FREQUENCY ALLOCATION FOR DATA AND VIDEO

Rezin E. Pidgeon and David H. Slim

SCIENTIFIC-ATLANTA, INC.

INTRODUCTION

The use of broadband co-axial cable as a medium for data communications is a very attractive proposition. The "institutional" cables, available principally in the larger cities, are natural candidates for this service, and even those business users who have access only to "entertainment" cables will find that, in most cases, a sufficient amount of unused bandwidth is available to carry a large number of data channels. However, the implementation of these services has proceded in a most desultory fashion, and one technical reason for this is the lack of precise knowledge, both theoretical and empirical, of those characteristics of the broadband medium which are likely to affect the transmission of data and which may cause reciprocal effects upon video signals.

While it is not possible to exactly characterise all cable systems, bearing in mind the diversity of topography and gross performance specifications, some general theoretical and practical observations can be made here which may smooth the way for a more enlightened approach to this application of cable TV networks.

TOTAL AVAILABLE BANDWIDTH

CATV manufacturers are now offering distribution equipment with an upper frequency limit of 450 MHz. Equipment capable of handling signals up to 400 MHz has been available for approximately 3 years from most manufacturers and, based on an analysis of recent shipments, accounts for some 70% of new system construction. However, if the current state of the U.S. CATV industry is analyzed in terms of the total number of systems currently in use, it will be found that by far the majority are using equipment with an upper frequency limit of 216 or 270 MHz. The fundamental requirement imposed on a CATV system by interactive data services is the availability of 2-way operation, and it is known that only a minority of the 216 and 270 MHz systems possess or can be adapted to provide 2-way transmission without complete replacement of amplifier stations. These types of system, therefore, will not be discussed here. In mitigation, it must be pointed out that these systems are to be found principally in rural or suburban environments (a circumstance which follows logically from the historical development of Community Antenna T.V.) and, therefore, may not be counted as major candidates for business data communications services.

Potential available bandwidth in the remaining systems (300, 330, 400 and 450 MHz) for data communications purposes is determined by the number of channels currently unused, and by the upstream capacity. While there is universal agreement on the frequency limits of the sub-split format, the situation with regard to mid-split and high-split is not so well defined, and it is advisable for the would-be data user or equipment supplier to determine exactly the upstream and downstream cut-off frequencies in the system under investigation.

Even when excess bandwidth in both upstream and downstream paths is available, the locations of the unused downstream channels can place a constraint on the selection of data communications equipment. Some modem suppliers offer a limited choice of carrier frequencies, and there have been moves to specify "paired" transmit and receive channels (1). While these pairings represent a much-needed standardization, they can cause conflict in both sub-split entertainment and institutional systems. A CATV system operator is understandably reluctant to re-locate existing T.V. channels, and, therefore, should examine proposed data modem frequency allocations carefully.

LIMITATIONS DUE TO NOISE

The problem of noise in the upstream signal path is universally acknowledged, if not thoroughly understood. Analysis has shown that there are seven basic mechanisms by which noise can enter the upstream path:

1. Ingress

2. Conducted and radiated emission from switching power supplies.

3. Thermal noise crossover from downstream amplifier.

4. Intermodulation crossover from downstream amplifier.

5. Intermodulation generated at non-linear connections.

6. Intrinsic thermal noise in reverse amplifiers.

7. Intermodulation generated in reverse amplifiers.

Of these, only Items 3 and 6 can be subjected to simple statistical analysis and used to produce an estimate of total white gaussian noise (WGN) arriving at the system headend. (This noise is also the only parameter which can be handled by simple mathematics to determine the anticipated bit-error-rate (BER) for a given modem modulation scheme, as will be shown later.) It should also be noted that emission from switching power supplies (Item 2) can generally be ignored.

The other noise sources, representing discrete interfering signals in the reverse path, are not amenable to the same statistical treatment, and vary widely from system to system. However, the conclusion which can be drawn from these facts, and which is of greatest interest to the system operator, is that the intrinsic thermal noise processes are predictable yet unavoidable, while the discrete interfering processes are unpredictable yet avoidable. (That is, their short-term characteristics are not absolutely determinable a priori.) The theoretical upper limit of reverse system performance can therefore be estimated in advance, and can form the basis for a discussion whether or not to proceed with data communications services.

