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ABSTRACT

Questions pertaining to home terminals in the cable environment are examined. The functions of subscriber-owned television receivers in this new setting are examined and the details of set-top converters are closely scrutinized. Also explored are augmented one-way and two-way services which will require such added equipment in the home as a camera, microphones, digital devices, sensors, printers, and tape recorders. Lastly, characteristics of the augmented home terminal are examined in an attempt to identify the demands which the new services may place upon the cable systems. (Author)

OT REPORT 73-13

A SURVEY OF TECHNICAL REQUIREMENTS FOR BROADBAND CABLE TELESERVICES VOLUME 2

OT

U.S. DEPARTMENT OF COMMERCE/Office of Telecommunications

SUBSCRIBER TERMINALS AND NETWORK INTERFACE

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OFFICE OF TELECOMMUNICATIONS

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FOREWORD

As information transfer becomes more important to all levels of society, a number of new telecommunication services to homes and between institutions will be required. Many of these services may require broadband transmission. The new services may, in part, evlove from those provided by cable television.

This is one of a series of reports resulting from a survey of the CATV industry and related technological industries. The survey identifies some of the important technical factors which need to be considered in order to successfully bring about the transition from the technical state of today's cable television and services to those new teleservices which seem to be possible in the future.

The current and future broadband capabilities of telephone networks are not discussed since they are described in many Bell Laboratory and other telephone company publications. Also, the tremendous load projected for common carrier telephone and data systems in voice and data communication suggests that two-way, interactive, broadband networks, not now in existence, may be required in addition to an expanded telephone network. The many aspects of economic viability, regulation, social demand, and other factors that must be considered before the expectation of the new teleservices can be fulfilled are not within the scope of these reports. These reports concentrate on technical factors, not because they are most important, but because they have been less considered.

A report about the state-of-the-art and projections of future requirements in a complete technology draws material from a vast number of sources. While many of these are referenced in the text, much information has been obtained in discussions with operators, manufacturers, and consulting engineers in the CATV industry. Members of the National Cable Television Assoication, particularly, have been most helpful in providing information, discussing various technical problems, and in reviewing these reports.

Because of the substantial amount of material to be discussed it was believed most desirable to present a series of reports. Each individual report pertains to a sub-element of the total system. However, since some technical factors are common to more than one sub-component of the system, a reader of all the reports will recognize a degree of redundancy in the material presented. This is necessary to make each report complete for its own purpose.

The tilte of the report series is: A Survey of Technical Requirements for Broadband Cable Teleservices. The seven volumes in the series will carry a common report number: OTR 73-13. The individual reports in the series are sub-titled as:

A Summary of Technical Problems Associated with Broadband Cable Teleservices Development, OT Report No. 73-13, Volume 1.

Subscriber Terminals and Network Interface, OT Report No. 73-13, Volume 2.

Signal Transmission and Delivery Between Head-End and Subscriber Terminals, OT Report No. 73-13, Volume 3.

System Control Facilities: Head-ends and Central Processors, OT Report No. 73-13, Volume 4.

System Interconnections, OT Report No. 73-13, Volume 5.

The Use of Computers in CATV Two-Way Communication Systems, OT Report No. 73-13, Volume 6.

A Selected Bibliography, OT Report No. 73-13, Volume 7.

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SUBSCRIBER TERMINALS AND NETWORK INTERFACE

B. Wieder, R. Espeland, and C. Chilton *

ABSTRACT

It is the purpose of this report to examine the question of home terminals in the cable environment. The functions of subscriber-owned television receivers in this new environment is examined in detail. Characteristics of set-top converters are also examined in detail from the same point of view. Augmented one-way services and two-way services will add equipment in the home that can contain among others, a camera, microphones, digital devices, sensors, printers, and tape recorders. Characteristics of the augmented home terminal are examined in an attempt to identify the demands the new services may place on the cable systems.

1. INTRODUCTION

Traditionally, broadband cables have been used to retransmit over-the-air TV signals to subscribers who, for geographical or topological reasons, were unable to adequately receive the signals directly. Under these circumstances, the subscriber terminal, i.e., the TV receiver, performed more than adequately, since the cable more often than not provided a high level, high signal-to-noise input to the subscribers receiver. Indeed, low quality, inexpensive sets would work adequately on the cable where they might have proved inadequate for reception of the over-the-air signals.

Now that modern cable systems are expected to supply more than just the 12 over-the-air VHF signals, and also undertake to provide two-way communications on the cable, the subscriber-owned TV receiver will exist in a new environment in which it may not function

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effectively. It is the purpose of this chapter to examine the TV receiver as representing probably the most important single component of subscriber equipment in its new environment. The evidence indicates that the TV receiver will probably have to be a superior, high quality set, with special design features, in order to function effectively in an environment in which it must select from among a large number of cable-delivered video signals. In addition, it must be designed so that it will not deleteriously affect the quality of the signals on the cable.

The augmented one-way services and, in particular, two-way services will add equipment at the home terminal that can be as simple as a set-top converter, but may be as complicated as a complex of devices that contain, among others, a video camera, microphones, logic devices for encoding and decoding digital messages, keyboards, alarm sensors, printers, facsimile machines, frame grabbers, and video tape recorders. This report also examines some characteristics of the augmented home terminal in an attempt to identify what demands the new services place on system bandwidth and other system functions, and to see if a commonality of design exists so that "standards" can be identified. Standardization has the advantage that mass-production techniques can be brought to bear on the manufacture of many components with important economic benefits to both system operators and subscribers. Further, standardization could allow for subscriber ownership of equipment so that he could move from locale to locale with the full expectation that the equipment will work in his new site, as well as minimizing the consumer education needed to generate acceptance of new services.

2. SUMMARY AND CONCLUSIONS

To fully utilize the spectrum space on the cable, all channels available must be used effectively Subscriber terminal equipment, particularly the TV receiver, may impose limitations on the spectrum use and thereby cause wasteful loss of otherwise useful bandwidth. Many of the TV reception problems have been avoided in the past by the judicious allocation of the VHF frequency bands. Local oscillator frequencies and image frequencies were arranged to lie outside the active VHF frequency bands. However, these frequency intervals are now being considered for additional cable channels so that problems of local oscillator interference and image rejection must be resolved in order that the systems function properly. Further, adjacent channel signals will interfere with desired reception if passband characteristics of the TV receiver do not provide for adequate rejection of the undesired signals.

Perhaps the five most important factors which affect receiver performance characteristics and determine many of the design requirements for a TV set in the cable environment are co-channel interference, adjacent channel isolation, local oscillator leakage levels at the input terminals, image rejection, and receiver noise figure and sensitivity. The major conclusions drawn from the available literature on these factors and their implications in TV receiver design are as follows.

The reduction of co-channel TV interference with multiple interfering signals has classically been resolved by the use of the offset carriers. This method has been investigated in considerable detail by the Television Allocations Study Organization (TASO) and other investigators. The data thus obtained has led the FCC to specify offsets of ± 10 kHz (or ± 20 kHz) for co-channel transmissions in adjacent cities. Although the co-channel interference rejection was not optimum, this produced an improvement over non-offset frequencies that could be realized for all coverage areas. Direct pickup of an over-the-air signal by the TV receiver which interferes with the co-channel signal delivered via the cable is a particular form of co-channel interference of concern in broadband cable operations. Elimination of direct pickup of undesired co-channel signals through any path other than through the antenna terminals is basically a problem of shielding the sensitive parts of the receiver, such as the tuner, from ambient RF signals. Co-channel protection levels of up to 41 dB are required for "passable" picture quality. Current practice is to shift the cable signal to unused channels in order to avoid the interference problem, but this is wasteful and could become a problem as demands for spectrum space grows.

The susceptibility of the TV receiver to interference from adjacent channel signals is determined by the pass-band selectivity of the receiver and by the relative levels of the adjacent channel signals. The tolerable ratios of desired to undesired signal are very dependent upon the adjustment and stability of the adjacent channel traps. Upper adjacent channel interference comes mainly from the undesired picture carrier and requires about a 25 dB protective ratio. Lower adjacent channel interference results mainly from the undesired sound carrier, and a protection ratio of about 30 dB is needed when the sound carrier is 10 dB below its channel picture carrier. These protection ratios apply to color reception; monochrome protection ratios are considerably reduced from these. Given that the video carrier levels on adjacent channels is maintained within 3 dB on cable systems, and that the audio carrier is maintained 13 to 17 dB below the video carrier, the TASO evaluation would indicate that most TV sets would have enough selectivity to work satisfactorily in the cable environment even in the presence of adjacent channel signals.

Local oscillator leakage levels become important in cable operation where midband and superband channels are being used. Local oscillator frequencies for the conventional FCC assigned channels lie in these bands and can interfere with the desired signals. Allowing cable losses of 10 dB, port-to-port isolation of 20 dB at the cable tap, a +6 dBmV desired signal, and a signal-to-interference protection ratio of 57 dB, allowed L.O. levels would have to be -21 dBmV. Measured local oscillator leakage levels at the input terminals to TV receivers have been measured as great as + 24 dBmV and no set could meet the -21 dBmV criterion. Further, instances of strong second harmonic radiation of local oscillators have been reported. To solve this problem, better shielding is required on TV tuners, or set-top converters with good shielding will be required as a buffer between the cable system and the subscriber sets.

Projected use of midband and superband channels have prompted examination of image rejection capacilities of TV sets since images of the conventional channels lie in these bands. It has been found in practice that interfering signals must be between 50 and 60 dB below the wanted signal in order that there be no perceptible effect. Image rejection ratios varying from about 40 to 80 dB have been measured on modern TV sets. Thus, many sets will have inadequate image rejection capabilities for systems using more than 12 channels. Set-top converters that use high local oscillator frequencies can adequately reject all images. However, systems in which some subscribers use converters and some do not will have to face the difficult limitations imposed by image rejection deficiencies in TV receivers. Rejection ratios of 60 dB will be needed for effective performance in the cable environment.

Receiver noise figure and dynamic range apparently will play a minor role for TV receivers in the cable environment. Cable operation standards now require signal-to-noise levels of 36 dB, a level which produces a picture that 70 percent of viewers (by TASO standards) would accept as a "fine" quality picture. With signal levels at 0 dBmV on the cable, the noise figures of modern receivers (5 to 6 dB) will not seriously degrade picture quality. Since, in addition, the cable systems will maintain signals at the subscriber terminals at a uniform level, dynamic range requirements for TV receivers will be minimal.

The high-level, high-quality signals that cable systems supply can provide a salubrious climate in which TV receivers can operate. The receivers, however, must meet minimum standards of performance for the system to function. In addition to reduced local oscillator radiation levels, better image rejection ratios, and adequate co-channel isolation, the sets should provide a common equipment ground so that the unbalanced cable can be directly connected to the set.

A good input impedance match is important since low level reflections from a multitude of improperly matched connections can add up to degraded performance of systems. The TASO investigation indicated VSWR values as high as 6, with this number applying only to frequencies the set is tuned to. At other frequencies the receivers are likely to appear as either a dead short or as an open circuit. Further, a terminal may be inadvertently broken or disconnected. One method of overcoming these difficulties is to provide high isolation between the receiver and cable system.

TV receivers often have inadequate stability of traps and oscillators. This stability is important when adjacent channel assignments are made.

The set-top converter not only will allow for an augmented number of channels, but can also provide good grounding, improved rejection of co-channel signals, and resolution of the problem of local oscillator interference and image rejection through judicious selection of local oscillator frequencies. For local oscillator frequencies well above all bands of interest, questions of leakage levels become moot (although radiation levels must conform to FCC standards). Stability of local oscillators remain a problem, however, and the FCC has relaxed tolerances on visual carrier frequencies from ± 25 kHz to ± 250 kHz, thus recognizing the difficulties of frequency stability in these converters. Since converters are relatively new, little actual data is available on performance characteristics, other than manufacturers specifications. The specifications indicate that the converters generally have limited dynamic range (taking advantage of the uniform signal levels delivered on the cable), high local oscillator frequencies to avoid interference and image rejection problems, VSWR ratios of about 2:1, good shielding for ambient field isolation and acceptably low levels of cross modulation and spurious signals. Thus, the set-top converter becomes a vehicle for resolving many of the problems that now need to be solved with regard to TV receivers operating in a cable environment.

Additional one-way broadcast services can involve unscramblers or decoders in the form of special converters. Addressed services will require an address decoder and recording device. The recording device can take the form of a scan-converter storage tube, a charge transfer device, a video tape "frame-grabber", or facsimile unit.

With a two-way capability on a urban broadband communication system, the interface combinations that allow some sort of communications interaction between the subscriber or between a subscriber and program originators add complexity to the subscriber terminals. Several levels of interface exist. These involve a diversity of types of equipments and categories of services provided. These can consist of devices as simple as a touchtone telephone for the upstream communication unit to modems providing full data, voice, and video capability.

Two-way systems are still in the developmental phase and remain largely untested. A survey of systems under development indicates a wide diversity of approaches with little commonality of equipments.

Although standardization would provide significant benefits to both operators and subscribers, the systems appear too diverse to attempt to apply standards. These advantages lie in opportunities to interconnect systems easily, in minimizing the amount of consumer education required to generate acceptance of new services and develop skills to operate the equipments, and for subscribers to own their own terminals that could be universally used on any broadband communication system anywhere in the country. As the situation stands now, the subscriber modems are designed as integral parts of each particular communication system and must be supplied by the system operators. Further, cost savings on common software packages (software in the sense of computer control programs) cannot be realized because of the lack of uniformity among systems.

This diversity is likely to inhibit the development of mass-produced, low-cost equipment for home terminal use. Costs of subscriber terminals increase with increasing complexity and can skyrocket if each service requires specialized equipment. Careful thought must go into planning for flexible terminal equipment that can meet a multiplicity of needs.

In addition, to further reduce costs, all communication channels into the home should be integrated in a way that they can all contribute to meeting the telecommunication needs of the community, since many of the services to be supplied can be handled by systems other than cable. The greater the extent to which equipment can be used that is already commonly available in the home (TV receiver, radio, telephone, tape recorders, etc.), the greater the economic viability of the services.

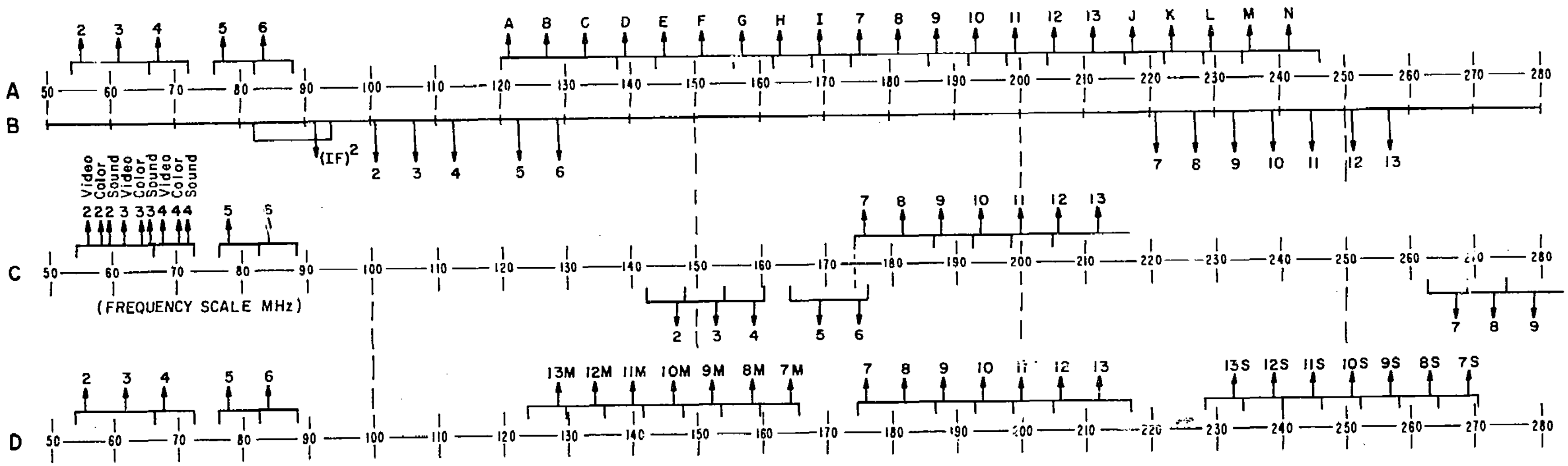
3. QUESTIONS OF FREQUENCY ALLOCATION

To facilitate interpretation of the discussion that follows, it is convenient to display the VHF spectrum and show the positions of the various channel allocations, local oscillator positions, and image locations. Figure 1 is such a display. On line C, with arrows pointing upwards to denote the position of the video carrier, the 12 over-the-air channels are shown. Channels 2 through 6 occupy a 34 MHz frequency range from 54 MHz through 88 MHz, with a 4 MHz interval between 72 MHz through 76 MHz that is reserved for navigation use. (In cable systems, AGC pilot tones are often injected in this frequency interval.) Channels 7 through 13 occupy a 42 MHz interval between 174 MHz and 216 MHz. The video carrier frequency is located 1.25 MHz above the lower channel edge, the aural carrier is located 4.5 MHz above the video carrier, and the color burst frequency 3.579545 MHz above the video carrier. The position of these frequencies for channels 2, 3, and 4 are indicated in the figure. The position of the adjacent channel frequencies, particularly the lower adjacent channel aural carrier and the upper adjacent channel video carrier, figure in an important way in the discussion that follows, since the adjacent channel picture and sound carriers are only 1.5 MHz from the desired channel picture and sound carriers. A more complete discussion of the TV signal is found in OT Report No. 73-13, Vol. 4.

