AMI-to-NRZI-direct-conversion circuit tolerates unequalized pulse tails

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AMI (alternate-mark inversion) is a three-level—positive, zero, negative—copper-cable transmission code with the useful property of having no dc component for ease of ac coupling using capacitors or line-coupling transformers and a spectral peak at one-half the symbol rate. The zeros symbols transmit as 0V; the ones symbols transmit at half-unit intervals with alternating-line polarity to maintain the dc balance.

An interesting feature of the three-level AMI code is that you can easily translate it directly from and to the two-level NRZI (non-return-to-zero-inverted) code. The basis for NRZI is a transition, not a level; an NRZI edge in either the rising or the falling direction signifies a logic one. A lack of transition in a given symbol interval signifies a logic zero. Thus, the NRZI code is invertible without destroying the logic sense. Absolute level is meaningless. The only information content is the change or no change of level at the expected transition time. Likewise, the AMI code is invertible; you need not worry about the twisted-pair polarity. **Figure 1** shows the relationships between NRZ (non-return-to-zero), NRZI, and AMI codes.

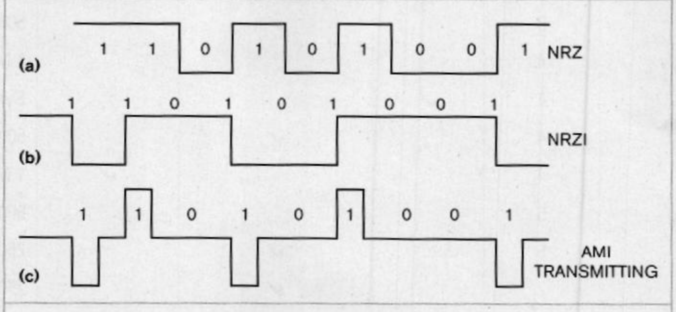

Figure 1 These waveforms illustrate an NRZ-to-NRZI-to-AMI conversion. Only when NRZ (a) is at logic one does NRZI (b) change at bit boundaries. AMI marks at the polarity of the NRZI transition (c).

The usual received-data-recovery method for AMI comprises a pair of voltage-level slicers, or comparators, that combine the transmission-line-positive and -negative marking symbols into a two-level RZ code (**Figure 2a** through **d**). The symbols are then further changed into the standard NRZ-logic representation (not shown), typically with a D-type sampling flip-flop or similar circuitry.

One impediment to successful AMI transmission over distance is the "pulse-tail"-cable artifact. When you do not drive the cable to a positive- or a negative-marking pulse, such as in a zero following a one, the last transmitted marking pulse extends in time and slowly decays to zero. This effect becomes more pronounced as the cable gets longer, and, unless you eliminate it through the use of a frequency-equalization network that matches the cable-length and -attenuation characteristics, it will wreak havoc on the data-recovery slicers (**Figure 2e** and **f**).

You can easily convert two-level NRZI to three-level AMI through a straightforward algorithm that you can implement with a few gates and line drivers, a transformer, and a delay line if the system clock is unavailable. If no NRZI transition exists, transmit nothing for that symbol interval. For every rising NRZI edge, transmit a marking pulse, usually with a duration of one-half-symbol interval. For convenience, assign this pulse polarity as positive. For every falling NRZI edge, transmit a similar marking pulse of the opposite polarity to that of the rising edge. This step automatically creates the alternate marking polarities. Again for convenience, assign this pulse polarity as negative.

Recovering the NRZI directly from the AMI is likewise a straightforward algorithm (**Figure 3a** and **b**). If there is no received-voltage-threshold crossing of opposite polarity to that of the previous marking-threshold crossing, retain the last received-marking state at logic high or logic low. If the received-AMI voltage crosses a threshold at a polarity opposite to the current state of the detector output, toggle the detector output to the state associated with that new polarity. Again, for convenience, if the AMI-pulse-threshold crossing is positive above the midlevel, or zero, toggle the detector output to a rising edge; if the AMI-pulse-threshold crossing is negative below the midlevel, or zero, toggle the detector output to a falling edge.

From these algorithms, you can see that this receiving method directly translates the AMI code into the NRZI code. Also, by its requirement for alternate marks to cross the zero level and the subsequent opposite threshold to cause an output toggle, this method is immune to the marking-pulse tails that poorly or nonequalized lengths of transmission line cause (**Figure 3c** and **d**). This effect gives rise to the possibility of eliminating the amplitude/frequency-equalizer portion of the receiver for high-bit-rate data transmission on medium-length copper cables.

