به نام خدا
دانشگاه تهران
پردیس دانشکده‌های فنی
دانشکده مهندسی برق و کامپیوتر

درس الکترونیک دیجیتال

نیمسال اول (02-01)

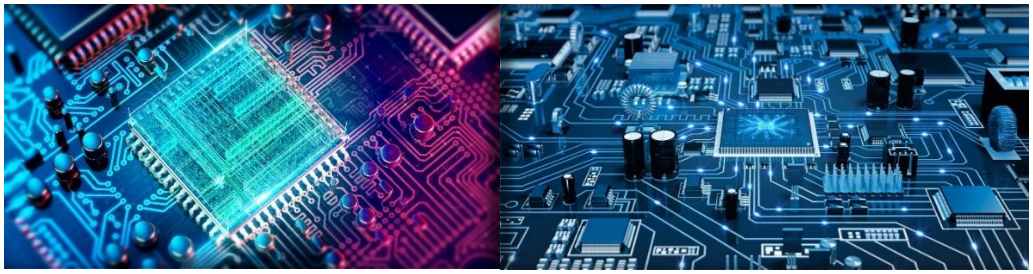
استاد درس: دکتر شقایق وحدت

تمرین کامپیوتری اول :

شبیه سازی مدار تمام جمع کننده (Full-Adder)

محمدمهدی عبدالحسینی

810 198 434

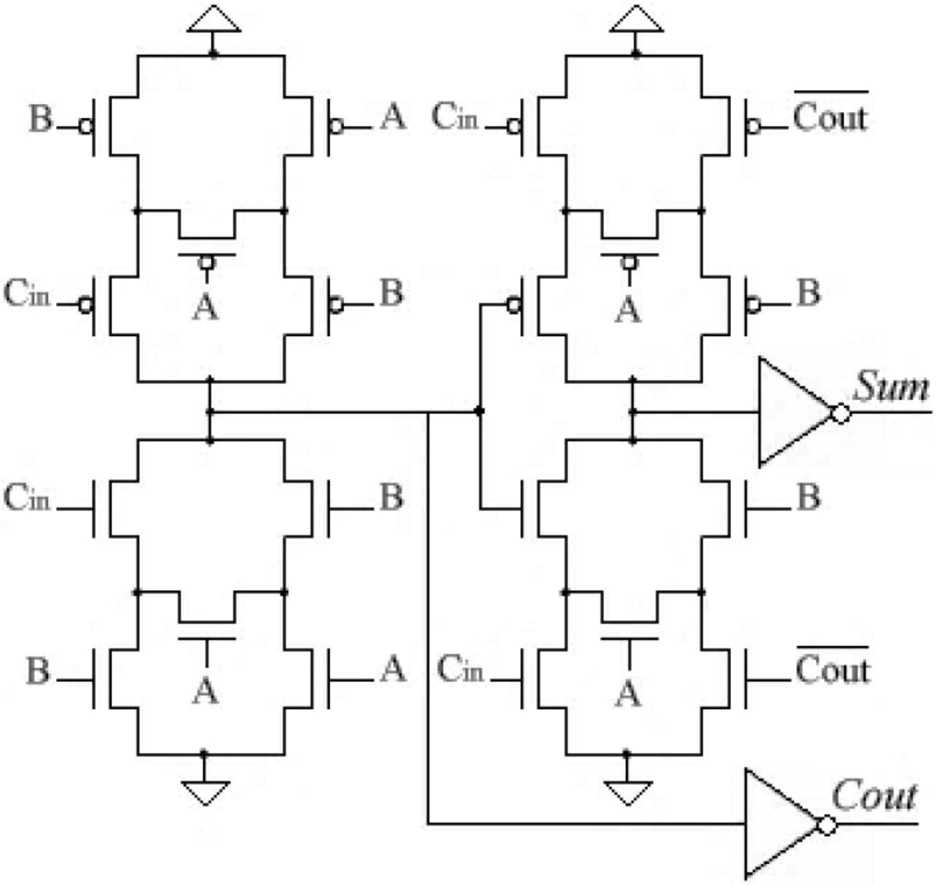


Digital Electronic Circuits

فهرست مطالب

الف) شبیه‌سازی مدار تمام جمع کننده :

در این بخش قصد داریم ساختار مدار تمام جمع کننده CMOS در شکل 1 را در HSPICE شبیه‌سازی کنیم.



