Baseband and Passband Transport Systems for Interactive Video Services

Baseband has emerged as the preferred approach for today's interactive video services applications.

J. Richard Jones

The subject of interactive video services (IVS) has recently been prominently featured in major publications [1,2]. This attention reflects both the interest by consumers in obtaining such services and the effort of media giants, telephone companies, and cable companies scrambling to address the delivery of these services. It is predicted that the drive to provide IVS will result in the building of the so-called information super highway to connect subscribers to the information providers [3]. Regulatory and legal barriers are dropping amid this clamor. For example, the FCC's Video Dial Tone ruling has freed telephone companies to transport and provide IVS in their regions provided certain restrictions are met [4]. Bell Atlantic has filed suit and won the right to provide cable TV services in its own region. In response to the mega mergers of cable/media companies and telephone companies (at this writing U S WEST has purchased 25 percent of Time Warner, Southwestern Bell has invested in Cox Cable Communications, and NYNEX has made a major investment in Viacom), legislation has been introduced in Congress which will attempt to create an enabling environment for competition in the deployment of networks for delivering IVS while putting the appropriate "safeguards" in place.

Given that essentially none of the existing telecommunication networks (cable or telco) are capable of providing IVS, network providers have begun to consider in earnest the network architecture that is best to deploy. Two approaches have to date received most of the consideration. Because of the embedded base of broadcast, coax-based cable TV networks [5] and because of the unconfirmed demand for IVS, much attention has been paid to upgrading these networks to provide IVS transport even though extensive modification would be required. These networks are referred to as passband networks because of the use of modulated subcarriers as the signal transport mechanism. The alternative approach under consideration is the use of fiber-to-the-curb transport systems [6]. Because such networks transport IVS directly as baseband signals without subcarrier modulation, they are known as baseband networks. This article compares the baseband and passband approaches in several areas including: compatibility with the optical transmission medium; compatibility with IVS source/sink equipment; compatibility with the emerging telecommunications interoffice and feeder networks; and the cost of deployment. In addition, the recent history in which passband and baseband approaches competed to become the preferred transport mechanism in LAN applications is reviewed. The fact that in that case baseband emerged as the preferred approach has important implications for the selection of the preferred approach in today's IVS applications.

Before proceeding with the above discussion, the constituent elements and transport requirements of the end-to-end network for delivering IVS are reviewed.

The End-To-End Network

It is enlightening to describe the implementation and requirements of the end-to-end network for providing IVS. The nature of that network and its traffic characteristics help determine the best approach for the transport system that carry IVS to subscribers. Figure 1 illustrates the end-to-end network. The purpose of that system is to provide a connection between an IVS server and the subscriber's set-top on an on-demand basis. The connection is made through a switch (preferably an ATM switch) and transported through a feeder and distribution system (collectively referred to as the transport system) and terminated at the set-top. The set-top provides the decoding and graphic display function in addition to the network interface function. In time, the set-top functions could be provided directly by the consumer electronics which display or manipulate the IVS signal (TV set, computer, CD-I player, game box, etc.). The set-top-to-server connection is managed by a packet-based signaling network that

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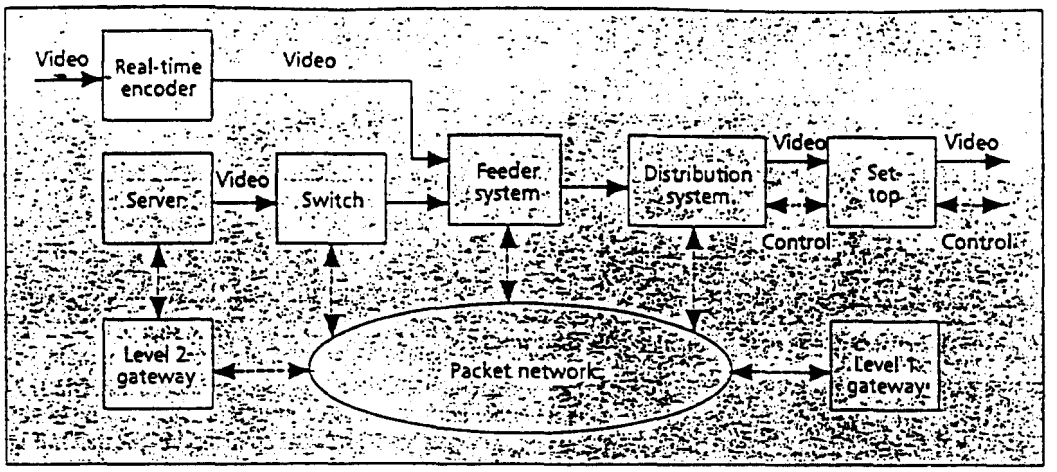


■ Figure 1. *The end-to-end network for providing interactive services.*

implements a two-level connection hierarchy following the FCC Video Dial Tone model [4]. Specifically, a Level 1 gateway manages the channel or service provider selection process as implemented by the network and switch, and a Level 2 gateway manages the specific service selection process as implemented by the server. In other words, the Level 1 gateway allows the channel in which the desired services reside to be selected, while the Level 2 gateway provides the interface for the specific services to be selected. For example, for a movies-on-demand service, one would select the "video store" channel by interacting with the Level 1 gateway. Once connected to that channel, the Level 2 gateway leads the user through the selection of the specific movie that is to be viewed.

Also shown in the figure is a path for broadcast channels to be encoded and introduced into the transport system for distribution to subscribers. A second stage of switching can be provided in the transport system to allow access to those channels without the need to connect through the switch further back in the network. Other options, such as the use of a broadcast overlay, could be implemented to avoid having to encode the broadcast signal. That option is described later in this article.

There are many technology options for implementing the elements of this network, as summarized in the box on this page. A comprehensive discussion of these various approaches is beyond the scope of this article, which will instead focus on the transport portion of the network.

Technology Options for Network Implementation

Server
- Robotic mass storage
- Supercomputer, disk storage
- Burst transfer, distributed cache
- Download, local storage

Gateways
- Software defined (user-controlled)
- Hardwired (proprietary)

Switch
- Circuit (digital cross connect)
- ATM

Encoder
- MPEG main profile (B-frame)
- MPEG simple profile
- MPEG1 vs. MPEG2

Feeder
- SONET
- Fiber (fiber-to-the-node)
- Coax
- Wireless

Distribution
- Fiber
- Coax
- Wireless
- Twisted pair (ADSL)

Set-Top
- Level of processing power
- B-Frame
- Complexity of user interface
- MPEG1 vs. MPEG2

Transport System Requirements

Requirements for the IVS transport system can be summarized as follows:

- Large channel capacity to accommodate multiple information providers.
- Format independence to accommodate many signal formats and data rates; formats could range from stillframe video to HDTV.
- Sufficient forward channel capacity per subscriber to provide "nonblocking" service.
- Low-latency reverse channel with sufficient capacity to allow nonblocking real-time navigation, interactive games and work-at-home network services.
- Low initial capital cost.
- Maintainable network, including operational support systems to reduce lifecycle costs.
- Signal security.

While all of the above requirements are important, a critical one, which is helpful in the baseband versus passband comparison shown later in this article, is the forward bandwidth requirement. Today's broadcast video networks are nonblocking, i.e., all channels are brought to the subscriber's TV set. While some channels may be scrambled to prevent viewing, every time the subscriber selects a channel, it is available, even if it is scrambled. This characteristic sets the expectation for IVS networks. When the subscriber requests a service, the expectation will be that the service will be immediately available. Since IVS require dedicated bandwidth between the server and the subscriber, sufficient capacity must be available to allow subscribers nonblocking access — just how much bandwidth can be estimated using a traffic analysis of the anticipated subscriber usage patterns.

For purposes of estimating the forward bandwidth requirements, a traffic analysis was performed using an Erlang B model with 1 percent blocking

Service	Peak viewing period	Peak busy per sub	Call attempts per call per period	Holding time per call	Bandwidth per port
Movies on demand	Fri./Sat. night (3.5 hrs./night)	7 Hrs.	1.5	2 Hrs.	Variable (3 to 20 Mb/s)
Time-shifted TV	Weeknights (4 hrs./night)	20 Hrs.	2	1 Hr.	Variable (3 to 8 Mb/s)
Interactive education	Weeknights (3 hrs./night)	15 Hrs.	1	0.5 Hrs.	1.5 Mb/s

■ Table 1. *Services characteristics assumed in traffic analysis.*

IVS penetration (in percent)	Movies on demand	Time-shifted TV	Interactive education
5	22	8	5
10	37	13	7
15	51	17	8
20	65	20	10
25	79	24	11
30	93	28	13
35	107	31	14
40	120	35	15
45	134	38	17
50	147	42	18

■ Table 2. *Broadband ports per 600 living unit serving area.*

probability [7]. A 600-living-unit serving area was assumed. The assumed services available to subscribers and an average subscriber's viewing habits for each service are given in Table 1. Three services were assumed for this analysis: a movies-on-demand service, a time-shifted TV service in which a subscriber can view a previously shown program at their convenience, and a multimedia interactive education service.

Table 2 summarizes the results of the analysis listing the number of server ports required for each service as a function the penetration rate (i.e., the percentage of the serving area that are subscribers) of each service.

