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SOLUTIONS MANUAL

DIGITAL DESIGN

WITH AN INTRODUCTION TO THE VERILOG HDL Fifth Edition

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rev 02/14/2012

CHAPTER 1

1.1 Base-10: 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32
Octal: 20 21 22 23 24 25 26 27 30 31 32 33 34 35 36 37 40
Hex: 10 11 12 13 14 15 16 17 18 19 1A 1B 1C 1D 1E 1F 20
Base-12 14 15 16 17 18 19 1A 1B 20 21 22 23 24 25 26 27 28

1.2 **(a)** 32,768 **(b)** 67,108,864 **(c)** 6,871,947,674 **1.3**

$(4310)_5 = 4 * 5^3 + 3 * 5^2 + 1 * 5^1 = 580_{10}$

$(198)_{12} = 1 * 12^2 + 9 * 12^1 + 8 * 12^0 = 260_{10}$

$(435)_8 = 4 * 8^2 + 3 * 8^1 + 5 * 8^0 = 285_{10}$

$(345)_6 = 3 * 6^2 + 4 * 6^1 + 5 * 6^0 = 137_{10}$

1.4 16-bit binary: 1111_1111_1111_1111 Decimal
equivalent: $2^{16} - 1 = 65{,}535_{10}$
Hexadecimal equivalent: $FFFF_{16}$

1.5 Let b = base

(a) 14/2 = (b + 4)/2 = 5, so b = 6

(b) 54/4 = (5*b + 4)/4 = b + 3, so 5 * b = 52 – 4, and b = 8

(c) (2 *b + 4) + (b + 7) = 4b, so b = 11

1.6 $(x - 3)(x - 6) = x^2 - (6 + 3)x + 6*3 = x^2 - 11x + 22$

Therefore: 6 + 3 = b + 1m, so b = 8
Also, $6*3 = (18)_{10} = (22)_8$

1.7 $64CD_{16} = 0110\_0100\_1100\_1101_2 = 110\_010\_011\_001\_101 = (62315)_8$

1.8 **(a)** Results of repeated division by 2 (quotients are followed by remainders):

431_{10} = 215(1); 107(1); 53(1); 26(1); 13(0); 6(1) 3(0) 1(1) Answer: $1111\_1010_2 = FA_{16}$

(b) Results of repeated division by 16:

431_{10} = 26(15); 1(10) (Faster)
Answer: FA = 1111_1010

1.9 **(a)** $10110.0101_2 = 16 + 4 + 2 + .25 + .0625 = 22.3125$

(b) $16.5_{16} = 16 + 6 + 5*(.0615) = 22.3125$

(c) $26.24_8 = 2 * 8 + 6 + 2/8 + 4/64 = 22.3125$

(d) DADA.B_{16} = $14*16^3 + 10*16^2 + 14*16 + 10 + 11/16$ = 60,138.6875

(e) 1010.1101_2 = 8 + 2 + .5 + .25 + .0625 = 10.8125

1.10 **(a)** $1.10010_2 = 0001.1001_2 = 1.9_{16} = 1 + 9/16 = 1.563_{10}$

(b) $110.010_2 = 0110.0100_2 = 6.4_{16} = 6 + 4/16 = 6.25_{10}$

Reason: 110.010_2 is the same as 1.10010_2 shifted to the left by two places.

1.11

```
             1011.11
101 | 111011.0000
      101
      01001
        101
         1001
          101
          1000
           101
           0110
```

The quotient is carried to two decimal places, giving 1011.11

Checking: $111011_2 / 101_2 = 59_{10} / 5_{10} \cong 1011.11_2 = 58.75_{10}$

1.12 **(a)** 10000 and 110111

1011	1011
+101	x101
$10000 = 16_{10}$	1011
	1011
	$110111 = 55_{10}$

(b) 62_h and 958_h

$2E_h$	0010_1110	$2E_h$
$+34_h$	0011_0100	$x34_h$
62_h	$0110\_0010 = 98_{10}$	B^38
		8^2A 9 5
		$8_h = 2392_{10}$

1.13 **(a)** Convert 27.315 to binary:

	Integer Quotient	Remainder	Coefficient
27/2 =	13	+ ½	$a_0 = 1$
13/2	6	+ ½	$a_1 = 1$
6/2	3	+ 0	$a_2 = 0$
3/2	1	+ ½	$a_3 = 1$
½	0	+ ½	$a_4 = 1$

$27_{10} = 11011_2$

	Integer	Fraction	Coefficient
.315 x 2 =	0	+ .630	$a_{-1} = 0$
.630 x 2 =	1	+ .26	$a_{-2} = 1$
.26 x 2 =	0	+ .52	$a_{-3} = 0$
.52 x 2 =	1	+ .04	$a_{-4} = 1$

$.315_{10} \cong .0101_2 = .25 + .0625 = .3125$

$27.315 \cong 11011.0101_2$

(b) 2/3 ≅ .6666666667

	Integer	Fraction	Coefficient
.6666_6666_67 x 2 =	1	+ .3333_3333_34	$a_{-1} = 1$
.3333333334 x 2	= 0	+ .6666666668	$a_{-2} = 0$
.6666666668 x 2	= 1	+ .3333333336	$a_{-3} = 1$
.3333333336 x 2	= 0	+ .6666666672	$a_{-4} = 0$
.6666666672 x 2	= 1	+ .3333333344	$a_{-5} = 1$
.3333333344 x 2	= 0	+ .6666666688	$a_{-6} = 0$
.6666666688 x 2	= 1	+ .3333333376	$a_{-7} = 1$
.3333333376 x 2	= 0	+ .6666666752	$a_{-8} = 0$

$.6666666667_{10} \cong .10101010_2 = .5 + .125 + .0313 + ..0078 = .6641_{10}$

$.101010102 = .1010\_1010_2 = .AA_{16} = 10/16 + 10/256 = .6641_{10}$ (Same as (b)).