شکل 1) مدار تمام جمع کننده CMOS

قطعه کد زده شده در این بخش بصورت زیر میباشد.

```
*nnnnnnnnnnnnnnnnnnnnnnnnnnnnnnnn*
*        ==> LIBRARY              *
*uuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuu*
.lib    'mm018.l' tt

*//\/\/\//\/\/\/\/\//\/\/\\/\/\///\\/\/\/\//\\//\/\/\/\//\/\/\/\\\//\/\//\/\\/\/\\/\\/\\/\\/\/\\/\\/\
*nnnnnnnnnnnnnnnnnnnnnnnnnnnnnnnn*
*        ==> PARAMETERS           *
*uuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuu*
.param  Wmin = 220n
+       Lmin = 180n
+       Wnmos = '2*Wmin'
+       Wpmos = '6*Wmin'
+       vdd = 1.8
+       gnd = 0
+       t = 10p

*//\/\/\//\/\/\/\/\//\/\/\\/\/\///\\/\/\/\//\\//\/\/\/\//\/\/\/\\\//\/\//\/\\/\/\\/\\/\\/\\/\/\\/\\/\
*nnnnnnnnnnnnnnnnnnnnnnnnnnnnnnnn*
*        ==> INVERTER             *
*uuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuu*
.SUBCKT         Inverter        in      out
vdd     vdd     gnd     vdd
Mp      out     in      vdd     vdd     pmos    w = Wnmos       l = Lmin
```

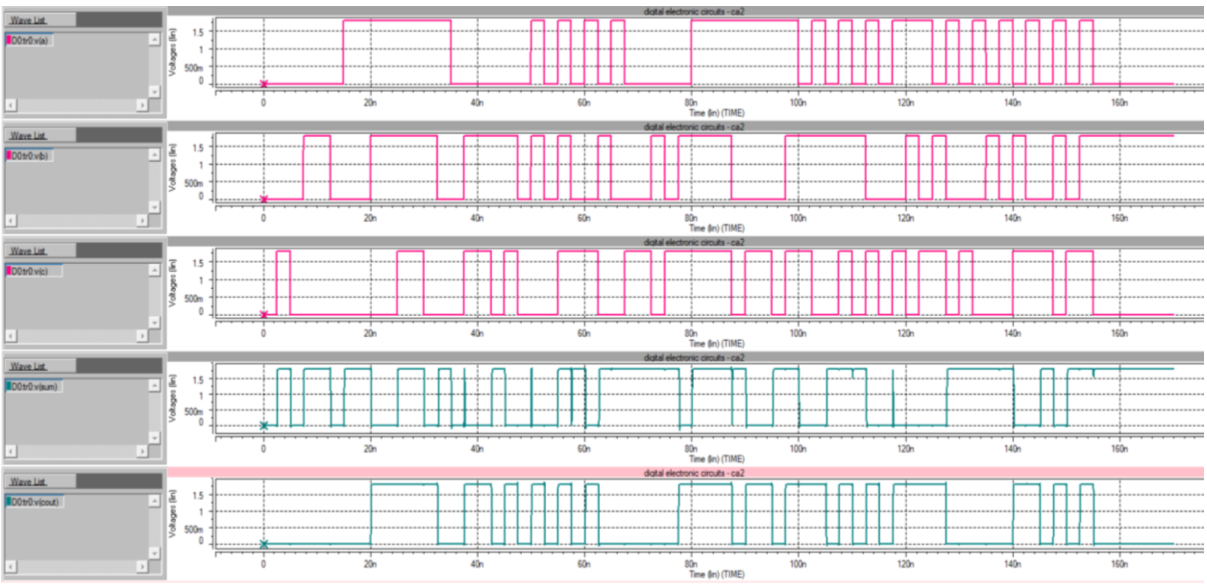
```
Mn      out     in      gnd     gnd     nmos    w = Wmin        l = Lmin
.ENDS           Inverter

*//\/\/\/\//\/\/\/\/\//\/\/\/\///\/\/\/\//\/\/\/\//\/\/\/\/\\\//\/\//\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\
*nnnnnnnnnnnnnnnnnnnnnnnnnnnnnnnnn*
*       ==> COMPONENTS          *
*uuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuu*
vdd     vdd     gnd     dc      1.8v
Mp1     n1      B       vdd     vdd     pmos    w = Wpmos       l = Lmin
Mp2     n2      A       vdd     vdd     pmos    w = Wpmos       l = Lmin
Mp3     n1      A       n2      vdd     pmos    w = Wpmos       l = Lmin
Mp4     n3      C       n1      vdd     pmos    w = Wpmos       l = Lmin
Mp5     n3      B       n2      vdd     pmos    w = Wpmos       l = Lmin
Mn6     n3      C       n4      gnd     nmos    w = Wnmos       l = Lmin
Mn7     n3      B       n5      gnd     nmos    w = Wnmos       l = Lmin
Mn8     n4      A       n5      gnd     nmos    w = Wnmos       l = Lmin
Mn9     n4      B       gnd     gnd     nmos    w = Wnmos       l = Lmin
Mn10    n5      A       gnd     gnd     nmos    w = Wnmos       l = Lmin
Mp11    n6      C       vdd     vdd     pmos    w = Wpmos       l = Lmin
Mp12    n7      n3      vdd     vdd     pmos    w = Wpmos       l = Lmin
Mp13    n6      A       n7      vdd     pmos    w = Wpmos       l = Lmin
Mp14    n8      n3      n6      vdd     pmos    w = Wpmos       l = Lmin
Mp15    n8      B       n7      vdd     pmos    w = Wpmos       l = Lmin
Mn16    n8      n3      n9      gnd     nmos    w = Wnmos       l = Lmin
Mn17    n8      B       n10     gnd     nmos    w = Wnmos       l = Lmin
Mn18    n9      A       n10     gnd     nmos    w = Wnmos       l = Lmin
Mn19    n9      C       gnd     gnd     nmos    w = Wnmos       l = Lmin
Mn20    n10     n3      gnd     gnd     nmos    w = Wnmos       l = Lmin

X1      n3      Cout    Inverter
X2      n8      SUM     Inverter
```