It can be shown that the aggregate thermal noise per 4 MHz band, N_T, arriving at the system headend, is given approximately by:

$$N_T = N_I(\sum^{n} f + m) \text{ mV}$$

where N_I is the minimum noise level in a 75 ohm system, n is the total number of active devices in the reverse path, m is the number of active feeders, and f is the noise factor of a reverse amplifier, corrected for degradation due to thermal noise crossover.

This will yield a result in the more familiar units of dBmV if written:

$$N_T = -59 + 20\log_{10}\{\sqrt[2]{n.10^{(\frac{f}{10})}+m}\} \quad \text{dBmV}$$

where F is the noise figure in dB. ($F = 20\log_{10}f$).

For a small system of 18 trunk amplifiers and 23 line extenders in 10 feeders, assuming F = 10 dB, a value for N_T of -29.38 dBmV is found, which agrees well with experimental results (see below).

When discrete interfering signals are analyzed empirically, decisions can be made regarding the cost and complexity of attempts to reduce their effects, if indeed such measures are necessary. These decisions will also be influenced by a knowledge of a given modem's ability to ignore adjacent or in-band interference. (See below, "Characteristics of Broadband Modems".)

FIGURE 1

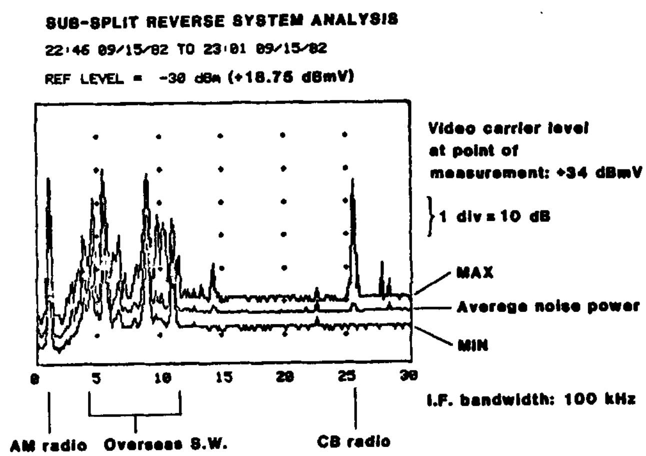


Figure 1 shows the results of measurements on a typical small distribution system, during a period of moderate interference. Measurements like this, taken over a 24-hour period, provide certain valuable facts about the system:

1. The average WGN level is -28 dBmV.

2. The maximum level of any interfering signal in the 24-hour period was 0 dBmV.

3. A band of frequencies between 15 and 25 MHz is the most noise-free, with a maximum interfering carrier level of -10 dBmV.

(Note: The apparent noise levels designated "MAX" and "MIN" in Figure 1 are produced by the sampling system which recorded the results. They can be regarded as defining the instantaneous maximum and minimum excursions of the noise signal.)

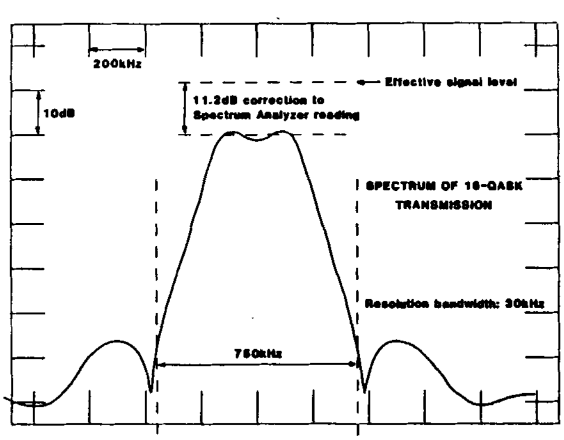
As will be discussed later, this system can accommodate data transmission from modems utilizing high-level modulation techniques.

