

SOLUTIONS MANUAL

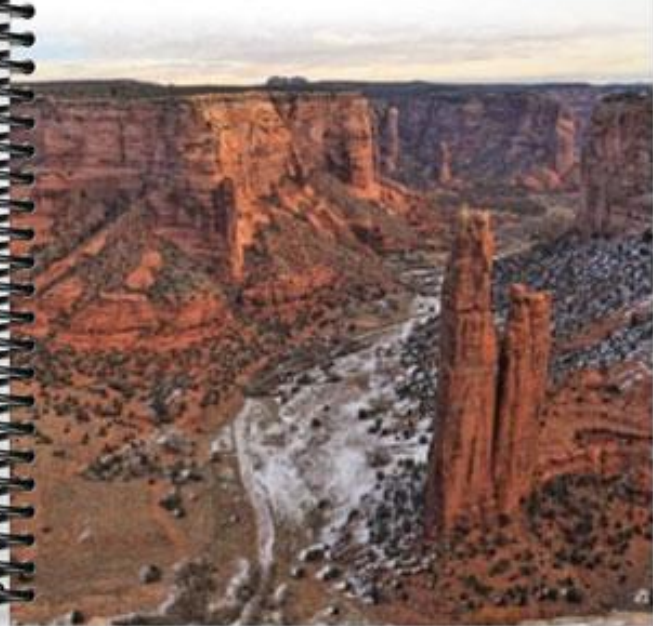


DIGITAL DESIGN

With An Introduction to the Verilog HDL

FIFTH EDITION

M. MORRIS MANO | MICHAEL D. CILETTI



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**WITH AN INTRODUCTION TO THE VERILOG HDL
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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: FFFF₁₆
- 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) $DADA.B_{16} = 14*16^3 + 10*16^2 + 14*16 + 10 + 11/16 = 60,138.6875$

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

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

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

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

$$1.11 \quad \begin{array}{r} \underline{1011.11} \\ 101 \overline{) 111011.0000} \\ \underline{101} \\ 01001 \\ \underline{101} \\ 1001 \\ \underline{101} \\ 1000 \\ \underline{101} \\ 0110 \end{array}$$

The quotient is carried to two decimal places, giving 1011.11

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

$$1.12 \quad (a) 10000 \text{ and } 110111$$

$$\begin{array}{r} 1011 \\ +101 \\ \hline 10000 = 16_{10} \end{array}$$

$$\begin{array}{r} 1011 \\ \times 101 \\ \hline 1011 \\ 1011 \\ \hline 110111 = 55_{10} \end{array}$$

$$(b) 62_h \text{ and } 958_h$$

$$\begin{array}{r} 2E_h \quad 0010_1110 \\ +34_h \quad 0011_0100 \\ \hline 62_h \quad 0110_0010 = 98_{10} \end{array}$$

$$\begin{array}{r} 2E_h \\ \times 34_h \\ \hline B^38 \\ \hline 8^2A \\ \hline 9 \ 5 \ 8_h = 2392_{10} \end{array}$$

$$1.13 \quad (a) \text{ Convert } 27.315 \text{ to binary:}$$

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

$$27_{10} = 11011_2$$

	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	$a_4 = 1$

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

$$27.315 \approx 11011.0101_2$$

$$(b) \ 2/3 \approx .666666667$$

	Integer	Fraction	Coefficient
.6666_6666_67 x 2 =	1	+ .3333_3333_34	$a_1 = 1$
.333333334 x 2 =	0	+ .666666668	$a_2 = 0$
.666666668 x 2 =	1	+ .333333336	$a_3 = 1$
.333333336 x 2 =	0	+ .666666672	$a_4 = 0$
.666666672 x 2 =	1	+ .333333344	$a_5 = 1$
.333333344 x 2 =	0	+ .666666688	$a_6 = 0$
.666666688 x 2 =	1	+ .333333376	$a_7 = 1$
.333333376 x 2 =	0	+ .666666752	$a_8 = 0$

$$.666666667_{10} \approx .10101010_2 = .5 + .125 + .0313 + .0078 = .6641_{10}$$

$$.10101010_2 = .1010_{10} = .AA_{16} = 10/16 + 10/256 = .6641_{10} \text{ (Same as (b))}$$

