# THE HISTORY OF MODERN CABLE TELEVISION TECHNOLOGY

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Cable television is one of the most important technologies available to the average citizen. While television has become the preferred source of information for the masses, cable television has been the reason viewers have many choices. In fact, if cable had to be described with just one word, that word would have to be:

"***choice***".

**The Current Picture of Cable in the United States**

Choice is made possible by cost effective massive bandwidth for delivering programming to almost seventy percent of the 108.4 million households having television receivers in the United States. Since cable passes over ninety percent of television households, nearly everyone has the opportunity to subscribe to cable. In the United States, more people have television receivers than telephones, and most of those people have cable service.

Cable television is not the only multi-channel video provider. Direct Broadcast Satellite, DBS, has become a major alternative with about 22 million subscribers. This is about the same number of subscribers as served by the largest cable Multiple System Operator, MSO, Comcast and about double the second largest MSO, Time Warner Cable. Cable penetration of television households, TVHHs, has declined slightly over the last few years from a peak of 69.2% in 2001 to 67.7% in 2003, losing some market share to DBS. At the same time, cable's share of the public's viewing has grown while the Broadcast network's share has steadily fallen. In 2003, basic cable had 57% of TVHHs while broadcast had 38%. 1996 was the year the Broadcast network share dropped below 50%.

There are over 372 "channels" on the satellites that feed nearly ten thousand cable headends. An additional 127 planned "channels" are in the start up mode. Cable systems must select some of the programs they will make available to their subscribers from this set since no analog cable system has sufficient capacity to carry them all and many digital systems would be hard pressed to maintain an attractive analog offering while taking all of these channels and still providing other services. In addition, cable systems carry the local broadcasts and sometimes programs locally originated or designated for local citizen access. In some cable systems, the local schools, library, or local government have channels to deliver programs of special interest. In this way, the needs of a democratic society are served while citizens become well-informed, and entertained as well.

The broadband cable infrastructure can deliver an appealing analog service while simultaneously adding hundreds of digital channels. This hybrid service is important for the transition to digital television since an abrupt change over from analog to digital television would be chaotic. Most citizens will continue to enjoy analog television for many years to come. Even those who purchase a digital television receiver for their principal viewing room will have analog receivers in the rest of the house. None the less, there is increasing interest in converting to all digital video or at least mostly all digital video. High Definition Television, HDTV, is generating a lot of interest (and a lot of confusion) among consumers. HDTV is available on cable to over 84% of cable subscribers. More than 16 cable networks are producing HDTV programming. Sports seem to be the main driver.

The cable infrastructure is inherently two-way, requiring only modest additional investment and maintenance to implement. When activated, this capability facilitates interactive cable services and other non-traditional cable services such as high speed data services, telephony, Internet telephony (termed Voice of Internet Protocol, VoIP) and even video telephony.

High speed data services using cable modems are currently available to nearly 90% of cable subscribers. There are more than 16 million cable modem subscribers. Digital video cable subscribers number over 22 million. The cable industry spends over ten billion dollars a year on infrastructure, having peaked at over 16 billion in 2001. Cable systems spend over 11 billion a year purchasing programming. The average monthly price of expanded basic service is $36.59. Expanded basic is the most popular level of service and is one level up from basic. Basic includes the mandatory broadcast and franchise required local channels and occasionally a few others. Very few subscribers take just basic. The cable industry has revenues from subscribers of $52 billion and advertising revenues of $16 billion.

Current areas of high interest encompass the "triple play" offering of video, voice, and data. Digital video includes Video on Demand, VOD, HDTV, and Digital Video Recorders, DVRs (also called Personal Video Recorders, PVRs). DVRs employ a computer hard disk to record tens of hours of programming while providing the Video Cassette Recorder, VCR, features of pause, fast forward, and rewind. An appealing feature for subscribers and an appalling capability for advertisers is found in the DVR's ability to skip commercial messages. The cable industry is struggling with how to serve subscriber's desires for this capability without ruining the important advertising revenue stream.

