Hamming Code - Error Detection & Correction

Introduction to Hamming Code

Hamming code is a linear error-detecting and error-correcting code developed by Richard Hamming in 1950.
It is used in digital systems to ensure data reliability in communication and memory storage.

Features:

- Detects up to 2-bit errors and corrects 1-bit errors.
- Efficient: Uses a small number of parity bits for error correction.
- Widely used in computer memory (ECC RAM), networking, and wireless communication.

General Formula:

A Hamming code follows the format (n, k), where:
- n = Total number of bits (data + parity)
- k = Number of data bits
- r = Number of parity bits (where n = k + r)

Encoding Process

Each parity bit is responsible for checking specific bits. The parity bits are calculated as follows:
- P1 = D1 XOR D2 XOR D4
- P2 = D1 XOR D3 XOR D4
- P4 = D2 XOR D3 XOR D4

Example (Encoding 1011 in Hamming Code)

For data 1011, the encoded 7-bit Hamming code is 0111011.

Verilog Code for Hamming (7,4) Decoder

```
module Hamming74_Encoder_Decoder (
    input [3:0] data_in,
    output [6:0] encoded_out
);
    wire p1, p2, p4;
    assign p1 = data_in[0] ^ data_in[1] ^ data_in[3];
    assign p2 = data_in[0] ^ data_in[2] ^ data_in[3];
    assign p4 = data_in[1] ^ data_in[2] ^ data_in[3];
    assign encoded_out = {data_in[3], data_in[2], data_in[1], p4, data_in[0], p2, p1};
endmodule
```

Applications of Hamming Code

- Memory Systems: Used in ECC RAM to detect and correct errors.
- Wireless Communication: Ensures data integrity in noisy channels.
- Networking: Used in error detection mechanisms for reliable data transmission.
- Data Storage: Prevents data corruption in hard drives and SSDs.

Conclusion

Hamming code is a fundamental error-correcting technique that ensures data reliability in digital communication. The (7,4) Hamming code provides an efficient way to detect and correct single-bit errors, making it a critical part of modern computing systems.