TESTABILITY MEASURES

What are Testability measures
A fault is testable if there exists a well specified procedure to detect it & is implementable at reasonable cost.
Any ckt is testable w.r.t fault list when every fault in the list is testable.
& Testability measure is measure of diff of making a ckt testable based on 2 parameters.

Observability
(how diff it is to measure off at)

Controllability
(how diff it is to set logic at)

SCOAP (Sandia Controllability/Observability Analysis Program) is analyzing the ckt w.r.t testability measures & rank the faults by difficulty in testing.

others → COMET, VICTOR etc

→ Static analysis

→ values of controllability vary b/w $1-\infty$ (easy (difficult))

" " observability " " $0-\infty$ (completely observable)

. higher no ⇒ more difficult to control / observe

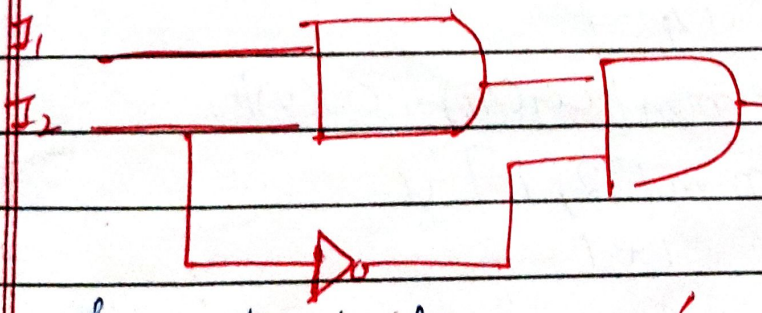
MEASURES

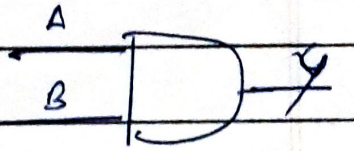
Combinational	Sequential
CC0 → difficulty in setting to 0	SC0
CC1 → " " " " to 1	SC1
CO → " " observing	SO

stuck at 0/1

PROCEDURE

1) Calculate observability & controllability separately.
2) Set initial value to ∞
3) for controllability start from PI.

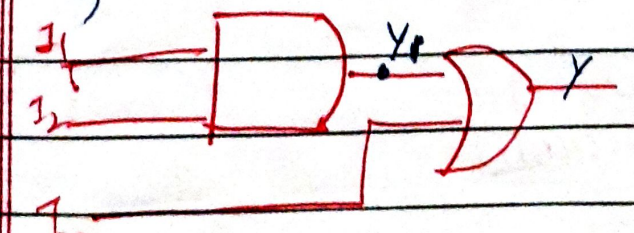




From I/Ps to O/P

$CC1(Y) = \sum_{i=1}^{n} CC(i) + 1$

if all I/Ps smaller



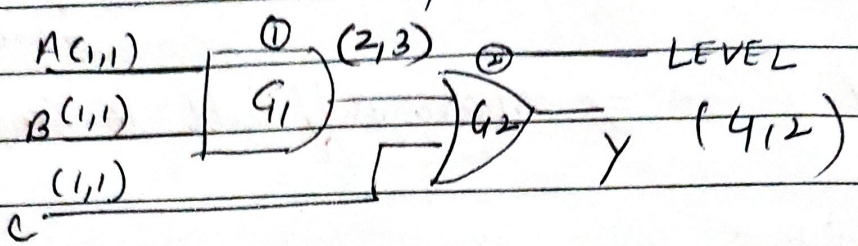
$CC0(Y) = \min(CC0(A), CC0(B)) + 1$

if one I/P determines

3. $CC1(Y) =$

All PI set = 1

Determine level, PI level 0
format of PI same level as PI



(CC0, CC1) pair at each I/P.

