A UNIFIED APPROACH TO DATA TRANSMISSION OVER CATV NEWORKS

THOMAS E. O'BRIEN JR.

JERROLD DIVISION, GENERAL INSTRUMENT CORPORATION

ABSTRACT

Many feel that data services will compel both rural and urban cable systems to form a national communication network. Concurrance of video and data services can be achieved through establishment of CATV data transmission standards. The characteristics of data transmission, including channel capacity, bandwidth, signal to noise ratio, modulation, error rate, error detection and encoding methods are investigated, a distributed processing complex supporting multiple service offerings is detailed and finally, a full set of quantitative parameters for CATV data transmission is recommended.

INTRODUCTION

Through the 1980's and beyond, the quality of life will be improved in many different ways. A large part of the anticipated enrichment will accrue through progress in communication technology, as it applies to the common man. CATV networks, initially constructed for the purpose of bringing entertainment to rural areas, are now being built in major cities. By the end of this decade, interconnection between individual systems will enable the carriage of information over a national communication network.

The CATV manufacturer stands today, on the threshold of a challenging opportunity. As the emphasis within the network shifts from entertainment toward information, the equipment and techniques offered to support the needs of CATV operators must remain viable. Engineering philosophies now being developed, must be designed to fulfill not only the current requirements, but also the needs of the future. It is, therefore, prudent to establish a set of guidelines for data transmission over CATV networks. The individual characteristics embodied in such a philosophy, are too numerous to explore in detail; however, it is instructive to identify the major technical implications and the resulting benefits of the approach.

INFORMATION TRANSMISSION

All information passed through a communication system is degraded to some extent by distortion and the addition of interfering signals and noise. The degradation results in decoding uncertainty (error rate) whose tolerance is somewhat application dependent and, in general, may be improved by reduction of information rate and/or higher system cost. A suitable philosophy should, therefore, allow for variations in modulation method, bandwidth, error rate and carrier frequency assignments, while providing established guidelines for channel usage, signal levels, interference with other signals and compatability with other equipment and services on the CATV network. Before proposing parameters for CATV networks, it will be helpful to review the general problem of information transmission.

Figure 1 illustrates the data transmission system as it applies to CATV networks. Although a one-way system is shown for simplicity, the concept is the same when extended to two-way.

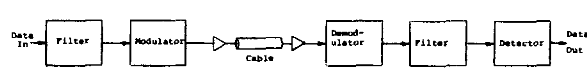

Figure 1
Data Transmission System

The system consists of a modulator, transmission path (CATV cable network) and demodulator. The filters, whether part of the transmission process, or used intentionally, are necessary to assure adequate signal to noise ratio. However, they also reduce the ability to separate the individual transmitted bits, which is called intersymbol interference. The information handling capability of the transmission system, or the maximum rate of transmission of data over the channel, is referred to as the channel capacity. The maximum possible rate of transmission of binary digits over a channel limited to bandwidth W, with mean signal power S and mean noise power N, was found by Shannon[1] to be given by

$$C = w \log_2 (1 + S/N)$$

It should be noted that in order to achieve this rate, the information must be coded in the most efficient manner which will generally involve highly complex circuitry and incur large time delays in transmission. It is evident that for a specified channel capacity, bandwidth and signal power can be exchanged for each other. The modulation method is essentially a means for effecting this exchange, however, the process is highly inefficient since one must increase the power exponentially to effect a corresponding linear decrease in required bandwidth. It should be obvious that in CATV systems, direct transmission of baseband data is not practical due to the amount of bandwidth required. Instead the whole spectrum is shifted to a higher frequency by modulating an RF carrier. This process gives rise to upper and lower sidebands and hence, the required bandwidth is doubled.

As indicated above, virtually error free digital transmission could be achieved (provided channel capacity is not exceeded), by appropriately coding the binary message sequence. Specifically, at a binary transmission rate of R bits/sec., if R<C it may be shown that the probability of error is bounded by

$$Pe \leq 2^{-E(R,C)T} \quad R<C$$

as shown in Figure 2. As the transmission rate R approaches the channel capacity the probability of error approaches 1. The parameter T indicates the time required to transmit the encoded signal. With the transmission rate and channel capacity fixed, the probability of error may be reduced by increasing T.