- 1.14**
- | | | | | | |
|------------|-----------|------------|-----------|------------|-----------|
| (a) | 0001_0000 | (b) | 0000_0000 | (c) | 1101_1010 |
| 1s comp: | 1110_1111 | 1s comp: | 1111_1111 | 1s comp: | 0010_0101 |
| 2s comp: | 1111_0000 | 2s comp: | 0000_0000 | 2s comp: | 0010_0110 |
| (d) | 1010_1010 | (e) | 1000_0101 | (f) | 1111_1111 |
| 1s comp: | 0101_0101 | 1s comp: | 0111_1010 | 1s comp: | 0000_0000 |
| 2s comp: | 0101_0110 | 2s comp: | 0111_1011 | 2s comp: | 0000_0001 |
- 1.15**
- | | | | |
|------------|------------|------------|------------|
| (a) | 25,478,036 | (b) | 63,325,600 |
| 9s comp: | 74,521,963 | 9s comp: | 36,674,399 |
| 10s comp: | 74,521,964 | 10s comp: | 36,674,400 |
| (c) | 25,000,000 | (d) | 00000000 |
| 9s comp: | 74,999,999 | 9s comp: | 99999999 |
| 10s comp: | 75,000,000 | 10s comp: | 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)** $2,579 \rightarrow 02,579 \rightarrow 97,420$ (9s comp) $\rightarrow 97,421$ (10s comp)
 $4637 - 2,579 = 2,579 + 97,421 = 2058_{10}$
- (b)** $1800 \rightarrow 01800 \rightarrow 98199$ (9s comp) $\rightarrow 98200$ (10 comp)
 $125 - 1800 = 00125 + 98200 = 98325$ (negative)
 Magnitude: 1675
 Result: $125 - 1800 = 1675$

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

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

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

<p>(a) 0_10010 1s comp: 1_01101 2s comp: 1_01110 0_10011 Diff: 0_00001 (Positive) Check: $19 - 18 = +1$</p>	<p>(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: $34 - 38 = -4$</p>
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<p>(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)</p>	<p>(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: $40 - 21 = 19_{10}$</p>
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1.19 $+9286 \rightarrow 009286$; $+801 \rightarrow 000801$; $-9286 \rightarrow 990714$; $-801 \rightarrow 999199$

(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 $+49 \rightarrow 0_110001$ (Needs leading zero extension to indicate + value);
 $+29 \rightarrow 0_011101$ (Leading 0 indicates + value)
 $-49 \rightarrow 1_001110 + 0_000001 \rightarrow 1_001111$
 $-29 \rightarrow 1_100011$ (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 accommodate 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 $+9742 \rightarrow 009742 \rightarrow 990257$ (9's comp) $\rightarrow 990258$ (10s) comp
 $+641 \rightarrow 000641 \rightarrow 999358$ (9's comp) $\rightarrow 999359$ (10s) comp

(a) $(+9742) + (+641) \rightarrow 010383$

(b) $(+9742) + (-641) \rightarrow 009742 + 999359 = 009102$
 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)
<u>0110</u>	<u>0101</u>	<u>1000</u>	(+658)
1101	1110	1001	
<u>0110</u>	<u>0110</u>		
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)

 6,248₂₄₂₁ 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

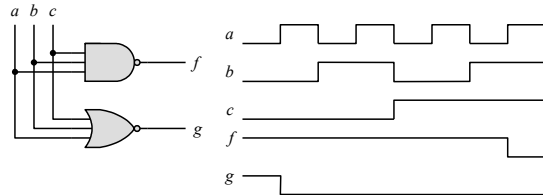
1.32 bit 6 from the right

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

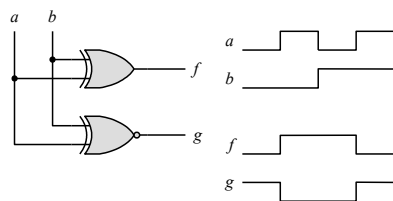
1.34 ASCII for decimal digits with even parity:

(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)

xyz	$x+y+z$	$(x+y+z)'$	x'	y'	z'	$x'y'z'$	xyz	(xyz)	$(xyz)'$	x'	y'	z'	$x'+y'+z'$
000	0	1	1	1	1	1	000	0	1	1	1	1	1
001	1	0	1	1	0	0	001	0	1	1	1	0	1
010	1	0	1	0	1	0	010	0	1	1	0	1	1
011	1	0	1	0	0	0	011	0	1	1	0	0	1
100	1	0	0	1	1	0	100	0	1	0	1	1	1
101	1	0	0	1	0	0	101	0	1	0	1	0	1
110	1	0	0	0	1	0	110	0	1	0	0	1	1
111	1	0	0	0	0	0	111	1	0	0	0	0	0

(b)

xyz	$x+yz$	$(x+y)$	$(x+z)$	$(x+y)(x+z)$
000	0	0	0	0
001	0	0	1	0
010	0	1	0	0
011	1	1	1	1
100	1	1	1	1
101	1	1	1	1
110	1	1	1	1
111	1	1	1	1

(c)

xyz	$x(y+z)$	xy	xz	$xy+xz$
000	0	0	0	0
001	0	0	0	0
010	0	0	0	0
011	0	0	0	0
100	0	0	0	0
101	1	0	1	1
110	1	1	0	1
111	1	1	1	1

(e)

xyz	x	$y+z$	$x+(y+z)$	$(x+y)$	$(x+y)+z$
000	0	0	0	0	0
001	0	1	1	0	1
010	0	1	1	1	1
011	0	1	1	1	1
100	1	0	1	1	1
101	1	1	1	1	1
110	1	1	1	1	1
111	1	1	1	1	1

(d)

xyz	yz	$x(yz)$	xy	$(xy)z$
000	0	0	0	0
001	0	0	0	0
010	0	0	0	0
011	1	0	0	0
100	0	0	0	0
101	0	0	0	0
110	0	0	1	0
111	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) $(A+B)(A'+B') = (A'B')(AB) = (A'B')(BA) = A'(B'B)A = 0$

(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) $A'C' + ABC + AC' = C' + ABC = (C + C')(C' + AB) = AB + C'$

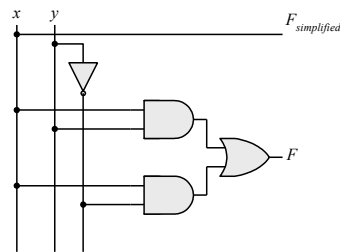
(b) $(x'y' + z)' + z + xy + wz = (x'y')z' + z + xy + wz = [(x + y)z' + z] + xy + wz =$
 $= (z + z')(z + x + y) + xy + wz = z + wz + x + xy + y = z(1 + w) + x(1 + y) + y = x + y + z$

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

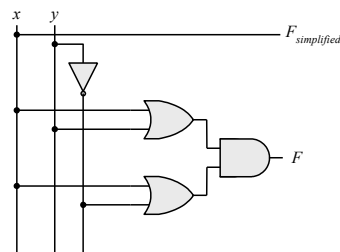
(d) $(A' + C)(A' + C')(A + B + C'D) = (A' + CC')(A + B + C'D) = A'(A + B + C'D)$
 $= AA' + A'B + A'C'D = A'(B + C'D)$

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

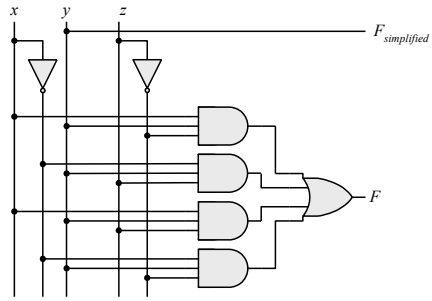
2.5 (a)