Level ① G1

$CC0(G1) = \min[CC0(A), CC0(B)] + 1$

$= 1 + 1 = 2$

$CC1(G1) = CC1(A) + CC1(B) + 1$

$= 3$

Level ②

$CC0(G2) = CC0(G1) + CC0(C) + 1$

$= 2 + 1 + 1$

$= 4$

$CC1(G2) = \min[CC1(G1) + CC1(C)] + 1$

$= \min[2, 1] + 1$

$= 1 + 1$

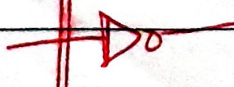
$= 2.$

$CC0(Y) = \min[CC0(A), CC0(B)] + 1$

$CC1 = CC1(A) + CC1(B) + 1$

$CC0(Y) = CC0(A) + CC0(B) + 1$

$CC1(Y) = \min[CC1(A), CC1(B)] + 1$



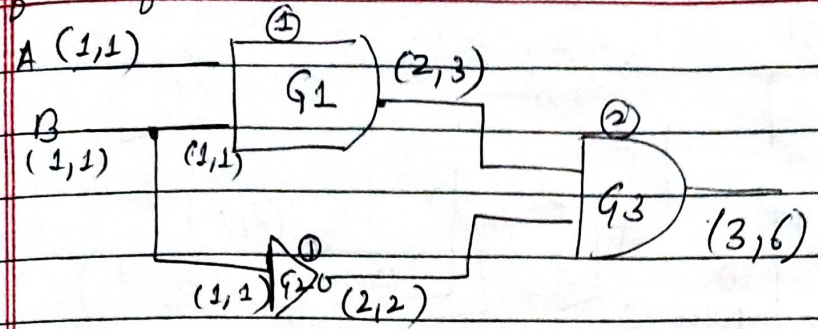
$CC0(Y) = CC1(A) + 1$

$CC1(Y) = CC0(A) + 1$

for fanout stem:

$CCO(C_1) = CCO(C_2) = \ldots = CC(a)$

if a is fanout stem & $c_1, c_2 \ldots$ are branches.