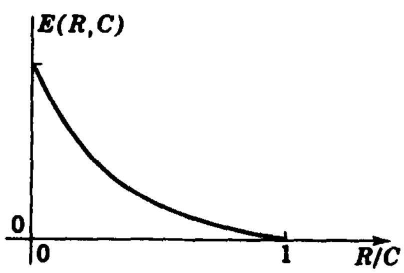

Figure 2
Probability of Error vs. (R,C)

A great deal of research activity is being devoted to the investigation of various modulation and encoding methods. This work froms the basis of communication theory.

MODULATION METHODS

There are essentially three ways of modulating a sine wave carrier: variation of its amplitude, frequency or phase in accordance with the transmitted information. These are commonly known as ASK, FSK and PSK respectively. FSK systems perform better than ASK, while PSK systems perform still better. The major factors affecting the selection of modulation method lie in the demodulation or detection process. The two commonly used detection methods are envelope detection and synchronous detection. ASK may use envelope detection, FSK may use differentiation (to convert frequency variation to amplitude variation) followed by envelope detection, while PSK requires synchronous detection. Synchronous detection requires a locally generated receiver clock of the same frequency and phase synchronized or slaved to the transmitter clock to within much less than a fraction of a cycle. This is difficult and costly to achieve in practice, for example, at a data rate of 3.5 MHz the required accuracy is much less than 60 nanoseconds. The signal to noise ratio of AM versus FM is also important. As indicated previously, widening the transmission bandwidth (as is required for wideband FM) improves the signal to noise ratio. With AM, the signal to noise ratio is linearly dependent on carrier to noise ratio and cannot be improved. In fact, any bandwidth increase beyond what is actually required serves only to increase noise, thereby, lowering the signal to noise ratio. With FM, as illustrated in Figure 3, it becomes obvious that significant improvement in signal to noise ratio is possible by increasing the modulation index at the expense, of course, of increased bandwidth. Notice that the signal to noise ratio beyond the 12 dB carrier to noise point, results in a constant linear improvement of $3\beta^2$, where β is the modulation index - the ratio of FM deviation to modulating frequency.

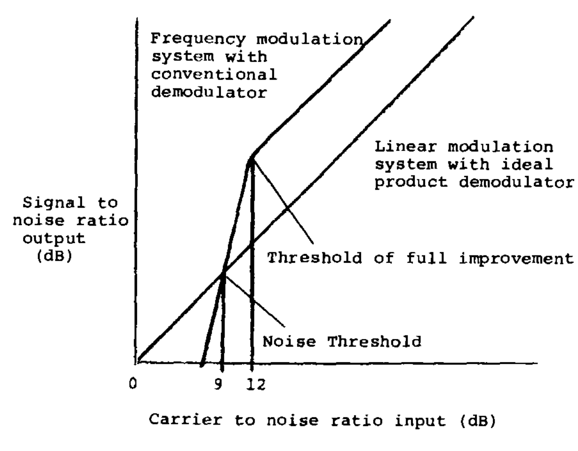

Figure 3

The resulting increase in bandwidth is illustrated in Figure 4. Notice that the AM spectrum consists of only one pair of sidebands per sinusoidal component of the modulation signal and has an effective bandwidth of 2Fm. The FM spectrum has multiple pairs of sidebands, and an effective bandwidth of 2Fm + 2ΔF (where ΔF is the frequency deviation). The noise improvement factor of FM is proportional to the ratio of ΔF to Fm. This improvement corresponds to wide transmission bandwidth ($\beta >> 1$) and better than 10 dB carrier to noise ratio. With narrowband FM ($\beta < 1$) the deviation is constrained to produce a bandwidth of 2Fm (as in AM), therefore, no signal to noise ratio improvement over AM can be obtained.