در ادامه میخواهیم تمامی 64 حالت ممکن برای ورودی را شبیه سازی کنیم. برای اینکار مقادیر ورودی را بصورت زیر اعمال میکنیم.

```
*//\/\/\/\//\/\/\/\/\//\/\/\/\///\/\/\/\//\/\/\/\//\/\/\/\/\\\//\/\//\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\
*nnnnnnnnnnnnnnnnnnnnnnnnnnnnnnnnn*
*       ==> INPUTS              *
*uuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuu*
Vina A 0 PWL 0n 0, '15n-t' 0, 15n vdd, '35n-t' vdd, 35n 0, '50n-t' 0, 50n vdd, '52.5n-t' vdd, 52.5n 0,
'55n-t' 0, 55n vdd,
+ '57.5n-t' vdd, 57.5n 0, '60n-t' 0, 60n vdd, '62.5n-t' vdd, 62.5n 0, '65n-t' 0, 65n vdd, '67.5n-t' vdd,
67.5n 0,
+ '80n-t' 0, 80n vdd, '100n-t' vdd, 100n 0, '102.5n-t' 0, 102.5n vdd, '105n-t' vdd, 105n 0, '107.5n-t'
0, 107.5n vdd,
+ '110n-t' vdd, 110n 0, '112.5n-t' 0, 112.5n vdd, '115n-t' vdd, 115n 0, '117.5n-t' 0, 117.5n vdd, '125n-
t' vdd, 125n 0,
+ '127.5n-t' 0, 127.5n vdd, '130n-t' vdd, 130n 0, '132.5n-t' 0, 132.5n vdd, '135n-t' vdd, 135n 0,
'137.5n-t' 0, 137.5n vdd,
+ '140n-t' vdd, 140n 0, '142.5n-t' 0, 142.5n vdd, '145n-t' vdd, 145n 0, '147.5n-t' 0, 147.5n vdd, '150n-
t' vdd, 150n 0,
+ '152.5n-t' 0, 152.5n vdd, '155n-t' vdd, 155n 0, 162.5n 0



Vinb B 0 PWL 0n 0, '7.5n-t' 0, 7.5n vdd, '12.5n-t' vdd, 12.5n 0, '20n-t' 0, 20n vdd, '32.5n-t' vdd,
32.5n 0, '37.5n-t' 0, 37.5n vdd,
+ '47.5n-t' vdd, 47.5n 0, '50n-t' 0, 50n vdd, '52.5n-t' vdd, 52.5n 0, '55n-t' 0, 55n vdd, '57.5n-t' vdd,
57.5n 0,
+ '62.5n-t' 0, 62.5n vdd, '65n-t' vdd, 65n 0, '72.5n-t' 0, 72.5n vdd, '75n-t' vdd, 75n 0, '77.5n-t' 0,
77.5n vdd,
+ '87.5n-t' vdd, 87.5n 0, '97.5n-t' 0, 97.5n vdd, '112.5n-t' vdd, 112.5n 0, '120n-t' 0, 120n vdd,
'122.5n-t' vdd, 122.5n 0,
+ '125n-t' 0, 125n vdd, '127.5n-t' vdd, 127.5n 0, '135n-t' 0, 135n vdd, '137.5n-t' vdd, 137.5n 0, '140n-
t' 0, 140n vdd,
+ '142.5n-t' vdd, 142.5n 0, '147.5n-t' 0, 147.5n vdd, '150n-t' vdd, 150n 0, '152.5n-t' 0, 152.5n vdd,
162.5n vdd
Vinc C 0 PWL 0n 0, '2.5n-t' 0, 2.5n vdd, '5n-t' vdd, 5n 0, '25n-t' 0, 25n vdd, '30n-t' vdd, 30n 0,
'37.5n-t' 0, 37.5n vdd,
```

```
+ '42.5n-t' vdd, 42.5n 0, '45n-t' 0, 45n vdd, '47.5n-t' vdd, 47.5n 0, '55n-t' 0, 55n vdd, '62.5n-t' vdd,
62.5n 0,
+ '67.5n-t' 0, 67.5n vdd, '72.5n-t' vdd, 72.5n 0, '75n-t' 0, 75n vdd, '87.5n-t' vdd, 87.5n 0, '90n-t'
0, 90n vdd,
+ '95n-t' vdd, 95n 0, '97.5n-t' 0, 97.5n vdd, '102.5n-t' vdd, 102.5n 0, '107.5n-t' 0, 107.5n vdd, '110n-
t' vdd, 110n 0,
+ '112.5n-t' 0, 112.5n vdd, '115n-t' vdd, 115n 0, '117.5n-t' 0, 117.5n vdd, '120n-t' vdd, 120n 0,
'122.5n-t' 0, 122.5n vdd,
+ '127.5n-t' vdd, 127.5n 0, '130n-t' 0, 130n vdd, '132.5n-t' vdd, 132.5n 0, '140n-t' 0, 140n vdd,
'147.5n-t' vdd, 147.5n 0,
+ '150n-t' 0, 150n vdd, '155n-t' vdd, 155n 0, 157.5n 0


*//\/\/\//\/\/\/\/\//\/\/\\/\/\///\\/\/\//\\//\/\/\/\//\/\/\/\\//\/\//\/\\/\/\\/\\/\\/\\/\/\\/\\/\
*nnnnnnnnnnnnnnnnnnnnnnnnnnnnnnn*
*        ==> SIMULATIONS          *
*uuuuuuuuuuuuuuuuuuuuuuuuuuuuuuu*
.option post=2
.TRAN 10p 180n

*//\/\/\//\/\/\/\/\//\/\/\\/\/\///\\/\/\//\\//\/\/\/\//\/\/\/\\//\/\//\/\\/\/\\/\\/\\/\\/\/\\/\\/\
.end
```

