CableLabs®

Cable Television

in the United States

- An Overview -

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Table of Contents

Table of Contents

Table of Contents

Section	Page

List of Figures

An Overview of Cable Television
in the United States

This paper is intended to provide a technical briefing on cable television in the United States. It is organized into three sections. Section 1 gives a casual review of cable technology and the cable business in the U.S. Section 2 is a more detailed look, and the third section provides data and specifications. The reader can use the three sections independently depending on his background and needs.

1.0 Introduction

According to A. C. Nielsen, cable television service is enjoyed by more than 59 million U.S. households. This is a market penetration of over 63%. Cable service passes 95% of U.S. households. It is expected that cable penetration growth will continue.

Because cable television has been so successful and has enjoyed such vigorous growth and acceptance, it has spawned competitive technologies including pre-recorded media (pre-recorded tape and disk sales and rentals), direct broadcast satellite (DBS), and the interest of the telephone industry. Its high visibility also has attracted the attention of regulators and legislators. Important public policy issues are involved. Understanding what cable television is, how it works, and its economics will help decision makers in these arenas. This understanding also will aid technologists in determining which technologies are appropriate for cable television applications and which are not. For some readers, the main interest in this paper is simply a better understanding of the technology that supplies their home with video.

1.1 <u>Historical Perspective</u>

Cable television is an important part of the way in which the citizens of the United States are informed and entertained. It is a means of providing large numbers of television channels to more than half of the U.S. population in a cost-effective way.

Prior to the 1990s, cable television systems were not intended to be general-purpose communications mechanisms. Their primary and often sole purpose was the transportation of a vari-

ety of entertainment television signals to subscribers. Thus, they needed to be one-way transmission paths from a central location, called a headend, to each subscriber's home, delivering essentially the same signals to each subscriber. The signals are intended for use with the consumer-electronics equipment that subscribers already own. This equipment is built to operate on the current U.S. television technical standard called *NTSC* after the organization that created it in 1941, the National Television Systems Committee. This black-and-white television standard was modified in 1953 to provide compatible color information to color television receivers, and again in 1984 to add compatible stereo sound.

The original purpose for cable television was to deliver broadcast signals in areas where they were not received in an acceptable manner with an antenna. These systems were called community antenna television, or CATV. In 1948, Ed Parson of Astoria, Oregon, built the first CATV system consisting of twin-lead transmission wire strung from housetop to housetop. In 1950, Bob Tarlton built a system in Lansford, Pennsylvania, using coaxial cable on utility poles under a franchise from the city.

In most CATV systems, off-air signals were not available or were very weak because of the terrain or the distance of the receiver from television transmitters. In some areas, such as New York City, multiple signal reflections and shadows cast by buildings made reception difficult. In both of these environments, a hard-wire method of delivery of signals to subscribers was welcomed. The first operators of these systems were retail TV receiver dealers who sought to expand the market for the sale of their products by also providing the signals that the products required. By the late 1960s, nearly all of the areas of the U.S. that could benefit from a community antenna had been served. Growth in the cable industry all but stopped.

In the mid 1970s, an embryonic technology breathed new life into cable television. This technology was satellite delivery of signals to cable systems, which added more channels than were available from terrestrial broadcasters. While satellites and earth stations were very expensive investments, these programming pioneers understood that the costs could be spread over many cable operators who, in turn, serve many subscribers.

Three categories of signals came into existence: 1) "Super stations" - local stations that are distributed nationally over satellite and became mini-networks. (The Turner Broadcasting

System of Atlanta, Georgia, pioneered the concept.); 2) Specialized channels for news, sports, weather, education, shopping, etc.; and 3) Movie channels such as Home Box Office (HBO), that sparked new excitement in the business. Cable television became much more than just a community antenna for areas with poor reception. Cable television became a means of receiving programming otherwise unavailable.

Cable subscribers are offered a variety of video services. The foundation service required of all subscribers is called *basic*. Off-air channels, some distant channels, and some satellite-delivered programs are included. The satellite programs include the super stations and some of the specialty channels. *Pay television* constitutes premium channels, usually with movies and some special events, that are offered as optional channels for an extra monthly fee. Some cable systems offer *pay-per-view* (PPV) programming that is marketed on a program-by-program basis. Recent movies and special sports events are the mainstay of PPV programming. *Impulse pay per view* (IPPV) allows the subscriber to order the program spontaneously, even after it has begun. The ordering mechanism usually involves an automated telephone link or, occasionally, two-way cable.

Ways of providing conditional access to allow for a limited selection of service packages at differing price points are often included in the cable system. Simple filters remove the unsubscribed channels in some systems, while other cable systems use elaborate video and audio scrambling mechanisms.

During the early-to-mid 1980s, a wide variety of other services was offered repeatedly to cable subscribers: videotext, teletext, other forms of "electronic publishing" and "information-age" services, home security, and digital audio programming.

The late 1980s and early 1990s brought a high level of interest in and excitement about the "Information Superhighway," also called the National Information Infrastructure (NII). A variety of drivers are energetically pushing the NII.

Early efforts came from the telephone industry seeking to justify upgrading heavily depreciated plant. Since the twisted-pair plant did a fine job of delivering plain old telephone service (POTS), another reason for replacing it was needed. That reason needed to be a bandwidth hog. Digitized voice did not fill the bill. It could be handled over the existing twisted-copper

pairs. Only computer data and digitized video held the promise of providing a justification for declaring twisted-copper pair obsolete. So the telephone systems began a quest for permission to add fiber and digital technology to the rate base. Congressmen caught the bug and decided that a vast government-sponsored program was needed to build the Information Superhighway. The NII was born.

The cable industry realized that it had a major advantage in this race. It passed almost all households with a truly wideband delivery capability. The cable industry and the telephone industry both strove to convince government that a publicly funded program was not needed. Private industry could do the job effectively and efficiently.

Since cable television systems must utilize the public right-of-way to install their cables, they (like power, telephone, and gas companies) must obtain a franchise from the local governmental authorities. This is a non-exclusive franchise. However, experience with multiple cable systems has shown that the economics of the business generally only support one system per community.

1.2 **Spectrum Re-use**

Compared with nearly any other communications need, video is a bandwidth hog. While telephone-quality voice needs only 3 kHz of spectrum and high-fidelity sound takes 20 kHz or so (40 kHz for stereo), the current video standard consumes 4.2 MHz. High-definition television (HDTV) requires about 30 MHz for each of the red, green, and blue signals that make up a color picture. Extensive bandwidth-compression techniques will reduce the amount of spectrum required by HDTV to the 6 MHz allowed by the Federal Communications Commission (FCC). These signals must then be modulated onto carriers to deliver multiple signals to the consumer's equipment. The modulation process further expands the spectrum required.

For NTSC, each television channel consumes 6 MHz because of vestigial side-band amplitude modulation, VSB-AM. Compared with double side-band amplitude modulation's need for 8.4 MHz, VSB-AM transmits one complete side-band and only a vestige of the other. At the time the standard was created, electronics consisted of vacuum tubes. It was important to avoid the complexities of single side-band receivers while not consuming the bandwidth required by double side-band transmission. VSB-AM was an effective compromise for the constraints of

the times. The design requirements of practical filters determined the amount of side-band included. The consumer's receiver selected the channel to be watched by tuning to a 6-MHz portion of the assigned spectrum. In the terrestrial broadcast environment, channels must be carefully assigned to prevent interference with each other. The result of this process is that most of the terrestrial broadcast television spectrum is vacant. Better television antennas and better television circuits would allow more of the spectrum to be utilized. However, with more than 200 million receivers and more than 100 million VCRs in consumers' hands, the changeover process to upgraded systems would be difficult, costly, and require something like 20 years.

The remaining terrestrial spectrum that is not assigned to broadcast has other important uses. These include aircraft navigation and communications, emergency communications, and commercial and military applications. The terrestrial spectrum is too limited to supply the video needs of the U.S. viewer. Cable television is made possible by the technology of coaxial cable. Rigid coaxial cable has a solid aluminum outer tube and a center conductor of copper-clad aluminum. Flexible coaxial cable's outer conductor is a combination of metal foil and braided wire, with a copper-clad, steel center conductor. The characteristic impedance of the coaxial cable used in cable television is 75 ohms. The well-known principles of transmission line theory apply fully to cable television technology.

The most important characteristic of coaxial cable is its ability to contain a separate frequency spectrum and to maintain the properties of that separate spectrum so that it behaves like over-the-air spectrum. This means that a television receiver connected to a cable signal will behave as it does when connected to an antenna. A television-set owner can become a cable subscriber without an additional expenditure on consumer-electronics equipment. Much of the cable service can be enjoyed simply by connecting the TV or VCR to the cable system. Other services are enjoyed through adapters provided as part of the cable subscription. The subscriber can also cancel the subscription and not be left with useless hardware. This ease of entry to and exit from an optional video service is a fundamental part of cable's appeal to subscribers.

Since the cable spectrum is tightly sealed inside an aluminum environment (the coax cable), a properly installed and maintained cable system can use frequencies assigned for other pur-

poses in the over-the-air environment. This usage takes place without causing interference to these other applications or without having them cause interference to the cable service. New spectrum is "created" inside the cable by the "re-use" of spectrum. In some cable systems, dual cables bring two of these sealed spectra into the subscriber's home, with each cable containing different signals.

The principal negative of coaxial cable is its relatively high loss. Coaxial cable signal loss is a function of its diameter, dielectric construction, temperature, and operating frequency. A ballpark figure is 1 dB of loss per 100 feet. Half-inch diameter aluminum cable has 1 dB of attenuation per 100 feet at 181 MHz; at one-inch diameter, the attenuation drops to 0.59 dB per 100 feet. The logarithm of the attenuation of cable (in dB) varies with the square root of the frequency. Thus, the attenuation at 216 MHz (within TV channel 13) is twice that of 54 MHz (within TV channel 2) since the frequency is four times as great. If channel 2 is attenuated 10 dB in 1,000 feet, channel 13 will be attenuated 20 dB. Figure 1.1 demonstrates this relationship for 1,000 feet of half-inch aluminum cable.
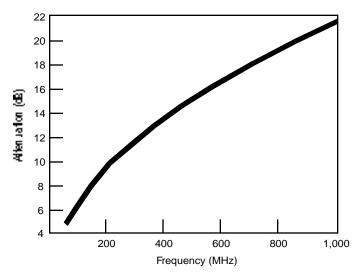
FIGURE 1.1 - COAX CABLE ATTENUATION VS. FREQUENCY

1.3 Cable Network Design

While current cable practice involves extensive use of fiber optics in new construction and upgrades, it is important to understand cable techniques used prior to fiber's introduction. This is partly because a significant fraction of cable systems have not yet upgraded to fiber and because these older cable techniques illustrate important cable technical principles.

Since cable television of the 1980s was not a general-purpose communications mechanism, but rather a specialized system for transmitting numerous television channels in a sealed spectrum, the topology or layout of the network was customized for maximum efficiency. The topology that has evolved over the years is called tree-and-branch architecture. Many small- and intermediate-sized systems fit this model. When analyzed, most large systems can be seen as having evolved from this prototype.

There are five major parts to a traditional coaxial cable system: 1) the headend, 2) the trunk cable, 3) the distribution (or feeder) cable in the neighborhood, 4) the drop cable to the home and in-house wiring, and 5) the terminal equipment (consumer electronics).

Flexible coaxial cable is used to bring the signal to the terminal equipment in the home. In the simplest cases, the terminal equipment is the television set or VCR. If the TV or VCR does not tune all the channels of interest because it is not "cable compatible," a converter is placed in the home between the cable and the TV or VCR tuner.

Broadcast channels 2 through 13 are not in a continuous band. Other radio services occupy the gaps. Cable can re-use these frequencies because its spectrum is self-contained within the coaxial environment. The cable converter has a high-quality broadband tuner and output circuitry that puts the desired cable channel on a low-band channel not occupied in the local off-the-air spectrum. Typically this is channel 2, 3, 4, or 5. The TV or VCR is tuned to this channel and behaves as a monitor. If programming of interest to the subscriber is scrambled, a descrambler is required. It is usually placed in the converter. Figure 1.2 shows the cable frequency plan.
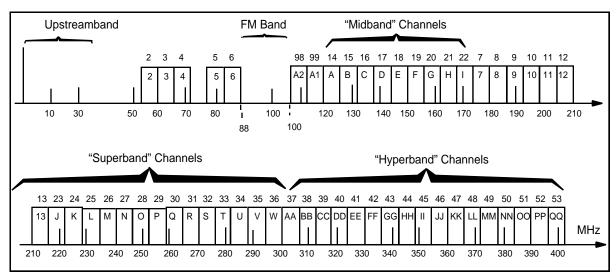
FIGURE 1.2 - FREQUENCY PLAN

Numbers above the rectangles are the new Electronics Industry Association standard designations. Historical designations are inside the rectangles

The home is connected to the cable system by the flexible drop cable, typically 150 feet long. See Figure 1.3.
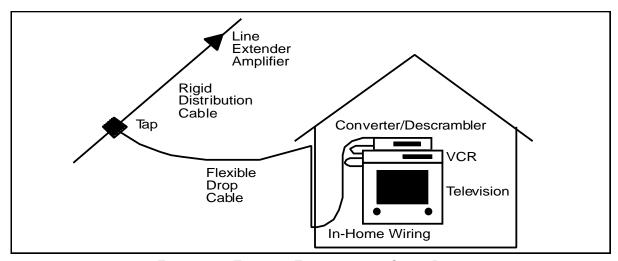
FIGURE 1.3 - TERMINAL EQUIPMENT AND CABLE DROP

The distribution cable in the neighborhood runs past the homes of subscribers. This cable is tapped so that flexible drop cable can be connected to it and routed to the residence. The distribution cable interfaces with the trunk cable through an amplifier called a bridger amplifier, that increases the signal level for delivery to multiple homes. One or two specialized amplifiers, called line extenders, are included in each distribution cable. Approximately 40% of the system's cable footage is in the distribution portion of the plant and 45% is in the flexible drops to the home. See Figure 1.4.
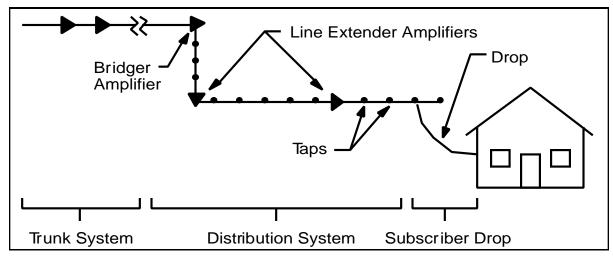
FIGURE 1.4 - DISTRIBUTION PLANT

The trunk part of the cable system transports the signals to the neighborhood. Its primary goal is to cover distance while preserving the quality of the signal in a cost-effective manner. Current practice uses fiber to bring the signal to the neighborhood. Older cable systems that haven't been rebuilt or upgraded still have coaxial cable in the trunk portion of the cable plant. With coaxial cable, broadband amplifiers are required about every 2,000 feet depending on the bandwidth of the system. The maximum number of amplifiers that can be placed in a run or cascade is limited by the build-up of noise and distortion. Twenty or 30 amplifiers may be cascaded in relatively high-bandwidth applications. Older cable systems with fewer channels may have as many as 50 or 60 amplifiers in cascade. Approximately 15% of a cable system's footage is in the trunk part of the system.

The headend is the origination point for signals in the cable system. It has parabolic or other appropriately shaped antennas for receiving satellite-delivered program signals, high-gain directional antennas for receiving distant TV broadcast signals, directional antennas for receiving local signals, machines for playback of taped programming and commercial insertion, and studios for local origination and community access programming. See Figure 1.5.
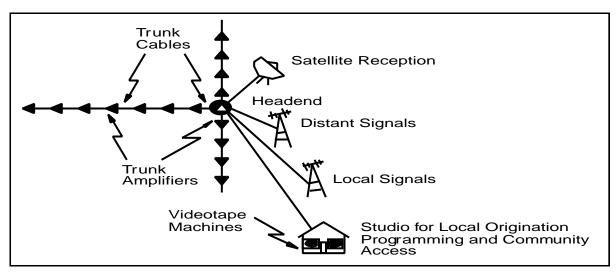
FIGURE 1.5 - CABLE SYSTEM HEADEND

Local origination is programming over which the cable operator has editorial control. It can range from occasional coverage of local events to a collection of programming almost indistinguishable from that of an independent broadcaster. Often mobile coverage of events is provided with microwave links back to the headend or back-feed of the signal up the cable system to the headend.

The channel and time for Community Access is mandated by the local franchise for programming by community groups. The cable system typically cannot exercise editorial control over quality or content of Community Access programming.

When the whole picture is assembled, the tree shape of the topology is evident. The trunk and its branches become visible. See Figure 1.6.
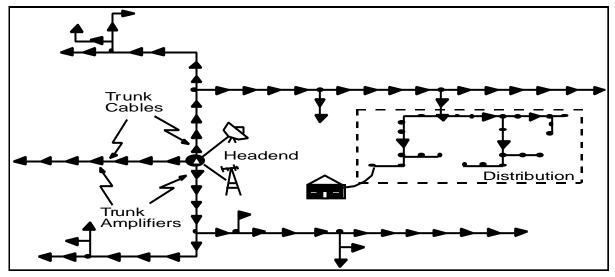
FIGURE 1.6 - TREE-AND-BRANCH TOPOLOGY

1.4 <u>Signal Quality</u>

The ultimate goal of the cable system is to deliver pictures of adequate quality at an acceptable price while satisfying stockholders, investors, and holders of the debt generated by the huge capital expenses of building the cable system plant. This is a difficult balancing act. It would be a simple matter to deliver very high-quality video if cost were not a consideration. Experience teaches that subscriber satisfaction is a complex function of a variety of factors led by program quality and variety, reliability of service, video and sound quality, and the amount of the subscriber's cable bill.

The principal picture impairments can be divided into two categories: coherent and non-coherent. Coherent impairments result in a recognizable interfering pattern or picture. They tend to be more objectionable than non-coherent impairments of equal strength.

The principal non-coherent picture impairment is *noise*. Random noise behavior is a well-understood part of general communications theory. The familiar Boltzmann relationship, noise figure concepts, etc., applies fully to cable television technology. Random noise is the consequence of the statistical nature of the movement of electric charges in conductors. This creates a signal of its own. This noise is inescapable. If the intended analog signal is ever allowed to become weak enough to be comparable to the noise signal, it will be polluted by it, yielding a snowy pattern in pictures and a sea shore-sounding background to audio.

Noise levels are expressed in cable system practice as ratios of the video carrier to the noise in a television channel. This measure is called the carrier-to-noise ratio (CNR) and is given in decibels (dB). The target value for CNR is 48 dB to 50 dB. Noise in the picture, called snow, is just visible when CNR is 42 dB to 44 dB. Snow is objectionable at CNRs of 40 dB to 41 dB.

Coherent interference includes ingress of video signals into the cable system, reflections of the signal from transmission-line impedance discontinuities, cross modulation of video, and cross modulation of the carriers in the video signal. This latter phenomenon gives rise to patterns on the screen that are called beats. These patterns often look like moving diagonal bars or herringbones.

