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Modulation of Signals

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ABSTRACT

This paper addresses the technique of rapidly updating the weights of an adaptive filter to cancel non-stationary interference. This method is used, for example, in radar systems that receive coherent multipath interference, known as "hot clutter" or "terrain scattered jamming". We develop a framework for understanding how this rapid weight updating (inadvertently) modulates signals. Two principal types of modulation are studied: random modulations induced by finite-length training sets and non-randommodulations induced by the coherence of the interference. Our framework is then used to assess the impact of these modulations on the overall performance of various well-known jammer multipath mitigation algorithms. Several techniques for controlling this modulation are proposed.

KEYWORDS

modulation; signal modulation; pulse modulation; bandwidth; carrier signal

INTRODUCTION

In electronics and telecommunications, **modulation** is the process of varying one or more properties of a periodic waveform, called the *carrier signal*, with a modulating signal that typically contains information to be transmitted.

In telecommunications, modulation is the process of conveying a message signal, for example a digital bit stream or an analog audio signal, inside another signal that can be physically transmitted. Modulation of a sine waveform transforms a baseband message signal into a passband signal.

A **modulator** is a device that performs modulation.
A **demodulator** (sometimes *detector* or *demod*) is a device that performsdemodulation, the inverse of modulation.

A modem (from **mo**dulator–**dem**odulator) can perform both operations.

The aim of **digital modulation** is to transfer a digital bit stream over an analog bandpass channel, for example over the public switched telephone network (where a bandpass filter limits the frequency range to 300–3400 Hz), or over a limited radio frequency band.

The aim of **analog modulation** is to transfer an analog baseband (or lowpass) signal, for example an audio signal or TV signal, over an analog bandpass channel at a different frequency, for example over a limited radio frequency band or a cable TV network channel.

Analog and digital modulation facilitate frequency division multiplexing (FDM), where several low pass information signals are transferred simultaneously over the same shared physical medium, using separate passband channels (several different carrier frequencies).

The aim of **digital baseband modulation** methods, also known as line coding, is to transfer a digital bit stream over a baseband channel, typically a non-filtered copper wire such as a serial bus or a wired local area network.

The aim of **pulse modulation** methods is to transfer a narrowband analog signal, for example a phone call over a wideband baseband channel or, in some of the schemes, as a bit stream over another digital transmission system.

In music synthesizers, modulation may be used to synthesise waveforms with an extensive overtone spectrum using a small number of oscillators. In this case the carrier frequency is typically in the same order or much lower than the modulating waveform. See for example frequency modulation synthesis or ring modulation synthesis

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ANALOG MODULATION METHODS

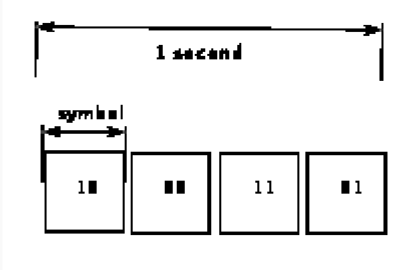
In analog modulation, the modulation is applied continuously in response to the analog information signal. Common analog modulation techniques are:

- Amplitude modulation (AM) (here the amplitude of the carrier signal is varied in accordance to the instantaneous amplitude of the modulating signal)
  - Double-sideband modulation (DSB)
    - Double-sideband modulation with carrier (DSB-WC) (used on the AM radio broadcasting band)
    - Double-sideband suppressed-carrier transmission (DSB-SC)
    - Double-sideband reduced carrier transmission (DSB-RC)
  - Single-sideband modulation (SSB, or SSB-AM)
    - SSB with carrier (SSB-WC)
    - SSB suppressed carrier modulation (SSB-SC)
  - Vestigial sideband modulation (VSB, or VSB-AM)
  - Quadrature amplitude modulation (QAM)

- Angle modulation, which is approximately constant envelope
  - Frequency modulation (FM) (here the frequency of the carrier signal is varied in accordance to the instantaneous amplitude of the modulating signal)
  - Phase modulation (PM) (here the phase shift of the carrier signal is varied in accordance with the instantaneous amplitude of the modulating signal)

DIGITAL MODULATION METHODS

In digital modulation, an analog carrier signal is modulated by a discrete signal. Digital modulation methods can be considered as digital-to-analog conversion, and the corresponding demodulation or detection as analog-to-digital conversion. The changes in the carrier signal are chosen from a finite number of M alternative symbols (the*modulation alphabet*).