شکل موج‌های رسم شده برای ورودی‌ها و خروجی‌ها به شکل زیر خواهد بود.



شکل 2) شبیه‌سازی 64 حالت ممکن برای یک Full-Adder

ب) محاسبه پارامترهای تأخیر، توان پویای متوسط و توان ایستا :

برای محاسبه تأخیر، زمان صعود و نشست سیگنال‌های خروجی را اندازه‌گیری میکنیم. با توجه به حالت‌های مختلف ورودی، ممکن است مقادیر متفاوت باشد. بنابراین بهتر است به ازای تمامی حالات این مقادیر را حساب کرده و سپس بیشترین مقدار آن را به عنوان زمان صعود و نشست در نظر بگیریم.

با توجه به ورودی‌های داده شده، قطعه کد زیر برای محاسبه زمان صعود و نشست سیگنال‌های خروجی نوشته شده است.

```
*//\/\/\/\//\/\/\/\/\//\/\/\\/\/\///\\/\/\//\\//\/\/\/\/\/\/\/\\\//\/\//\/\/\\/\/\\/\/\\/\/\/\\/\\/\
*nnnnnnnnnnnnnnnnnnnnnnnnnnnnnnnnn*
*       ==> MEASUREMENTS *
*uuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuu*
****************************** RISE Time (SUM) ******************************
*********************************************************************************
.MEASURE TRAN            t_rise_sum_1
+trig           V(SUM)          td = 2n         val = '0.1*vdd'         rise = 1
+targ           V(SUM)          td = 2n         val = '0.9*vdd'         rise = 1
.MEASURE TRAN            t_rise_sum_2
+trig           V(SUM)          td = 7n         val = '0.1*vdd'         rise = 1
+targ           V(SUM)          td = 7n         val = '0.9*vdd'         rise = 1
.MEASURE TRAN            t_rise_sum_3
+trig           V(SUM)          td = 13n        val = '0.1*vdd'         rise = 1
+targ           V(SUM)          td = 13n        val = '0.9*vdd'         rise = 1
.MEASURE TRAN            t_rise_sum_4
+trig           V(SUM)          td = 24n        val = '0.1*vdd'         rise = 1
+targ           V(SUM)          td = 24n        val = '0.9*vdd'         rise = 1
.MEASURE TRAN            t_rise_sum_5
+trig           V(SUM)          td = 32n        val = '0.1*vdd'         rise = 1
+targ           V(SUM)          td = 32n        val = '0.9*vdd'         rise = 1
.MEASURE TRAN            t_rise_sum_6
+trig           V(SUM)          td = 42n        val = '0.1*vdd'         rise = 1
+targ           V(SUM)          td = 42n        val = '0.9*vdd'         rise = 1
.MEASURE TRAN            t_rise_sum_7
+trig           V(SUM)          td = 54n        val = '0.1*vdd'         rise = 1
+targ           V(SUM)          td = 54n        val = '0.9*vdd'         rise = 1
.MEASURE TRAN            t_rise_sum_8
+trig           V(SUM)          td = 57n        val = '0.1*vdd'         rise = 1
+targ           V(SUM)          td = 57n        val = '0.9*vdd'         rise = 1
.MEASURE TRAN            t_rise_sum_9
+trig           V(SUM)          td = 62n        val = '0.1*vdd'         rise = 1
+targ           V(SUM)          td = 62n        val = '0.9*vdd'         rise = 1
.MEASURE TRAN            t_rise_sum_10
+trig           V(SUM)          td = 78n        val = '0.1*vdd'         rise = 1
+targ           V(SUM)          td = 78n        val = '0.9*vdd'         rise = 1
.MEASURE TRAN            t_rise_sum_11
+trig           V(SUM)          td = 94n        val = '0.1*vdd'         rise = 1
+targ           V(SUM)          td = 94n        val = '0.9*vdd'         rise = 1
.MEASURE TRAN            t_rise_sum_12
+trig           V(SUM)          td = 104n       val = '0.1*vdd'         rise = 1
+targ           V(SUM)          td = 104n       val = '0.9*vdd'         rise = 1
.MEASURE TRAN            t_rise_sum_13
+trig           V(SUM)          td = 126n       val = '0.1*vdd'         rise = 1
+targ           V(SUM)          td = 126n       val = '0.9*vdd'         rise = 1
.MEASURE TRAN            t_rise_sum_14
+trig           V(SUM)          td = 144n       val = '0.1*vdd'         rise = 1
+targ           V(SUM)          td = 144n       val = '0.9*vdd'         rise = 1
.MEASURE TRAN            t_rise_sum_15
+trig           V(SUM)          td = 149n       val = '0.1*vdd'         rise = 1
+targ           V(SUM)          td = 149n       val = '0.9*vdd'         rise = 1

****************************** FALL Time (SUM) ******************************
*********************************************************************************
.MEASURE TRAN            t_fall_sum_1
+trig           V(SUM)          td = 4n         val = '0.9*vdd'         fall = 1
+targ           V(SUM)          td = 4n         val = '0.1*vdd'         fall = 1
.MEASURE TRAN            t_fall_sum_2
+trig           V(SUM)          td = 12n        val = '0.9*vdd'         fall = 1
