INTRODUCTION – DIGITAL COMMUNICATION & MODULATION

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• Suggested Activity: Brainstorming

• What do you understand by communication?

• ANSWERS:

» From Students
Elements of Communication systems

• **Analogy**: Chinese and Indian want to communicate

• **ANSWERS**
  – The different elements of a communication system are an information source, a receiver, a transducer and a medium.
Analog vs. Digital

- **Analogy**: Song which is stored in the cassette and the song which is stored in CD.
  - Song which is stored in the cassette is analog type and deteriorates over years. The song which stored in the CD is digital its reproduction is good even after 10 Years. Digital songs can compress and expanded using MP3 Technology. This shows digital signals highly compatible.

**ANSWERS**

- Listening song Via radio which is analog transmission and listening song through satellite radio which is digital transmission. Digital transmission quality is good compared to Analog Transmission.
Block Diagram of Digital Communication System

General structure of a communication system

Source → Transmitter → Channel → Receiver → User

Transmitter:
- Discrete info source
- Source encoder
- Channel encoder
- Modulator

Receiver:
- Destination
- Source decoder
- Channel decoder
- Demodulator
Digital Communication: Advantages and Disadvantages

• **Advantages**

• The effect of distortion, noise and interference is less in a digital communication system. This is because the disturbance must be large enough to change the pulse from one state to the other.

• Regenerative repeaters can be used at fixed distance along with the link, to identify and regenerate a pulse before it is degraded to an ambiguous state.

• Digital circuits are more reliable and cheaper when compared to analog circuits.

• The hardware implementation is more flexible than analog hardware because of the use of microprocessors, Very-large-scale-integration (VLSI) chips, etc.

• Signal processing functions like encryption and compression can be employed to maintain the secrecy of the information.

• Error detecting and error correcting codes improve the system performance by reducing the probability of error.

• Combining digital signals using Time-division multiplexing (TDM) is simpler than combining analog signals using Frequency-division multiplexing (FDM). The different types of signals such as data, telephone, TV can be treated as identical signals in transmission and switching in a digital communication system.

• We can avoid signal jamming using spread spectrum technique.
Advantages of digital communication system are:

• Highly immune to the noise.

• Highly Compatibility and flexible.

• Error correction and detection is possible.

• Due to development VLSI technology and high speed computer it is very easy to implement digital communication system.
Disadvantages

• Larger system bandwidth: Digital transmission requires a large system bandwidth to communicate the same information in a digital format as compared to analog format.

• System synchronisation: Digital detection requires system synchronisation whereas the analog signals generally have no such requirement.
Quite often we have to send digital data through analog transmission media such as a telephone network. In such situations it is essential to convert digital data to analog signal. Basic approach is shown in Fig. This conversion is accomplished with the help of special devices such as modem (modulator-demodulator) that converts digital data to analog signal and vice versa.
Define MODULATION

- Suggested Activity: Story Telling and Question and Answer

Preethi goes to a shoe shop, to buy a shoe to wear on her friend’s wedding reception. She likes a brown color and decides to buy it. While trying it on, she finds that the readymade shoe needs altering. She takes the stuff to a cobbler and asks him to resize it accordingly to her size and requirements. The cobbler does exactly as she says. Now, the shoes fit her well. Quite content with her selection and the work of the cobbler, Preethi wears it to her friend’s wedding reception.

Based on this story, we can ask a few questions and subsequently introduce the term modulation.

1. On what criteria the readymade shoes are altered?
   Expected answers from the learners: Based on the size, shape, and preference of the customer buying the shoes.

   From the discussion, we can see that certain parameters of shoes are altered based on the shape, and preference of the customer.

   Similarly, in communication system, some parameters of a high frequency carrier signal are modified according to a low frequency signal. This process of varying some parameter of a high frequency carrier signal accordingly to a modulating signal is called as modulation.
Definition – MODULATION

• Modulation is changing one or more of the characteristics of a signal (known as the carrier signal) based on the value of another signal (known as the information or modulating signal) to produce a modulated signal.
• A carrier is a sinusoidal of high frequency with one of its parameters (amplitude, phase, or frequency) is varied in proportion to the message $m(t)$
• Famous Types
  • Amplitude Modulation (AM): varying the amplitude of the carrier based on the information signal as done for radio channels that are transmitted in the AM radio band.
  • Phase Modulation (PM): varying the phase of the carrier based on the information signal.
  • Frequency Modulation (FM): varying the frequency of the carrier based on the information signal as done for channels transmitted in the FM radio band.
Classification of Modulation Techniques

Modulation Techniques can be broadly classified as follows:

- Digital versus Analog Modulation
- Baseband versus Bandpass (Passband) Modulation
- Binary versus M-ary Modulation
- Memoryless Modulation versus Modulation with memory
- Linear versus Nonlinear Modulation
- Constant envelope versus Non-constant envelope Modulation
- Power efficient versus Bandwidth efficient Modulation
Various factors should be considered for choosing a particular modulation scheme to be used in a communications system.

