AN INTRODUCTION TO DIGITAL MODULATION

This article provides readers a simple overview of the various popular methods used in modulating a digital signal. The relative merits of each of these modulation techniques along with their applications, is also discussed.

INTRODUCTION

As every CATV technician knows, modulation is essential for transmission of two or more signals simultaneously. Modulation avoids any interference between the two signals and also ensures that signal errors are avoided during transmission.

We are all familiar with the common Analog modulation techniques of Amplitude Modulation (AM) and Frequency Modulation (FM). It may come as a surprise for us to realise that the first modulation of electrical signals was really digital modulation. Samuel Morse invented the Morse Code where every English alphabet and number was coded as a sequence of a dot (.) and a dash (-). This is similar to translating each character of the English alphabet into either a zero (0) or a one (1), of the digital code as we know it today.

THE DIGITAL BIT

Before we dwell further on the topic lets take a brief look at the term "Bit". All digital information is transmitted as a series of zeros (0) and ones (1). These two symbols are called Bits. The number of Bits could be considered also as a unit to express the amount of information that is being transmitted. As an example, if a million symbols (0 & 1) were transmitted, it would imply 1 Mega Bit.

To help transmit digital Bits over any significant distances, different modulation schemes have been devised. However, the requirements for broadcasting a satellite signal would be rather different from the requirements for transmitting a digital signal over a cable network. We will take a look at these shortly.
DVB

We have been used to referring to Digitally compressed Video Broadcasts simply as DVB. Usually we have referred only to Satellite DVB broadcasts. Satellite DVB broadcasts are more correctly DVB-S. Similarly DVB broadcast for cable are correctly referred to as DVB-C, and for Terrestrial Digital broadcasts it is DVB-T.

MODULATION BASICS :

We are all familiar with the two most common forms of Analog Modulation viz. Amplitude Modulation (AM) and Frequency Modulation (FM). For Amplitude Modulation, the signal strength of the carrier is varied or modulated. For FM, the frequency of the carrier is modulated.

For Digital Modulation, instead of varying either the Amplitude or Frequency of the carrier, it is preferred to vary or modulate the Phase of the carrier (for a brief explanation of the Phase of a signal, refer to the next page).

Phase Modulation is preferred for Digital transmissions because it offers better protection for transmitting signals which carry binary information i.e. are either 0 or 1 i.e. fully ON or fully OFF. If AM or FM was used with digital signals, the modulation would vary between two extremes of full modulation or no modulation only. This would further complicate accurate demodulation as well as affect the spectral density of the transmitted signal. Often a combination of Both Phase & Amplitude Modulation is used.

UNDERSTANDING PHASE

A cyclically varying electrical signal (Fig i) can possess 3 variations viz.:

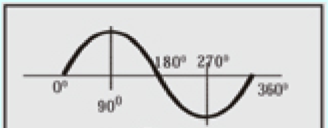

Fig. i


Fig. A

Changes in the signal strength or level. These are also referred to as Amplitude Changes. Two signals with different amplitudes, but otherwise identical are shown in Fig. A.

Alternatively, the signal level or amplitude may remain fixed but its frequency may be varied. This is shown in Fig. B.

Modulation methods that change the frequency or amplitude of a signal are quite common in consumer electronics and referred to as Amplitude Modulation (AM) and Frequency Modulation (FM) respectively.


Fig. B

Phase is a property which compares the starting point of two signals. A complete signal cycle is shown in Fig. i and has a total phase variation of 360 Degrees.

Two signals are said to be in phase when the timing of their starting points coincide.

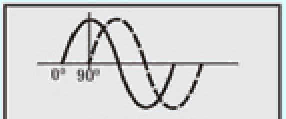

Fig C : 90° Out of Phase

Two signals are said to be out of phase by 90 degrees if one of them is at its starting point (or zero crossing) and the other is Out of Phase or delayed by 90 degrees.

From this it is apparent that signals can be characterised and therefore separated, based on their phase differences between each other. This property is used in phase modulation which is a key technique for modulating digital signals.

DIGITAL MODULATION:

There are two major categories of Digital Modulation. One category uses a constant amplitude carrier and carries the information in Phase or Frequency variations, known as Phase Shift Keying or Frequency shift keying (FSK). The vast majority of frequency hopping Wireless LAN and Spread Spectrum based systems today employ simple FSK modulation schemes.

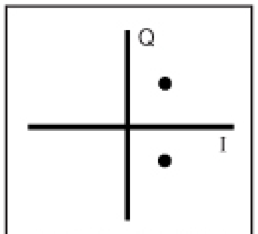

Figure 1: FSK Modulation

Digital (DVB-S) satellite broadcasts universally use Phase Modulation - actually QPSK, as we shall see shortly.