Determining the forward bandwidth required in the transport system for "nonblocking" service is simply a matter of multiplying the bandwidth per port for each service and summing the resulting bandwidth as a function of penetration rate of IVS. For ease of analysis, it is assumed that the transport system is engineered to allow all three services to be simultaneously transported. While this is a somewhat conservative assumption, it is a likely approach that would be used to give a slight safety factor in the bandwidth engineering. For the TV-based services, a variable bit rate per port is assumed to allow for different signal resolution to be transmitted as appropriate to a given service and to allow for assessment of the impact that migration to HDTV would have on the transport system capacity requirements.

A convenient metric for assessing the transport-system bandwidth requirements is the bit rate per home passed (HP) in a given serving area, or Mb/s/HP. Aggregating the results of the traffic analysis including the effects of varying the bit rate per port gives the information plotted in Fig. 2 which shows Mb/s/HP as a function of IVS penetration rate for three scenarios:

- "Low resolution TV driven" (movies-on-demand: 3 Mb/s per port, time shifted TV: 3 Mb/s per port and interactive education: 1.5 Mb/s per port)
- "Action TV driven" (8 Mb/s, 8 Mb/s, and 1.5 Mb/s, respectively)
- "HDTV Driven" (20 Mb/s, 8 Mb/s, and 1.5 Mb/s, respectively).

As can be seen from the figure, bandwidth requirements can vary from 1 Mb/s/HP to 5.5 Mb/s/HP at 50 percent penetration depending on the nature of the delivered signal. This result will be used in the analysis comparing passband and baseband approaches given below.

Description of Passband and Baseband Approaches

Passband Approach

As mentioned earlier, a passband system uses RF subcarrier modulation to transport signals through a shared access transport system. Typically, the shared access is accomplished using a coax cable bus. Microwave radio systems are also passband systems. Consideration will be limited to coax systems in this article because they are by far the more prevalent approach. A block diagram of a coax-based passband system [5] is shown in Fig. 3. The diagram shows the equipment required to transmit telephony services, broadcast video services, and IVS. Each equipment group is separately identified.

The equipment for transporting broadcast video services consists of modulators and a hybrid analog fiber-optic and coax transmission system. The latter includes a fiber node that terminates the fiber link and serves a few hundred living units using a coax bus distribution system. IVS are provided using a digital feeder system that connects the server/switch to the distribution system. Modulators transport the IVS channels over a separate fiber link to the node where the IVS output spectrum is combined with the broadcast video services spectrum for distribution on the coax. A separate fiber link is used from the broadcast video services link because the modulation demands are quite different for each application. Broadcast video services required highly linear distributed feedback lasers [8] while IVS can use less expensive Fabry-Perot lasers [9]. The telephony services equipment consists of a host digital terminal with output modems and a subscriber terminal at the residence, which

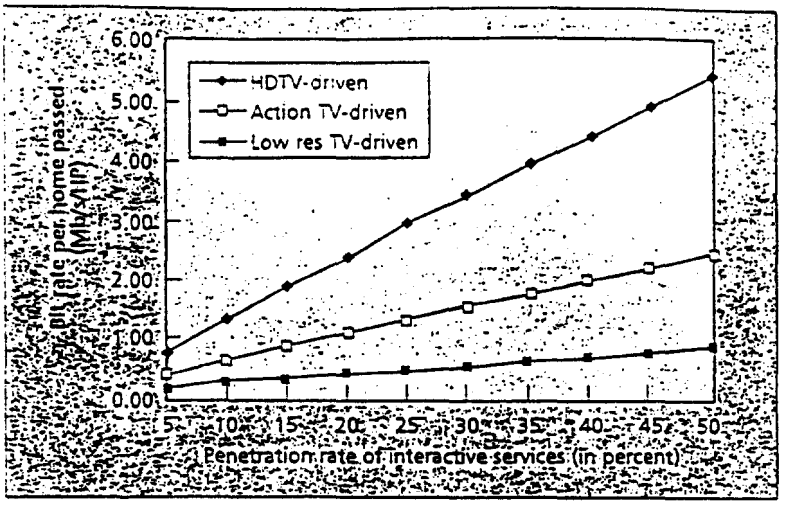
provides the digital-to-analog conversion and other telephony functions such as battery, ringing, etc. necessary for the telephony service.

Note that a different subcarrier or band of subcarriers is used for each service. In the case of broadcast video services, the 50 to 450 MHz band is used for one-way, broadcast signals. In the case of telephony services, selected subcarriers in the 50 to 450 MHz band carry downstream traffic while upstream traffic is carried in the 5 to 30 MHz band. Downstream IVS signals are carried on the 450 to 650 MHz band while upstream control signals are carried in the 5 to 30 MHz band. In the case of IVS, the capacity of the dedicated-bandwidth feeder system and number of modulators which carry the IVS signals increases as the penetration rate of IVS increases. As a result, the "Mb/s/HP" factor increases as more equipment is added.

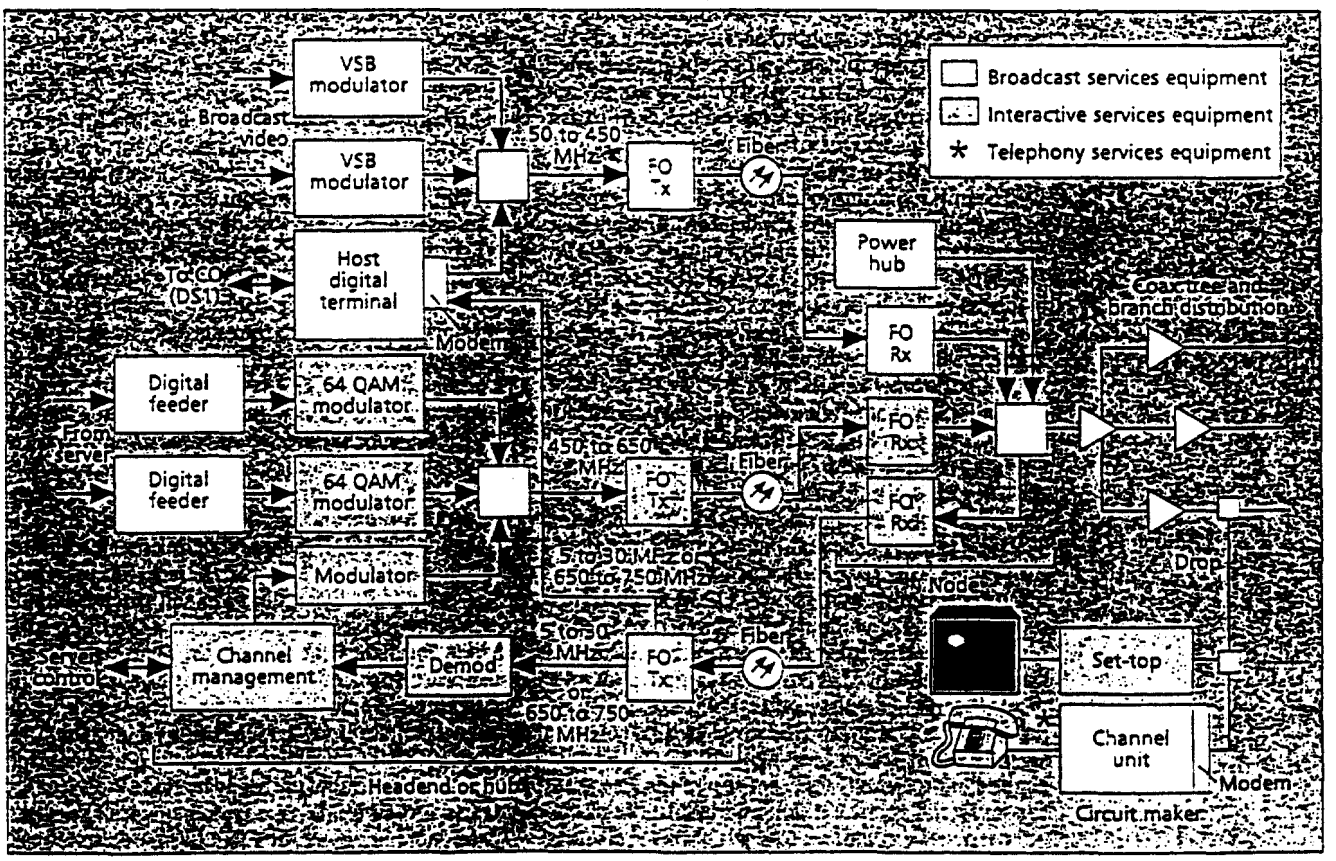
An attractive approach for the future is to combine all services into one high-speed data stream. This would reduce the number of modems required to bring services to subscribers. That approach, however, requires simultaneous high penetration of all services. If that is not the case, then only one service would bear the cost of delivery via the high-speed data stream with a resulting higher cost for that service. Until all services achieve high penetration (particularly high bandwidth services such as IVS), it is more cost-effective to use the multiple modem approach described above. As a result, that approach will be the basis for the comparisons made in the balance of the paper.

Service connections are achieved as follows: For broadcast video services, the TV set (or set-top converter) simply tunes to the appropriate subcarrier ("channel") in the 50 to 450 MHz passband and "eavesdrops" on the signal. The bandwidth for this service is not dedicated to individual subscribers, therefore the modulation and transport costs are low on a per-home-passed basis.