Line B of Figure 1 shows the position of the local oscillator frequencies for the 12 FCC assigned channels. Each is located 47 MHz above the lower channel edge (45.75 MHz above the video carrier frequency of each channel). It is important to note that for a 12 channel system the local oscillator frequencies lie outside the intervals where the 12 active video channels occur. Thus, local oscillator radiation and interference has been no problem in cable systems that have simply reproduced over the 12 over-the-air TV broadcast channels.

On line C in Figure 1, with the arrows pointing down, the position of image frequency intervals for the 12 channels are shown. Here again, the image bands fall outside the intervals where the 12 television

Figure 1



VHF spectrum showing the channel allocations, local oscillator frequencies, and image positions.

channels occur. The only exception is that the image of channel 6 may come through and interfere with reception on channel 7. Also, the second harmonic of the IF frequency, which may be generated within the receivers, can possibly interfere with channels 5 and 6. These are well known problems and are considered in the design of tuners in home receivers.

Thus, through judicious allocation of the VHF television frequency bands, problems of image-frequency rejection and interference from local oscillator signals has been avoided. However, with the advent of broadband concepts of cable use where the unused frequency intervals is being considered for additional channels, the interference portential from local oscillator radiation and from possible image frequency interference needs to be reassessed.

In addition, to fully utilize the spectrum space on the cable, adjacent channels will be used. This may impose more stringent requirements on the adjacent channel rejection characteristics of television receivers which have been designed for an environment where adjacent channel (in the sense of continuous frequencies) over-the-air transmission assignments are not made in a particular city. Also involved in the question of frequency allocation is the one of co-channel interference where over-the-air signals interfere with signals delivered on the same channel via the cable. Interference can result from inadequate tuner shielding when the over-the-air signals are strong enough to be picked up by the receivers even without antenna connection.

4. THE T V SET

What has been euphemistically dubbed the "Subscriber Terminal" is primarily the TV set itself (although there are related peripheral equipments such as set-top converters and various hybrid systems which will be discussed in later sections). Whatever the broadband communication capabilities that will be developed, standards of performance for television receivers will undoubtedly play an important role. Because of the huge national investment in television sets and continuing over-the-air television broadcasts, CATV systems will have to be made compatible with existing TV sets. Alternatively, and hopefully, the new designs in TV receivers will undoubtedly take into account the new requirements of CATV systems and of broadband communications services in general.

That the television industry is evolving continually is a historical reality. It need only be pointed out that the first country to have tunable television receivers was the U.S.A., where thirteen channels were allocated for transmission during the post-war commercial development of TV. In 1937 the FCC allocated 19 channels: the low 7 (44-50, 50-56, 66-72, 78-84, 84-90, 96-102, 102-108) and 12 channels in the range 156-294 MHz (Fink, 1943, p. 263, 4). Then FM was given 40-50 MHz in exchange for 60-66 MHz (ch. 3). After WW II, FM was pushed to 88-108 MHz and the present allocations resulted. As early as 1950 many of the larger cities had more than two stations in operation. By 1957, there were approximately 300 TV stations operating on 12 VHF channels and more than 100 on the 70 recently allocated UHF channels. During this period, the development involved in the design of these TV tuners was so specialized that only two main forms -- the switch tuner and the turret tuner -- ultimately survived the evolutionary process. It was also during this period (Monochrome Standard, 1939; Color, 1954) that the groundwork was laid for the establishment of the "Standards" of television transmission and reception by the FCC, which on 31 August 1956 issued its Public Notice 35638. This resulted in the establishment of the Television Allocations Study Organization (TASO). The work of TASO, which established the engineering basis for the present standards, is given in the report, "Engineering Aspects of Television Allocations" (TASO Report, 1959).

The more important receiver performance characteristics summarized by TASO Panel 2 are given in Table 1. The table shows the poorest (P), the average (A), and the best (B) results for each of the characteristics listed. The data were obtained from 16 manufacturers. It is the wide variability of the several parameters that indicate possible difficulties when the sets are used in conjunction with CATV systems. Tuner 3 dB bandwidths can vary from 3.5 MHz to as much as 14 MHz so that most of the adjacent channel attenuation must be controlled through the IF amplifier and/or the video detector characteristics. Yet, these characteristics apparently are such that the adjacent lower sound carrier may be attenuated by as much as 60 dB or as little as 14 dB, while the attenuation of the adjacent upper picture carrier can vary from about 24 dB to about 56 dB.

TASO Panel 6, charged with evaluation of levels of picture quality, made a more detailed study of receiver performance. Table 2 gives the TASO quality rating scale. The scale is rather subjective. Figure 2 is an example of the curves produced in the TASO evaluations for the effects of signal-to-noise on picture quality. There appears to be wide latitude in the subjective response of individuals. The evaluations by the TASO panel are given in terms of the median (50 percent) viewer's estimate of a "passable" picture. More stringent criteria would lead to larger signal-to-interference ratios. For example, in the case portrayed in Figure 2, for 90 percent of the viewers to accept a "passable" quality picture, about 5 dB would have to be added to the signal-to-noise ratio.

4.1. Co-channel Interference

Most of the work on co-channel interference (Middlekamp, 1958; Behrend, 1959; RCA Labs., 1950; Dean, 1960; Fredendall and Behrend,

Table 1

Receiver Performance Characteristics
(TASO Report, 1959)

Channel	2-6			7-13		
Characteristic (1)	P	A	B	P	A	B
Noise Factor, db	9.7	6.5	4.6	12.2	8.5	6.5
Sensitivity, uv	150	40	4	270	57	6
Image Ratio, db	41	73+	80.5	45	68+	80
IF Interference Ratio, db	36	57+	76	53.5	68+	91
Tuner Bandwidth (2) 3 db down, mc	10.5	7.5	4.0	14.0	9.4	3.5
Tuner Bandwidth (2) 20 db down, mc	22.5	14.9	6.0	37.0	23	8.0
Five Min. Warm-up Drift, mc	.52	.09	.015	.65	.14	.017
One Hour Warm-up Drift, mc	.45	.21	.03	.40	.23	.035
Input VSWR	6.0	2.7	1.0	6.0	2.4	1.0
Adj. Lwr. Snd. (3) Car. Atten, db	14	40	60	20	38	60
Adj. Upr. Pic. (4) Car. Atten, db	26	40	56	24	39	52

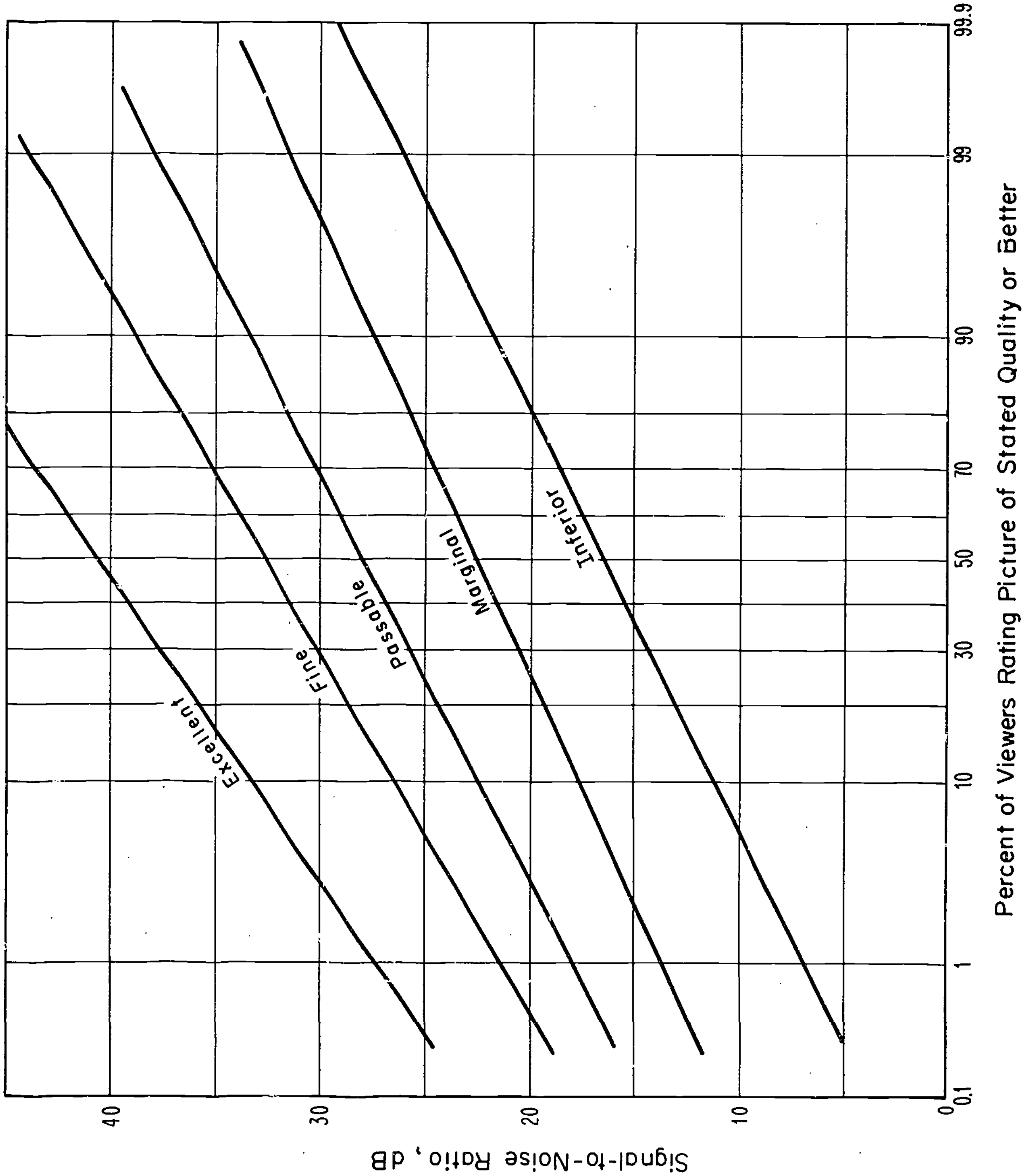
(1) P, A, and B stand for Poorest, Average and Best, respectively.
(2) In general, the broadest bandwidth is considered poorest. A lower number is generally more favorable down to about 6 mc.
(3) Channels used: 3-6; 8-13; 15-40; 41-65; 66-83.
(4) Channels used: 2-5; 7-12; 14-40; 41-65; 66-82.

Table 2

TASO Grade Scale for Qualitative Evaluation of TV Pictures (TASO Report, 1959)

Grade No.	Name	Description
1	Excellent	Picture is of extremely high quality, as good as you could desire.
2	Fine	Picture is of high quality providing enjoyable viewing. Interference is perceptible.
3	Passable	Picture is of acceptable quality. Interference is not objectionable.
4	Marginal	Picture is poor in quality and you wish you could improve it. Interference is somewhat objectionable.
5	Inferior	Picture is very poor but you could watch it. Definitely objectionable interference is present.
6	Unusable	Picture is so bad that you could not watch it.

Figure 2



TASO curves for signal-to-noise ratio (After O'Conner, 1968)

1960) produced data from experiments with synchronized television carriers. It was found that when two co-channel television stations are operated normally, the carrier frequencies may differ by only a few cycles to as much as several hundred cycles. The resultant beat between the carrier of the desired signal and the carrier of the interfering signal appears as horizontal moving black bars in the television picture. With increased interfering signal, the undesired picture appears in the background of the desired picture. The experiments have shown that the horizontal bars due to carrier beat become objectionable even when the undesired picture in the background is barely visible. With the two carriers precisely synchronized in frequency, the movement of the bars is completely eliminated. Under this condition of precise synchronization, further improvement can be obtained depending upon the relative phases of the two carriers at the receiving point. If the two carriers could be held precisely in phase quadrature, the largest improvement is obtained. The least improvement is achieved when the carriers are in phase or in phase opposition. If the two carriers are synchronized, the undesired picture becomes the basic source of interference. In observer tests carrier out to assess the effects of co-channel signal to interference ratios, observers were shown a TV picture with an unsynchronized signal as a source of interference, and then the interfering signal was adjusted to a value which the observer indicated to be objectionable. Next, the carrier frequencies were synchronized, adjusted to the least favorable phase, and the undesired signal increased until the observer felt that the interference was as objectionable as the unsynchronized condition. The improvement factor was taken as the number of dB which the undesired signal was increased from one case to the other. The results of the co-channel tests gave the following requirements for the passable rating of 50 percent of the observers: 22 dB for 360 Hz offset, 41 dB for 604 Hz, 24 dB for 9985 Hz, 17 dB for 10,010 Hz, 29 dB for 19,995 Hz, and 17 dB for 20,020 Hz. These ratings stem from highly variable reactions of individuals, but indicate the values for the median respondent estimate of a "passable" quality picture. The interference generated by the different frequency offsets produced moving horizontal black and white bars. The spacing and motion of the bars were more objectionable at certain offset frequencies than at others. Experiments by Middlekamp (1958) and by Chapin, et al. (1958) showed that co-channel interference produced minimum picture degradation when the frequency offset between channels was an even multiple of the frame rate. This effect is reflected in the above data.

The improvement resulting from synchronization with the frame rate is superimposed on another effect. When two stations are transmitting on the same frequency, precise synchronization is required in order to avoid a near zero beat that causes a very noticeable flicker effect. To avoid as much interference of this type as possible, the FCC normally assigns adjacent channels to neighboring cities. Where they must assign identical channels to stations just beyond these neighboring cities, they allocate the channel frequencies with offsets of ±10 kHz, or sometimes ±20 kHz. Some of the early studies (Fredendall, 1953; Behrend, 1956) of co-channel interference indicated that optimum offsets occurred at odd multiples of 7.875 kHz, (i.e., at odd multiples of half the horizontal oscillator line frequency) and was worst at nearly zero frequency offset and at multiples of 15.750 kHz (i.e., at multiples of the horizontal oscillator line frequency). The data indicate an improvement of about 20 dB in the perception of a co-channel interfering signal when odd multiples of 7.875 were used instead of even multiples of 15.750 kHz.

To allow for possible 3 station interference, the FCC has specified the ±10 kHz (or ±20 kHz) offsets so that improvement over non-offset frequencies could be realized for all the coverage areas. Dworkin and Chuang (1970) discuss some of the interference effects and propose a 10 kHz (or 20 kHz, as appropriate) filter in the video circuits to overcome the residual co-channel interference. Chapin, et al. (1958) also have proposed trap designs at the offset frequencies to reduce the co-channel interference.

Co-channel and random-noise interference in combination produce a visual effect of narrow horizontal bars moving through a "snowy" picture. The contrast of the bars is proportional to the level of co-channel interference, and the "snowiness" is proportional to the magnitude of the random noise. The more favorable offsets lead to a fine line structure and reduced visibility of the bar pattern. For co-channel and random-noise interference, the requirement for passable rating by 50 percent of the observers was 27 dB on the basis of RMS sync amplitude to RMS noise, over the 6 MHz channel.

