New Pseudoternary Line Code For High Speed Twisted Pair Data Links

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HPL-95-103
September, 1995

line code, ternary, D.C.-free, twisted pair, run-length limited

Regulated Mark Inversion (RMI) is a new pseudoternary line code which minimizes high frequency spectral components in a similar way to the FDDI TP-PMD MLT3 code, and yet also has bounded running digital sum. The code has significantly lower D.C. content than standard MLT3, and lower high frequency content than run-length limited MLT3 codes.

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Abstract: Regulated Mark Inversion (RMI) is a new pseudoternary line code which minimizes high frequency spectral components in a similar way to the FDDI TP-PMD MLT3 code, and yet also has bounded running digital sum. The code has significantly lower d.c. content than standard MLT3, and lower high frequency content than run-length limited MLT3 codes.

As the speed of data transmission on twisted pair cable has moved beyond 100 Mb/s in several Local Area Network (LAN) applications, much effort has been concentrated on reducing the levels of transmitted signal energy at higher frequencies in order to avoid infringement of the various radiated emissions regulations, all of which are stringent at frequencies greater than 30 MHz. For example, the IEEE 802.12 Demand Priority 100Mb/s LAN standard has specified a scheme for transmission on four parallel twisted pairs in a single sheath, so that the data rate on each pair is only 25Mb/s [1]. Another approach to this problem has been the use of pseudoternary line codes such as MLT3 [2] which, when combined with rectangular pulse amplitude modulation, redistributes signal energy to lower frequencies.

The MLT3 coding scheme is described in [2] and [3]. MLT3 suffers from two drawbacks: both the running digital sum (r.d.s.) and the maximum run length of coded data are unbounded. The code therefore has relatively large power spectral density (p.s.d.) at low frequencies ($f < 0.01 \times B$, where B is the symbol rate), making it less than ideal for transmission over transformer coupled twisted pair channels. In [3] a 5B6T block code was described with a high frequency spectrum similar to MLT3 but having the advantage of a bounded r.d.s. The disadvantage of this block code is the 20% increase in the symbol rate.

More recently, Cook [4] has proposed a modified line code, called MLT3$_m$, which ensures that the r.d.s. may only take values in a range with peak to peak value *m*. For small *m*, the p.s.d. of MLT3$_m$ is significantly less than that of standard MLT3 at frequencies less than $0.01 \times B$. However, we note two penalties for this improvement. First, the p.s.d. increases at higher frequencies, which, for *B* of the order of 100 MBaud, include the range above 30 MHz covered by radiated emissions regulations. Second, the code introduces transitions between the outer symbol levels, which cause increased timing jitter in the transmitted waveform.

We describe a new pseudoternary line code which, like MLT3$_m$, has bounded r.d.s but improves upon the spectrum of MLT3$_m$ at frequencies greater than 30 MHz. This code is similar to Alternate Mark Inversion in that a zero is transmitted as 0 volts and a 1 is transmitted as either +1 or -1. The polarity of the 1 symbol is regulated as follows:

- the peak to peak r.d.s. variation is bounded by *x*, and if the r.d.s. equals either[1] $\left\lceil \frac{x}{2} \right\rceil$ or $\left\lceil \frac{-x}{2} \right\rceil$ the next 1 is transmitted as either -1 or +1 respectively.
- if the r.d.s. is positive(negative) and at least two 0’s have been transmitted since the last +/-1, then the next 1 is transmitted as -1(+1).

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[1] The $\lceil y \rceil$ notation denotes the smallest integer value that is not less than y.

- if the r.d.s. is positive(negative) and at least two 1’s follow any number of 0’s, then those 1’s are transmitted as -1(+1).
- otherwise, the polarity of 1’s is reversed each time a run of at least one 0 occurs.

We shall refer to this code as Regulated Mark Inversion with r.d.s. bounded by *x*, or RMI_x. The state diagram description of the code is shown in figure 1. The coding rules described above control the r.d.s. in two ways. First, the r.d.s. is bounded to a range with peak to peak value *x*, in a similar way to the $\mathrm{MLT3}_m$ code. In addition the polarity of 1’s is chosen such that the r.d.s. is always forced towards zero, unless this would result in the transmitted patterns +1, 0 ,+1, 0 or -1, 0, -1, 0. In this respect, RMI_x differs significantly from $\mathrm{MLT3}_m$, which also forbids the patterns +1, 0^k, +1 or -1, 0^k, -1 for any value of *k* (0^k represents a run of *k* consecutive 0’s). As a result, for the same constraint on the peak to peak r.d.s. variation (i.e. x=m) RMI_x provides a smaller low frequency asymptote than $\mathrm{MLT3}_m$, as shown in figure 2. (The power spectra were calculated using the technique described by Cariolaro and Tronca [5].)