The other category conveys the information in carrier amplitude variations and is known as amplitude shift keying (AMP). A combination of FSK & AMP are employed for CATV & Terrestrial Digital Transmissions. More advanced modulation techniques convey multiple bits of information simultaneously by providing multiple states in each symbol of transmitted information. This helps transmit more digital data. Quadrature Phase Shift Keying (QPSK) conveys 2 bits per symbol and is prevalent in satellite communication.

B.E.R.

Better accuracy of the transmitted digital signal is measured by "Bit Error Rate" (BER). Simply put, Bit Error Rate is:

The number of Error Bits
BER = ----------------------------------
The total number of Bits

A lower Bit Error Rate implies that the signal has been more accurately transmitted and demodulated. As we shall see later, a Bit Error Rate of one error in 10,000 Bits transmitted is quite normal for modulated signals. After error correction is applied, the Error further falls down to one part in 100,000 Million Bits !

QPSK MODULATION

Satellite transmissions have a few unique characteristics viz.:

* The signal has to travel an extremely large distance (36,000 kilometers) from the ground to the satellite and then another similar distance back to the earth.

* The signal from the satellite experiences an attenuation of approximately 200 dB before it reaches a dish antenna on the ground.

* The satellite transmission is subjected to a broadband noise which is practically uniform at all frequencies.

* Since multiple channels are broadcast from the same satellite, the modulation technique should not be prone to Inter Channel interference.

* A satellite transponder has a fairly large bandwidth. Full transponders often have a bandwidth of 72 MHz with some broadcasters utilising only a half transponder bandwidth of 36 MHz. The trend now is shifting towards a half transponder bandwidth of 27 MHz. This is still a fairly wide bandwidth, particularly when compared with the 7 or 8 MHz allotted to a channel on a cable systems.

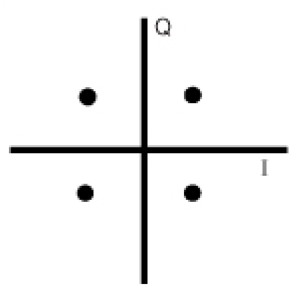

Fig. 2 Representation of QPSK Modulation

Hence a Digital Modulation technique used for Satellite Broadcasting (DVB-S) can use a fairly large bandwidth but should be capable of preserving the signal and maintaining a low Bit Error Rate (BER) even for very low signal strength.

The QPSK Modulation system provides an ideal solution for this. Quadrature Phase Shift Keying (QPSK) is a very simple but robust form of Digital Modulation. While the name sounds extremely elaborate it is fairly straight forward.

The word Quadrature simply means - Out of Phase by 90 Degrees. Hence, as shown in Fig.2, QPSK provides for 4 different states or possibilities for encoding a Digital Bit. This is because 2 components are used - one In Phase (I) & the other Out of phase or Quadrature (Q). This doubles the number of possible variations, from 2 to 4, that simple PSK offers. The QPSK system is now universally used, for all satellite DVB broadcasts.

CATV TRANSMISSION - Q.A.M :

Quadrature Amplitude Modulation (QAM) systems utilise changes of BOTH, Phase Shift Keying and Amplitude Shift Keying to increase the number of states per symbol. Each state is defined with a specific variation of BOTH - Amplitude AND Phase. This means that the generation and detection of symbols is more complex than a simple phase detection as in QPSK employed for Satellite Transmissions (DVB-S) because in Q.A.M. the Amplitude changes have also to be detected.

QAM modulation is ideal for use in CATV networks.

A cable system provides different transmission characteristics compared to satellite transmissions. A system such as QAM must be able to address the following needs, if it is to be successfully employed for Digital Modulation in a CATV system.

* The bandwidth allocated per channel is restricted - just 6 to 8 MHz (depending on the TV system such as PAL, NTSC or Secam, employed. Hence the Digital Modulation system must densely pack the digital data in a small bandwidth (unlike a satellite based transmission).

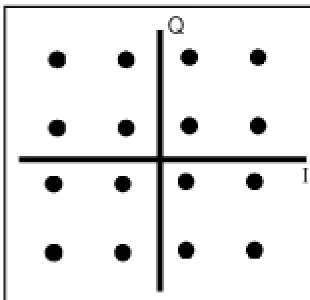

Fig. 3a 16 QAM

* The signal levels are significantly higher than for satellite transmissions. Since the Carrier (signal strength) is larger, the Carrier to Noise (C/N) ratio is always fairly good in a CATV network.

* A large number of channels are modulated and carried simultaneously on the same cable. Hence the modulation scheme should provide good Inter Channel Interference suppression.

QAM comfortably meets all these requirements.