The evaluation of signal quality takes place on two planes, objective and subjective. In the objective arena, measurements of electrical parameters are used. These measurements are repeatable. Standardized, automated test equipment has been developed and accepted by the video industries. Figure 1.7 lists the parameters usually considered important to signal quality and the values of good, current practice. They are described in the remaining text.

Parameter	Symbol	Value
Carrier / Noise (CNR)	C/N	48 to 50 dB
Composite Second Order	CSO	-53 dB
Composite Triple Beat	CTB	-53 dB
Signal Level at TV		0 to +3 dBmV

FIGURE 1.7 - SIGNAL QUALITY TARGET VALUES

The ultimate performance evaluation involves the subjective reaction of viewers. One example of the difficulties experienced in evaluating signal quality is the fact that different frequencies of noise have differing levels of irritation. High frequency noise tends to become invisible while low frequency noise creates large moving blobs that are highly objectionable. Subjective reactions to these phenomena are influenced by such factors as the age, gender, health, and attitude of the viewer. The nature of the video program, the characteristics of the viewing equipment, and the viewing conditions also affect the subjective evaluation of signal quality.

Signal processing in the TV receiver changes the impact of signal impairments. Noise in the band of frequencies used to transmit color information is demodulated and converted into lower frequency, more objectionable noise. Noise in the synchronization part of the TV signal can cause the picture to break up entirely, resulting in much greater impairment than the same strength noise confined to other portions of the signal.

In 1959, the Television Allocations Study Organization (TASO) studied the amount of noise, interference, and distortion that viewers will tolerate in a TV picture. The results were expressed in a five-point scale with grades named excellent, fine, passable, marginal, and inferior.

It is important to realize that the demand for signal quality is a function of time. A CableLabs subjective study conducted in 1991 indicated that viewers are more discerning and demand

higher quality pictures than at the time of the TASO report. Ten to 15 years ago, consumer-electronics products were not capable of displaying the full resolution of the NTSC signal. Gradually, these products improved until high-end models are now capable of more performance than the NTSC signal can deliver. The Super VHS and Hi-8 video tape systems have greater resolution than broadcast NTSC. As time progresses, the level of performance of consumer electronics will continue to increase. As advanced TV (ATV) and high-definition television (HDTV) are introduced, still more demands will be made on cable system performance. The trend to larger screen sizes also makes video impairments more evident.

1.5 Cable System Trade-offs

The experienced cable system designer of the 1980s had learned how to balance noise, non-linear distortions, and cost to find a near optimal balance. The various configurations of then-available components had been thoroughly explored and the best choices understood. The explosion of technology in the 1990s has changed all of this carefully sorted-out technique. The latest technology has dramatically increased the options available to the cable system designer. Construction of optimum designs now requires knowledge, experience, creativity, and a complete familiarity with the latest components.

Signals in cable systems are measured in dB relative to 1 mV(millivolt) across 75 ohms. This measure is called dBmV. Applying the well-known Boltzmann noise equation to 75-ohm cable systems yields an open-circuit voltage of 2.2 μv (microvolts) in 4 MHz at room temperature. When terminated in a matched load, the result is 1.1 μv. Expressed in dBmV, the minimum room-temperature noise in a perfect cable system is -59.17 dBmV.

Starting at the home, the objective is to deliver at least 0 dBmV, but no more than 10 dBmV to the terminal on the television receiver. Lower numbers produce snowy pictures and higher numbers overload the television receiver's tuner, resulting in cross modulation of the channels. If a converter or a descrambler is used, its noise figure must be taken into account. There are two reasons for staying toward the low side of the signal range: cost and the minimization of interference in the event of a signal leak caused by a faulty connector, damaged piece of cable, or defects or inadequate shielding in the television receiver. Low signal levels may cause poor pictures for the subscriber who insists on unauthorized splitting in the home to

serve multiple receivers. Working our way back up the plant, we need a signal level of 10 to 15 dBmV at the tap to compensate for losses in the drop cable.

The design objectives of the distribution part of the cable system involve an adequate level of power not only to support the attenuation characteristics of the cable, but to allow energy to be diverted to subscribers' premises. Energy diverted to the subscriber is lost from the distribution cable. This loss is called *flat loss* because it is independent of frequency. Loss in the cable itself is a square-root function of frequency and is therefore contrasted to flat loss. Because of flat losses, relatively high power levels are required in the distribution part of the plant, typically 48 dBmV at the input to the distribution plant. These levels force the amplifiers in the distribution part of the plant to reach into regions of their transfer characteristics that are slightly non-linear. As a result, only one or two amplifiers, called line extenders, can be cascaded in the distribution part of the plant. These amplifiers are spaced 300 to 900 feet apart depending on the number of taps required by the density of homes.

Because the distribution part of the plant is operated at higher power levels, non-linear effects become important. The television signal has three principal carriers, the video carrier, the audio carrier, and the color subcarrier. These concentrations of energy in the frequency domain give rise to a wide range of "beats" when passed through non-linearities. To minimize these effects, the audio carrier is attenuated about 15 dB below the video carrier.

In the days when cable systems only carried the 12 VHF channels, second-order distortions created spectrum products that fell out of the frequency band of interest. As channels were added to fill the spectrum from 54 MHz to as much as 750 MHz (1 GHz in a couple of systems), second-order effects were minimized through the use of balanced, *push-pull* output circuits in amplifiers. The third-order component of the transfer characteristic dominates in many of these designs. Figure 1.8 demonstrates the triple-beat phenomena. The total effect of all the carriers beating against each other gives rise to an interference called *composite triple beat* (CTB). CTB is measured with a standard procedure involving 35-channel carriers. In a 35-channel cable system, about 10,000 beat products are created. Channel 11 suffers the most with 350 of these products falling in its video passband. Third-order distortions increase nearly 6 dB for each doubling of the number of amplifiers in cascade. A 1-dB reduction in amplifier output level will generally reduce CTB by 2 dB. If these products build to visible

levels, horizontal lines will be seen moving through the picture. When these components fall in the part of the spectrum that conveys color information, spurious rainbows appear.
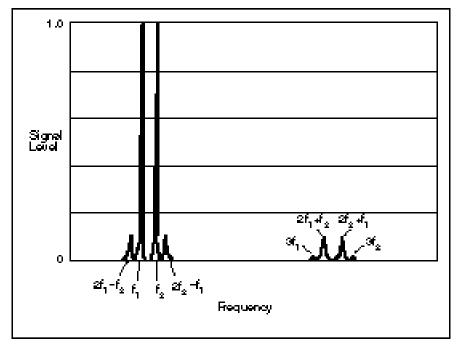
FIGURE 1.8 - TRIPLE BEAT

If we assign a design level of noise and non-linear distortion at the subscriber's television receiver that is below the threshold of visibility, we can conceive of a budget of noise and distortion to be "spent" in the various parts of the system design. The distribution part of the system has relatively high powers and has used up most of the budget for non-linear distortions. On the other hand, little of the noise budget has been consumed. It can be allocated to the trunk part of the system, which brings the signals into the neighborhood.

The design objective of the trunk part of the cable system is to move the signal over substantial distances with minimal degradation. Because distances are significant, fiber or lower-loss cables are used. One-inch- and 0.75-inch-diameter cable is common in the trunk while 0.5-inch cable is found in the distribution. Signal levels in the trunk at an amplifier's output are 30 to 32 dBmV depending on the equipment used.

It has been determined through analysis and confirmed through experience that optimum noise performance is obtained when the signal is not allowed to be attenuated more than about 20 to 22 dB before being amplified again. Amplifiers are said to be "spaced" by 20 dB. The actual distance in feet is a function of maximum frequency carried and the cable's attenuation

characteristic. High-bandwidth cable systems have their amplifiers fewer feet apart than older systems with fewer channels. Since attenuation varies with frequency, the spectrum in coaxial cable develops a slope. This is partially compensated with relatively simple equalization networks in the amplifier housings.

The attenuation of the cable is a function of temperature and aging of components. These amplifiers use a pilot signal to control automatic-gain-control (AGC) circuits. A second pilot signal at a substantially different frequency than the first allows the slope of the attenuation characteristic to be monitored and compensation to be introduced with automatic slope control (ASC) circuits. Thus, long cascades of amplifiers can, once properly set up, maintain their performance over practical ranges of temperature and component aging.

Since the signal is not repeatedly tapped off in the trunk part of the system, high power levels are not required to feed splitting losses. As a result, signal levels are lower than in the distribution portion of the plant. Typical levels are about 30 dBmV. For the most part, the amplifiers of the trunk are operated within their linear regions. The principal challenge of trunk design is keeping noise under control. Each doubling of the number of amplifiers in the cascade results in a 3-dB decrease in the CNR at the end of the cascade and a nearly 6-dB increase in the amount of CTB. If the noise at the end of the cascade is unacceptable, the choices are to employ lower noise amplifiers, shorter cascades, or a different technology such as microwave links or fiber optic links.

1.6 **Cable Economics**

The most recent (1993) figures compiled indicate that the U.S. cable industry has 11,217 cable systems. These range in size from a few hundred customers to the largest system, that serves about a million subscribers, in New York City and is operated by Time Warner. The cable industry employs about 110,000 people and has annual revenues of $25 billion.

The economics of cable television is governed by a number of factors. Included in these are the cost of construction, the cost of programming, the willingness of subscribers to pay for the service, and operating costs of the system.

It is difficult to define a "typical" cable system because of the variety of local factors. A rough approximation to such an entity is a 42-channel, two-way capable, one-way activated system with 50,000 subscribers. Population density is about 75 homes per mile of cable plant. Penetration of subscribers is about 59% of homes passed. The current cost to build such a system is between $600 and $1,200 per subscriber, depending on local geography, economics, and construction rules. The cost of cable system construction varies greatly depending on the circumstances of the location. A major variable is whether the cable system plant is underground or on poles. In the U.S., only about 20% of the plant is underground.

Figure 1.9 shows an approximate distribution of cable construction costs. The labor to install each component is included with the cost of that component. Hardware includes the mechanism for supporting the cable. In aerial construction, a strong, heavy wire called strand is mounted on the poles. A thinner wire, called lashing, is spiral-wrapped around the cable and strand to support the cable. Strand also supports amplifiers and passive components. The passive devices split the signal and tap into the cable for distribution to the home. Electronics include amplifiers and microwave links.
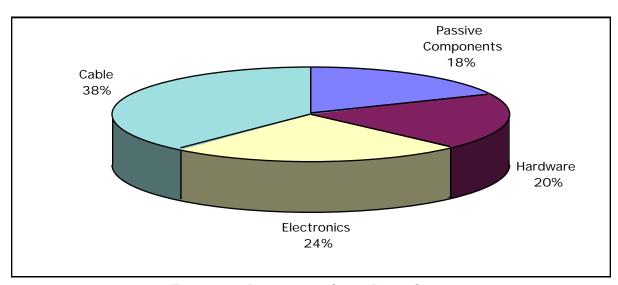
FIGURE 1.9 - DISTRIBUTION CABLE PLANT COSTS

The market value of cable systems recently sold varies from $1,800 to a high of $2,500 or more per subscriber. These values are determined by both the current cash flow and the potential for increased penetration and new revenue streams. Cash flow averages about $180 per subscriber per year. The cable business is a capital-intensive business that is currently experiencing dramatic increases in programming costs.

According to statistics gathered in 1993 by the cable industry trade organization, the National Cable Television Association (NCTA), subscribers paid about $21 per month for basic service and $10.50 per month for each optional pay service such as HBO. While not every basic subscriber takes an optional pay service, some take more than one. Average per-month revenue is about $32.

A late 1980s study by another cable trade organization, the Cable Telecommunications Association (CATA), makes an interesting point about the cost of cable television compared to that of "free" over-the-air television. By dividing the total dollars spent on broadcast television advertising in the U.S. by the number of television households, CATA determined the true cost per TV household for support of "free" television. The amount comes to $297 per year or $24.75 per month. These are additional dollars families pay for goods and services that go to support "free" television. This can be viewed as an involuntary subscription to a very limited number of channels. The individual has no readily available option to cancel this "subscription." This is true even if the individual lives in an area where there is no on-the-air signal available or if he does not even own a television set. In contrast, the cable subscriber elects to pay for service. In the year of the CATA study, the average cable subscriber paid about $26 per month. A subscriber may cancel at anytime; subscribing is completely discretionary. While cable systems derive some revenue from advertising, the fraction is small, but on the increase.

2.0 Technical Detail

Section 2 concentrates in more detail on issues relating to the technical performance of cable systems. Some generalizations have been made in order to group explanations. This section is intended to serve as a briefing, so selective trade-offs were made on the amount of detail given. There are always exceptions, for cable systems do not neatly fall into clear types. (A reading list is provided in Section 4, Bibliography.) The following topics will be covered:

- Channel capacities and system layouts

- Signal transportation systems

- FCC spectrum regulation

- Means of increasing channel capacity

- Maintaining cable television plant and minimizing picture impairments

- Scrambling methods

- The interface between the cable and the customer's equipment

- Fiber in cable television practice
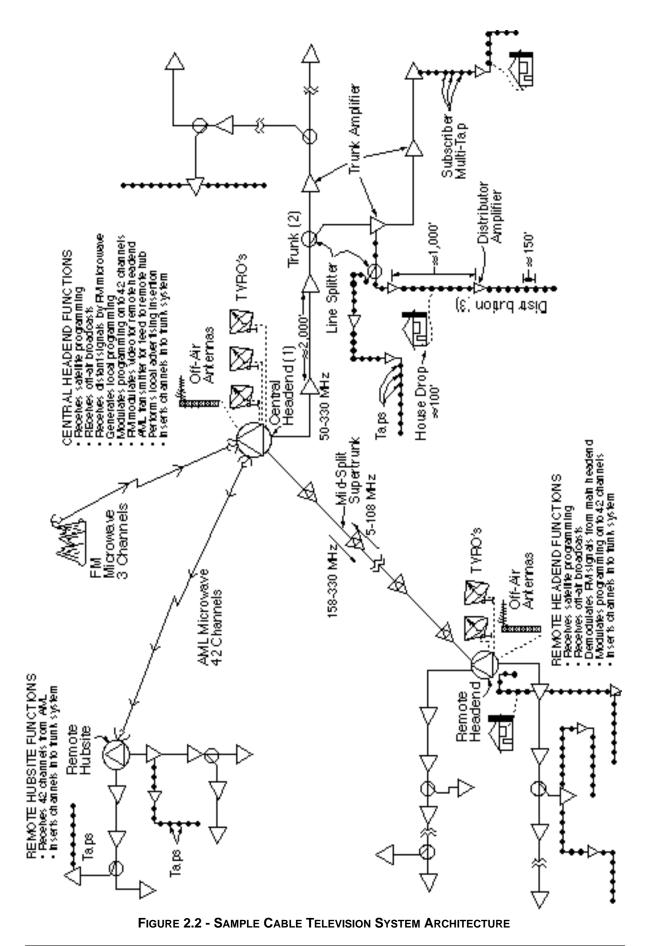
2.1 System Configurations and Trends

2.1.1 Channel Carriage Capacity

Channel carriage capacity is based on radio frequency (RF) bandwidth. It is a useful characteristic for classifying cable systems. As shown in Figure 2.1, there are three types of systems. Systems are categorized by their highest operating frequency. Downstream signals are transmitted to the customers' homes.

	Bandwidth	Operating Frequencies (RF range)	Number of Channels
Small	170 MHz	50 MHz-220 MHz	12-22 (single coax)
	220 MHz	50 MHz-270 MHz	30 (single coax)
Medium	280 MHz	50 MHz-330 MHz	40 (single coax)
	350 MHz	50 MHz-400 MHz	52 (single coax)/104 (dual coax)
Large	400 MHz	50 MHz-450 MHz	60 (single coax)/120 (dual coax)
	500 MHz	50 MHz-550 MHz	80 (single coax)
	700 MHz	50 MHz-750 MHz	110 (single coax)
	950 MHz	50 MHz-1,000 MHz	150 (single coax)

FIGURE 2.1 - DOWNSTREAM SIGNALS: RANGES OF OPERATING FREQUENCIES AND CHANNELS

FIGURE 2.2 - SAMPLE CABLE TELEVISION SYSTEM ARCHITECTURE

Referring to Figure 2.2, a cable system configuration consists of: (1) the headend (the signal reception, origination, and modulation point); (2) main, coaxial trunk (or tree) cable that runs through central streets in communities; (3) coaxial distribution (branch) cable to the customer's neighborhood, including distribution taps; (4) subscriber drops to the house; and (5) subscriber terminal equipment (television sets, converter/descramblers, VCRs, etc.). Distribution plant is sometimes called *feeder* plant. Programming comes to the headend by satellite signals, off-air signals from broadcast stations, and signals imported via terrestrial microwave. Signals originating from the headend are from a co-located studio facility, VCRs, character generators, or commercial insertion equipment.

Plant mileage is calculated using the combined miles of strand that support the coaxial cables in the air and the footage of trenches where cables are installed in the ground. There are about a million miles of plant in 11,217 U.S. cable systems.

Extension cables, or drops, interconnect main coaxial plant lines to customers' homes. They are not included in plant mileage. Drop cables are smaller in diameter than mainline coaxial cable plant. They interconnect between a power splitter, called a multitap directional coupler, and the customer's interface, usually a television set. The tap is located in the utility easement. In an average cable system[1], there will be 6,625 feet of drop cable per plant mile and 7,040 feet of hard-line coaxial cable. Put another way, 48% of the total plant is drop cable and associated F-connectors, which are the connectors used to connect coaxial cable to equipment. With the cable industry targeting subscriber penetration at 70%, in an average system 55% of the plant will be drop cable. About 45% of service calls are related to problems with the drop portion of the plant. About one-third of the drop-related service calls are caused by problems at the F-connectors. Cable systems replace approximately 10% of drops annually.

Small-capacity cable systems operate in the 50 to 220 MHz range with a bandwidth of 170 MHz. Twelve to 22 television channels are activated. These systems were constructed from the mid '50s to the late '70s. They account for less than 10% of total plant mileage.

At the small end of the scale, 220-MHz systems built 15 or more years ago are found in rural areas or in areas with clusters of small established communities. A few of these systems oper-

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1.   75 homes per mile, 53% penetration, drop length of 125 feet, 1:3 trunk footage-to-feeder footage ratio.

ate trunk lines running over 20 miles with 50 or more amplifiers in cascade. Total plant mileage for an average 220 MHz system extends from 50 to 500 miles and services up to 10,000 cable customers.

Medium-capacity cable systems operate with upper frequencies at 330 MHz and 400 MHz, and total bandwidths of 280 MHz and 350 MHz, respectively. Systems with 330 MHz deliver 40 channels, while 400-MHz systems deliver 52. Although new cable systems are seldom built with 40-channel capacity, plant extensions to existing 270-MHz, 300-MHz and 330-MHz systems occur. Electronic upgrade is frequently employed to increase 270-MHz systems to 330 MHz. Some 220-MHz systems are upgrading to 300 MHz.