Level ① Controlling I/P

$CC0(G1) = \min[CC0(A), CC0(B)] + 1$

$= (1+1)$

Level ②

$CC1(G2) = CC1(A) + CC1(B) + 1$

$= 1+1+1 = 3$

Level ③

$CC0(G2) = CC1(B) + 1$

$= 1+1 = 2$

$CC1(G2) = CC0(B) + 1$

$= 2$

G3

$CC0(G3) = \min[CC0(G1), CC0(G2)] + 1$

$= 2+1 = 3$

$CC1(G3) = CC1(CG1) + CC1(G2) + 1$

$= 2+3+1 = 6$

$CC0(Y) = \min[CC0(A) + CC0(B), CC1(A) + CC1(B)] + 1$

$CC1(Y) = \min[(CC1(A) + CC0(B)), CC0(A) + CC1(B)] + 1$

$CC0(Y) = CC1(A) + CC1(B) + 1$

$CC1(Y) = \min[CC0(A), CC0(B)] + 1$

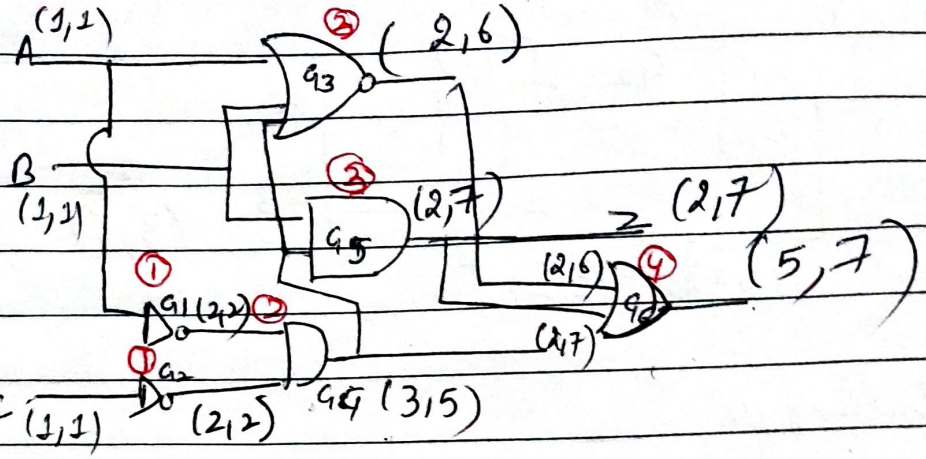
$CC0(Y) = \min(CC1(A), CC1(B)] + 1$

$CC1(Y) = CC0(A) + CC0(B) + 1$

$CC0(Y) = \min[CC1(A) + CC0(B), CC0(A) + CC1(B)] + 1$

$CC1(Y) = \min[CC0(A) + CC0(B), CC1(A) + CC1(B)] + 1$

fanout rule : each fanin
1/f.



Level 1

$CCO(G1) = CCO(A) + 1$
$= 1 + 1 = 2$

$CC1(G1) = CC1(A) + 1$
$= 1 + 1 = 2$

$CCO(G2) = CCO(C) + 1$
$= 1 + 1 = 2$

$CC1(G2) = CC1(C) + 1$
$= 1 + 1$

Level ②

$CCO(G4) = \min[CCO(G2) + CCO(G1)] + 1$

$= 2 + 1 = 3$

$CC1(G4) = CC1(G2) + CC1(G1) + 1$
$= 5$

Level ③ (NOR)

$CCO(G3) = \min[CC1(A) + CC1(B) + CC1(G4)] + 1$
$= (1 + 1 + 5) + 1 = (1) + 1$
$= 2$ ✓

$CC1(G3) = [CCO(A) + CCO(B) + CC1(G4)] + 1$
$= \min(1 + 1 + 3) + 1$
$= 6$

$CCO(G5) = \min[CCO(B), CCO(G4)] + 1$
$= \min[1, 3] + 1 = 2$

$CC1(G5) = CC1(B) + CC1(G4) + 1$
$= 1 + 5 + 1 = 7$

$CC0(Q6) = CC0(Q3) + CC0(Q5) + 1$

$= 2 + 2 + 1 = 5$

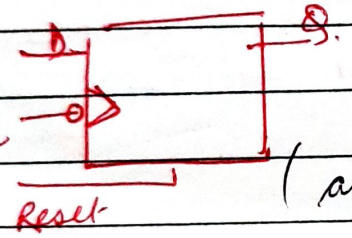
$CC1(Q6) = \min[CC1(Q3), CC1(Q5)] + 1$

$= \min(6, 7) + 1 = 6 + 1 = 7$

For Sequential ckts:

∴ major diff for seq. ckts,
+1 in CC measures is added only when signals propagate fwm I/p to o/p (Q/$\bar{Q}$) or backward fwm D, C

- feedback must be taken into account in fb. loop.



(assumes syn reset)

SCO
SC1 measure no of times F/Fs be clocked to ctrl a signal.