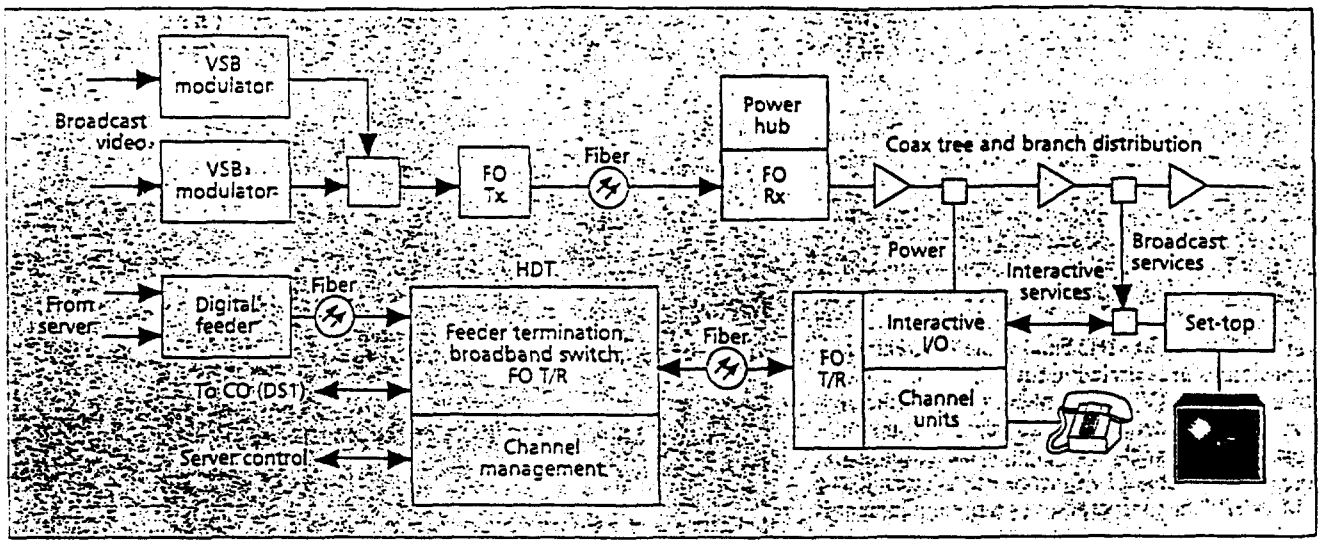
For telephony service [10], a group of digitized multiplexed 64 kb/s signals each carrying a digitized voice circuit is transmitted downstream from the Host Digital Terminal (HDT) on a given subcarrier in the 50 to 450 MHz passband. A subscriber terminal or "circuit maker" box at the residence tunes to the appropriate subcarrier, demodulates the signal to its baseband multiple 64-kb/s signals, demultiplexes the appropriate 64-kb/s signal(s) and converts it to the analog interface for the telephone supplying battery



■ Figure 2. *Bandwidth requirements as a function of IVS penetration rate.*



■ Figure 3. *Block diagram of passband system.*



■ Figure 4. *Block diagram of baseband system.*

feed, ringing, etc., as today's telephone sets expect. Power is supplied from the network with battery back up to allow lifeline service during commercial power outages. In the reverse path, the encoded telephone signal is multiplexed with other signals from other subscribers using a multiple-access protocol. The resulting signal modulates a subcarrier in the 5 to 30 MHz passband for transmission in the upstream direction. At the network end of the link, the HDT equipment receives the modulated 5 to 30 MHz subcarriers, demodulates them to baseband digital signals which are then multiplexed for transmission as DS1 signals through a loop carrier system or directly to a central office switch. The HDT also provides call processing, circuit provisioning, testing and maintenance functions for the telephony service. In the case of this service, bandwidth and equipment are dedicated on a per-subscriber basis. It should be noted that such an approach has a limited bandwidth for transporting services other than voice circuits. The 5 to 30 MHz return path is capable of 480 DS0 circuits requiring node sizes of 400 homes passed or less in high penetration applications. Under those circumstances, no additional capacity is available for ISDN or DS1 (or partial DS1) services for small business or residential video conferencing applications. This problem can be solved by serving fewer homes passed per node with a consequent increase in cost per home passed.

For IVS, dedicated channels carrying signals from the IVS servers are broadcast in the 450 to 650 MHz passband. These signals are multiplexed digital video signals that are modulated using complex techniques such as 64 QAM [11] or 16 VSB [12] in order to have sufficient numbers of channels available for on-demand services. One announced approach uses 64 QAM modulation of a 45 Mb/s DS3 signal capable of transmitting nine 4 Mb/s digital video signals in a 12 MHz passband slot [13]. Using that approach as a model for this discussion, the 450 to 650 MHz passband can carry 16 DS3s or 144 digital video signals. In order to gain access to a dedicated channel, a frequency-agile set-top sends a request for service in the upstream channel to the channel management subsystem which in turn scans the incoming channels for an available one. Upon finding a free channel, the Channel Management subsystem notifies the set-top to tune to that channel. Once tuned to the appropriate channel, the set-top then demodulates, demultiplexers and decodes the appropriate digital video signal. Because the multiple access coax system represents a hostile environment for 64 QAM signals [14], additional signal processing is required in the link to overcome impairments. As reported in the literature, such signals operate at high bit-error ratios (up to 10^{-4}) thereby necessitating adaptive equalization and forward error correction in order to operate at acceptable error rates. This adds complexity to the set-top. In the case of this service, as was the case for telephony services, bandwidth and equipment are dedicated on a per-subscriber basis in order to provide IVS.

Baseband Approach

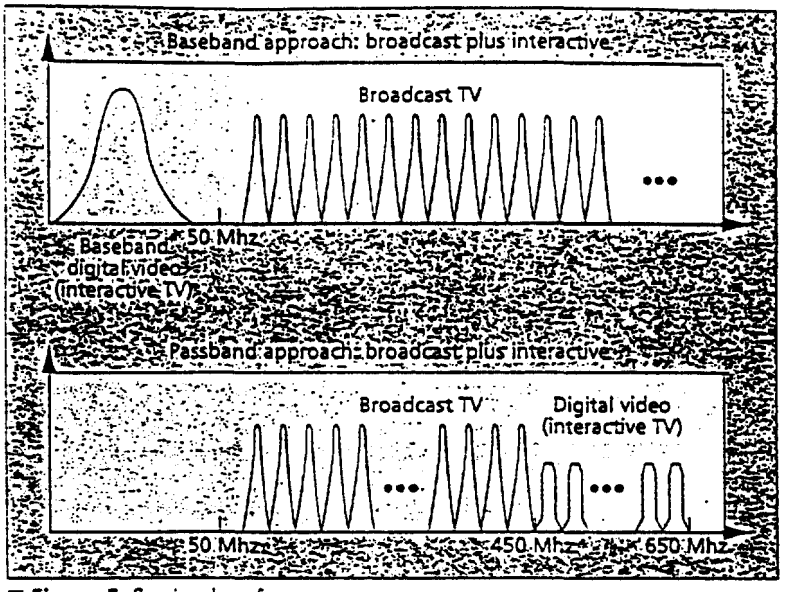
The baseband system transmits the digital IVS and telephony signal directly as "bits" through a dedicated (or moderately shared) transmission path to the subscriber. No subcarrier modulation is used as is the case in passband systems, and the transmission path does not use highly shared facilities.

Figure 4 illustrates the block diagram for the baseband approach [15]. The diagram shows the equipment required to transmit telephony services, IVS and broadcast video services. The equipment consists of an HDT that functions similarly to that used in the passband system except that its output is a baseband signal rather than a modulated subcarrier. Both telephony and IVS services are transmitted through the HDT, which serves as a multiplexer to combine those services. The output of the HDT drives a fiber link that terminates at a curbside optical network unit (ONU) which serves up to 24 living units via dedicated coax and twisted-wire service drops. The coax drop provides the video services while the twisted-wire drop provides conventional telephony. The ONU contains a demultiplexing function which separates the telephony and IVS signals and the telephony digital to analog conversion and related functions. Note that the broadcast video services are transported using an adjunct system that uses coax cable to power the ONU and simultaneously provides a path for broadcast video services. The IVS

from the ONU and broadcast video services from the adjunct coax are passively combined at the coax service drop. Figure 5 shows the frequency spectrum transmitted on that drop. Note that the IVS signals are transmitted via a baseband signal in the spectrum below 50 MHz. This is in contrast to the passband system in which IVS signals are transmitted in the 450 to 650 MHz spectrum using QAM modulators. The contrasted passband system spectrum is also shown in the figure.

Service connections for the baseband system are achieved as follows: broadcast video services are transmitted in the same way to the subscriber as was the case in the passband approach. The coax facility used to power the ONU provides the transmission path. Note that this facility could be an already in-place coax system overlaid with the baseband system to provide telephony services and IVS. This coax-based, broadcast approach is used for broadcast video services because, in the initial deployment of IVS, penetration rates for IVS are anticipated to be low. Under these circumstances, transporting broadcast video services through the IVS delivery system would be too costly. The broadcast video services channels would have to be digitally encoded and switched, requiring a set-top to provide the decoding and signaling functions at each TV set that accesses broadcast video services. Given a low penetration of IVS, that approach is expensive for broadcast video services; hence, the broadcast adjunct. As IVS penetration increases and set-tops for these services become common, or the TV set itself or other adjunct equipment incorporates the decoding and signaling function, it will become economical to pass the broadcast video services through the IVS system. At that time the coax bus would be relegated to being a power system only. Hence, the broadcast adjunct is used during the transition period to provide broadcast video services until it is economical to provide broadcast video services through the baseband digital IVS system. Since the cost of the broadcast adjunct can be justified solely on the basis of its providing power to the ONU, the transport of broadcast video services comes at a very low incremental cost.