Schematic of 4 baud (8 bit/s) data link containing arbitrarily chosen values.

A simple example: A telephone line is designed for transferring audible sounds, for example tones, and not digital bits (zeros and ones). Computers may however communicate over a telephone line by means of modems, which are representing the digital bits by tones, called symbols. If there are four alternative symbols (corresponding to a musical instrument that can generate four different tones, one at a time), the first symbol may represent the bit sequence 00, the second 01, the third 10 and the fourth 11. If the modem plays a melody consisting of 1000 tones per second, the symbol rate is 1000 symbols/second, or baud. Since each tone (i.e., symbol) represents a message consisting of two digital bits in this example, the bit rate is twice the symbol rate, i.e. 2000 bits per second. This is similar to the technique used by dialup modems as opposed to DSL modems.

According to one definition of digital signal, the modulated signal is a digital signal, and according to another definition, the modulation is a form of digital-to-analog conversion. Most textbooks would consider digital modulation schemes as a form of digital transmission, synonymous to data transmission; very few would consider it as analog transmission.

FUNDAMENTAL DIGITAL MODULATION METHODS

The most fundamental digital modulation techniques are based on keying:

- PSK (phase-shift keying): a finite number of phases are used.

- FSK (frequency-shift keying): a finite number of frequencies are used.
- ASK (amplitude-shift keying): a finite number of amplitudes are used.
- QAM (quadrature amplitude modulation): a finite number of at least two phases and at least two amplitudes are used.

In QAM, an inphase signal (or I, with one example being a cosine waveform) and a quadrature phase signal (or Q, with an example being a sine wave) are amplitude modulated with a finite number of amplitudes, and then summed. It can be seen as a two-channel system, each channel using ASK. The resulting signal is equivalent to a combination of PSK and ASK.

In all of the above methods, each of these phases, frequencies or amplitudes are assigned a unique pattern of binary bits. Usually, each phase, frequency or amplitude encodes an equal number of bits. This number of bits comprises the *symbol* that is represented by the particular phase, frequency or amplitude.

If the alphabet consists of $M = 2^N$ alternative symbols, each symbol represents a message consisting of *N* bits. If the symbol rate (also known as the baud rate) is f_S symbols/second (or baud), the data rate is $N f_S$ bit/second.

For example, with an alphabet consisting of 16 alternative symbols, each symbol represents 4 bits. Thus, the data rate is four times the baud rate.

In the case of PSK, ASK or QAM, where the carrier frequency of the modulated signal is constant, the modulation alphabet is often conveniently represented on a constellation diagram, showing the amplitude of the I signal at the x-axis, and the amplitude of the Q signal at the y-axis, for each symbol.

MODULATOR AND DETECTOR PRINCIPLES OF OPERATION

PSK and ASK, and sometimes also FSK, are often generated and detected using the principle of QAM. The I and Q signals can be combined into a complex-valued signal *I*+*jQ* (where *j* is the imaginary unit). The resulting so called equivalent lowpass signal or equivalent baseband signal is a complex-valued representation of the real-valued modulated physical signal (the so-called passband signal or RF signal).