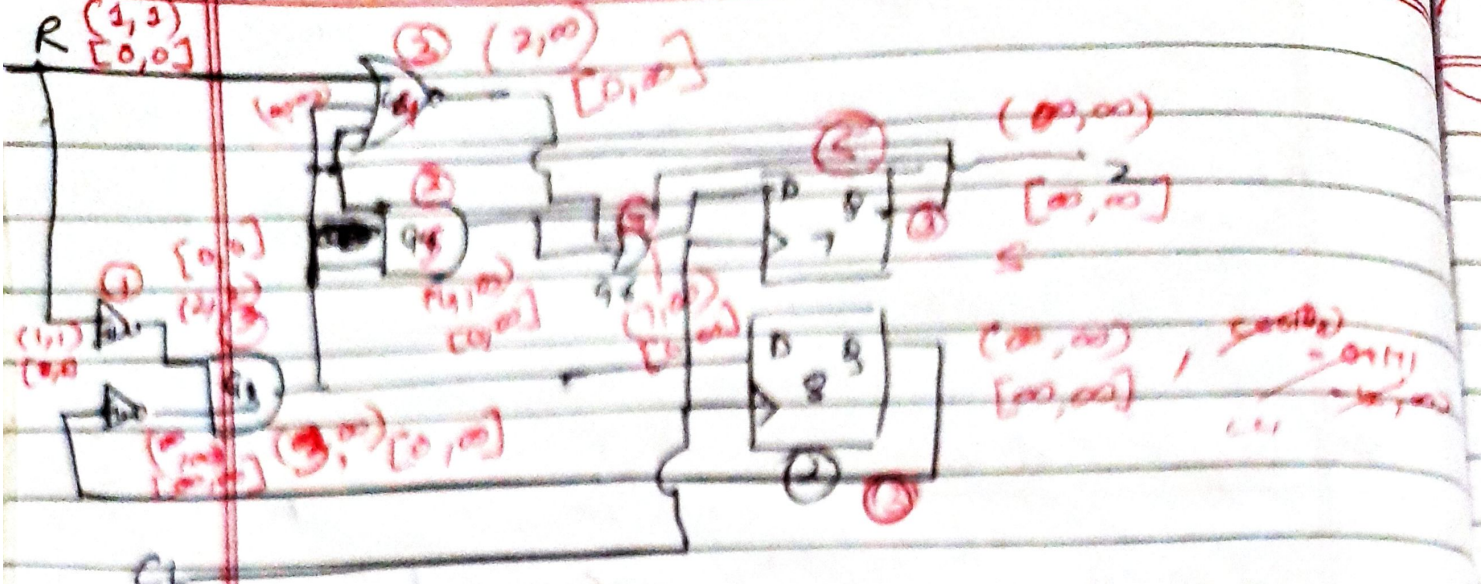
signals reqd. to make Q=1

eg. $CC1(Q) = CC1(D) + CC1(C) + CC0(C) + CC0(reset)$

$SC1(Q) = SC1(D) + SC1(C) + SC0(C) + SC0(reset) + 1$

$CC0(Q) = \min[(CC0(D) + CC1(C) + CC0(C), CC1(reset) + CC1(C) + CC0(C)]$

$SC0(Q) = \min[SC1(reset) + SC1(C) + SC0(C), SC0(D) + SC1(C) + SC0(C)] + 1$



CC0, CC1 for PIs = 1] for all other nodes
SC0, SC1 " = 0 ↓
CC0 = CC1 = ∞
SC0 = SC1 = ∞

I-1

CC0(G1) = ~~min [CC0(?), CC0(?)]~~, CC1(R) + 1 = 1+1 = 2
CC0(G2)

CC1(G1) = CC0(R) + 1 = 2
SC0(G1) = [0,0]

