MODULATION CONSIDERATIONS FOR DIGITAL TELEVISION

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Abstract

The modulation technique selected for the Advanced Television standard may not necessarily be optimum for the Cable environment. In fact there may be technical and financial reasons for having alternate modulation techniques for each application.

COFDM Modulation

Different modulation methods are being proposed and tested in various transmission environments. The developers of the European Advanced Television System for High Definition Television (HDTV) are investigating a method which sends hundreds of low bit rate carriers in the normal 8 MHz wide television channel. Each of these carriers is modulated by data using a higher complexity modulation technique such as 16 Quadrature Amplitude Modulation (16 QAM). In experimental systems built so far, the carriers are generally spaced at a frequency close to the 15 KHz Horizontal Line rate of the systems. This is a Frequency Division Multiplex (FDM) system. Since the carriers are very close together, the sideband energy overlaps the adjacent carriers to some extent. In order to minimize the inter-symbol interference (ISI), the adjacent carriers are in quadrature with each other. Quadrature in geometric terms is Orthogonal: Thus the name OFDM. Unfortunately, the phase modulation part of QAM information sometimes looks like the orthogonal relationship of the adjacent carriers and data is subject to corruption. In order to minimize this problem, the data bits on alternate carriers are delayed in transmission and the system uses heavy Forward Error Correction Coding (FEC). The result is COFDM; Coded Orthogonal Frequency Division Multiplex. In an 8 MHz RF Channel, about 512 carriers spaced at 15.625 KHz would fit exactly. If each of those carriers were modulated at 50 KHz using a 16 QAM the total data rate would be 26 MBits/s. If roughly ¼ of those bits were for FEC, the true data rate would be 19.5 MBits/s. The United States TV channels are only 6 MHz wide and the TV Horizontal line rate is about 15.750 KHz. This would permit about 380 channels, and following the same logic, a true data rate of about 14.5 MBits/s. This does not compare favorably with the present 19 MBits/s supplied by both 8 VSB and 32 QAM. There are proposed implementations which use up to 1856 carriers spaced every 2.93 KHz and 64 QAM modulation.[1] A system of this complexity would really stress the phase noise performance of the recovery circuitry. Rather than build hundreds, or thousands, of transmitters and receivers, the signals are generated by supplying the instantaneous value of the digital symbol for all the 500 or more sub-channels to a Digital Signal Processor (DSP) chip. This DSP does an Inverse Fast Fourier Transform (IFFT) and generates the frequency spectrum associated with the data. When this is transmitted, any delay distortions (ghosts) theoretically are minimized in effect because the ghosts are predicted to be shorter that the length of the symbols being transmitted. At the receiver site, a Fast Fourier Transform (FFT), is used to recover the individual data bits prior to being reconstructed for use. This technique has tested well, in spontaneous tests, in the European environment where one channel is reused by low power transmitters in adjacent cities. The European plan is to use one channel countrywide for the same program. Interference from adjacent cities appears as a ghost and is therefore eliminated. Another advantage of this system is that the IFFT can be generated with the frequencies at and around the normal picture and sound carriers of a normal Amplitude Modulated Vestigial Sideband television eliminated. This removes one interference method in which the Digital signal gets into the normal television picture creating a low frequency beat. The reason that the beat could be seen is that the transmitted bits are multi-microseconds long, and therefore look like a relatively low frequency if considered as a noise source. As a side benefit, this method of transmission eliminates the need for an adaptive equalizer. The trade-off does not seem to present any compelling reason to select this modulation and transmission method for the United States where the transmission constraints are different. The U.S. uses transmission frequencies which are not available in adjacent cities because of other reasons. One of the reasons is that the television sets already in homes have selectivity and radiation limitations which restrict using those frequencies in a normal way.

While COFDM seems to work well in the particular broadcast environment where it has been tested, it is not expected to be ready for use until about the year 2000. Another limitation is potentially attempting to do some sort of a double rate transmission for the more benign Cable TV environment. The European market is still planning to use 64 QAM for Cable TV distribution.

QAM Modulation

Two generic modulation techniques were being considered for the U.S. HDTV standard. Both have their advantages and disadvantages for the environments in which they must operate.