One of the possible conditions for co-channel interference would be the "direct pickup" of the over-the-air signal by the subscriber terminal. Indeed, all the symptoms and difficulties of co-channel interference can result from non-synchronization of the carrier on the cable and the carrier as received over the air. It has been recently pointed out (Hand, 1972) that one of the major problems that could limit the growth of CATV is the performance of the average television receiver in locations of high field intensity from off the air TV broadcast stations.

The elimination of direct pickup of undesired co-channel signals through any path other than through the antenna terminals is basically a problem of shielding the most sensitive parts of the receiver, such as the tuner, from RF signals. Hand (1972) presents some measurements that were made on receivers which "represent collectively the industry's present day production." He concludes from this data that:

"1. Receivers using a conventional 300 ohm input switch-type tuner without special provision for CATV, connected to 100 feet of terminated RG6A/U type double-shielded coaxial cable through a typical 300 to 75 ohm unshielded balun, can pick up signals equivalent to levels as high as 25 mV across 75 ohms when in a 275 mV/Meter field.

2. Receivers modified to incorporate completely shielded tuners and a 75 ohm input, using chassis without power-line isolation ("transformer-less" chassis), can pick up signals equivalent to levels in the order of 1 mV in a 275 mV/Meter field when the input coaxial cable shield is power-line isolated from the chassis by a 1000 PF coaxial feed-through capacitor.

3. Receivers modified to incorporate completely shielded tuners with a 75 ohm input and mounted directly on a power-line isolated (transformer-type) chassis, with minimum length interconnections between tuner and chassis, can pick up signals equivalent to levels in the order of 5 to 10 microvolts in a 275 mV/Meter field.

The best case condition indicated in item 3 is marginally acceptable if the results are extended to a 0.5 V/Meter field. This marginal condition would require some cushion be provided in receiver designs to ensure that all production receivers could meet the limit. Evaluations to date indicate that mounting the tuner separate from the chassis makes reduction of direct pickup increasingly difficult.

There have been no published studies to indicate how many receivers connected to CATV systems would be subjected to 0.5 V/Meter or other specific fields. Without such a study, it does not appear reasonable to set specific receiver immunity requirements."

There are published figures indicating the population inside Grade A contours (2.5 or 3.5 mV/m at 30 ft.). If we assume a 1000 foot transmitter antenna height, 100 kW on channel 4, the Grade A contour occurs at 37 miles, while the 0.5 V/m contour appears at 2.2 miles. Thus

$$\frac{\text{Population under} \geq 0.5 \text{ V/m contour}}{\text{Population under Grade A}} = \frac{\pi(2.2)^2}{\pi(37)^2} = \frac{1}{282} \simeq 0.35\% .$$

Hence, if 100 million people nationwide receive Grade A service, then 350 thousand people are in an area of TV field in excess of 0.5 V/m at 30 ft. above ground. As 30 ft. above ground is a fair estimate for the average apartment dweller, there are probably less than 1/2 million people living in areas of high ambient field. Nevertheless, co-channel protection levels of 17 to 41 dB are required for passable pictures. It would appear that one of the major problem areas in interfacing the CATV and subscriber-terminals may be co-channel interference from "over-the-air" signals. Current practice is to shift the cable-delivered signal to unused channels in order to avoid the co-channel interference problem. This is wasteful of useful spectrum space, and will become an increasing problem as demands for spectrum space grows. The use of carefully designed set-top converters, or well-shielded tuners, will be required in order to reduce co-channel interference to acceptable levels.

4.2. Adjacent Channel Isolation

The susceptibility of the television receiver to interference from adjacent channel signals is determined by the pass-band selectivity of the receiver and by the relative levels of the adjacent channel signals. The TASO data are reproduced in Tables 3 through 6. TASO Panel 6 evaluated 5 receivers (2 color and 3 monochrome). Table 3 essentially describes the passband characteristics of the receivers. The frequencies used are identified as follows:

Pop-up frequency below adjacent sound	- ~ 2 MHz below picture carrier
Adjacent channel sound	- 1.5 MHz below picture carrier
Band center	- 1.75 MHz above pciture carrier
Color subcarrier	- 3.6 MHz above picture carrier
Desired sound carrier	- 4.50 MHz above picture carrier
Pop-up beyond sound trap	- ~ 5 MHz above picture carrier
Adjacent picture carrier	- 6.0 MHz above picture carrier.

Here again the performance characteristics of the receiver passbands appear highly variable, particularly on the band skirts. Near the band center, the characteristics are much more uniform. In addition, the two color sets appear to have much better and more uniform characteristics than the monochromatic sets.

The data in rightmost column of Tables 4, 5, and 6 are adjusted to reflect the variable response of the receivers from set to set. Table 4 indicates that the signal-to-interference ratio of the adjacent picture carrier (using the criterion of a "passable" picture for the mean observer) has to be in the 20-25 dB range at the video detector for color TV reception and only in the 8-15 dB range for black and white reception.

Tables 5 and 6 give the results for "passable" reception when the lower adjacent sound carrier is the interfering signal. When the sound carrier level is 3 dB below the picture carrier level, a signal-to-interference ratio of 34 dB is required for the color receivers and a ratio of 27 to 30 dB for the monochrome sets. When the sound carrier level is reduced to 10 dB below the picture carrier level, these ratios become about 30 to 32 dB for the color set and about 20 dB for the black and white set.

Table 3

Level in dB Relative to Picture Carrier

Receiver	Pop-up	Adjacent Sound	Band Center	Color Subcarrier	Sound	Pop-up	Adjacent Picture
1 (color)	-37	< -60	+6	0	< -60	-31	-48
2 (mono)	-33	-51	+6	-1	-22*	-23	-33
3 (color)	-34	< -60	+6	0	-58	-31	-50
4 (mono)	-28	-54	+7	0	-26	-24	-43
5 (mono)	-24	-48	+8	0	-20	-10	-25

*Sound trap measured -24 but was shifted 1/4 Mc high (at R. F.).

Table 4

Signal-to-Interference Ratio of the Adjacent Picture Carrier

Receiver	Attenuation of upper adjacent frame picture carrier frequency in receiver-db*	-cps	Mean observer signal/interference ratio for Passable picture-db	Signal/Interference ratio adjusted for zero attenuation of adjacent picture carrier in receiver-db
1 (color)	-48	30	-26	+22
		29.97	-27	+21
3 (color)	-50	30	-25	+25
		29.97	-27	+23
2 (mono)	-33	30	-20	+13
		29.97	-25	+ 8
4 (mono)	-43	30	-29	+14
		29.97	-33	+10
5 (mono)	-25	30	-10	+15
		29.97	-16	+ 9

Table 5

Passable Ratios for Sound Carrier 3 db below Picture Carrier

Receiver	Attenuation of lower adjacent sound carrier in receiver - db	Mean observer signal/interference ratio for Passable picture - db	Signal/interference ratio adjusted for zero attenuation of lower adjacent sound carrier in receiver - db
1 (color)	-60	-26	+34
3 (color)	-60	-26	+34
2 (mono)	-51	-24	+27
4 (mono)	-54	-24	+30
5 (mono)	-48	-19	+29

Table 6

Passable Ratios for Sound Carrier 10 db below Picture Carrier

Receiver	Attenuation of lower adjacent sound carrier in receiver - db	Mean observer signal/interference ratio for Passable picture - db	Signal/interference ratio adjusted for zero attenuation of lower adjacent sound carrier in receiver - db
1 (color)	-60	-30	+30
3 (color)	-60	-28	+32
2 (mono)	-51	-30	+21
4 (mono)	-54	-33	+21
5 (mono)	-48	-28	+20

Given that the video carrier levels on adjacent channels is maintained within 3 dB on cable systems, and that the audio carrier is maintained 13 to 17 dB below the video carrier, the TASO evaluation would indicate that TV sets would have enough selectivity to work satisfactorily in the cable environment even in the presence of adjacent channel signals. Ellsworth (1972), however, reports that recent tests have verified "the generally accepted minimum tolerable interference ratio of 57 dB for coherent interference from signals in the vicinity of the video carrier." From this he concludes that a 47 dB rejection ratio is required for the adjacent channel sound carrier. Ellsworth also quotes Archer Taylor as suggesting a 35 to 40 dB lower adjacent channel sould carrier threshold (requiring a selectivity ratio of between 25 to 30 dB). Ellsworth (1972) also states that a 40 dB rejection of the unwanted adjacent picture carrier is required.

Table 7 shows the average values reported by Hand (1972) for tests on one sample from one manufacturer. They appear to be consistent with the assessments given above. To avoid adjacent channel interference in an "over-the-air" broadcast environment where the signal levels can be highly variable, adjacent channels are generally no assigned. Of course, this practice wastes spectrum space. In the cable environment where adjacent channel use is important to system operation, the bandpass characteristics of TV receivers becomes increasingly important.

4.3. Local Oscillator Radiation

It was pointed out in the section on co-channel interference that an unshielded tuner might be capable of picking up interfering signals in the receiver. Another important reason for good shielding is that of local oscillator radiation. The local oscillator operates at a

Table 7

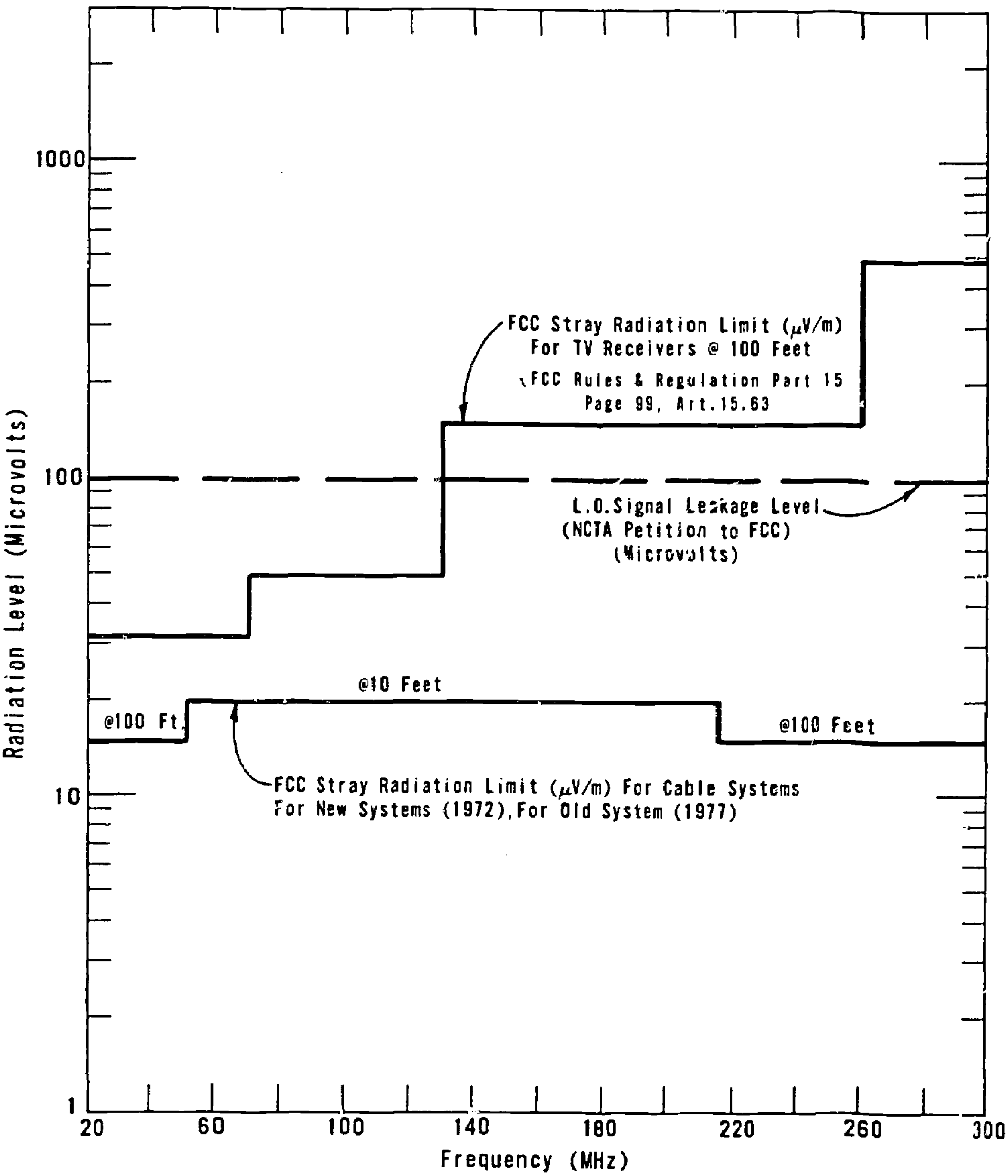
Interfering Signal	Minimum Desired to Undesired Ratio in db at Detector Input for Imperceptible Interference.	
	IN295 Diode Detector	Low Level Detector
Adjacent Picture	27	25
Adjacent Sound W/Mod.	45	46
Adjacent Sound W/O Mod.	52	55
Accompanying Sound W/Mod.	39.7	35.7
Accompanying Sound W/O Mod.	42.7	36.7

high level, and unless particular care is taken, the fundamental and harmonic frequencies will be radiated at levels far above those of the incoming desired signals. If some standardization or limitation is not imposed, this radiation could cause serious interference with all sorts of services apart from the reception of other television channels by other set users. Figure 1 shows diagrammatically some likely interference combinations in the various bands under consideration for CATV augmented service.

Radiation from the local oscillator must pass to the input terminals of the TV set connected to the tuner through the other parts of the receiver, along the power lead, or as "stray radiation." Many of these aspects have been considered by the radio industry and the FCC, and the recommendations are indicated in the diagram of Figure 3. Stray radiation level requirements for TV receivers and for cable systems are indicated, as is the maximum level of local oscillator voltage that the NCTA suggests should appear across the input terminals of a TV receiver.

Recent measurements on six late model TV receivers (Jeffers, 1970; Levine, 1972) of local oscillator radiation at the antenna terminals are given in Table 8. The measurements indicate that an average TV set has a high level of L. O. leakage. These L. O. frequencies are produced in the midband and superband portions of the spectrum, which, although they do not affect the twelve VHF channels, will limit the degree to which these portions of the spectrum can be used by the cable system. The worst case occurs in what is referred to as "mixed systems" where a cable company has both subscribers with converters that can receive mid- and superband frequencies and subscribers without converters. Jeffers (1970), Levine (1972), and Ellsworth (1972) treat the case of two adjacent subscribers on the same distribution line and assume cable drop losses of 5 dB, a directional multitap isolation loss of 20 dB, and a desired signal at + 6 dBmV. Allowed L. O. signal levels would have to be -21 dBmV (80 μV) for an allowable signal to interference level of -57 dB. Table 8 indicates that L. O. leakage levels for practically all the sets tested are far too high. Second harmonics of the local oscillators can also cause

Figure 3



FCC standards for TV receiver radiation levels. Also shown is the L. O. Leakage level proposed by the NCTA to the FCC

Table 8

TV Set Local Oscillator Leakage Levels in dBmV, Measured at Antenna Input Terminals

	Color	Mono	Color	Color	Color	Mono
Channel	A	B	C	D	E	F
4	-22.0	-12.0	-15.0	-12	-13.0	-24.0
5	-14.0	+ 2.0	-13.0	-11	- 8.0	-30.0
6	-11.0	+ 4.0	-13.0	- 9.5	- 7.5	-30.0
7	- 3.0	+19.0	- 4.0	+ 6	- 3.0	-18.0
8	+ 1.0	+21	- 4.0	+ 5.5	- 1.5	-14.0
9	+ 1.0	+21	- 2.0	+ 8.0	- 2.0	-10.0
10	0.0	+24.5	- 3.0	+ 9.0	- 4.0	-20.0
11	- 3.0	+20.0	- 4.0	+10.0	- 8.0	-20.0
12	- 7.0	+11.0	0.0	+ 8.0	- 3.0	-11.0
13	- 5.0	+10.0	- 1.0	+ 6.0	- 4.0	-12.0

interference, particularly in the configuration where more than one receiver is attached to the cable terminal.

Ellsworth (1972) indicates that the proposed 100 microvolt limitation on local oscillator signal level at the input terminals of the TV receiver can be achieved by the use of shielding and traps (based upon a design study conducted by a tuner manufacturer) at some additional cost. He concludes with the statement, "Adoption of the 100 microvolt limit would control only one part of the problem -- new television receivers. However, the interference produced by existing receivers in systems with more than 12 channels will be a continuing problem."

