Chapter 16

Evolution of pulse code modulation

TEC/NOT/024

This paper describes the evolution of Pulse Code Modulation (PCM). The following topics are discussed:

16.1 Overview

PCM is the process of sampling an analog signal's amplitude at fixed intervals, converting the amplitudes into discrete levels (quantization) and assigning digital codes to represent those levels. This paper outlines the development of wireless communication from Guglielmo Marconi’s demonstration of the wireless telegraph in 1895, the use of amplitude and frequency modulation and mechanical commutators evolving into electronic switches and multiplexors. In particular, it discusses the development of the different methods used in communications: Stage I, mechanical commutators; Stage II, the introduction of the integrated circuit; and Stage III, Acra KAM-500.

16.2 History

Telemetry comes from the Greek and Latin words for distance and measurement. It is based on the studies of James Clerk Maxwell, who developed the mathematical theory of electromagnetic waves, and Heinrich Hertz, who devised an apparatus for generating and detecting them.

Guglielmo Marconi, recognizing the possibility of using these waves for a wireless communication system, gave a demonstration of the wireless telegraph, using Hertz's spark coil as a transmitter for Amplitude Modulation (AM) in 1895. AM (see the following figure) is the modulation method used in the AM radio broadcast band. In this system, the intensity or amplitude of the carrier wave varies in accordance with the modulating signal. The frequency components of the modulating signal are translated to occupy a different position in the spectrum. It is essentially a multiplication process in which the time functions that describe the modulating signal and carrier are multiplied together.

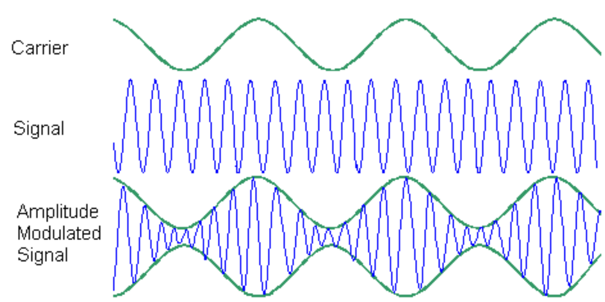

Figure 16-1: Amplitude Modulation

In 1906, the transmission of music and speech became possible with the work of Reginald Fessiden and Ernst F.W. Alexanderson. However, it was not until Major Edwin H. Armstrong invented the superheterodyne radio receiver in 1918 that long-range radio reception became practicable. To this day almost all radio receivers are of this type.

Twenty-seven years later, in 1933, Armstrong was granted patents on a Frequency Modulation (FM) system that he promoted as a superior alternative to the established AM broadcasting service. In FM, the frequency of the carrier wave is varied in such a way that the change in frequency at any instant is proportional to another signal that varies with time (see the following figure). Its principal application is also in radio, where it offers increased noise immunity and decreased distortion over the AM transmissions at the expense of greatly increased bandwidth.

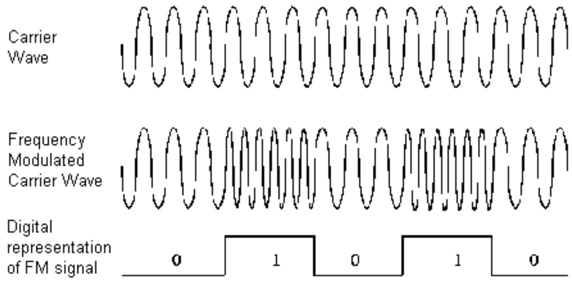

Figure 16-2: Frequency Modulation

16.3 Sampling

In 1928, Harry Nyquist developed criteria for the correct reception of telegraph signals transmitted over discrete channels in the absence of noise. Much of Nyquist's early work was applied later to the transmission of digital data over discrete channels. He introduced a sampling theorem, which states that a signal can be completely recovered from knowledge of its samples taken at a rate of 2W samples per second for a band-limited signal with a bandwidth of W Hertz.

An important feature of the sampling process is the conservation of time. That is, the transmission of the message sampled engages the transmission channel for only a fraction of the sampling interval on a periodic basis, and in this way some of the time intervals between adjacent samples are cleared for use by other independent message sources on a time-shared basis, giving rise to Time Division Multiplexing (TDM).

This method of transmission was first broadcast via mechanical commutators (see stage I of the following figure). A commutator was originally a rotating mechanical switch with many contacts used for sequentially switching voltages. Early telemetry systems used two synchronized units (called a commutator and decommutator) to pass analog voltage samples through a link between the units. Commutators can be connected in series and driven at different speeds to allow channels to be sampled at different rates. Modern telemetry systems use electronic switches and multiplexors. This strategy required some way of knowing where in a sequence of data a given point would be. One solution to this problem was to introduce a synchronization pattern, which in turn could also be used to calibrate the gain and offset of the receiver.

Faster signals were connected more often to the commutator, giving rise to the term super-commutation for signals sampled more than once per periodic rotation of the main commutator. Slower signals were connected to a second (or third) commutator, which revolved at a slower rate than the main commutator, giving rise to sub-commutation.