A modulation scheme should be spectral efficient and possess low bit error rate (BER) especially at lower signal-to-noise ratios (SNR).

A modulation scheme should also perform well in multipath and fading environments. Cost effective and simple implementations are also key desirable features.

Existing modulation techniques do not offer all these features simultaneously. Some modulations are spectral efficient, however their BER performance is not exceptional. Bandwidth efficiency and energy efficiency are the two parameters used to quantify the performance of modulation techniques. Bandwidth or spectral efficiency is the number of bits transmitted per second per hertz of bandwidth or data-rate per hertz (bits/s/Hz). Energy efficiency is the ratio of signal energy per bit to noise power spectral density (Eb/N0) required for certain BER at the receiver.
Factors affecting choice of modulation

Practical application, the choice of digital MODEM depends on:

- Signal-to-noise ratio (SNR)

- **Probability of symbol error or Probability of bit error is related to:**
  - Power Efficiency, \( hp \)
    - Power efficiency is a measure of how much received power is needed to achieve a specified BER (inversely proportional to BER). As BER increases, \( hp \) decreases since transmitted power is “wasted” on more bad data
  - Bandwidth Efficiency
    - Bandwidth Efficiency (or Spectral Efficiency), \( hB \) is defined as the ratio of the bit rate to the channel bandwidth

If \( R \) is data rate and \( B \) is the RF signal bandwidth, then the capacity of a digital system is directly related to \( hB \)

Note: Binary systems are more Power Efficient, but less Spectral Efficient than M-ary systems
choice of modulation (Contd..)

For example, in wireless communications, it is important to select MODEM based on the following requirements:

- High Spectral Efficiency
- High Power Efficiency
- High Fading Immunity

- **Practical Modulation Schemes**
  - FM Þ AMPS
  - MSK Þ CT2
  - GMSK Þ GSM, DCS 1800, CT3, DECT
  - QPSK Þ NADC (CDMA) - base transmitter
  - OQPSK Þ NADC (CDMA) - mobile transmitter
  - 4-DQPSK Þ NADC (TDMA), PDC (Japan), PHP (Japan)
  - MPSK Þ (some wireless LANs)
Need of Modulation

• **Why to modulate?**
• Antenna size is inversely proportional to the frequency. Antenna size has to be comparable to the wave length. \( c=\lambda f \)
• To receive transmitted signals from multiple sources without interference between them, they must be transmitted at different frequencies (frequency division multiplexing, FDM) by modulating carriers that have different frequencies with the different information signals. (like painting with colors).
• To improve the propagation. Low frequency penetrates walls better than high frequency signals
M ary Signaling

• Instead of just varying amplitude, phase and frequency of signal, modern modulation techniques allow both envelope (amplitude frequency) of the RF carrier to vary. Because the envelope and phase provide two degrees of freedom, such modulation techniques map baseband data into four or more possible RF carrier signals. Such modulation techniques are known as M-ary modulation. In M-ary modulation scheme, two or more bits are grouped together to form symbols and one of possible signals $S_1(t)$, $S_2(t)$, ..., $S_m(t)$ is transmitted during each symbol period $T_s$. Normally, the number of possible signals is $M = 2^n$, where $n$ is an integer. Depending on whether the amplitude, phase or frequency is varied, the modulation is referred to as M-ary ASK, M-ary PSK or M-ary FSK, respectively. M-ary modulation technique attractive for use in bandlimited channels, because these techniques achieve better bandwidth efficiency at the expense of power efficiency. For example, an 8-PSK technique requires a bandwidth that is $\log_2 8 = 3$ times smaller than 2-PSK (also known as BPSK) system. However, M-ary signalling results in poorer error performance because of smaller distances between signals in the constellation diagram. Several commonly used M-ary signalling schemes are discussed below.
Since modulation involves operations on one or more of the three characteristics of the carrier signal, namely amplitude, frequency and phase, three basic encoding or modulation techniques are available for the conversion of digital data to analog signals as depicted below. These techniques, referred to as amplitude shift keying (ASK), frequency shift keying (FSK) and phase shift keying (PSK), are discussed in the following lesson. There are many situations where these techniques are combined together in a technique known as Quadrature Amplitude Modulation (QAM). In this lesson, these modulation techniques are introduced.
Modulation Types
The faculty can narrate the following **analogy** to the learners:

In transportation, a baud is analogous to a car and a bit is analogous to a passenger. A car can carry one or more passengers. If 10 cars can go from one point to another, carrying only one passenger, then 10 passengers are transported. If each car carries 4 passengers then 40 passengers are transported. The number of cars tells the traffic not the number of passengers.
An analog message signal, representing voice for example, has continuous amplitude and frequency values that vary with time. Analog communication systems transmit the complete analog waveform. But instead of transmitting the analog signal, it is possible to transmit discrete pulses (or samples) that represent some parameter of the message signal’s waveform at regular intervals in time.