+targ           V(SUM)          td = 12n        val = '0.1*vdd'         fall = 1
.MEASURE TRAN            t_fall_sum_3
+trig           V(SUM)          td = 19n        val = '0.9*vdd'         fall = 1
+targ           V(SUM)          td = 19n        val = '0.1*vdd'         fall = 1
.MEASURE TRAN            t_fall_sum_4
+trig           V(SUM)          td = 29n        val = '0.9*vdd'         fall = 1
+targ           V(SUM)          td = 29n        val = '0.1*vdd'         fall = 1
.MEASURE TRAN            t_fall_sum_5
```

```
+trig           V(SUM)          td = 34n        val = '0.9*vdd'         fall = 1
+targ           V(SUM)          td = 34n        val = '0.1*vdd'         fall = 1
.MEASURE TRAN           t_fall_sum_6
+trig           V(SUM)          td = 44n        val = '0.9*vdd'         fall = 1
+targ           V(SUM)          td = 44n        val = '0.1*vdd'         fall = 1
.MEASURE TRAN           t_fall_sum_7
+trig           V(SUM)          td = 57n        val = '0.9*vdd'         fall = 1
+targ           V(SUM)          td = 57n        val = '0.1*vdd'         fall = 1
.MEASURE TRAN           t_fall_sum_8
+trig           V(SUM)          td = 59n        val = '0.9*vdd'         fall = 1
+targ           V(SUM)          td = 59n        val = '0.1*vdd'         fall = 1
.MEASURE TRAN           t_fall_sum_9
+trig           V(SUM)          td = 75n        val = '0.9*vdd'         fall = 1
+targ           V(SUM)          td = 75n        val = '0.1*vdd'         fall = 1
.MEASURE TRAN           t_fall_sum_10
+trig           V(SUM)          td = 89n        val = '0.9*vdd'         fall = 1
+targ           V(SUM)          td = 89n        val = '0.1*vdd'         fall = 1
.MEASURE TRAN           t_fall_sum_11
+trig           V(SUM)          td = 99n        val = '0.9*vdd'         fall = 1
+targ           V(SUM)          td = 99n        val = '0.1*vdd'         fall = 1
.MEASURE TRAN           t_fall_sum_12
+trig           V(SUM)          td = 112n       val = '0.9*vdd'         fall = 1
+targ           V(SUM)          td = 112n       val = '0.1*vdd'         fall = 1
.MEASURE TRAN           t_fall_sum_13
+trig           V(SUM)          td = 139n       val = '0.9*vdd'         fall = 1
+targ           V(SUM)          td = 139n       val = '0.1*vdd'         fall = 1
.MEASURE TRAN           t_fall_sum_14
+trig           V(SUM)          td = 146n       val = '0.9*vdd'         fall = 1
+targ           V(SUM)          td = 146n       val = '0.1*vdd'         fall = 1

*=============================================================================================================
****************************** RISE Time (Cout) ******************************
*************************************************************************
.MEASURE TRAN           t_rise_cout_1
+trig           V(Cout)         td = 18n        val = '0.1*vdd'         rise = 1
+targ           V(Cout)         td = 18n        val = '0.9*vdd'         rise = 1
.MEASURE TRAN           t_rise_cout_2
+trig           V(Cout)         td = 35n        val = '0.1*vdd'         rise = 1
+targ           V(Cout)         td = 35n        val = '0.9*vdd'         rise = 1
.MEASURE TRAN           t_rise_cout_3
+trig           V(Cout)         td = 44n        val = '0.1*vdd'         rise = 1
+targ           V(Cout)         td = 44n        val = '0.9*vdd'         rise = 1
.MEASURE TRAN           t_rise_cout_4
+trig           V(Cout)         td = 49n        val = '0.1*vdd'         rise = 1
+targ           V(Cout)         td = 49n        val = '0.9*vdd'         rise = 1
.MEASURE TRAN           t_rise_cout_5
+trig           V(Cout)         td = 54n        val = '0.1*vdd'         rise = 1
+targ           V(Cout)         td = 54n        val = '0.9*vdd'         rise = 1
.MEASURE TRAN           t_rise_cout_6
+trig           V(Cout)         td = 59n        val = '0.1*vdd'         rise = 1
+targ           V(Cout)         td = 59n        val = '0.9*vdd'         rise = 1
.MEASURE TRAN           t_rise_cout_7
+trig           V(Cout)         td = 75n        val = '0.1*vdd'         rise = 1
+targ           V(Cout)         td = 75n        val = '0.9*vdd'         rise = 1
.MEASURE TRAN           t_rise_cout_8
+trig           V(Cout)         td = 89n        val = '0.1*vdd'         rise = 1
+targ           V(Cout)         td = 89n        val = '0.9*vdd'         rise = 1
.MEASURE TRAN           t_rise_cout_9
+trig           V(Cout)         td = 96n        val = '0.1*vdd'         rise = 1