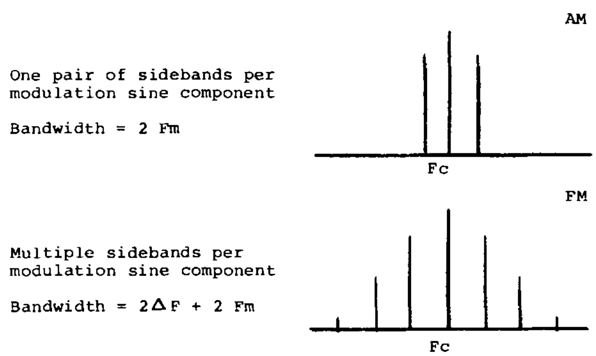

Figure 4

With the previous emphasis on signal to noise ratio, it is important to note that various methods have been devised for coding, modulation, and demodulation of digital signals for the purpose of matching the data integrity with information quality. The selection of technical parameters should, therefore, be tied to the application of the information. For example, in a Teletex application, a decoding error in received data may show up on the screen as a missing letter. The viewer will seldom object to this, because the value of the missing character can usually be implied from the context of remaining text. On the other hand, an error byte in a banking transaction could have drastic implications.

FSM vs. TDM

The two methods of simultaneous transmission of several band limited signals on a channel are frequency and time division multiplexing. In frequency division systems, all of the signals are modulated on different carriers and transmitted continuously. In time division systems, all of the signals are mixed in time and modulated on a single carrier, each signal occupying a distinct time interval. TDM seems to offer a cost advantage, in that, only one carrier need be generated and relatively simple circuits can separate the data intended for each distination. With TDM, the data intended for any individual receiver will occur in bursts as shown in Figure 6, whereas with FDM once the channel is selected, all the data is intended for the individual receiver. Channel capacity, as previously indicated, is a function of channel bandwidth and signal to noise ratio. Consider the 6 MHz bandwidth allowed for a TV signal. With 10 dB signal to noise ratio, the highest usable data rate using ASK is about 3.5M bits/sec. Compared with FSK at β = .6, the available 6 MHz accomodates 62 channels of 56K bits/sec. which is 3.47M bits/sec., or roughly the same channel capacity. There are numerous "holes" in the cable spectrum as shown in Figure 7, which are too narrow for conventional video services, for example, the FM band. Virtually, every cable system has FM channels which are unassigned, and are essentially wasted bandwidth. Data services in such holes can provide a new revenue source, while not reducing the capacity for carriage of traditional services. Since no two cable systems have the same spectral holes, however, a mechanism is needed to allow the terminals to tune themselves to the desired channel. Recent advances in integrated circuit technology make accurate and inexpensive frequency control systems not only possible, but cost effective as well.

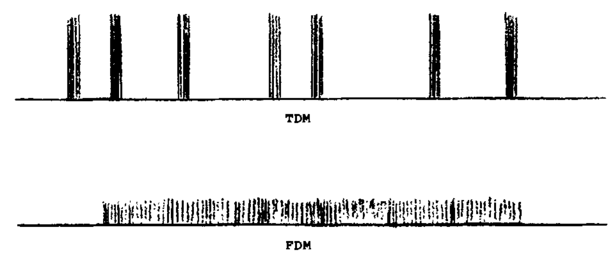

Figure 6
Data Rate Receiver vs. Multiplex Method

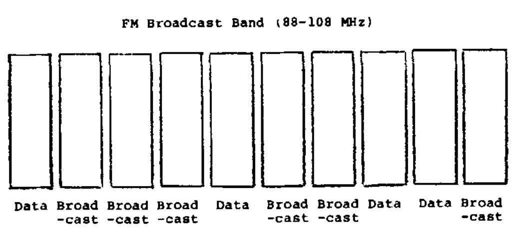

Figure 7

FDM FM is particularly interesting from the viewpoint of interfering carriers. Figure 8 illustrates the allowable interference carrier level versus frequency for an FM transmission with a minimum signal to noise ratio of 10 dB and modulation index of 5. Notice that an interfering carrier within a $\pm$200 KHz range of the desired carrier need be only 6 dB down to be essentially rejected. In fact, an interfering carrier $\pm$400 KHz away can be as high as 25 dB above the desired carrier without degrading data reception.