The success of cable has stimulated other broadband competitors, all using the programming services made possible by cable's investments and commitments to provide audience. The cable industry has financed and developed these program services, tested their market place demand, sorting out those wanted by subscribers from those rejected, and demonstrated that subscribers have a voracious appetite for programming. Cable's competitors merely have to supply alternate infrastructure and attempt to attract customers to a proven business model. The major risks have already been taken.

**Historical Perspective**

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 two thirds of the U.S. population in a cost-effective way.

The cable television system was not originally intended to be a general purpose communications mechanism. Only recently has cable's role expanded to include more general purpose communications services in some cable systems. But even in those cases, the new services are built, as much as possible, on cable's older foundations. Cable's primary and often sole purpose is the transportation of entertainment television signals to subscribers. In those applications, it needs only to be a one-way transmission path 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 which 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 for 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. Martin Malarkey opened his cable system in Pottsville, Pennsylvania, almost simultaneously (within a week of Tarlton). Malarkey used Radio Corporation of America, RCA, Antennaplex equipment which was originally developed for the in-house distribution of the National Broadcasting Company's, NBC's, signals in the RCA building in New York. Tarlton used Jerrold Corporation's antenna booster amplifier. Malarkey is a pioneer who organized and developed the National Community Television Association, NCTA which later was renamed the National Cable Television Association and more recently renamed again as the National Cable Telecommunications Association.

In most of the original cable systems, viewers found that off-air signals were either not available or were very weak because of the terrain or the distance 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 entrepreneurial broadcasters or retail TV receiver dealers who sought to expand the market for the sale of their products by also providing the signals the products required. By the late 1960s, nearly all of the areas of the U.S. which could benefit from a community antenna had been served.

In the mid 1970s, an embryonic technology breathed new life into cable television.

This technology was the satellite delivery of signals to cable systems. The pioneering movie channel, Home Box Office, HBO, showed the way. HBO's dramatic relay of the Ali-Frazier heavyweight prize fight in October 1975 from Manila to cable systems in Mississippi and Florida effectively triggered the development of the satellite network industry. 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 which 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. 3) Movie channels such as HBO, 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 from broadcasters.

At present, subscribers are offered a variety of video services. The foundation service all subscribers are required to take 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, which are offered as optional channels for an extra monthly fee. Some cable systems offer Pay-Per-View, PPV, programming which 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 two-way cable or, occasionally, an automated telephone link.

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

A wide variety of other services has been repeatedly offered to cable subscribers: videotext, teletext, other forms of "electronic publishing," and "information age" services, home security, and digital audio programming. Subscribers to date have shown a remarkable lack of interest in these services. It is interesting to speculate on the reasons for this disinterest, but the negative experience has been without exception. While subscribers have been very enthusiastic about video, particularly entertainment-oriented video, other services have left them cold. This has caused cable operators to concentrate their cable system design efforts on efficient, cost-effective video delivery.

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 teaches that the economics of the business generally only supports one system per community.

**Spectrum Re-use**

Compared with nearly any other communications technology, video is a bandwidth hog. While telephone-quality voice needs only 4 kHz of spectrum and high-fidelity sound takes 20 kHz or so (40 kHz for stereo), the current baseband video standard in the United States consumes 4.2 MHz. When modulated, the television signal takes up 6 MHz of spectrum. 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 reduce the amount of spectrum required by HDTV to more acceptable amounts. These signals must then be modulated onto carriers to deliver multiple signals to the consumer's equipment.

