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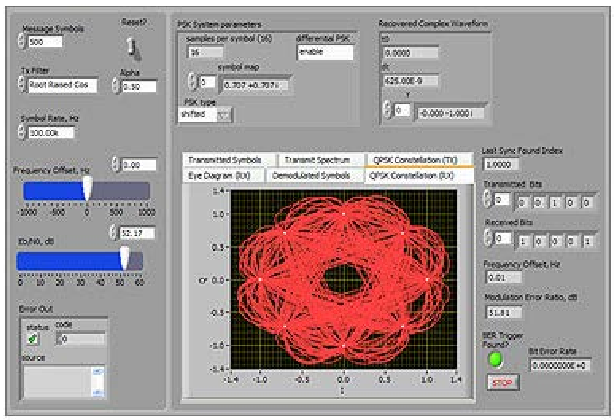
Managing Modulation and Demodulation

Digital modulation/demodulation formats provide options in terms of bandwidth efficiency, power efficiency, and complexity/cost when meeting a modern communications system's data-transfer needs.

Modulation and demodulation provide the means to transfer information over great distances. As noted in the first part of this article (see *"Basics of Modulation and Demodulation"* on mwrf.com), analog forms of modulation and demodulation have been around since the early days of radio. Analog approaches directly encode information from changes in a transmitted signal's amplitude, phase, or frequency. Digital modulation and demodulation methods, on the other hand, use the changes in amplitude, phase, and frequency to convey digital bits representing the information to be communicated.

With growing demands for voice, video, and data over communications networks of all kinds, digital modulation and demodulation have recently replaced analog modulation and demodulation methods in wireless networks to make the most efficient use of a limited resource: bandwidth. In this second part, we explore how some higher-order modulation and demodulation formats are created, and how software and test equipment can help to keep different forms of modulation and demodulation working as planned.



1. The Modulation Toolkit of LabVIEW simulation software allows users to predict performance of different modulation formats under changing conditions. (Courtesy of National Instruments)

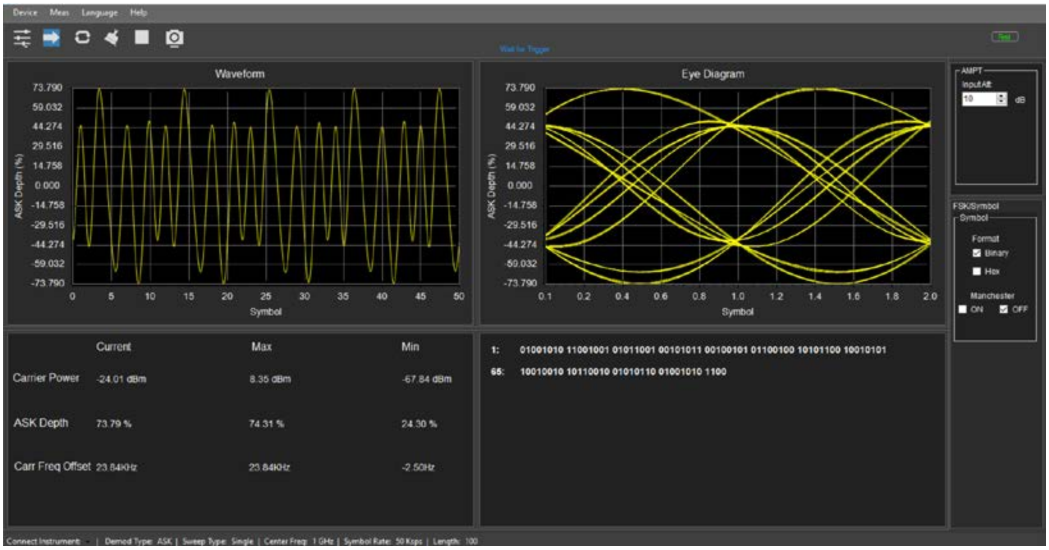
ENHANCING EFFICIENCY

Efficiency is a common goal of all modulation/demodulation methods, whether they involve conserving bandwidth, power, or cost. Digital modulation/demodulation formats, in particular, have been found able to transfer large amounts of information with minimal bandwidth and power. While increased data capacity tends toward increased complexity in digital modulation/demodulation, high levels of integration in modern ICs have made possible communications systems capable of reliable, cost-effective operation with even the most advanced digital modulation/demodulation formats.

Reasonable bandwidth efficiency is possible with standard digital modulation formats, such as amplitude-shift keying (ASK), frequency-shift keying (FSK), and phase-shift keying (PSK). By executing additional variations, more complex digital modulation formats can be created with improved data capacity and bandwidth efficiency, as measured in the number of digital bits that can be transferred in a given amount of time per unit amount of bandwidth (b/s/Hz).

For example, with minimum-shift keying (MSK), essentially a form of FSK, peak-to-peak frequency deviation is equal to one-half the bit rate. A further variation of MSK is Gaussian MSK (GMSK), in which the modulated signal passes through a Gaussian filter to minimize instantaneous frequency variations over time and reduce the amount of bandwidth occupied by the transmitted waveforms. GMSK maintains a constant envelope and provides good bit-error-rate (BER) performance in addition to its good spectral efficiency.

