SOLUTIONS MANUAL

DIGITAL DESIGN

WITH AN INTRODUCTION TO THE VERILOG HDL

Fifth Edition

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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^3 8
                             8^2 A
                             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) $2/3 \cong .6666666667$

		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)	(b)	(c)
	0001_0000	0000_0000	1101_1010
1s comp:	1110_1111	1111_1111	0010_0101
2s comp:	1111_0000	0000_0000	0010_0110

	(d)	(e)	(f)
	1010_1010	1000_0101	1111_1111
1s comp:	0101_0101	0111_1010	0000_0000
2s comp:	0101_0110	0111_1011	0000_0001

`

1.15

	(a)	(b)
	25,478,036	63,325,600
9s comp:	74,521,963	36,674,399
10s comp:	74,521,964	36,674,400

	(c)	(d)
	25,000,000	00000000
9s comp:	74,999,999	99999999
10s comp:	75,000,000	100000000

1.16

	C3DF	C3DF:	1100_0011_1101_1111
15s comp:	3C20	1s comp:	0011_1100_0010_0000
16s comp:	3C21	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

Full file at https://testbankuniv.eu/Digital-Design-5th-Edition-Mano-Solutions-Manual

(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

Full file at https://testbankuniv.eu/Digital-Design-5th-Edition-Mano-Solutions-Manual

(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)**

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

(b)

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

1.27 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.)

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

1.29 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

1.31 62 + 32 = 94 printing characters

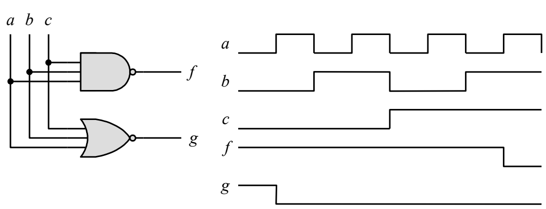
1.32 bit 6 from the right

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

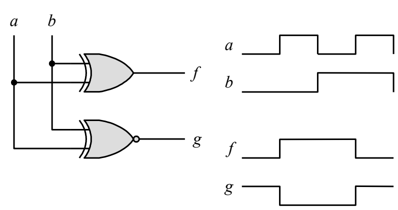
1.34 ASCII for decimal digits with even parity:

(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'	y'	z'	$x'y'z'$
0 0 0	0	1	1	1	1	1
0 0 1	1	0	1	1	0	0
0 1 0	1	0	1	0	1	0
0 1 1	1	0	1	0	0	0
1 0 0	1	0	0	1	1	0
1 0 1	1	0	0	1	0	0
1 1 0	1	0	0	0	1	0
1 1 1	1	0	0	0	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)

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

(c)

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	$y + z$	$x + (y + z)$	$(x + y)$	$(x + y) + z$
0 0 0	0	0	0	0	0
0 0 1	0	1	1	0	1
0 1 0	0	1	1	1	1
0 1 1	0	1	1	1	1
1 0 0	1	0	1	1	1
1 0 1	1	1	1	1	1
1 1 0	1	1	1	1	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)** $A'C' + ABC + AC' = C' + ABC = (C + C')(C' + AB) = AB + C'$

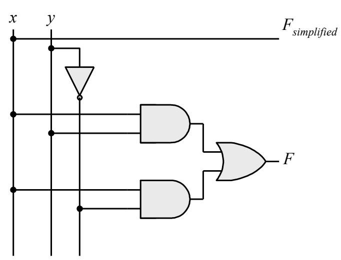
(b) $(x'y' + z)' + z + xy + wz = (x'y')'z' + z + xy + wz = [(x + y)z' + z] + xy + wz =$
$= (z + z')(z + x + y) + xy + wz = z + wz + x + xy + y = z(1 + w) + x(1 + y) + y = x + y + z$

(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)**



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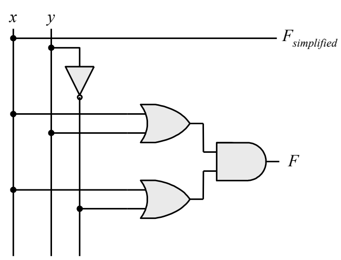
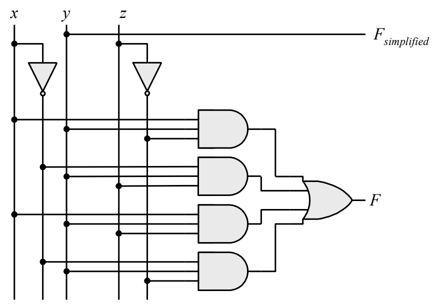


