, antenna, building, land, and fencing.

[c] Largely aerial plant. These costs are on a per subscriber basis.

[d] This is the number of CATV systems in 1968.

[e] This is the number of subscribers to CATV systems in 1968.

COMPARISON OF BROADCASTING, CATV, AND CONSUMER INVESTMENT

Table 24 compares the capital and annual investments by broadcasters for transmission and interconnection, by CATV operators for distribution, and by consumers for reception on a per-household basis. It is clear that cable distribution represents a radical change compared to the pattern of broadcaster investment.

Table 24 does not reflect all costs passed on directly or indirectly to the consumer. For the CATV subscriber, there is a direct monthly charge that generally lies between $2.50 and $10. The typical value is $5 per month. Since the total amount spent on television advertising was $2.5 billion† in 1966 [1], this corresponds to $43 per household (television-equipped or not). Thus the annual consumer investment of $120 (Table 22) for over-the-air reception of television can, in a sense, be said to be $163; and for those on cable, it can be considered typically $223.††

With television receiving equipment investment in the hands of the consumer, marketing practices tend to force equipment design toward the degradation of performance to minimum standards. There is loose Federal regulation of the industry, which leads to a reliance on self-regulation, both for television set producers and broadcasters. In the telephone and electric utilities, capital investment is largely in industry hands. The equipment meets high performance standards and there is strong Federal regulation. If CATV becomes ubiquitous and eventually constitutes a

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†This is the total television broadcast industry revenue for 1966. It includes Puerto Rico and the Virgin Islands, and is the total time-sale of all three networks and of 608 stations, plus commission to regularly established agencies, representatives, brokers and others, plus revenues from such incidental broadcast activities as the sale of talent and program material.

††$120 + ($5/mo x 12mo) + $43/household.

Table 24

A COMPARISON OF INVESTMENTS PER TELEVISION HOUSEHOLD FOR TRANSMISSION AND RECEPTION

Investment	Capital	Annual
Broadcaster investment for transmission and distribution[a]	$ 10	$ 2[b]
Cable television operator investment for distribution	160	40
Consumer investment in receiving sets and antennas	410	120[c]

[a] Calculated for the 504 VHF and 145 UHF commercial stations plus the 72 VHF and 75 UHF educational stations listed in Table 18.

[b] Includes $38 million for intrastate and interstate interconnection circuits.

[c] Assumes that annual maintenance and amortization costs are 30 percent of investment (Table 17).

monopoly, it is likely to be required to meet high performance standards and to be under strict Federal regulation.

QUANTITY OF TELEVISION CHANNELS

How many channels does this large investment per household provide? A Nielsen National Sample of September 1967 [7] showed an average of 5.6 commercial television broadcast stations received per household (no ETV stations were included in the sample). Table 25 shows the complete distribution. This distribution is not permanently fixed. Because the number of authorized commercial television stations is greater than the number currently on the air (see Fig. 16), the average number of broadcast stations received will increase beyond the 5.6 of the sample. Thus, spectrum limitations and interference problems have not halted all growth.

Table 26 presents another view of the distribution of television stations, which indicates the limited number of channels provided by over-the-air broadcasting in the 100 largest market areas of the United States. The table covers all home market stations on the air in early 1968. Although stations can be received outside their home market area, the signal quality may not be satisfactory, particularly for color television receivers. Figure 20 roughly relates these markets to population.

The average number of channels available for 86 of the 100 largest markets is only 3.4. Six of these markets do not even contain an affiliate of all three networks. Despite the obeisance paid to local programming, 65 of the 86 do not have a single independent station. Of the 86 markets, 71 do not have a single ETV station.

In its report on ETV, the Carnegie Commission suggested that an ETV system of 380 broadcast stations be set up in the United States [8]. At the time of the Carnegie study,

Table 25

NEILSEN NATIONAL SAMPLE[a]

(September 1967)

Number of TV Stations	Percent of Households Able to Receive This Number
1	0.8
2	2.6
3	16.3
4	16.0
5	13.0
6	18.7
7	16.0
8	7.0
9	4.0
10	3.4
11	1.6
12	0.5
13	0.1
Total	100.0

[a] As given in Ref. 7. This is based on a geographically stratified random sample of 500 counties in the contiguous United States and is supposed to be representative of all U.S. households with television.

