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# Low Power Digital System Design

## On-chip Interconnects (Cont.)

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# Comparison between Minimally Encoded and LWC

| Symbol | Minimally Encoded | | 2-LWC | | 1-LWC | |
|---|---|---|---|---|---|---|
| | Codewords | # Trans. | Codewords | # Trans. | Codewords | # Trans. |
| 0 | 0000 | 0.5 | 00000 | 0 | 000000000000000 | 0 |
| 1 | 0001 | 1.5 | 00001 | 1 | 000000000000001 | 1 |
| 2 | 0010 | 2.5 | 00010 | 1 | 000000000000010 | 1 |
| 3 | 0011 | 1.5 | 00011 | 2 | 000000000000100 | 1 |
| 4 | 0100 | 2.5 | 00100 | 1 | 000000000001000 | 1 |
| 5 | 0101 | 3.5 | 00101 | 2 | 000000000010000 | 1 |
| 6 | 0110 | 2.5 | 00110 | 2 | 000000000100000 | 1 |
| 7 | 0111 | 1.5 | 11000 | 2 | 000000001000000 | 1 |
| 8 | 1000 | 1.5 | 01000 | 1 | 000000010000000 | 1 |
| 9 | 1001 | 2.5 | 01001 | 2 | 000000100000000 | 1 |
| 10 | 1010 | 3.5 | 01010 | 2 | 000001000000000 | 1 |
| 11 | 1011 | 2.5 | 10100 | 2 | 000010000000000 | 1 |
| 12 | 1100 | 1.5 | 01100 | 2 | 000100000000000 | 1 |
| 13 | 1101 | 2.5 | 10010 | 2 | 001000000000000 | 1 |
| 14 | 1110 | 1.5 | 10001 | 2 | 010000000000000 | 1 |
| 15 | 1111 | 0.5 | 10000 | 1 | 100000000000000 | 1 |
| Average | | 2 | | 1.5625 | | 0.9375 |

- This result has been obtained for serial interconnects but it also holds for parallel interconnects.

# Redundancy in LWC

- Low power encoding by adding redundancy in the form of extra bus lines.

- *M*-LWC:
  - *N*=Length of M-LWC codewords
  - *K*=Length of minimally encoded codewords

$$\sum_{i=0}^{M} \binom{N}{i} \geq 2^{K} \qquad R = \frac{N-K}{K}$$

# Optimal LWC

- A perfect *M*-LWC satisfies $$\sum_{i=0}^{M}\binom{N}{i}=2^{K}$$

- a semiperfect *M*-LWC consists of all possible codewords with weight $\leq M-1$ and only some with weight *M*, and satisfies

$$\sum_{i=0}^{M}\binom{N}{i}>2^{K}$$

- Perfect and semiperfect limited weight codes are optimal in the sense that any other code with the same length cannot have better statistical properties for low power.

# Bus-Invert vs. LWC

- Bus-Invert
  - Level Signaling
  - One-to-many context dependent coding
  - Parallel interconnects

- LWC
  - Transition Signaling
  - One-to-one context independent coding
  - Both parallel and serial interconnects

# References

M.R. Stan, et. al., "Low-Power Encodings for Global Communication in CMOS VLSI", IEEE Transactions on VLSI, 1997.

M.R. Stan and W.P. Burleson. ”Limited-Weight

Codes for Low Power I/O”, IEEE/ACM International Workshop on Low Power, 1994.