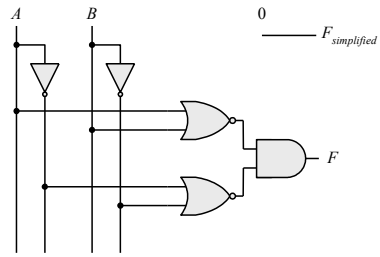
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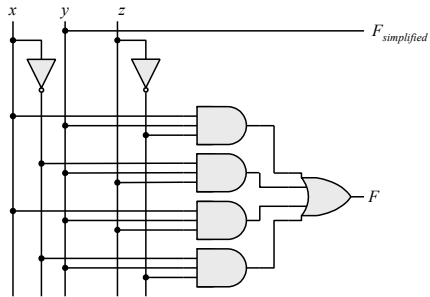
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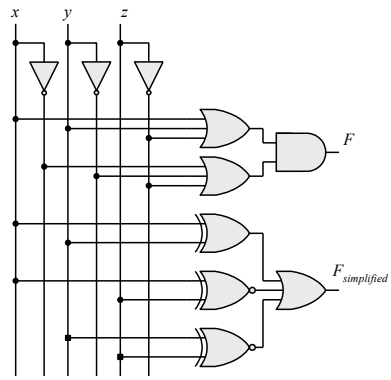
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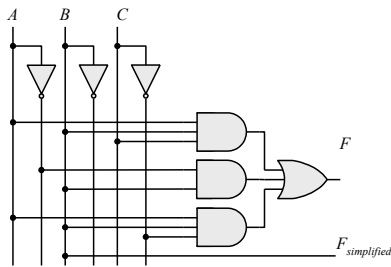
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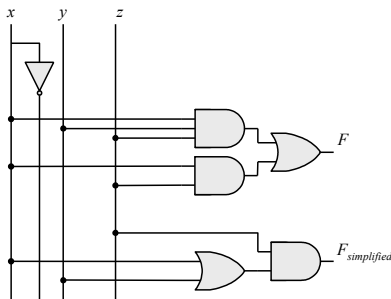
(f)



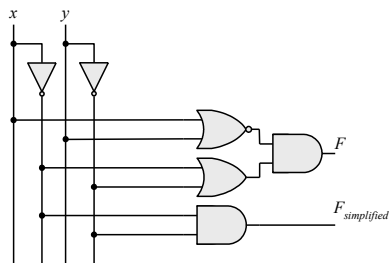
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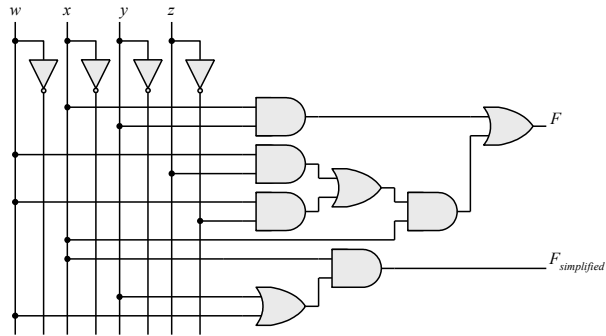
(b)



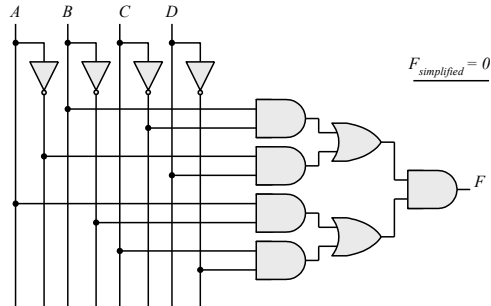
(c)



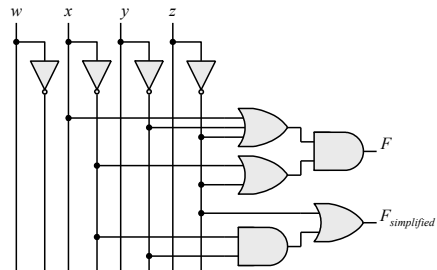
(d)