Medium-capacity systems account for about 75% of total plant mileage. They serve a wide range of communities, from rural areas (populations of 5,000 to 50,000) to some of the largest systems built in the late '70s. The San Antonio system, a medium capacity system, passes 420,000 homes, consists of 4,000 miles of plant with over 2,000 trunk amplifiers, and has in excess of 11,000 distribution amplifiers. The longest cascade in the system is 37 trunk amplifiers. There are 300-MHz systems with cascades of 45 or more trunk amplifiers.

Large-capacity cable systems achieve high channel capacities through extended operating frequencies and through the installation of dual, co-located, coaxial cable. Single coaxial cable systems range from 52-channel, 400-MHz to 80-channel, 550-MHz. Recent practice includes building capacities to 750 MHz for 110 channels. With dual cable, it is not unusual to find 120 channels. The Time Warner system in Queens, New York, has a 1-GHz (1,000 MHz) capacity with 150 channels.

Large-capacity cable systems account for about 15% of total cable plant miles. They are primarily high-tech systems designed for large urban areas previously not cabled. They serve 50,000 to 150,000 customers and consist of 400 to 2,000 miles of plant. They began construction in 1981. The earliest were 52-channel, 400-MHz systems. Then came 60-channel, 450-MHz systems. These were quickly followed by dual-cable, 400- or 450-MHz systems with carriage of 108-120 channels. The dual-cable trend has tapered off and the remaining urban systems are being built with a single cable, 450 to 750 MHz.

Large-capacity systems are designed, and some operate, as two-way cable plant. In addition to the downstream signals to the customers (50 MHz to upper band edge), upstream signals are carried from customers to the cable central headend, or hub node. They are transmitted using frequencies between 5 and 30 MHz. Some recent systems operate 5 to 40+ MHz. The "Full Service Network" in Orlando, Florida, also has an upstream path above 900 MHz.

Systems with 550 MHz average at least twice as many amplifiers per mile of cable plant as 220-MHz systems. If too many amplifiers are put in cascade, and 54 or more channels are transmitted, there would be objectionable distortion from the cascaded amplifiers. Technology has become available that reduces the number of required amplifiers to the number per mile in 300-MHz plant. In the 400+ MHz systems, amplifier cascades are kept to less than 30.

2.1.2 Industry Trends

When franchises come up for renewal, many civic authorities have required an increase in channel capacity. Upgrades to 550 or 750 MHz are occurring in some urban U.S. markets. On the west coast, large bandwidth upgrades are occurring in systems with as few as 20,000 subscribers because of the competitive climate.

Advanced television (ATV) will put pressure on operators to expand plant bandwidth. One of the most debated forms of ATV is HDTV, but the most talked about form is digital video compression.

The last few years have brought exciting trends employing new technologies. Fiber is now being installed to upgrade older systems and as part of rebuilds and new builds. The old trunk system of long cascades of amplifiers is now considered obsolete. Work on new amplifier technologies will allow a realization of cable's inherent bandwidth, which exceeds 1 GHz.

A bandwidth of 1 GHz contains 160 slots of 6 MHz. These can be allocated to NTSC, HDTV simulcast, and to new services. The most exciting potential lies with utilizing video-compression technology to squeeze four or more NTSC-like quality signals in a 6-MHz slot. This opens the door for hundreds of channels. "Near video on demand" becomes practical, i.e., the most popular movies could be repeated every few minutes to minimize the wait time before a movie starts. The average wait time could be made shorter than the trip to the video store, and

the subscriber does not have to make a second trip to return the movie. He is assured that the movie is always "in." A microprocessor can keep track of which channel to return to should the subscriber wish to pause. It is possible to design systems that behave as if they are switched even though they remain more like a traditional cable tree-and-branch structure.

2.1.3 Channelization

There are three channelization plans to standardize the frequencies of channels. The first plan has evolved from the frequency assignments that the FCC issued to VHF television broadcast stations. This plan is called the standard assignment plan.

The second channelization plan is achieved by phase locking the television channel carriers. It is called the IRC plan (incrementally related carriers). The IRC plan was developed to minimize the effects of third-order distortions generated by repeated amplification of the television signals as they pass through the cable plant. As channel capacities increased beyond 36 channels, composite, third-order distortions became the limiting distortion.

The third channelization type is the HRC plan (harmonically related carriers). It differs from the standard and IRC plan by lowering carrier frequencies by 1.25 MHz. With HRC, carriers are phase locked and fall on integer multiples of 6 MHz starting with channel 2 at 54 MHz. This plan was created to further reduce the visible impact of amplifier distortions.

The channelization plans were designed to reduce the visibility of distortion products by making their frequencies synchronous with the interfered carrier. Since carriers present in the downstream signal path add to the distortions, cable systems carry non-video carriers at a level that is 13-17 dB below the video carrier's amplitude. This drastically reduces distortion contributions. With broadcast TV channels carried on cable, special processing equipment is used that reduces the aural carrier. This amplitude reduction does not significantly affect the audio signal-to-noise ratio (SNR) quality of monaural television sound. However, this lower level created SNR problems at the end of the cable system for higher bandwidth signals such as FM stereo. When stereo television audio was developed, careful attention was focused on encoding techniques that would promote SNR immunity of the difference channel.

FM radio services are carried at an amplitude that is 15-17 dB below channel 6's video carrier level. The services are carried on cable in the FM band slot of 88-108 MHz. In an IRC channel plan, channel 6's aural carrier falls at 89.75 MHz, which reduces the available FM band to 90-108 MHz.

Low-speed data carriers are transmitted in the FM band or in the guard band between channels 4 and 5 in a standard frequency plan. The amplitude of these carriers is at least 15 dB below the closest video carrier level.

2.2 Signal Transportation Systems

Transportation systems were developed to deliver high-quality signals from the central head-end to remote headend or hub locations where cable signals are injected into cable trunking systems. (See Figure 2.2.) The increase in channel capacity and subsequent need to decrease amplifier cascades directly affected the development of transportation systems. Urban franchises cover large areas, yet wish to transmit downstream signals from a common headend point. Other motivating factors include increased local programming originating from the cable system's studio, the requirement to deliver city government programming originating from municipal locations, a new business opportunity for the insertion of local commercials to satellite-delivered services, and the development of pay-per-view (PPV) programming.

Several transportation methods have become popular over the last 10 years: amplitude modulated microwave link (AML), frequency modulated microwave link (FML), frequency modulated coaxial link (FMCL), amplitude modulated coaxial "supertrunks," and fiber interconnects.

2.2.1 AML and FML Microwave Links

AML allows the delivery of the entire downstream cable spectrum through the air to reception points located eight to 10 miles away from the microwave transmit site. An AML microwave transmitter provides adequate power to deliver signals to eight reception hubs. The advantage of AML is that the receiver simply performs a wideband, block-down conversion. The entire downstream frequency spectrum (e.g., 50-400+ MHz) is reproduced at an appropriate level for direct insertion into the cable plant, without the need for individual channel frequency shifting or processing. The only equipment required at an AML reception site is the micro-

wave receive antenna and a microwave receiver. These can be mounted to a small tower or telephone pole.

AML up converts each television channel and combines it at its respective microwave frequency, with one frequency per channel, using a complex wave guide system. In some cases, each channel added lowers the maximum power per channel. This may either shorten path lengths or increase the probability of signal degradation during rain fades.

One of the main uses of FML is to cover distances not feasible with AML or where video SNR in excess of 56 dB is required. FML is a single-channel, frequency-modulated microwave transmission system. FML occupies significantly more bandwidth than amplitude-modulated systems, from 12.5 MHz to 25 MHz per channel, depending on path length. Fewer channels are available for use. Since this transmission system delivers FM signals, demodulation and vestigial-sideband-amplitude remodulation (VSB-AM) and frequency translation must occur before insertion into the cable plant. The FML system is often used to deliver specialized programming (e.g., local origination) to a remote headend.

2.2.2 Frequency Modulated Coaxial Trunk

FMCL is an adaptation of FM microwave designed for transmission over coaxial cable plant. There are FM modulators for each television channel at the originating end and FM demodulators at the remote site. VSB-AM remodulation must occur before these channels can be inserted into the cable that provides direct service to subscribers. The primary use of FMCL is for studio-quality transmission of specialized programming from the origination site to the headend. Since it involves single-channel modulation and operates in a sealed coaxial environment, differing modulation bandwidth may be used.

2.2.3 Amplitude Modulated Coaxial Supertrunk

The amplitude-modulated supertrunk transportation system can be as simple as a conventional coaxial trunk transporting VSB-AM signals between two headends. Or the supertrunk can link a primary headend directly to the beginning of the normal cable distribution trunk. The television channels can be combined at their final frequency assignments for direct insertion into the distribution trunk. Or they can be grouped to fit into a reduced coaxial bandwidth (e.g., 5-108 MHz) for transportation on a special service coaxial trunk. An example of this trunk is a

mid-split system, which is a bidirectional trunk using 158-330 MHz downstream and 5-108 MHz upstream.

Another variation of AM supertrunk is split-band trunking. The spectrum from 50 to 450 MHz is split into two groups of 30 television channels each and inserted on two side-by-side trunks that connect two sites. The signals are equally loaded onto two trunk cables to improve television signal quality. This is achieved because the distortion produced is directly related to the number of channels carried on each trunk cable.

Whenever signals are not transported on their final frequency assignment, frequency translation devices called channel processors are used to frequency shift the television signals. AM supertrunks can be similar to cable distribution trunk. The difference is that the AM supertrunk will use new technology trunk amplifiers, such as *feedforward*. These transport with significantly fewer distortions and better CNR.

2.2.4 Fiber Interconnect

Fiber optic transportation systems are now used. In early systems, the signals were carried with FM modulation. Analog fiber networks carry six to 12 FM video signals per fiber. Currently, analog video fiber technology is preferred for this application, although occasionally cable systems use digital video. The focus of current research is to optimize fiber optic transmitters and receivers. The goal is the broadband carriage of 40-60 NTSC, amplitude-modulated video channels over a single fiber on path lengths up to 20 kilometers, approximately 12.5 miles.

The initial application of this technology was in Orlando, Florida, in 1988 as a backup to microwave links. Heavy rain causes these links to fade or suffer complete blockage. Automatic equipment switches signals to the fiber link. The AM fiber technology is now commonly used instead of microwave in many applications.

Digital fiber links are used when video signals are partially transported in a digital common carrier network. The video interfaces used operate at a DS-3 rate of 45 Mbps, which routes through common carrier points of presence and switching networks.

2.3 Frequency Band Usage

2.3.1 Frequencies Under Regulation

FCC rules and regulations govern the downstream cable frequencies that overlap with the over-the-air frequencies used by the Federal Aviation Administration (FAA). The frequencies are from 108 to 137 MHz and from 225 to 400 MHz. They are used by the FAA for aeronautical voice communications and navigational information. Since cable plant is not a perfectly sealed system, the FCC and the FAA want to maintain a frequency separation between signals carried on cable and frequencies used by airports near the cable system boundaries. In 400-MHz systems, over 30 channels are affected by the FCC rules on frequency offset and related operating conditions.

2.4 Increasing Channel Capacity

There are several ways to increase channel capacity. If the actual cable is in good condition, channel capacity is upgraded by modifying or replacing the trunk and distribution amplifiers. If the cable has seriously deteriorated, the cable plant is completely rebuilt.

2.4.1 Upgrades (Retrofitting) and Rebuilds

An upgrade is defined as a plant rehabilitation process that results in the exchange or modification of amplifiers and passive devices (such as line splitters, directional couplers, and customer multitaps). Nearly all upgrades involve adding (or increasing the amount of) fiber from the headend to the neighborhood. A simple upgrade requires new amplifier circuit units called hybrids. A full upgrade replaces all devices in the system. In an upgrade project, most of the feeder cable is retained. Goals of an upgrade project include increasing the plant's channel capacity and system expansion to outlying geographic areas. Upgrades are often the least expensive solution to providing expanded service.

In a rebuild, the outside plant is replaced. Customer drops are replaced on an as-needed basis. The strand that supported the old cable is occasionally retained. A rebuild is the most expensive solution to providing upgraded service. However, it requires a minimum of system downtime, since both old and new plant are active for a period of time. This allows the customer's drop to be switched directly from the old system to the new.

Once the plant has been rebuilt or upgraded, customers are provided newer converters with additional capabilities. The displaced units are moved to other systems or used for the basic tier of service.

2.5 <u>System Distortion and System Maintenance</u>

Constraints on the design and implementation of cable systems are imposed by each device used to transport or otherwise process the television signal. Each active device adds small distortions and noise to the signal. Even passive devices contribute noise. The distortions and noise compound so that with each additional device the signal becomes less perfect.

Any nonlinear device, even bimetallic junctions, cause distortions. The primary contributors are the slight non-linearities of amplifiers. Because the amplifiers are connected in cascade, the slight damage to the signal accumulates.

Noise in any electronic system can come from many sources. The major source is the random thermal movement of electrons in resistive components. For a cable system at 20°C or 68°F, the thermal noise voltage in a single channel's bandwidth will be 1.1 microvolts or -59.1 dBmV. This is the minimum noise level, or noise floor. Noise contributions from amplifiers add on a power basis, with the noise level increasing 3 dB for each doubling of the number of identical amplifiers in cascade. Eventually, the noise will increase to objectionable levels. The difference between the RF peak level and the noise level is measured to quantify the degree of interference of the noise power. The power levels in watts are compared as a ratio. This is called the signal-to-noise ratio, or SNR. In a cable system, the apparent effect of noise is its interference with the video portion of the TV channel. This level is compared to the video carrier and is called the carrier-to-noise ratio (CNR).

As the CNR value decreases, the interference of noise with the signal becomes visible as a random fuzziness, called snow, that can overwhelm the picture resolution and contrast. The point where the picture becomes objectionably noisy to viewers is at a CNR = 40 dB. In well-designed systems, the CNR is maintained at 46 dB, preferably at 48 to 50 dB. While an increase in signal level would improve the CNR, unfortunately, there can be no level increase without increases in distortions.

The distortion products of solid-state devices used in cable amplifiers are a function of the output levels and bandwidths. The higher the signal level, the greater the distortion products produced. Modern amplifiers use balanced configurations that almost completely cancel the distortion caused by the squared term of the amplifier's transfer characteristic. The dominant remaining distortions are called triple beats. They are caused by the cubed term in the voltage transfer function. Because distortion products add approximately on a voltage basis, the CTB-to-carrier ratio changes by nearly 6 dB for each doubling of the number of amplifiers in cascade, whereas the CNR decreases by 3 dB for each doubling.

The operating parameters of amplifiers determine the number that can be cascaded and, hence, the distance that can be covered. This is critical to the design philosophy of coaxial trunks in cable systems. While fiber is now used in trunk construction and rebuilds, the following discussion demonstrates important cable principles, none the less. It also helps one appreciate the importance of fiber in overcoming coaxial cable's limitations.

A cable system's operating limits are defined in terms of its noise floor and distortion ceiling. In Figure 2.3, the noise floor and distortion ceiling are presented as a function of the number of amplifiers in cascade for a system at 300 MHz. The diagram shows that a cascade of 46 trunk amplifiers is possible while realizing a 46 dB CNR and a 53 dB CTB. However, other operating realities dictate that substantially more headroom for both distortion and noise be incorporated into the design. The other factors to consider include: change in cable attenuation and noise with temperature, automatic gain control (AGC) and automatic slope control (ASC) tolerances, system frequency response, accuracy of field test equipment, designs anticipating ATV, and maintenance probabilities. In the example cited, allowing 1 dB of AGC/ASC change, a 3 dB peak-to-valley and 2 dB of test equipment uncertainty results in a 6 dB tolerance. Limiting distortion, CTB, implies that the cascade should only be half the length predicted in the chart, or 23 amplifiers.

The foregoing discussion is applicable only to the trunk portion of the system. As signal levels are increased in the distribution sections, additional allowances must be made in the system design. As a rule of thumb, CNR is determined primarily by the conditions of trunk operation and signal-to-distortion ratio (SDR) is determined primarily by the conditions of distribution operation.

Two other factors limit the geography of a cable system. Cable attenuation rises with increasing frequency. More equal gain amplifiers are required to transmit the signal a given distance. But noise limits the maximum number of amplifiers used. The second factor is that amplifier distortion is a function of channel loading: The more channels carried, the greater the distortions.
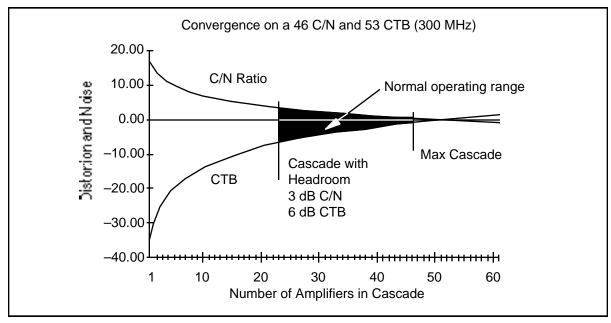
FIGURE 2.3 - DISTORTIONS IN A CASCADE

To obtain optimum cascade length, AGC/ASC tolerance, accurate alignment, calibrated test equipment, and well-founded system maintenance programs are of paramount importance. Maintenance programs are designed to ensure that system alignment is kept within acceptable limits. Where trunk lines carry signals through cascades of up to 40 trunk amplifiers, it is crucial that each amplifier have a flat amplitude-versus-frequency response. The additive effects of even minimal amplitude response variations in each amplifier create significant system flatness problems at the end of long cascades.

2.5.1 Maintaining Amplitude-Versus-Frequency Response

A maintenance program objective should be to achieve a system amplitude-versus-frequency response of less than [(N/10)+1] dB peak-to-valley, where N is the number of trunk amplifiers in the cascade.This will minimize the degradation of CNR which occurs in channels that fall in the valleys of the system response. It is imperative that the optimum response is maintained at each amplifier. Recommended practice calls for no more than 3 dB difference in adjacent

channel video carrier amplitudes provided to the customer. All channels must fall within a 12-dB overall passband response window.

The common method of evaluating a system's frequency response is a sweep generator that injects a rapidly swept carrier over the system's passband. The sweep generator is set to sweep from 50 MHz to the upper system passband frequency with a duration time as short as 1 millisecond. The field sweep receiver is then synchronized to the generator. The portable receiver provides a display of the system's response at each amplifier as the maintenance technician progresses through the trunk cascade.

Another tool for checking system flatness is the spectrum analyzer. To determine the overall system response, the individual video carrier amplitude of each television channel is measured. Because the carrier amplitudes are usually adjusted for a sloped amplifier output to minimize distortion products, more interpretation is needed with a spectrum analyzer. The sweep system allows the amplifiers to be adjusted for the flattest response.