While The Grand Alliance, a consortium of HDTV proponents, has decided to recommend 8 VSB over 32 QAM for the terrestrial broadcast and 16 VSB over 256 QAM for Double Rate (carriage of two HDTV broadcast channels on one Cable TV channel)[2], we will discuss the merits of both techniques.

Quadrature Modulation can be considered to be the individual modulation of the in-phase and quadrature (90 degree phase shift) carrier phases. In the simplest level of modulation, the in phase carrier can signify either a zero or a one. Likewise the quadrature carrier can also signify a zero or a one. These values are established by either turning the carriers on or off at the sample time. The resultant carrier is the sum of the two amplitude and phases and has four possible values. These are defined as zero, if both bits being sent are zero, to any combination of the two bits. The result of this special case modulation is that there are four possible states of carrier phase and amplitude and the modulation method is called Quadrature Phase Shift Keying (QPSK). In a similar way, each carrier phase could transmit two bits of information by sending an instantaneous value as generated by a Digital to Analog Converter. This would give amplitudes of 0, 1, 2, and 3 to each phase of the carrier. The combination of two phases creates 16 instantaneous phase and amplitude possibilities, giving what we call 16

Quadrature Amplitude Modulation (QAM). Higher orders of linear modulation are easily derived. Three bits per phase yields 8 possible levels per phase with 64 possible amplitude-phase points. Four bits yield 16 values and 256 QAM locations. It can be seen that going from QPSK to 16 QAM doubles the data rate and going to 256 QAM doubles it again. The complexity of going to 256 QAM from 16 QAM is significant.

QAM signals occupy frequency spectrum based on the number of symbols transmitted every second. A 6 MHz channel can support about 5 Mega-Symbols per second since the signal looks similar to a double sideband, suppressed carrier modulated signal. This means that the total data bit rate for a 16 QAM signal would be 4 bits per symbol times 5 MS/sec or 20 MBits/sec. 64 QAM yields about 30 MBits/sec and 256 QAM, 40 MBits/sec.

In QAM modulated signals, echoes and multipath (ghosts) in the transmission path can modify the received signal in both the net resultant amplitude and phase. Because of the short symbol time, 200 ns in the case of a 5 MS/sec system, broadcast length echoes of up to 24 or so microseconds requires an adaptive equalizer of 256 taps. Two taps are commonly used per symbol time. This gives 100 ns per tap correction resolution. For more information on adaptive equalization, see ref 3. The important issue here is that cable systems usually don't have strong and long echoes at the same time. This means that cable system transmission is relatively benign in this respect.

VSB Modulation

The Modulation method recommended by the Grand Alliance for broadcast HDTV is 8 Vestigial Sideband (8 VSB). This technique could be considered to be a single phase carrier, amplitude modulated by the value of the digital data. The actual signal is implemented by using signal shaping and a quadrature modulator to cancel the second sideband. Ideally only one sideband would be sent, but this is not practical in real systems, and a small part of the second sideband is sent along with the desired sideband. A small amount of carrier is added back to the signal to aid in locking the receiving circuitry. Because of the vestigial sideband, the carrier must be displaced somewhat into the channel. Even with this displacement, the symbol rate can be double that of a system with the carrier centered in the channel. With the depressed carrier and 6 MHz channel bandwidth limitation, about 10 MegaSymbols per second may be sent. This means that if a two level bit was to be sent, 10 MBits/sec could be transmitted. Divide the amplitude into 4 levels (4 VSB) and you get 20 MBits/sec. Doubling that again to 16 VSB gets to 40 MBits/sec. The problem is that for 16 VSB, the resolution of the sampling must be as fine as for 256 QAM. That makes is highly unlikely to be acceptable for broadcast HDTV. An advantage of this system is that since all the information is in phase with the carrier, it is not necessary to have as complex an adaptive equalizer.

The modulation methods being considered for broadcast HDTV are more complex than straight VSB or QAM. In the VSB system, a number of unique operations are included which improve the performance of the system while making some other operational aspects more complex. The VSB signal implementation has a repetitive sync period to improve synchronization of the electronic circuits. With the incorporation of a sync signal, the adaptive equalizer can adapt to optimize the sync waveshape, and by implication, the data symbols. The down side to this is that the sync only appears every 65 micro-seconds, compared to that of the blind adaptive equalization of QAM which can fine tune values at the symbol rate. The Grand Alliance HDTV will probably use Blind Equalization with the 8 VSB.