A circuit that fulfills the receiver algorithm is a Schmitt trigger with an upper trip point and a lower trip point that are above and below the midlevel of the AMI three-level signal. You can easily set this point as a hardware bias with ac coupling of the dc-balanced AMI signal because there is virtually no baseline wander with AMI (**Figure 4**). Gain and drive level are not critical as long as sufficient pulse amplitude exists to cross the trip thresholds. If the signal is excessively strong or the trip thresholds are close to the midsignal level, the circuit still correctly translates data as long as no end-of-pulse ringing crossing into the opposite trip thresholds occurs. If this scenario occurs, pulse tails are beneficial, and you can artificially introduce them for the minimum operational cable length if necessary. For some oscilloscope-photo waveforms using the ECL Schmitt trigger of **Figure 4**, go to www.edn.com/080306di.EDN

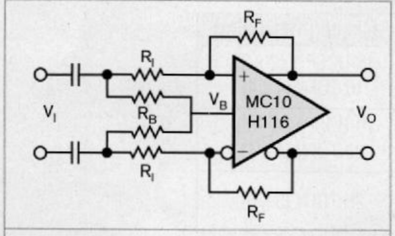

Figure 4 An MC10 H116 configured as a Schmitt-trigger circuit uses an ECL-amplifier stage. R_F supplies the positive feedback; the ratios of R_F to R_I set the hysteresis and thus the upper- and lower-trip-point-voltage levels. To remain within the linear region of the MC10 H116 transfer function, ±100 to 200 mV from center zero level is suggested.

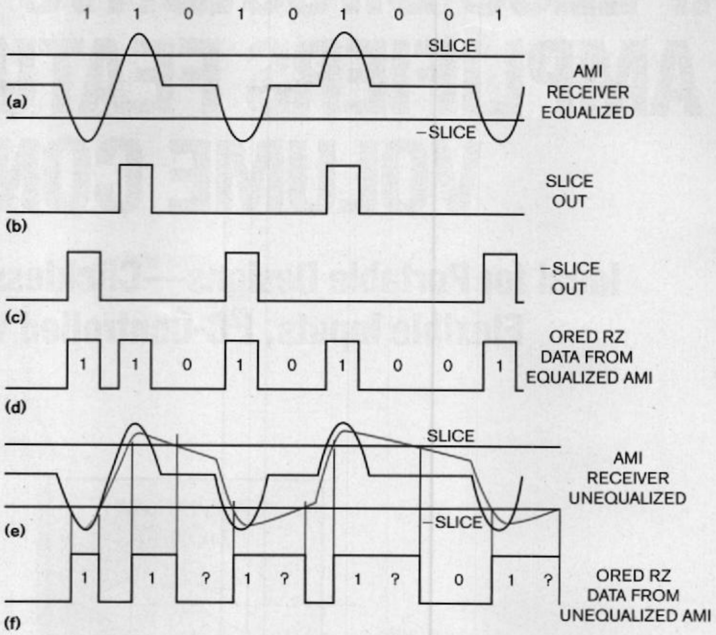

Figure 2 These waveforms show the usual transcoding of AMI to RZ. Two digital comparators slice bandlimited, equalized AMI (a). ORing the comparators, one for positive polarity (b) and one for negative polarity (c) produces RZ data (d). The digital comparators may themselves be Schmitt triggers for clean switching and immunity to small noise levels riding on the analog AMI. Unequalized AMI, superimposed on equalized AMI (e) causes the marking pulse tails, resulting in a highly distorted and error-filled RZ data waveform (f).

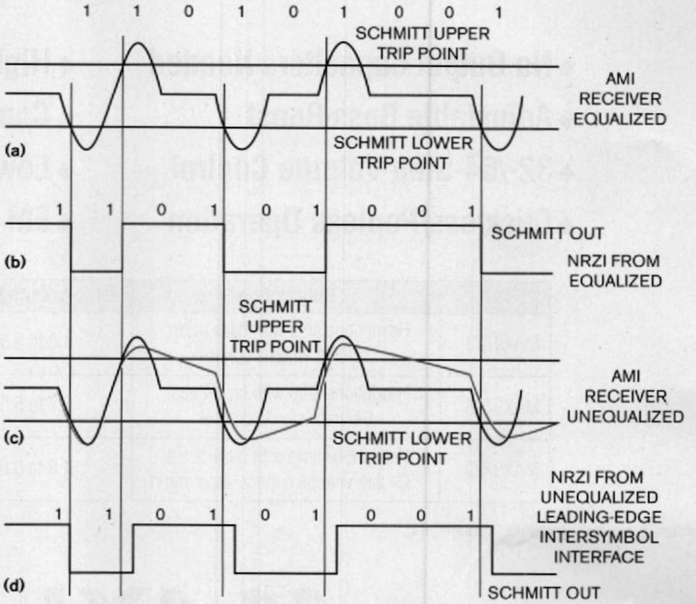

Figure 3 A Schmitt trigger directly converts bandlimited, equalized AMI (a) into the original NRZI (b). Once AMI crosses a trip point, no further transition at Schmitt output (c) is possible until the AMI crosses the opposite trip point. Unequalized AMI, superimposed on equalized AMI, cause marking pulse tails, resulting in little waveform distortion (d). Some data-dependent timing jitter occurs because of leading-edge intersymbol interference.