For NTSC, each television channel is assigned 6 MHz because of the need to share limited spectrum with other services. With double sideband modulation, the 6 MHz straitjacket allows only about 2.5 MHz for the demodulated video, after allowing room for the sound carrier. In 1941, Vestigial Side Band Amplitude Modulation, VSB-AM, was invented. This modulation approach enabled television engineers to achieve higher resolution within the 6 MHz limit. Compared with double side-band amplitude modulation, VSB-AM transmits one complete side-band and only a vestige of the other. At the time the standard was created, the design requirements of practical filters determined the amount of side-band included. The consumer's receiver selects the channel to be watched by tuning 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 300 million receivers and more than 200 million VCRs in consumers' hands, the changeover process to upgraded systems would be difficult, costly, and require something like 20 years. Consumers continue to purchase about twenty-five million color receivers and about fifteen million VCRs per year. The reliability of the products is phenomenal. Their “half life” is about ten to twelve years.

The rest of the terrestrial spectrum which 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 practice 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. The properties of that separate spectrum allow it to behave 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. The subscriber can also cancel the subscription and not be left with useless hardware. This ease of entry 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 purposes 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 those frequencies. 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 ball-park figure is 1 dB of loss per 100 feet. Half-inch diameter aluminum cable has around 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 attenuation of cable 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.

**Cable Network Design**

Since cable television was originally 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 which has evolved over the years is called tree-and-branch architecture.

There are five major parts to a cable system: 1) the headend, 2) the trunk, 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 (set top terminals and consumer electronics hardware).

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 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 co-axial environment. The cable converter has a high-quality broadband tuner and output circuitry which puts the desired cable channel on a low-band channel not occupied in the local off-the-air spectrum. Typically this is channel 3 or 4 and occasionally 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. When the subscriber has purchased a product labeled “cable ready”, the requirement to use a set top terminal can be a sore point.

Cable systems have been built to slightly in excess of 1 GHz with more than 150 analog channels. Cable systems with bandwidths of 750 MHz are not uncommon and 550 MHz is typical for upgrades and new construction.

The home is connected to the cable system by the flexible drop cable, typically 150 feet long. 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, which increases the signal level for delivery to multiple homes. One or two specialized amplifiers called line extenders are included in each distribution cable. A little less than half of the system's cable footage is in the distribution portion of the plant and half is in the flexible drops to the home.

Prior to the use of fiber optics, the trunk part of the cable system transported the signals to the neighborhood. Its primary goal is to cover distance while preserving the quality of the signal in a cost-effective manner. Broadband amplifiers were required about every 2,000 feet depending on the bandwidth of the system. The maximum number of amplifiers which can be placed in a run or cascade is limited by the build up of noise and distortion. Twenty or thirty amplifiers may be cascaded in relatively high-bandwidth applications. Older cable systems with fewer channels may have as many as fifty or sixty amplifiers in cascade. Approximately 12% 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.

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. Local origination also includes alpha-numeric text as well as studio productions and video tape. In many systems, text may be the only form of local origination.

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

**Signal Quality**

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., apply 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 visual 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 45 dB to 46 dB. Subjective data was compiled in 1991 in a project sponsored by the cable industry's research and development consortium Cable Television Laboratories, CableLabs. The work, supervised by Dr. Bronwyn Jones, indicates "perceptible but not annoying" CNR at about 47-50 dB. The "slightly annoying" category was within about 1 dB of 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 which are called beats. These patterns often look like moving diagonal and horizontal 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.

The ultimate performance evaluation involves the subjective reaction of viewers. One example of the difficulties experienced 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 which 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 impact the result.

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.

Subjective assessment of viewer reaction to picture impairments have been made using various methods. In 1959, the Television Allocations Study Organization, TASO, studied the amount of noise, interference, and distortion viewers will tolerate in a TV picture. The results were expressed in a six-point scale with grades named excellent, fine, passable, marginal, inferior, and unusable. These are very old data and the scale is no longer accepted by psychometric experts because it mixes impairment and picture quality assessments. Additionally, the lack of a mid-scale category causes difficulties in the statistical analysis. However, the broadcast industry still uses this scale even though it is considered obsolete by psychometric practitioners. The most widely accepted standard for subjective measurements of impairment is now a five-point scale which was also used in the tests sponsored by CableLabs. However, the most widely published data on subjective impact of video impairments is based on the Bell Telephone Laboratory seven-point scale not used in any other study.