These are the general steps used by the modulator to transmit data:

1. Group the incoming data bits into codewords, one for each symbol that will be transmitted.
2. Map the codewords to attributes, for example amplitudes of the I and Q signals (the equivalent low pass signal), or frequency or phase values.
3. Adapt pulse shaping or some other filtering to limit the bandwidth and form the spectrum of the equivalent low pass signal, typically using digital signal processing.
4. Perform digital to analog conversion (DAC) of the I and Q signals (since today all of the above is normally achieved using digital signal processing, DSP).
5. Generate a high frequency sine carrier waveform, and perhaps also a cosine quadrature component. Carry out the modulation, for example by multiplying the sine and cosine waveform with the I and Q signals, resulting in the equivalent low pass signal being frequency shifted to the modulated pass band signal or RF signal. Sometimes this is achieved using DSP technology, for example direct digital synthesis using a waveform table, instead of analog signal processing. In that case the above DAC step should be done after this step.
6. Amplification and analog band pass filtering to avoid harmonic distortion and periodic spectrum

At the receiver side, the demodulator typically performs:

1. Band pass filtering.
2. Automatic gain control, AGC (to compensate for attenuation, for example fading).

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3. Frequency shifting of the RF signal to the equivalent baseband I and Q signals, or to an intermediate frequency (IF) signal, by multiplying the RF signal with a local oscillator sine wave and cosine wave frequency (see the super heterodyne principle).
4. Sampling and analog-to-digital conversion (ADC) (Sometimes before or instead of the above point, for example by means of under sampling).
5. Equalization filtering, for example a matched filter, compensation for multipath propagation, time spreading, phase distortion and frequency selective fading, to avoidintersymbol interference and symbol distortion.
6. Detection of the amplitudes of the I and Q signals, or the frequency or phase of the IF signal.
7. Quantization of the amplitudes, frequencies or phases to the nearest allowed symbol values.
8. Mapping of the quantized amplitudes, frequencies or phases to codewords (bit groups).
9. Parallel-to-serial conversion of the codewords into a bit stream.
10. Pass the resultant bit stream on for further processing such as removal of any error-correcting codes.

As is common to all digital communication systems, the design of both the modulator and demodulator must be done simultaneously. Digital modulation schemes are possible because the transmitter-receiver pair have prior knowledge of how data is encoded and represented in the communications system. In all digital communication systems, both the modulator at the transmitter and the demodulator at the receiver are structured so that they perform inverse operations.

Non-coherent modulation methods do not require a receiver reference clock signal that is phase synchronized with the sender carrier wave. In this case, modulation symbols (rather than bits, characters, or data packets) are asynchronously transferred. The opposite is coherent modulation.

LIST OF COMMON DIGITAL MODULATION TECHNIQUES

The most common digital modulation techniques are:

- Phase-shift keying (PSK):
  - Binary PSK (BPSK), using M=2 symbols
  - Quadrature PSK (QPSK), using M=4 symbols
  - 8PSK, using M=8 symbols
  - 16PSK, using M=16 symbols
  - Differential PSK (DPSK)
  - Differential QPSK (DQPSK)
  - Offset QPSK (OQPSK)
  - π/4–QPSK
- Frequency-shift keying (FSK):
  - Audio frequency-shift keying (AFSK)
  - Multi-frequency shift keying (M-ary FSK or MFSK)
  - Dual-tone multi-frequency (DTMF)
- Amplitude-shift keying (ASK)
- On-off keying (OOK), the most common ASK form
  - M-ary vestigial sideband modulation, for example 8VSB
- Quadrature amplitude modulation (QAM) - a combination of PSK and ASK:
  - Polar modulation like QAM a combination of PSK and ASK.[citation needed]
- Continuous phase modulation (CPM) methods:
  - Minimum-shift keying (MSK)
  - Gaussian minimum-shift keying (GMSK)
  - Continuous-phase frequency-shift keying (CPFSK)
- Orthogonal frequency-division multiplexing (OFDM) modulation:
  - Discrete multitone (DMT) - including adaptive modulation and bit-loading.
- Wavelet modulation
- Trellis coded modulation (TCM), also known as trellis modulation
- Spread-spectrum techniques:

- Direct-sequence spread spectrum (DSSS)
- Chirp spread spectrum (CSS) according to IEEE 802.15.4a CSS uses pseudo-stochastic coding
- Frequency-hopping spread spectrum (FHSS) applies a special scheme for channel release
- SIM31 (SIM) New digital Mode SIM31 SIM63 takes SWL Tunisian

MSK and GMSK are particular cases of continuous phase modulation. Indeed, MSK is a particular case of the sub-family of CPM known as continuous-phase frequency-shift keying (CPFSK) which is defined by a rectangular frequency pulse (i.e. a linearly increasing phase pulse) of one symbol-time duration (total response signalling).

