Introduction to Digital Communications

Ali Grami



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Exhibit 1018 Page 1

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and echo, but it is significantly more dominant in radio communications. Interference can be generated by other users of the same frequency or by equipment that inadvertently transmits energy outside its band and into the bands of adjacent channels or systems.

There are various ways to practically remove or significantly minimize radio interference in most cases. They include appropriate filtering with stringent requirements, appropriately-placed physical barriers, transmit and receive antennas with high directivity, spatial (geographical) separation between wanted and interfering sources, and strict requirements set by regulatory bodies on the emission properties of equipment.

2.6.4 Noise

Noise refers to unwanted, ever-present, random waves that tend to disturb the transmission and processing of signals in a communication system, thus yielding a corrupted version of the transmitted signal. There are several types of noise, such as ***thermal noise*** (due to the random motion of electrons in a conductor), ***shot noise*** (due to the discrete nature of current flow in electronic devices), and ***impulse noise*** (due to natural sources, such as lightning, and man-made sources, such as high-voltage power lines).

Noise is generally assumed to be added to the signal. Filtering can be used to maximize SNR at the receiver (i.e., it can reduce noise contamination), but there inevitably remains some amount of noise that cannot be eliminated. Moreover, due to the central limit theorem, the aggregate of a number of different noises can be assumed to have a Gaussian distribution. It is also generally assumed that noise is white and thus emanates an equal amount of noise power per unit bandwidth at all frequencies. To this effect, ***additive white Gaussian noise*** (AWGN) is the most common type of noise considered in digital communication systems, and constitutes one of the most fundamental system limitations. The effects of noise cannot be eliminated, but by appropriate filtering the SNR value can be maximized.

2.7 MODULATION PROCESS

Modulation is defined as a process through which an information-bearing message (i.e., modulating) signal is used to modify (i.e., modulate) some parameter (e.g., amplitude, frequency, phase) of a periodic (such as a high-frequency sinusoidal) signal known as a carrier wave, individually or in combination, to produce the modulated signal for transmission. This is similar to when a musician modulates a tone by varying its volume (amplitude), its timing (phase), and its pitch (frequency).

We have three distinct modulation categories: ***amplitude modulation*** (AM), ***frequency modulation*** (FM), and ***phase modulation*** (PM). However, in the context of digital communications, the term ***shift keying*** is generally used instead of the word modulation. To this effect, we have ***amplitude-shift keying*** (ASK), ***frequency-shift keying*** (FSK), and ***phase-shift keying*** (PSK). There is also another category in digital communications, which is a hybrid of ASK and PSK, known as ***quadrature amplitude modulation*** (QAM). It is important to note that PSK and QAM are used in digital communication systems far more often than ASK and FSK. In some cases, the modulated signal is simply related to the message signal, such as with ASK, and in some cases, the relationship is rather complicated, such as with QAM.

A ***modem*** is a device that provides two-way communications, and thus performs both modulation in the transmitter and demodulation (i.e., the inverse operation of modulation) in the receiver. Modulation is performed to achieve one or more of the following objectives:

Modulation for efficient radio transmission: For radio communications, antennas are needed to radiate (transmit) and receive the modulated signal. The size of the antenna depends on the wavelength and the application. Modulation helps translate the message signal with low frequency components into a signal with much higher frequency components. The resulting modulated signal can thus possess a much smaller wavelength, and that in turn allows much smaller antennas. The signal wavelength λ can be found using $\lambda = \frac{c}{f}$, where f is the signal frequency in Hertz (Hz), c is the speed of light in meters per second (mps), and λ in meters (m). As an example, efficient electromagnetic radiation for line-of-sight radio propagation generally requires antennas whose physical dimensions are at least 10% of the signal's wavelength. Therefore, an audio signal with frequency components up to 100 Hz requires an antenna about 300 km, but with modulation at 300 MHz, the antenna needs to be only about 10 cm long. Another example is that for cellular mobile telephones, antennas are typically 25% of the signal wavelength, so for the above-mentioned audio signal, an antenna spanning 750 km would be required, but with modulation at 900 MHz, the equivalent antenna diameter would be only about 8 cm.

Modulation to match channel characteristics: Modulation allows modification of the message signal to a form suited to the characteristics of the transmission channel. The majority of practical channels have bandpass characteristics and modulation translates the frequency components of the lowpass message signal to the passband range, so the spectrum of the transmitted signal can match the characteristics of the channel. Applications may include satellite TV, in which baseband video signals with frequency components up to 6 MHz are converted into RF signals operating at 14 GHz, and cellular phones, in which baseband speech signals with frequency components up to 4 kHz are converted into RF signals operating at 900 MHz.

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Exhibit 1018 Page 4