CC0(G2) = CC1(D8) + 1 = ∞ + 1 = ∞ , SC0(G2) = ∞
CC1(G2) = CC0(D8) + 1 = ∞ SC1(G2) = ∞

Level 0

CC0(G3) = min [CC0(G1), CC0(G2)] + 1
= min [2, ∞] + 1 = 2 + 1 = 3

CC1(G3) = CC1(G1) + CC1(G2) + 1
= 2 + ∞ + 1 = ∞

SC0(G3) = min [SC0(G1), SC0(G2)] = 0
[0, ∞] = 0

SC1(G3) = SC0(G1) + SC1(G2)
= 0 + ∞ = ∞

Level 3

$CCO(G4) = \min[CC0(R) + CC0(G3), CC1(D_7)] + 1$

$= \min[1, 3, \infty] + 1 = 1 + 1 = 2$

$CC1(G4) = CC0(R) + CC0(G3) + CC1(D_7) + 1$

$= 1 + \infty + \infty + 1 = \infty$

$SCO(G4) = \min[SC1(R), SC1(G3), SC1(D_7)]$

$= \min[0, 0, \infty] = 0$

$SC1(G4) = SCO(R) + SCO(G3) + SC1(D_7)$

$= 0 + 0 + \infty = \infty$

$CCO(G5) = \min[CC0(G3), CC0(D_7)] + 1$

$= \min[3, \infty] + 1 = 3 + 1 = 4$

$CC1(G5) = CC1(G3) + CC1(D_7) + 1$

$= \infty + \infty + 1 = \infty$

$SCO(G5) = \min[SCO(G3), SCO(D_7)]$

$= \min[0, \infty] = 0$

$SC1(G5) = SC1(G3) + SC1(D_7) + 1$

$= \infty + \infty + 1 = \infty$

Level 4

G6

$CCO(G6) = CCO(G4) + CCO(G5) + 1$

$= 2 + 4 + 1 = 7$

$CC1(G6) = \min[CC1(G4), CC1(G5)] + 1$

$= \min[\infty, \infty] + 1 = \infty + 1 = \infty$

$SCO(G6) = SCO(G4) + SCO(G5) = SCO(D)$

$= 0 + 0 = 0$

$SC1(G6) = \min[SC1(G4), SC1(G5)] = SC1(D)$

$= \min[\infty, \infty] = \infty$

Level 5

② For first iteration — same as previous