OFDM is based on the idea of frequency-division multiplexing (FDM), but the multiplexed streams are all parts of a single original stream. The bit stream is split into several parallel data streams, each transferred over its own sub-carrier using some conventional digital modulation scheme. The modulated sub-carriers are summed to form an OFDM signal. This dividing and recombining helps with handling channel impairments. OFDM is considered as a modulation technique rather than a multiplex technique, since it transfers one bit stream over one communication channel using one sequence of so-called OFDM symbols. OFDM can be extended to multi-user channel access method in theorthogonal frequency-division multiple access (OFDMA) and multi-carrier code division multiple access (MC-CDMA) schemes, allowing several users to share the same physical medium by giving different sub-carriers or spreading codes to different users.

Of the two kinds of RF power amplifier, switching amplifiers (Class D amplifiers) cost less and use less battery power than linear amplifiers of the same output power. However, they only work with relatively constant-amplitude-modulation signals such as angle modulation (FSK or PSK) and CDMA, but not with QAM and OFDM. Nevertheless, even though switching amplifiers are completely unsuitable for normal QAM constellations, often the QAM modulation principle are used to drive switching amplifiers with these FM and other waveforms, and sometimes QAM demodulators are used to receive the signals put out by these switching amplifiers.

AUTOMATIC DIGITAL MODULATION RECOGNITION (ADMR)

Automatic digital modulation recognition in intelligent communication systems is one of the most important issues in software defined radio and cognitive radio. According to incremental expanse of intelligent receivers, automatic modulation recognition becomes a challenging topic in telecommunication systems and computer engineering. Such systems have many civil and military applications. Moreover, blind recognition of modulation type is an important problem in commercial systems, especially in software defined radio. Usually in such systems, there are some extra information for system configuration, but considering blind approaches in intelligent receivers, we can reduce information overload and increase transmission performance.[1] Obviously, with no knowledge of the transmitted data and many unknown parameters at the receiver, such as the signal power, carrier frequency and phase offsets, timing information, etc., blind identification of the modulation is a difficult task. This becomes even more challenging in real-world scenarios with multipath fading, frequency-selective and time-varying channels.[2]

There are two main approaches to automatic modulation recognition. The first approach uses likelihood-based methods to assign an input signal to a proper class. Another recent approach is based on feature extraction.

PULSE MODULATION METHODS

Pulse modulation schemes aim at transferring a narrowband analog signal over an analog baseband channel as a two-level signal by modulating a pulse wave. Some pulse modulation schemes also allow the narrowband analog signal to be transferred as a digital signal (i.e. as a quantized discrete-time signal) with a fixed bit rate, which can be transferred over an underlying digital transmission system, for example some line code. These are not modulation schemes in the conventional sense since they are not channel coding schemes, but should be considered as source coding schemes, and in some cases analog-to-digital conversion techniques.

Analog-over-analog methods:

- Delta modulation (DM or Δ-modulation)
- Delta-sigma modulation (∑Δ)
- Continuously variable slope delta modulation (CVSDM), also called Adaptive-delta modulation (ADM)
- Pulse-density modulation (PDM)
- Pulse-amplitude modulation (PAM)
- Pulse-width modulation (PWM) AND Pulse-depth modulation (PDM)
- Pulse-position modulation (PPM)

Analog-over-digital methods:

- Pulse-code modulation (PCM)
- Differential PCM (DPCM)
- Adaptive DPCM (ADPCM)

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