4.4. Image Rejection

As pointed out earlier, the judicious choice of VHF frequencies for over-the-air television broadcast had eliminated the need for any serious consideration of image rejection. The image frequencies were outside the broadcast bands, so that no special precautions were particularly required.

Typical image rejection ratios given by Jeffers (1970) were obtained from tuner and set manufacturers:

A. Three circuit tuners used in low cost TV sets:

Low VHF Band	50 dB
High VHF Band	35 dB

B. Four circuit tuners used in better monochrome sets and in color sets:

All VHF Channels	60 dB

The TASO investigation indicates image rejection ratios from about 41 dB to greater than 80 dB in the low VHF band and from about 45 dB to 80 dB for the high VHF band (see Table 1).

It has been found in practice that the interfering signal must be between 50 and 60 dB below the wanted signal level in order that there be no preceptible effect. With the selectivity already built into the receivers, signals in the over-the-air frequency bands where the image frequencies lie (air navigation) created no particular problems for the TV set user.

The projected use of midband and superband channels, however, has prompted several of the cable companies to look in detail at this problem (Jeffers, 1970; Levine, 1972; Powers, 1972). Several of the midband and superband channels appear where the VHF channels have images. Line A in Fig. 1 shows proposed midband frequencies in which channels D through I lie in the region where channels 2 through 5 have images. Line D shows a possible allocation involving a block conversion scheme where channels 7M, 8M, 9M, 10M, 7S and 8S lie in image regions of the spectrum. Since the level of the additional channels will normally be maintained within 3 dB of the other channels, it is clear that the poorer sets listed by TASO will not adequately reject the additional channels where they appear as images of the VHF channels.

A possible solution to the problem lies in providing a set-top converter to each subscriber which adequately rejects all images. This can be done through a combination of adequate selectivity and by using high-frequency local oscillators in a double conversion heterodyne process. However, Levine (1972) has raised the question of operating mixed systems; i.e., a system in which some subscribers have set-top converters to receive the additional channels, while other subscribers do not. He concludes that it would be necessary to leave unused those channels that would like in the image frequency range. This would eliminate essentially the frequency band from about 142 MHz through about 174 MHz and from 260 MHz upward. Since the local oscillator frequencies associated with the VHF channels block most of the remaining unused spectrum (see Figure 1), additional channels void of interference become difficult to find without supplying the subscribers without the set-top converters some sort of adequate band filter.

4.5. Receiver Noise Figure and Dynamic Range

The dynamic range (or more precisely, sensitivity) of a linear receiver is a measure of its ability to receive weak signals and produce an output of usable level and acceptable quality. A linear receiver is defined (CCIR, 1970) as one operating in such a manner that the signal-to-noise ratio at the output is proportional to the signal level at the input, and/or to the degree of modulation. The noise factor is defined as the ratio-of-noise power measured at the output of the receiver to the noise power which would be present at the output if the thermal noise due to the resistive component of the source impedance were the only source of noise in the system. Noise powers are determined at an absolute temperature of the source equal to $T = 293^{o}K$. The noise temperature is defined as the value by which the temperature of the resistive component of the source impedance should be increased, if it were the only source of noise in the system such as to cause the noise power at the output of the receiver to be the same as in the actual system.

For television and sound broadcast receivers, a maximum sensitivity is defined (CCIR, 1970) as the minimum input signal applied--in series with the specified source impedance (dummy antenna)--to the input of the receiver for which any usable signal with a specified output level can be obtained. For the purposes of presenting and comparing data for particular classes of linear receivers and classes of emission (normally noise-limited), and for a particular frequency range, the reference sensitivity should be defined as the maximum usable sensitivity for specified values of S/N ratio, receiver bandwidth, degree of modulation, and source impedance. According to the CCIR (1970), the methods of test of TV receivers have not, as yet, been standardized in the various countries. Nevertheless, the CCIR does give tables (Tables 9 through 12) of representative values of the sensitivity of the vision and sound channels of typical TV receivers. However, these data must be regarded as tentative and incomplete. Although the more complete data in these tables is for the 405 line British system, some data applicable to the 525-line U.S. system is given in Table 10. In this table the sensitivity of the vision channel has been taken as the input signal required to produce at the output: (a) a vision signal output level of 20 Volts p-p; or (b) a vision S/N

Tables 9 to 12

Sensitivity and noise factor for television receivers

Frequency range (MHz)	Class of emission		Maximum usable sensitivity noise-limited (dB relative to 1 μV)	Maximum usable sensitivity gain-limited (dB relative to 1 μV)	Maximum sensitivity (dB relative to 1 μV)	Noise factor (dB)	Remarks
(1)	(2)	(3)	(4)			(5)	(6)
Table 9 (1) *(405-line system)*							
41-68	A5 (picture)	Max.	56	57	34	14	14 receivers of different types tested (12 noise-limited, 2 gain-limited). Maximum sensitivity for 5 receivers
		Mean	66	54	29	7	
		Min.	38	51	26	4	
	A3 (sound)	Max.	28	35	13	13	14 receivers of different types tested (9 noise-limited, 5 gain-limited)
		Mean	21	27	8	8	
		Min.	15	20	7	4	
174-216	A5 (picture)	Max.	49		40	8	Four receivers tested
		Mean	—		—	7	
		Min.	40		32	6·5	
	A3 (sound)	Max.	20		20	8	Four receivers tested
		Mean	—		16	7	
		Min.	18		11	6·5	
Table 10 (2) *(625-line system, video band 5 MHz and 525-line system, video band 4·2 MHz)*							
41-68	A5 (picture)	Max.				11·8	Mass-production receivers. Noise factor for 20 receivers tested
		Mean	43		36	7·5	
		Min.				4	
	F3 (sound)	Max.					
		Mean	34·5				
		Min.					
174-216	A5 (picture)	Max.				11·8	
		Mean	49		44	7·5	
		Min.				5	
	F3 (sound)	Max.					
		Mean	40·5				
		Min.					
470-890	A5 (picture)	Max.				18	Ten receivers of different types tested
		Mean				12	
		Min.				9	
Table 11 (3) *(625-line system, 6 MHz video band)*							
41-68	A5 (picture)	Mean	56	50			Few receivers tested. Receivers of different type and design
Table 12 *(819-line system)*							
162-216	A5 (picture)	Mean	43	57	33	8	

(1) See Doc. 11/29, Geneva, 1962.
(2) See Docs. 398, Warsaw, 1956, 11/3, Geneva, 1958, and 11/31, Geneva, 1962.
(3) See Doc. 215, Warsaw, 1956.

ratio of approximately 38 dB (p-p values of vision signal and rms values of noise). If the gain is insufficient to enable (a) and (b) to be satisfied simultaneously, the receiver is referred to as gain-limited, otherwise it is noise-limited. On the other hand, if (a) is satisfied and if the signal-to-noise ratio defined in (b) refers to "any usable" picture, the sensitivity should be described as maximum sensitivity.

Twenty years ago, noise figures in the range of 8 to 10 dB were considered representative for television tuners (TASO Report, 1959, see Table 1). Technical progress during the last few years in the design of input circuits for TV tuners and the advent of the transistor has resulted in some improvement; noise figures in the 5 to 6 dB range are now considered representative (Ellsworth, 1972).

The significance of specifying a minimum S/N ratio can only be determined by considering what it looks like to the viewer on a television screen. The minimum S/N ratio specified by the FCC is 36 dB in a 4 MHz bandwidth. The results of the TASO panel 6 tests (Ellsworth, 1972) are shown in Figure 2. From this figure we see that this S/N ratio results in a picture excellent for 20 percent of the viewers, fine for 70 percent, and passable for approximately 95 percent of the viewers.

For a noisy video source, the signal level delivered to the input terminals of the subscriber's receiver must be higher than would be the case for a noise-free source and a noise-free receiver; i.e., in setting the video carrier level range at the subscribers receiver input, the optimum low-end signal level limit should be set at a point where the receiver noise contribution would be insignificant. The point at which the receiver noise becomes insignificant is related to the receiver noise figure and the incoming video carrier signal-to-noise ratio. Ellsworth (1972) has given the following mathematical relationship between signal power (P_{signal}), receiver noise power (P_N), and the overall signal to noise ratio of a noisy video source $(S/N)_{Video\ Carrier}$:

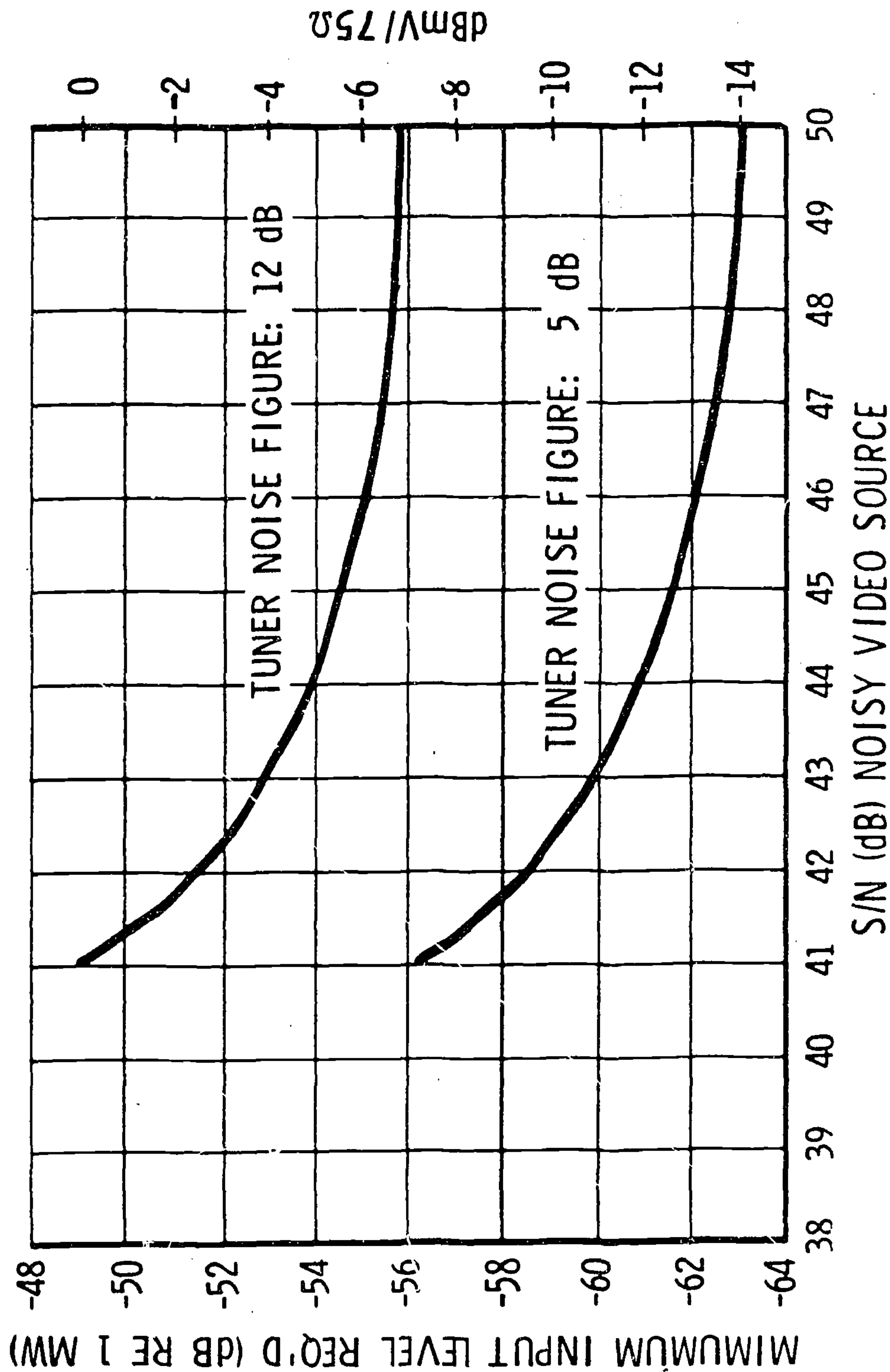
$$(S/N)_{Picture} = \frac{P_{Cable\ Signal}}{P_{Noise,\ Receiver} + \dfrac{P_{Cable\ Signal}}{(S/N)_{Video\ Carrier}}}$$

Figure 4 presents his results of a computer run of computed input levels required at the receiver to achieve $(S/N)_{picture} = 40$ dB as a function of $(S/N)_{video\ signal}$ ratios 38 to 50 dB, and for tuner noise figures of 5 dB and 12 dB. The Video Carrier (S/N) Ratio includes all sources of noise in video signal generation, as well as noise added by the cable distribution system. In order to achieve a $(S/N)_{picture} = 40$ dB, the video carrier S/N ratio at the input to the receiver must be greater than 40 dB and must be delivered at a level appreciably greater than just 40 dB above the equivalent receiver noise (Ellsworth, 1972).

An examination of these curves of Figure 4 shows that, for a noisy video source with S/N = 44 dB, a tuner with a 5 dB noise figure would require a cable signal level of -12 dBmV, whereas, a tuner with a 12 dB noise figure would require a cable signal level of -5 dBmV. Further inspection of the figure shows that the required signal level to maintain viewer picture S/N level increases rapidly as the video carrier S/N (Noisy Video Source) is reduced.

Since signal levels on cables are to be maintained at a nominal 0 dBmV at the subscriber terminal, it would appear that the signal-to-noise limitation will not be in the noise figure of the receivers. Many cable systems, however, will not meet this design level, so that poor receivers may not function adequately on signals delivered via the cable.

Figure 4



Input signal level required for 40 dB picture quality vs S/N ratio, noisy video source.
(After Ellsworth, 1972)

4.6. Compatibility with Coaxial Systems

There appear to be several additional questions that have to be considered when the TV receiver is used in the cable environment. Some are listed here:

a) Equipment ground. Some mention of this has been made in connection with co-channel interference effects. A good ground is required to adequately reject over-the-air signals in order that they not interfere with the cable-delivered signals. The cable ground may not be the same as equipment ground, and may require the use of polarized power plugs or electrical isolation through power transformers.

b) Matching Input Impedance. VSWR (return loss) information indicates that the match between the receivers and a 300 Ω (or 75Ω) system is not particularly good. The TASO investigation indicates VSWR's range from 1 to 6. In the latter instance more than 70 percent of the incident signal is reflected back into the system. Further, these numbers appear to apply only to the frequencies for the channel the set is tuned to. At all other frequencies, the receivers are likely to appear either as an open circuit or a dead short. Switzer (1971) suspects that "short-spaced low-level reflections from a multitude of connections, splices, and other disturbances in a cable transmission system" add up to a general "soft smear" in cable pictures. Hand (1972) indicated a requirement for electrical isolation between the CATV system and receiver terminals because of the low return loss (high VSWR) and because the system must operate with cable connections removed from the receiver.

Receiver isolation is also required to isolate spurious signals from the receivers from entering the cable system. This question is discussed at length in connection with local oscillator radiation.

c) Tuning Stability. TV receivers often have inadequate stability of traps and tuning (Switzer, 1971). Oscillator stability and trap stability affect the ability of the sets to operate in a cable environment where all channels are fully allocated. Ellsworth (1972) feels that in the future thermal drift of local oscillators can be controlled within tolerable limits, and in conjunction with solid state filters and AFT, adjacent channel interference should not be discernable.

4.7. Measurement Methods and Standards

It is generally not well known that there are several organizations which are interested and active in the establishment of television performance standards. The CCIR (International Radio Consultative Committee) is an advisory organization of International Telecommunications Union, one of the specialized agencies of the U.N. which establishes recommendations in the fields of radio and television. The CCIR membership is composed of many countries and organizations, including the U.S. It sponsors various international study groups which prepare reports and recommendations which are sometimes complex, because they are required to cover all the different television standards used throughout the world. Another important organization is the EIA (Electronic Industries Association). In addition to its other activities, this group sponsors various technical committees to prepare recommended performance standards in the video field. Additional organizations are the NTC (Network Transmission Committee), made up of representatives from the major U.S. television networks and the Bell System; the National Television System Committee (NTSC); the National Cable Television Association (NCTA); and all the related video signal transmission and reception sub-committees and committees of the IEEE. One important distinction between the IEEE standards and other industrial standards such as those issued by the EIA is that IEEE standards deal with methods of measurement and definitions of terms, but generally do not specify performance limits. EIA standards, on the other hand, may adopt methods of measurements originated by the IEEE, but will additionally recommend minimum performance characteristics for good engineering practice. Although we will mainly be concerned with the standards for television receivers, since it is receiver performance that most impacts on cable system capacities, the standards for transmitters and receivers are so interrelated that one cannot discuss or set standards for the one without at least being familiar with the standards set for the other. For this reason the EIA Electrical Performance Standards for Television Broadcast Transmitters (1961) and the NTSC Signal Specifications (IRE, 1954), which were approved by the FCC as their "TV Technical Standards", should also be consulted. The original standards adopted in 1941 by the Federal Communications Commission (FCC) were the result of the Radio Manufacturers Association agreeing --at the request of the FCC--to set up a committee comprising representatives of all companies and organizations interested in television. The Proceedings of this National Television System Committee (in an edited form) are reproduced in the book Television Standards and Practice (Fink, 1943).