Digital IVS signals are transmitted through a digital feeder to the HDT. At the HDT those signals are passed through a switching matrix (an ATM cell router) that provides an access port for signal security and a flexibility point for switching multicast channels. The switch outputs are multiplexed with the telephony signals that have been transmitted to the HDT through a loop carrier system (the HDT is the remote terminal of the loop carrier system). The multiplexed signal steam is transmitted in baseband form over a fiber link to the ONU. Either a point-to-point or a moderately shared point-to-multipoint link can be used. The latter is limited to a 1 x 4 split ratio due to the loss limitations of the broadband digital signal carrying both IVS and telephony [16]. At the ONU, the IVS and telephony signals are demultiplexed, the IVS signals continuing as baseband digital signals to the set-top where they are decoded. Note that demodulation and forward error correction are not required at the set-top in the baseband system as was the case in the passband system because the combination of baseband signal transport and a point-to-point drop provides a nonhostile link. As a result,



■ Figure 5. *Service drop frequency spectrum.*

the baseband input simplifies the set-top considerably. The demultiplexed digital telephony signals are fed to channel units at the ONU, which convert them to analog and provide the battery, ringing and other telephony functions. Battery backup is provided through the power feed system. The resulting analog telephony signals are transmitted over twisted-wire drops to telephone sets inside the residence.

Comparing Passband and Baseband

The preceding discussion lays the groundwork for a comparison of the passband and baseband approaches. The approaches are compared in four areas:

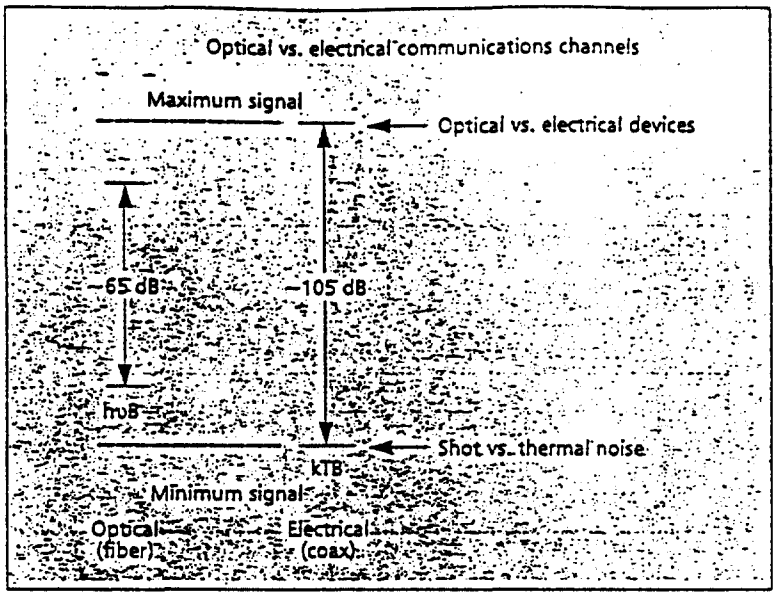
- Compatibility with the optical transmission medium.
- Compatibility with IVS signals and IVS source/sink equipment.
- Compatibility with the emerging interoffice and feeder networks.
- Cost of deployment.

The comparisons are presented from the point of view of why baseband is the preferred approach.

Compatibility with Optical Medium

Both the baseband and passband approaches utilize fiber optic transmission. The baseband system uses fiber links to a node serving up to 24 living units while the passband system uses fiber links to nodes serving a few hundred living units. It is anticipated that as passband systems evolve, fiber will penetrate deeper into the network, perhaps to nodes serving as few as 24 to 36 living units [17]. Therefore compatibility with fiber transmission is important to both approaches.

Digital baseband transmission is a better match to the fiber transmission medium because of two fundamental constraints [18]. First, the photon-detection process that converts transmitted optical signals to electrical signals has a noise floor about 40 times higher than that of the electron-detection process used in wireline and microwave communication systems. Second, light sources



■ Figure 6. *Dynamic range comparison: optical versus electrical communications.*

used to convert electrical signals to optical signals for transmission over fiber are limited in their power-output levels such that the available signal is up to 250 times less than levels available from amplifiers used in wireline and microwave electron-detection systems. Even as very powerful light sources become available, such as externally modulated CW lasers, the fiber itself becomes the limiting factor. Above a given power level, beginning in the vicinity of 10 mW, the fiber becomes nonlinear in its transmission characteristics due to Stimulated Brillouin Scattering mechanisms [19]. The result is that fiber systems have up to 10,000 times (40 dB) less dynamic range (the ratio of the highest signal level to the noise floor) than wireline and microwave systems, as illustrated in Fig. 6.

These "deficiencies" are compensated by 100 times lower loss in fiber compared with coaxial cable at frequencies of interest, and by using binary digital signaling rather than multilevel or analog modulation. Binary, or on-off keyed (OOK) signaling requires only 21.6 dB peak signal to rms noise [20] to achieve data-transmission-quality error rates of 1 in 10^9 bits. This is significantly less demanding than analog passband methods for transmitting digital video which require signal-to-noise ratios of 30 to 37 dB (or more) to achieve one error in 10^6 bits after forward error correction [14, 21]. Passband AM-VSB television signals require still higher ratios of 45 to 53 dB. For fundamental reasons, fiber is a transport medium best suited to baseband digital signals. For baseband systems, this result leads to less complex modulation schemes, simpler design rules, no post-installation "tweaking," lower cost optical components in the transmitters and receivers, etc., when compared to passband systems.

Compatibility with IVS Equipment

All IVS signals presently envisioned originate digitally because they are stored digitally at the IVS servers. Furthermore, the switching equipment to be used for connecting servers to subscribers will be (in some cases already is) digital equipment. Digital servers and switches will be common to both passband and baseband applications, the same units will be used in either case [15]. Furthermore, the IVS sink equipment is evolving toward becoming digital. Today's CD-I players and game players are digital devices with the exception of their analog output stages used for driving TV monitors. Even the TV sets themselves are incorporating more and more digital processing technology for picture-in-picture or digital noise reduction. With the emergence of digital HDTV proposals, the television industry began to set its sights on an all-digital approach [22]. The baseband approach better matches the emerging IVS source/sink devices because it directly transmits the digital signals inherent to IVS applications. The passband approach is fundamentally an analog approach requiring modems to transmit digital signals, as discussed earlier, and this fact has a cost impact to be described later.

The comments above relative to IVS also apply to telephony services. Those services are rapidly moving toward becoming digital services. Certainly on the network side, digital switching is becoming dominant. With the penetration of ISDN, the subscriber side of the network will evolve toward digital interconnects at the residence. Interestingly, both the baseband and passband approaches bring telephone signals in digital form to the curbside (baseband) or the side of the residence (passband). In other words, telephony service is a baseband digital signal in both applications. Recall that modems are required to transmit the digital signal through the passband network. Such modems are not required in the baseband approach. This is clearly evident in the comparison of Figs. 3 and 4. The same HDT and channel-unit functions are used in both the passband and baseband architecture, the difference being the use of modems for transmission path in the passband system. Additional cost for equipment is the result.

The above discussion clearly points out the nature of the trade-off between passband and baseband approaches. It is a classical and often seen trade-off in communication systems: one can implement shared transmission facilities with the consequence of increased complexity of terminal equipment or use more "wire" and less complex terminal gear. A simple example: a traditional telephone station set has a direct wire connection to the switch (simple terminal gear, more wire), whereas a cellular telephone shares the "wire" (a shared access RF connection) connecting it to the switch (less wire, more complex terminal). Such is the case with passband (less wire, more complex terminal) versus baseband (more wire, less complex terminal). How this effects the cost trade offs between the two approaches is discussed later in this article.

Compatibility with the Emerging Network

A dominant trend in telecommunications networks over the last several years has been toward the implementation of all-digital networks. A more recent trend has been the implementation of synchronous transmission. The interoffice and feeder portions of the existing and planned networks for both telephony and cable television use or will use baseband digital SONET facilities designed for survivability [23]. The concept of service delivery over SONET-based survivable rings is also being promoted

within the cable industry [24]. These ring networks which utilize the SONET path overhead provide easy access to embedded signals through the use of add/drop multiplexing. Furthermore, such networks provide direct baseband interfaces to narrowband and ATM switches. These "back-end" networks will be common to any access network approach whether baseband or passband, telco or cable. Baseband is a simpler approach for access networks, it can directly extend baseband switch interfaces and survivability features to the end user because those features are inherent to the baseband signals. Passband approaches require the baseband signals to be modulated onto subcarriers, thereby removing the ability to monitor them directly in order to gain these advantages. Direct access (observability) to subrate channels, an important property of SONET, is lost with passband. The result is either a loss of the ability to implement survivability, or the addition and standardization of new modulation/demodulation steps which add considerable delay and cost. While this may not be an issue in the near term for residential subscribers, it will be an issue for small businesses also served by the same local access network, and in the longer term for residences as services carried over the network become increasingly important (e.g., home-based health care or telecommuting). The construction of physically separate networks based on segregation of residential customers and business customers should be seen as an unnecessary and costly expense. Clearly, implementing synchronous digital approaches in back-end networks together with analog passband systems for distribution applications goes against the trend toward all-digital networks.