Excessive response variations can cause additional distortions since some carriers will now exceed the amplitude at which the system's amplifiers were designed to operate. To keep these response variations from becoming excessive, amplifier manufacturers make a response control device known as a *mop-up circuit*. It is installed at periodic locations in trunk amplifiers throughout the cascade. These mop-up circuits are tunable filters adjusted to remove small peaks (less than 1.5 dB) caused by the amplifiers or cable. Incorrect use of these devices to solve defective equipment problems (e.g., bad cable sections, splices, or line passives) can cause impairment to a video channel by changing its in-band frequency response or its chrominance-to-luminance delay characteristics.

2.5.2 Group Delay Through the Cable Plant

Trunk amplifiers with bidirectional capability exhibit group delay as a result of the band-splitting diplex filters. The visible effect of the filtering is a loss of resolution in the picture. The diplex filters, which are high-pass and low-pass filters with a 40-MHz crossover frequency, are part of the trunk amplifier's circuitry.

Channels 2, 3, and 4 suffer from the repeated effects of the filtering. Other locations where filtering occurs are apartment complexes, hotels/motels, or hospitals, where channels are deleted from the spectrum by special band stop filters. Locally originated channels are inserted in the deleted portions of the spectrum.

Filtering occurs at the headend or hub in connection with channel processing equipment or the channel modulators. The effects of these filters are taken into account when the headend equipment is designed. There is only one of these devices per channel. Thus, the delay effects of this equipment rarely create problems. However, with some configurations of signal transportation systems, additional single-channel or multiple-channel filtering may take place and cause delays at hubs.

2.5.3 System Reflections

Signal reflections occur throughout the cable plant and are called *micro-reflections*. They are caused by the individual slight errors in impedance match. The severity of the mismatch is measured by the magnitude of the return-loss ratio. The larger the return loss, the better. Perfection is infinite. Mismatches include connectors, splices, and even damage to the cable itself. The example in Figure 2.4 is a splice installed in a trunk line approximately 150 feet past an amplifier. The splice, which may only have a 12 dB return loss, reflects signals back upstream that have only been attenuated by 13.5 dB (1.5 dB in cable attenuation plus the return loss of the splice). The reflected signals then arrive back at the output of the amplifier attenuated by a total of 15 dB (1.5 dB additional cable loss for the upstream trip plus the previous 13.5 dB). The signals are now reflected by the amplifiers output mismatch: A return loss of 16 dB is common. At this point, the reflected signal has an amplitude that is 31 dB below the primary signal and delayed by the round-trip propagation through 300 feet of cable, which takes about 350 nanoseconds. The signal is horizontally delayed approximately 1/7 inch on a 27-inch television set. This is not enough to become a visible ghost or second image. However, depending on the relative phases of the RF carriers of the primary and reflected signal, the visual effect may be enough to cause a softening of a previously well-defined luminance level transition. With repeated mismatches, the crispness of the pictures may be noticeably reduced. This softening effect is easily seen on displays of character-generated text pages.
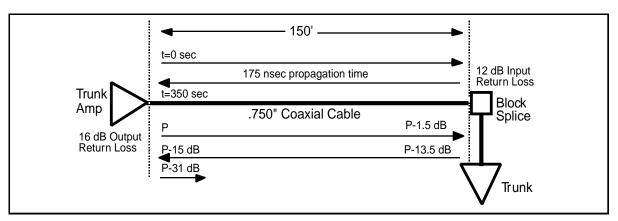
FIGURE 2.4 - EXAMPLE OF SYSTEM REFLECTION

2.5.4 Phase Noise

Phase noise is added to the original signal through modulation and frequency conversion processes. A significant amount of phase noise must be added to the NTSC video carrier before generated impairments become perceptible. Narrowband phase noise (measured 20 kHz from the video carrier) in a TV channel produces variations in the luminance and chrominance levels that appear as horizontally streaked lines within the picture. The perceptibility level of phase noise on the video carrier is 53 dB below the carrier at 20 kHz. If the frequency conversion or modulation processes are operating close to specification, phase noise impairments should not be perceptible on the customer's TV unless the converter/descrambler is malfunctioning or is of poor quality.

2.5.5 Amplifier Distortions and Their Effects

Amplifier technology based on feedforward and power-doubling techniques increases power levels with fewer distortions. However, additional sources of minutely delayed signals have been created. The signal delays produced in these amplifiers have similar end results in picture degradation as the delayed signals generated by reflected signals in the cable plant. But they are caused by a different mechanism. These amplifiers use parallel amplification technology. The signals are split, separately amplified, and then recombined.

With a feedforward amplifier, the signals are purposely processed with delay lines. If the propagation time is not identical through each of the amplifiers' parallel circuits, signals that are delayed by different amounts of time will be recombined. In most circumstances, the amount of differential delay is small and will not produce a visible ghost, but it may cause loss of pic-

ture crispness. Since the hybrids used in these amplifiers are normally provided in matched pairs or in a single hybrid package, these delays are only a problem when the hybrids are not replaced as a matched set.

In systems that carry more than 30 channels, CTB is the limiting distortion. However, cross modulation (X-MOD) distortion, which is often the limiting factor in systems with less than 30 channels, can reappear as the controlling factor in dictating system design. The HRC and IRC channelization plans discussed in the first section were developed to minimize the visible degradation in picture quality that is caused by CTB.

X-MOD is one of the easiest distortions to identify visually. Moderate cross modulation appears as horizontal and vertical synchronizing bars that move across the screen. In severe cases, the video of multiple channels is visible in the background.

Moderate CTB is the most misleading distortion since it appears as slightly noisy pictures. Most technicians conclude that there are low signal levels and CNR problems. CTB becomes visible as amplifier operating levels exceed the design parameters. Once CTB reaches a severe stage, it becomes more readily identifiable because it causes considerable streaking in the picture.

Composite second-order beats (CSO) can become a limiting factor in systems that carry 60 or more channels and use the HRC or IRC channelization plans. This distortion appears as a fuzzy herringbone pattern on the television screen. The CSO beats fall approximately 0.75 MHz and 1.25 MHz above the video carrier in a television channel. An IRC channelization will frequency-lock these beats together while increasing their amplitude relative to the carrier level.

Hum modulation caused by the 60-Hz amplifier powering is identified by its characteristic horizontal bar that rolls through the picture. If the hum modulation is caused by the lack of ripple filtering in the amplifier power supply, it will appear as two equally spaced horizontal bars that roll through the picture.

2.5.6 Frequency Bands Affected by Radio Frequency Interference

Discrete beat products can be difficult to identify by the displayed picture impairment. Radio frequency interference that leaks into the cable system from nearby RF transmitters causes spurious carriers to fall in the cable spectrum. Common sources of signal leakage are cracked cables and poor-quality connections. When either of these situations happen, strong off-air television and FM radio broadcast signals interfere.

If television stations are carried at the same frequency on cable as broadcast and if the head-end channel processing equipment is phase-locked to the off-air signal, the effects of this interference will be ghosting. The ghost appears before (to the left of) the cable signal, since propagation time through the air is less than through cable. If the signals are not phase-locked together, lines and beats appear in the picture.

Under HRC or IRC, the headend channel processing and modulating equipment is already locked to a reference oscillator. It is not possible to lock the unit to both the cable channelization plan and the off-air signal. In the IRC plan, it may be desirable to unlock a channel from the reference source and lock it to the off-air station. However, the group phase-locking advantage is lost. Several dB of distortion resistance on that channel is sacrificed. With HRC systems, video-carrier frequencies fall 1.25 MHz lower than their off-air channel counterpart. It is impossible to carry any channel on the off-air assignment unless the upper adjacent channel slot is not used. With the exception of the new 550-MHz cable systems, the interference from these sources is limited to the VHF channels 2-13 and the FM broadcast spectrum of 88-108 MHz.

Often there is interference from off-air signals due to consumer-electronics hardware design. If the internal shielding of the equipment is inadequate, the internal circuits will directly pick up the signal. This phenomenon is called DPU for *direct pick-up interference*. This is the original motivation for cable converters. Those early set-top boxes tuned no more channels than the TV set, but they protected against DPU by incorporating superior shielding and connecting to the TV set through a channel not occupied off-air.

DPU can be misleading. When the subscriber switches to an antenna, he might receive better pictures than from the cable connection. He concludes that his TV receiver is operating cor-

rectly and the cable system is faulty. The only convincing argument is a demonstration with a receiver which does not suffer from DPU. Viacom Cable has measured off-air field intensities of eight volts per meter. The German specification for immunity to DPU is four volts per meter. The U.S. has no such specification. However, TV receivers sold in the U.S. are built to comply with the Canadian specification of one-tenth of a volt per meter. This is inadequate. VCR tuners are generally inferior to TV tuners because the VCR market is even more price-competitive. JEC, the Electronics Industries Association (EIA) and NCTA Joint Engineering Committee, is studying this issue under its work on IS-23, the Interim Standard on the RF cable interface.

The second most likely source of radio frequency interference is created by business band radios, paging systems, and amateur radio operators. These signals leak into the cable system and interfere with cable channels 18 through 22 and channels 23 and 24 (145-175 and 220-225 MHz). It is easy to determine that these signals are caused by an RF transmitter because of the duration of the interference and, sometimes, by hearing the broadcast audio. Since the signals are broadcast intermittently, it is almost impossible to determine the exact location(s) of ingress. Cable systems that operate above 450 MHz may find severe forms of interference. They are subjected to high-power UHF television stations, mobile radio units and repeaters, as well as a group of amateur radio operators signals in the top 10-12 channels. The extreme variation of shortwave signals in time and intensity makes location of the point(s) of infiltration of these signals difficult.

The upstream 5-40-MHz spectrum is a problem for operators who have two-way cable systems. There are many sources of interference and these signals accumulate upstream. In two-way plant, a single leak in the system can make that portion of the upstream spectrum unusable throughout the entire plant; whereas in the downstream spectrum, a leak may only affect a single customer's reception.

2.6 <u>Signal Security Systems</u>

Means of securing services from unauthorized viewership of individual channels range from simple filtering schemes to remote controlled converter/descramblers. The filtering method is the commonly used method of signal security and is the least expensive.

2.6.1 Trapping Systems

There are two types of filtering or trapping schemes: positive trapping and negative trapping. In the positive trapping method, an interfering jamming carrier(s) is inserted into the video channel at the headend. If the customer subscribes to the secured service, a positive trap is installed at the customer's house to remove the interfering carrier. The positive trapping scheme is the least expensive means of securing a channel to which *fewer than* half the customers subscribe.

A drawback to positive trap technology is its defeatability by customers who obtain their own filters through theft, illegal purchase, or construction. Another drawback is the loss of resolution in the secured channel's video caused by the filter's effect in the center of the video passband. Pre-emphasis is added at the headend to correct for the filter's response, but loss of picture content in the 2-3-MHz region of the baseband video signal remains.

Negative trapping removes signals from the cable drop to the customer's home. The trap is needed for customers who do not subscribe. This is the least expensive means of securing a channel to which *more than* half the customers subscribe. The negative trap is ideal. There is no picture degradation of the secured channel because the trap is not in the line for customers who take the service. A drawback occurs for customers who do not subscribe to the secured service, but want to view adjacent channels. These customers may find a slightly degraded picture on the adjacent channels due to the filter trapping out more than just the secured channel. This problem becomes more significant at higher frequencies, due to the higher Q (efficiency) required of the filter circuitry. From a security standpoint, it is necessary for the customer to remove the negative trap from the line to receive an unauthorized service. Maintaining signal security in negative-trapped systems depends upon ensuring that the traps remain in the drop lines.

2.6.2 Scrambling and Addressability

There are two classes of scrambling technologies: RF synchronization suppression systems and baseband scrambling systems.

The concept of addressability should be considered separately from the scrambling method. Non-addressable converter/descramblers are programmed via internal jumpers or a semicon-

ductor memory chip called a PROM (programmable read only memory) to decode the authorized channels. These boxes' authorizations must be physically changed by the cable operator. Addressable converters are controlled by a computer-generated data signal originating at the headend either in the vertical blanking interval (VBI) or by an RF carrier. This signal remotely configures the viewing capabilities of the converter. Impulse-pay-per-view (IPPV) technology is supported by addressable converter/descrambler systems.

2.6.2.1 *RF Synchronization Suppression Systems*

Converter-based scrambling systems that perform encoding and decoding of a secured channel in an RF format comprise the commonly used scrambling technology. There are two basic RF scrambling formats. The more common is known as *gated* or *pulsed* synchronization suppression. With this method, the horizontal synchronizing pulses (and with some manufacturers, the vertical synchronization pulses) are suppressed by 6 dB and/or 10 MHz dB. This is done in the channel's video modulator at the IF frequency. The descrambling process in the converter/descrambler occurs at its channel output frequency. This is accomplished by restoring the RF carrier level to its original point during the horizontal synchronization period. Variations of this method pseudo-randomly change the depth of suppression from 6 dB to 10 dB or only randomly perform suppression.

The other popular format is known as *sine-wave* synchronization suppression. In this format, the scrambling effect is achieved by modulating the video carrier signal with a sine wave. This causes the synchronization to be suppressed, as well as changing the characteristic content of the basic video information. This encoding process is performed at the IF frequency in the channel's video modulator at the headend. The decoding process in the converter/descrambler is accomplished by modulating the secured channel with a sine wave of the same amplitude and frequency as in the headend, but whose phase is reversed.

A phase-modulated RF scrambling technique based on precision matching of surface acoustic wave (SAW) filters constructed on the same substrate has been introduced. This low-cost system is extending operators' interest in RF scrambling techniques for use within addressable plants.

2.6.2.2 *Baseband Scrambling Systems*

Baseband converter/descrambler technology provides a more secure scrambling technology for delivering video services. The encoding format is a combination of random or pseudo-random synchronization suppression and/or video inversion. Because the encoding and decoding are performed at baseband, these converter/descramblers are more complex and more expensive.

Maintenance of the system's video quality is an ongoing issue. The encoders are modified video-processing amplifiers. They provide controls to uniquely adjust different facets of the video signal. The potential for set-up error in the encoder, in addition to the tight tolerances that must be maintained in the decoders, has presented challenges to the cable operator.

A recent extension to baseband video scrambling involves the addition of digitized and encrypted audio to the video signal's vertical and horizontal synchronization pulse intervals. While there are issues of Broadcast Television Systems Committee (BTSC) stereo compatibility, providers of these products claim that the combination of video scrambling with audio encryption provides the highest degree of security that can be afforded by the industry.

2.6.3 Off-Premises Systems

The off-premises approach is compatible with recent industry trends to become more consumer-electronics friendly and to remove security-sensitive electronics from the customer's home. This method controls the signals at the pole rather than at a decoder in the home. This increases consumer-electronics compatibility since authorized signals are present in a descrambled format on the customer's drop. Customers with cable-compatible equipment can connect directly to the cable drop without the need for converter/descramblers. This allows the use of all VCR and TV features.

Signal security and control in the off-premises devices take different forms. Nearly all off-premises devices are addressable. Specific or all channels are controlled remotely. While there were several attempts to take modified addressable converter/descramblers and enclose them on the pole, this approach was not successful. The system was costly and less consumer friendly than having the converter/descrambler in the home because it delivered only a single

channel at a time to the entire residence. With the growth in the number of multiple TV and multiple VCR homes, this is an unacceptable limitation.

Interdiction technology involves a scheme similar to that of positive trap technology. In this format, the pay television channels to be secured are transported through the cable plant in the clear (not scrambled). The security is generated on the pole at the subscriber module by adding interference carrier(s) to the unauthorized channels. An electronic switch is incorporated allowing signals to be turned off. In addition to being consumer-electronics friendly, this method of security does not degrade the picture quality on an authorized channel.

2.7 The Signal and the Customer's Equipment

2.7.1 Signal Splitting at the Customer's Premises

The common devices at the cable drop to the customer's home are grounding safety devices called *ground blocks* and a two-way signal splitter that sometimes has a built-in grounding terminal.

Some systems use ground blocks or two-way splitters that incorporate a high-pass filter. These filters are used in two-way plant to minimize RF ingress into the cable plant in the 5-40-MHz reverse (upstream) spectrum. These filters have a low enough crossover frequency not to cause group delay in the downstream video channels.

Splitters or ground blocks should have little effect on picture quality provided there is adequate signal to handle the splitter's loss. The signal strength may be below specifications due to an excessively long drop or more activated cable outlets in the house than the cable design anticipated. To compensate, some systems use an AC-powered drop amplifier. These amplifiers can create problems – a reduced CNR or increased distortions.

consumer-electronics switching devices, designed to allow convenient control and routing of signals between customer products and cable systems' converters/descramblers, have built-in amplification stages to overcome the losses associated with the internal splitters. These amplifiers add distortions or noise. When most cable systems were designed, consumer-electronics switching devices were not taken into account because they did not exist.

Signal splitting in VCRs can be a problem. To compensate for recording SNR deficiencies, inexpensive VCRs sometimes split the signal unequally between the bypass route and the VCR tuner. This gives the VCR a stronger signal than the TV receiver to improve VCR performance. In addition, this strategy reduces the quality of the signal routed to the TV. When it is compared with VCR playback, the disparity in performance is reduced.

2.7.2 Consumer-Electronics Compatibility

About 12 years ago, a Joint Engineering Committee (JEC) was formed under the sponsorship of the EIA and the NCTA. The purpose of the JEC was to bring together technical representatives from the cable and the consumer-electronics industries to attempt to find ways to make cable service and consumer-electronics products more compatible. It was soon recognized that the cable subscriber and the consumer-electronics customer were one and the same. In order to better serve that customer, cooperation between the two industries was necessary.

The two industries had, for decades, evolved slowly, but without coordination. As technology began to accelerate, a serious divergence became apparent. It was the consumer who ultimately suffered. The high-minded goal of improving the situation for the consumer ran into a few practical problems.

On the consumer side, costs were very critical issues. Additional expense is hard to recover in higher prices because of the extreme competitiveness of that industry. That competitiveness is a consequence of the ability to produce larger quantities of very reliable, high-quality products than the marketplace can easily absorb. This over-capacity makes price almost impossible to sustain, much less raise. The nature of technology is such that it is impossible to contain it. Any technical advance quickly spreads throughout the industry, making differences between most brands difficult for the consumer to distinguish.

On the cable side, technology made possible experimentation in new services and the expansion of channel capacity. Many of these experimental services fail. Because these services are offered in set-top boxes owned by the cable operator, the consumer is protected from financial loss when service experiments end-up in disappointment. Additionally, the basis of subscription service is the ability to deny that service to those who choose not to pay. If service is easily available to all, few will pay. Without payment, programming cannot be purchased and

those who create that programming cannot be compensated. So signal security is critical to the delivery of subscription services.

Early on, it was clear that three things were needed:

1) A channel plan vs. frequency

2) Tuner specifications

3) A decoder interface

With these three elements, much of the difficulty could be resolved.

A major feature of cable television is its self-contained spectrum. Because this spectrum is isolated from the spectrum in the environment, the usual restrictions placed on broadcast television do not apply. The entire spectrum can be filled with television signals. Early cable practice utilized a variety of methods for labeling these channels. This diversity made it difficult to use a common labeling scheme for consumer-electronics products with extended tuning range. A frequency plan was necessary to allow common nomenclature.