(c)



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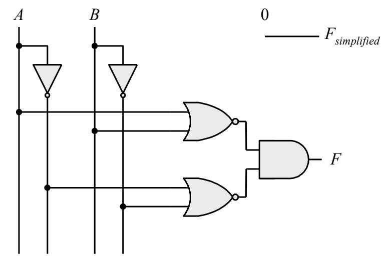

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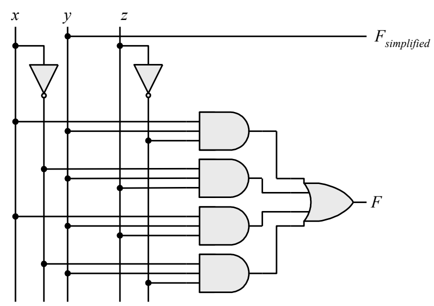

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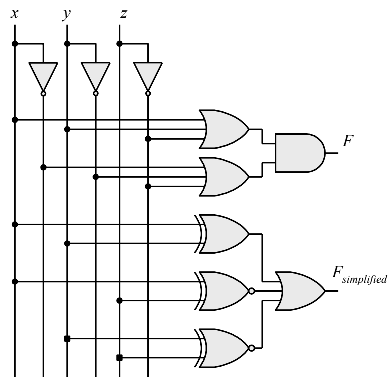
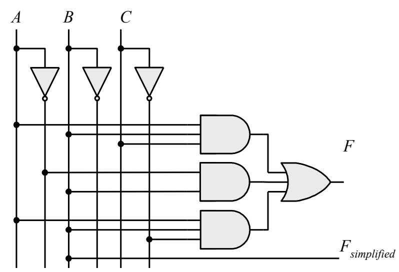
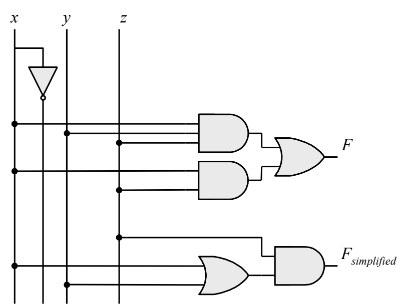

x
y
z
F
$F_{simplified}$

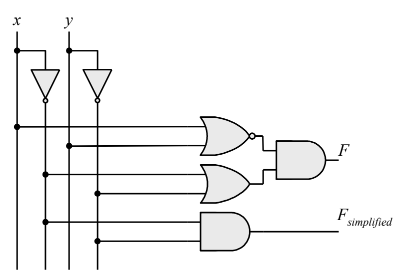
2.6 **(a)**


A
B
C
F
$F_{simplified}$

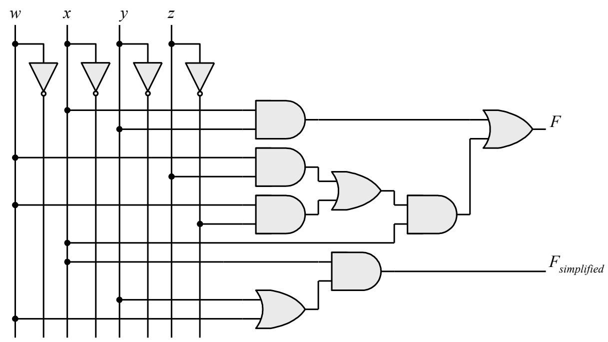
(b)


x
y
z
F
$F_{simplified}$

(c)

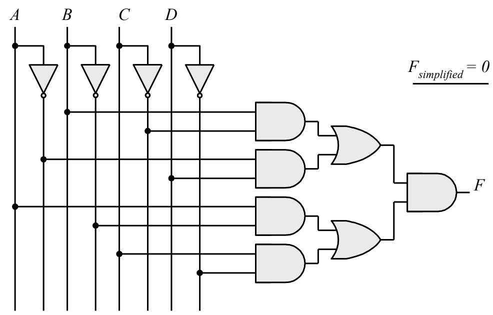

x
y
F
$F_{simplified}$

(d)



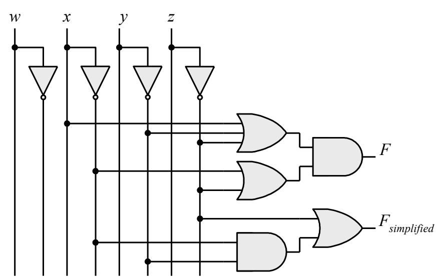
w
x
y
z
F
F simplified

(e)