no change in F/F controllability

$SCO(7) = SCO(D) + SCO(C) + SCI(C) + 1$

$= 0 + 0 + 0 + 1 = 1$

After 1st deviation

$SCI(7) = SCI(D) + SCI(C) + SCO(C) + 1$

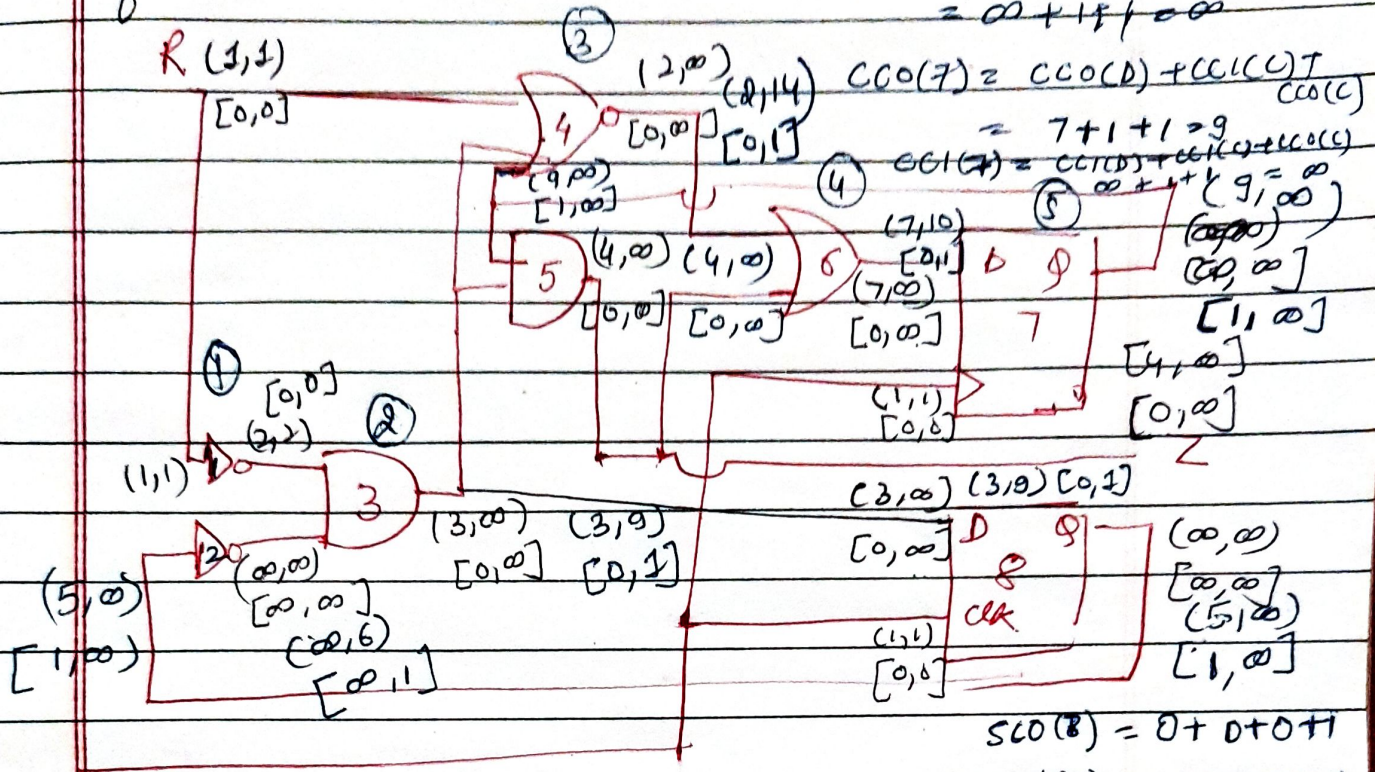
$= \infty + 1 + 1 + \infty$

$CCO(7) = CCO(D) + CCI(C)$ $\overline{CCO(C)}$

$= 7 + 1 + 1 = 9$

$CCI(7) = CCI(D) + CCI(C) + CCO(C)$

$\infty + 1 + 1 = \infty$ $(9, \infty)$



$SCO(8) = 0 + 0 + 0 + 1$

$SCI(8) = \infty + 0 + 0 + 1$

$CCO(8) = 3 + 1 + 1 = 5 = \infty$

$CCI(8) = \infty + 1 + 1 = \infty$

clk = 1

① $CCO(1) = CCI(R) + 1 = 2$

$CCI(1) = CCO(R) + 1 = 2$

$SCO(1) = 0, \; SCI(1) = 0$

$CCO(Q2) = CCI(1|P) + 1 = \infty$

$CCI(Q2) = CCO(1|P) + 1 = 6$ (5)

$SCI(Q2) = SCO(1|P) = 1$

$SCO(Q2) = SCI(1|P) = \infty$

② $CCO(3) = \min[CCO(Q1), CCO(Q2)] + 1$

$= \min[2, \infty] + 1 = 3$

$CCI(3) = CCI(Q1) + CCI(Q2) + 1$

$= 2 + 6 + 1 = 9$

$SCO(3) = \min[0, \infty] = 0$

$SCI(3) = SCI(1) + SCI(2)$

$= 0 + 1 = 1$

③ $CCO(Q4) = \min(CCI(R) + CCI(7) + CCI(Q3)) + 1$

$= (1 + \infty + 9) + 1 = 2$

$CCI(Q4) = CCO(R) + CCO(7) + CCO(Q3) + 1$

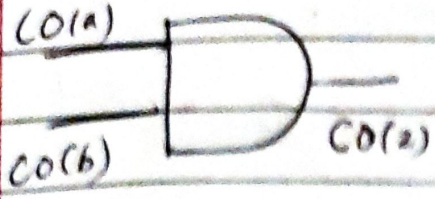
$= 1 + 9 + 3 + 1 = 14$

$SCO(Q4) = \min[SCI(R), SCI(7), SCI(Q3)] = [0]$

$SCI(Q4) = SCO(R) + SCO(7) + SCO(Q3)$

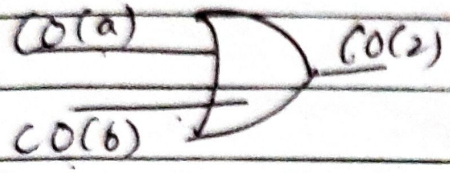
$= 0 + 1 + 0 = 1$

OBSERVABILITY:



$CO(a) = CO(z) + CC1(b) + 1 \quad = 0 + 1 + 1 = 2$

$CO(b) = CO(z) + CC1(a) + 1 \quad = 0 + 1 + 1 = 2$

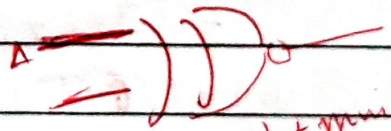


$CO(a) = CO(z) + CC0(b) + 1$

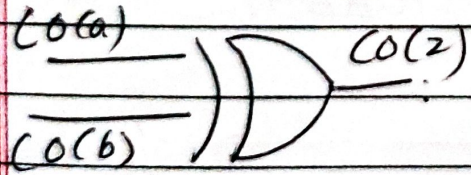
$CO(b) = CO(z) + CC0(a) + 1$

$CO(a) = CO(z) + 1$

$\bar{A}\bar{B} + A\bar{B}$



$CO_A = CO(z) + \min[CC1(B), CC0(B)] + 1$



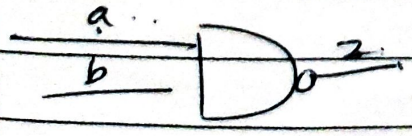
$A\bar{B} + \bar{A}B$

$CC0(b) \quad CC1(b)$

$CO(a) = \cancel{CO(z) + \min}\left[\begin{matrix} CC0(b) + CC1(a) + 1, \\ \cancel{CC1(b) + CC0(a) + 1} \end{matrix}\right]$

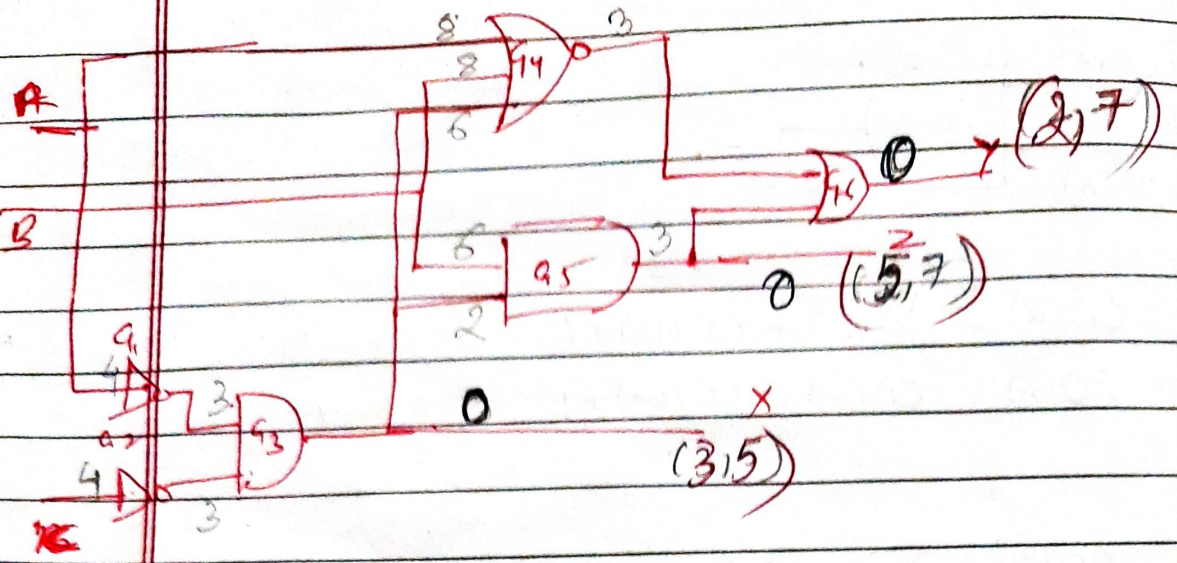
$CO(a) = CO(z) + \min[CC0(b), CC0(b)] + 1$

$CO(b) = CO(z) + \min[CC0(a), CC1(a)] + 1$



$CO(z) = CO(a) + CC1(b) + 1$

$CO(b) = CO(z) + CC1(a) + 1$



G6

$CO(I4) = CO(Y) + CCO(G5) + 1$

$= 0 + 2 + 1 = 3$

$CO(5) = CO(X) + CCO(G4) + 1$

$= 0 + 2 + 1 = 3$

G4

$CO(A) = CO(G4) + CCO(B) + CCO(3) + 1$

$= 3 + 1 + 3 + 1 = 8$

$CO(B) = CCO(A) + CO(G4) + CCO(3) + 1$

$= 1 + 3 + 3 + 1 = 8$

$CO(G3) = CO(G4) + CCO(A) + CCO(B) + 1$

$= 3 + 1 + 1 + 1 = 6$

G5

$CO(B) = CO(5) + 1 + CC1(G3)$

$= 3 + 0 + 2 = 6$

$CO(G3) = CO(5) + CC1(B) + 1$

$= 0 + 1 + 1 = 2$

→ O/P selection I/P at G6 (CO 3)