Cost of Deployment

The cost of both passband and baseband approaches was modeled assuming transport of broadcast video services, IVS and telephony services. A "model" community layout was established and the cost to install fiber, coax and drop cables was predicted based on current buried plant installation practices [25]. Two installation scenarios were modeled. The first was a new-build situation where new plant was installed assuming a "desert start." The second was a rebuild situation. The latter case requires some explanation. For the passband system, a rebuild consisted of rebuilding an in-place coax distribution system from an assumed 330 MHz one-way capability to a 750 MHz two-way capability. This involves replacing all active and passive components in the coax system and moving amplifier sites as required to achieve the higher bandwidth. The drop is assumed to be reused in the rebuild. Fiber feeder costs were added as appropriate for a 600-living-unit-per-node application. Rebuild for the baseband system consisted of overlaying a baseband system transporting IVS and telephony services on an in-place 330 MHz coax system (used for broadcast video services). A new fiber distribution facility for feeding IVS and telephony signals to the ONUs is assumed to be installed in this rebuild scenario. Slight modifications were assumed for the in-place coax to allow for power taps for the baseband ONUs and combiners at the coax service drop. The in-place coax drop is assumed to be reused and a new twisted-pair drop is installed when telephony services are delivered. The costs for the rebuild are given in the boxes on this page. These costs are based on predicted costs for major rebuilds such as the type assumed herein [25, 26]. Installation costs could vary from those assumed in this analysis. The effect would be to change the absolute cost results but not the relative results since the same conditions were assumed for all cases.

The equipment assumed in the analysis is that shown in Figs. 3 and 4 for the passband and baseband systems, respectively. Volume pricing was assumed for all equipment. Server and switching costs were not included in either analysis even though somewhat more switching equipment may be required in passband networks in order to implement equal access due to the channel capacity limitations in the transport system. Equipment

Passband Cost Assumptions

Density: 100 homes passed per mile

750 MHz, 2-way coax distribution system (buried plant)
- $20,000/mile new build, installed.
- $15,000/mile rebuild, installed.
- $65 drop cost, installed.

600 homes passed per node
- Migrates to 300 HP/node when interactive services require more bandwidth per home passed.

Interactive services transported via DS3s carrying ATM cells (36 Mb/s payload)
- Up to 16 DS3s in 450-650 MHz passband (12 MHz per DS3).
- Transport cost: $8000/DS3, installed.
- Modulator Cost: $2000/DS3 (64 QAM), installed.
- Two-way fiber link for RF transport: $10,000/node, installed.

Channel Management Cost
- $40,000/node, installed.

Telephone costs (1.1 POTS lines per subscriber)
- HDT: $33,000 (per 500 lines), installed.
- Premises: $350 (per line), installed.

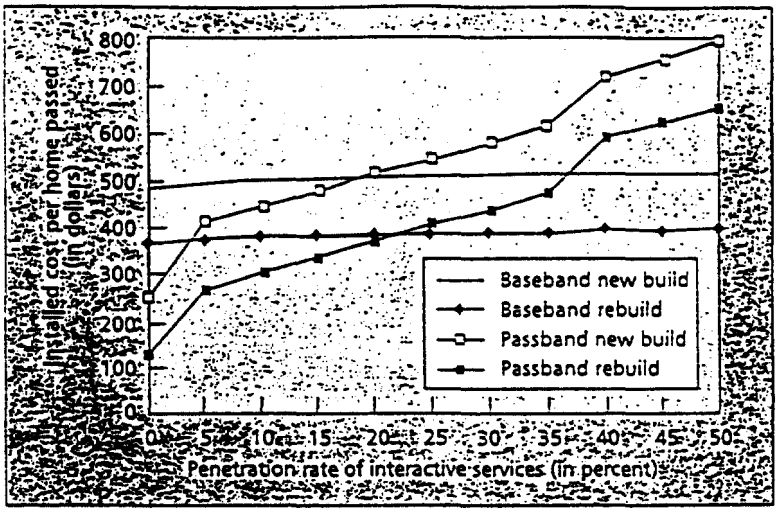
Baseband Cost Assumptions

550 MHz, one-way coax distribution system for broadcast service and ONU powering (buried plant)
- Co-installed with fiber distribution system: $5900/mile.
- Partial drop (ONU to lot line), co-installed: $2300/mile.
- $65 drop cost, installed.
- If existing coax system is reused, minor upgrade plus partial drops should be installed: $2800/mile, installed.

Fiber distribution system (buried plant)
- $19,000/mile, installed.

Equipment Cost Video Only
- HDT: $150,000, installed; includes digital feeder (1536 homes passed).
- ONU: $2000, installed (24 homes passed).

Equipment costs, video plus telephony (1.1 POTS lines per subscriber)
- HDT installed cost (includes digital feeder)
  - 20 percent penetration: $150,000 (1536 homes passed).
  - 100 percent penetration: $110,000 (288 homes passed).
- ONU cost increment: $200 per 4 lines, installed.



■ **Figure 7.** *Cost as a function of IVS penetration for video-only systems.*

configurations vary depending on which services are deployed. The rebuild scenarios do not affect the equipment that is deployed, only the outside plant costs are affected.

The first box on the previous page lists the costs assumed for the passband system. Note that a 100-homes-passed-per-mile density is assumed. The second box lists the costs assumed for the baseband system. The same installation assumptions were applied to both. Three application situations were considered. Case 1 is a video-only (broadcast video services and IVS) system in which costs were calculated as a function of IVS penetration. The results of the traffic analysis presented earlier (specifically, the lowest values for Mb/s/HP from Fig. 2) are used to predict the feeder and modulator requirements for passband and the feeder requirements for baseband. Costs are calculated on a per-home-passed basis, set-top costs are excluded. Case 2 is a video-services system with 20 percent telephony penetration (an "out-of-region" telephone company partnered with an incumbent cable company) with the same IVS penetration situation as Case 1. Case 3 assumes video services with a 100 percent telephony penetration (an "in region" telephone company). Figs. 7, 8, and 9 present the results of the cost analysis.

The cost comparison brings out several points. From Fig. 7, one can see that for broadcast video services only (the "0 percent penetration" point), the passband system has a cost advantage. As IVS penetration increases, a cost crossover occurs at 17 percent or 22 percent penetration depending on whether a new-build or rebuild situation applies. The shape of the cost curves is fairly intuitive. The passband system increases in cost with penetration because more and more feeder capacity and more and more modulators are required as additional bandwidth is needed for IVS (i.e., as more subscribers come online). The baseband system stays relatively flat because a large bandwidth capacity is placed near residences as a result of bringing fiber to the curb. In fact, the bandwidth capacity is large enough that the bandwidth required for IVS does not exceed it, therefore no additional bandwidth-generating equipment is necessary as penetration increases thereby keeping the cost flat. From the figure, one can conclude that baseband systems can be cost effective once IVS penetration reaches nominally 20 percent. It should be pointed out that the baseband system is delivering considerably higher bandwidth in the distribution system than the passband system. In fact, for the example analyzed, the baseband system delivers 18 Mb/s per home passed independent of IVS penetration, while the passband system delivers a maximum of 1.3 Mb/s/HP at 50 percent penetration, lower at lower penetration. The baseband system delivers more than an order of magnitude greater bandwidth!

The other two scenarios (Figs. 8 and 9) show a more favorable result for the baseband system. In the case of broadcast video services plus 20 percent telephony services penetration, the costs favor the baseband system at less than 5 percent penetration of IVS. The same is true for the 100 percent telephony services penetration. Note again that the baseband system is delivering more than an order of magnitude higher IVS capacity per home passed than the passband system.

An interesting result: by examining the figures, one can surmise that it is actually less costly to overlay a baseband system on an existing passband broadcast video services system (the "rebuild" case for the baseband system) than it is to rebuild the existing broadcast video services passband system to carry IVS and telephony services. This is seen by comparing the "rebuild" cost results for both systems. In the worst case (the video-only case), the cost crossover occurs at 22 percent IVS penetration. In the other cases, the cost crossover is at less than 5 percent IVS penetration. This illustrates the point that it is best (and least costly) to deliver baseband digital services using a baseband system rather than a passband system. This has been seen before, as is described in the following section.

Set-top costs have not been included in the models. Both the passband and baseband approach require a set-top to implement IVS. The set-top used in each case is similar, both have digital to analog converters, both have video display "engines" to manipulate the video output, etc. The major difference is that the passband set-top uses an RF front end to demodulate the QAM signal to baseband for processing by the rest of the set-top. Also included in this front end is adaptive equalization and forward error correction. Since the output of the RF front end is a baseband signal, it is intuitive that the "front end" of a baseband set-top is much simpler since it terminates a baseband signal directly. The difference in complexity leads to a higher cost for the passband set-top. Even if the cost difference is only a few dollars, the number of set-tops deployed in a high IVS penetration environment can lead to significant cost savings for the baseband system.