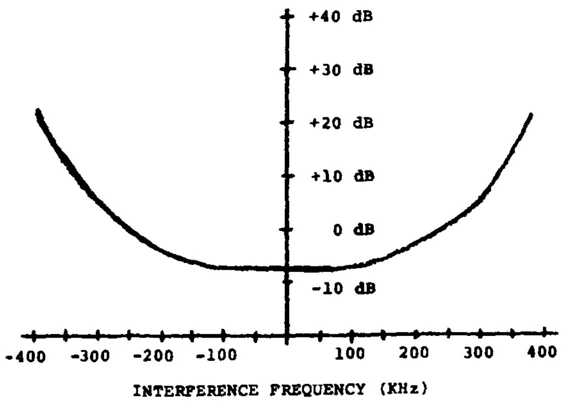

Figure 8
FDM FM Interfering Carrier Rejection

The multiplex method, therefore, should be selected on the basis of cost, available space, and desired error rate.

DATA ENCODING

The maximum baud rate inferred from Shannon's capacity is 2W elements/sec. or 2 bauds/sec. for every hertz of available bandwidth. The signalling rate (or baud rate as it is commonly known) which is defined as the minimum elapsed time interval between successive signal elements, places an upper bound on the achievable data rate. This limit relates to the data encoding scheme in terms of the number of transitions per data cell or baud/bit. Figure 9 shows some commonly used data

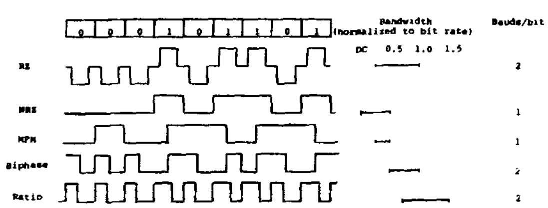

Figure 9

encoding schemes. Three factors are involved in the selection of an encoding scheme:

1) the ratio of maximum to minimum frequency which defines the detector passband filter characteristic

2) the inverse of the minimum time between transitions or baud rate which defines the upper bandwidth limit

3) the presence of a DC component which defines the bandwidth lower limit, precludes the use of AC coupling in the detector, and requires the use of a separate transmission method for the bit clock.

It should be noted that the MFM scheme makes use of previous bit history to reduce the baud rate, with no apparent increase in bandwidth. The advantage of this technique is somewhat negated by the requirement for a preamble to acquire clock synchronization. A preamble is a known bit pattern appended to the front of each message.

ERROR DETECTION

As we have seen above, error probability in digital transmission is a direct function of signal to noise ratio. If, for a given application, the signal to noise ratio is maximized and the error rate is still unacceptably high, then error control coding can provide the solution. Error control coding is simply the calculated use of redundancy, where extra bits or words (or both) are added to the message. They convey no new information themselves, but make it possible for the receiver to detect or even correct errors in the information bits. A multitude of error detecting and correcting codes have been devised to suit various applications. They may be used alone or in combination, for example, a single parity bit on each transmitted word, and a longitudinal checksum on the entire message. For many applications, errors can be rendered harmless if they are simply detected with no attempt at correction. In a two-way communication link, the fact that an error has been detected can be sent back to the transmitter for appropriate action, namely, retransmission.

HEADEND

There are many application similarities regarding data communication when viewed from the data processing end of the CATV network. Figure 10 shows the headend

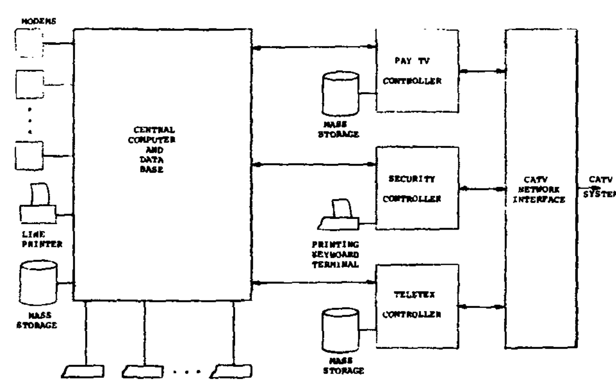

Figure 10

equipment complex for controlling a variety of two-way services. Note that separate controllers are used for each service type, along with the peripheral compliment required by the application. This functional distribution of computing power leads to the following advantages:

1) the controllers can operate standalone because of minimum application requirements (ie: cost), of the central computer is shut down for repair or maintenance.