(e)

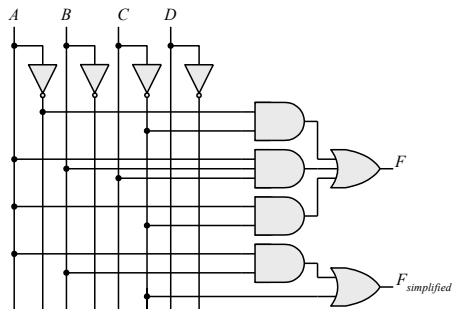


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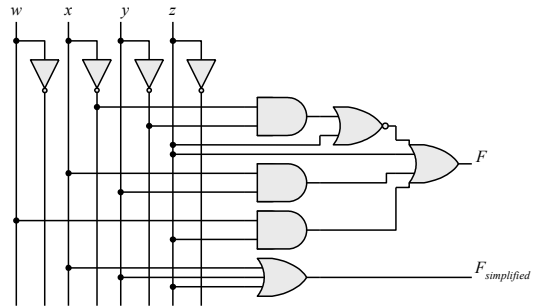


2.7

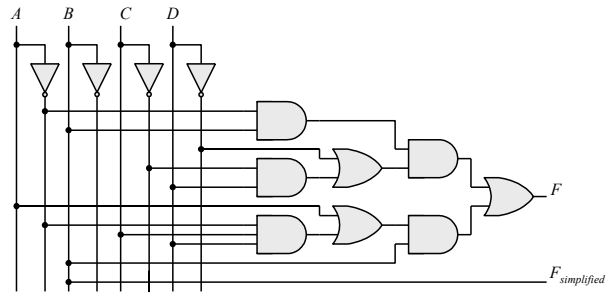
(a)



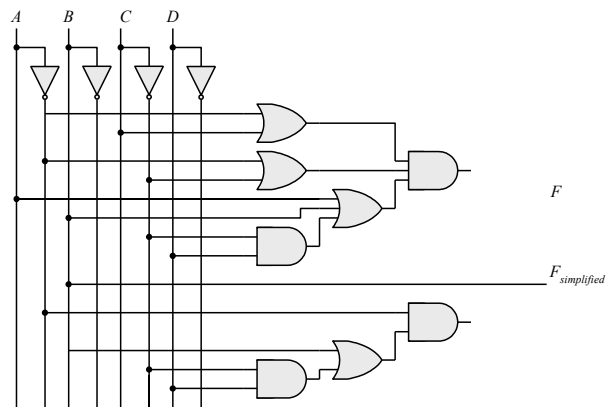
(b)



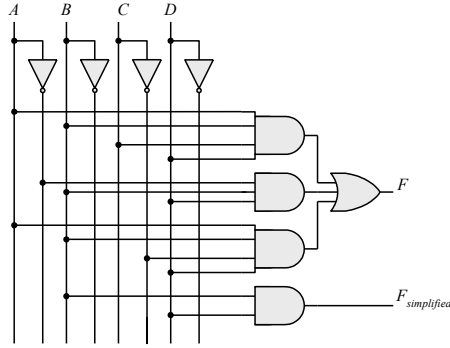
(c)



(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) $F_1 + F_2 = \sum m_{1i} + \sum m_{2i} = \sum (m_{1i} + m_{2i})$

(b) $F_1 F_2 = \sum m_i \sum m_j$ where $m_i m_j = 0$ if $i \neq j$ and $m_i m_j = 1$ if $i = j$

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

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

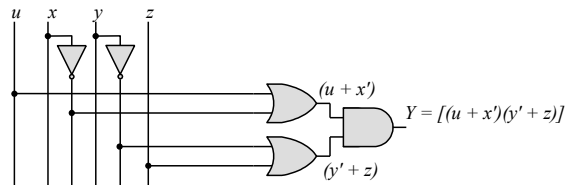
$F = xy + xy' + y'z$		$F = bc + a'c'$	
x y z	F	a b c	F
0 0 0	0	0 0 0	1
0 0 1	1	0 0 1	0
0 1 0	0	0 1 0	1
0 1 1	0	0 1 1	1
1 0 0	1	1 0 0	0
1 0 1	1	1 0 1	0
1 1 0	1	1 1 0	0
1 1 1	1	1 1 1	1