In the case of pulse amplitude modulation (PAM), the amplitude of the analog waveform is sampled at discrete (i.e., discontinuous) time instants, and transmitted as a sequence of pulses. Notice, however, that this sampling produces amplitudes that can still take any value, hence the scheme is not fully digital (unlike PCM which will be studied in a subsequent lab, and which uses quantization to represent the discrete samples by a finite number of bits).
Advantages of PAM

- There are a number of advantages for transmitting PAM pulses rather than complete analog signals. For example, if the duration of the PAM pulse is small, the energy required to transmit the pulses is much less than the energy required to transmit the full analog signal. For a sampling pulse train with a duty cycle fraction $PW/T$ (i.e., the sampling pulse duration is $PW$, and its period is $T$), it can be shown that the power of the sampled PAM signal $P_p$ is only a fraction of the total analog signal power $P_s$, given by: $P_p = (PW/T)P_s$.

Another advantage of PAM has to do with the ability to multiplex (or combine) several different signals and transmit them on the same communication channel. Although this is also possible with analog communication (using for example frequency division multiplexing-FDM), it is much simpler and more economical to implement with digital or discrete systems like PAM using what’s known as time division multiplexing (TDM). Since PAM sends amplitude pulses of a given signal at discrete periodic time slots (or intervals), it is then possible to assign the remaining time slots for other signals, thereby maximizing the utilization of the channel. There is obviously a need for maintaining adequate synchronization at the transmitter and receiver levels to distinguish the different signals. This type of TDM transmission is very efficient and widely used in practical communication systems such as telephone networks, particularly in combination with Pulse Code Modulation-PCM (which is similar to PAM, but uses additional amplitude quantization as will be seen in a following lab).
INTRODUCTION - QAM

• Quadrature Amplitude Modulation or QAM is a form of modulation which is widely used for modulating data signals onto a carrier used for radio communications. It is widely used because it offers advantages over other forms of data modulation such as PSK, although many forms of data modulation operate along side each other.

• Quadrature Amplitude Modulation, QAM is a signal in which two carriers shifted in phase by 90 degrees are modulated and the resultant output consists of both amplitude and phase variations. In view of the fact that both amplitude and phase variations are present it may also be considered as a mixture of amplitude and phase modulation.
What is phase shift keying?

Although phase modulation is used for some analog transmissions, it is far more widely used as a digital form of modulation where it switches between different phases. This is known as phase shift keying, PSK, and there are many flavours of this.

Quadrature amplitude modulation (QAM)

It is even possible to combine phase shift keying and amplitude keying in a form of modulation known as quadrature amplitude modulation, QAM.

The list below gives some of the more commonly used forms of phase shift keying, PSK, and related forms of modulation that are used:

- PSK - Phase Shift Keying
- BPSK - Binary Phase Shift Keying
- QPSK - Quadrature Phase Shift Keying
- O-QPSK - Offset Quadrature Phase Shift Keying
- 8 PSK - 8 Point Phase Shift Keying
- 16 PSK - 16 Point Phase Shift Keying
- QAM - Quadrature Amplitude Modulation
- 16 QAM - 16 Point Quadrature Amplitude Modulation
- 64 QAM - 64 Point Quadrature Amplitude Modulation
- MSK - Minimum Shift Keying
- GMSK - Gaussian filtered Minimum Shift Keying
Quadrature amplitude modulation, QAM may exist in what may be termed either analog digital formats. The analog versions of QAM are typically used to allow multiple analog signals to be carried on a single carrier. For example, it is used in PAL and NTSC television systems, where the different channels provided by QAM enable it to carry the components of chroma or colour information. In radio applications a system known as C-QUAM is used for AM stereo radio. Here the different channels enable the two channels required for stereo to be carried on the single carrier.