With the strict timing involved with the relationship of sync to data, the makers of Studio Transmitter Links (STL) used to carry data from Production Studios to the transmitter are having problems. This is because the addition of HDTV to the present STL links is difficult. The FCC has not given any additional STL bandwidth when they assigned HDTV broadcast channels. The plan now is to multiplex the digital HDTV signal with a digitized NTSC signal on the STL, and the precise timing requirements are causing concern.

The good overall performance of VSB requires close matching of the transmit and receive filtering. In order to accommodate the transmitter non-flatness, a receiver was incorporated into the tested transmitter so any error created by the transmitter was sent back to the transmitter equalizer filter to pre-distort the transmitted signal. There is also come concern that filtering associated with frequency conversion may present problems.

8 VSB is what was 4 VSB with one bit per symbol added in a scheme called trellis coding. 16 VSB does not use trellis coding. Trellis coding is used in both VSB and QAM systems and works by making it impossible to get to new signal locations from the closest Euclidean location. This means that the likelihood of some symbols is not possible from some previous symbols. This technique uses a more complex constellation and transmits more bits overall while improving the system equivalent carrier to noise by 1 to 3 db. Three db is the equivalent of doubling the transmitted power. The 32 QAM system tested uses a trellis code which gives a constellation which is not rectangular, but rather looks like a 6 by 6 constellation with the corners removed. For more information on coding for transmission, see reference 4.

Discussion of Issues

For reference, some of the data which was used to decide the modulation method of choice are listed below[2].

Modulation Format	32 QAM	8 VSB	256 QAM	16 VSB
C/N (dB)	14.8	14.8	29.3	27.6
dB Min Tap Isolation	14.0	20.7	24.0	30.0
dB Peak-Avg Carrier Pwr	5.8	6.4	6.4	6.5
Fiber Optic Clipping				
Depth of Mod	>6.3%	6.2%	3.8%	4.7%
C/total Dist	<26.9 dB	26.4 dB	48.6 dB	38.9 dB
CSO dB	<42.9	42.2	79.5	57.2
CTB dB	<36.6	35.3	60.2	53.8

The results shown above were made using equipment with performance about as close to theoretical as can be achieved with present technology. Using technology and techniques common to Consumer Product design, some relaxing of performance may be expected. Tap isolation is a particular case in point. While static changes are compensated by the adaptive equalizer, it can be reasonably assumed that customers on adjacent taps could cause each others' Digital receiver to stumble when they "surfed" channels. From the chart above, up to 30 dB minimum isolation was required for glitch free reception. Considering that millions of taps are installed which have only 20 or 25 dB isolation; even with drop line loss, some problems may develop especially on lower frequency channels. Some protection can be achieved by using isolation amplifiers, which would need low band bypass for return path applications, thus adding complexity. Fiber optic clipping is another area of concern. The higher order digital modulation formats have a low depth of modulation tolerance by modern standards.

Both systems described above would give a high enough net bit rate to conveniently allow simple transcoding of two broadcast HDTV programs into one CATV channel. The Forward Error Correction (FEC) ideally would be different for cable than for over the air broadcast. Broadcast FEC coding is a combination of Reed Solomon and the aforementioned Trellis Coding. The Cable environment might manage with only a strong Reed Solomon, however a more economical combination may be to use a simpler Reed Solomon in conjunction with a simple Trellis code.

As can be seen from the preceding, it may not be possible to have a simple scheme which would double the number of Broadcast HDTV channels in a CATV channel.

Conclusions

COFDM seems to best fit the channel reuse concept being proposed in Europe. It appears that either 64 QAM or 8 VSB will work on cable with few problems. Both of the higher order, 256 QAM and 16 VSB, modulation formats present risk in their ability to work well in all cable systems.

For non-technical reasons, cable may find that is beneficial to select one modulation scheme over the others.

It is also reasonable to believe that an inexpensive digital demodulator could be developed that would automatically reconfigure itself so as to receive and process both QAM and VSB signals.

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