By applying some small changes, it is also possible to improve power efficiency. Quadrature PSK (QPSK) is basically a four-state variation of simple PSK. It can be modified in different ways—e.g., offset QPSK (OQPSK)—to boost efficiency.



2. S1220 software, when used with a series of commercial spectrum analyzers, is aimed at optimizing ASK and FSK demodulation in IoT applications. (Courtesy of RIGOL Technologies USA)

In QPSK, the in-phase (I) and quadrature (Q) bit streams are switched at the same time, using synchronized digital signal clocks for precise timing. A given amount of power is required to maintain the timing alignment.

In OQPSK, the I and Q bit streams are offset by one bit period. Unlike QPSK, only one of the two bit streams can change value at any one time in OQPSK, which also provides benefits in terms of power consumption during the bit switching process. The spectral efficiency, using two bit streams, is the same as in standard QPSK, but power efficiency is enhanced due to reduced amplitude variations (by not having the amplitudes of both bit streams passing at the same time). OQPSK does not have the same stringent demands for linear amplification as QPSK, and can be transmitted with a less-linear, more-power-efficient amplifier than required for QPSK.

THE ROLE OF FILTERING

The bandwidth efficiency of a modulation/demodulation format can be improved by means of filtering, removing signal artifacts that can cause interference with other communications systems. Various types of filters are used to improve the spectral efficiency of different modulation formats, including Gaussian filters (with perfect symmetry of the rolloff around the center frequency); Chebyshev equiripple, finite-impulse-response (FIR) filters; and lowpass Nyquist filters (also known as raised-cosine filters, since they pass nonzero bits through the frequency spectrum as basic cosine functions).

The goal of filtering is to improve spectral efficiency and reduce interference with other systems, but without degrading modulation waveform quality. Excessive filtering can result in increased BER due to a blurring of transmitted symbols that comprise the data stream of a digital modulation format. Known as intersymbol interference (ISI), this loss in integrity of the symbol states (phase, amplitude, frequency) make it difficult to decode the symbols at the demodulator and receiver in a digitally modulated communications system.

An ideal filter is often referred to as a "brickwall" filter for its instant changeover from a passband to a stopband. In reality, filters do not provide an ideal reduction in signal bandwidth due to the need for some amount of transition between a filter passband and its stopband; longer transitions require more bandwidth.

Filters for digital modulation/demodulation applications are regularly characterized by a parameter known as "alpha," which provides a measure of the amount of occupied bandwidth by a filter. For example, a "brickwall" filter, with instant transition from stopband to passband, would have an alpha value of zero. Filters with longer transitions will maintain larger values of alpha. Smaller values of filter alpha result in increased ISI, because more symbols can contribute to the interference.

MODELING AND MEASURING

A wide range of suppliers offer modulators and demodulators in various formats, from highly integrated ICs to discrete components. A number of those highly integrated transceiver ICs can be used for both functions—as transmitters/modulators and receivers/demodulators. Some are even based on software-defined-radio (SDR) architectures with sufficient bandwidths to serve multiple wireless communications standards and modulation/demodulation requirements.

Modeling software helps simplify the determination of requirements for a communications system's modulation/demodulation scheme. Some software programs provide general-purpose modulation/demodulation analysis capabilities, allowing users to predict the results of using different analog and digital modulation schemes. For example, the Modulation Toolkit *(Fig. 1)* from National Instruments (www.ni.com) works with the firm's popular LabVIEW design software to simulate communications systems based on different analog and digital modulation/demodulation formats. The software makes it possible to experiment with different variables, such as carrier frequency, signal strength, and interference; and predict different performance parameters, such as BER, bandwidth efficiency, and power efficiency, under different operating conditions.

In contrast, S1220 software from RIGOL Technologies USA (www.rigol.com) simulates ASK and FSK demodulation, in particular for Internet of Things (IoT) applications *(Fig. 2)*. The software teams with the company's spectrum analyzers to study modulation/demodulation over a carrier frequency range of 9 kHz to 3.2 GHz (and to 7.5 GHz with options). It provides an ASK symbol rate measurement range of 1 to 100 kHz and FSK deviation measurement range of 1 to 400 kHz.

Test instruments are an important part of achieving good modulation/demodulation performance. Numerous test-equipment suppliers offer programmable signal generators, such as arbitrary waveform generators, that can create different modulation formats to be used with or without a carrier signal generator for emulating modulated test signals. Spectrum analyzers provide windows to the modulation characteristics of waveforms within their frequency ranges. And some specialized measurement instruments have been developed for the purpose of testing modulation and demodulation and associated components, such as modulation domain analyzers (MDAs).

A number of different display formats provide ways to visualize modulated signals—with both signal analyzers and software—including constellation diagrams, eye diagrams, polar diagrams, and trellis diagrams (for trellis modulation). For example, separate eye diagrams can be used to show the magnitude versus time characteristics of two separate I and Q data channels, with I and Q transitions appearing as "eyes" on a computer or instrument display screen. Different modulation formats will show as different types of displays; for instance, QPSK will appear as four distinct I/Q states, one in each quadrant of the display screen. A high-quality signal creates eyes that are open at each symbol.