+targ           V(Cout)         td = 96n        val = '0.9*vdd'         rise = 1
.MEASURE TRAN           t_rise_cout_10
+trig           V(Cout)         td = 106n       val = '0.1*vdd'         rise = 1
+targ           V(Cout)         td = 106n       val = '0.9*vdd'         rise = 1
.MEASURE TRAN           t_rise_cout_11
+trig           V(Cout)         td = 111n       val = '0.1*vdd'         rise = 1
+targ           V(Cout)         td = 111n       val = '0.9*vdd'         rise = 1
.MEASURE TRAN           t_rise_cout_12
+trig           V(Cout)         td = 116n       val = '0.1*vdd'         rise = 1
+targ           V(Cout)         td = 116n       val = '0.9*vdd'         rise = 1
.MEASURE TRAN           t_rise_cout_13
+trig           V(Cout)         td = 139n       val = '0.1*vdd'         rise = 1
+targ           V(Cout)         td = 139n       val = '0.9*vdd'         rise = 1
.MEASURE TRAN           t_rise_cout_14
```

```
+trig           V(Cout)         td = 146n       val = '0.1*vdd'         rise = 1
+targ           V(Cout)         td = 146n       val = '0.9*vdd'         rise = 1
.MEASURE TRAN           t_rise_cout_15
+trig           V(Cout)         td = 151n       val = '0.1*vdd'         rise = 1
+targ           V(Cout)         td = 151n       val = '0.9*vdd'         rise = 1

****************************** FALL Time (Cout) ******************************
********************************************************************************
.MEASURE TRAN           t_fall_cout_1
+trig           V(Cout)         td = 31n        val = '0.9*vdd'         fall = 1
+targ           V(Cout)         td = 31n        val = '0.1*vdd'         fall = 1
.MEASURE TRAN           t_fall_cout_2
+trig           V(Cout)         td = 41n        val = '0.9*vdd'         fall = 1
+targ           V(Cout)         td = 41n        val = '0.1*vdd'         fall = 1
.MEASURE TRAN           t_fall_cout_3
+trig           V(Cout)         td = 47n        val = '0.9*vdd'         fall = 1
+targ           V(Cout)         td = 47n        val = '0.1*vdd'         fall = 1
.MEASURE TRAN           t_fall_cout_4
+trig           V(Cout)         td = 51n        val = '0.9*vdd'         fall = 1
+targ           V(Cout)         td = 51n        val = '0.1*vdd'         fall = 1
.MEASURE TRAN           t_fall_cout_5
+trig           V(Cout)         td = 57n        val = '0.9*vdd'         fall = 1
+targ           V(Cout)         td = 57n        val = '0.1*vdd'         fall = 1
.MEASURE TRAN           t_fall_cout_6
+trig           V(Cout)         td = 61n        val = '0.9*vdd'         fall = 1
+targ           V(Cout)         td = 61n        val = '0.1*vdd'         fall = 1
.MEASURE TRAN           t_fall_cout_7
+trig           V(Cout)         td = 86n        val = '0.9*vdd'         fall = 1
+targ           V(Cout)         td = 86n        val = '0.1*vdd'         fall = 1
.MEASURE TRAN           t_fall_cout_8
+trig           V(Cout)         td = 92n        val = '0.9*vdd'         fall = 1
+targ           V(Cout)         td = 92n        val = '0.1*vdd'         fall = 1
.MEASURE TRAN           t_fall_cout_9
+trig           V(Cout)         td = 105n       val = '0.9*vdd'         fall = 1
+targ           V(Cout)         td = 105n       val = '0.1*vdd'         fall = 1
.MEASURE TRAN           t_fall_cout_10
+trig           V(Cout)         td = 109n       val = '0.9*vdd'         fall = 1
+targ           V(Cout)         td = 109n       val = '0.1*vdd'         fall = 1
.MEASURE TRAN           t_fall_cout_11
+trig           V(Cout)         td = 114n       val = '0.9*vdd'         fall = 1
+targ           V(Cout)         td = 114n       val = '0.1*vdd'         fall = 1
.MEASURE TRAN           t_fall_cout_12
+trig           V(Cout)         td = 125n       val = '0.9*vdd'         fall = 1
+targ           V(Cout)         td = 125n       val = '0.1*vdd'         fall = 1
.MEASURE TRAN           t_fall_cout_13
+trig           V(Cout)         td = 142n       val = '0.9*vdd'         fall = 1
+targ           V(Cout)         td = 142n       val = '0.1*vdd'         fall = 1
.MEASURE TRAN           t_fall_cout_14
+trig           V(Cout)         td = 149n       val = '0.9*vdd'         fall = 1
+targ           V(Cout)         td = 149n       val = '0.1*vdd'         fall = 1
.MEASURE TRAN           t_fall_cout_15
+trig           V(Cout)         td = 154n       val = '0.9*vdd'         fall = 1
+targ           V(Cout)         td = 154n       val = '0.1*vdd'         fall = 1
```