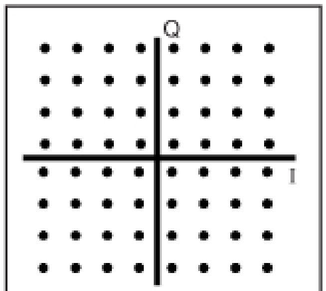

Fig 3b 64 QAM

Since the Phase and Amplitude are varied in QAM Modulation, a large number of states or possible discreet values can be created to provide dense Digital Modulation. Hence designers have created 16 Bit and 64 Bit QAM Modulation. Fig.3a & 3b shows graphically 16 QAM and 64 QAM.

Each time the number of states or options per symbol is increased, the bandwidth efficiency also increases. This bandwidth efficiency is measured in bits per second/Hz.

As higher density modulation schemes are adopted, the Decoder or Demodulator gets progressively more complex. A benefit of digital technology is that higher complexity does not necessarily mean a higher cost to the customer, since Large Scale Integration (LSI) ICs can be mass produced at reasonable cost, if a large demand exists. Consumers can look forward to fairly sophisticated QAM Receivers or Demodulators, at reasonable prices.

TERRESTRIAL TRANSMISSION - O.F.D.M.

The biggest concern for proper reception of terrestrial broadcast is multi path distortion, or " Ghosts ". This happens when a signal arrives at the receiving antenna from multiple paths or direction. These multiple signals add up at the antenna, creating multiple images or "Ghosts" on the TV screen. This distortion is most pronounced in densely populated cities particularly those with high rise buildings.

Analog transmissions cannot prevent "Ghosts". The only hope is to realign the antenna to minimise the extent of ghosts. Hence it was a top priority for engineers to device a Digital Modulation scheme that would eliminate any possibility of ghosts images.

Further the Terrestrially transmitted Television signal should preferably not interfere with other terrestrial transmissions such as those for wireless radio etc.

To overcome these problems engineers have created a modulation scheme that appears to be extremely complex.

Orthogonal Frequency Division Multiplexing (OFDM) is a type of Frequency Multiplexing. In Frequency Multiplexing, multiple carriers are used at different frequencies, as shown in Fig.4

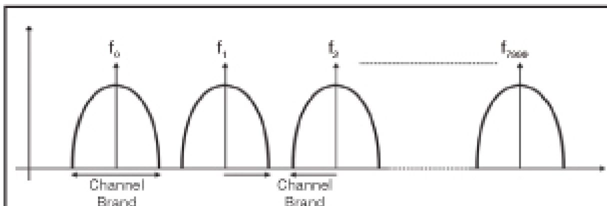

Fig 4 : OFDM Carriers

Each carrier is separated by an unused band of frequencies called a "Guard Band". Ofcourse, the guard band is a waste of the bandwidth resource.

A Digital Terrestrial transmission (DVB-T) for a single television channel can utilise upto 8000 separate carriers ! Even a Digital Audio broadcast which requires much smaller amount of data to be transmitted compared to a Television channel, employs 1500 separate carriers.

To fit these large number of carriers into the typical 8 MHz bandwidth allocated for terrestrial broadcasts, engineers employed a further Orthogonal variation. Orthogonal here refers to a phase difference of 90 Degrees between two adjacent carriers. This is shown in Fig.5

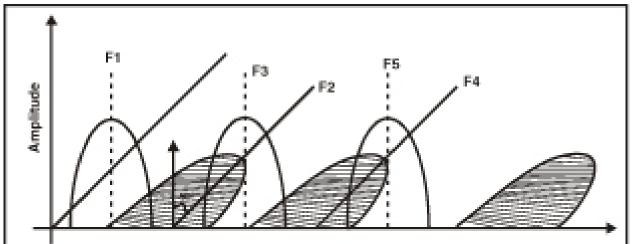

Fig. 5 : Overlapping 90° out of Phase Carriers in OFDM system

Using Orthogonal Frequency Division Multiplexing (OFDM) Modulation, 2 Adjacent Carriers will overlap without causing any interference because the two carriers are out of phase by 90 degrees. The overlapping of carriers avoid wastage of frequency bandwidth.

OFDM causes less interference to analog transmissions than an analog signal would, because it doesn't have the same strong carrier and subcarrier elements. Also, because there is a specific spacing between carriers of the same phase (guard interval), the signal is immune to multi path reflections or " Ghosts ".

Further, OFDM Modulation can be used in so called Single Frequency Networks, where a chain of transmitters can all use the same frequency for transmission.

ERROR CORRECTION

Digital Data like any other data is prone to errors during transmission. As explained earlier in this article, Digital Modulation aims to minimise the errors (BER). Even fairly high BERs can cause visible deterioration in the picture. Hence some additional methods for further correcting errors during transmission have been devised.