Early in the development of TV standards, the approach was taken that "unnecessary standardization would discourage the advancement of the art, whereas intelligent standardization should accelerate progress and encourage competition", (Fink, 1943). As a result of this approach, receiver standards have taken the form of measurement standards such as the first IRE Standard 48 IRE 22. S1., "Standards on Television: Methods of Testing Television Receivers, 1948." This Standard was subsequently replaced in 1960 by the "IRE Standards

(60 IRE 17, S1) on Television: Methods of Testing Monochrome Television Broadcast Receivers, 1960", which appears to be the basic reference for all subsequent standards (i.e., ANSI C16.13-1961; EIA RS-378; RS-207) on television receivers. In this Standard (IRE, 1960), it is stated, "At a later date, a standard for color television receivers will be introduced"; to date this promised standard has yet to be introduced. Other organizations have also developed television standards. These include the FCC Technical Standards, the IEEE Standards on Television, CCIR Technical Standards, NCTA Technical Standards, and the EIA Standards.

Although the IEEE standards have been adequate for over-the-air broadcasting, the possibility has now arisen that new standards may be needed to cover the case of the television receiver in the cable TV environment. It has been suggested (Switzer, 1971) that some serious shortcomings in present day TV receivers may occur when they are operated in the cable environment since many designs have, for example, inadequate adjacent channel rejection, inadequate stability of traps and tuning high local oscillator leakage levels, and inadequate shielding.

The IEEE currently has an effort under way to establish engineering standards for the CATV industry. The FCC has established a cable television advisory committee to examine the needs for standards on CATV receivers, cable systems, technical operations, and other important facets of the broadband communications.

5. THE SET-TOP CONVERTER

In the previous section, the TV set has been discussed as the principal equipment used for the subscriber terminal. The discussion was directed to the equipment characteristics that determined the quality of TV reception and identified possible problems in reception when the TV set is operated from a cable.

This section will deal with the characteristics of set-top converters. The set-top converter can provide for an augmented number of channels and can also correct some of the difficulties that occur when TV sets are used alone.

The assignment of channels for "off-the-air" service were made in a way that there was a "guard" channel between each active channel, which greatly reduced co-channel interference. This same condition existed with the early cable systems because they were built to service areas with weak "off-the-air" reception and served only to redistribute these signals. Thus, a TV receiver which performed well for "off-the-air" reception usually provided equally good performance on the cable.

As the use of CATV was extended to service in or near metropolitan areas, set-top converters evolved as a means of solving the direct pickup provlem prevalent in these strong signal areas (Walding, 1971). The method used was to down-convert the cable signals to a 44 MHz I-F and then up-convert to a channel that was unoccupied by a broadcast signal. The R.F. circuitry used to perform this function was enclosed in a well shielded metal compartment to reduce over-the-air pickup. However, the basic tuning methods used were the well established VHF TV tuner concepts and hardware so that spurious local oscillator signals at the input terminals were significant. With the growth of CATV signals to the mid and superbands, the local oscillator signals, which fall in these new bands, had to be suppressed. Modern design of converters overcomes this deficiency.

The set-top converter provides a means of greatly expanding the channel capability without having to change the present channel assignments. and permits the use of a standard "off-the-air" TV receiver on the cable system. With proper design it can overcome the problems of co-channel interference, local oscillator radiation, and image rejection.

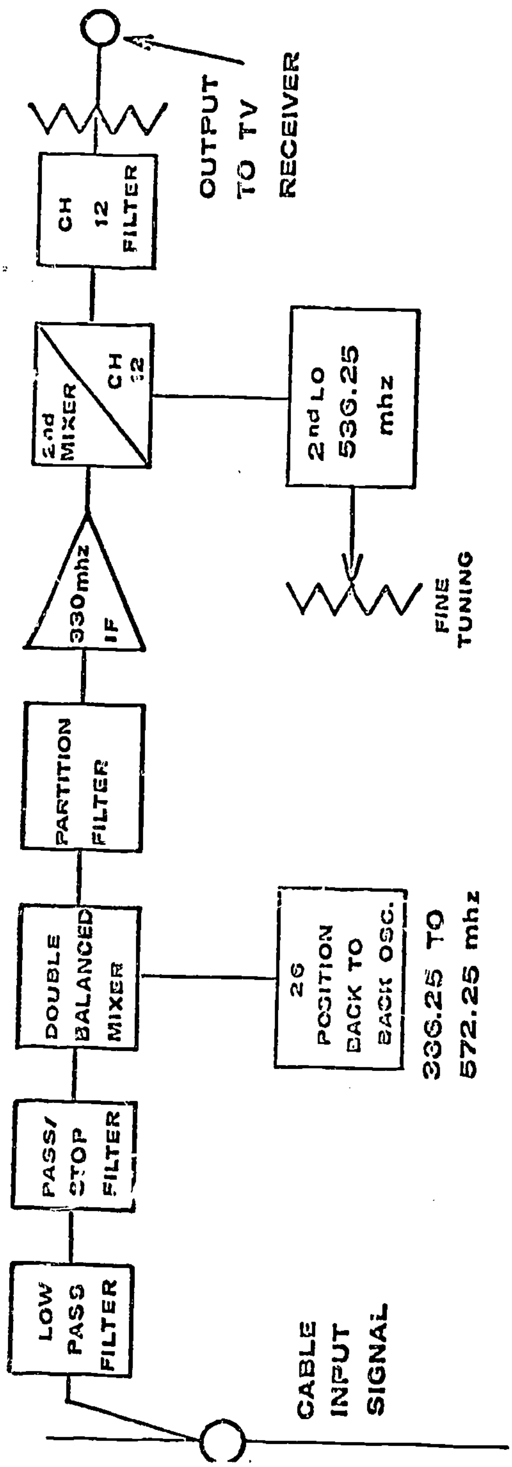
There are basically two types of converters, the step converter and the block converter. A third device, the scrambler, is designed for control of channel access. It may be considered as a component that can be integrated with other equipment in a subscriber's home.

5.1. Step Converter

Step converters are designed to receive all VHF channels (2-13) and a number of "letter channels." How many channels and the frequencies allocated to these channels may vary by manufacturer, but a generally accepted set of channels are indicated in the third line of Figure 1. Connection of the converter is simple. It only involves connection of the cable to the input of the converter and the output of the converter to the input of the subscriber's television set. Usually on-off switching, channel selection, and fine tuning or AFT control are all accessed on the converter. Some units provide for remote control channel selection, but most involve the use of a push-button or a turret switch to select the input channel. The input channel is converted to give one of the standard VHF channels at the output. The TV set is simply tuned to the converter output channel and is left at that setting.

A block diagram of a modern converter design is shown in Figure 5. The converter is designed to suppress second order distortion products through the use of filters and a double balanced mixer. The tuner uses double conversion with local oscillator frequencies that fall far outside the useful frequency range. Further, all the image frequencies lie well above any frequency of interest. The low pass filter helps prevent local oscillator signals from leaking out of the converter. The IF

Figure 5



Block diagram of a modern step frequency set-top converter.
(After Walding, 1971)

amplifier provides gain and selectivity to the up-converted signal. Combined with a fixed-tuned second local oscillator, the signal is down-converted to the desired output channel. Since the cable system signal levels operate over a narrow range (-6 to 12 dBmV), a dynamic AGC front end is not required.

The data is Table 13 shows the range of input video carriers, the range over which the first L. O. tunes, the IF, the second L. O. and the corresponding output video carrier for three converter models. It also shows the range of image frequencies that could affect the system. It is apparent that the frequencies of the local oscillators the IF of the converter, and all image frequencies are all well above the 300 MHz upper band limit of most cable systems.

5.2. Block Converter

The block converter functions somewhat similarly to the step converter. The basic difference is that, instead of the channels being selectable on the converter, a block of channels is converted to the standard VHF channels. Generally, seven channels from the midband or superband are converted to standard channels (7-13). Line D of Figure 1 indicates one possible configuration of block converted channels. The block converter has a switch that selects either the converted block or the normal block, and the TV receiver provides the individual channel selection and fine tuning. The block signals are not "upright" (i.e., chrominance and audio frequencies are below the video carrier frequency), but the block conversion rectifies the position.

These devices have been designed with performance specifications similar to those of the step converters. For example, for the block conversion scheme in Figure 1, line D, the local oscillator frequencies are at 339 MHz for the midband frequencies, and at 443 MHz for the

Table 13

Video carriers, local oscillators, and the IF frequencies for three converter models

Company Designation	Range of Input Carrier Frequencies (MHz)	First L. O. Tuning Range (MHz)	Converter I. F. (MHz)	Second L. O. (MHz)	Output Video (MHz)	Range of Image Frequencies (MHz)
A	55.25 to 241.25	386.25 to 572.25	330.00	536.25	205.25 (Channel 12)	715.25 to 901.25
B	55.25 to 265.25	600.00 to 810.00	544.75	726.00	181.25 (Channel 8)	1144.75 to 1354.75
C	55.25 to 259.25	433.25 to 637.25	378.00	433.25	55.25 (Channel 2)	811.25 to 1015.25

highband frequencies. These high local oscillator frequencies push the image frequencies to well above 500 MHz. The block converter is not quite as versatile as the step converter. It requires both a switch on the converter and normal tuning on the set. Furthermore, it does not provide as much increased channel capacity as a step converter. Seven channels are added with two units.

5.3. Controlled Channel Access

A third type of converter or cable interface involves an encoding and decoding that provides controlled access to any CATV channel (Eldridge, 1972a, b). It is a means for transforming a 6 MHz channel into a private channel that is available only to those who have decoders. The process involves encoding a channel at the head-end and decoding at the subscriber terminal. It could be useful as a means to implement pay TV, deliver information and services of a private nature, and provide exclusive leased channels.

One method that can be used to encode and decode all channels -- standard and non-standard -- has a trade name EnDe-Code (Reiter, 1971). The heart of the system is the patented "gray blank" method of encoding video by replacing the synchronizing and blanking components of the composite video signal with a steady voltage midway between black and white. The color reference burst is superimposed on the steady voltage. Proper synchronization on a normal television receiver is lost because the receiver attempts to lock on the blackest portions of the video signal. The sound is encoded by positioning the FM sound carrier 1 MHz below the video carrier. Pulse signals that are used to restore the video to normal are amplitude modulated on the repositioned sound carrier. Decoding is accomplished without demodulating the video or audio.

At present, a number of pay TV systems are being developed for use on cable. Many of these are aimed primarily at hotel and motel applications. Some of the types of systems are summarized in Table 14 (Eldridge, 1972b). Most of the currently available pay TV systems would use one-way cable; none would be suitable for sending large numbers of short, individual private messages addressed to any of thousands of specific terminals in a large city.

5.4. Specifications

The data in Table 15 sets forth the manufacturers performance claims for the various equipment identified. The data pertaining to four step converters and three block converters are included. The spaces left blank indicate that the manufacturer did not include that information in his specifications sheet. In general, detailed explanations of the data are not included in this write-up, but the table is included as a summary of the pertinent information regarding set-top converters.

If a set-top converter is supplied by the system operator, and is the last item of equipment connecting to the subscriber's receiver, then the set-top converter output terminals are considered to be the effective cable terminals for that subscriber. The subscriber terminals are the points in the system at which conformity with the FCC technical standards is determined (Lines, 1972). In light of this interpretation, it would seem likely that most converter manufacturers would attempt to meet the FCC standards for subscriber terminals. The one variance in the ruling in regard to converters is that the specification requiring that the tolerance on the visual carrier frequency be $\pm$ 25 kHz at the subscriber terminal. When set-top converters are supplied by the cable system, the applicable tolerance is relaxed to $\pm$ 250 kHz. This was done in recognition of the difficulties of obtaining the more restrictive frequency stability in set-top converters of current design.

Table 14

SUMMARY OF PAY TV SYSTEM DEVELOPMENTS

Name of System	Type of Cable System Required	Method of Excluding Non-Paying Viewers	Method of Accounting for Service Charges	Estimated Incremental Capital Costs
BTVision	One-Way	Video sync pulse and audio signal sent on separate channels, and recombined with video signal at receiver	Identification code for each program recorded on audio cassette and returned periodically by mail	$100 per Terminal
EnDeCODE	One-Way	Similar to BTVision	Fixed rate for service	$40 per Terminal
Computer Television	Two-Way	Viewer transmits program requests to central control station via cable. Central control remotely sets varactor tuners in subscriber terminals	Central control records program request	$600 per Terminal
K'Son	One-Way	Viewer telephones requests to central control station. Central control remotely sets program selector units to desired channel	Central control records programs requested	$100 per Terminal
Optical Systems	One-Way	Encoded signals sent from headend which are decoded at receiver by use of decoder cards or plug-in decoder cartridges	Viewer buys decoder cards or plug-in decoder cartridges for series of programs	$35 per Terminal
Phonevision and Theatre Vison	One-Way	Encoded signals sent from headend which are decoded at receiver by subscriber ticket and decoder control unit	Viewer buys decoder tickets for individual programs	Not specified

Table 15

SET-TOP CONVERTERS

Manufacturer (Model)	Type	Input Channels	Output Channels	Freq. Ranges (MHz)	1st L. O. (MHz)	I. F. (MHz)	2nd L. O. (MHz)	VSWR Input	VSWR Output	Gain	Noise Figure	Input Levels	Ambient Field Intensity Isolation (shielding)	Input/Out Isolation	Cross Modulation and Other Spurious Signals	Oscillator Frequency Stability	Image Rejection	Oscillator Radiation	Output Oscillator Fine Tuning
Oak Industries, Inc. Gamut 26	Step Convert-er	26 (2-13) & (A-N)	12 or 13	54 to 246	386.25 to 572.25	326.5 331.0	536.25 @ Ch 12	2:1 (max)	2:1 (max)	6dB ±3dB	12dB (max)	-6dBmV (min) ±12dBmV (max)	In a field of 1V/m, output is 10μV or less. (100dB)	> 70dB	Not visible on any channels over specified range	± 250 kHz (max) for 20° rise above ambient	70dB (min)	Meets FCC standards	± 0.75 MHz
Oak Industries, Inc. V-26 or 31 AFC	Step Convert-er	26 (2-13) & (A-N) or 31 (2-13), (A-I) & (A-R)	3 or 4	54 to 270				2:1 (max)	2:1 (max)	5dB ±3dB	11dB (typical)	-6dBmV (min) +12dBmV (max)	In a field of 1V/m, output is 10μV or less. (100dB)	> 70dB		Automatic Frequency Control			No fine tuning required
Hamlin MCC-1000-8	Step Convert-er	30 (2-13) & (A-R)	7 or 8	54 to 270	600 to 810.00	540.25 544.75	726 @ Ch 8		6dB pad absorbs reflection in set	10dB ± 1dB	12dB (typical)	-3dBmV to +10dBmV	100dB (min)		@10dBmV 30 channel imput. -60dB worst case.	Long term ± 300 kHz. Short term ± 100 kHz.		Meets FCC standards & above all freq. of interest	± 25 kHz
Jerrold RSC-2 or RSC-3	Step Convert-er	30 (2-13) & (A-R)	2 or 3	45 to 270	433.25 to 637.25	373.5 378.0	433.25 @ Ch 2.	2.5:1 (max)	1.5:1 (max)	6dB (min) 11dB (max)	13dB (max)				Cross mod. -64dB 2nd order -66dB			0dBmV max. L.O. [illegible] at input connection	± 1.5 MHz
Jerrold Mid-Band BC-19	Block Convert-er	19 Inverted (2-13) & (A_i-G_i)	2 thru 13	54 to 159						6dB	13dB	0dBmV to ±15dBmV		60dB(min)	Cross mod. -66dB 2nd order -66 dB @45dBmV 19 ch input	± 200 kHz			
AEL Mid-Band CVT-3CM	Block Convert-er	26 (2-13) & 127.75 to 163.75	2 thru 13	54 to 270						0dB (±2dB)		-4dBmV to +6dBmV			Cross mod. -55dB (max) other 60 dB below output				
AEL Super-Band CVT-3-CS	Block Convert-er	(2-13) & (231.75 to 267.75)	2 thru 13	54 to 267.75															

Certain design goals have been obtained in CATV converters to overcome some of the problems encountered when operating a TV receiver directly off the cable. These are:

(1) Image rejection and oscillator interference -- the use of a double conversion process in the converter which places both oscillator frequencies and the intermediate I F well above the cable transmission frequencies prevents the oscillator energy from entering the cable system. This also places the frequencies well into the UHF band to avoid image interference.

