NRZ versus QRS

Bandwidth demands for multimedia, data mining, machine vision/learning, etc., have led to development of high-speed connections such as USB3, PCI Express (PCIe)[1,2], Thunderbolt, and Ethernet. All use one or more pairs of wires with differential (NRZ) signaling, using two or more levels (symbols) to encode data. Referred to as Pulse Amplitude Modulation (PAM), symbol count is in the name for a system—PAM2 used in PCIe, PAM5 used in gigabit Ethernet (1000BASE-T), and PAM16 used in 10gigabit Ethernet (10GBASE-T). In spite of these advances, bandwidth demands are outstripping current connection technologies[3,4].

High-res machine vision will require uncompressed DCI-4K video[5]–60 frames per second (FPS) @4096×2160 pixels, 32 bits/pixel. This generates 17 gigabits per second (Gbps), requiring PCIe x4 with 32 wires. 10GBASE-T requires 5 cables with 40 wires. 3D high-res 4K–required for autonomous machines, humanoid robotics, and similar applications–needs 2+ cameras and up to 1,000 FPS[6]. This generates up to 350 Gbps per camera. Using PCIe 3.1 requires >40 lanes (320 wires), and using 10GBASE-T requires >100 cables (800 wires) ***for each camera***.

Figure 1 shows the symbols for PAM2, PAM5, and PAM16. Each blue vertical bar represents a symbol in a given PAM system. Symbol size represents relative energy compared to the other symbols. Symbols must be distinguished from each other to decode data. Noise can cause one symbol to be indistinguishable from another. For small signals, noise can make it impossible to recognize the signal.

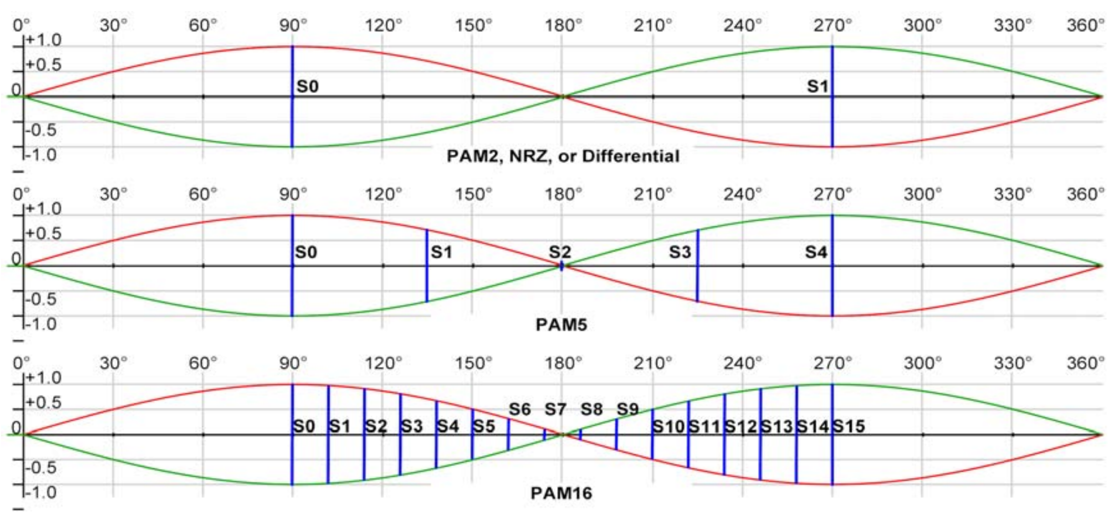

Figure 1. NRZ (PAM2, PAM5, PAM16) Symbol Relative Intensities

The superimposed sine-waves show the symbol envelopes for NRZ. As can be seen in Figure 1, all of the symbols for NRZ, whether PAM2, PAM5, or PAM16, lie between 90° and 270°, or half of the sine period.

Taken together, these reveal critical flaws with NRZ.

Limitations of NRZ

First, half of the sine period is wasted. NRZ does not permit use of the other half of the period because the symbols repeat; there is no way to distinguish a PAM16 symbol at 150° from one at 30°.

Second, as number of symbols increases, distinguishability decreases. Distinguishing between S_0 and S_1 in PAM2 is easier than with PAM5, and far easier than distinguishing S_0 and S_1 with PAM16, because in PAM16, noise can make one look like the other.

Third, symbol power changes for each symbol, creating interference (EMI) and noise.

We propose a better way.

We introduce balanced 3+ wire connections (called QRS), encoding up to 16x more per symbol over NRZ, yet retaining NRZ benefits of noise immunity and reliability.

Furthermore, QRS achieves this with constant power and reduced EMI. Figure 2 shows how this is achieved. We use 3 sine waves, offset by 120° from each other, to define the symbol space. In the figure, 12 trivial symbols are defined, S0...S11.

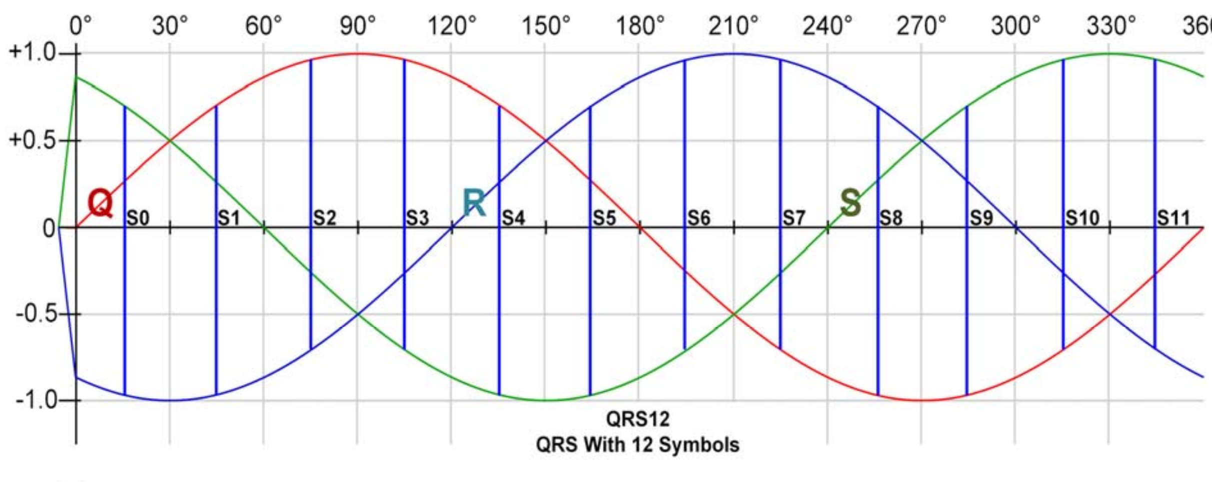

Figure 2. QRS12 Example With 12 Symbols

Each symbol in QRS12 is distinguished by comparing the relative levels of the Q, R, and S wires, so no voltage or current comparisons are needed for decoding. QRS symbols are larger than 60% of the PAM5 symbols, and larger than 62.5% of PAM16 symbols, thus improving noise immunity. QRS doubles the encodable symbol space vs NRZ, which also improves noise immunity by increasing inter-symbol spacing.

WIth QRS, 3D machine vision with high-res 4K at 1K FPS, requires only 3 QRS lanes with 9 wires–a drastic reduction of materials, infrastructure, and maintenance vs PCIe and 10GBASE-T.

QRS opens the path for bandwidth increases needed for the foreseeable future.

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