SELECTION OF AN OPTIMUM MODULATION SCHEME FOR CATV DATA TRANSMISSION

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Two-way data transmission on CATV cables is growing rapidly. Unfortunately, TV and FM signals occupy most of the available frequencies in current cable systems leaving very little for data signals. Return channels, however, are usually vacant but often very noisy and suffer from outside signal leakage. Most, if not all, current CATV data systems use FSK because of its inherent signal-to-noise improvement properties. This is helpful in the return path but not necessary in the path into the home where signals are very good quality. Furthermore, if signal-to-noise improvement is desired, FSK must have a deviation greater than the signal bandwidth so it uses up the available spectrum with fewer data channels. A better approach would be to use different modulation schemes in different directions while choosing them to keep both the home unit cost and data error rate low.

INTRODUCTION

Some general requirements for a two-way CATV data transmission system serving a large number of homes are:

1. Reliability-low data error rates.
2. Low cost of home unit.
3. Ability to serve a large number of homes on an existing cable system.
4. Minimum use of additional frequency spectrum.
5. No interference with television signals.

A low data error rate necessitates either a good signal-to-noise ratio or a complex modulation scheme. Since the TV signal into the home is generally much better than that required for very good data transmission at reasonable data rates, it should be possible to use relatively simple modulation scheme in this direction.

It would also be desirable to keep the frequency used for data transmission into the home relatively low so expensive filtering or complex frequency conversion schemes are not needed.

Assuming the use of the existing two-way cable arrangements, transmission of data out of the home must be between 5 and 30 MHz. However, unlike in the other direction, the return path is usually noisy because the summing effect of noise from the reverse channel amplifiers and pickup of external signals is often quite severe especially around the 27 MHz CB frequency. Thus, return signals must lie between approximately 5 and 25 MHz. This is a bandwidth of 20 MHz, and, if a large number of homes is to be served, there will necessarily be a trade-off between data rates and occupied bandwidth. For example, if 300,000 homes are served and each channel frequency selected serves 3000 homes, 100 channels will be needed. This leaves 200 KHz for the channel spacing. Filter selectivity requirements will reduce the allowable channel bandwidth to about 150 KHz. It will be shown later that this channel bandwidth puts a severe restriction on the maximum data rate depending on the type of modulation selected.

Thus, if it were easy to generate in the home, a relatively complex modulation scheme requiring a sophisticated central receiver which performed well in the presence of noise should be used. It would, as mentioned above, still have to operate within the channel bandwidth constraints. Since each central receiver-transmitter will serve a large number of homes, its cost and complexity in relation to the whole system is relatively unimportant.

MODULATION POSSIBILITIES

Basically, there are only 3 ways an RF carrier can be modulated: Its amplitude, frequency, or phase can be changed by the modulating signal. Since only modulation with pulses is being considered here, these would be referred to as OOK (on-off keyed), FSK (frequency-shift keyed) and PSK (phase-shift keyed). OOK is referred to here as AM (amplitude modulation) because in reality the modulation can be anything from a 80% to 100% change in the carrier amplitude.

The bandwidth required to transmit a pulse depends on its minimum width and the type of modulation used. A pulse of width t seconds has a bandwidth of approximately 1/t hertz. However, when this pulse modulates a carrier, the occupied bandwidth is always equal to or greater than 2/t hertz because the modulation process translates the frequency spectrum of the pulse from being centered at zero frequency to being centered at the carrier frequency. PSK modulation in which the pulses shift the carrier phase by 180° and AM both produce an occupied spectrum bandwidth of 2/t hertz. (1) In data transmission terms, the bandwidth would then be equal to twice the baud rate since the minimum pulse width is 1/baud rate. FSK, on the other hand, produces an occupied bandwidth which depends on how much the carrier is shifted. A commonly used expression for the occupied bandwidth B is:

$$BW = 2\Delta f + 2\ B \qquad (1)$$

$$\text{or} \quad BW = 2\Delta f + 2\ (\text{baud rate}) \qquad (2)$$

(Δf = peak frequency deviation)

FSK usually is used because it offers a signal-to-noise improvement over AM, but this is only true if Δf is large enough. A commonly used criterion is that for $\Delta f/B = .6$, FSK is approximately equal to AM. (2) Thus, in order to gain any significant improvement in signal-to-noise ratio using FSK, the occupied bandwidth must be greater than the bandwidth of an AM signal. If $\Delta f/B = 1$, the occupied bandwidth of FSK is 2 times that of AM and the signal-to-noise improvement is about 5 dB. This is true, however, for carrier-to-noise power ratios above approximately 2 dB. Almost the same performance can be obtained at this level by using AM with a synchronous (phase locked) demodulator. Another comparison can be made by comparing the calculated bit error probabilities for the different types of modulation. (3) AM has the poorest performance and an error probability $P_e = 10^{-8}$ requires a carrier-to-noise power ratio C/N of 18 dB. FSK with incoherent detection (not using a phase locked loop detector) achieves the same P_e for C/N of 15.5 dB. PSK, however, is 3.5 dB better than FSK and requires a C/N of only 12 dB. The problem is that PSK is sometimes difficult to demodulate especially when a large number of non-coherent signals must be detected. This occurs when a receiver using a phase locked loop (PLL) acquires the PSK signal. The PLL cannot tell if the phase it starts with is 0° or 180° unless some method of determining this is built into the data. Complicating things further is the problem of acquiring a signal rapidly and then being able to remain at 0° when a long 180° data pulse is received. If only one signal such as that from a space probe is being received, this is not a problem because, for these applications, the phase locked loop can have a very long time constant. When a new signal of unknown phase must be locked on to every few milliseconds, however, the loop must be relatively fast and so will also change phase and lock onto the 180° datapulse when it occurs. These factors make PSK demodulation somewhat more difficult than other schemes.