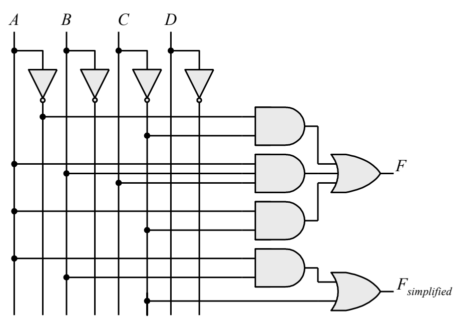
A
B
C
D
F simplified = 0
F

(f)



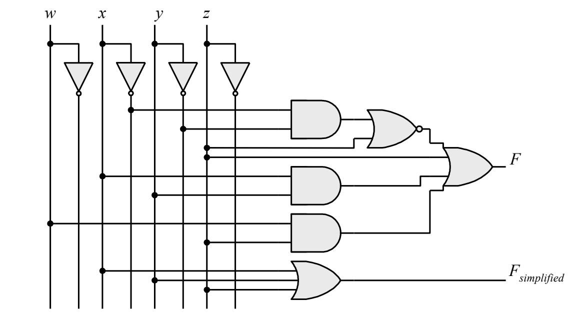
w
x
y
z
F
F simplified

2.7 **(a)**

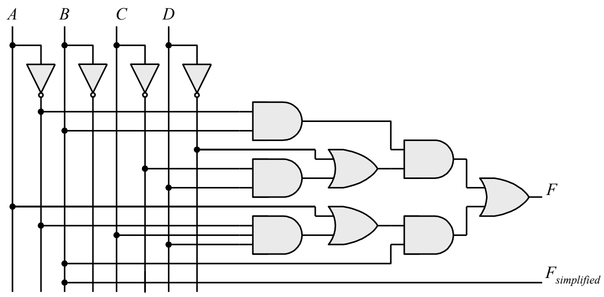


A
B
C
D
F
F simplified

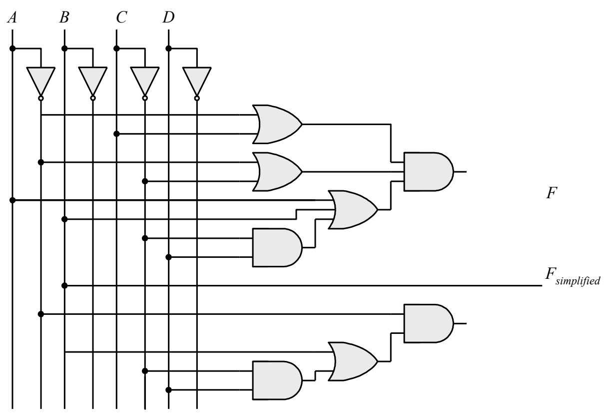
(b)



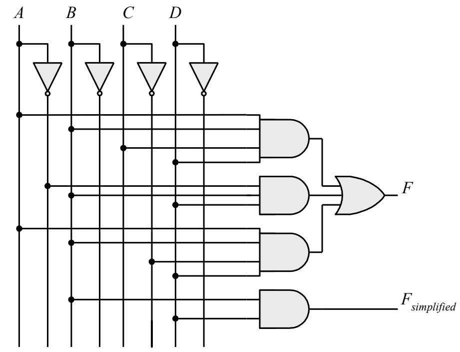
(c)



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

$F = xy + xy' + y'z$

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

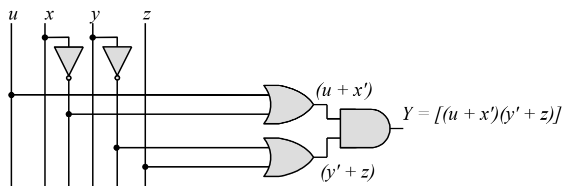
$F = bc + a'c'$

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

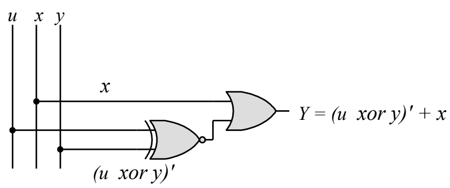
2.12 $A = 1011\_0001$
$B = 1010\_1100$

(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*

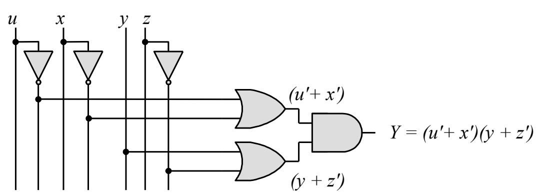
2.13 **(a)**



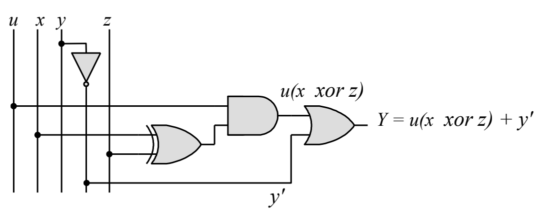
(b)