(2) Off-air signal pickup -- placing the R F circuitry in a well-shielded metal compartment greatly reduces or eliminates "off-the-air" signal pickup. Table 15 indicates that manufacturers claim to provide shielding that will limit local signal pickup to -100 dBmV.

There is a mode of operation in which converters can present a problem. If only a portion of the subscribers request the extra channels, the system is faced with the problems of a "mixed system." This has been discussed in an earlier section.

It must be pointed out that set-top converters remain dependent on the TV set for passband characteristics and for adjacent channel rejection properties. Therefore, although image rejection, local oscillator interference, and co-channel pickup problems are resolved, a good quality TV set is still required for proper functioning of the system.

6. THE SUBSCRIBER TERMINAL ON TWO-WAY SYSTEMS

With a two-way capability on a urban broadband communication system, the interface combinations that allow some sort of communications interaction between the subscribers or between a subscriber and program originators add complexity to the subscriber terminals.

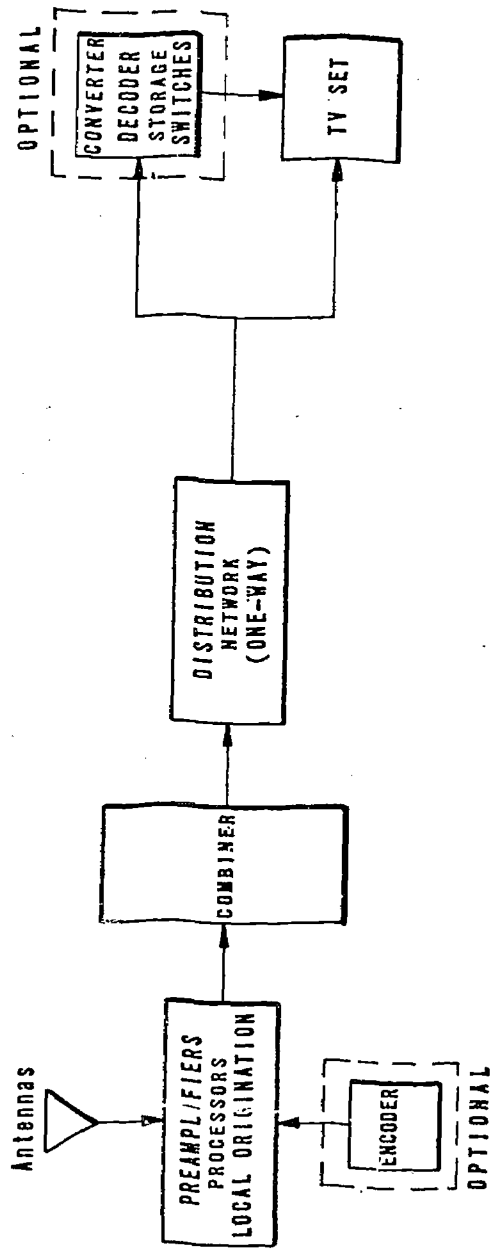
Several levels of interface are discussed, showing the types of equipments used and the category of services provided.

For the sake of completeness and comparison, the first level will be the system to provide conventional one-way service. A simple block diagram of this system is shown in Figure 6. The diagram consists of the head-end equipment, the distribution equipment, and the subscriber terminal equipment. For this discussion, the only area of interest is the subscriber terminal interface. The terminal equipment consists of the TV set with an optional converter. The communications capacity is 12 channels (one-way) or up to 30 channels (one-way) with the converter. Various types of additional optional equipment could be added. A recorder or frame-grabber would provide a storage capability, and an encoder-decoder unit would provide for reception of privately addressed material. Even with all these optional equipments, the system is still limited to one-way communication.

6.1. TV Set, Converter, and Polling

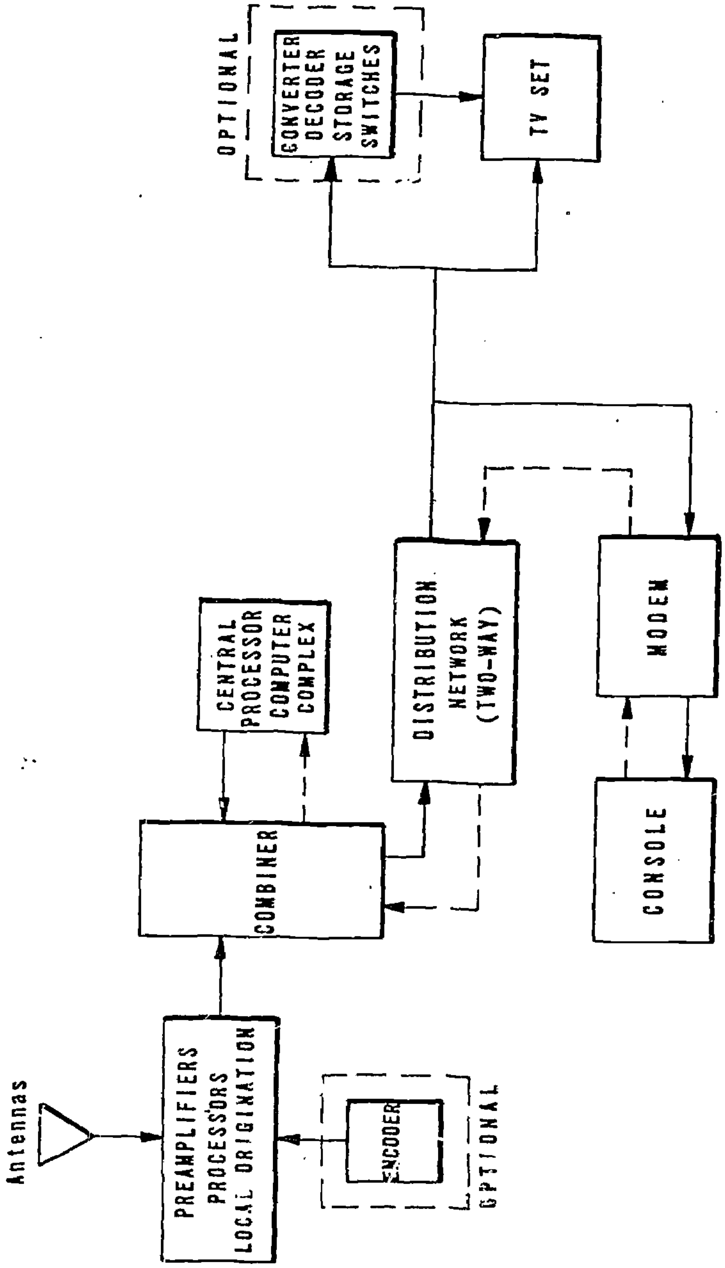
The first level of two-way communications using the CATV system involves equipment at the subscriber terminal with which the subscriber can respond to questions asked via a normal downstream video channel. The equipment required at the subscriber terminal would include the TV set plus any of the optional equipment shown in Figure 6 and a subscriber response unit. Also somewhere in the system, there is need for a control or local processor. The block diagram of equipment for this level of interface is shown in Figure 7. Again, the system is divided into headend, distribution, and subscriber terminals. At the head-end a central processor computer complex has been added; the distribution network now has two-way capability. At the subscriber terminal a modem and subscriber console have been added. The central processor at the head-end must provide the means for

Figure 6



A block diagram of a one-way CATV system.

Figure 7



A block diagram of a basic two-way CATV system.

sending interrogation messages to each subscriber in a sequence and able to receive and tabulate the return answers. At the subscriber terminal, the console provides a means for the subscriber to reply. The simplest console which permits the "polling" level of interaction would have three buttons, permitting a "yes", "no", or "undecided" answer or some coded combination of the three buttons. Certain types of games and other limited answering types of activities could be performed with this equipment. It is possible that the console and modem could be incorporated into the converter chassis.

6.2. TV Set, Converter, Polling, and Digital

This level of equipment is not too much more complex than the equipment required at the previous level, but does give the subscriber considerably more flexibility in the correspondence. He no longer is restricted to an answering role, but can both originate messages and ask questions. The additional equipment required would be a more sophisticated console at the subscribers terminal and added hardware and computer software at the central processor. The subscriber would have keys or buttons for all ten digits and such additional command keys as send, space, start-of-message, and end-of-message. Also it would probably include a hard-copy printer, such as a teletype machine, for permanent record of the correspondence. At the head-end, computer peripheral equipment and computer programs would be added to facilitate the increased message and data handling. The diagram in Figure 7 can also be used for this model. Additional interface, now possible, but not shown in the diagram, could include transponders to read meters, sense alarms, and so forth.

6.3. TV, Converter, Polling, Digital, Voice, Video, Etc. Full Two-Way

This final level of interface can include all the additional equipment necessary to facilitate a two-way video and "face-to-face" conversation. This level would require full video bandwidth (both upstream and downstream) and a technique for retransmitting the upstream video and audio to a downstream channel. Video and processing equipment would be required at each subscriber terminal desiring this service. Obviously, there are several orders of complexity that can be implemented at this level. For example, in a teaching situation it may not be necessary to have full two-way video for effective teaching to take place. Other services that come in at this level would be computer interface (such as time-share), facsimile, etc. The block diagram for this level of interface is shown in Figure 8. Here the added equipment is shown at the subscribers terminal. Similar added capability would be needed at the central processor; a local origination studio, other subscriber terminals, or combinations of these. In the next section, greater detail is given to describing the channel characteristics of these several interface assemblies.

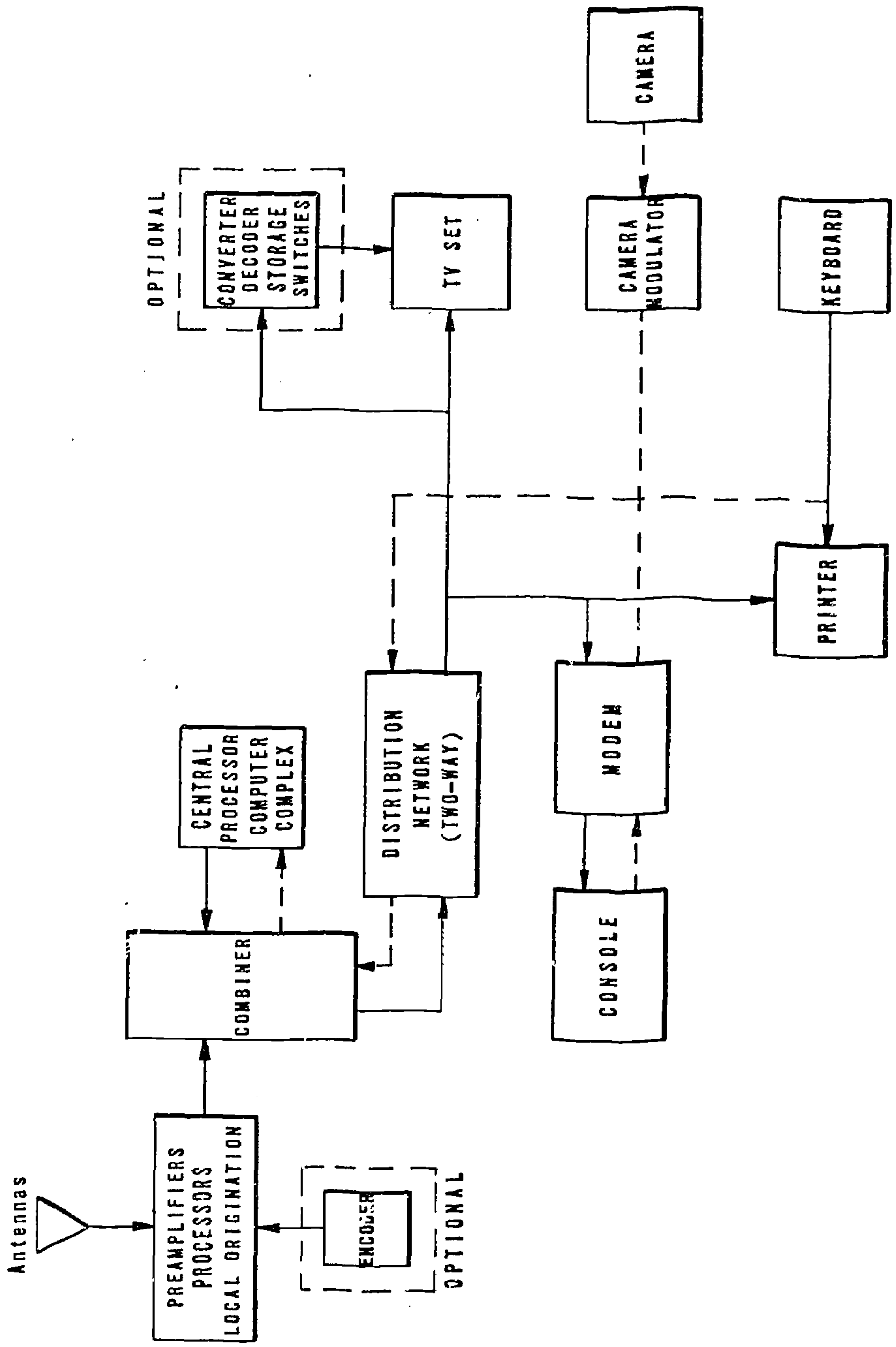
6.4. Transmission Characteristics

To facilitate a two-way communications on a CATV system, there are several basic message requirements. These are described briefly below. The downstream messages include:

(1) Normal video and audio -- these would be the up to 30 channels with 6 MHz bandwidth each to carry the off-air and locally originated traffic.

(2) Subscriber terminal monitor or status check -- this is a method of handling subscriber requests and checking accessory sensors. It is akin to the "time-share" operation in computer use.

Figure 8



Block diagram of a full two-way CATV system.

(3) Enabling messages -- these control messages keep the traffic flow orderly and permit certain subscriber terminal functions to be activated.

(4) Digital word messages -- these messages would include the bulk of messages not in the form of video and audio (normal TV).

The upstream messages are as follows:

(1) Status response -- this is the subscriber's response to the central control inquiry.

(2) Digital word messages -- these would include all subscriber word messages.

(3) Sensor status or output -- these would contain the readings of meters and status of alarms, for example.

(4) Video and/or voice -- these would be any upstream 6 MHz data or separate voice data.

To enable this range of communications, certain interface equipment is needed at both the central processor and subscriber terminals. A central control unit, such as a computer with certain peripherals, is required for input and output. Logic for encoding, decoding, and timing is required at both ends of the system. Modulators are needed at both ends to put the messages in a form for transmission and demodulators are required to recover the messages.

The manner in which each of these functions (control, logic, encoding, decoding, modulation, and demodulation) is performed varies by manufacturer. In order to make a meaningful presentation and comparison of the techniques used to accomplish these functions, it would be useful to first discuss the workings of a representative system. The system described is an example and is neither an endorsement, nor a criticism, of any particular approach to two-way cable communications. The present work being done on two-way services around the country is developmental and intended to assess the feasibility of concepts and subscriber acceptance of the services rendered. The following material, therefore, is a description of a typical communication interaction required for two-way cable communications.

The system shown in Fig. 9 consists of a CATV distribution network with two-way capability plus a processing center with a computer complex at the head end and subscriber terminal equipment made up of a modem, TV set, and console at the subscribers terminal. The two-way communications take place between the computer complex and the subscriber terminals.