1.14

(a) 0001_0000
1s comp: 1110_1111
2s comp: 1111_0000

(b) 0000_0000
1s comp: 1111_1111
2s comp: 0000_0000

(c) 1101_1010
1s comp: 0010_0101
2s comp: 0010_0110

(d) 1010_1010
1s comp: 0101_0101
2s comp: 0101_0110

(e) 1000_0101
1s comp: 0111_1010
2s comp: 0111_1011

(f) 1111_1111
1s comp: 0000_0000
2s comp: 0000_0001

`

1.15

(a) 25,478,036
9s comp: 74,521,963
10s comp: 74,521,964

(b) 63,325,600
9s comp: 36,674,399
10s comp: 36,674,400

(c) 25,000,000
9s comp: 74,999,999
10s comp: 75,000,000

(d) 00000000
9s comp: 99999999
10s comp: 100000000

1.16

	C3DF
15s comp:	3C20
16s comp:	3C21

C3DF: 1100_0011_1101_1111
1s comp: 0011_1100_0010_0000
2s comp: 0011_1100_0010_0001 = 3C21

1.17 **(a)** 2,579 → 02,579 →97,420 (9s comp) → 97,421 (10s comp)
$4637 – 2,579 = 2,579 + 97,421 = 2058_{10}$

(b) 1800 → 01800 → 98199 (9s comp) → 98200 (10 comp)
125 – 1800 = 00125 + 98200 = 98325 (negative)
Magnitude: 1675
Result: 125 – 1800 = 1675

(c) 4,361 → 04361 → 95638 (9s comp) → 95639 (10s comp)
2043 – 4361 = 02043 + 95639 = 97682 (Negative)
Magnitude: 2318
Result: 2043 – 6152 = -2318

(d) 745 → 00745 → 99254 (9s comp) → 99255 (10s comp)
1631 -745 = 01631 + 99255 = 0886 (Positive)
Result: 1631 – 745 = 886

1.18 Note: Consider sign extension with 2s complement arithmetic.

(a)
0_10010
1s comp: 1_01101
2s comp: 1_01110
0_10011
Diff: 0_00001 (Positive)
Check:19-18 = +1

(**b**)
0_100110
1s comp: 1_011001 with sign extension
2s comp: 1_011010
0_100010
1_111100 sign bit indicates that the result is negative
0_000011 1s complement
0_000100 2s complement
000100 magnitude
Result: -4
Check: 34 -38 = -4

(c)
0_110101
1s comp: 1_001010
2s comp: 1_001011
0_001001
Diff: 1_010100 (negative)
0_101011 (1s comp)
0_101100 (2s complement)
101100 (magnitude)
-44_{10} (result)

(**d**)
0_010101
1s comp: 1_101010 with sign extension
2s comp: 1_101011
0_101000
0_010011 sign bit indicates that the result is positive
Result: 19_{10}
Check: 40 – 21 = 19_{10}

1.19 +9286 → 009286; +801 → 000801; -9286 → 990714; -801 →999199

(a) (+9286) + (_801) = 009286 + 000801 = 010087

(b) (+9286) + (-801) = 009286 + 999199 = 008485

(c) (-9286) + (+801) = 990714 + 000801 = 991515

(d) (-9286) + (-801) = 990714 + 999199 = 989913

1.20 +49 → 0_110001 (Needs leading zero extension to indicate + value);
+29 → 0_011101 (Leading 0 indicates + value)
-49 → 1_001110 + 0_000001→ 1_001111
-29 → 1_100011 (sign extension indicates negative value)

(a) (+29) + (-49) = 0_011101 + 1_001111 = 1_101100 (1 indicates negative value.)
Magnitude = 0_010011 + 0_000001 = 0_010100 = 20; Result (+29) + (-49) = -20

(b) (-29) + (+49) = 1_100011 + 0_110001 = 0_010100 (0 indicates positive value) (-29) + (+49) = +20

(c) Must increase word size by 1 (sign extension) to accomodate overflow of values:

(-29) + (-49) = 11_100011 + 11_001111 = 10_110010 (1 indicates negative result)

Magnitude: 01_001110 = 78_{10}

Result: (-29) + (-49) = -78_{10}

1.21 +9742 → 009742 → 990257 (9's comp) → 990258 (10s) comp

+641 → 000641 → 999358 (9's comp) → 999359 (10s) comp

(a) (+9742) + (+641) → 010383

(b) (+9742) + (-641) →009742 + 999359 = 009102

Result: (+9742) + (-641) = 9102

(c) -9742) + (+641) = 990258 + 000641 = 990899 (negative)

Magnitude: 009101

Result: (-9742) + (641) = -9101

(d) (-9742) + (-641) = 990258 + 999359 = 989617 (Negative)

Magnitude: 10383

Result: (-9742) + (-641) = -10383

1.22 6,514

BCD: 0110_0101_0001_0100

ASCII: 0_011_0110_0_011_0101_1_011_0001_1_011_0100

ASCII: 0011_0110_0011_0101_1011_0001_1011_0100

1.23

```
      0111 1001 0001 ( 791)
      0110 0101 1000 (+658)
      1101 1110  1001
      0110 0110
0001 0011  0100
0001 0001
   0001 0100 0100 1001 (1,449)
```

1.24 **(a)** **(b)**

6 3 1 1	Decimal	6 4 2 1	Decimal
0 0 0 0	0	0 0 0 0	0
0 0 0 1	1	0 0 0 1	1
0 0 1 0	2	0 0 1 0	2
0 1 0 0	3	0 0 1 1	3
0 1 1 0	4 (*or* 0101)	0 1 0 0	4
0 1 1 1	5	0 1 0 1	5
1 0 0 0	6	1 0 0 0	6 (*or* 0110)
1 0 1 0	7 (*or* 1001)	1 0 0 1	7
1 0 1 1	8	1 0 1 0	8
1 1 0 0	9	1 0 1 1	9

1.25 **(a)** $6{,}248_{10}$ BCD: 0110_0010_0100_1000

(b) Excess-3: 1001_0101_0111_1011

(c) 2421: 0110_0010_0100_1110
(d) 6311: 1000_0010_0110_1011

1.26 6,248 9s Comp: 3,751

2421 code: 0011_0111_0101_0001

1s comp c: 1001_1101_1011_0001 (2421 code alternative #1)

$6{,}248_{2421}$ 0110_0010_0100_1110 (2421 code alternative #2)

1s comp c 1001_1101_1011_0001 Match

For a deck with 52 cards, we need 6 bits ($2^5 = 32 < 52 < 64 = 2^6$). Let the msb's select the suit (e.g., diamonds, hearts, clubs, spades are encoded respectively as 00, 01, 10, and 11. The remaining four bits select the "number" of the card. Example: 0001 (ace) through 1011 (9), plus 101 through 1100 (jack, queen, king). This a jack of spades might be coded as 11_1010. (Note: only 52 out of 64 patterns are used.)