CHARACTERISTICS OF BROADBAND MODEMS

The function of a broadband data modem is to provide the interface between data terminal equipment and the R.F. transmission medium (2). For this purpose, there are a myriad of possible modulation and detection schemes differing in efficiency, complexity and performance. The various modulation schemes include mutli-level amplitude modulation ("amplitude shift keying"), multiphase modulation (e.g. QPSK) and frequency-shift keying (FSK). Also, for a given type of modulation, different techniques for demodulation and signal processing exist. Thus, a comparison of such diverse systems in a meaningful manner is not simple. Therefore, it seems prudent to eliminate from our discussion those modems which utilize relatively simple processing and low efficiency modulation techniques, and which are more tolerant of adverse CATV system conditions. Instead, we will examine a high-speed (1.544 Mbps), high-efficiency device using 16-level Quadrature Amplitude Shift Keying (16-QASK). (3)

In this system, the binary data is sampled in groups of 4 bits, encoded and transmitted as 16 possible phase-amplitude states of the modulated carrier. The symbol (baud) rate is 386 KHz (2), and filtering confines the transmitted spectrum to a band somewhat less than 750 KHz wide. Thus, eight data channels running at 1.544 Mbps can be placed in a 6 MHz T.V. channel. Figure 2 shows the spectrum of the 16-QASK transmission.

FIGURE 2



The immunity of a given modem transmission to gaussian noise is ultimately defined by the manufacturer's specification, and it is generally unsafe to predict actual performance from theoretical considerations, since these take no account of implementation losses in the encoding, modulation, demodulation and decoding processes. However, for the sake of completeness, we have included Figure 3, which presents the ideal probability of error, Pb, to be expected for a given signal-to-noise ratio. The parameters Eb and No are defined:

Eb: energy per bit

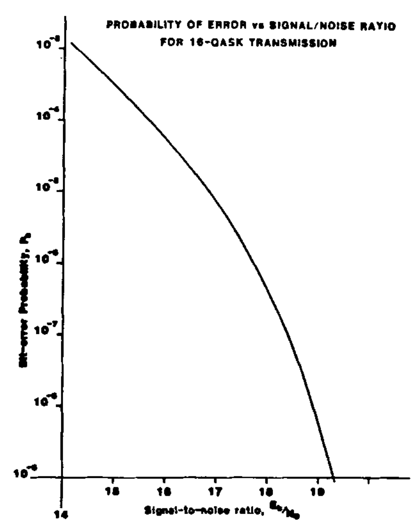
No: rms noise power measured in a 1 Hz bandwidth.

In order to achieve $Pb = 10^{-9}$, the ratio Eb/No must be 19.36 dB. To convert this figure into the conventional S/N parameter, where N is the rms gaussian noise measured in a 4 MHz bandwidth, and S is the average signal power of the data transmission, we write:

$$S/N = 10\log_{10}(10^{\frac{Eb}{No.10}} \times 1.544 \times 10^6) - 10\log_{10}(4 \times 10^6) = 15.23 \text{ dB}$$

Now, if S is 10 dB below video carrier level C, the required system carrier-to-noise ratio is 15.23 + 10 = 25.23 dB.

FIGURE 3



As stated above, this figure represents an ideal, and in practice a value of 33 dB is found to be more realistic.

In order to communicate between two widely-spaced points in a CATV system, a data transmission must travel via the upstream path to the headend, where it will be processed by a frequency up-converter ("translator"), and then via the downstream path to its destination. Therefore, the total available C/N must be calculated taking this route into consideration. If we assume that the one-way C/N is at its worst-case FCC limit of 36 dB, and the translator has a noise figure of 7 dB, then the overall path C/N will be approximately 33 dB. Hence, it can be seen that the practical requirement of 33 dB C/N for 16-QASK transmission is met by a system operating at the minimum permissible performance. If a 6 MHz channel is fully loaded with 8 data signals using the modems described above, when the average data signal power is 10 dB below video carrier level, the total power in the channel will be 1 dB below TV channel power.

To determine the ability of the modem transmission to ignore interference from discrete carriers, a series of tests was conducted in which the BER of a transmission was monitored as a carrier was added to the RF signal at varying levels and offsets from the data signal center frequency. At the same time, white noise was added to the transmission, so that the system was operating with a carrier-to-noise ratio (video) of 33 dB: the worst-case condition.