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

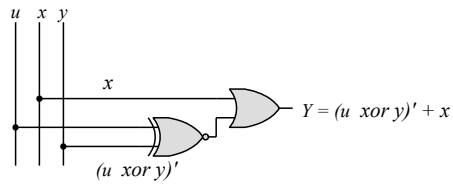
- (a) $A \text{ AND } B = 1010_0000$
 (b) $A \text{ OR } B = 1011_1101$
 (c) $A \text{ XOR } B = 0001_1101$
 (d) $\text{NOT } A = 0100_1110$
 (e) $\text{NOT } B = 0101_0011$

2.13

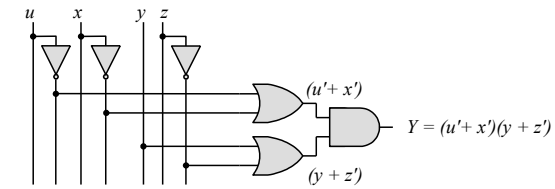
(a)



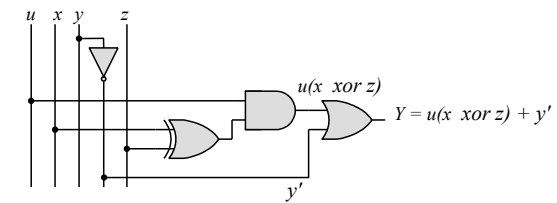
(b)



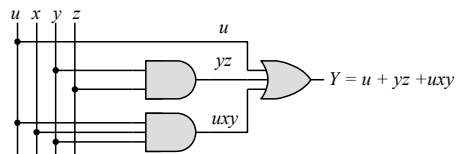
(c)



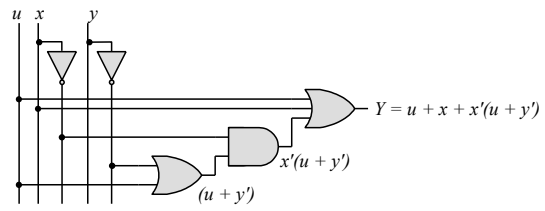
(d)



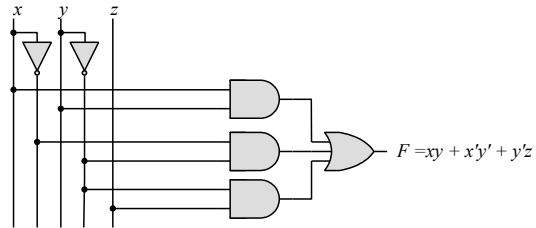
(e)



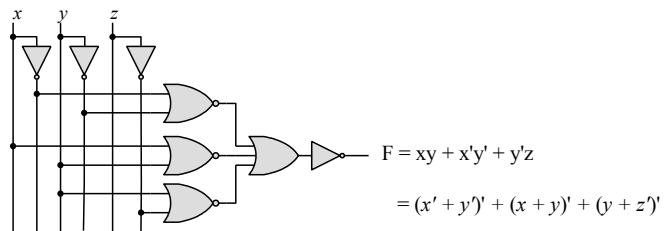
(f)



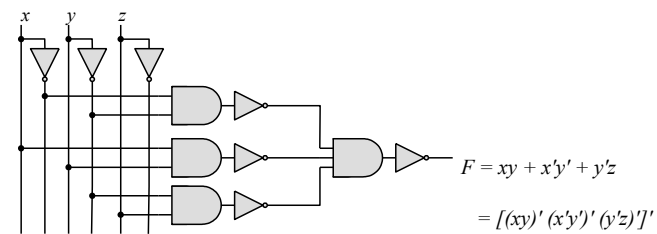
2.14 (a)