O/P = 2 (CO 0)

$CO(G5) = \min(0, 3)$

$= 0$

G3

$CO(G3)$ $\min(6, 2, 0) = 0$

$CO(G1) = CO(G3) + CC(G2) + 1$

$= 0 + 2 + 1 = 3$

$CO(G2) = CO(G3) + CC1(G1) + 1$

$= 0 + 2 + 1 = 3$

G1 $CO(R) = CO(G1) + 1$

$= 3 + 1 = 4$

G2 $CO(R) = CO(G3) + 1$

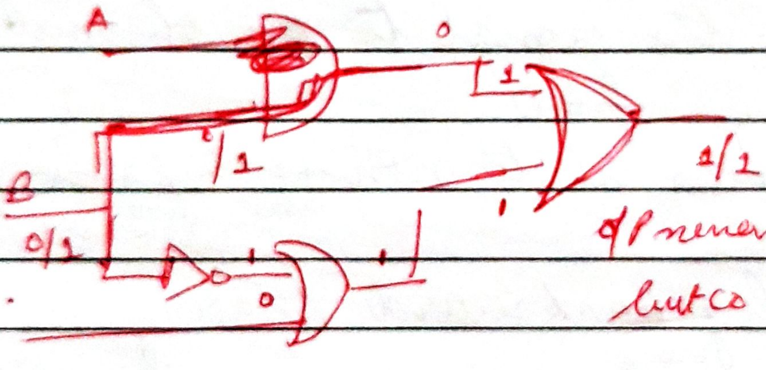
$= 4$

$CO(A) = \min(8, 4) = 4$

$CO(B) = \min(8, 6) = 6$

$CO(C) = 4$

drawback of SCOAP

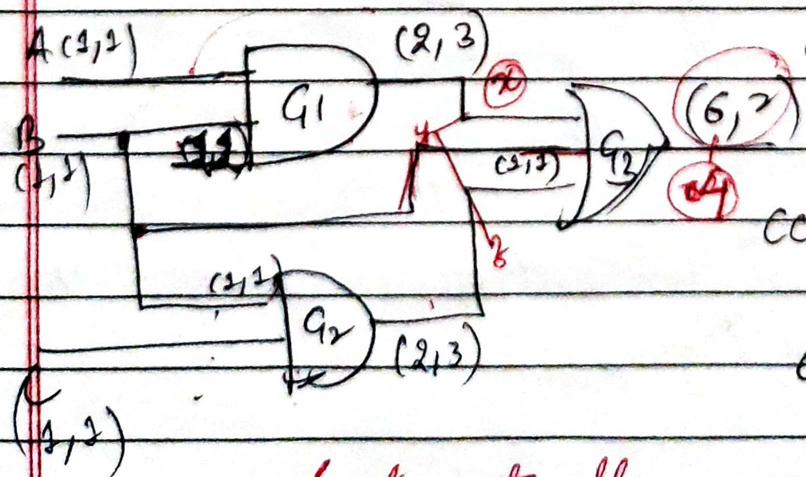


o/p never '0'

but co will not be ∞

= inadequate for reconvergent fanouts.

error in reconvergent fanout -



$CC0(G1) = \min[CC0(A), CC0(B)] + 1$

$CC1(G1) = 1 + 1 = 2$

$= (1+1) + 1$

$CC0(G3) = (2 + 1 + 2) + 1$

$CC1(G3) = \min(3, 1, 3) + 1$

$= 1 + 1$

but actually $CC0_{G3}$ = if $y = 0 \Rightarrow x = 0$, $CC_0 = 1$, $z = 0$, $CC_{0x} = 1$

Similarly $CC1_{G3}$ (4)