The performance of RMI_x at higher frequencies may be compared with that of $\mathrm{MLT3}_m$ by examining the ratios of the p.s.d.’s $\frac{\mathrm{RMI}_x(f)}{\mathrm{MLT3}(f)}$ and $\frac{\mathrm{MLT3}_m(f)}{\mathrm{MLT3}(f)}$. These are given in table 1 for $f = 0.5 \times B$. For the same constraint on peak-peak r.d.s. variation, the p.s.d. increase over standard MLT3 for RMI_x is always less than that for $\mathrm{MLT3}_m$.

The advantage of RMI_x over $\mathrm{MLT3}_m$ increases further if we choose values of *x* and *m* which result in similar low frequency aymptotes, for example, $x = 10$ and $m = 5$ (see figure 2). From table 1, the p.s.d. of RMI_{10} when $f = 0.5 \times B$ is 1.89 dB less than that of $\mathrm{MLT3}_5$. The spectra of these two codes are plotted in figure 3, which confirms that the RMI_{10} p.s.d. is less than the $\mathrm{MLT3}_5$ p.s.d. over a broad range of frequencies above $.15 \times B$. We note that the favorable RMI_{10} high frequency p.s.d. is due to a relatively large p.s.d. at frequencies between $0.01 \times B$ and $0.1 \times B$. However, this is acceptable in applications where B is of the order of 100 MBaud since these frequencies are then both less than 30 MHz and within the passband of coupling transformers.

A useful benefit of RMI$_x$ is that undesirable transitions between the outer symbol levels may be eliminated for some formats of input data. These transitions only occur when a run of 1's of length greater than the absolute value of the maximum (or minimum) r.d.s. is input to the encoder. Transitions between outer symbol levels will not occur if the maximum run length of the input data is suitably constrained, perhaps by block coding. For example, no such transitions occur if $x = 10$ and the input data has a maximum run length of 5.

RMI$_x$ has other advantages over MLT3 and MLT3$_m$ codes: RMI$_x$ does not suffer from error propagation caused by differential coding schemes such as MLT3, MLT3$_m$ and NRZI. Furthermore, RMI$_x$ allows for simpler decoding than MLT3$_m$ or MLT3 since data may be recovered by simply rectifying the transmitted signal.

References:

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[2] American National Standards Institute, X3T12, “FDDI twisted pair physical layer medium dependent (TP-PMD)”. American National Standard, 1994.

[3] Mowbray, M., Coles, A.N., Cunningham, D.G., “New 5B/6T code for data transmission on unshielded twisted pair cable”. Electronics Letters, vol. 29, no. 12, June 1993, pp. 1107-1108.

[4] Cook, J.W., “Spectra of a class of run-length limited MLT3 codes”. Electronics Letters, Vol. 30, no.16, August 1994, pp. 1284-1285.

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Table 1: Relative p.s.d. of $RMI_x(f)$ and $MLT3_m(f)$ at f=0.5B.

m,x	$RMI_x(f)/MLT3(f)$ (dB)	$MLT3_m(f)/MLT3(f)$ (dB)
5	-	2.08
6	0.79	1.63
8	0.39	1.31
10	0.19	1.08
12	0.10	0.92

Figure 1 State Diagram for RMI$_x$. (Notation: "d_n", "d_{n+1}" represent current and next input bits respectively; "r" respresents r.d.s.; "min" = $\left\lceil \frac{-x}{2} \right\rceil$; "max" = $\left\lceil \frac{x}{2} \right\rceil$; "o/p" represents the current output symbol; "." denotes the logical AND operation; "+" denotes the logical OR operation.)