These cable signals can be very well-controlled in their relative strength. This is in sharp contrast to broadcast signals. To prevent broadcast co-channel interference, channels are spaced. The VHF and UHF bands have gaps where others have claim on the spectrum. It is common for the broadcast tuner to attempt to tune a distant weak signal centered between nearly adjacent strong local signals. Thus the demands on tuners designed for broadcast and for cable are very different. It is difficult to make a tuner that performs well in both situations.

A most serious difference in the requirements of tuners designed for cable and those designed for broadcast is the issue of direct pick-up. A broadcast tuner needs minimal shielding. The spectrum being tuned is only occupied by the broadcast signal. A cable tuner has another problem. Because the propagation speed through cable is about two-thirds that of free space, the broadcast signal arrives at the TV first. A few microseconds later, the cable signal arrives. If the tuner directly responds to the over-the-air signal, the two signals will be mixed and interference will result. The solution to this problem is covered by a now-expired U.S. Patent, the Mandell patent. The cable signal is selected by a tuner specifically designed for the purpose. It is well-shielded and has the ability to discriminate against immediately adjacent channels. One constraint is relaxed. Signal levels across the tuned band differ only slightly in level.

This tuner's output is converted to a single channel chosen to be one not used locally. There-fore, there is no off-air signal to be directly picked up by the TV and mixed with that delivered by the cable system. The problem of direct pick-up is solved only because the output of the converter is a single channel on a frequency not used locally.

The use of the set-top converter solves one problem, but makes the TV's tuner useless. Those features that depend on the tuner are also made inoperable. In particular, the remote control that came with the TV or VCR is only used to turn those devices on and off. The set-top's remote control changes channels. In the case of the VCR, the timer which changes channels is crippled because it cannot change the channels of the converter. Taping different channels consecutively becomes impossible.

In order for a "cable-ready" TV or VCR to provide acceptable performance when connected to cable, it has to have a minimum amount of shielding to make it immune to direct pick-up interference. Also, it must not radiate spurious signals up the cable. These signals can come from the local oscillator or from the harmonics of all of the digital signals that provide on-screen displays and drive other features. These signals can cause interference to other receiv-ers in the same residence or in adjacent residences if they are allowed to enter the cable. All of these issues have been covered by a cable RF specification.

Cable's requirement for signal security caused the need for set-top boxes to move beyond mere frequency conversion. It took on the function of descrambling signals in the early 1980s. Even if a "cable ready" TV or VCR were designed with adequate tuning range, adequate shielding against direct pick-up, and the ability to handle a full spectrum of adjacent signals without overload, it might still require a set-top descrambler. This would duplicate the cir-cuitry in the TV, provide slight additional signal degradation, and interfere with certain fea-tures built into TVs and VCRs. The solution to this problem was the decoder-interface connector. This was a 20-pin connector on the back of TVs and VCRs that brought video and audio signals out of the consumer-electronics product for external processing. The descram-bled signals were returned to the consumer-electronics product for display or recording. The decoder-interface connector was given the name "MultiPort" by the EIA because it was envi-sioned to have multiple uses. The main advantage of the MultiPort was that it made scram-bling nearly transparent to the user. Cable subscribers loved it. Somewhere between three

hundred thousand and a million TVs were produced with the plug. Several thousand descrambler plug-ins were made. However, only certain segments of the cable industry promoted the MultiPort. Much of the rest of the industry experienced so few complaints from subscribers that they didn't feel motivated. Additionally, many of these cable operators were enjoying a healthy revenue stream from the rental of remote controls. Since the MultiPort didn't need an additional remote control, that revenue stream was threatened. Another practical problem was locating consumers who bought MultiPort-equipped sets. The consumer-electronics industry lost patience. They did not promote the feature and most consumers who acquired these products had no idea what they had purchased. To this day, there are several hundred MultiPort plug-ins still in cable operator inventories. Knowledgeable installers call this to the attention of subscribers when they stumble across an old MultiPort TV. This results in a happy customer.

In an attempt to improve upon and formalize the MultiPort, the JEC created a standard that was adopted by the American National Standards Institute (ANSI). It is called the ANSI/EIA 563 Decoder Interface Standard. Even though it was a closely related cousin to the MultiPort, this standard was never implemented in products sold to the public.

Then, Congress passed the 1992 Cable Act that has far-reaching implications for cable system operation and economics. An amendment to the Cable Act requires the FCC to create rules with the intent of improving the compatibility between consumer-electronics products and cable operations. These rules regulate the conditions under which scrambling can be employed and provide a technical definition for "cable-ready" products. That definition included the channel plan created by the JEC, specifications on tuner performance, and the inclusion of a decoder-interface connector. Products that do not comply with the Commission's technical specifications cannot be sold as "cable ready," "cable compatible," or under any other term that might mislead consumers.

Cable operators will be required to provide plug-in modules for those subscribers who have "cable ready" products and request the modules. Cable service will have to be compatible with the decoder interface.

The technical details of the decoder interface are many and complex. The JEC and its subcommittees continue to struggle with them. Progress has been made, but it has been difficult. As complex and difficult as the decoder interface has been, the digital television future presents even more interesting challenges. The technology is still embryonic. It is evolving at a rapid pace taking advantage of the fact that we now can afford to put well over a million transistors into consumer products to process signals. Additional millions of transistors can be included in memory elements. This tremendous processing power offers a wide variety of options for digital video compression and new interactive and multimedia services. The biggest unknowns center on the consumer. Which services will find acceptance? How much tolerance exists for the new and different digital artifacts that this new signal processing brings?

As we consider setting standards for these new digital services, we must keep a few things clearly in mind. First, we must never do anything that inhibits experimentation in new services. This experimentation and risk-taking is what gives the marketplace an opportunity to evaluate new services. Those services are rewarded with success and become candidates for standardization or are rejected and fall to the scrap heap of bad ideas. In the latter case, years of standardization meetings, non-reoccurring engineering costs, and tooling costs are avoided.

The very nature of digital systems accommodates the ability to do something in software and to allow digital components to be reconfigured electronically. Thus, closely related, but not necessarily identical, approaches can be handled with little or no extra cost. This was not easily possible in the analog world. As more functionality is absorbed into software-based systems, the need for a single strictly enforced standard is diminished. Multiple approaches and self-adaptation will ease the burden.

Another issue becomes important as we move towards subscriber ownership of the electronics that implement services, that is, in most cases, the set-top box. In the old paradigm, the service provider answered questions and supplied training in the use of the equipment. The equipment was repaired at no additional cost. If the service failed to enjoy sustaining support, the cable operator absorbed the equipment loses. In the new world of subscriber ownership, the retailer and manufacturer of the equipment must stand ready to answer questions on usage and provide training and repair. The consumers' expectations must be adjusted to accept situations in which the equipment becomes no longer useful because the service failed or was replaced

with a improved version. The cable operator will no longer be absorbing the losses since the equipment is no longer his.

An additional complication arises. If subscriber-owned set-top boxes introduce interfering signals into the cable system, they will have to be disconnected. If the subscriber insists on using them, that subscriber will have to be disconnected. There will be charges for service calls to solve these problems. Consumers will be angry when the hardware they purchase cannot be used on the cable system because of interference it may cause.

As we read the trade press, we see a massive interest in set-top boxes for interactive television, multimedia, the NII, telco-provided video, etc. These set-top boxes will make it possible for consumers with older TVs and VCRs to try out new services and new service providers. They will allow purchasers of new, inexpensive TVs and VCRs to participate in these new services.

An open and fully functional decoder-interface standard is needed if consumers are to enjoy consumer-electronics products that give access to these new services. It will be in nearly everyone's best interests to facilitate a situation where consumer-electronics products can accept plug-in modules giving equal and open access to these new services and service providers. Failure to do this will make the set-top box the only choice consumers have for participating in new services and subscribing to new service providers.

2.8 High-Capacity Cable Systems

2.8.1 The Hybrid Fiber Coax Architecture and Digital Video

The two main drivers of current progress in cable are the hybrid fiber coax (HFC) architecture and digital video. These have changed cable from a stable, well-understood, even stale technology into something with massive possibilities and choices.

In the early 1990s, the vision of what fiber in the cable plant could accomplish inspired the cable industry to dramatically upgrade its physical facilities. Much of that work has already been done. More is underway. The current vision driving progress in the cable industry is digital video compression (DVC). In the mid-to-late 1990s, DVC will facilitate massive increases in the amount of programming cable can deliver.

2.8.1.1 *The Hybrid Fiber Coax Architecture*

A cable system can be considered to be made up of three main parts: the trunk, the feeder, and the drop. The trunk is intended to cover large distances, up to 10 miles. When the trunk is made of coaxial cable, amplifiers are required about every 2,000 feet. Surprisingly, the trunk portion of the cable plant only covers about 12% of the total footage. The feeder portion of the cable system supports taps for subscribers. It has a maximum length of about a mile and a half. This limitation comes from the fact that energy is tapped off to feed homes. Consequently, the power levels must be relatively high. These higher power levels reach into the slightly nonlinear regions of the amplifiers. As a result only a few amplifiers can be used before the distortion begins to degrade the picture quality. Approximately 38% of the total footage in a cable system is in the feeder portion of the plant. The drop is the flexible cable which goes to the home. It has a maximum length of 400 feet. Typically, it is more like 150 to 200 feet in length. Approximately half of the total footage of cable in a system is in the drop and the flexible wiring in the home.

The feeder portion of the cable plant is a hotbed of activity. Every day new subscribers are added and others are removed. Approximately 20% of Americans move to a new residence every year. When they move out, the drop is usually disconnected. When they move to their new residence, the drop must be re-connected. It is important that the technology used in the feeder portion of the trunk supports this constant activity. It must be "craft-friendly;" that is, it must be easy with which to work. The trunk portion of the cable plant is relatively stable. There are very few changes made.

The lasers that drive the fibers are expensive, costing many thousands of dollars. The receivers that convert the optical energy into signals TVs and VCRs can use are also relatively expensive. To be practical, these components must serve hundreds of subscribers each so that the costs can be shared. This is accomplished by fibers that feed small coaxial systems, which in turn serve a few hundred to a couple thousand subscribers.

The HFC architecture has made it possible to cost effectively increase bandwidth, signal quality, and reliability, while reducing maintenance costs and retaining a craft-friendly plant. It makes two-way service practical. The bandwidth of coaxial cable has no sharp cutoff. It is the cascade of amplifiers that limits the bandwidth. Twenty to 40 amplifiers in cascade not only

reduce bandwidth, but also constitute a severe reliability hazard. Overlaying low-loss fiber over the trunk portion of the plant eliminates the trunk amplifiers. This in turn leaves only the distribution portion of the plant with its relatively short distances and only two or three amplifiers. Wider bandwidth is thus facilitated. Two-way operation becomes practical for two reasons. First, the fiber itself is not subject to ingress of interfering signals. Secondly, the cable system is broken up into a large number of small cable systems, each isolated from the others by its own fiber link to the headend. If ingress should cause interference in one of these small cable systems, that interference will not impair the performance of the other portions of the cable plant. The Time Warner Quantum cable system has been in operation for several years at 1.047 GHz and 150 analog channels.

Today it is common practice to install passive components (taps, splitters, amplifier housings) that will pass 1 GHz. Actual 1-GHz amplifiers are still too costly. However, some systems are being built "GHz ready" so that the addition of GHz amplifier modules will upgrade the system with little waste of installed plant. While GHz capability is a future possibility, 750 MHz upgrades are commonplace today.

The fiber-backbone approach breaks the cable system into a multitude of much smaller cable systems with amplifier cascades limited to four to six amplifiers. Each of these small cable systems is fed with a fiber link to the headend. (See Figure 2.5.) The advantages include significantly lowered vulnerability to amplifier outages, reduced bandwidth restrictions and noise buildup due to amplifiers in series, and greatly reduced ingress. The latter effect makes two-way cable practical. A major attraction of the fiber backbone is that its implementation cost is low. Fiber is "overlashed" onto the existing trunk plant. The in-place cable is broken into segments and used for the small-scale cable systems. Some of the amplifiers are reversed in direction. Nothing is wasted.
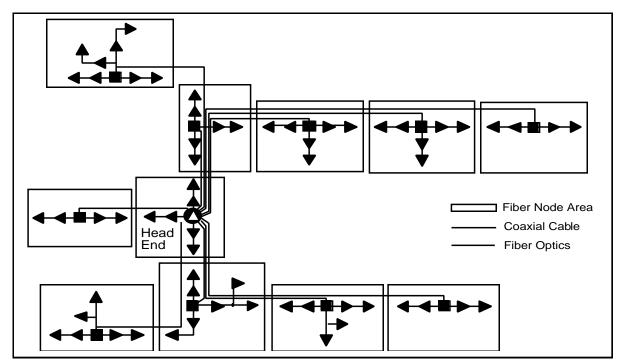
FIGURE 2.5 - CABLE SYSTEMS WITH FIBER OPTIC BACKBONE TRUNK

If we now turn our attention to the distribution plant, we find that we must run higher signal levels to support the tapping of energy to serve drops to customers. The higher signal levels mean that we begin to reach into nonlinear areas of the amplifier's operating characteristic. Nonlinear distortion builds up. In addition, the taps are not perfectly impedance-matched to the cable. Consequently, the signal is reflected back and forth between the taps resulting in a smearing of the picture. This phenomena is called micro-reflection for two reasons: The strength of the reflection is low, and the time delay of the reflection is short.

Rogers Cable Systems Ltd. of Canada has suggested the answer to these difficulties. They have called their technique "super distribution," also known as express feeder. In one form of its implementation, line-extender amplifiers are structured to have up to three hybrid amplifier chips. One feeds the next line-extender amplifier, one feeds half of the taps back to the previous line extender, and the third feeds half of the taps to the next line extender. The existing tapped feeder cable is cut in half between line extenders. New, untapped cable is overlashed to connect line extenders. The consequences are that the signal level between amplifiers is lower since that cable is not tapped. The signal level on the tapped runs is lower because they are shorter. Non-linearities are reduced and they do not build up as in the previous structure. Also, signal leakage may be less of a problem because of the lower signal levels. In addition, the number of taps in series in any cable is drastically reduced, thereby reducing the amount of

micro-reflections experienced by any one subscriber. This technique effectively cures the ills of the distribution portion of the plant. See Figure 2.6.
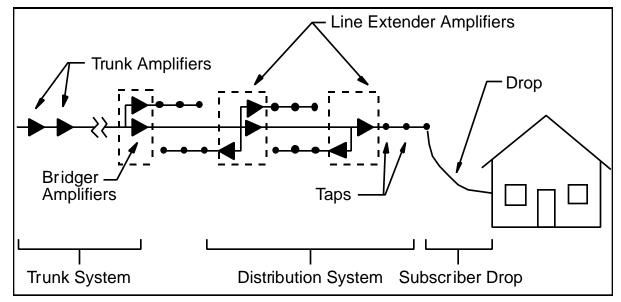
FIGURE 2.6 - "SUPER" DISTRIBUTION PLANT

With fewer amplifiers in series, the constraints on their design and operation are reduced. Higher bandwidths become practical.

2.8.1.2 *Digital Video Compression*

Digital video compression (DVC) along with digital modulation has given massive capacity to the cable spectrum. DVC gained its first momentum in the pursuit of HDTV – also called advanced television (ATV). The analog bandwidth of signals from an HDTV camera consist of something like 30 MHz each of red, blue, and green. Nearly 100 MHz of analog signals would require more than a gigabit per second for straight digital transmission. The FCC, which sets federal regulations on spectrum usage, only allows 6 MHz. As a result, there is a need to remove a lot of the redundancy in the picture. In fact, the HDTV signals have been squeezed into the 6-MHz channel. The question was asked, can the same technology be used to squeeze multiple standard-definition signals into the same 6 MHz. The answer, of course, is in the affirmative. When DVC is used to put multiple current quality signals into 6 MHz, the result is called standard definition television (SDTV).

In fact, the American consumer is likely to be more interested in SDTV than in HDTV because, given a choice, Americans generally pick "more" over "better." As an example, consider the mode switch on the videocassette recorder. In the two-hour "standard play" mode it

yields noticeably better video and dramatically better audio than in the six-hour "EP" mode. Yet consumers continue to use the "extended play" mode so they can get more out of their less-than-two-dollar blank video tapes!

DVC is in use by consumers now in the direct broadcast satellite (DBS) environment. Both DirecTV and PrimeStar are using a version of the Moving Pictures Expert Group (MPEG) standard. DVC compresses signals by removing redundancy in each still picture, by removing redundancy between the series of still pictures that make up a motion sequence, and by deleting those aspects of the image that have minimal visibility to the human eye. As an example of the latter, the human eye is more sensitive to horizontal motion than to vertical motion. It is even less sensitive to diagonal motion. This is likely because in the distant past, when we were hunters (and were hunted), most prey and most predators moved in the horizontal direction. Little food-capturing activity took place vertically or diagonally. As a result, those of our ancestors who had better visual sensitivity to horizontal movement, ate well. Those who didn't were eaten and did not pass on their genes as effectively. Sensitivity to vertical and diagonal motion did not have the same Darwinian influence.

It is commonly felt that movies may eventually be digitized effectively at a three mega-bit-per-second (Mbps) rate while live video may require 4 or 5 Mbps. Data rates currently used in market trials are somewhat higher because of the preliminary nature of the equipment. Once full MPEG-2 decoders for the home and more integrated digital video compressors for the signal source become available, data rates should be lowered at least a little more. The reasons for the lower data rate with movies stems from two main factors. First, movies have a 24-frames-per-second rate, while video has 30 frames per second. Motion reproduction in video is better than in movies. But, there is a 25% increase in data required for the same image quality. Secondly, movies can be processed in non-real time. This means that they can be iteratively processed. The compressor parameters can be adjusted on a scene-by-scene basis. Much more processing can be brought to bear since the computations do not have to be done "in real time."

The other factor that determines the packing density of movies in the 6-MHz television channel is the modulation method. The two main competitors are quadrature amplitude modulation (QAM) and vestigial sideband (VSB) modulation. These come in various data-speed capaci-

ties. The two most interesting for cable applications are 256-QAM or 16-VSB. Both are "double data-rate" systems in that they operate at about double the data rate required to deliver one HDTV signal in 6 MHz. The Advanced Television Test Center (ATTC) completed tests of 16-VSB on cable in Charlotte, North Carolina. The 16-VSB system tested delivered 38.5 Mbps in all locations. Some older cable systems were included in the tests. The longest amplifier cascade was forty-eight. Fiber links and microwave amplitude modulated links (AML) were also included. 256-QAM is expected to be able to deliver similar results. Thus, it is possible to transmit 12 DVC movies in 6 MHz at 3 Mbps. Cable operators in the U.S. are deploying 64-QAM because it maps one 27-MHz satellite transponder capacity into one 6-MHz channel.