G (dot) (space) B o o l e
11000111_11101111_01101000_01101110_00100000_11000100_11101111_11100101

Steve Jobs

1.30 73 F4 E5 76 E5 4A EF 62 73

73: 0_111_0011 s
F4: 1_111_0100 t
E5: 1_110_0101 e
76: 0_111_0110 v E5:
1_110_0101 e
4A: 0_100_1010 j
EF: 1_110_1111 o
62: 0_110_0010 b
73: 0_111_0011 s

62 + 32 = 94 printing characters

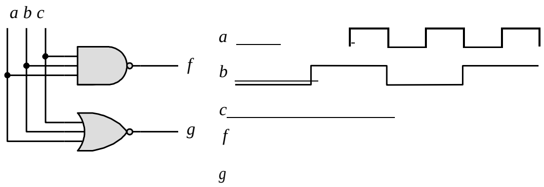
bit 6 from the right

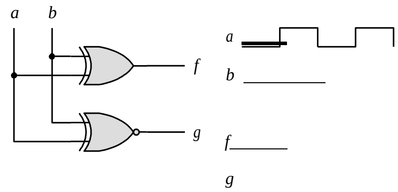
1.33 **(a)** 897 **(b)** 564 **(c)** 871 **(d)** 2,199

1.34 ASCII for decimal digits with even parity:

(0): 00110000 (1):
10110001 (2): 10110010 (3): 00110011
(4): 10110100 (5): 00110101
(6): 00110110 (7): 10110111
(8): 10111000 (9):
00111001

1.35 **(a)**





1.36

CHAPTER 2

2.1 **(a)**

x y z	x + y + z	(x + y + z)′	x′
0 0 0	0	1	1
0 0 1	1	0	1
0 1 0	1	0	1
0 1 1	1	0	1
1 0 0	1	0	0
1 0 1	1	0	0
1 1 0	1	0	0
1 1 1	1	0	0

x y z	(xyz)	(xyz)′	x′	y′	z′	x′ + y′ + z
0 0 0	0	1	1	1	1	1
0 0 1	0	1	1	1	0	1
0 1 0	0	1	1	0	1	1
0 1 1	0	1	1	0	0	1
1 0 0	0	1	0	1	1	1
1 0 1	0	1	0	1	0	1
1 1 0	0	1	0	0	1	1
1 1 1	1	0	0	0	0	0

′

(b)

(c)

x y z	*x + yz*	*(x + y)*	*(x + z)*	*(x + y)(x + z)*
0 0 0	0	0	0	0
0 0 1	0	0	1	0
0 1 0	0	1	0	0
0 1 1	1	1	1	1
1 0 0	1	1	1	1
1 0 1	1	1	1	1
1 1 0	1	1	1	1
1 1 1	1	1	1	1

x y z	*x(y + z)*	*xy*	*xz*	*xy + xz*
0 0 0	0	0	0	0
0 0 1	0	0	0	0
0 1 0	0	0	0	0
0 1 1	0	0	0	0
1 0 0	0	0	0	0
1 0 1	1	0	1	1
1 1 0	1	1	0	1
1 1 1	1	1	1	1

(c)

x y z	*x*	*y + z*	*x + (y + z)*
0 0 0	0	0	0
0 0 1	0	1	1
0 1 0	0	1	1
0 1 1	0	1	1
1 0 0	1	0	1
1 0 1	1	1	1
1 1 0	1	1	1
1 1 1	1	1	1

(d)

x y z	*yz*	*x(yz)*	*xy*	*(xy)z*
0 0 0	0	0	0	0
0 0 1	0	0	0	0
0 1 0	0	0	0	0
0 1 1	1	0	0	0
1 0 0	0	0	0	0
1 0 1	0	0	0	0
1 1 0	0	0	1	0
1 1 1	1	1	1	1

2.2 **(a)** $xy + xy' = x(y + y') = x$

(b) $(x + y)(x + y') = x + yy' = x(x + y') + y(x + y') = xx + xy' + xy + yy' = x$

(c) $xyz + x'y + xyz' = xy(z + z') + x'y = xy + x'y = y$

(d) $(A + B)'(A' + B')' = (A'B')(A B) = (A'B')(BA) = A'(B'B)A = 0$

(e) $(a + b + c')(a'b' + c) = aa'b' + ac + ba'b' + bc + c'a'b' + c'c = ac + bc + a'b'c'$

(f) $a'bc + abc' + abc + a'bc' = a'b(c + c') + ab(c + c') = a'b + ab = (a' + a)b = b$

2.3 **(a)** $ABC + A'B + ABC' = AB + A'B = B$

(b) $x'yz + xz = (x'y + x)z = z(x + x')(x + y) = z(x + y)$

(c) $(x + y)'(x' + y') = x'y'(x' + y') = x'y'$

(d) $xy + x(wz + wz') = x(y + wz + wz') = x(w + y)$

(e) $(BC' + A'D)(AB' + CD') = BC'AB' + BC'CD' + A'DAB' + A'DCD' = 0$

(f) $(a' + c')(a + b' + c') = a'a + a'b' + a'c' + c'a + c'b' + c'c' = a'b' + a'c' + ac' + b'c' = c' + b'(a' + c')$
$= c' + b'c' + a'b' = c' + a'b'$

2.4 **(a)** $A'C' + ABC + AC' = C' + ABC = (C + C')(C' + AB) = AB + C'$

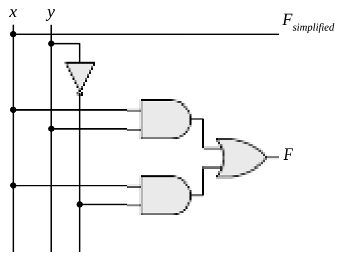
(b) $(x'y' + z)' + z + xy + wz = (x'y')'z' + z + xy + wz = [(x + y)z' + z] + xy + wz =$
$= (z + z')(z + x + y) + xy + wz = z + wz + x + xy + y = z(1 + w) + x(1 + y) + y = x + y + z$

(c) $A'B(D' + C'D) + B(A + A'CD) = B(A'D' + A'C'D + A + A'CD)$
$= B(A'D' + A + A'D(C + C') = B(A + A'(D' + D)) = B(A + A') = B$

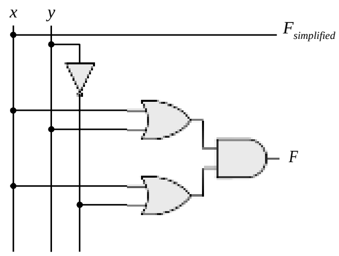
(d) $(A' + C)(A' + C')(A + B + C'D) = (A' + CC')(A + B + C'D) = A'(A + B + C'D)$
$= AA' + A'B + A'C'D = A'(B + C'D)$