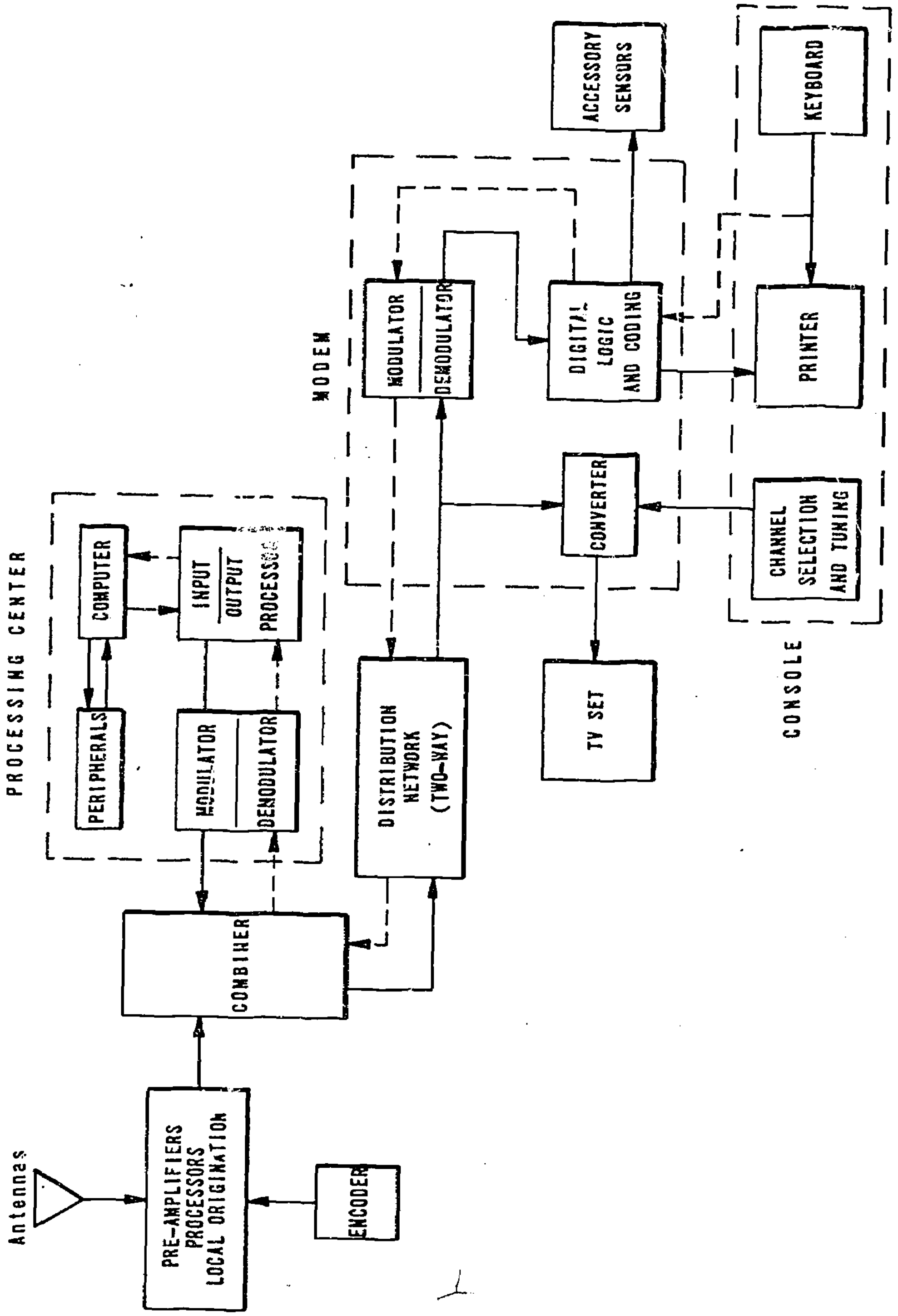
The modem contains a 26 channel converter that furnishes a signal on a fixed channel to the TV set. The modem also performs all of the radio frequency modulation and demodulation and most of the digital signal processing required at the subscriber terminal. It also furnishes the interface for all accessories used in the system. The modem requires no operating controls and is designed for installation at an unobtrusive location, nominally behind the TV set, in a closet, or even hung at the cable drop location outdoors.

All operating controls for the terminal are located at the subscriber's console. The console is interconnected to the modem by a small diameter cable which allows a separation between the units depending on the installation requirements at the subscriber's location.

In addition to a TV channel selector switch, the console contains a keyboard and printer, allowing the subscriber to engage in two-way communications with the local processing center.

Communications upstream from the subscriber terminal to the local processing center are transmitted back from the modem, either over the same cable network with suitable upstream amplifiers and

Figure 9



A diagram of the two-way CATV system showing the processing center, modem, and console in greater detail.

filter networks to by-pass the existing downstream amplifiers or over a separate cable in a two cable system.

The downstream control signals occupy a 4 to 6 MHz bandwidth in the 108 to 114 MHz region. The downstream form of communications is digital, and the digital data is then used to frequency shift key (FSK) the carrier. The upstream control signals occupy a similar bandwidth in the 6 to 30 MHz region. The upstream form of communication is also digital, and the digital data is used to phase shift key (PSK) the carrier.

All communications are initiated by the computer at the processing center. An interrogation message addressed to each subscriber in sequence is sent at a periodic rate. The subscriber terminal will reply to the interrogation with any of a number of possible requests or statements. The reply will be sent upstream with an identification address and a number of bits devoted to the content of the message.

If a particular subscriber has initiated no requests, the terminal will automatically reply, giving a terminal status report. The absence of a return signal will indicate either a physical break in the cable path or a defective subscriber terminal.

Each subscriber is interrogated in turn until a group of 1000, say, subscribers has been processed. Following the interrogation period, the computer carries out the subscriber's request. When 1000 subscribers have been interrogated and serviced, the process is repeated for the next 1000 subscribers, and so on. The capacity provided might reach 65,000 subscribers per processing center. The communication sequence is claimed to be so rapid that, for a system of 10,000 active subscribers, the time required for a subscriber to receive a reply in response to his manually initiated request has been estimated by the manufacturer to be less than 2 seconds, even in the prime times of heavy evening hour traffic. Apparently this would require a very costly computer. This question is examined in Volume 6 in this series. Queuing questions are discussed in Volume 5 of this series.

Upstream messages are initiated by the subscriber at the console keyboard. The subscriber may enter messages in groups of up to twenty characters at a time. Assuming the message required more than 20 characters, a "Busy" indicator would light after entering the first twenty. The "Busy" lamp would be extinguished, usually within a second or two, indicating the computer has received the message, and the next 20 bits of the message could then be entered. As the subscriber enters the data, it is printed by the printer allowing him to check for errors and providing a permanent hard copy record of purchases or other financial transactions. Alphanumeric character messages may be transmitted downstream by the computer and would also appear on the printer.

The required type and number of peripheral equipment needed at the process center for operational use will, of course, depend on the nature and number of the services provided, the number of subscribers in the system, and the anticipated or actual traffic volume Modular expansion capability is also provided in the process center and software design to accommodate such growth situations.

Inputs to the computer can be made by punched cards or paper tape, or by manual operation of the teletypewriter. The computer system is designed to operate unattended except for routine maintenance.

At the subscriber terminal, the downstream TV video is separated from the control signal and is routed to the converter which furnishes the video input to the TV set. The control signal is demodulated and processed in the modem unit to furnish signals to the external accessories or to the operator's console depending on the particular message sequence.

Upstream data orginates at the operator's console, or at the accessory sensors and devices. It is encoded and stored at the modem to await upstream transmission. In transmission, the data is fed to the control signal phase modulator, passed through a low pass filter, and on to the subscriber's drop cable.

Not shown in the system block diagram, Figure 9, are such interface equipment as required to display alphanumeric characters on the TV screen, thus making it an auxilliary display or monitor. Also such items as TV cameras, video tape recorders, or separate voice equipment might be used at the subscriber terminal.

With this study of the workings of a representative system as a background, a review of the techniques used and proposed by several companies to accomplish the communications required for two-way CATV may be easier to follow. This data is compiled in Table 16. The parameters reviewed are separated into two groups: those pertaining to downstream communications and those pertaining to upstream communications. The categories listed include downstream/upstream frequencies and bandwidth, message frequencies and bandwidth, data rates, type of modulation used, and word lengths.

Of the eight systems or techniques reviewed in Table 16, all, of course, provide for downstream TV transmissions, and all but two [Ameco Inc. (Hickman and Kleykump, 1971) and Rediffusion International Limited (Gabriel, 1972)] uses the conventional one-way band (between 50 and 300 MHz) for downstream video channels. With the same exception, this band also contains the frequencies used for the downstream messages. Of these latter six systems, four [Theta-Com (Callais, 1972), Electronic Industries Engineering (Chandler, 1971), Cas Manufacturing Co.

Table 16

A review of the techniques used and proposed by several companies for two-way CATV communications.

	Downstream Communications							Upstream Communications						
	Downstream Freq.	Downstream Bandwidth	Message Freq.	Message Bandwidth	Data Rates	Type Modulation	Word Lengths	Upstream Freq.	Upstream Bandwidth	Message Freq.	Message Bandwidth	Data Rates	Type Modulation	Word Lengths
Theta-Com Co.	54 to 270 MHz	216 MHz	108 to 112 MHz	4 MHz	1 Mbit/s	digital (PCM) PSK on 110 MHz carrier	20 charac-ters	5 to 25 MHz	20 MHz	21 to 25 MHz	4 MHz	1 Mbi /s	digital (PCM) PSK on 23 MHz carrier	20 charac-ters
Electronic Ind. Engr.	50 to 260 MHz	210 MHz	FM Channel 88 to 108 MHz	200 kHz	-	42 kHz digital code FM	32 bits	10 to 30 MHz	20 MHz	12 to 14 MHz	2 MHz	-	675 kHz digital code FM	128 Data Bits
Cas Mfg. Co.	52 to 300 MHz	248 MHz	Selected freq. near 50 MHz	-	-	Pulse Code	10 bits	6 to 30 MHz	24 MHz	Selected freq. 10 MHz, 10.8 MHz 12 MHz, etc.	-	-	Pulse Code	16 Bits
Vicom Mfg. Co.	Conventional System 54 to 246	192 MHz	108 to 114 MHz	6 MHz	1 Mbit/s	FSK 113.0 MHz 111.0 MHz	16 charac-ters	6 to 30 MHz	24 MHz	6 to 10 MHz	4 MHz	1 Mbit/s	PSK 8.0 MHz	16 charac-ters
Scientific Atlantic, Inc.	Conventional System 54 to 246	192 MHz	113.9 MHz 111.1 MHz	2 MHz	-	FSK	16 bits	6 to 30 MHz or separate cable (RG-59)	24 MHz or 0.275 MHz	275 kHz 275 kHz	0.050 MHz	-	FSK	16 bits
Mitre Corp. (demonstration system)	Conventional Cable 54 to 246	192 MHz	Channel 13	6 MHz	60 pictures per sec.	Encoded picture frame or alpha-numeric characters	16 element address	-	-	Touch tone telephone		Six standard telephone lines (special circuit to one line for audio answer back)		
Ameco, Inc.	10 to 50 MHz two channels per cable	40 MHz	(Two-way interactive equipment not developed. System concept provides for separate (40 MHz) cable upstream and area distribution centers with switching to 24 sub-scribers per center.)					10-50 MHz two channels per cable	40 MHz	(see downstream)				
Rediffusion International Limited	Multipair cable (large pair) 3-9 MHz	6 MHz	(The small pair of the cable has a usable bandwidth of 3 MHz. It is used for switched selection of down-stream video and can be for voice or digital data.)					(large pair) 9 to 15 MHz	6 MHz	(see downstream)				

(Osborn, 1971) and Vicom Manufacturing Co . (Jurgen, 1971)] use the frequency band between 5 and 30 MHz for all upstream communications.

Although, there is generally adequate bandwidth allocated for upstream video, only limited use of the upstream capability has been made to date. Theta-Com demonstrated upstream capability in a laboratory facility, and Vicom demonstrated a system where a student and teacher had audio and visual contact with each other. The limited exploitation of the upstream capability is understandable in that a great deal of useful two-way communication can take place without upstream video, whereas, adding this capability to a practical system greatly increases the subscriber terminal costs.

The operations concept generally used to control the communications flow within these systems is one akin to the time-share concept in multi-terminal computer systems. This concept is described in the representative system discussed earlier in this section. The processing center (computer) interrogates the subscriber terminals regarding their status, and then controls any resulting traffic flow. The specific frequencies and the types of modulation used for the message and address data are listed in Table 16. The information is generally in a digital or pulse form which is then used to modulate the selected carrier. The message information is divided into address information and the actual message content. Message bandwidths run up to 4 MHz, with available data rates of up to 1 megabit per second.

Some of the proposed systems depart markedly from the pattern described above. This does not mean that they are better or worse, just different. Scientific Atlantic, Inc. (Roth, 1971) offers a low-cost reverse transmission cable (RG-59) instead of replacing all unidirectional components on an existing one-way distribution system. Amplifiers, power supplies, and directional taps are available to build the reverse system. The message frequencies and bandwidth are much smaller than available in the previously described system.

Another system concept included in the table, but on which no two-way communications has been tried, is the Ameco system. The central idea there is to use the frequency band between 10 and 50 MHz for both downstream and upstream communications, but to use separate cables for each. Also, this system limits each cable to a two channel capacity for video and uses an area distribution center to switch single channels to each subscriber. Up to 24 subscribers are served by one area distribution center.

Another system that uses the switched concept is the system designed by Rediffusion International, Ltd. (Gabriel, 1972). In this system each subscriber is connected to a switching exchange by means of two balanced pairs of wires in a cable of special construction. The larger pair has a bandwidth of 16 MHz and carries the TV programming. The smaller pair, with a 3 MHz bandwidth, is used for audio and switching control and in various other ways.

The last system included in the table is a demonstration system being operated by the Mitre Corporation, a not-for-profit Federal contract research center (Volk, 1971; Stetten and Mason, 1971). This system uses touch-tone telephone sets as subscriber consoles and standard telephone lines for upstream communications. Specially designed equipment at the processing center and video tape recorders at the subscriber terminal are coordinated so that individual picture frames can be used to display alphanumeric characters on the TV set. The alphanumeric information is controlled by a computer at the processing center.

This review of some of the types of systems and terminal equipment planned for use in providing two-way communication on CATV gives some insight into the concepts and techniques considered. Obviously, much more effort is required to develop these experimental systems into full-fledged operational systems. The strong points and problem areas will emerge as these systems receive further use and testing. One purpose of this investigation was to identify technical similarities between systems to see if some degree of standardization was possible. Clearly, the systems are too diverse to attempt to apply standards. The advantage of standardization lies in opportunities to interconnect systems easily, minimizing the amount of consumer education required to generate acceptance of the new services, and for subscribers to own their own modems that could universally be used on any broadband communication system. As the situation stands now, the subscriber modems are designed as integral parts of each particular communication system and must be supplied by the system operators. This diversity is likely to inhibit the development of mass-produced, low-cost equipment for home terminal use.

The problem is complicated by the fact that even for a particular approach there can be alternative equipment that can meet the system requirement. The device variously called a "frame grabber", "frame freezer", or "frame interceptor" is a case in point. It is intended as a device to store and display selected information and video pictures that are received at the subscriber terminal. Some of the technologies being developed and tested include the use of a "storage module" or "scan converter" (storage tube), forms of rotating magnetic discs and video tape recorders, and various methods of storing and decoding alphanumeric information for display on the TV set or console printout. The latter method depends heavily on a central processing computer for traffic control and data sequencing.

A system recently described in the literature (Momberger, 1973) that uses the "scan converter" technique is known as FIRST (Frame Intercept and Readout System for Television). The storage element is a television camera tube with a special target made of silicon and silicon dioxide. This is the system developed by GTE Sylvania; other companies have similar scan converters. The tube is an electrical input, electrical output, single-ended electron tube which utilizes a high resolution vidicon gun to address a special target storage surface. The storage surface consists of a high conductivity "N" type silicon substrate upon which a layer of oxide has been grown. Etching of the oxide creates a mosaic of very small SiO_2 dots or "islands" which constitute the storage surface. A 0.8 inch square mosaic contains 2.56×10^6 of the storage islands. The half-life of stored data is about 25,000 read cycles. This corresponds to about 15 minutes of steady reading at standard television rates.

In operation, a charge pattern is established on the target surface during the write mode. In the read mode the charge pattern modulates a target current which results from landing of the electron beam. The target current is amplified, recreating the stored electrical signal.