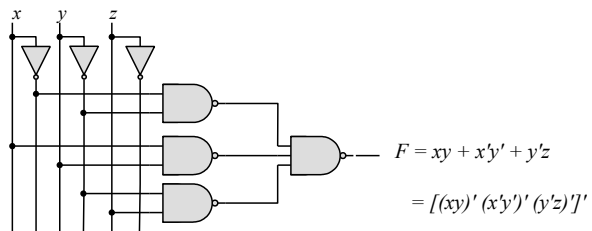
(b)



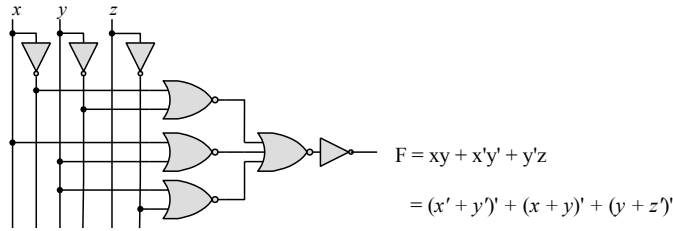
(c)



(d)



(e)



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

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

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

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

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

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

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) $F(x_1, x_2, x_3, \dots, x_n) = \Sigma m_i$ has $2^{n-1}/2$ minterms with x_1 and $2^{n-1}/2$ minterms with x_1' , which can be factored and removed as in (a). The remaining 2^{n-1} product terms will have $2^{n-2}/2$ minterms with x_2 and $2^{n-2}/2$ minterms with x_2' , which can 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 $F = x_n G + x_n' G$ with $G = 1$. So $F = (x_n + x_n')G = 1$.

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

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	0
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) $bd' + acd' + ab'c + a'c' = \Sigma(0, 1, 4, 5, 10, 11, 14)$

$$F' = \Sigma(2, 3, 6, 7, 8, 9, 12, 13, 15)$$

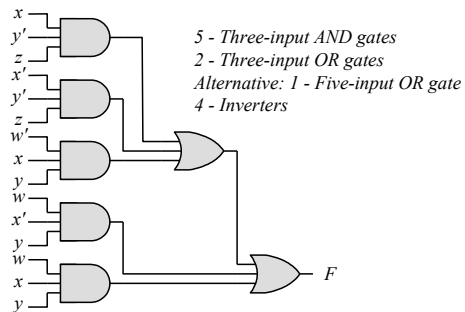
$$F = \Pi(0, 2, 3, 6, 7, 8, 12, 13, 15)$$

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	$F = xy'z + x'y'z + w'xy + wx'y + wxy$ $F = \Sigma(1, 5, 6, 7, 9, 10, 11, 13, 14, 15)$
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	

(b)

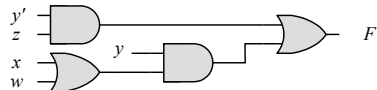


(c)
$$F = xy'z + x'y'z + w'xy + wx'y + wxy = y'z + xy + wy = y'z + y(w + x)$$

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

<i>ABCD</i>	<i>ABCD</i>	<i>ABCD</i>
$\overline{B}D$	$A\overline{B}D$	$\overline{B}D$
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) $F(x, y, z) = \Pi(3, 5, 7)$
 $F' = \Sigma(3, 5, 7)$

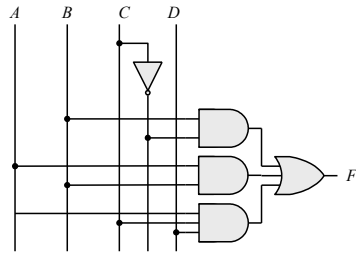
2.21 (a) $F(x, y, z) = \Sigma(1, 3, 5) = \Pi(0, 2, 4, 6, 7)$