Current thinking is to allocate the lower end of the downstream cable spectrum to analog signals. This covers the 50 to 450 MHz (or 550-MHz) frequencies. A basic unscrambled tier of broadcast signals would be at the low end of the spectrum. At higher channel numbers, trapped pay services or analog scrambled services would be supplied. Above 450 or 550-MHz, digital signals would be provided to the band edge located at 750 MHz or 1 GHz. Thus, from 200 MHz (33 six-MHz channels) to 550 MHz (91 six-MHz channels) will be available. With 12 movies per 6 MHz, 396 to 1,092 movies may be offered simultaneously. Of course, digitized video signals (rather than movies) also may be offered by reducing the total number of programs.

2.8.2 Competition

The combination of HFC and DVC has dramatically and completely changed the course of cable's evolution. An important *reality* that must be appreciated in creating the next vision of cable's future is that technology cannot be contained. The nature of technology is that it is available to all who wish to apply it. Thus, the HFC architecture has been adopted by most in the telephone industry as a practical approach. "Fiber to the home" has essentially been abandoned. Likewise, DVC is available to all who wish to compete with cable. From the consumer's perspective, it's the programming that matters. The delivery mechanism and the industry delivering the programming are secondary as long as certain minimum standards of signal quality, reliability, and cost are maintained.

One of cable's main advantages in the past has been **massive capacity** due to a wider bandwidth than is available to most potential competitors. DVC makes much of that advantage

available to many potential competitors by more efficient utilization of whatever bandwidth those competitors have available.

The fact is that cable has never been a true monopoly with competition precluded by law. The cable franchise is almost always non-exclusive. Those who consider cable to be overly profitable were always able to gather up investors and build a second or third cable system and compete. This has been attempted in a number of situations only to result in financial losses in most cases. It's only human nature to believe that "the grass is always greener on the other side." There have only been a few instances of success following this course of action.

Except for building a second cable system, there really was no effective method of deploying direct competition to cable before DVC. Cable's high bandwidth gave it so much programming that other delivery means were anemic in comparison. DVC changes that. Now it is possible for a competitive service to be launched with sufficient programming to be a reasonable alternative even with less available actual bandwidth.

Video delivery competition comes from several sources:
- Direct broadcast satellite
- Telephone plant delivering video
- Alternative cable plant builders
- Cellular TV
- Microwave Multipoint Delivery System (MMDS)
- Broadcast
- Physical distribution.

The vision of cable in the late 1990s has to include the reality that government regulation will play a bigger role. That role will limit what can be done and how it can be financed. It also will affect the way competitors behave and will change the balance between cable and its opponents.

It is interesting to note that the owners of DirecTV made it clear that they would not launch their service unless they had access to cable's programming. It was the 1992 Cable Act that forced cable to share its programming with competitors. This programming was developed

and financed by cable investors and subscribers. Only this forced sharing of cable's programming made cable's competitors viable. From a public policy point of view, it might have been more prudent to require cable's competitors to develop their own programming. Then consumers would have choice in programming rather than just in the delivery mechanism. Since it is programming that consumers want, wouldn't they be better off with more of it to choose from rather than the same thing delivered in different ways? Some might argue that it would not be possible for competition to develop if it had to repeat cable's arduous path of program development, investment, and infrastructure construction. The answer to that objection doesn't take a lot of imagination. If the framers of public policy put in a *temporary access with a fixed phase-out*, cable's competitors could use cable's programming to get started and then have a gradual period of time to develop their own alternatives. In that way, consumers would eventually have more from which to choose. Competition in programming would give consumers more variety, exposure to different ideas, pressure for better quality, and lower prices. These forces are now at work *only* in the delivery mechanism. They have not been applied to the programming itself. And it is programming that consumers want, not necessarily high-tech delivery.

2.8.3 Video Services

There appear to be three kinds of visions for video service under discussion:

    1) Video Electronic Publisher
    2) Video Common Carrier
    3) Video Internet.

These three visions vary considerably in how practical they are and how closely they approach reality.

2.8.3.1 *Video Electronic Publisher*

The Video Electronic Publisher is the model of traditional cable television. The cable operator selects programming thought to be of interest to subscribers and packages it in convenient form. A selection of local off-air channels, satellite delivered programming, and local origination is divided into tiers. If the cable operator selects and packages programming that interests the subscriber, the reward is acceptance and profits. If the programming does not please the subscriber, the result will be financial difficulties.

This service is a broadcast service in that all subscribers get essentially the same programming. A possible exception is that in some cases, special ethnic programming is delivered on a neighborhood-by-neighborhood basis. This takes advantage of the fact that several different trunk lines leave the cable headend and go to diverse geographic areas. The signaling is mostly one-way. The only need for two-way is for the ordering of impulse-pay-per-view (IPPV) programs. Spectrum is scarce. There are more than 100 programs that could be packaged and delivered via satellite to subscribers. Other ideas for new channels arise continuously. In the analog world, there is only capacity to carry about 80 total channels. After local broadcasters and other mandated channels are accommodated, there is room for only around 60 of these satellite delivered programs.

This service is not "lifeline." There is no fundamental need for it. Just as with magazines and newspapers, subscription is voluntary. While this service passes 95% of U.S. television households, only 63% actually subscribe. That comes to 59 million subscribers who paid average rates in 1993 of $20.75 for basic service and $10.48 for premium pay. About 20% of U.S. households move every year. These families must be re-marketed when they move into their new residence.

This cable service consists of several levels. Basic service includes all of the mandated broadcast channels plus the Public, Educational, and Government (PEG) channels required by the local franchise. The 1992 Cable Act requires that these channels be unscrambled. A group of tiers can then be created out of the satellite delivered channels. The tiers can be as simple as just one cluster or a set of clusters based on genre of programming. When a set of channels is offered on an individual channel basis, that service is called "à la carte." At the next level are pay channels such as HBO or Showtime. These are premium channels with a substantially higher price. They are sold on a monthly subscription basis. Next are IPPV channels that sell individual program viewings. These consist mostly of movies, but also include concerts and sporting events. A special case of IPPV is true video on demand (VOD) or near video on demand (NVOD) to be discussed below in more detail. Then there are the new multimedia and interactive services that are considered part of the NII.

The 1992 Cable Act has given broadcasters new rights. Broadcasters are allowed to choose between "must-carry" status or "retransmission-consent" status. Must-carry status means that

the broadcaster's signal must be carried on the channel number the broadcaster selects. That selection is made from those channel numbers occupied on two specified dates or the broadcaster's own channel number. Selection of must-carry status foregoes any right to compensation for the signal. Alternatively, broadcasters can choose retransmission-consent status which precludes cable carriage without the consent of the broadcaster. The broadcaster and the cable operator negotiate on the terms. Broadcasters can change their status every three years.

Margins are the revenue minus the cost of the service. Margins are highest for basic service because the cost of the programming is the lowest. Promotional and transaction costs are also the lowest. Margins are lower for satellite services because there are monthly fees that must be paid per subscriber. While they range from pennies to perhaps a half a dollar, the costs add up for the number of channels involved. Pay services require payments of usually just under half of the revenue to the pay-service provider. In addition, promotional costs are larger because consumer resistance is higher due to the price. Transaction costs are greater and there is a need to provide some form of signal security so that subscribers who do not elect to pay for the service do not receive it. As a consequence, margins for pay service are lower. IPPV service has higher costs. The studio that supplied the movies or the source of the event usually wants half the revenue plus a guaranteed minimum. Additionally, these sources of programming are more concerned about the security of their signal than the conventional programmers. This kind of programming has high per-program promotional and transactional costs as well. Margins can be rather thin. As more advanced forms such as NVOD or VOD are considered, margins become even thinner. Multimedia and interactive services will likewise be more costly to produce, promote, and administer. Simple cable systems that have only basic, perhaps one tier, and pay services in 60 or so channels have overall margins of about 45% to 50%.

Past cable practice involved requiring subscribers to march through the ranks of services and take them in order of decreasing margin. Thus pay might be available only to those who took a tier of satellite channels. IPPV might be available only to those who took at least one pay service. The 1992 Cable Act has given subscribers new rights. Where it is technically feasible, subscribers are only required to take the basic service to have access to any other service. This is called "anti-buy through." The requirement to buy through the layers is forbidden. In 10 years, "anti-buy through" will be required of all cable systems. It is now required only of those which are fully supplied with addressable equipment.

2.8.3.2 *The Video Common Carrier*

The Video Common Carrier model is sometimes called "video dialtone." As can be assumed from its name, this is the kind of service proposed by many telephone operators. While originally "fiber to the home" was proposed, all such projects now involve an HFC architecture. Like the Video Electronic Publisher model, this model has a portion of its programming that is essentially a broadcast service. Everyone gets the same signals in this part of the Video Common Carrier service. The main difference is that the video dialtone provider does not have any editorial control over what is presented. In principle, enough capacity is provided so that any programmer who wishes carriage can have it on a non-discriminatory basis. The Video Common Carrier model is mostly one-way downstream signaling with a small upstream capacity for ordering programming.

The second portion of the Video Common Carrier model includes subscriber selection of programming either through a NVOD or a VOD approach. VOD implements the full promise of video dialtone.

There are some proposals to use asymmetric digital subscriber Line (ADSL) technology with switching. A relatively low bit-rate signal is switched onto the subscriber twisted-pair copper loop based on a very low bit-rate request signal sent to the point of origination. In this model, no common services exist. All services are specifically requested one at a time. Decompression converts the digital signal into a form suitable for display on consumers' TVs and VCRs.

2.8.3.3 *Video Internet*

The Video Internet is the most "visionary" and least practical approach of all. It envisions a symmetrical capacity in both directions. Subscribers can obtain all the normal cable services plus they can originate programming and send it to those who would wish to view it. This is the most expensive of the three service models and has the least in common with the cable plant already installed.

The Video Internet requires digital video switching and symmetrical or near-symmetrical signal capacity. The costs of implementing this kind of service will be very high. Unlike the current Internet service, whose costs are partially government supported, the Video Internet

would be expensive to use. It remains to be seen if consumers will find these services of enough value to be willing to pay the price that suppliers would need to ask.

An interesting irony exists when digital video and digital voice services are compared. People watch video for hours and video requires mega (millions of) bits per second. People talk on the telephone for minutes and voice requires only kilo (thousands of) bits per second. The ratio of the number of bits needed for telephony compared to the number of bits needed for video is in the range of hundreds of thousands. If "bits are bits" and their transport and switching comes at a given cost, either digital video will be incredibly expensive and digital voice affordable or digital video will be affordable and digital voice essentially free! If this is not the case, then the "bits-are-bits" paradigm must be somehow violated.

2.8.4 VOD vs. NVOD

A major choice to be made is that between VOD and NVOD. Here is where the practicality and the reality of the vision of the Information Superhighway come into stark contrast. The greatest unknown is what does the consumer want and what is he/she willing to pay.

VOD is any video, any time, with full virtual VCR functions. That is, the ability to do stop, fast forward, rewind, pause, slow motion, etc. It doesn't take too much to realize that this is essentially impossible. There must be some compromises. The question is how much compromise will be acceptable to the consumer? What is the consumer's desire in the trade off between cost and convenience?

NVOD is an engineering approximation to VOD. It is based on the Pareto Principle which states that most of the desire for video will be for the most popular titles. Perhaps 80% of all demand will be for the top 20% of titles – perhaps for even fewer. So the first engineering approximation is to limit the number of titles. The next is to limit the frequency of access. Rather than allow everyone instant (or near-instant) access to the video of their choice, the most popular movies will be stagger started on several channels. In the Time Warner Quantum system in Queens, New York, the top five movies were started on a staggered basis about every half hour. Thus, the maximum wait time for a top movie to start is a half hour. The average wait time is 15 minutes. Since they were approximately two hours long, each of these

movies required four channels. The Quantum cable system has 1 GHz of bandwidth and 150 analog channels.

With compressed digital video, it is possible to offer many more movies with much more convenient start times. The target for wait times in NVOD is to make most of them slightly less than the time to drive to the video store. An example can be illustrative:

Consider a cable system with a 750-MHz maximum frequency. The range of frequencies from 50 MHz to 450 MHz is allocated to ordinary analog television. (Below 50 MHz, the system is used for upstream communications.) This 400 MHz of spectrum contains 66 analog 6-MHz channels. This would make a fine ordinary cable service.

The 300 MHz from 450 to 750 MHz contains 50 channels of 6 MHz each. If we are able to compress movies into 3-Mbps data streams and if we use a modulation scheme such as 16 VSB, 256 QAM, or 64 QAM, which have payloads of 38.5, 38.5, or 27 Mbps respectively, we'll be able to carry 12, 12, or 9 movies respectively in each 6-MHz frequency slot. Since there are 50 of these slots, there's a total of 600, 600, or 450 virtual channels respectively for movies.

Consider offering the top 10 movies (each approximately 135 minutes long) on 12 virtual channels each. This makes the stagger time 11.24 minutes and occupies 120 total virtual channels. Now put the next 20 most popular movies on eight virtual channels each for a repeat time of 16.9 minutes that will use up 160 channels. Put the next 40 most popular movies on roughly half-hour repeats (like in the Quantum system). That will take four channels each and occupy a total of 160 channels. Take 60 more movies and repeat them continuously in 60 more channels. We have 130 movie titles occupying 500 virtual channels. This leaves us with 100 channels.

In the remaining 100 channels, all analog scrambled signals will be duplicated in the digital format so that a digital subscriber doesn't need any analog processing. This will likely take another twenty channels. This leaves eighty channels for continuous repeat of short subjects such as shopping channels dedicated to single categories each.

This provides a tremendously convenient and comprehensive service with no switching and no complex headend server. The headend is a rather straight forward playback center.

2.9 The Information Services

2.9.1 PC vs. TV and Interactivity

There is a great deal of debate about what the consumer of the future will expect in a television set. Those from the computer industry want to build TVs into personal computers (PCs) and those from the consumer-electronics industry want to build PCs into TVs. Of course, the whole world seems to want to put PCs into set-top boxes.

A few moments of thought about how these products are used should shed some light on what evolution is likely to be supported by consumers. All one needs to do is recall how it feels to be in the family room watching TV with someone who has a remote control in hand and is flipping channels. It is extremely annoying. Certainly, this is the lowest level of interactive television. Anything more interactive will be intensely aggravating to others in the room. The conclusion seems to be that interactive television is an individual activity.

Now consider the information-packing density of the television screen. The television technical standard can just barely support text consisting of 40 characters across and 20 rows. That is woefully inadequate for anyone who has used modern PCs. The input device for a television set, the remote control, is also very limited. It is easy to conclude that the proper instrument for serious information highway work (or play) is the PC.

The user of the personal computer is accustomed to upgrading performance, to spending a few hundred dollars on software or hardware modules, and to monthly subscriptions to on-line services costing $10-$20. The average personal computer user spends thousands of dollars on the hardware and software and sees great utility from this. There may even be a motivation of providing learning opportunities for the children.

Contrast this with the average TV and VCR user. They have spent not thousands but mere hundreds of dollars for their equipment. That equipment has relatively low resolution, low speed, and has few other capabilities. These are the consumers who complained bitterly about monthly cable bills of around $20 for basic and $10 for premium service. The average TV

lasts 12 to 15 years and the average VCR about five years. They are not upgradeable in any way.

The TV and VCR are likely to be used when the day is done and there is no more energy left and it's "wind-down" time. For most people interested in or capable of "interactivity," the personal computer is where it's done. Even when these highly interactive people turn on their TV or VCR, it's because they have no more energy to interact with anything! They just want good passive entertainment.

2.9.2 The Electronic Program Guide, Interactivity for the Common Man

While we have concluded that the interactivity vision is primarily a PC activity, there are a limited number of very appropriate interactive applications the consumer will likely want for the TV receiver and VCR. By far the most promising is the electronic program guide (EPG). The EPG is most appropriate because it fits the TV and VCR application. It helps the consumer navigate through the multitude of channels. There is consumer motivation to learn to use it.

An interesting form of EPG is the "mood guide." It is based on the theory that there are a limited number of "moods" viewers have when they turn on the TV. Those moods can be studied, understood, and programming categorized so that it is associated with the set of moods. When the TV is turned on, the first thing seen is a list of possible moods. The viewer reflects briefly and then indicates the mood of the moment. The EPG responds with all the programming that is appropriate to the moods of the viewer. It also suggests what may be available later for viewing or taping. Thus, the likelihood that the viewing experience will be satisfying is increased.

Another important role for the EPG is to keep a record of which types of programs each family member watches. Over a few months, enough information is gathered to allow the EPG to advise the viewer that programming consistent with past viewing patterns is available for viewing or taping. It becomes less likely that programming of interest will be missed. This increases the value of the subscription to the subscriber and increases retention. In general, the satisfaction of the consumer increases.

The EPG contains all of the information necessary for automatic operation of a VCR. The time, the channel, and the program category are available in digital form. The consumer's main responsibility is to ensure blank tape is loaded in the machine!

2.9.3 The Fax Machine, E-Mail, and the NII for the Common Man

In the early 1990s, E-Mail and the Internet have become important parts of the professional workplace. Those who are enthusiastic about these modern communication tools envision them becoming part of ordinary daily life for nearly everyone in the late 1990s. This may be the case for a minority; but the reality is that the average consumer does not have the interest or the skills to work these systems.

However, there is a very cost-effective device that is much easier to use and nicely demonstrates the Pareto Principle: the fax machine. The fax machine is rapidly becoming a consumer-electronics product. There are a large number of models under $300 and the price is rapidly approaching $200.

Even more importantly, the fax machine is easy to use. It does not require any complicated ability to navigate through menus or complex computer commands. The fax machine requires minimal skills to operate. It requires no touch-typing. Nearly everyone can operate the fax machine. The Information Superhighway for the fax machine already exists: the phone system.

In many cases, the fax machine can send a page at less than the cost of postage. Certainly, the speed of delivery is greater and more assured. When E-Mail and other alternatives are considered, the fax machine is an extremely cost effective and easy-to-use alternative.

2.10 Public Policy Issues

2.10.1 Universal Service

The term "universal service" is itself an overly enthusiastic extension of the concept. No one is yet proposing that it is everyone's right to have digital information services whether they can pay for them or not. Taken to extreme, such thinking can result in concepts like "fiber to the homeless" and "information stamps" for those who can't afford to "pay" their fair share

for information. A more correct name for what is being proposed is "universal access." The concept is that access to these services should be provided to everyone in order to prevent a society of "information haves" and "information have-nots." There is a strong public policy debate about this. Lost in that debate is the issue of whether any consumer wants this. If so, how pervasive is that want? Is it reasonable to believe that a population with an average eighth-grade reading skill and a small minority with keyboard skills is starving for the Information Superhighway? This concept deserves careful and rational thought because it is a very expensive proposition, indeed.

Let's first take a look at the history of the concept of universal access. It arises in telephony. But it was not part of the telephone industry from the beginning. Telephony started as a large number of small competing companies. In many cases, multiple telephone companies served the same town with some areas having more than one phone company to choose from and others having none at all. As time went on, the phone companies merged and some local monopolies were formed. ***Universal access became the quid pro quo for the government granting a legal monopoly status***. This is a very important difference from what is happening here. The present situation is one where **competition** is being promoted. Universal access is a difficult concept to mix with competition! How do you enforce competition for customers in difficult-to-reach areas with very expensive construction costs? How do you enforce competition for customers who don't have the money to pay? How do you enforce competition for customers who have no idea what is being offered and/or no interest in it at all?