A second method of storage uses a helican scan video tape recorder (VTR). This technique has been developed by the Mitre Corporation (Volk, 1971). With a helical scan video tape recorder, the recording track is at an acute angle from the direction of the tape motion. Each slanted recording track is about seven inches long and contains all the pictorial information for a 1/60th-of-a-second picture frame. The adjacent recording tracks contain the picture information for the picture field 1/60th of a second before and after. The VTR has a drum around which the tape makes a loop in a helical fashion. Two record/playback heads are located within the drum and spin at a rate such that a track is transversed in 1/60th of a second. As the heads make one revolution (because of the helical winding of the tape around the drum), they follow slanted tracks on the tape that is wrapped around the drum. The take-up and supply reels and their controlling mechanisms move the tape so that 1/60th of a second the tape moves only enough so that the record/playback heads are positioned over the beginning of the next slanted track as they start to move down across them.

For this application, if the take-up and supply reel mechanism is disabled, the tape recorder will record a 1/60th of a second picture frame and then play it back continuously. At the completion of recording a frame, the recorder can be placed automatically in a playback mode.

Both techniques require coupling to the cable system through a coupler/decoder which enables the "frame grabber" only when the transmitted picture address matches the decoder's address. There is a considerable amount of digital logic involved, which suggests that ultimately digital memory devices will become competitive.

The scan converter has several apparent advantages. More than one frame can be stored by appropriately segmenting the storage surface, and there are no rotating mechanisms with inherent wear, adjustment, and dirt accumulation problems. Circuits can be configured integrally and shared with the TV receiver to provide some savings in costs. The tape recorder technique, of course, has the advantage that the instrument can be used in a normal video tape mode for viewing program materials recorded on tapes, or for storing TV programs for later viewing.

7. INTEGRATED SYSTEMS

Discussion of services on two-way cable systems usually lead to extensive lists of new services. Although most are technically feasible, many are not economically viable. Others require such low data rates that the broadband capabilities of cable systems are under-utilized; they can be justified only if a two-way broadband capability already exists since the incremental costs of providing the low data rate services via cable may be competitive with other means of service delivery.

A list of categories of new cable communication services has been compiled by Baer (1971) and is reproduced here as Table 17. The categories are arranged in order of increasing complexity, the complexity (and cost) being largely contained in the requirements of the head-end equipment and of the subscriber equipment. Figure 10 gives Baer's (1971) estimate of subscriber terminal costs. A somewhat more optimistic estimate of costs for many of the same services has been given by Mason (1971) and is reproduced in Figure 11. Figure 11 also includes TV receiver costs.

Review of the services list indicates that many of the two-way services can be supplied by systems other than cable. For example, computer input/output or computer control can be delivered via telephone, as can facsimile and many business or banking transactions. Downstream services can be delivered by conventional TV or radio broadcasts, or on special frequencies that might be allocated for this use. Low data rate upstream communications could be handled on the telephone. Indeed, some two-way systems now use the telephone in this way.

As a consequence of the development of TV time (Jesperson and Fey, 1972), National Bureau of Standards personnel have suggested that portions of the blank vertical interval in a normal TV broadcast could be used for transmitting digital information on time, weather, captioning for the deaf, or other information. Special decoders are required, but large-scale integrated (LSI) circuit chips incorporated

Table 17

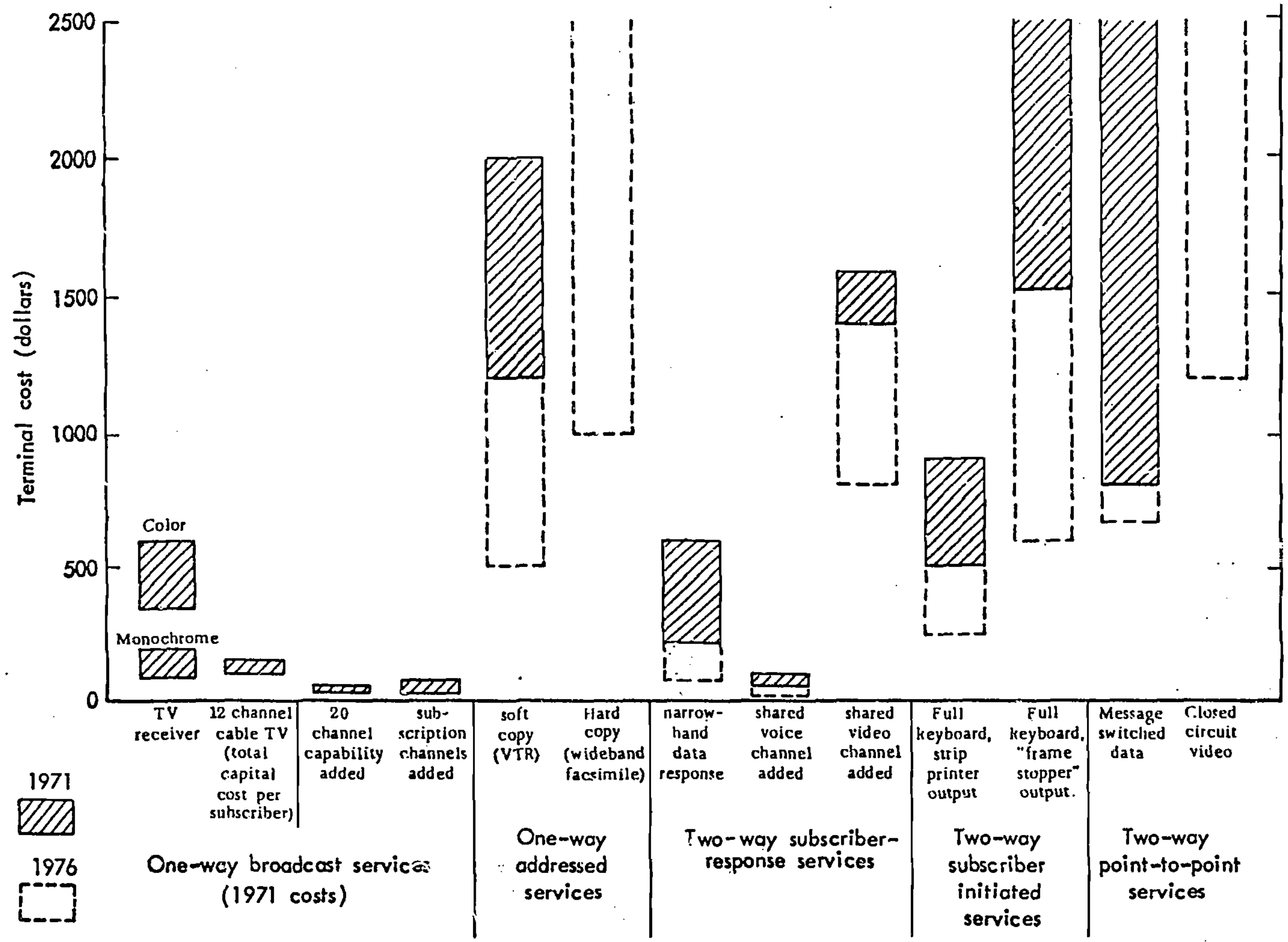
CATEGORIES OF NEW CABLE COMMUNICATIONS SERVICES

Service Category	Downstream Signals	Upstream Signals	Equipment Requirements: Headend Equipment	Equipment Requirements: Subscriber Equipment
I. *One-way broadcast services*	6 MHz broadcast video channels (FDM)	None, except for local origination which may require one or more video channels from origination points to headend	Additional signal processing and multiplexing equipment; origination equipment	Converter or switch to receive > 12 channels
A. Additional channels TV entertainment programs instructional programs coverage of local events local program origination community bulletin board municipal services information (health, housing, welfare, etc.) local ombudsman				
fm radio foreign radio recorded music	200 KHz radio channels (FDM)			
B. Subscription channels movies entertainment programs instructional programs sports and special events			Signal scrambler or encoder	Unscrambler, decoder or special converter
II. One-way addressed services electronic mail delivery newspaper and periodical delivery selective video	Individually addressed wideband signals (FDM or TDM)	None	Information storage facilities; document scanner; address generator; communications controller	Address decoder and logic unit; video tape recorder, facsimile or other recording unit
III. Narrowband subscriber response services	Broadcast video (FDM), plus individually addressed narrowband polling signals (TDM) of 100 or fewer bits	Narrowband response digital data (TDM of 100 or fewer bits from individuals to headend	Central polling scanner, and communications controller (mini-computer); files, displays and other peripherals	Basic control unit (receiver, digital decoder, control logic, digital encoder and transmitter): buttons or keyboard, channel monitor
A. Interactive television entertainment programs instructional programs opinion polling remote shopping municipal services information				A. identification or authorization key
B. Sensor monitoring audience counting alarm monitoring meter reading cable system maintenance				B. channel sensor fire and intrusion sensors meter encoders amplifier and other component sensors

Table 17 (Cont.)

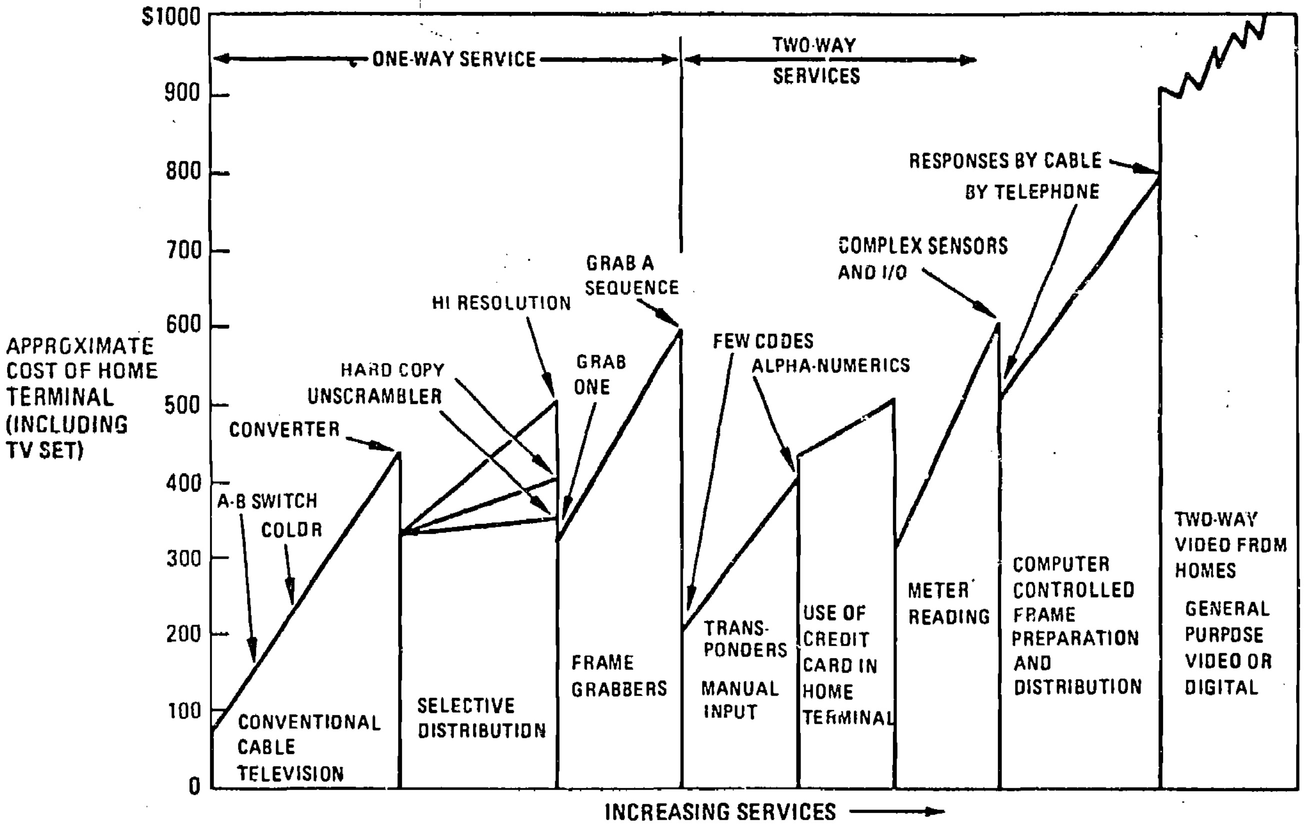
Service Category	Downstream Signals	Upstream Signals	Equipment Requirements: Headend Equipment	Equipment Requirements: Subscriber Equipment
C. Control of remote devices alarm sounding utility load control				C. switches and links to controlled devices
D. Subscription television			D. Signal encoder; billing mechanism	D. Decoder or special converter; *authorization key*
IV. Shared two-way channels	Same as III.	III, plus	III, plus equipment to recognize and queue requests, enable and disable subscriber equipment	III, plus
A. Voice response instructional programs *entertainment programs* community service information special interest group conversations local ombudsman		A. 3-4 KHz voiceband channel(s) (FDM)		A. Microphone, speaker and associated equipment
B. *Video response* instructional programs remote medical diagnosis neighborhood program origination		B. 4-6 MHz video channel(s) (FDM)		B. *Camera* and associated equipment
V. Subscriber initiated services catalog shopping stock quotations ticket and reservation services information from various *directories and references* *computer time sharing* *computer assisted instruction* checkbook balancing and other banking services dial-up video library business credit checks	*III*, plus individually addressed information (alphanumeric message or picture); bandwidth dependent on type of information, but usually voiceband or greater	*III*, with narrowband (but sometimes > 100 bit) response	*III*, plus source data bases (digital data, pictures, etc.) connected to central controller; billing mechanism	*III*, *plus extended keyboard, local storage* (buffer or refresh) and output display device (character generator, strip printer, frame *freezing device*, video tape recorder or facsimile)
VI. *Point-to-point services*	*Individually addressed*, variable bandwidths for data, voice and video transmission; primarily FDM with TDM for data	*Individually addressed*, variable bandwidths for data, voice and video transmission; primarily FDM with TDM for data		
A. Message-switched services message transmission business transactions *computer input/output*			A. Store-and-forward processor	A. III, plus buffer storage and keyboard printer
B. Point-to-point circuits high speed data exchange facsimile fingerprint or photograph *identification* teleconferencing closed circuit TV videophone			B. Equipment to set up private or multiparty channels	B. Data, voice, and video terminals as required; special frequency converters and associated logic for channel selection

Figure 10



Subscriber terminal costs for new cable communications services. (After Baer, 1971).

Figure 11



Approximate cost of home terminal equipment including the TV set. (After Mason, 1971) into TV receivers at the time of manufacture would add only a few dollars to the receiver costs.

An extension of this idea leads to the concept of digital information entering the subscribers home via telephone, on a subcarrier of an FM radio signal, in the blank vertical interval of a TV broadcast, on special transmissions via a broadband cable, or any other appropriate medium. Many of the downstream services now being discussed for delivery via cable can be provided by innovative use of presently available communications channels.

Similar considerations suggest that data transmission in digital form, with conversion for display on the TV screen at the subscriber terminal, is likely to be both a relatively inexpensive and spectrum-conserving method for downstream addressed message delivery. This method would probably be competitive with the frame grabber approach now being developed in various forms, and would have the added flexibility of being able to accept data over narrow band devices such as the telephone or radio (FM subcarrier, for example).

The format of several of the service categories are likely to be specified by individuals or institutions other than the cable operator. For example, the postal service will undoubtedly be involved in specifying the nature of equipment for electronic mail delivery, and public utilities will want to specify meter reading equipment. Schools will want to specify the nature of the terminals developed for interactive instruction. And so the list goes on. Clearly, costs for subscriber terminals will skyrocket if each service requires specialized equipment. Careful thought must go into planning for flexible terminal equipment that can meet a multiplicity of needs. The greater the extent to which equipment can be used that is already commonly available in the home (TV receiver, radio, telephone, tape recorders, etc), the greater the economic viability of the services. Further, future versions of subscriber terminals should interface easily with two-way cable systems in any of the forms that they may take, and should be sufficiently "standard" that they can be easily maintained by either the cable operators or by what are equivalent to future TV repairmen.

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15. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

It is the purpose of this report to examine the question of home terminals in the cable environment. The functions of subscriber-owned television receivers in this new environment is examined in detail. Characteristics of set-top converters are also examined in detail from the same point of view. Augmented one-way services and two-way services will add equipment in the home that can contain among others, a camera, microphones, digital devices, sensors, printers, and tape recorders. Characteristics of the augmented home terminal are examined in an attempt to identify the demands the new services may place on the cable systems.

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