(e) $ABC'D + A'BD + ABCD = AB(C + C')D + A'BD = ABD + A'BD = BD$

2.5 **(a)**

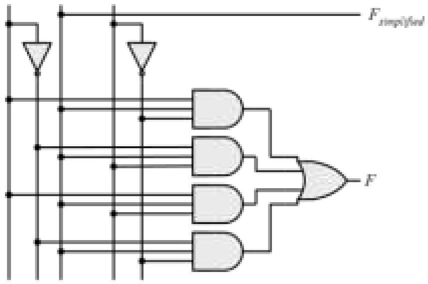


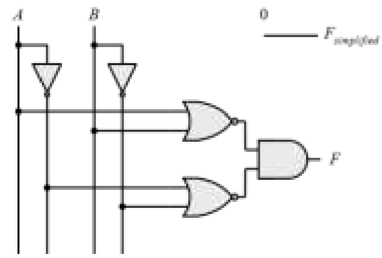
(b)



(c)

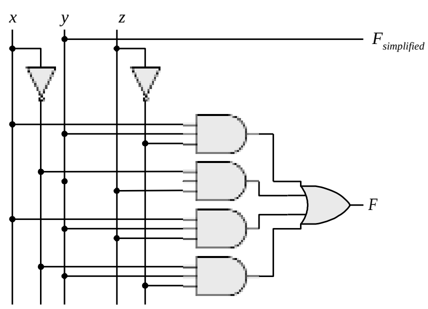
x y z





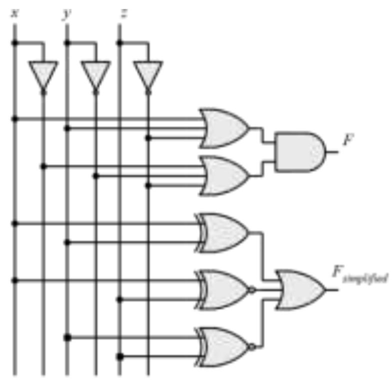
(d)

(e)

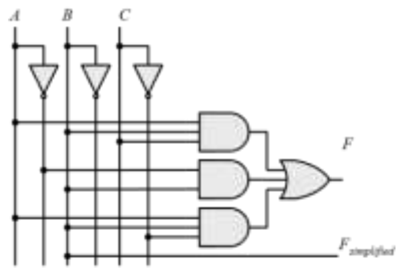


(f)

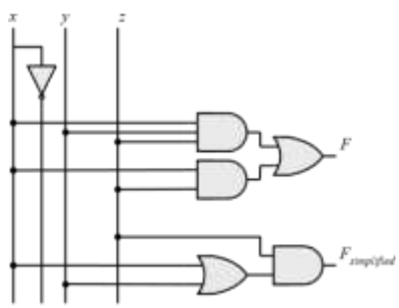
2.6 **(a)**

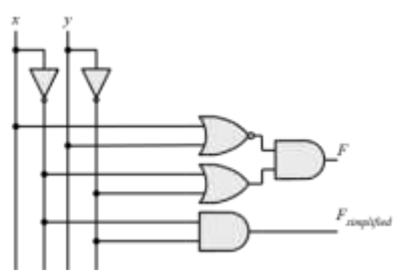

x
y
z
F
F simplified

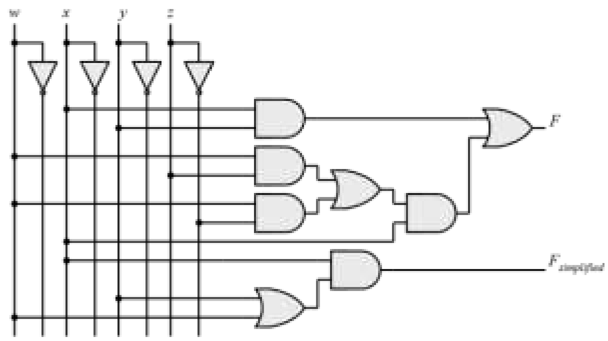
(b)


A
B
C
F
F simplified

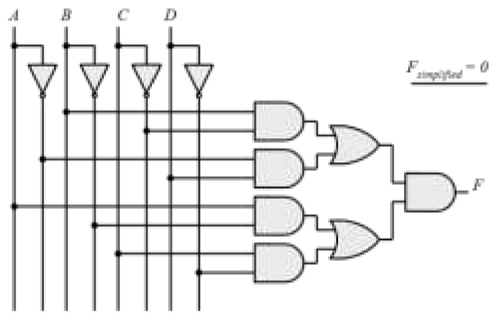
(c) (d)


x
y
z
F
F simplified

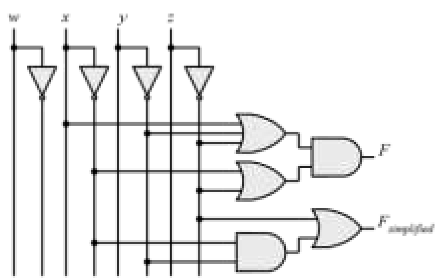

x
y
F
F simplified


w
x
y
z
F
F simplified

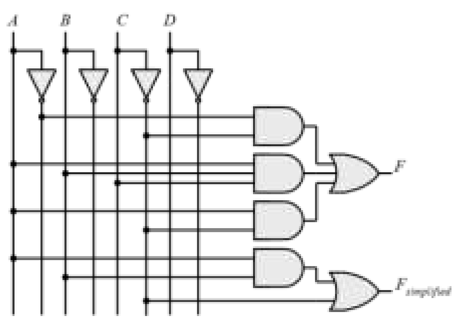
(e)


A
B
C
D
F simplified = 0
F

(f)

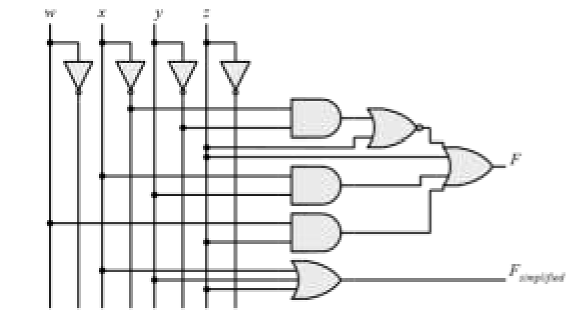

w
x
y
z
F
F simplified

2.7 **(a)**


A
B
C
D
F
F simplified

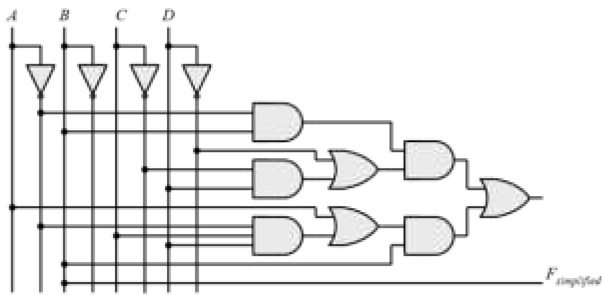
(b)