A second major difference between the telephony model and the Information Superhighway model is that there is a natural benefit to all telephone users to have access to essentially everyone else. It is especially important to businesses to have access to all potential customers. This provides the rationale for a subsidization of residential service by business costs and for an averaging of costs over easy and difficult situations. There is no similar benefit here. The potential exception is in the Video Internet. If the Video Internet develops, it may some day have a need to access most, if not all, of the population.

A third major difference between telephony and video services is content. In the case of telephony, the "content" is the message provided by the users. In the case of video services, the "content" is programming provided by artists and creative contributors protected by copy-

right. Telephony messages don't contribute to the cost of the service, copyrighted video programming is a major cost of its service.

And that brings us to another point. In the launching of a new and expensive service, it is prudent not to load it up with questionable costs when the acceptance of the service itself is questionable. It would be much wiser to allow entrepreneurs to risk their capital to determine which services will find acceptance by consumers and which will be rejected. Then, when the demand and utility of these services is well understood, public policy can be formed on the basis of experience. The public will be better served. Instead, there appears to be a race to regulate before there is anything to regulate. This will have a chilling effect on investment and may abort the embryonic industry before it is born and before it can get a healthy start.

Looking to the Electronic Publisher model, we have to recognize that as important a social concept as freedom of the press is, it was never required to be a universal service or to offer universal access. Perhaps that is because it was never granted a government protected monopoly. If more than 200 years of history have not seen a requirement for universal service or access for a *constitutionally* protected principle, why is it important to force this on an unproved, developing business?

Television broadcasting has close similarities to the services being contemplated. Yet broadcasting has never been a universal service or had a universal access requirement.

2.11 The Role of Standards

In order for there to be standards that allow digital TVs and VCRs to be made for the Information Superhighway, a number of issues need to be standardized. These include:

- Transmission (modulation)
- Equalization training signals
- Multiplexing methods for programs
- Identification of multiplexed programs
- Transport standards (headers, etc.)
- Error detection, protection, masking, etc.
- Video Compression memory requirements
- Audio Compression

- Ancillary data formats (captioning, electronic program guide's, interactive services, etc.)

- Signal Security interface

- Video raster formats: number of lines, frames, etc.

A major issue is the compatibility between compressed SDTV and HDTV. The consumer-electronics industry is very anxious that there be a great deal of similarity between the two sets of standards.

The consumer-electronics industry's wish is that the two standards be "hierarchical," i.e., compressed SDTV would be a subset of HDTV in all aspects. This will be very difficult to achieve. The cable industry feels it would be unfair to force compatibility between compressed SDTV and HDTV, but not require compatibility of other media such as DBS, video dialtone, ADSL, MMDS, pre-recorded media, etc. In the area of modulation, we already have issues. DirecTV for DBS must use quadrature phase shift keying (QPSK) modulation since that is what makes sense for satellite transmission. DirecTV presents a critical competitive challenge for cable operators. In order to meet that challenge, many cable operators have already ordered set-top boxes with digital compression. The modulation method chosen for those boxes is QAM. But the HDTV "Grand Alliance" chose VSB modulation for HDTV broadcast. So there already are three different transmission methods being implemented. Cable operators generally believe their more controlled technical environment will permit operation at twice the speed of broadcasters so that they can get two HDTV signals in 6 MHz. The data rate on cable will likely be higher than for broadcast.

In addition, DirecTV had to commit to production before the MPEG-2 standards were completed. DirecTV has launched its satellite in December of 1993 and in-home hardware through Thomson Consumer Electronics in mid-1994. Because of this early introduction, DirecTV of necessity is not able to be fully compatible with MPEG-2.

The National Renewable Security Systems (NRSS) Joint Subcommittee has come close to an agreement for a fully removable security system that plugs into a standard interface. This would allow TVs and VCRs to have plug-in digital descramblers without having to agree on a national standard for digital scrambling. The cable industry and most of the consumer-elec-

tronics industry are in agreement that there will not be a single national digital scrambling standard—and that there is no need for one. The NRSS interface will suit the needs of both industries.

Some in the consumer-electronics industry feel that this solves the most difficult major issue in the way of digital standards. However, the cable industry has additional concerns. A major unresolved issue involves the human interface for advanced services. How will the on-screen displays be handled? How will compressed sub-channels be identified? How will EPGs be done? These issues have not been resolved and may be very controversial.

The only reason we are able to consider digital video compression at this time is that for the first time we can afford to put a few million transistors in a set-top converter. Moore's Law, named after the Intel Chairman Gordon Moore, is based on historical observations of developments in the digital integrated circuit industry. Every 18 to 24 months, the number of transistors that can be had for a given price approximately doubles. A corollary of this rule is that every 18 to 24 months, the price of a given number of transistors on an integrated circuit drops by half. This has been happening over the history of the microcomputer. The first Intel microprocessor in an IBM personal computer had only 30,000 transistors. The Intel 486 has approximately 1.2 million transistors and the Pentium has over three million. This has all taken place in a period of about 12 years. Extrapolating this into the next decade yields about 100 million transistors in a set-top converter. Even a much more conservative estimate puts the number of transistors at tens of millions. Certainly, it will be possible to do better, cheaper digital video compression/decompression with tens of millions of transistors eventually costing as much as with just a couple million currently! Wavelets, fractals, and other techniques not practical now may offer advantages in the future.

There are a wide variety of consumer choices to be made. The consumer must decide the trade-off between video image quality and the number of available channels. The range of services and the degree of interactivity are also choices the consumer should make. None of these choices should be made for the consumer by a committee of engineers.

2.12 <u>Summary</u>

This paper was prepared for the reader who is unfamiliar with the characteristics of U.S. cable operations. It covered a broad range of subjects including technical detail on aspects of cable system architecture, transportation systems, regulatory issues, maintenance, and issues associated with developing technologies.

The information was grouped for discussion and generalizations were made. In reality, cable operations do not always fall into neat categories. This is particularly the case because of the wave of cable acquisitions and clustering. These business activities account for many upgrades and rebuilds that are creating large systems out of small, contiguous ones. The configurations developed from these activities can be quite different from basic cable systems.

While the information in this overview is not all-inclusive, it does provide a conceptual profile upon which to build with further reading and by visiting and observing cable operations. The appendices provide reference items and further details. A bibliography is included that can be used for more in-depth research when considering the impact of new technology on cable operations.

3.0 Appendices - Data and Specifications

3.1 330-MHz Channel Lineup

Standard Channel Bands (MHz)	Video Carrier Frequency (MHz)	Channel	Service	Tier	Program Source
54 - 60	55.25	2	Tempo	Basic	Satellite
60 - 66	61.25	3	USA Network	Basic	Satellite
66 - 72	67.25	4	WTTV	Basic	Broadcast TV
76 - 82	77.25	5	CNN Headline News	Basic	Satellite
82 - 88	83.25	6	WRTV	Basic	Broadcast TV
174 - 180	175.25	7	CBN	Basic	Satellite
180 - 186	181.25	8	WISH	Basic	Broadcast TV
186 - 192	187.25	9	WGN	Basic	Satellite
192 - 198	193.25	10	Local Orig./Prog. Guide	Basic	Studio/Headend
198 - 204	199.25	11	ESPN	Basic	Satellite
204 - 210	205.25	12	WXIN	Basic	Broadcast TV
210 - 216	211.25	13	WTHR	Basic	Broadcast TV
120 - 126	121.2625	14	Lifetime	Basic	Satellite
126 - 132	127.2625	15	C-SPAN	Basic	Satellite
132 - 138	133.2625	16	C-SPAN II / Government Access	Basic	Sat./Institute
138 - 144	139.25	17	WTBS	Basic	Satellite
144 - 150	145.25	18	Arts Access	Basic	Headend
150 - 156	151.25	19	The Nashville Network	Basic	Satellite
156 - 162	157.25	20	WFYI	Basic	Broadcast TV
162 - 168	163.25	21	Higher Education Access	Basic	Institutional
168 - 174	169.25	22	Video Hits - One	Basic	Satellite
216 - 222	217.25	23	MTV	Basic	Satellite
222 - 228	223.25	24	Arts and Entertainment	Basic	Satellite
228 - 234	229.2625	25	The Disney Channel	Basic	Satellite
234 - 240	235.2625	26	Cable News Network	Basic	Satellite
240 - 246	241.2625	27	Leased Channel	Basic	Studio
246 - 252	247.2625	28	Cinemax	Pay TV	Satellite
252 - 258	253.2625	29	Customer Information	Basic	Headend
258 - 264	259.2625	30	Score	Basic	Satellite
264 - 270	265.2625	31	WTIU	Basic	Broadcast TV
270 - 276	271.2625	32	BET	Basic	Satellite
276 - 282	277.2625	33	Discovery	Basic	Satellite
282 - 288	283.2625	34	Educat. Access/Commun. B.B.	Basic	Headend
288 - 294	289.2625	35	Community Program	Basic	Studio
294 - 300	295.2625	36	Nickelodeon	Basic	Satellite
300 - 306	301.2625	37	Health Access	Basic	Headend
306 - 312	307.2625	38	Showtime	Pay TV	Satellite
312 - 318	313.2625 39		Color Radar	Basic	Data Line
318 - 324	319.2625	40	WHMB	Basic	Broadcast TV
324 - 330	325.2625	41	HBO	Pay TV	Satellite
88 - 108	-	-	FM Band	Bas/Pay	Brdcst/Satellite
114 - 120	115.275	99	X-Change (Data Srvc 150 kHz)	Basic	Satellite

3.2 Generic Cable Distribution Network

Figure 3.2 shows the components of a generic cable system from satellite downlinks to subscriber TV. Each item is identified by a letter and its characteristics are tabulated in the following sections. These components are identified on Figure 3.2 by circled letters:

A   Central Headend

B   Remote Hubsite/Headend

C   AML Microwave Link

D   FML Microwave Link

E   Supertrunk Amplifier

F   Supertrunk Cable and Connectors

G   Trunk Amplifier

H   Trunk Cable and Connectors

J   Line Splitters

K   Line Extender

L   Distribution Cable and Connectors

M   Multitap

N   Indoor Splitters

P   Subscriber Drop Cable and Connectors

Q   Converter

R   Video Cassette Recorder

S   Television.
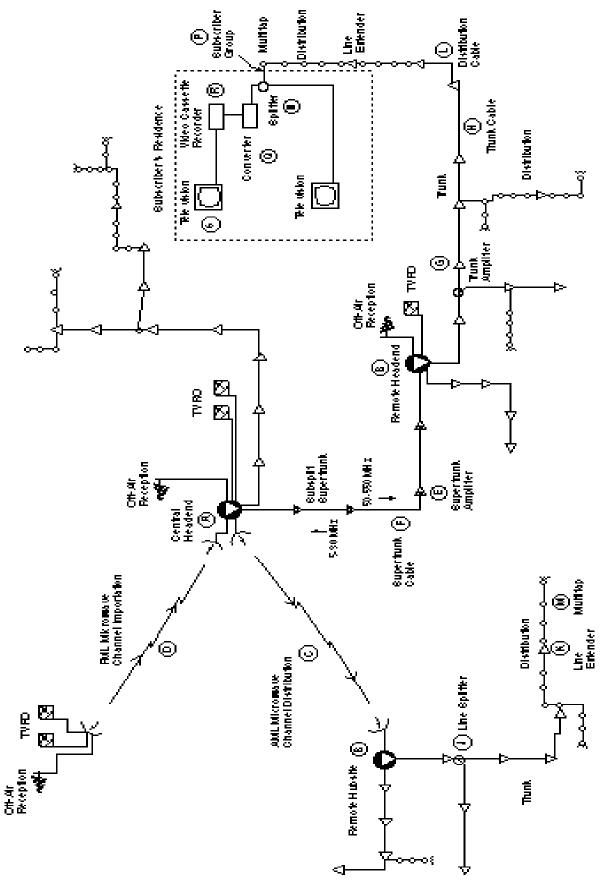
FIGURE 3.2 - GENERIC CABLE SYSTEM

3.2.1 A - Central Headend

The central headend is the main signal reception, origination, and modulation point for the cable system. It performs the following functions:

- Receives satellite programming via Television Receive Only (TVRO) sites
- Receives off-air broadcasts of television and radio
- Receives distant signals by FML microwave or return band cable
- Modulates programming onto channel assignments for distribution (up to 80 channels)
- FM modulates video for remote headend
- Performs local advertising insertion
- Inserts channels into trunk system.

3.2.1.1 *Characteristics of Equipment*

The basic TVRO station consists of an antenna, a low-noise amplifier (LNA) or low noise block converter (LNB), an FM receiver, and interconnecting cable.

The LNA, typically attached directly to the antenna, accepts the incoming downlink signal from the antenna and amplifies this signal for input to the receiver. The downlink frequencies in use are in two bands – the C band (3.7 to 4.2 GHz) and the Ku band (10.95 to 14.5 GHz) – each of which is broken into smaller sub-bands. The LNB not only amplifies, but also down converts the entire band to UHF or L-band frequencies.

TVRO parabolic antennas are available in various sizes (2.8 to 10 m diameter) depending on the required gain. The antennas are adjusted to focus on a geosynchronous satellite to receive the available channels.

The receiver converts the downlink frequencies to UHF frequencies either one channel at a time or in a block and provides a signal ready for modulation onto the cable system.

3.2.1.2 *Typical Receiver Specifications*

RF Input
    Maximum Level   - 34 dBm
    Frequency Range   3.7 to 4.2 GHz
    Characteristic Impedance   50 ohms

Return Loss	> 20 dB
Noise Figure	15 dB maximum
Image Rejection	> 60 dB
LO Leakage	< - 70 dBm

IF

Intermediate Frequency	70 MHz
Effective Noise Bandwidth	32.4 MHz
Characteristic Impedance	75 ohms
Return Loss at IF Monitor Ports	> 20 dB
Dynamic Operating Range	40 dB

Baseband

De-emphasis 525-line	CCIR Rec. 405-1
Deviation range	6 to 12 MHz peak at de-emphasis cross-over frequency
FM Video Static Threshold	8 dB carrier-to-noise ratio with threshold extension demodulation (TED)

Video Level 1 V p-p $\pm$ 3 dB

Response (15 Hz - 4.2 MHz)	Standard: $\pm$ 0.5 dB $\pm$ 1.0 dB with TED
Characteristic Impedance	75 ohms
Return Loss	> 26 dB
Polarity	Black to White: Positive going
Clamping	40 dB dispersal rejection
Line-Time Waveform Distortion	< 1% tilt
Field-Time Waveform Distortion	< 1% tilt
Differential Phase	< $\pm$ 1˚: 10 to 90% APL
Differential Gain	< $\pm$ 2.5%: 10 to 90% APL

Audio

Subcarrier Frequency	6.8 MHz
Frequency Response	30 Hz to 15 kHz $\pm$ 0.5 dB
De-Emphasis	75 μs
Output Level Range	- 10 to + 10 dBm
Characteristic Impedance	600 ohms
Harmonic Distortion	< 1%

3.2.1.3 *Typical LNB Specifications*

Frequency Range	3.7 to 4.2 GHz
Input Level	- 75 dBm to - 95 dBm per channel
Input Return Loss	> 20 dB
Conversion Gain	56 dB $\pm$ 3 dB
Image Rejection	> 60 dB
IF Frequency Band	950-1450 MHz or 270-770 MHz
IF Output Characteristic Impedance	75 ohms
Output Return Loss	> 17 dB
Noise Temperature (25˚C)	90 to 100˚K

3.2.1.4 *TVRO Coaxial Cable Specifications (for use with LNA)*

Size	7/8"	1/2"
Characteristic Impedance	50 ohms	50 ohms
Propagation Velocity	85-91.5%	80%
Attenuation dB/30 m @ 4.2 GHz	2.96 dB	8.0 dB

3.2.1.5 *Typical Antenna Specifications*

4.5m diameter parabolic reflector

Operating Frequencies	3.7 to 4.2 GHz
Gain Referenced to OMT Port	43.6 dBi at 4.0 GHz
VSWR	1.3:1
Polarization	Dual Linear
Polarization Adjustment	360˚ continuous
Cross-Polarized Suppression	35 dB minimum on axis
Isolation Port-to-Port	35 dB minimum
3 dB beam width - Nominal	1.1˚ at 4.0 GHz
First Sidelobe Level	22 dB

Radiation Pattern Sidelobe envelope, where 0 is the angle off axis

29 - 25 log 0 dB:	$1˚ < 0 < 7˚$
+ 8 dBi:	$7˚ < 0 < 9.2˚$
32 - 25 log 0 dB:	$9.2˚ < 0 < 48˚$
- 10 dBi:	$48˚ < 0 < 180˚$

Antenna Noise Temperature (Referred to OMT Port) 4.0 GHz

Elevation	Ta
5˚	53 K
10˚	38 K
15˚	31 K
20˚	27 K
30˚	24 K
40˚	22 K
50˚	21 K
60˚	21 K

3.2.2 B - Remote Hub Site / Headend

A remote hubsite or headend is a scaled-down version of the central headend. It does not perform all of the functions of a central headend and may only process part of the cable spectrum.

Remote Headend Functions:

- Receives satellite programming

- Receives off-air programming

- Demodulates FM signals from central headend

- Modulates programming onto cable channels

- Inserts channels into trunk system

- Inserts channels in return path of supertrunk to central headend.

Remote Hubsite Functions:

- Receives channels from AML

- Inserts channels into trunk.

