

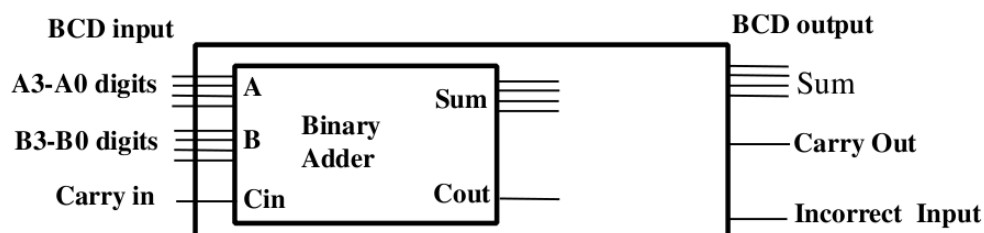
Tutorial 7: Binary Coded Decimal Adder

Small calculators work with BCD (binary-coded-decimal) digits. These use four bit binary numbers to represent the decimal digits 0 to 9. This means that six combinations of the four bits are not used. A common bit assignment for BCD digits are:

| Bits | 0000 | 0001 | 0010 | 0011 | 0100 | 0101 | 0110 | 0111 | 1000 | 1001 |
|-------|------|------|------|------|------|------|------|------|------|------|
| Digit | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

| Bits | 1010 | 1011 | 1100 | 1101 | 1110 | 1111 |
|-------|------|------|------|------|------|------|
| Digit | - | - | - | - | - | - |

In preparation for the design of a calculator, we want to build an adder of two BCD digits, which will be made up of a binary adder and some extra circuits. First, we need to design a circuit that recognises incorrect BCD input digits.

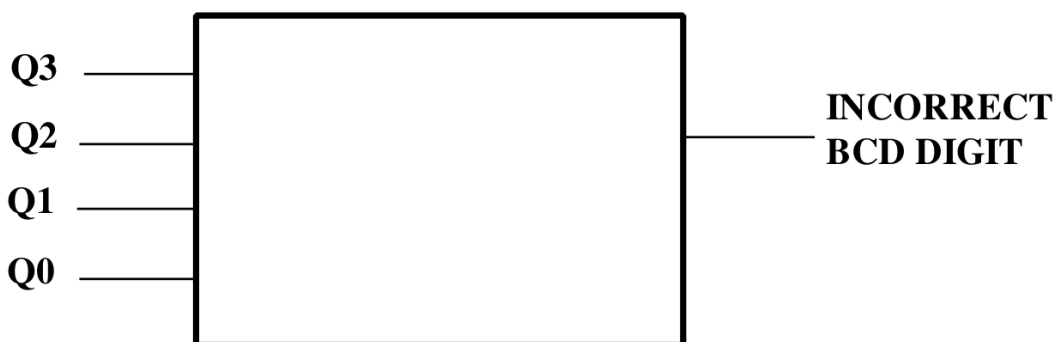


Problem 1

Design and draw the minimised circuit for the "incorrect BCD digit" signal generator. First draw the Karnaugh map and determine the minimised Boolean equation, then draw the actual circuit.

| | | Q1 Q0 | | | |
|------|----|-------|----|----|----|
| | | 00 | 01 | 11 | 10 |
| Q3Q2 | 00 | | | | |
| | 01 | | | | |
| | 11 | | | | |
| | 10 | | | | |

Incorrect BCD digit =



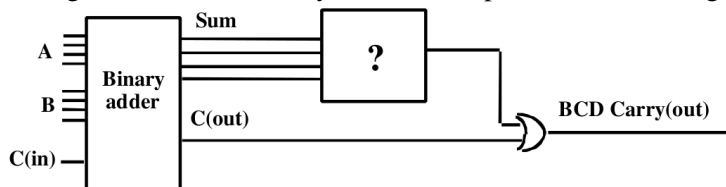
Two of the circuits of problem 1, and a two-input OR gate will be needed to provide an Incorrect Input signal which indicates that either or both input digits are made up of invalid bit combinations. We now plan to use a four-bit binary adder to provide the sum of two BCD digits.

Problem 2

Design the circuit for producing the BCD Carry Out. For a sum of less than 9 the Carry Out signal should have a 0 value. For larger sums it should be 1, equivalent to carry 10. For example two BCD digits, say 5 and 8 should produce 3 for the BCD output and a Carry Out of 1, read as 13. However the binary adder carry does not do this. The possibilities generating a carry are summarised by the following table.

| Sum | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|-------------|------|------|------|------|------|------|------|------|------|------|
| Binary Sum | 1010 | 1011 | 1100 | 1101 | 1110 | 1111 | 0000 | 0001 | 0010 | 0011 |
| Binary Cout | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| BCD Sum | 0000 | 0001 | 0010 | 0011 | 0100 | 0101 | 0110 | 0111 | 1000 | 1001 |
| BCD Cout | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

An ingenious classmate of yours comes up with the following scheme for the BCD Carry Out generator:



It works! Find the combinational circuit (shown with the question mark above) that will make it work:

| | | | | | |
|------|----|----|----|----|----|
| | | Q1 | | Q0 | |
| | | 00 | 01 | 11 | 10 |
| Q3Q2 | 00 | | | | |
| | 01 | | | | |
| | 11 | | | | |
| | 10 | | | | |

BCD Carry =

Problem 3

Only the binary sum of the two BCD digits has been generated so far. The same ingenious classmate of yours has a solution for generating the correct BCD output sum as well. All you have to do (she says) is to use another binary adder to fix up the output when a BCD carry is generated. What should the circuit (? on the diagram below) be? (Hint: The results will be simpler than you think!)