نتایج شبیه‌سازی به صورت زیر خواهد بود.

```
 t_rise_sum_1   =  55.8884p  targ=   2.6402n   trig=   2.5843n
 t_rise_sum_2   =  41.5404p  targ=   7.5874n   trig=   7.5459n
 t_rise_sum_3   =  57.6743p  targ=  15.1508n   trig=  15.0931n
 t_rise_sum_4   =  61.6159p  targ=  25.1639n   trig=  25.1023n
 t_rise_sum_5   =  62.6236p  targ=  32.8117n   trig=  32.7490n
 t_rise_sum_6   =  49.4199p  targ=  42.7509n   trig=  42.7015n
 t_rise_sum_7   =  36.4732p  targ=  55.0667n   trig=  55.0302n
 t_rise_sum_8   =  48.3036p  targ=  57.6856n   trig=  57.6373n
 t_rise_sum_9   =  47.1508p  targ=  62.7714n   trig=  62.7242n
 t_rise_sum_10  =  57.2608p  targ=  80.1597n   trig=  80.1024n
 t_rise_sum_11  =  59.9525p  targ=  95.2996n   trig=  95.2397n
 t_rise_sum_12  =  48.5904p  targ= 105.3100n   trig= 105.2614n
 t_rise_sum_13  =  67.3805p  targ= 127.7668n   trig= 127.6994n
 t_rise_sum_14  =  55.4746p  targ= 145.2821n   trig= 145.2267n
```

```
t_rise_sum_15  =  54.0212p  targ= 150.2711n   trig= 150.2171n

t_fall_sum_1   =  49.7198p  targ=   5.1744n   trig=   5.1247n
t_fall_sum_2   =  46.4794p  targ=  12.6083n   trig=  12.5618n
t_fall_sum_3   =  39.9531p  targ=  20.2221n   trig=  20.1821n
t_fall_sum_4   =  40.4260p  targ=  30.1228n   trig=  30.0824n
t_fall_sum_5   =  50.8546p  targ=  35.1559n   trig=  35.1050n
t_fall_sum_6   =  48.5106p  targ=  45.2165n   trig=  45.1680n
t_fall_sum_7   =  40.4247p  targ=  57.5940n   trig=  57.5536n
t_fall_sum_8   =  45.6117p  targ=  60.2721n   trig=  60.2265n
t_fall_sum_9   =  50.1649p  targ=  77.7884n   trig=  77.7383n
t_fall_sum_10  =  44.8301p  targ=  90.2336n   trig=  90.1888n
t_fall_sum_11  =  51.4411p  targ= 100.1576n   trig= 100.1061n
t_fall_sum_12  =  44.4735p  targ= 112.7288n   trig= 112.6843n
t_fall_sum_13  =  48.1463p  targ= 140.2452n   trig= 140.1970n
t_fall_sum_14  =  43.3875p  targ= 147.7265n   trig= 147.6831n

t_rise_cout_1  =  55.9106p  targ=  20.1434n   trig=  20.0875n
t_rise_cout_2  =  47.8511p  targ=  37.6149n   trig=  37.5671n
t_rise_cout_3  =  52.3898p  targ=  45.1259n   trig=  45.0735n
t_rise_cout_4  =  50.1861p  targ=  50.1507n   trig=  50.1005n
t_rise_cout_5  =  36.4120p  targ=  55.0830n   trig=  55.0466n