Table 26

TELEVISION STATIONS IN THE TOP 100 MARKETS[a]
(6 or More Stations)

No. of Cities	Network Stations	Independent Stations	ETV Stations	Total Stations
1	3	7	0	10
1	3	4	1	8
1	3	4	0	7
4	3	3	1	7
1	4	1	1	6
6	3	2	1	6
14				
		Under 6 Stations		
1	5	0	0	5
2	3	2	0	5
8	3	1	1	5
3	4	0	0	4
10	3	1	0	4
6	3	0	1	4
50	3	0	0	3
1	2	1	0	3
1	2	0	1	3
4	2	0	0	2
86				

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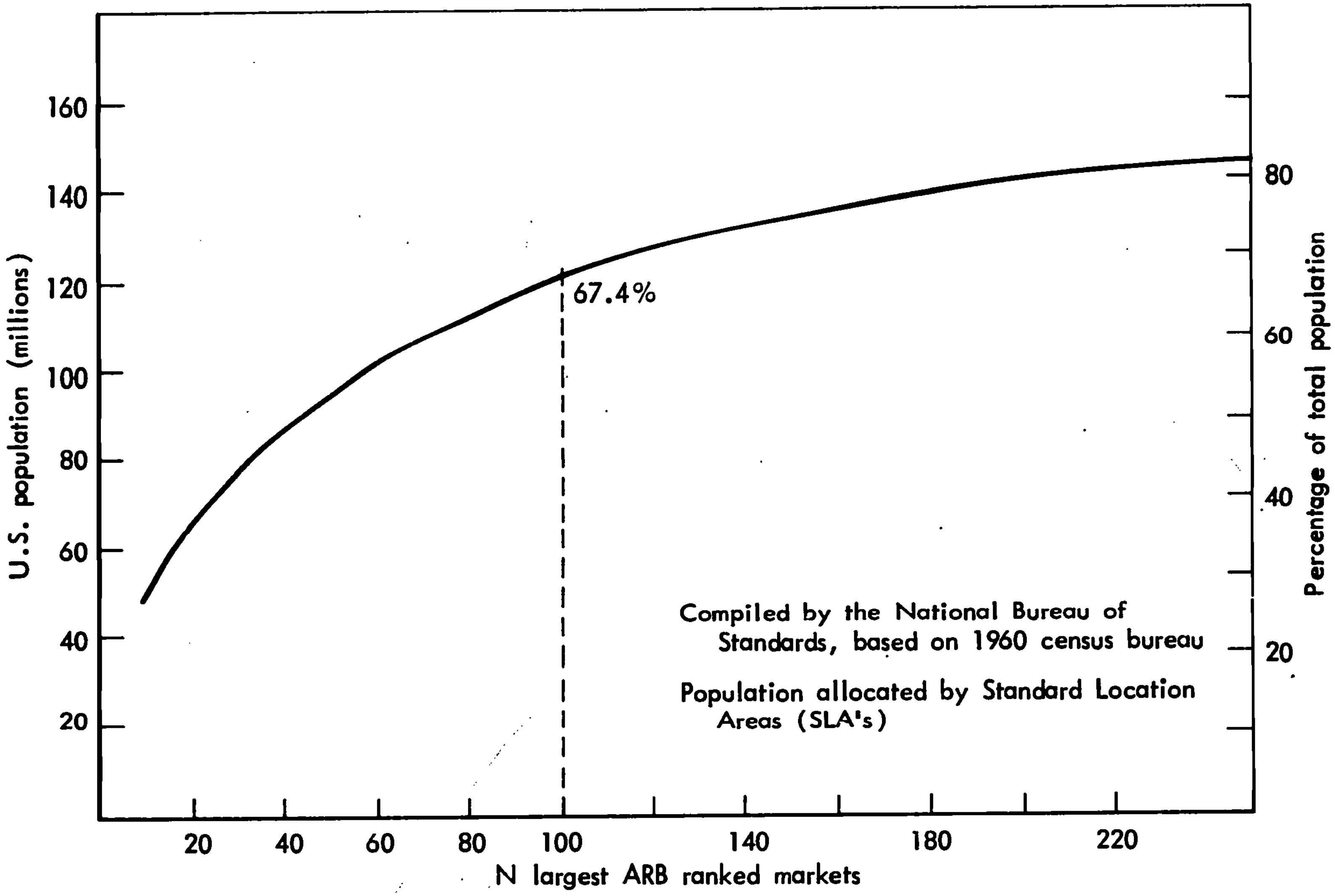
[a] Based on the 1968 Television Market Analysis of the American Bureau (ARB).