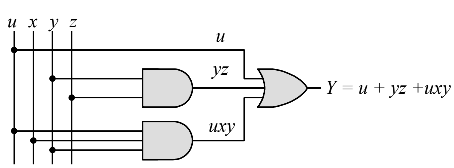
(c)



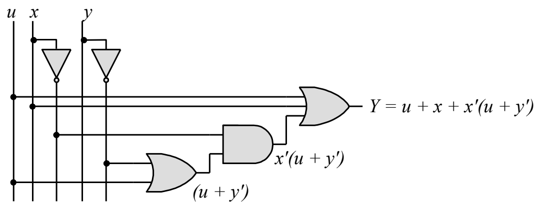
(d)



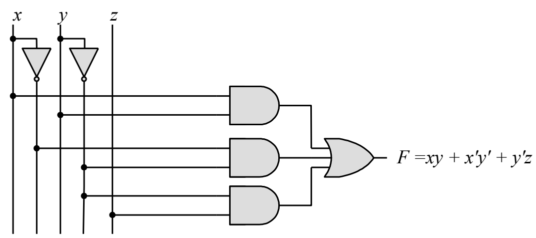
(e)



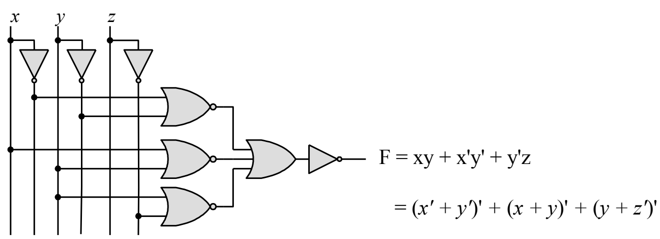
(f)


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

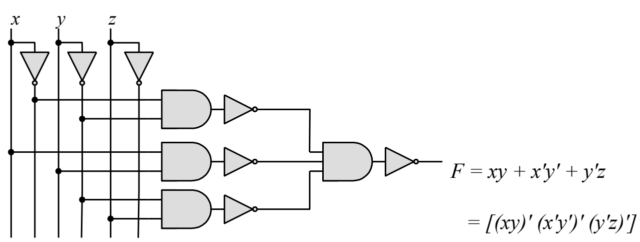
2.14 **(a)**


x y z
F =xy + x′y′ + y′z

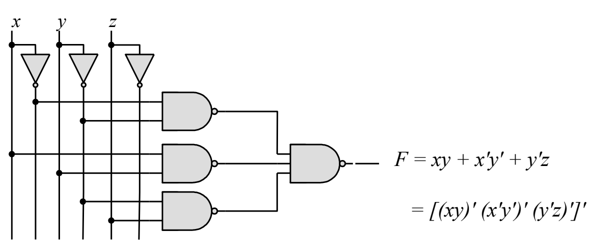
(b)


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

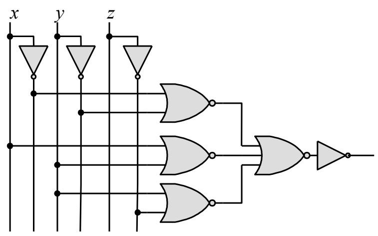
(c)


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

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

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

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

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

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

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) $F(x_1, x_2, x_3, \ldots, x_n) = \Sigma m_i$ 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 $F = (x_n + x'_n)G = 1$.

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

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	0
1 0 1 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
0 1 1 0	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

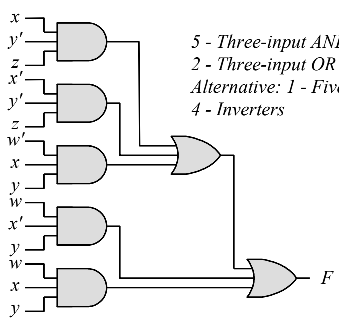
2.18 (a)

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)

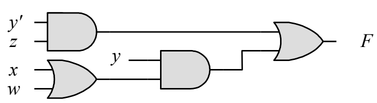


5 - Three-input AND gates
2 - Three-input OR gates
Alternative: 1 - Five-input OR gate
4 - Inverters

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

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

(e)