F

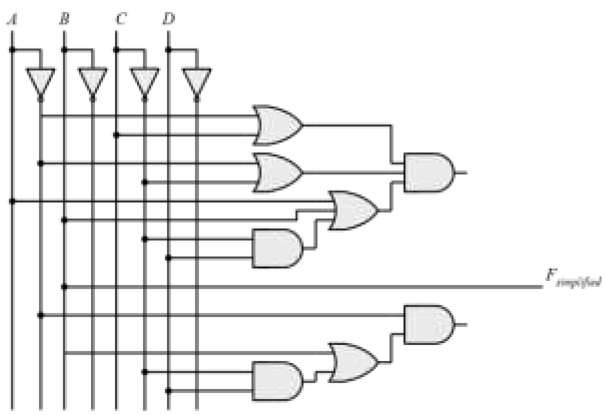


(c)

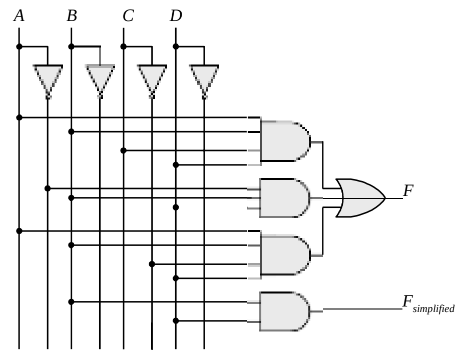
F



(d)



(e)



2.8 $F' = (wx + yz)' = (wx)'(yz)' = (w' + x')(y' + z')$

$FF' = wx(w' + x')(y' + z') + yz(w' + x')(y' + z') = 0$
$F + F' = wx + yz + (wx + yz)' = A + A' = 1$ with $A = wx + yz$

2.9 **(a)** $F' = (xy' + x'y)' = (xy')'(x'y)' = (x' + y)(x + y') = xy + x'y'$

(b) $F' = [(a + c)(a + b')(a' + b + c')]' = (a + c)' + (a + b')' + (a' + b + c')'$
$= a'c' + a'b + ab'c$

(c) $F' = [z + z'(v'w + xy)]' = z'[z'(v'w + xy)]' = z'[z'v'w + xyz']'$
$= z'[(z'v'w)'(xyz')'] = z'[(z + v + w') + (x' + y' + z)]$
$= z'z + z'v + z'w' + z'x' + z'y' + z'z = z'(v + w' + x' + y')$

2.10 **(a)** $F_1 + F_2 = \Sigma m_{1i} + \Sigma m_{2i} = \Sigma (m_{1i} + m_{2i})$

(b) $F1\ F2 = \Sigma m_i \Sigma m_j$ where $m_i m_j = 0$ if $i \neq j$ and $m_i m_j = 1$ if $i = j$

2.11 **(a)** $F(x, y, z) = \Sigma(1, 4, 5, 6, 7)$

(b) $F(a, b, c) = \Sigma(0, 2, 3, 7)$

$F = xy + xy' + y'z$ $F = bc + a'c'$

x y z	F
0 0 0	0
0 0 1	1
0 1 0	0
0 1 1	0
1 0 0	1
1 0 1	1
1 1 0	1
1 1 1	1

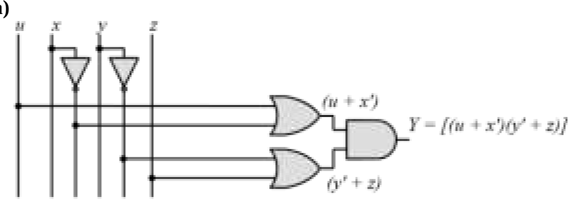
a b c	F
0 0 0	1
0 0 1	0
0 1 0	1
0 1 1	1
1 0 0	0
1 0 1	0
1 1 0	0
1 1 1	1

2.12 *A = 1011_0001*
B = 1010_1100

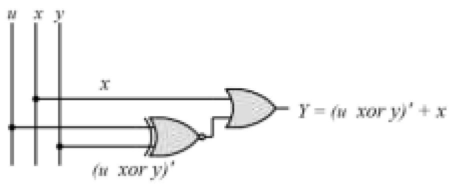
(a) *A AND B = 1010_0000*
(b) *A OR B = 1011_1101*

(c) *A XOR B = 0001_1101*
(d) *NOT A = 0100_1110*
(e) *NOT B = 0101_0011*

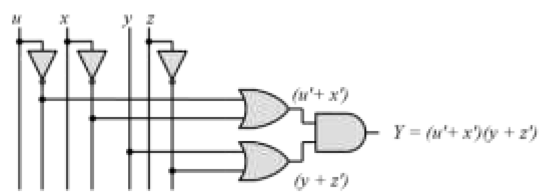
2.13 **(a)**



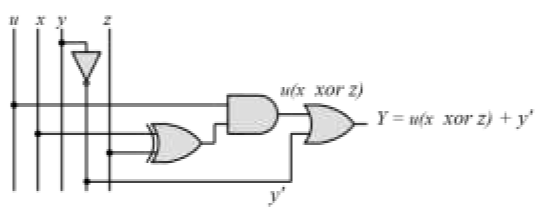
(b)



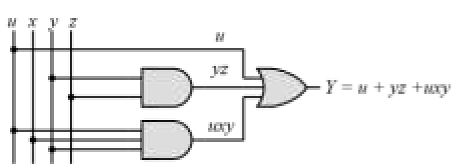
(c)



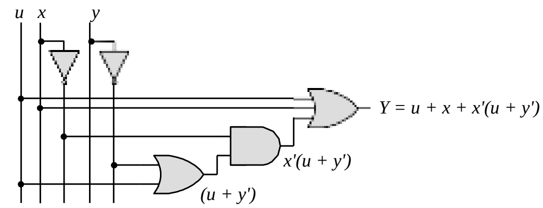
(d)