3.2.3 C - AML Microwave

- Transmitter: Upconversion of individual television channels
- Receiver: Wideband block down conversion of entire cable spectrum

3.2.3.1 *Receiver Specifications*

Frequency
  Input   FCC CARS Band 12.7 to 13.25 GHz
                                     - 35 to - 50 dBm nominal level

  Output
    40 Channels   54 to 330 MHz
    60 Channels   54 to 450 MHz
    80 Channels   54 to 550 MHz
  AGC Dynamic Range   35 dB
  AGC Flatness $\pm$ 1 dB
  Gain (adjustable)   20 dB nominal
  Gain Flatness $\pm$ 1.5 dB
  VHF Output Level $\pm$ 24 dBmV nominal
  Local Oscillator   Phase locked to transmitter
  Frequency Stability   or 1×10^{-6}/month
  Output Return Loss   16 dB
  Input Return Loss   20 dB
  Noise Figure   10 dB (5 or 7 dB with optional LNA)

Output Signal Quality (at CNR = 53 dB)

	40 channels	60 channels	80 channels
CTB			
w/o LNA	- 86 dB	- 80 dB	- 80 dB
with LNA	- 78 dB	- 72 dB	- 72 dB
XMod			
w/o LNA	- 85 dB	- 79 dB	- 79 dB
with LNA	- 77 dB	- 71 dB	- 71 dB

Hum Modulation 0.004 V rms

3.2.3.2 *Transmitter Specifications*

VHF Input Frequencies	54 to 550 MHz
Nominal Signal Input Level	
Video Signals	+ 40 dBmV (-9 dBm)
Audio and FM Broadcast signals	17 dB below video
Output Frequencies	CARS Band 12.7 to 13.25 GHz
Output Power (Single Channel)	
High Power	5 W (+ 37 dBm)
Low Power	63 mW (+ 18 dBm)
Frequency Stability	greater than ± 0.0005%
Modulation Type	
High Power	Single-Sideband Suppressed Carrier Amplitude Modulation (SSB-SC-AM)
Low Power	Vestigial Sideband Amplitude Modulation (VSB-AM)
Input Return Loss	16 dB
Output Return Loss	16 dB
Group Delay	± 25 ns
Differential Gain	0.4 dB
Differential Phase	2˚

3.2.4 D - FML Microwave

- Single channel transmission   25 MHz per TV channel (12.5 MHz optional)
- Wideband receiver

3.2.4.1 *System*

Microwave frequency range	12.7 to 13.25 GHz
Frequency stability	+ 0.0005%
Modulation	Frequency Modulation (FM)
Transmission Capacity	1 NTSC color video, plus 3 audio subcarriers

3.2.4.2 *Equipment Specifications*

Transmitter

Output Power	26 or + 37 dBm
Configuration	IF heterodyne
Deviation (with CCIR 405-1 emphasis)	± 2.75 MHz peak
Input Baseband Levels/	
Impedances/Return Loss/Connectors	
Video	1 V p-p, 75 ohms, 26 dB, BNC
Audio	- 10 dBm, 600 ohms, 26 dB, terminal strip
Audio subcarriers frequency	
offset from video carrier	4.5, 5.3 and 6.0 MHz
Audio Subcarrier Deviation	± 25 or ± 75 kHz peak
	with 25 or 75 μs emphasis

Receiver

Noise Figure	10 dB (optional 7.0 dB)
Threshold (for weighted	
SNR = 33 dB with 10 dB NF)	- 79 dBm
Configuration	dual conversion, 70 MHz 2nd IF
Output Levels/Impedances/	
Return Loss/Connectors	
Video	1 V p-p, 75 ohms, 26 dB BNC
Audio	+ 10 dBm, 600 ohms, 26 dB, terminal strip

3.2.4.3 *System Performance (Receiver Carrier Level -45 dBm)*

Video

Frequency Response, 10 kHz - 4.5 MHz	± 0.5 dB ref 1 MHz
Chrominance/Luminance Delay	45 nsec
Chrominance/Luminance Gain	± 0.4 dB
Field Time Distortion	3%
Line Time Distortion	1%
Short Time distortion	4%
Differential Gain (10 - 90% APL)	5%
Differential Phase (10 - 90% APL)	2°
Tilt (line or field time)	2%
SNR (CCIR weighted)	63 dB
Hum	-60 dB

Audio

Frequency Response, 50 Hz - 15 kHz	± 0.5 dB
Distortion (± 10 dBm output)	1%
SNR (50 Hz - 15 kHz)	57 dB

3.2.5 E - Supertrunk Amplifier

In order to get top-quality signals to a remote headend or hub site using cable, the distortions and noise associated with the equipment in the trunk must be minimized. A supertrunk is a method of transporting signals using cable rather than air as the transmission medium. The amplifiers usually use power-doubling or feedforward technology to reduce the distortion products. Low-gain amplifiers keep the signal levels high in order to maintain a good CNR.

3.2.5.1 *Typical Feedforward Supertrunk Amplifier Specifications*

	Forward	Reverse
Pass Band (MHz)	54 - 450	5 - 33
Operational Spacing		
(dB @ highest frequency)	21	17
	(700 m of 1", 0.87 prop. vel.)	
Number of Channels	60	4
Operating Levels (dBmV)		
Frequency (MHz)	450/54	33/5
Input, minimum (dBmV)	12/12	17/17
Output (dBmV)	33/30	34/34
Carrier to Interference Ratios		
CTB (dB)	102	–
Discrete Second Order (dB)	90.5	85
XMOD (dB)	97	94
Third Order Beat (dB)	–	104
CNR (dB)	59.5	69.5
Noise Figure (dB)	11.5	7.5
Minimum Full Gain (dB)	25	20
AGC Dynamic Range (dB)	± 3	–
Manual Gain Range (dB)	–	8
Manual Slope Range (dB)	- 3.5	–
Return Loss (minimum dB)		
Input	16	16
Output	16	16

3.2.6 F, H, L & P - Cable and Connectors

Cable is two-conductor, coaxial. Cables are usually categorized by the diameter of their outer conductor (0.412", 0.750", etc.) The smaller the diameter, the higher the attenuation per unit length. The dielectric separating the conductors also determines the attenuation characteristics.

Cables used in a supertrunk are usually of large diameter and high propagation velocity to reduce attenuation (0.750" to 1.000" in diameter). Normal trunk cable is generally 0.750", although modern, higher-frequency systems may use 0.860", 0.875", 1.0", or 1.125" cable. Distribution lines are typically of shorter length than trunks so smaller, less expensive cable may be used (0.412", 0.500" and 0.625"). The subscriber drop cable is the smallest cable of all and must be flexible, whereas the other cables are rigid. Another consideration is that while any single drop is relatively short (50 m average, the total length of drop cable in a cable system is enormous, so inexpensive cable is required [RG-59, RG-6]).

3.2.6.1 *General Specifications*

Characteristic Impedance	75 ohms
Structural Return	
Loss Trunk & Distribution Cable	> 30 dB
Drop Cable	> 26 dB
Time Delay	4.17 ns maximum
	(Velocity of Propagation = 80% min.)

3.2.6.2 *Cable Attenuation*

Velocity of Propagation = 82%, Attenuation (dB/100 m):

MHz	Cable Type					
	RG-59	RG-6	.412″	.500″	.750″	1.000″
5	2.55	2.00	0.75	0.56	0.39	0.33
30	6.27	4.94	1.90	1.38	0.95	0.79
50	8.42	6.65	2.53	1.94	1.36	1.08
300	20.00	16.00	5.94	4.89	3.44	2.58
450	24.60	19.80	7.47	6.07	4.40	3.58
550	27.20	21.90	8.37	6.81	4.90	4.03

Velocity of Propagation = 87%, Attenuation (dB/100m)

MHz	Cable Type							
	RG-59	RG-6	412″	.500″	.625″	.750″	.875″	1.000″
5	1.88	1.53	0.66	0.54	0.43	0.34	0.30	0.30
30	4.63	3.78	1.64	1.31	1.12	0.85	0.79	0.75
55	6.24	5.10	2.23	1.79	1.51	1.17	1.08	1.02
300	15.00	12.30	5.36	4.31	3.61	2.93	2.59	2.46
450	18.50	15.20	6.63	5.35	4.43	3.67	3.22	3.02
550	20.50	16.90	7.51	5.98	4.96	4.24	3.71	3.38

3.2.6.3 *Connectors*

There are two basic styles of connectors in use in the cable industry: feedthrough and pin type. The feedthrough connector allows the center conductor of the cable to pass through into the device to which the cable is connected. The pin type connector has a pin that clamps the center connector in a captive seizure mechanism that then goes into the device. Pin connectors allow the use of larger center conductors that may be too large for many passive devices.

3.2.6.4 *Typical Specifications*

        Attenuation   Negligible
        Return Loss   30 dB minimum

3.2.7 G - Trunk Amplifiers

Amplifiers on the trunk radiating from a hub or headend that are not intended to be super-trunks may have slightly reduced performance specifications. These may use push-pull or power-doubling technology for systems with up to 60 channels. The station gain of these trunk amplifiers may be higher than a supertrunk amplifier since the CNR or distortion is not as critical. Systems with longer cascades and higher channel loading usually use feedforward trunk amplifiers for improved performance.

3.2.7.1 *Typical Specifications for a Push-Pull Trunk Amplifier*

        Forward   Reverse
    Pass Band (MHz)54-300   5-40
    Operational Spacing (dB)25   13.5
        (700 m of 0.75,"
        0.82 prop. vel)

Number of Channels	35	4
Operating Levels (dBmV)		
Frequency (MHz)	300/54	30/5
Input	8/8	17/17
Output	33/26	30.5/30.5
Carrier-to-Interference Ratios		
CTB (dB)	90	–
Discrete Second Order (dB)79.5	90	
XMod (dB)	88	100
Third Order Beat (dB)	–	108
CNR (dB)	57.5	67.5
Noise Figure (dB)	9.5	8.5
Minimum Full Gain (dB)	29	17.5
AGC Dynamic Range (dB)	+ 3	–
Manual Gain Range (dB)	6	8
Manual Slope Range (dB)	-3.5	-3.5
Return Loss (minimum dB)		
Input	16	16
Output	16	16

3.2.7.2 *Typical Specifications for a Power-Doubling Trunk Amplifier*

	Forward	Reverse
Pass Band (MHz)	54-450	5-40
Operational Spacing (dB)	22	13
	(500 m of 0.75",	
	0.82 prop. vel)	
Number of Channels	60	4
Operating Levels (dBmV)		
Frequency (MHz)	450/54	30/5
Input	8/8	21/21
Output	30/24	34/34
Carrier-to-Interference Ratios		
CTB (dB)	110	–
Discrete Second Order (dB)	88	88
XMod (dB)	96	104
Third Order Beat (dB)	–	107
CNR (dB)	58.5	70.5
Noise Figure (dB)	8.5	9.5
Minimum Full Gain (dB)	29	15
AGC Dynamic Range (dB)	± 3	–
Manual Gain Range (dB)	10	15
Manual Slope Range (dB)	-10	-5
Return Loss (minimum dB)		
Input	16	16
Output	16	16

3.2.8 J - Line Splitters

Line splitters and/or directional couplers are used to split signals into two or three different cables or devices.

3.2.8.1 *Typical Specifications*

Description	2-way Splitter	3-way Splitter	DC-8	DC-12	DC-16
Maximum Loss (dB)	4.4	7.9[a]	8.0	12.8	16.3
Maximum Insertion Loss (dB)	4.4	4.4	3.1	1.5	1.2
Isolation		20dBminimum			
Return Loss		18 dB minimum			

a. Two Legs

3.2.9 K - Feeder Amplifiers

Feeder amplifiers or line extenders are used to amplify signals in the distribution areas.

Since there are many more feeder amplifiers in a cable system than trunk amplifiers, they must be less expensive. The lower cost usually means lower performance specifications, which can be tolerated because there are usually only two or three feeder amplifiers upstream of a subscriber's home.

Feeder amplifiers use either push-pull or power-doubling technology depending on how many channels are on the system and what specification must be met at the subscriber's terminal device.

3.2.9.1 *Typical Specification for Power Doubling Feeder Amplifier*

	Forward	Reverse
Pass Band (MHz)	54-450	5-40
Operational Spacing (dB)	31	18
	(300 m of 0.50," and multitaps)	
Number of Channels	60	4
Operating Levels (dBmV)		
Frequency (MHz)	450/54	30/5
Input	16/9	28/28
Output	47/40	46/46

Carrier to Interference Ratios
    CTB (dB)   61   –
Discrete Second Order (dB)   66.5   68
    XMod (dB)   61   76
Third Order Beat (dB)   –   84
    CNR (dB)   65.5   80.5
Noise Figure (dB)   9.5   6.5
    Minimum Full Gain (dB)   32   19
Manual Gain Range (dB)   8   10
Manual Slope Range (dB)   -4   –
Return Loss (minimum dB)
    Input   16   16
    Output   16   16

3.2.10 M - Multitaps

Multitaps allow for splitting the signals off the distribution cable for transmission along the drop cable into the subscriber's premises. Multitaps are actually a combination of directional couplers and splitters designed to give the lowest insertion loss possible for the number of tap legs and the tap loss desired. A common multitap spacing is 150 feet, although this varies greatly with residence density.

3.2.10.1 *Typical Specifications*

    Two-way:

Tap Loss (dB)	Insertion Loss (dB)		
	5 MHz	50 MHz	550 MHz
4	T[a]	T	T
8	3.2	2.9	3.6
11	1.8	1.5	2.2
14	0.9	0.8	1.5
17	0.7	0.6	1.2
20	0.5	0.4	1.0
23	0.5	0.4	0.9
26	0.4	0.4	0.9
29	0.4	0.4	0.8

a.   T=Terminating Multitap

Four-way:

Tap Loss (dB)	Insertion Loss (dB)		
	5 MHz	50 MHz	550 MHz
8	T	T	T
11	3.2	2.9	3.6
14	1.8	1.5	2.2
17	0.9	0.8	1.5
20	0.7	0.6	1.2
23	0.5	0.4	0.9
26	0.5	0.4	0.9
29	0.5	0.4	0.8

Eight-way:

Tap Loss (dB)	Insertion Loss (dB)		
	5 MHz	50 MHz	550 MHz
11	T	T	T
14	2.7	3.0	4.3
17	1.6	1.6	2.2
20	1.0	1.1	1.7
24	0.7	0.6	1.6
26	0.6	0.6	1.0
29	0.4	0.4	0.8

3.2.11 N - Indoor Splitters

Many subscriber premises are wired for more than one cable outlet. An indoor splitter accomplishes this task at a low cost.

3.2.11.1 *Typical Specifications*

Description	2-way splitter	3-way splitter	4-way splitter
Tap Loss (dB)	4.0	8.0[a]	8.0[b]
Insertion Loss (dB)	4.0	4.0	
Isolation		25 dB minimum	
Input Return Loss		18 dB minimum	
Output Return Loss		20 dB minimum	
RFI Isolation		100 dB minimum	

a. Two Legs
b. All Four Legs

3.2.12 Q - Converter

The set-top converter enables the subscriber to tune in the TV channels delivered by the cable system that are outside the normal channel 2 to 13 VHF tuner of the television. This is accomplished by down converting the selected channel to channel 2, 3, or 4.

A choice of channels is given so that interference from a local TV station can be avoided.

3.2.12.1 *Typical Specifications*

Input Bandwidth	54 to 450 MHz
Number of channels	60
Output channel	3 or 4
Channel Frequency Response	± 2 dB with6 MHz channel
Gain	0 to 9 dB
Noise Figure	13 dB
Return Loss	
Input	7 dB minimum on tuned channel
Output	11 dB minimum
Isolation Input/Output	60 dB
Spurious Response	
Input	- 37 dBmV
Output	- 57 dBmV in channel
Frequency Stability	± 250 kHz
Distortion at 15 dBmV;	
60-channel load, flat input	
Second Order	- 57 dB
XMod	- 57 dB
CTB	- 57 dB
Input Level	- 0 to + 20 dBmV

3.2.13 R - Video Cassette Recorder (VCR)

The VCR is the first device the cable signal encounters within the subscriber's premises that is beyond the control of the cable operator. A typical specification is difficult to obtain since there are so many brands and models. A consideration worth noting, however, is that most VCRs have a built-in splitter to enable the subscriber to record one channel while viewing another. This splitter will reduce the signal levels by another 4 to 5 dB before reaching the television.

3.2.14 S - Television

The television is the final device encountered by the cable signal. It is difficult to characterize a typical TV since there are many manufacturers and models that have been produced in the past 40 years or more. Like the VCR, this is another device that is beyond the control of the cable system operator

Government regulation provides for certain minimum specifications at the input to the subscriber's terminal device (usually a VCR or TV).

- TV carrier level input 0 to +14 dBmV
- Adjacent carrier levels within 3 dB
- Maximum difference between carrier levels within a 90-MHz band no greater than 8 dB
- Aural carrier level - 13 dB to -17 dB relative to video
- FM carrier levels -14 to +4 dBmV
- CNR minimum 36 dB
- Carrier-to-hum ratio 34 dB minimum
- Cross modulation ratio 48 dB minimum
- Carrier-to-beat ratio 58 dB minimum
- Carrier-to-composite beat ratio 53 dB minimum
- Echo Rating in any television channel 7% maximum
- Frequency response ± 1 dB within the 6 MHz television channel
- Chroma delay ± 150 nanoseconds.

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5.0 About the Author

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Most recently he was Vice President of Technology at Time Warner Cable. Walt joined American Television and Communications, the predecessor to Time Warner Cable, in December of 1982 as Vice President of Research and Development. Prior to that he was with Zenith Electronics Corporation, starting in 1965. He was Director of Sales and Marketing, Cable Products, from 1981 to 1982. Earlier at Zenith he was Manager, Electronic System Research and Development specializing in Teletext, Videotext and Video Signal Processing with emphasis on digital television technology and ghost canceling for television systems.

He has nine patents issued. He has presented over 100 papers and published about 50, two of which have received awards from the Institute of Electrical and Electronic Engineers (IEEE). Ciciora wrote monthly columns for *Communications Engineering and Design* (CED) magazine and for *Communications Technology* (CT) magazine for three years each.

He currently serves on the Executive Committee of the Montreux Television Symposium. He was a member of the board of directors of the Society of Cable Television Engineers (SCTE) for six years. He was Chairman of the Technical Advisory Committee of CableLabs for four years and Chairman of the National Cable Television Association (NCTA) Engineering Committee also for four years. He was president of the IEEE Consumer Electronics Society for two years and is a past Chairman of the IEEE International Conference on Consumer Electronics. He chaired the Joint Engineering Committee of the NCTA and the Electronic Industry Association (EIA) for eight years. He has served on several industry standard-setting committees.

Ciciora is a Fellow of the IEEE, a Fellow of the Society of Motion Picture and Television Engineers (SMPTE), and a Senior Member of the SCTE. Other memberships include Tau Beta Pi, Eta Kappa Nu, and Beta Gamma Sigma.

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vision.

Ciciora received the 1987 NCTA Vanguard Award for Science and Technology and was named "1990 Man of the Year" by CED magazine. CED also named him "1993 Man of the Year." He was the Fall 1994 Donald W. Levenson Memorial Lecturer at the National Cable Television Center and Museum at Pennsylvania State University.

He has a Ph.D. in Electrical Engineering from Illinois Institute of Technology (IIT) dated 1969. His BSEE and MSEE degrees are also from IIT. He received an MBA from the University of Chicago in 1979. He has taught electrical engineering in the evening division of IIT for seven years.

Hobbies include helping his wife with her horses, reading, wood working, photography, skiing, and a hope to someday become more active in amateur radio (WB9FPW).

6.0 Contributors

The original draft of Section 2 was written by Jay Vaughan of ATC Engineering and Technology. The second, third, fourth, and fifth revisions were by Walt Ciciora. Jean Braunstein, Jim Chiddix, Austin Coryell, Barbara Lukens, Raleigh Stelle, and Bill Thomas, all of ATC, supplied information and reviewed the paper. Other contributions were made by Nick Hamilton-Piercy, Bill Parks, and Tim Tophan of Rogers Cable in Canada; Ed Horowitz and Paul Heimbach formerly of HBO; Matt Miller formerly of Viacom; and Frank Bias of Viacom. The Generic Network of Section 3 came from Rogers Cable. Suzanne Nielsen of CableLabs was responsible for the final editing, formatting, and physical appearance. Special thanks to Suzanne for her help and patience.