The above results apply to a model system with fixed equipment costs. In an actual deployment situation, learning curve effects and varying IVS penetration rates will impact cost. For example, what would be the cost to deploy baseband or passband IVS systems in a multi-year, large-scale installation effort (greater than 10 million lines) with increasing IVS penetration rates? That is the situation one will likely encounter in practice. Since baseband systems have more optical fiber and more electro-optical devices than passband systems on a per-home-passed basis (fiber is brought to approximately 20 homes passed in baseband

applications versus a few hundred homes passed in passband systems), and since baseband systems have a larger content of strictly digital circuitry, one would expect more aggressive price reductions with volume for baseband technology [18]. Hence, as deployment volume increases, the cost of baseband systems decrease more rapidly than passband systems [27]. Furthermore, as seen in Figs. 7 through 9, baseband systems become more cost-effective versus passband as IVS penetration rates increase. When a multi-year, large-scale deployment is modeled and the learning curve effects and penetration rate effects are accounted for, it is found that deploying baseband systems can cost substantially less, up to 25 percent [28].

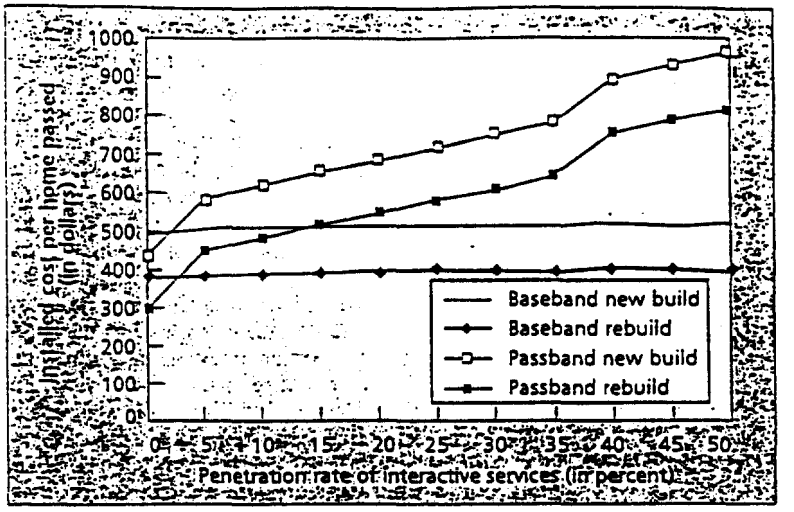
The conclusion reached from the above analysis is that baseband systems can be cost effective versus their passband counterparts. In fact, a "rule of thumb" emerges from the analysis: if any two of the three services is deployed (i.e. broadcast video services, IVS, or telephony), baseband systems are the least cost approach. If only one service is deployed (i.e., broadcast video services), then passband is the least cost approach.

Past Experience with Baseband and Passband Systems

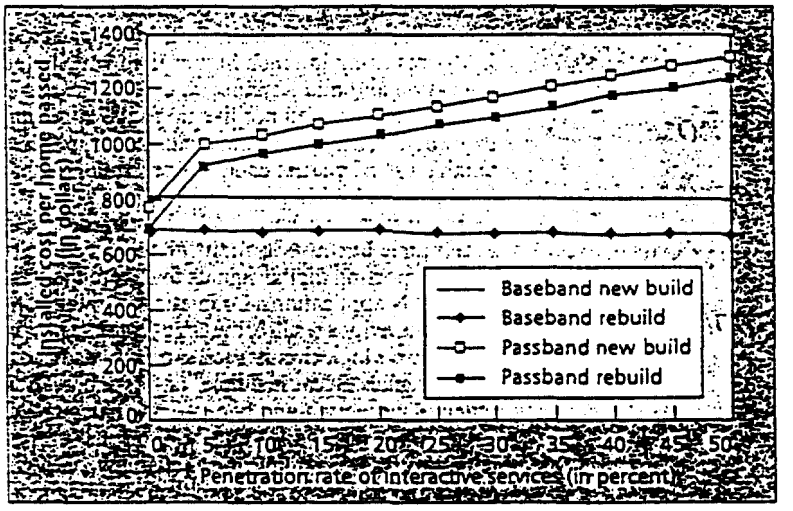
In the '80s, both passband and baseband approaches were considered for LANs. Standards were written for both [29]. The passband approach was the IEEE 802.4 token bus standard [30]. Two baseband approaches were standardized, the IEEE 802.3 CSMA/CD standard [31] and the IEEE 802.5 token ring standard [32]. Both passband and baseband had staunch proponents. New companies were formed to pursue each. In some cases, several companies pursued both independently. An intense battle was waged to determine the preferred approach. What was the result? The baseband approach was the resounding winner! The companies that pursued passband either went out of business or changed product lines. Support for the token bus passband standard has eroded to the point where there is little or no activity. What were the factors that led to this result and do they apply in the case of IVS systems considered herein?

Interviews with participants and references in the literature identify the cause. The fundamental reason for the demise of passband LANs is that RF subcarrier modulation on coax cable is inherently an analog transmission method. It is optimal for broadcasting analog signals to multiple users, but has significant drawbacks when it is used to transport digital signals to dedicated users as was the case in LAN applications [33]. This fundamental limitation manifested itself in several ways as passband LANs were deployed.

The inherent analog nature of the RF coax medium means that even digital signals are transmitted as analog signals. A modem is required to modulate an RF subcarrier to transport the signal. That adds complexity and cost to the system and it also adds maintenance problems. Digital signals degrade more precipitously than analog signals. They degrade catastrophically instead of gradually when signal levels or frequency response change.



■ Figure 8. *Cost as a function of IVS penetration for 20 percent telephony services penetration.*



■ Figure 9. *Cost as a function of IVS penetration for 100 percent telephony services penetration.*

For instance, a 10 dB drop in signal level for an NTSC TV signal results in more "snow" in the picture. A similar drop in a digital signal's level could result in catastrophic loss of the signal. This is particularly true of the more complex, multilevel signals that are used in RF subcarrier applications to minimize bandwidth use. For example, in the approach analyzed herein for transporting digital signals in cable TV systems for interactive services, 64-QAM modulation is used in order to get 45 Mb/s into a 12-MHz bandwidth [13]. This is a very complex signal; 64 different values of amplitude and phase are used to represent the "bits" of the digital signal. While an NTSC TV signal will tolerate seasonal fluctuations in RF amplitude and phase without serious degradation, such digital signals may not. This characteristic led to a significant maintenance problem in passband LANs [34]. Frequent adjustment was required to keep the RF levels balanced in order to maintain integrity of the digital signals. Seasonal maintenance was required even though most systems were indoors! Those familiar with telephone company analog coaxial cable carrier systems such as L-carrier can relate to these problems.

The premises communications environment is one of constant moves and adds of attached

It is interesting to note that the arguments against baseband in the early days of LAN applications were similar to those heard today in IVS applications.

users, and one in which upgrades to accommodate new services are routinely made in response to the evolving demands of the network users. In the RF coax environment, moving and adding unanticipated users ultimately results in the need to re-engineer the RF levels in the coax distribution system. Adding or changing the size of taps in the coax line results in changes in the delivered RF signal levels requiring "re-tuning" of the levels in order to guarantee performance of the signals delivered via the RF subcarriers. Upgrades to allow new services often required expanding the bandwidth of the coax system or changing the frequency at which the two directions of transmission in the coax were separated. The result was the re-engineering of the entire coax distribution system. A similar circumstance is seen today as CATV operators upgrade their networks from 330 MHz to 550 MHz or 750 MHz. All active (line amplifiers) and passive (taps and even connectors) components must be changed to accommodate such an upgrade. For passband LANs, these factors led to the constant tweaking of passband LANs resulting in much higher than anticipated operation and maintenance costs [35]. Passband LANs as a result did not live up to the hope that they would be the universal communications pipeline making use of mature cable TV technologies that can be put in and forgotten.

In contrast, baseband LANs found widespread acceptance because of their inherent simplicity for transporting digital signals that were the traffic in LAN applications. Dramatic cost reductions were achieved as a result of the large-scale integration of the simple logic circuits used to process and transmit the signals. Because simple "on-off" modulation schemes were used and because no analog or RF circuitry was required, seasonal adjustments were not necessary and communication reliability was high. Moves and adds were still a problem requiring rearrangement of facilities, but once facilities were put in place, they operated without seasonal adjustments. Operation and maintenance costs were low.

To summarize, passband lost in the LAN transport technology battle because it cost more to implement and maintain that its baseband counterparts. Using an inherently analog medium for digital signal transmission led to a variety of difficulties that resulted in the demise of passband.

Do these factors apply in today's IVS transport applications? Yes; in both cases, inherently digital signals are or are planned to be transmitted using analog subcarrier modulation techniques for point-to-point dedicated connections in a shared-medium architecture, the same problem that passband LANs faced. Architectures are similar in that LAN systems generally contained only a few line amplifiers due to the restricted geographical areas they served. Today's fiber-segmented passband networks also have only a few amplifiers in their coax distribution systems resulting in relatively small serving areas accessing the coax. One significant difference is that LAN-based networks were installed with greater care than today's cable systems because of stringent requirements for reliability and foreknowledge that the networks would be used for digital signals. Furthermore, today's proposed passband IVS systems are even more complex than their LAN counterparts. More complex modulation schemes are to be used and the applications are more demanding. Error tolerance in compressed video signals is very low, single uncorrected bit errors can lead to noticeable impairments. A further complication that coax-based IVS networks will face has to do with degradations suffered by coaxial cable after installation and the poor condition of existing systems. Specifically, coax loss increases with time after installation, particularly at higher frequencies, due to temperature cycling [36]. The higher frequency band is precisely where IVS will be transmitted, leading one to predict potential transmission reliability problems. The installed plant, particularly the passive components and wiring inside residences provide a hostile environment for the IVS signals carried in the 450 to 650 MHz band [21, 37]. The end result will likely affect the cost and reliability of the IVS network. Finally, the 5 to 30 MHz return-channel band represents a significant bottleneck for telephony and interactive services due to bandwidth limitations and noise ingress [38]. Again, cost and reliability of service are likely to be affected.