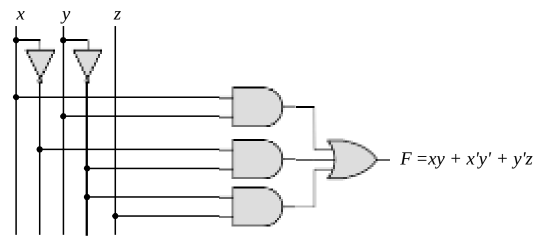
(e)



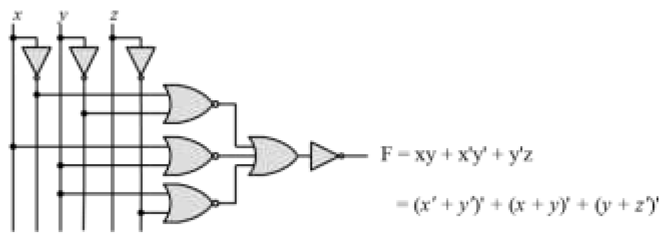
(f)


u x y
Y = u + x + x'(u + y')
x'(u + y')
(u + y')

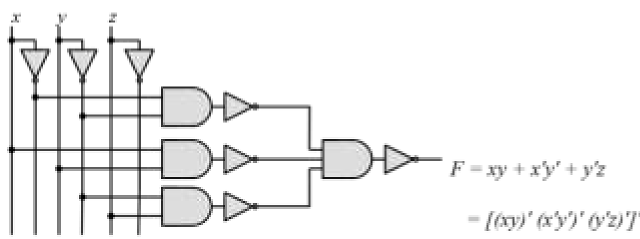
2.14 **(a)**


x y z
F =xy + x'y' + y'z

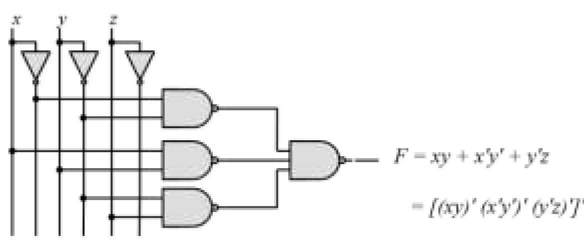
(b)


x y z
F = xy + x'y' + y'z
= (x' + y')' + (x + y)' + (y + z')'

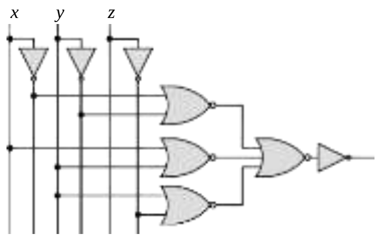
(c)


x y z
F = xy + x'y' + y'z
= [(xy)' (x'y')' (y'z)']'

(d)


x y z
F = xy + x'y' + y'z
= [(xy)' (x'y')' (y'z)']'

(e)



F = xy + x'y' + y'z

= $(x' + y')' + (x + y)' + (y + z')'$

2.15 **(a)** $T_1 = A'B'C' + A'B'C + A'BC' = A'B'(C' + C) + A'C'(B' + B) = A'B' + A'C' = A'(B' + C')$

(b) $T_2 = T_1' = A'BC + AB'C' + AB'C + ABC' + ABC$
$= BC(A' + A) + AB'(C' + C) + AB(C' + C)$
$= BC + AB' + AB = BC + A(B' + B) = A + BC$

$\sum(3,5,6,7) = \prod(0,1,2,4)$

$T_1 = A'B'C' + A'B'C + A'BC'$

$A'B'$ $A'C'$

$T_1 = A'B'\ A'C' = A'(B' + C')$

$T_2 = A'BC + AB'C' + AB'C + ABC' + ABC$

AC' AC

BC

$T_2 = AC' + BC + AC = A + BC$

2.16 **(a)** $F(A, B, C) = A'B'C' + A'B'C + A'BC' + A'BC + AB'C' + AB'C + ABC' + ABC$
$= A'(B'C' + B'C + BC' + BC) + A((B'C' + B'C + BC' + BC)$
$= (A' + A)(B'C' + B'C + BC' + BC) = B'C' + B'C + BC' + BC =$
$B'(C' + C) + B(C' + C) = B' + B = 1$

(b) $F(x_1, x_2, x_3, ..., x_n) = \Sigma m_i$ has $2^n/2$ minterms with x_1 and $2^n/2$ minterms with x'_1, which can be factored and removed as in (a). The remaining 2^{n-1} product terms will have $2^{n-1}/2$ minterms with x_2 and $2^{n-1}/2$ minterms with x'_2, which and be factored to remove x_2 and x'_2. continue this process until the last term is left and $x_n + x'_n = 1$. Alternatively, by induction, F can be written as $F = x_nG + x'_nG$ with $G = 1$. So $F = (x_n + x'_n)G = 1$.

2.17 **(a)** $F = (b + cd)(c + bd)\ bc + bd + cd + bcd = \Sigma(3, 5, 6, 7, 11, 14, 15)$
$F' = \Sigma(0, 1, 2, 4, 8, 9, 10, 12, 13)$

$F = \prod(0, 1, 2, 4, 8, 9, 10, 12, 13)$

a b c d	F
0 0 0 0	0
0 0 0 1	0
0 0 1 0	0
0 0 1 1	1

0 1 0 0	0
0 1 0 1	1
0 1 1 0	1
0 1 1 1	1
1 0 0 0	0
1 0 0 1	
1 0 1 0	0
0	
1 0 1 1	1
1 1 0 0	0
1 1 0 1	1
1 1 1 0	1
1 1 1 1	1

(b) $(cd + b'c + bd')(b + d) = bcd + bd' + cd + b'cd = cd + bd'$
$= \Sigma\ (3, 4, 7, 11, 12, 14, 15)$
$= \Pi\ (0, 1, 2, 5, 6, 8, 9, 10, 13)$

a b c d	F
0 0 0 0	
0	
0 0 0 1	0
0 0 1 0	0
0 0 1 1	1
0 1 0 0	1
0 1 0 1	0
1 1 0	
0 1 1 1	1
1 0 0 0	0
1 0 0 1	0
1 0 1 0	0
1 0 1 1	1
1 1 0 0	1
1 1 0 1	
0	
1 1 1 0	1
1 1 1 1	1

(c) $(c' + d)(b + c') = bc' + c' + bd + c'd = (c' + bd)$
$= \Sigma\ (0, 1, 4, 5, 7, 8, 12, 13, 15)$ *F*
$= \Pi\ (2, 3, 6, 9, 10, 11, 14)$