It is important to realize that the demand for signal quality is a function of time. 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 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 Television, ATV, and 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.

**Cable System Trade-offs**

The experienced cable system designer has learned how to balance noise, non-linear distortions, and cost to find a near optimal balance.

Signals in cable systems are measured in dB relative to 1 mV across 75 ohms. This measure is called dBmV. This is an unfortunate name which is the source of a great deal of confusion. Since the name of the measure ends in "V", it is natural to assume it refers to a voltage. It does not. The measure, dBmV is a power ratio with reference to 13.33 nanowatts of power, defined as one millivolt, 1 mv, (rms) across 75 ohms.

Applying the well-known Boltzmann noise equation to 75-ohm cable systems yields an open-circuit voltage of 2.2 microvolts in 4 MHz at room temperature. When terminated in a matched load, the result is 1.1 microvolts. Expressed in dBmV, the minimum room-temperature noise power in a perfect cable system is -59.17 dBmV.

Starting at the home, the objective is to deliver at least 0 dBmV of signal to the terminal on the television receiver, but no more signal than the amount that would produce overload in the consumer's tuner. Lower numbers produce snowy pictures and higher numbers overload the television receiver's tuner, resulting in cross modulation of the channels. Unfortunately, the overload point of television receivers is not well defined. As a result, the FCC rules merely state that it is to be avoided.

If a converter or 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 defect in the television receiver. Low signal levels may cause poor pictures when excessive signal splitting without prior amplification is used to serve too many receivers. Working our way back up the plant, we need a signal level of 10 dBmV to 15 dBmV at the highest frequency in the pass band 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. Note that 0 dBm (dB with respect to 1 mW) is equivalent to 48.75 dBmV. These levels force the amplifiers in the distribution part of the plant to reach into regions of their transfer characteristics which are slightly non-linear. There is no sharply defined "nonlinear" region; it is rather a matter of degree. As a result, only a small number of 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 (also called the "feeder") is operated at higher power levels, non-linear effects become important. The television signal has three principal carriers, the visual carrier, the aural carrier, and the color subcarrier. The visual carrier is by far the strongest with the chroma carrier the weakest. 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 aural carrier is attenuated about 15 dB below the visual carrier.

When cable systems carried only the 12 VHF channels, second-order distortions created spectrum products which fell out of the frequency band of interest. As channels were added to fill the spectrum, 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. The total effect of all the carriers beating against each other gives rise to an interference called Composite Triple Beat, CTB. CTB should be measured with the system fully loaded with all channels carried.

Third-order distortions increase about 6 dB for each doubling of the number of amplifiers in cascade. A 1 dB reduction in amplifier output level will generally improve CTB by 2 dB. If these products build to visible levels, diagonal lines will be seen moving through the picture. When these components fall in the part of the spectrum which conveys color information, spurious rainbows appear. The dominant non-linear effect in the feeders is the triple beat between multiple visual carriers, since the visual carriers are the points of concentration of most of the energy in the television signal.

If we assign a design level of noise and non-linear distortion at the subscriber's television receiver which 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 and / 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 in all-coaxial systems. 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. But with the advent of HFC systems described below, yielding very short amplifier cascades and high channel capacity, the trend is toward spacing as high as 30 dB to 40 dB. Since attenuation varies with frequency, the spectrum in coaxial cable develops a slope. This is compensated with equalization networks in the amplifier housings.

The attenuation of the cable is a function of temperature and aging of components. Modern amplifiers use a pilot signal to regulate 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 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.

**The Hybrid Fiber Coax Architecture**

The Hybrid Fiber Coax, HFC, 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.