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

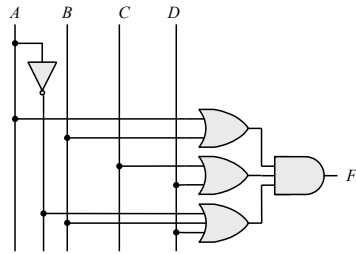
2.22 (a) $(u + xw)(x + u'v) = ux + uu'v + xxw + xwu'v = ux + xw + xwu'v$
 $= ux + xw = x(u + w)$
 $= ux + xw$ (SOP form)
 $= x(u + w)$ (POS form)

(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)

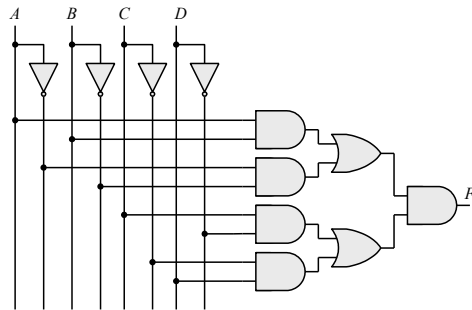
2.23 (a) $B'C + AB + ACD$



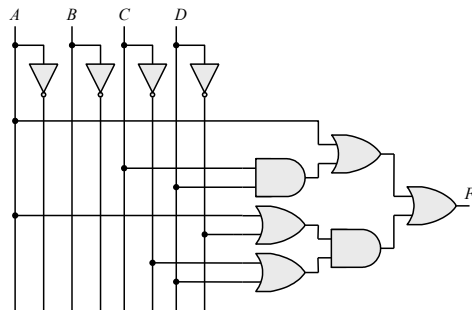
(b) $(A + B)(C + D)(A' + B + D)$



(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

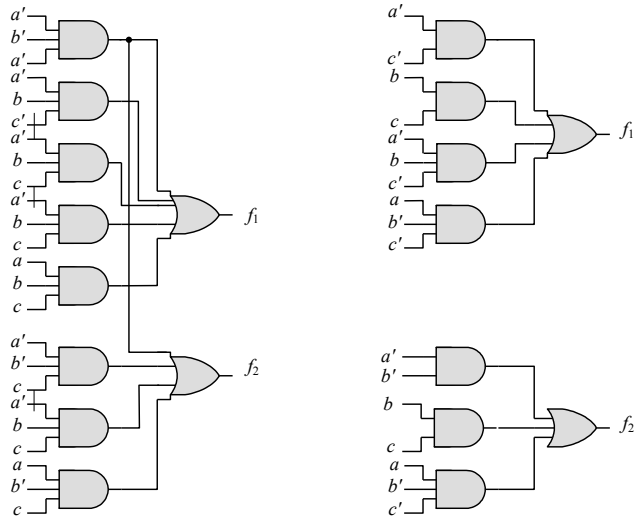
2.26

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

Gate		NOR (Positive logic)		NAND (Negative logic)	
x	y	z	z	x	y
L	L	H	1	1	0
L	H	L	0	1	1
H	L	L	0	0	1
H	H	L	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				
			$-b'c--f$	$-b'-d-f$	$-b'--ef$	
011000 = 24	010100 = 20	010010 = 18	001001 = 9	001001 = 9	000011 = 3	
011001 = 25	010101 = 21	010011 = 19	001011 = 11	001011 = 11	000111 = 7	
011010 = 26	010110 = 22	010110 = 22	001101 = 13	001101 = 13	001011 = 11	
011011 = 27	010111 = 23	010111 = 23	001111 = 15	001111 = 15	001111 = 15	
011100 = 28	011100 = 28	011010 = 26	101001 = 41	101001 = 41	100011 = 35	
011101 = 29	011101 = 29	011001 = 27	101011 = 43	101011 = 43	100111 = 39	
011110 = 30	011110 = 30	011110 = 30	101101 = 45	101101 = 45	101011 = 51	
011111 = 31	011111 = 31	011111 = 31	101111 = 47	101111 = 47	101111 = 55	

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

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

<i>ab cdef</i>	$y_1 y_2$	<i>ab cdef</i>	$y_1 y_2$	<i>ab cdef</i>	$y_1 y_2$	<i>ab cdef</i>	$y_1 y_2$
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