(d) $bd' + acd' + ab'c + a'c' = \Sigma\ (0, 1, 4, 5, 10, 11, 14)$
$F' = \Sigma\ (2, 3, 6, 7, 8, 9, 12, 13, 15)$
$F = \Pi\ (02, 3, 6, 7, 8, 12, 13, 15)$

a b c d	F
0 0 0 0	1
0 0 0 1	1
0 0 1 0	0
0 0 1 1	0
0 1 0 0	1
0 1 0 1	1
0 1 1 0	0
0 1 1 1	0
1 0 0 0	0
1 0 0 1	0
1 0 1 0	1
1 0 1 1	1
1 1 0 0	1
1 1 0 1	0
1 1 1 0	1
1 1 1 1	0

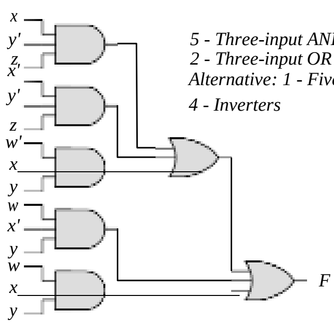
2.18 (a)

wx y z	F
00 0 0	0
00 0 1	1
00 1 0	0
00 1 1	0
01 0 0	0
01 0 1	1
01 1 0	1
01 1 1	1
10 0 0	0
10 0 1	1
10 1 0	1
10 1 1	1
11 0 0	0
11 0 1	1
11 1 0	1
11 1 1	1

$F = xy'z + x'y'z + w'xy + wx'y + wxy$

$F = \Sigma(1, 5, 6, 7, 9, 10\ 11, 13, 14, 15\ )$

(b)



5 - Three-input AND gates
2 - Three-input OR gates
Alternative: 1 - Five-input OR gate
4 - Inverters

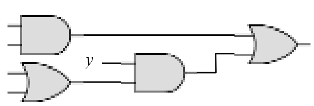
$F = xy'z + x'y'z + w'xy + wx'y + wxy = y'z + xy + wy = y'\ 'z + y(w + x)$

(c)

$F = y'z + yw + yx) = \Sigma(1, 5, 9, 13\ , 10, 11, 13, 15, 6,$
$7, 14, 15) = \Sigma(1, 5, 6, 7, 9, 10, 11,$
$13, 14, 15)$

(d)

(e)



y'
zF x
w

1 – Inverter, 2 – Two-input AND gates, 2 – Two-input OR gates

2.19 $F = B'D + A'D + BD$

ABCD *ABCD* *ABCD*

-B'-D	A'--D	-B-D
0001 = 1	0001 = 1	0101 = 5
0011 = 3	0011 = 3	0111 = 7
1001 = 9	0101 = 5	1101 = 13
1011 = 11	0111 = 7	1111 = 15

$F = \Sigma(1, 3, 5, 7, 9, 11, 13, 15) = \Pi(0, 2, 4, 6, 8, 10, 12, 14)$

2.20 **(a)** $F(A, B, C, D) = \Sigma(2, 4, 7, 10, 12, 14)$
$F'(A, B, C, D) = \Sigma(0, 1, 3, 5, 6, 8, 9, 11, 13, 15)$

(b) $F(x, y, z) = \Pi(3, 5, 7)$
$F' = \Sigma(3, 5, 7)$

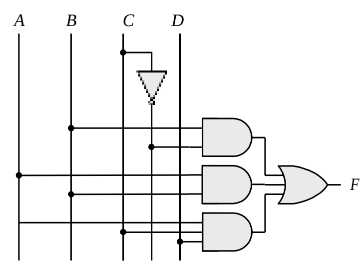
2.21 ***(a)*** $F(x, y, z) = \Sigma(1, 3, 5) = \Pi(0, 2, 4, 6, 7)$

(b) $F(A, B, C, D) = \Pi(3, 5, 8, 11) = \Sigma(0, 1, 2, 4, 6, 7, 9, 10, 12, 13, 14, 15)$

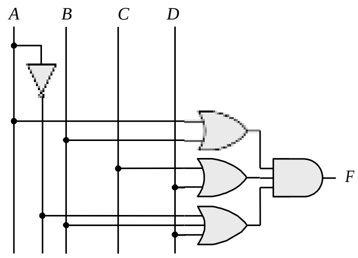
(a) $(u + xw)(x + u'v) = ux + uu'v + xxw + xwu'v = ux + xw + xwu'v$
$= ux + xw = x(u + w)$
$= ux + xw$ (SOP form)
$= x(u + w)$ (POS form)

(b) $x' + x(x + y')(y + z') = x' + x(xy + xz' + y'y + y'z')$
$= x' + xy + xz' + xy'z' = x' + xy + xz'$ *(SOPform)*
$= (x' + y + z')$ *(POS form)*

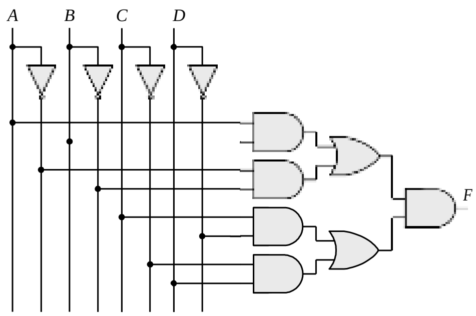
(a) $B'C + AB + ACD$



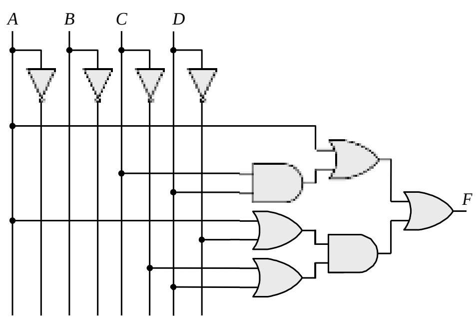
(b) $(A + B)(C + D)(A' + B + D)$



(c) $(AB + A'B')(CD' + C'D)$



(d) $A + CD + (A + D')(C' + D)$



2.24 $x \oplus y = x'y + xy'$ and $(x \oplus y)' = (x + y')(x' + y)$

Dual of $x'y + xy' = (x' + y)(x + y') = (x \oplus y)'$

2.25 **(a)** $x | y = xy' \neq y | x = x'y$ Not commutative

$(x | y) | z = xy'z' \neq x | (y | z) = x(yz')' = xy' + xz$ Not associative

(b) $(x \oplus y) = xy' + x'y = y \oplus x = yx' + y'x$ Commutative

$(x \oplus y) \oplus z = \sum(1, 2, 4, 7) = x \oplus (y \oplus z)$ Associative

2.26

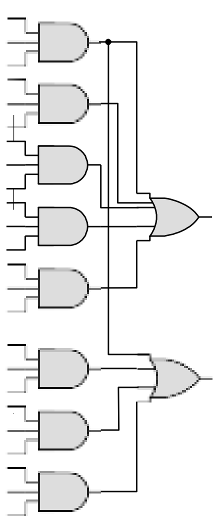
Gate x y	z	NAND (Positive logic) x y	z	NOR (Negative logic) x y	z
L L	H	0 0	1	1 1	0
L H	H	0 1	1	1 0	0
H L	H	1 0	1	0 1	0
H H	L	1 1	0	0 0	1