Surprisingly, the trunk portion of the cable plant only covers about twelve percent of the total footage. The feeder portion of the cable system supports taps for subscribers. It is usually constructed to no more than a mile and a half in length. 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 non-linear 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 is usually constructed to no more than 400 feet in length. Typically, it is more like 150 to 200 feet long. 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 twenty percent of Americans move to a new residence every year. When they move, the drop is usually disconnected. When they move to their new residence, that 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 to work with. The trunk portion of the cable plant is relatively stable. There, few changes are made.

The HFC architecture is an optimized combination of fiber in the trunk and coaxial cable in the feeder and drop. HFC 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 concepts behind HFC are straight forward. The bandwidth of coaxial cable has no sharp cut-off. It is the cascade of amplifiers that limits the system bandwidth. Twenty to forty amplifiers in cascade not only reduces bandwidth, but also constitutes a severe reliability hazard. Overlaying low-loss fiber over the trunk portion of the plant eliminates or reduces the number of trunk amplifiers. Wider bandwidth is thus facilitated. Two-way cable operation becomes practical because of two benefits of HFC. First, the cable system is broken up into a large number of smaller 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. Secondly, the fiber itself is not subject to ingress of interfering signals.

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 build “GHz ready” so that the addition of GHz amplifier modules will upgrade the system with little or no waste of installed plant. While GHz capability is a future possibility, 750 MHz upgrades are done today and 550 MHz is commonplace.

The lasers that drive the fibers are expensive, costing many thousands of dollars. The receivers that convert the optical energy into signals which TVs and VCRs can use are also modestly 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 of thousand subscribers.

A major attraction of HFC is that its implementation cost is low. Fiber is "over lashed" 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.

**Signal Security Systems**

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

**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 (or a set of multiple carriers) 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 in systems where less than half of the basic customers subscribe to the premium service.

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. New positive trap schemes take advantage of sharper Surface Acoustic Wave, SAW, or crystal filter technology. This approach allows the interfering carriers to be positioned a few kilohertz away from the secured channel's visual carrier in contrast to 2.25-2.75 MHz with the conventional approach. Illegal construction of these filters is much more difficult. The new technology has the promise of achieving greater signal security and a higher quality picture for the authorized customer, but at a higher price.

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 in systems where over half of the basic customers subscribe to the premium service. 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. Negative traps have a problem from a security standpoint. The customer merely has to remove the negative trap from the line to steal an unauthorized service. Maintaining signal security in negative trapped systems depends upon ensuring that the traps remain in the drop lines.

**Scrambling and Addressability**

There are two classes of scrambling technologies: (1) RF synchronization suppression systems and (2) 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 semiconductor memory chip called a prom (programmable read only memory) to decode the authorized channels. These terminals' authorizations must be physically changed by the cable operator. Addressable converters are controlled by a computer-generated data signal originating at the headend and placed either in the vertical blanking interval, VBI, or in a separate 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.

**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 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 older, and now less popular, format is known as sine-wave synchronization suppression. In this format, the scrambling effect is achieved by modulating the visual 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 SAW filters constructed on the same substrate has been introduced. This low-cost system has extended operators' interest in RF scrambling techniques for use within addressable plants.

**Baseband Scrambling Systems**

Baseband converter/descrambler technology provides a more secure scrambling technology for delivering video services. The common encoding format is a combination of random or pseudo-random synchronization suppression and/or video inversion. More complex and effective schemes have been invented but have not found broad acceptance because of cost. Because the encoding and decoding are performed at baseband, these converter/descramblers are complex and 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 stereo compatibility, providers of these products claim that the combination of video scrambling with audio encryption provides a significantly higher degree of security.

**Off-Premises Systems**

The off-premises approach is compatible with recent industry trends to become more consumer electronics friendly and it removes 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. 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 customer's equipment.

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.

**The Signal and the Customer’s Equipment**

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 5-30 MHz reverse (upstream) spectrum from noise sources in the home. These noise sources include appliances with motors, and consumer electronics products with spurious emissions in these frequencies. 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 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, low grade VCRs sometimes split the signal unequally between the by-pass 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 play-back, the disparity in performance is reduced.