It is very tempting to try to reuse the embedded coax cable systems for IVS, particularly for cable companies since it is hoped that upgrading would cost less than installing new networks. A similar temptation faced LAN designers in that reuse of available cable TV technology was going to lower implementation costs. After struggling to cost effectively overcome the limitations of the passband medium for transporting digital point-to-point signals, many LAN designers abandoned the passband approach in favor of baseband. It is interesting to note that the arguments against baseband in the early days of LAN applications were similar to those heard today in IVS applications. While it was acknowledged that baseband was the ultimate LAN approach (as is being said today for IVS applications), its detractors pointed out that new technology had to be developed to implement baseband and that its cost would be too high initially. The relative ease with which cost-effective new technology was developed (based on the fact that largely all-digital circuitry was required) and the reliability of the baseband approach once it was installed led to baseband being preferred. Baseband IVS technology is in a similar situation today.

In spite of the availability of coax systems and the rationale for upgrading them to allow provision of IVS, considerable modification will be required to implement the upgrade and even after that is complete, there are substantial risks that the resulting system will have performance problems as was the experience with passband LANs.

Summary

The baseband approach is the best choice for implementing the proposed network for transporting IVS for several reasons.

It is better matched to the properties of the optical fiber communication channel (the communications medium of choice). As a result, baseband systems will utilize simpler modulation schemes and lower cost components for the fiber optic transport system.

It is better matched to the emerging telecommunications network. Baseband systems continue the trend toward all-digital networks and allow

the advantages of synchronous transmission to be extended to distribution networks.

It is better matched to the emerging new services. Given that IVS will be and telephony services are becoming strictly digital signals, baseband systems transport such signals directly without the modems required in passband approaches thereby reducing implementation and operating costs.

Baseband systems will cost less to deploy, particularly as IVS penetration increases. Furthermore, past experiences in LAN applications with baseband systems indicate that they cost less to operate and evolve more gracefully than their passband counterparts. The passband approach is rooted in the desire to provide today's broadcast services more economically trading off the ability to provide tomorrow's interactive services efficiently. The baseband approach meets the future need, easily accommodating today's broadcast services using a straightforward overlay.

Baseband systems continue the trend toward all-digital networks and allow the advantages of synchronous transmission to be extended to distribution networks.

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Biography

J. RICHARD JONES received his B.S. in mechanical eLngineering in 1969 from Utah State Unviesity, and M.S. and Ph.D. degrees in applied physics from Cornell University, in 1970 and 1973, respectively. He has been employed by Bell Laboratories, Harris Corporation, Siecor Corporation, and Fiber LAN, working in the field of optical fiber communication systems. In 1988, he co-founded BroadBand Technologies, Research Triangle Park, North Carolina, in order to pursue the development of broadband fiber in the loop systems.

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BROADBAND® TECHNOLOGIES, INC.

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AT&T NETWORK SYSTEMS AND BROADBAND TECHNOLOGIES ANNOUNCE ENHANCED INTERACTIVE VIDEO NETWORK SYSTEM

MORRISTOWN, N.J.--Oct. 5, 1994--AT&T Network Systems and BroadBand Technologies, Inc. today announced an agreement to develop and market a new system that will allow telephone and cable companies to connect homes and offices with interactive multimedia services.

The new Switched Digital Video (SDV) feature for AT&T's SLC®-2000 Access System integrates BroadBand's industry-leading Fiber Loop Access (FLX®) switching and transport technology with AT&T's widely accepted SLC- 2000 system. The combination will create a powerful, cost-effective technology platform for new digital services that network operators want to offer.

"AT&T Network Systems is committed to providing our customers with total solutions for the explosive new interactive multimedia market," said Richard A. McGinn, President and CEO, AT&T Network Systems.

"BroadBand Technologies adds a cost-effective, high-performance video capability to our SLC-2000 Access System that will meet the switched digital video requirements that have already been identified by many of our customers," said McGinn.

"The addition of a SLC-2000 SDV feature with FLX technology to our access product line extends AT&T's ability to offer service providers the broadest range of architectural choices for solving unique application and service requirements with end-to-end total solutions," he said.

The SLC-2000 SDV feature will meet existing and emerging industry standards including SONET, TR303, MPEG2 and ATM. The system will be marketed, sold and serviced in the US and Canada by AT&T Network Systems with full support from BroadBand Technologies. Under the terms of the agreement, BroadBand Technologies will be the sole provider of the SDV capability for SLC-2000.

P.O. Box 13737 Research Triangle Park, NC 27709-3737 Phone Number: (919) 544-0015 Fax Number: (919) 544-3459

"In addition to their world-class equipment, AT&T's critical systems integration capabilities will facilitate communications service providers' rapid deployment of advanced broadband networks," said Salim A. L. Bhatia, President and CEO of BroadBand Technologies. "Our alliance with AT&T provides a strong endorsement for our switched digital video and fiber-to-the-curb technology and provides us with the marketing and field support to address this exciting market."

BroadBand Technologies, Inc., (NASDAQ: BBTK) based in Research Triangle Park, NC., was founded in 1988. Its mission is to provide network operators with the systems required to bring the power of interactive switched digital broadband technology to consumers. The company's FLX System is currently being deployed by Bell Atlantic and Southwestern Bell and has been in trials at most regional operating companies, GTE and a number of international telephone companies.

AT&T Network Systems is one of the world's largest manufacturers and providers of network telecommunications equipment, offering communications service providers virtually everything they need to build and operate their networks. AT&T provides communications services, equipment and computer systems to consumers, businesses and communications companies around the world.

(a) FLX is a registered trademark of BroadBand Technologies, Inc. SLC is a registered trademark of AT&T

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BROADBAND TECHNOLOGIES AND AT&T MICROELECTRONICS ANNOUNCE COST, TECHNOLOGY BREAKTHROUGH FOR INTERACTIVE VIDEO NETWORKS

RESEARCH TRIANGLE PARK, NC, December 6, 1994 -- BroadBand Technologies, Inc. (NASDAQ: BBTK) and AT&T Microelectronics today announced a technology breakthrough that further reduces the cost of "fiber-to-the-curb" networks. This new use of encoding technology enables BroadBand's Fiber Loop Access (FLX®) System and AT&T's SLC-2000® Access System with SDV, which incorporates FLX technology, to deliver voice and broadband digital interactive services over the twisted pair wire that is commonly used between the curbside and homes, reducing the installation cost for the FLX System.

The encoding technology also enables the FLX System to provide a simple, affordable solution for those subscribers who only want standard broadcast cable services. Because the encoding technology uses a frequency that is well below the range of standard broadcast channels and above those used for ordinary voice or digital network services, the FLX System can deliver analog television and voice signals over the same wire as the interactive services. This allows the reuse of both existing telephone drops (analog twisted pair) to the home, as well as the coax cable within the home.

The two companies are integrating 16-CAP, a standard encoding and compression technology developed by AT&T Bell Laboratories, into BroadBand's FLX System. 16-CAP (16-Carrierless Amplitude and Phase Modulation) is a data encoding technique that reduces the bandwidth required for video transmission to one quarter of what is required for non-encoded video. This implementation provides for the transport of a robust digital baseband signal as well as a high-speed upstream signal for interactive services over standard telephone wiring.

"BroadBand is dedicated to driving down the installation costs of switched digital video and accelerating the time to market of the industry's most powerful interactive services network

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architecture," said Rick Jones, Executive Vice President and co-founder of BroadBand Technologies. "Utilizing AT&T Microelectronics' implementation of 16-CAP technology in the FLX System enables network providers to deploy fiber-to-the-curb for high bandwidth communications, and use the industry standard wiring the final yards to the home for ease of installation and cost effectiveness. The ability to transport digital signals on twisted pair wiring creates one more cost-effective and elegant option for network providers deploying the FLX System in the real world."

"Cost of implementation and compatibility with today's networks have been the major considerations for the growth of interactive services," said Gerry Pepenella, transmission and access IC marketing director for AT&T Microelectronics. "Thanks to the excellent collaboration between the two companies, there's now a cost-effective solution to add new, interactive video and data service capabilities to the existing infrastructure.

"Not only does the existing wiring and customer equipment remain intact," he added, "since 16-CAP is an industry standard, it brings us closer to the day when the public network is able to deliver a whole range of new combined voice, video and data services into homes and offices at an affordable price."

16-CAP modulation/demodulation allows an encoded signal to be sent over Category 3 Unshielded Twisted Pair (UTP) wiring, the standard for curbside-to-home installation. Because this transmission can be accomplished without the use of carrier modulation schemes or forward error correction, it is highly cost-effective when compared to competing encoding/modulation technologies.

BroadBand Technologies' FLX System is a switched digital video system that incorporates asynchronous transfer mode (ATM) switching and transport to provide broadcast and interactive services over fiber-to-the-curb networks. The FLX system enables network operators to provide telephone service and advanced services such as enhanced cable TV, impulse pay-per-view movies and movies-on-demand, multi-media home shopping, electronic yellow pages, interactive educational programs, and telemedicine on up to 1,500 interactive channels. The BroadBand FLX system allows consumers to choose when and what to watch, transforming the idea of an unwieldy

cable TV system with hundreds of channels into an easy-to-use, interactive channel that is customized for each consumer.