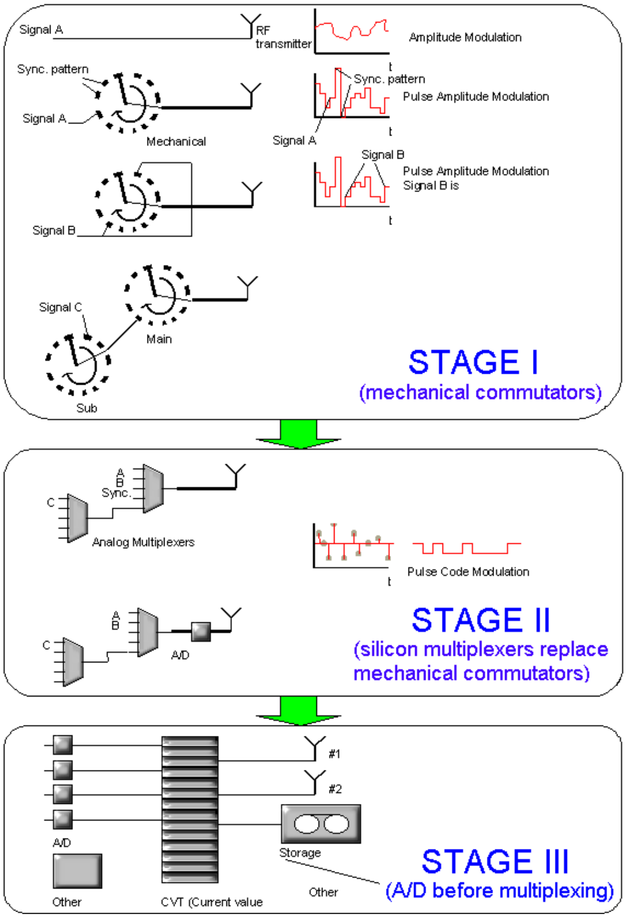

Figure 16-3: The evolution of communication technology

16.4 Digital communication

In 1948, the theoretical foundations of digital communications were laid by Claude Shannon in a paper entitled, *A Mathematical Theory of Communication*. Shannon's paper was received with immediate and enthusiastic acclaim. Prior to the publication of Shannon's 1948 classic paper, it was believed that increasing the rate of information transmission over a channel would increase the probability of error; the communication theory community were taken by surprise when Shannon proved that this was not true, provided that the transmission rate was below the channel capacity.

Many developments in the method of communication took place during Stage I (see the previous figure) of the communication technology evolution. All of these methods, however, were improved significantly by the introduction of the integrated circuit in 1958 by Jack Kilby of Texas Instruments and Robert Noyce of Fairchild Semiconductor Corp. This development in technology was the beginning of Stage II.

In 1939, The English inventor Alec H. Reeves developed PCM for the digital encoding of speech signals. The technique was developed during World War II to enable the encryption of speech signals. A full-scale, 24-channel system was used in the field by the United States military at the end of the war. It was used to transmit information over long distances with hardly any interference or distortion. With built in mathematical redundancy and error checking of the received signal, offering higher noise rejection and response speed, PCM had become the most important form of pulse modulation. However, PCM had to await the discovery of the transistor and the subsequent development of large-scale integration of circuits for its commercial exploitation.

PCM is the process of sampling an analog signal’s amplitude at fixed intervals, converting the amplitudes into discrete levels (quantization) and assigning digital codes to represent those levels. This process is sometimes referred to as analog to digital (A/D) conversion. The higher the sample rate, the greater the number of quantization levels, and therefore the closer the representation of the digital codes will be to the original analog signal.

The number of quantization levels depends on the number of bits in the digital code used to represent the signal's amplitude. If a 4-bit binary code was used, then there would be 16 quantization levels. The analog signal would be sampled and assigned codes of the form: 0101, 0111, 1100 and so on. The difference between the original analog signal amplitudes and the assigned discrete levels is called quantization noise. The greater the number of quantization levels, the smaller the quantization steps, which results in lower quantization noise. Quantization may be linear (using a uniform step size) or non-linear.

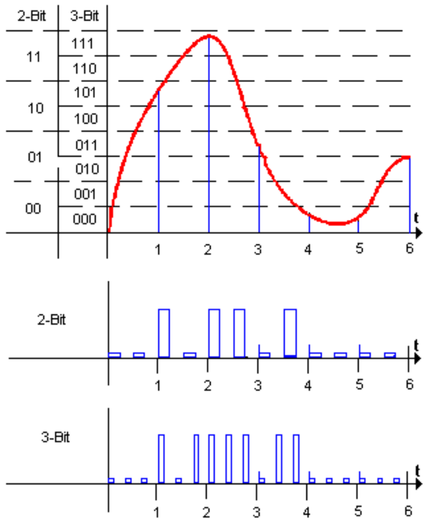

Figure 16-4: Pulse code modulation

In 1996, Stage III of the communications technology evolution brought with it large advances in the methods of PCM transmission, by repositioning the A/D converters, which were placed after the circuit's combinational logic in STAGE II. The quality of the incoming signal is heightened with the A/D converters placed before the logic. This method protects the signal from deteriorating through the multiplexers before being sampled. This leads to a more improved approximation of the original signal.

This technology has been implemented within the Acra KAM-500 system, which is used in over 25 countries in the most demanding applications and harshest of environments including aircraft flight test, vehicle crash test, and turbine telemetry.

16.5 References

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