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

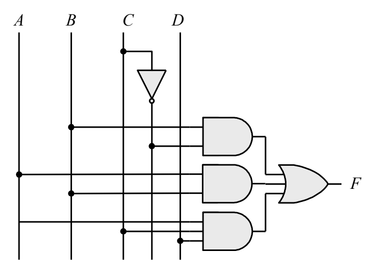
2.21 ***(a)*** $F(x, y, z) = \Sigma(1, 3, 5) = \Pi(0, 2, 4, 6, 7)$

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

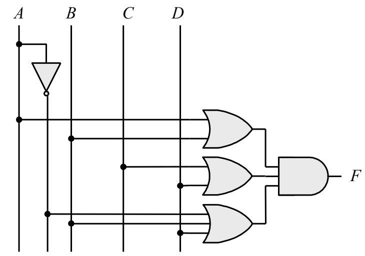
2.22 **(a)** $(u + xw)(x + u'v) = ux + uu'v + xxw + xwu'v = ux + xw + xwu'v$
$= ux + xw = x(u + w)$
$= ux + xw$ (SOP form)
$= x(u + w)$ (POS form)

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

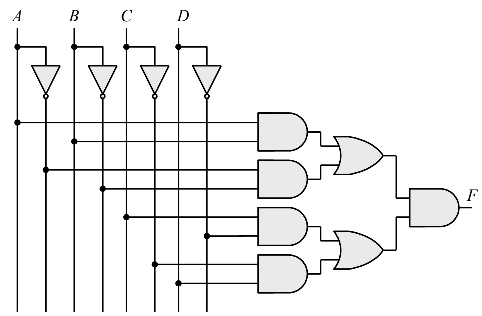
2.23 **(a)** $B'C + AB + ACD$



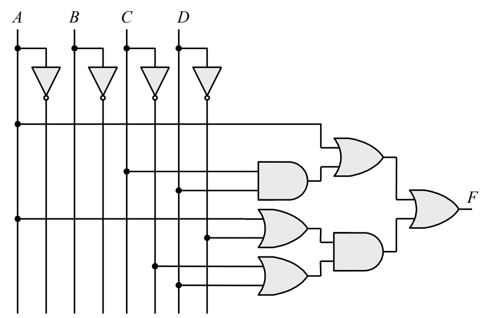
(b) $(A + B)(C + D)(A' + B + D)$



(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

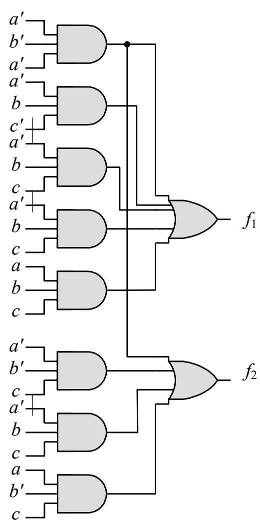
2.26

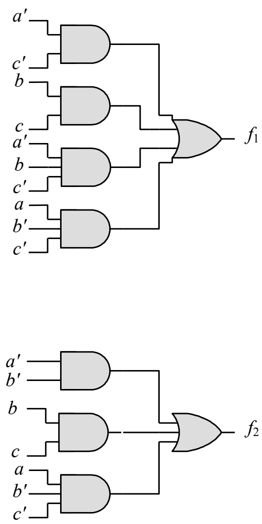
Gate		NAND (Positive logic)		NOR (Negative logic)	
x y	z	x y	z	x y	z
L L	H	0 0	1	1 1	0
L H	H	0 1	1	1 0	0
H L	H	1 0	1	0 1	0
H H	L	1 1	0	0 0	1

Gate		NOR (Positive logic)		NAND (Negative logic)	
x y	z	x y	z	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

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

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





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	
011000 = 24	010100 = 20	010010 = 18	
011001 = 25	010101 = 21	010011 = 19	
011010 = 26	010110 = 22	010110 = 22	
011011 = 27	010111 = 23	010111 = 23	
011100 = 28	011100 = 28	011010 = 26	
011101 = 29	011101 = 29	011001 = 27	
011110 = 30	011110 = 30	011110 = 30	
011111 = 31	011111 = 31	011111 = 31	

-b' c--f	-b' -d-f	-b' --ef
001001 = 9	001001 = 9	000011 = 3
001011 = 11	001011 = 11	000111 = 7
001101 = 13	001101 = 13	001011 = 11
001111 = 15	001111 = 15	001111 = 15
101001 = 41	101001 = 41	100011 = 35
101011 = 43	101011 = 43	100111 = 39
101101 = 45	101101 = 45	101011 = 51
101111 = 47	101111 = 47	101111 = 55

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$y_1 = \Sigma$ (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