2) if a controller needs repair, only one service is affected.

3) services may be added through standard interface modules

4) the central computer need not occupy the same physical premises as the controllers

5) one central computer may serve multiple cable systems through the use of more than one controller of the same type

The data path between the central computer and each controller uses a standard communication protocol such as X.25. This allows each controller to use the same type interface hardware and, in a non co-located application, permits the use of standard telco communication links.

Figure 11 shows the recommendations for the central computer and the interface between the central computer and the rest of the system. Figure 12 lists the controller to central computer and controller to digital communication hardware interface recommendations. Note that the signalling speed is either 3.58 MHz or a submultiple of it. This technique permits the use of low cost crystals in subscriber terminals and simplified clock regeneration in coherent detection schemes.

<u>Central Computer</u>

CPU Type:	mini or midi
Word Length:	16 or 32 bit
Mass Storage:	Winchester disk
Capacity:	1K bytes/sub/service
Terminals:	Intelligent
Capacity:	64
Speed:	9600 BPS
Electrical:	RS-232C
Protocol:	X.25

Figure 11

<u>Controller</u>

Central computer	interface
Data link:	Serial line
Capacity:	16
Speed:	Selectable (up to 38.4 KBPS)
Electrical:	RS-424C
Protocol:	X.25
CATV Network Interface	
Data link:	Serial line
Impedance:	75 Ohm co-ax
Voltage:	TTL (0=0.8V, 1=2.0V)
Speed:	Selectable (up to 3.58 MBPS)
Coding:	Manchester biphase

Figure 12

A list of recommended bit rates is shown in Figure 13.

Divide Ratio	Bit Rate
1	3.58M
2	1.79M
4	895K
8	447K
16	224K
32	112K
64	56K
128	28K
256	14K

Figure 13

The CATV network interface consists of the modulators necessary to convert the preformatted digital data to RF sine wave carriers and demodulate the upstream carriers in a two-way system. Figure 14 describes the recommended RF parameters applied to the CATV network, showing the application dependence described above.

APPLICATION	TV GAMES	PAY TV	SECURITY	TELETEX	HOME SHOPPING
DOWNSTREAM					
Multiplex	FDM	-	-	TDM	FDM
Modulation	FSK	FSK	FSK	ASK	FSK
Bandwidth	±200 KHz	±200 KHz	±200 KHz	6 MHz	±100 KHz
Coding	Biphase	Biphase	Biphase	NEZ	Biphase
Error Method		parity + checksum		CRC	CRC
Protocol		unique		Prestel	HDLC
Bit Rate	14 KHz	14 KHz	14 KHz	3.58 MHz	28 KHz
UPSTREAM					
Multiplex		-	FDM	-	FDM
Modulation		PSK	PSK	PSK	FSK
Bandwidth		±200 KHz	±200 KHz	±100 KHz	±100 KHz
Coding	N/A	Biphase	Biphase	Biphase	Biphase
Error Method		parity + checksum			CRC
Protocol		unique			HDLC
Bit Rate		14 KHz	14 KHz	28 KHz	28 KHz

Figure 14

<u>SUMMARY</u>

With CATV equipment manufacturers rushing to respond to the demand for data services, now is the right time to establish standards for data transmission. The development of guidelines must begin with an understanding of transmission schemes, CATV networks, and the equipment used to provide data services. The parameters of data transmission have been discussed along with some comments and recommendations on channel usage, data rates, encoding techniques and the various tradeoffs involved. The philosophy embodied herein is intended to provide incentive toward the establishment of universally acceptable data transmission standards, designed to achieve harmony between data and video services. Once established, standards will enable CATV manufacturers to produce fully compatible equipment for both current and future systems, while avoiding product rejection or early obsolescence.

1 C.E. Shannon, Communication in the Presence of Noise, Proc. IRE, Vol. 37, pp. 10-21, January 1949