**Consumer Electronics Compatibility**

In the early 1980s, a Joint Engineering Committee, JEC, was formed under the sponsorship of the Electronic Industries Association, 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.

Problems on the consumer side stem from critical cost considerations. Additional expense is hard to recover by raising 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 prices 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.

Problems on the cable side come from the need for signal security and the desire to experiment with new services. A prerequisite to offering a subscription service is the ability to deny that service to those who choose not to 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. Technology makes possible experimentation in new services. Because these services are offered in set-top terminals owned by the cable operator, the consumer is protected from financial loss if service fails.

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

1) A standardized 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 which 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 electromagnetic shielding to protect it from outside signals. 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. Therefore, 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 which 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 electromagnetic 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 which provide on-screen displays and drive other features. These signals can cause interference to other receivers 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 terminals to move beyond mere frequency conversion. Set top terminals took on the function of descrambling signals in the early 1980's. If a "cable ready" TV or VCR were designed with adequate tuning range, adequate electromagnetic 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 circuitry in the TV, provide slight additional signal degradation, and interfere with certain features built into TVs and VCRs. The solution to this problem is the Decoder Interface connector. This is a twenty-six pin connector on the back of TVs and VCRs which brings video and audio signals out of the consumer electronics product for external processing. The descrambled signals are returned to the consumer electronics product for display or recording. The main advantage of the Decoder Interface is that it makes scrambling nearly transparent to the user.

In 1992, Congress passed the Cable Act which has far-reaching implications for cable system operation and economics. An amendment attached 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 which do not comply with the Commission's technical specifications cannot be sold as "cable ready", "cable compatible", or under any other term which might mislead consumers.

As complex and difficult as the Decoder Interface has been, the digital television future presents even more interesting challenges. Digital Television, DTV, takes advantage of the fact that we can now afford to put millions of digital 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?

The 1996 Telecommunications Act requires the FCC to establish rules for the availability of set top terminals at retail. As we move to subscriber ownership of the electronics which implement services, new issues become important. 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 terminals 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. Consumer will be angry when the hardware they purchase cannot be used on the cable system because of interference it may cause.

**Digital Video Compression:**

Digital Video Compression, DVC, has given massive capacity to the cable spectrum. DVC gained its first momentum in the pursuit of HDTV. The analog bandwidth of signals from an HDTV camera consists 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. The same technology can be used to squeeze multiple standard definition signals into the same 6 MHz. When DVC is used to put multiple current quality signals into 6 MHz, the result is called Standard Definition Television, SDTV.

DVC was first used by consumers in the Direct Broadcast Satellite, DBS, environment. DirecTV, EchoStar, and the former PrimeStar use(d) a version of the Motion Picture Experts 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 which have minimal visibility to the human visual system.

The reasons for the lower data rate with movies stems from two main factors. First, movies have a twenty-four frames per second rate while video has thirty frames per second. While motion reproduction in video is better than in movies, there is a twenty percent increase in data required for the same image quality. Secondly, movies can be processed iteratively. 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 which 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 Side Band, VSB, modulation. These come in various data speed capacities. The two most interesting for cable applications are 256-QAM or 16-VSB. Both are "double data rate" systems in that they can deliver data payloads of 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 Mb/s 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, AMLs, were also included. 256-QAM delivers similar results. Thus it is possible to transmit twelve DVC movies in 6 MHz at 3 Mb/s each.

Current thinking is to allocate the lower end of the down stream cable spectrum to analog signals. This covers the 50 MHz 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 twelve movies per 6 MHz, 396 to 1092 movies may be offered simultaneously. Of course, digitized video signals (rather than movies) may also be offered by reducing the total number of programs.

**Conclusion**

With this brief overview, the general concepts of cable television in the United States have been introduced. There are many suitable references for further investigation and study.