Most Digital Error Correction relies heavily on the pioneering work done by 3 mathematicians - Reed, Solomon and Viterbi. The Error Correction schemes have been named in their honour, Reed-Solomon (R-S) and Viterbi Error Correction.

An Error Correction system transmits a small amount of extra data which provides some indication (e.g. Checksum) of the previous Bits of information. If the extra Bit does not tally with the previous scheme of data, that particular data stream is considered to be in error and is rejected.

As a simple example of checksum - supposing the numbers 2,3 & 4 are to be transmitted, an extra Check-sum digit 9 will also be transmitted, viz : 2,3,4,9. The last digit 9 is a sum (total) to check the 1st 3 digits.

FORWARD ERROR CORRECTION (FEC)

When Digital data is transmitted over a system that provides two way communication i.e. from the sender to the receiver and back to the sender (This is often the case when computers exchange digital data). The receiver can request the sender to resend a packet of Bits that has not been received well.

However, in Digital Broadcasting (either DVB-T or C or S) there is no return path. Hence the Error Correction system must be powerful enough to recognise and recover the correct data even from a packet of corrupted Bits. Since the Error Correction has to function purely over a One Way or Forward Path, it is called Forward Error Correction (FEC).

As explained earlier, all schemes of Error Correction transmit extra data for the correction. An FEC system denoted as 3/4 implies that one extra Error Correction Bit is transmitted for every 3 data Bits. Similarly for a 7/8 FEC, one Error Correction Bit is transmitted extra for every 7 Bits of data. As one can imagine, an FEC of 3/4 provides better correction and is less prone to error and noise than an FEC of 7/8. To that extent, an FEC of 1/2 would be extremely robust since it would carry one correction Bit for every data Bit. Ofcourse an FEC of 1/2 would be extremely wasteful on transmitter capacity but could be considered where critical data is to be transmitted. An FEC of 1/2 is never utilised for broadcasting entertainment programmes.

MODULATION TRADE-OFFs

Similar to most engineering Trade-Offs, different Digital Modulation schemes too result in trade-offs. Relatively simple modulation such as QPSK offer excellent BER performance at even very low signal strengths. QPSK however requires a large bandwidth.

QAM is very bandwidth efficient efficient, but require strong signal strength for good BER. This is particularly so for the more dense bandwidth schemes such as 64 QAM.

Channel data rate and range are inversely related (as range increases, data throughput decreases). Alternately, a large signal strength should be maintained, but providing booster amplifiers in the signal path, as is normal in a CATV network.

Ensuring a strong signal strength is not easy for terrestrial transmissions (DVB-T).The size of the receiving antenna cannot also be increased beyond reasonable limits. In view of this DVB-T employs OFDM Digital Modulation.

OFDM modulation requires a complex decoder, capable of receiving upto 8000 simultaneous carriers. The level of each of these carriers is maintained very low, to insure that they do not interfere with other terrestrial transmissions. Infact OFDM is so robust that it can be transmitted simultaneously, with an Analog TV transmission at the SAME frequency, without any interference.

COMMERCIAL DVB-T

DVB-T (Terrestrial Broadcasts) have commenced in the UK, from October 1998. It is planned that the entire UK will be covered by DVB-T transmissions by the year 2001. There are even suggestions that Analog Terrestrial transmissions in UK would be discontinued after the year 2005.

Actually Terrestrial Digital transmissions in the UK are being implemented from existing sites of TV transmitters which will be broadcasting at non overlapping frequencies. Hence the need for "Single Frequency Networks" (SFN) were not necessary in this case. Hence the UK has adopted an OFDM system consisting of 2000 carriers (OFDM 2K) instead of an OFDM system with 8000 carriers (OFDM 8K)

The rest of Europe is likely to utilise Single Frequency Networks for their DVB-T transmissions. As a result, several hardware manufacturers are now planning Digital DVB-T Set Top Receivers and TV sets that can be switched for reception of either OFDM 2K or OFDM 8K signals.

DVB-T transmissions support high definition TV as well as the regular TV format and the wide - 16:9 screen. Since the transmissions are completely free of any ghosts, the picture looks extremely sharp and vivid, even for non high definition transmissions.

Subjectively many viewers have commented on the improvement provided by Digital television as similar to the difference between B&W and Colour Televisions !

CONCLUSION

Digital standards are now crystallising worldwide. As explained in this article, separate Digital Modulation methods are now adopted for Satellite, Terrestrial and Cable DVB broadcasting. While different variations of a particular scheme such as QAM 16 or QAM 64 may be adopted by different manufacturers, the principles and methods of modulation are now standardised. n

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