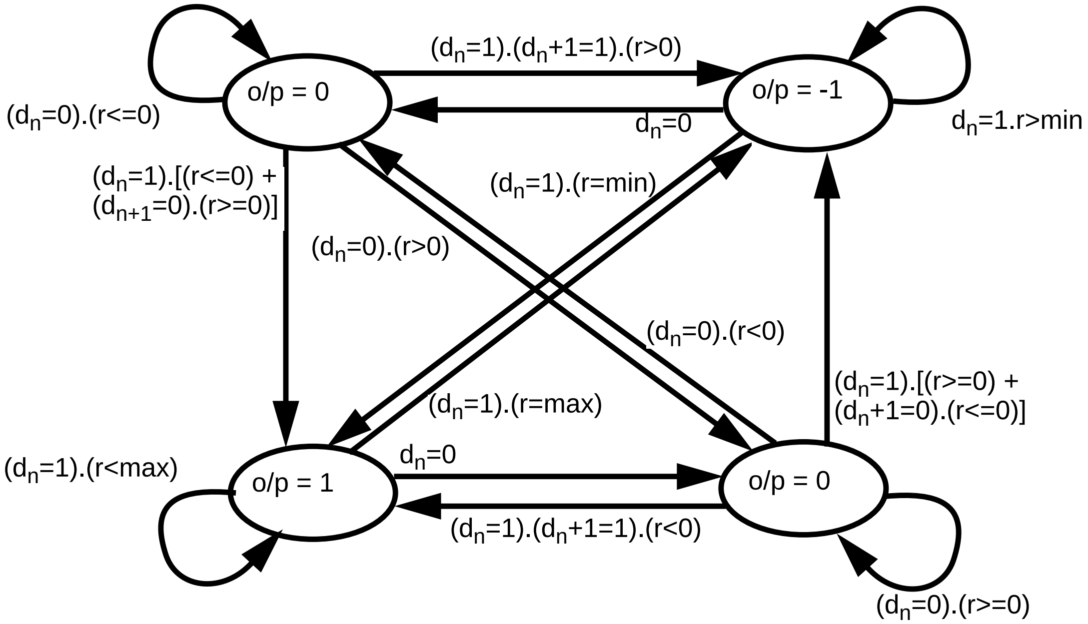

Figure 2 Low frequency spectrum of $MLT3_m$ and RMI_x

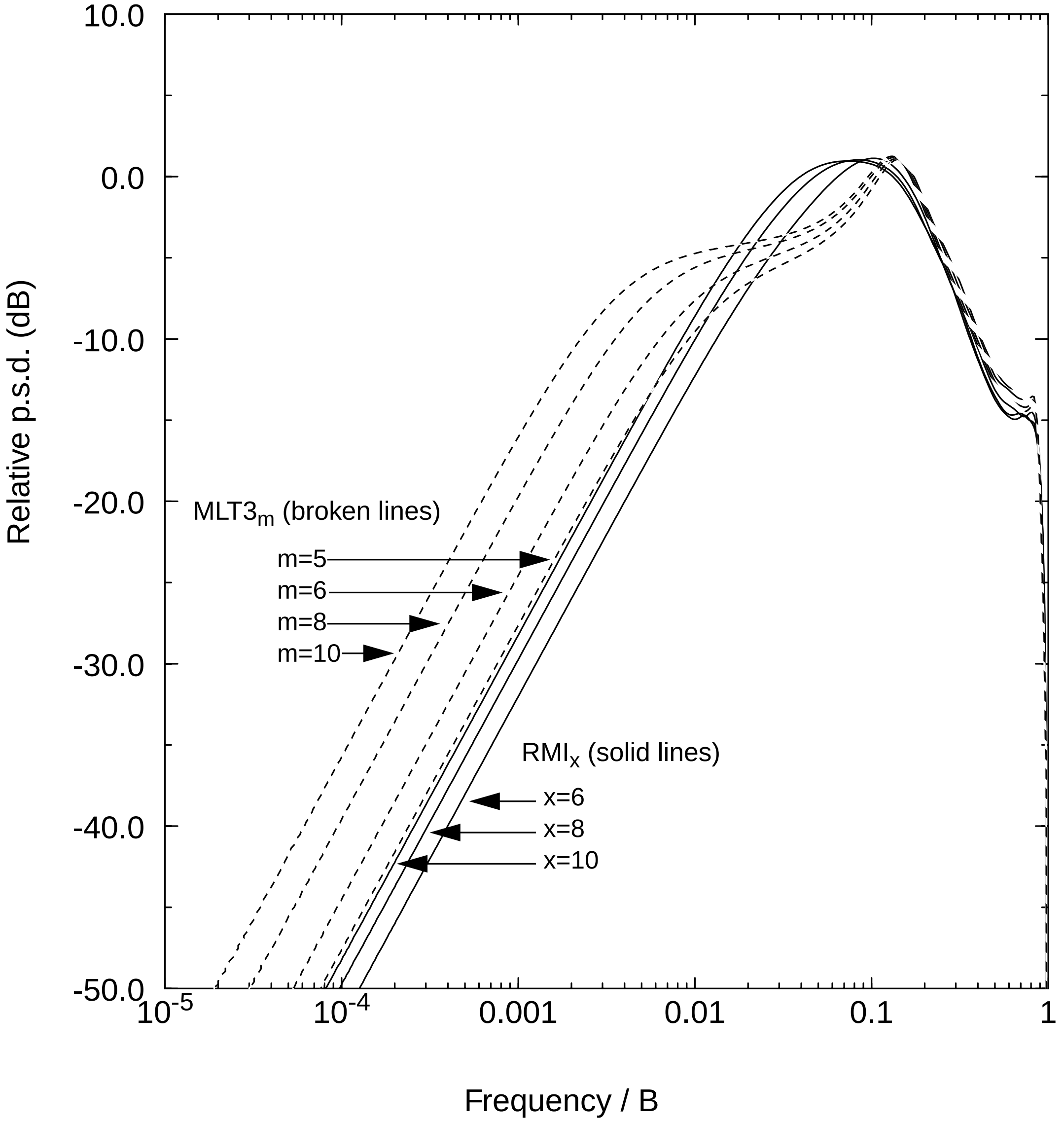

Figure 3 Comparison of RMI_{10} (heavy solid line), $MLT3_5$(dashed line), and MLT3 (light solid line).