**Modern Cable Television Technology, Video, voice, and Data Communications**, Second Edition, Walter Ciciora, James Farmer, David Large, Michael Adams, November 2003, The Morgan Kaufmann Series in Networking, ISBN: 1-55860-828-1, A sample chapter is available at http://books.elsevier.com/mk/default.asp?ISBN=1-55860-828-1

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**The History of Television, 1880 to 1941**, Albert Abramson, McFarland, 1987, ISBN 0-89950-284-9

The following URLs were relative and active at the time of this writing. The first URL is an excellent cable history "time line".

http://www.cablecenter.org/history/index.cfm

http://www.ncta.com/Docs/PageContent.cfm?pageID=86

http://www.ncta.com/Docs/PageContent.cfm?pageID=87

http://www.scte.org/home.cfm

http://www.fcc.gov/mb/

http://www.cablelabs.com/

http://www.cablemodem.com/

http://www.cablelabs.com/projects/cablehome/

http://www.packetcable.com/

http://www.opencable.com/

http://www.cablelabs.com/projects/go2/

http://www.cablelabs.com/projects/metadata/

http://www.ncta.com/Docs/PageContent.cfm?pageID=87

http://www.broadband-pbimedia.com/ct/

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***Biographical Sketch***

Dr. Ciciora is EVP of Technology of HBA-Matchmaker-Media and a consultant specializing in Cable Television, Consumer Electronics, and Telecommunications technology. He sits on several Corporate Boards and Advisory Boards. He serves as an expert witness in patent cases. He is co-founder and was EVP & CTO of EnCamera Science Corporation until the founders sold it to Dotcast, Inc. He coauthored "Modern Cable Television Technology" wining the Cable Center 2000 book award. He was the Senior Lecturer for the Cable & Telecommunications Association for Marketing, CTAM.

He was VP of Technology at Time Warner Cable, TWC until 9/93. Walt joined American Television and Communications, TWC's predecessor, in 12/82 as VP of R&D. He started with Zenith Electronics Corporation in 6/65. He was Director of Sales and Marketing, Cable Products, from 1981 to 1982. Earlier at Zenith he was Manager, Electronic System R&D, specializing in Teletext, Videotext and Video Signal Processing with emphasis on digital television technology and ghost canceling for television systems.

He has sixteen patents issued and several more pending. He has presented over two hundred papers and published about a hundred, two of which have received awards from the Institute of Electrical and Electronic Engineers, IEEE. Some of his papers have been translated into Japanese, Chinese, German and Spanish. Walt wrote monthly columns for Communications Engineering and Design, CED magazine and for Communications Technology, CT magazine for three years each. He continues in alternate months for CED.

He served on the Montreux (Switzerland) Television Symposium Executive Committee for over a decade. He is a member of the board of directors of the Society of Cable Telecommunication Engineers, SCTE, and previously served for six years. He was Chairman of the Technical Advisory Committee of CableLabs and a Board member and Chairman of the National Cable Telecommunications Association, NCTA, Engineering Committee, both 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 is on the board of directors of the IEEE Broadcast Technology Society. 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. He co-chaired the Cable Consumer electronics Compatibility Advisory Group and its Decoder Interface subcommittee.

Walt is a Fellow of the IEEE, a Fellow of the Society of Motion Picture and Television Engineers, SMPTE, and a Fellow of the SCTE. Other memberships include Tau Beta Pi, Etta Kappa Nu, and Beta Gamma Sigma.

Walt 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 Levenson Memorial Lecturer at Penn State University. In 2000 he was inducted into the Academy of Digital Television Pioneers and the SCTE Circle of Eagles and in 2001 into the Cable Pioneers.

Walt has a Ph.D. in Electrical Engineering from Illinois Institute of Technology, IIT, dated 1969. The BSEE and MSEE 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, working towards a general aviation pilot's license, reading, woodworking, photography, skiing, and a hope to someday become more active in amateur radio, WB9FPW