NOR Gate x y	z	x y	z	NAND (Positive logic) x y	z
L L	H	0 0	1	1 1	0
L H	L	0 1	0	1 0	1
H L	L	1 0	0	0 1	1
H H	L	1 1	0	0 0	1

(Negative logic)

2.27 $f_1 = a'b'c' + a'bc' + a'bc + ab'c' + abc = a'c' + bc + a'bc' + ab'c'$

$f_2 = a'b'c' + a'b'c + a'bc + ab'c' + abc = a'b' + bc + ab'c'$

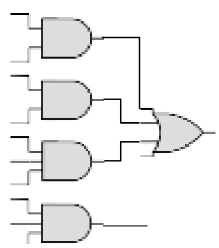


a'a'
b'
a'c' a'b b

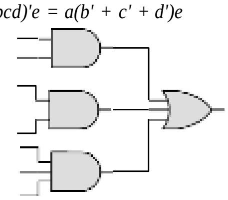
ac''ac'f1 bb cc'
a'a bf1
b' cc'
a b c a'

b' f2 a b' ' c

a' b
bf2 cc aa b'b'
cc'



2.28 **(a)** $y = a(bcd)'e = a(b' + c' + d')e$



$y = a(b' + c' + d')e = ab'e + ac'e + ad'e = \Sigma(17, 19, 21, 23, 25, 27, 29)$

a bcde	y	a bcde	y

0 0000	0	1 0000	0
0 0001	0	**1 0001**	1
0 0010	0	1 0010	0
0 0011	0	**1 0011**	1
0 0100	0	1 0100	0
0 0101	0	**1 0101**	1
0 0110	0	1 0110	0
0 0111	0	**1 0111**	1
	0		0
0 1000	0	1 1000	0
0 1001	0	**1 1001**	1
0 1010	0	1 1010	0
0 1011	0	**1 1011**	1
0 1100	0	1 1100	0
0 1101	0	**1 1101**	1
0 1110	0	1 1110	0
0 1111	0	1 1111	0

(b) $y_1 = a \oplus (c + d + e) = a'(c + d + e) + a(c'd'e') = a'c + a'd + a'e + ac'd'e'$ $y_2 = b'(c + d + e)f = b'cf + b'df + b'ef$ $y_1 = a\ (c + d + e) = a'(c + d + e) + a(c'd'e') = a'c + a'd + a'e + ac'd'e'$ $y_2 = b'(c + d + e)f = b'cf + b'df + b'ef$

a'-c---	*a'--d--*	*a'---e-*	*a-c'd'e'-*		
001000 = 8	000100 = 8	000010 = 2	100000 = 32		
001001 = 9	000101 = 9	000011 = 3	100001 = 33		
001010 = 10	000110 = 10	000110 = 6	110000 = 34		
001011 = 11	000111 = 11	000111 = 7	110001 = 35		
001100 = 12	001100 = 12	001010 = 10			
001101 = 13	001101 = 13	001011 = 11			
001110 = 14	001110 = 14	001110 = 14			
001111 = 15	001111 = 15	001111 = 15	-b' c--f		-b' --ef
				-b' -d-f	
011000 = 24	010100 = 20	010010 = 18	001001 = 9		000011 = 3
011001 = 25	010101 = 21	010011 = 19	001011 = 11	001001 = 9	000111 = 7
011010 = 26	010110 = 22	010110 = 22	001101 = 13	001011 = 11	001011 = 11
011011 = 27	010111 = 23	010111 = 23	001111 = 15	001101 = 13	001111 = 15
			101001 = 41	001111 = 15	100011 = 35
011100 = 28	011100 = 28	011010 = 26	101011 = 43	101001 = 41	100111 = 39
011101 = 29	011101 = 29	011001 = 27	101101 = 45	101011 = 43	101011 = 51
011110 = 30	011110 = 30	011110 = 30	101111 = 47	101101 = 45	101111 = 55
011111 = 31	011111 = 31	011111 = 31		101111 = 47	

$y_1 = \Sigma$ (2, 3, 6, 7, 8, 9, 10 ,11, 12, 13, 14, 15, 18, 19, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35)

$y_2 = \Sigma$ (3, 7, 9, 13, 15, 35, 39, 41, 43, 45, 47, 51, 55)

ab cdef	$y_1\ y_2$	*ab cdef*	$y_1\ y_2$	*ab cdef*	$y_1\ y_2$	*ab cdef*	$y_1\ y_2$

00 0000	0 0	01 0000	0 0	10 0000	1 0	11 0000	0 0
00 0001	0 0	01 0001	0 0	10 0001	1 0	11 0001	0 0
00 0010	1 0	01 0010	1 0	10 0010	1 0	11 0010	0 0
00 0011	1 1	01 0011	1 0	10 0011	1 1	11 0011	0 1
00 0100	0 0	01 0100	0 0	10 0100	0 0	11 0100	0 0
00 0101	0 0	01 0101	0 0	10 0101	0 0	11 0101	0 0
00 0110	1 0	01 0110	1 0	10 0110	0 0	11 0110	0 0
00 0111	1 1	01 0111	1 0	10 0111	0 1	11 0111	0 1
00 1000	1 0	01 1000	1 0	10 1000	0 0	11 1000	0 0
00 1001	1 1	01 1001	1 0	10 1001	0 1	11 1001	0 0
00 1010	1 0	01 1010	1 0	10 1010	0 0	11 1010	0 0
00 1011	1 0	01 1011	1 0	10 1011	0 1	11 1011	0 0
00 1100	1 0	01 1100	1 0	10 1100	0 0	11 1100	0 0
00 1101	1 1	01 1101	1 0	10 1101	0 1	11 1101	0 0
00 1110	1 0	01 1110	1 0	10 1110	0 0	11 1110	0 0
00 1111	1 1	01 1111	1 0	10 1111	0 1	11 1111	0 0