AT&T Microelectronics has pioneered the use of 16-CAP in telephone and interactive services networks. The ATM Forum, an industry-wide group developing standards for asynchronous transfer mode switching technology, has approved 16-CAP for communications over UTP wiring in local area networks, but today's announcement is the first involving 16-CAP technology for use in broadband networks that deliver voice, broadcast video, interactive video, and other services.

BroadBand will begin shipping the FLX System with 16-CAP technology in 1995.

AT&T Microelectronics offers a full line of high-performance components and electronic systems to original equipment manufacturers for applications in network communications, telecommunications, cellular/wireless and video. Included in the product line are CMOS, Bipolar and High Voltage custom and standard products, communications devices, graphics and speech processors, lightwave products, and power supplies.

BroadBand Technologies, Inc., based in Research Triangle Park, N.C., was founded in 1988. Its mission is to provide network operators with the systems required to bring the power of interactive switched digital broadband technology to consumers. The company's Fiber Loop Access (FLX) System is currently being deployed by Bell Atlantic and is being trialed by Southwestern Bell, and has been in trials at most regional operating companies, GTE, and a number of international telephone companies. The FLX System was selected by AT&T as its switched digital video (SDV) offering for the U.S. and Canadian markets.

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Note to editors: FLX is a registered trademark of BroadBand Technologies, Inc.

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BROADBAND® TECHNOLOGIES, INC.

FOR IMMEDIATE RELEASE

INTERACTIVE TV LEADERS COOPERATE TO DELIVER VIDEO-ON-DEMAND SERVICES

- BroadBand Technologies, Inc., Compression Labs, Inc., Digital Equipment Corp., Microware Systems Corp., and Philips Consumer Electronics Co. to Deliver First Standards-Based End-to-End System -

RESEARCH TRIANGLE PARK, NC, April 20, 1994 -- A group of leading communications hardware and software vendors today announced they are cooperating to deliver a standards-based, end-to-end system for providing interactive video-on-demand services to consumers. The system is the first open, end-to-end architecture delivered for the information superhighway, and uses industry standards such as ATM (Asynchronous Transfer Mode) for communications and MPEG (Moving Pictures Expert Group) for compressing video signals.

This adherence to standards will ensure seamless compatibility between data storage equipment, fiber-to-the-curb networks, and intelligent set-top devices, facilitating the delivery of high-performance video on demand to consumers.

Open, standards-based systems enable cost-effective delivery of new services, breaking price barriers to allow carriers to deploy interactive services in an economical manner.

The system incorporates Digital's video and interactive information server, a fiber-to-the-curb, digital, switched network system from BroadBand Technologies, terminals or "set-top" boxes from Philips Consumer Electronics Co. and Compression Labs, Inc. (CLI), and DAVID operating software from Microware Systems Corp. to build a broadband, all-digital, interactive information superhighway. The creation of an open, standards-based interface between the video server and networking elements of the information superhighway ensures that consumers will be able to access programming, such as movies-on-demand and home shopping, from all the different service providers.

P.O. Box 13737 Research Triangle Park, NC 27709-3737 Phone Number: (919) 544-0015 Fax Number: (919) 544-3459

The combined use of ATM and MPEG will enable unequaled levels of two-way video communication and provide the basis for advanced video-on-demand services.

Salim A.L. Bhatia, president and CEO of BroadBand Technologies, said, "By working together to define this open network architecture, we will speed the time-to-market of high-quality interactive video. This open, cost-effective ATM architecture will also allow a wide range of third-party service suppliers to deliver advanced video-on-demand to consumers."

"Open standards are vital to the success of video and interactive information initiatives," said Charles F. Christ, vice president of Digital's Storage Business Unit and the company's Video and Interactive Information Services group. "Availability of a single, cohesive end-to-end solution that integrates products from different suppliers opens the door to the effective delivery of high-quality interactive video services to users."

Kenneth Kaplan, president of Microware Systems, said, "We believe that open access to all networks and application interoperability are crucial for the growth of the interactive industry. Our DAVID software is a common operating system standard for interactive digital decoders that can be used in telephone, cable TV and wireless networks. DAVID's enabling technology has already been widely adopted in this industry, primarily because it's based on proven, immediately deliverable software."

Bill Kennedy, senior vice president at Philips Consumer Electronics, said, "Success of advanced services hinges on three dependent requirements: a large variety of interactive programming; a flexible, high-bandwidth delivery pipeline; and flexible, easy-to-use consumer hardware. Open, non-proprietary standards provide the greatest incentive for multiple supplier participation in each of these areas, which will build the business far faster than any closed approach."

Unlike other systems using ATM, the multi-vendor system will send ATM cells all the way to the set-top box instead of to the final active node in the system. Delivering ATM cells to the home provides subscribers with access to more powerful interactive services. Transporting MPEG information in ATM packets, the system will deliver up to 1500 channels of interactive programming. (See Figure 1)

Digital's integrated video server platform stores and transmits video-on-demand, and other interactive information services. It incorporates advanced technologies that enable it to process pure ATM data and connect seamlessly with broadband infrastructures. Currently a key element in a number of video-on-demand trials in the U.S. and abroad, the server platform incorporates Digital's powerful Alpha AXP processors, StorageWorks disk storage arrays, Digital Linear Tape library systems, an interactive gateway unit, a server management unit, GIGAswitch, a high-speed networking switch linking the various elements, and a complete software environment to manage the video server platform components and the interface back to the set-top box in the consumer's home.

BroadBand Technologies' Fiber Loop Access (FLX®) platform is a fiber-to-the-curb system that incorporates ATM switching and transport. The FLX system enables network operators to provide advanced services such as enhanced cable TV, impulse pay-per-view movies and movies-on-demand, multi-media home shopping, electronic yellow pages, interactive educational programs, and telemedicine on up to 1500 interactive channels. The BroadBand FLX system allows consumers to choose when and what to watch, transforming the idea of an unwieldy cable TV system with hundreds of channels into an easy-to-use, interactive channel that is customized for each consumer.

The intelligent interactive terminals developed and manufactured by Philips and CLI decode compressed digital signals entering the home over the broadband network into a standard signal usable by conventional TVs, stereos, and VCRs. The Digital Entertainment Terminals use the MPEG-2 international standard for digital video compression, and the MPEG-specified Musicam audio system. The terminals contain microprocessing capabilities equivalent to a powerful personal computer and have a total of over 5 Mbytes of random access memory (RAM). Performance of the terminals exceeds that of existing conventional TV broadcast and cable systems, offering picture resolution of 720x480 pixels accompanied by CD quality sound.

Microware Systems' DAVID (Digital Audio Video Interactive Decoder) is an open operating system that runs on interactive digital television decoders, including the Philips/CLI Digital Entertainment Terminals in the end-to-end system. At the heart of DAVID is Microware's

industry leading OS-9 Real-Time Operating System. The highly demanding functions of interactive decoders require the multi-tasking, real-time performance of OS-9. A set-top box running DAVID displays on-screen menus allowing subscriber access to the information superhighway. The subscriber can interact with the applications, or select different applications, via the set-top decoder's remote control. The easy to use screens will help navigate the user to virtually infinite data banks of video and interactive programs.

BroadBand Technologies, Inc., based in Research Triangle Park, N.C., was founded in 1988. Its mission is to provide network operators with the systems required to bring the power of interactive switched digital broadband technology to consumers. The company's Fiber Loop Access (FLX™) System is currently being deployed by Bell Atlantic and has been in trials at most regional operating companies, GTE, and a number of international telephone companies.

Compression Labs, Inc., based in San Jose, California, was founded in 1976 and is a leader in the compressed digital video (CDV) communications arena. The company's CDV technology digitizes and compresses full-motion video signals for practical and economical transmission over telephone, satellite, and cable. Since 1982, CLI has developed and marketed CDV technology across a broad spectrum of video communications applications such as video-conferencing, videophones, broadcast television and HDTV.

Digital Equipment Corporation is the world's leader in open client/server solutions from personal computing to integrated worldwide information systems. Digital's scalable Alpha AXP platforms, storage, networking, software and services, together with industry-focused solutions from business partners, help organizations compete and win in today's global marketplace.

Founded in 1977, Microware is one of the first microcomputer software houses serving the real-time software market. Microware is a "total solution" supplier of real-time system software products, providing high-performance real-time operating systems, high-quality development tools optimized for real time applications, and outstanding customer support. Microware offices are

located in Des Moines, Iowa, San Jose, California; Tokyo, Japan; Winchester, England; and Aix-en-Provence, France.

Philips Consumer Electronics Company (PCEC), based in Knoxville, Tenn., designs, manufactures and markets Philips and Magnavox consumer, professional/commercial and business electronics products and systems. The North American unit of Philips Digital Videocommunication Systems is based at PCEC. Working with Philips Laboratories, Briarcliff Manor, NY, PCEC maintains one of the nation's largest television, video and audio engineering capabilities. PCEC is a member of the Digital HDTV Grand Alliance, and part of Philips Electronics N.V., a global leader in compressed digital video and interactive media technologies.

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Note to editors: FLX is a trademark of BroadBand Technologies, Inc. Alpha AXP, Digital and the Digital logo, GIGA switch and StorageWorks are trademarks of Digital Equipment Corporation.

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