FIGURE 4

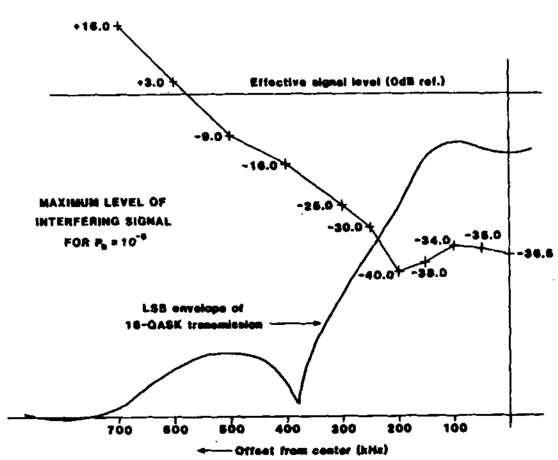


Figure 4 shows the maximum permissible interfering carrier level for a BER of better than 1 in 10^8. Note that the true power of the data transmission is obtained by applying a correction factor to the level observed on a spectrum analyzer. The reason for selecting a threshold of $Pb = 10^{-8}$ rather than 10^{-9} is one of simple expediency. To detect one bit-error in 10^9 bits requires a measurement interval of approximately 11 minutes, which must be repeated several times to obtain a statistically meaningful sample. If even one error is detected during these intervals, the level of the interfering carrier must be reduced fractionally, and the measurement re-started.

From these results, it can be seen that the 16-QASK transmission will tolerate an interfering carrier of equal amplitude at a separation of 600 KHz, while still maintaining a BER of 1 in 10^8. To relate this to a real environment, we recall that in the conclusions drawn from Figure 1, we noted that the maximum interfering carrier level in the interval 15-25 MHz was -10 dBmV. With a data transmission at 10 dB below video carrier level (34-10) dBmV, the interfering carrier proach within 250 KHz of the data transmission center frequency, before increasing the BER above 1 in 10^8.

We conclude that the potential available bandwidth must be carefully monitored over a period of time (preferably 24 hours) and the maximum interfering carrier level compared to the modem manufacturer's specifications. This is an unavoidable precaution, bearing in mind the unpredictable nature of signal ingress. It should also be stressed, however, that this type of interference can be reduced, assuming a thorough understanding of the cable system, and adequate system maintenance.

CONSTRAINTS IMPOSED BY HEADEND PROCESSING

As described above, the data signal will in most cases be routed through a frequency up-converter (translator) at the CATV system headend. This conversion will usually take place in bandwidth increments of 6 MHz, but it must be borne in mind that the effective conversion bandwidth must in reality be less than this ideal, due to the nature of practical filters and the need to reject adjacent 6 MHz channels. It is a common practice to use a standard signal processor for data translation, and these devices typically will have a bandwidth slightly less than 5 MHz at the half-power points. Furthermore, the passband will not be symmetrical with respect to the 6 MHz channel limits. The number of potential data signals lost due to this restriction will, of course, vary with the modem transmission bandwidth: in the case of the 16-QASK transmission described above, the number of data signals per available 6 MHz channel will be reduced from 8 to 6.

The frequency stability of the translator is also an important consideration: the maximum possible long-term drift should be compared to the received frequency "window" as specified by the modem manufacturer.

CONCLUSION

Much work still remains to be done in the characterization of CATV systems for data transmission. We have not yet reached the point at which accurate performance predictions can be made for a wide variety of systems, as is common place with video-only installations, when dealing with very large numbers of modems and volumes of traffic. Such predictions will be possible, we feel, in the very near future: manufacturers are now performing the experiments which will reveal in detail the performance of CATV systems under varying loads of mixed video and data traffic. In addition, as the demand for business data communications using alternative transmission media increases, the body of theoretical and empirical knowledge will grow and contribute its share to a more exact understanding of the field.

In the meantime, we are confident that the information which has been presented here will provide reasons for a high degree of optimism in beginning the excursion into a new area of CATV system applications.

REFERENCES

1. IEEE Project 802, Local Network Standards Committee, Status Report. April, 1982.

2. "Data Communications Via Broadband Cable: Definition of Terms". Scientific-Atlanta Applications Note AN0582-01. (Slim, David H.)

3. "Bandwidth Efficient, High-Speed Modems for Cable Systems". Scientific-Atlanta Applications Note AN0582-01. (Klare, Stephen W. and Rozmus, J. M.)