Compiled by the National Bureau of Standards, based on 1960 census bureau

Population allocated by Standard Location Areas (SLA's)

Fig. 20--Aggregate U.S. Population Within 35-mile Zones of Television Market Cities

there were 124 ETV stations; they were thus recommending slightly more than tripling their number.[†]

The Carnegie Commission's 380 educational broadcast stations would have provided at least one ETV channel to roughly 95 percent of the population and at most two educational channels in some 43 major metropolitan areas covering between 20 and 50 percent of the population. However, the 95-percent estimate neglects terrain and man-made structures and is thus an upper bound. At the time of the Carnegie Commission study (1966), about two-thirds of the population was theoretically within reach of one ETV station.[††] Thus, ETV added less than one channel to the 5.6 commercial channels received on the average (Table 25).

How does CATV compare? Table 27 gives the distribution of channel capacity for all 2300 CATV systems.

Table 27

NOMINAL CHANNEL CAPACITY OF EXISTING CATV SYSTEMS[a]

(As of Feb. 7, 1969)

Over 12		29
6-12		1559
5 only		511
Under 5		61
Not available		140
	Total	2300

[a] From Ref. 10, p. 79-a.

[†] As of January 8, 1969, there were 75 VHF and 97 UHF ETV stations on the air (a total of 172 ETV stations), and 674 commercial television broadcast stations.

[††] See p. 22 of Ref. 8.

A more detailed examination of cable capacity than that presented in Table 27 was carried out using data on the 162 largest CATV systems of Fig. 19.

The 162 largest CATV systems have a total of 1,384,163 subscribers, or an average of 8550 subscribers each. Almost all these systems have a nominal capacity of 12 channels, as is evident in Table 28.

Because 12 percent of the 162 systems time-share some channels among various broadcasters, the number of stations carried by these systems exceeds their nominal capacity. For those CATV systems indicating that they switch between stations on a given cable channel, the ratio of stations carried to nominal capacity was 1.207. Many stations operate below nominal capacity because of interference problems on some channels (due to strong off-the-air signals), or because of the unavailability of local off-the-air signals. The FCC generally prohibits the importation of distant signals in the 100 largest markets. For the 67 percent of stations operating below nominal capacity,[†] the ratio of channels carried to nominal channel capacity is 0.715; on the average they supply 8.6 channels. Twenty percent of the systems operate at full capacity, i.e., the number of stations carried equals the nominal capacity of the cable. The average CATV system with 5000 or more subscribers supplies 9.2 channels, and the average subscriber receives 9.3 channels.[††] Table 29 shows the complete distribution.

[†] Since no data are readily available to indicate the precise number of channels unavailable due to strong off-the-air signals, we cannot accurately measure the effect of prohibiting distant signal importation.

[††] This is the product of actually received channels per system and subscribers per system divided by the total number of subscribers.

Table 28

NOMINAL CHANNEL CAPACITY FOR CABLE SYSTEMS WITH OVER 5000 SUBSCRIBERS

Nominal Capacity (Number of Channels[a])	Number of Systems Having that Capacity
5	13
9	1
11	2
12	143
20[a]	2
Unknown	1
Total Number of Systems	162
Nominal average number of channels per system	11.5

[a] Some of these systems are still being built.

Table 29

ACTUAL NUMBER OF TELEVISION CHANNELS SUPPLIED FOR CABLE SYSTEMS WITH OVER 5000 SUBSCRIBERS

Actual Capacity Number of Channels	Number of Systems Delivering That Number of Channels		Number of Subscribers Receiving That Number of Channels
4	5		41,526
5	16		128,916
6	4		27,586
7	17		145,908
8	19		152,654
9	20		155,718
10	26		220,403
11	13		91,416
12	41		414,036
17	1		6,000
Total Number of Systems	162	Total Number of Subscribers	1,384,163

Average number of channels filled per system = 9.18

Average number of channels received per subscriber = 9.32

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