Digital formats of QAM are often referred to as "Quantised QAM" and they are being increasingly used for data communications often within radio communications systems. Radio communications systems ranging from cellular technology through wireless systems including WiMAX, and Wi-Fi 802.11 use a variety of forms of QAM, and the use of QAM will only increase within the field of radio communications.
Advantages and Disadvantages of QAM

• Advantages:
• QAM appears to increase the efficiency of transmission for radio communications systems by utilising both amplitude and phase variations,
• Drawbacks
• more susceptible to noise because the states are closer together so that a lower level of noise is needed to move the signal to a different decision point. Receivers for use with phase or frequency modulation are both able to use limiting amplifiers that are able to remove any amplitude noise and thereby improve the noise reliance. This is not the case with QAM.
• The second limitation is also associated with the amplitude component of the signal. When a phase or frequency modulated signal is amplified in a radio transmitter, there is no need to use linear amplifiers, whereas when using QAM that contains an amplitude component, linearity must be maintained. Unfortunately linear amplifiers are less efficient and consume more power, and this makes them less attractive for mobile applications.
• QAM is in many radio communications and data delivery applications. However some specific variants of QAM are used in some specific applications and standards.

• For domestic broadcast applications for example, 64 QAM and 256 QAM are often used in digital cable television and cable modem applications. In the UK, 16 QAM and 64 QAM are currently used for digital terrestrial television using DVB - Digital Video Broadcasting. In the US, 64 QAM and 256 QAM are the mandated modulation schemes for digital cable as standardised by the SCTE in the standard ANSI/SCTE 07 2000.

• In addition to this, variants of QAM are also used for many wireless and cellular technology applications.
Quadrature amplitude modulation, QAM, when used for digital transmission for radio communications applications is able to carry higher data rates than ordinary amplitude modulated schemes and phase modulated schemes. As with phase shift keying, etc, the number of points at which the signal can rest, i.e. the number of points on the constellation is indicated in the modulation format description, e.g. 16QAM uses a 16 point constellation.

When using QAM, the constellation points are normally arranged in a square grid with equal vertical and horizontal spacing and as a result the most common forms of QAM use a constellation with the number of points equal to a power of 2 i.e. 2, 4, 8, 16 . . . .

By using higher order modulation formats, i.e. more points on the constellation, it is possible to transmit more bits per symbol. However the points are closer together and they are therefore more susceptible to noise and data errors.

To provide an example of how QAM operates, the table below provides the bit sequences, and the associated amplitude and phase states. From this it can be seen that a continuous bit stream may be grouped into threes and represented as a sequence of eight permissible states.
Quadrature Amplitude Modulation uses the phase and amplitude of the carrier signal to encode data. QAM finds widespread use in current and emerging wireless standards, including Wi-Fi, Digital Video Broadcast (DVB), WiMAX, IEEE 802.11n, and HSDPA/HSUPA.

The QAM modulation scheme encodes data by varying both amplitude and phase of the carrier signal. Thus, it is sometimes viewed as a combination of ASK and PSK modulation. A more fundamental way of viewing QAM thought is that it encodes data by varying the amplitude of two carrier signals that are in-quadrature (phase difference of 90). Hence the name “quadrature-amplitude modulation”. We will now leverage our understanding of IQ data to understand this idea. As we have seen, a modulated carrier signal can be expressed in terms of its IQ components as:

\[ A_c \cos(2\pi f_c t + \phi) = I \cos(2\pi f_c t) - Q \sin(2\pi f_c t) \]

where \( I = A_c \cos(\phi) \) and \( Q = A_c \sin(\phi) \)

where \( I \) and \( Q \) are the amplitudes of the in-phase and quadrature-phase components respectively. Thus, we can change the amplitude () and phase () of the carrier signal by varying the \( I \) and \( Q \) values.
The constellation diagrams show the different positions for the states within different forms of QAM, quadrature amplitude modulation. As the order of the modulation increases, so does the number of points on the QAM constellation diagram.

The diagrams below show constellation diagrams for a variety of formats of modulation:
Let’s look at the time-domain representation of QAM signals. Taking 4-QAM as an example, suppose we wish to transmit the bitstream 100111. We map these to 4 QAM symbols representing 10, 01, 11. The resulting time-domain waveform for this bitstream is shown in Figure 53. Each symbol is represented by one period of the sine wave and has a unique phase shift. In this respect, 4-QAM might be considered a special case of QAM where the amplitude is the same for all symbols.
The constellation plot in this Figure shows the phase and amplitude transitions of the carrier signal. The raw IQ data is represented by the red trace with the white dots representing those samples of IQ data that occur on symbol clock periods and that are mapped back to digital bit patterns based on the 4-QAM symbol map. We note that the transitions go through the origin. This causes abrupt amplitude variations between consecutive symbols and causes noise to be injected in the transmitted symbol due to the amplifier turning off and back on abruptly. This problem can be fixed by using offset-QAM. Refer to the offset-PSK modulation scheme discussed earlier for more details.
Conclusion

• Quadrature Amplitude Modulation is an important modulation scheme with many practical applications, including current and future wireless technologies. Some examples of communication systems that use QAM are Wi-Fi, cable modems, Digital Video Broadcast (DVB) and WiMAX.
References


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