HOME RECEIVER POSSIBILITIES

As was mentioned earlier, low cost is the most important requirement for the home receiver. Its performance specifications are not severe because of the large signal level and good signal-to-noise ratio into the home. If the 108 to 120 MHz band is used, the home receiver should be able to operate reliably with signal levels which would usually satisfy the FCC limitation of 10^{-5} watts anywhere on the cable system in this band. Another consideration mentioned earlier is that home receiver frequency should be kept relatively low to keep costs down. If it is crystal or synthesizer controlled and only L-C filters are used, 300 MHz is about the upper frequency limit. Unfortunately, this lies in the middle of the TV band, and, if it is undesirable to use up TV channels for data transmission, the 108 to 121 MHz frequency range is all that is available. This works out well, however, because most cable systems would have a problem with the FCC limits if they used these frequencies for TV signals.It is a relatively small band, but if modulation and data rates are carefully chosen,any practical numberof homes can be accommodated.

HOME TRANSMITTER POSSIBILITIES

As with the receiver, the home transmitter should also be low cost. It is probably desirable to set its frequency also with a crystal or synthesizer arrangement. If a crystal is used, FSK becomes difficult or expensive. If a synthesizer is used, it is not as difficult, but a problem occurs because the "0" output frequency must be on one side of the channel center frequency and the "1" frequency on the other. This is more likely to result in adjacent channel interference problems between unmodulated and modulated carriers because the receiver must be tuned to the center of the channel.

AM and PSK, on the other hand, are very easy to generate. AM is generated by simply turning the carrier on and off either with a gate or by turning the RF amplifier stages on and off. PSK can be generated by switching between a 0° and 180° signal from the oscillator or phase inverter. Thus, from the standpoint of the home transmitter, AM or PSK are the easiest to generate.

CENTRAL RECEIVER POSSIBILITIES

As was mentioned earlier, cost is not an important consideration in the central receiver. It should have the best possible performance in the presence of noise and its received signal must not occupy too much bandwidth because of the limited frequency range available. Unlike with the signals going into the home, the available frequency range is limited to 5 to 25 MHz and the possibility of using a TV channel for data doesn't exist. The Central Receiver has another unique requirement in that it must rapidly demodulate signals which last only a few milliseconds from many homes in succession. These signals may also have levels which vary as much as 15 dB at the receiver. The level variation occurs because it is almost impossible to set and maintain several thousand homes on a given frequency so they all produce the same level at the Central Receiver. This complication just about precludes the use of AM in the return path: If the AGC system must settle in less than 2 ms, then the longest data pulse must be much less than 2 ms. If no AGC is used, then the 15 dB level variation would cause quite a problem with a preset threshold. The most obvious solution to the level variation problem is to use a receiver containing a limiter and to use either FSK or PSK modulation. A phase locked loop could be used to demodulate either with good results, but the PSK is better in terms of lower error probability and uses up less bandwidth. As was mentioned in the paragraph on types of modulation, PSK may present some difficult problems in polled systems where signals must be rapidly acquired and demodulated. It could be assumed that since the Central Receiver's cost is not important, these problems could be overcome and PSK would be the best choice.

CENTRAL TRANSMITTER POSSIBILITIES

The Central Transmitter must provide a good signal with very low spurious outputs, but it is the least constrained of all the systems by modulation limitations. FSK would be the most difficult to generate and AM the least difficult. However, it must be concluded that the Central Transmitter would not have any influence on the selection of a modulation scheme.

CONCLUSION

The following tables summarize the preceding discussion (the lowest number indicates the most desirable).

A. Occupied BW

1 AM or PSK
2 FSK

B. Noise Performance

1 PSK
2 FSK
3 AM

C. Home Receiver Cost

1 AM
2 FSK
3 PSK

D. Home Transmitter Cost

1 AM
2 PSK
3 FSK

E. Central Receiver Performance

1 PSK
2 FSK
3 AM

When factors A, C, and D are considered, AM seems to be the best choice for signals going into the home. When factors A, B, D, and E are considered, PSK seems to be the best choice for signals going from the home to the Central Receiver.

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