t_rise_cout_6  =  70.8367p  targ=  60.2156n   trig=  60.1448n
t_rise_cout_7  =  54.2229p  targ=  77.6319n   trig=  77.5776n
t_rise_cout_8  =  74.7793p  targ=  90.1947n   trig=  90.1199n
t_rise_cout_9  =  37.4548p  targ=  97.5813n   trig=  97.5438n
t_rise_cout_10 =  37.4192p  targ= 107.5822n   trig= 107.5448n
t_rise_cout_11 =  75.0937p  targ= 112.6971n   trig= 112.6220n
t_rise_cout_12 =  61.8038p  targ= 117.7059n   trig= 117.6441n
t_rise_cout_13 =  52.2077p  targ= 140.1164n   trig= 140.0642n
t_rise_cout_14 =  56.1232p  targ= 147.6463n   trig= 147.5902n
t_rise_cout_15 =  37.6289p  targ= 152.5821n   trig= 152.5445n

t_fall_cout_1  =  41.2917p  targ=  32.6094n   trig=  32.5681n
t_fall_cout_2  =  69.3640p  targ=  42.6729n   trig=  42.6036n
t_fall_cout_3  =  29.5055p  targ=  47.5758n   trig=  47.5463n
t_fall_cout_4  =  30.3956p  targ=  52.5880n   trig=  52.5576n
t_fall_cout_5  =  40.1374p  targ=  57.6178n   trig=  57.5777n
t_fall_cout_6  =  69.0259p  targ=  62.6949n   trig=  62.6259n
t_fall_cout_7  =  36.6833p  targ=  87.5807n   trig=  87.5441n
t_fall_cout_8  =  48.2460p  targ=  95.1184n   trig=  95.0701n
t_fall_cout_9  =  70.0932p  targ= 105.2252n   trig= 105.1551n
t_fall_cout_10 =  60.7430p  targ= 110.1633n   trig= 110.1025n
t_fall_cout_11 =  30.3223p  targ= 115.0886n   trig= 115.0582n
t_fall_cout_12 =  41.3514p  targ= 127.5841n   trig= 127.5427n
t_fall_cout_13 =  44.3934p  targ= 145.1367n   trig= 145.0923n
t_fall_cout_14 =  44.2155p  targ= 150.1298n   trig= 150.0856n
t_fall_cout_15 =  60.7407p  targ= 155.1623n   trig= 155.1016n
```

بیشترین مقدار را به عنوان زمان صعود و نشست در نظر می‌گیریم.

Outputs	T_{Rise}	T_{Fall}
SUM	67.3805 ps	51.4411 ps
C_{out}	75.0937 ps	70.0932 ps

در ادامه به محاسبه توان پویای متوسط می‌پردازیم. به این منظور قطعه کد زیر نوشته شده است.

```
*===============================================================================================
****************************** DYNAMIC POWER ********************************
*************************************************************************
.measuretran    pow     AVG     power   from = 1ns      to = 170ns
```

نتیجه شبیه‌سازی برای محاسبه توان پویای متوسط به صورت زیر خواهد بود.

```
pow=  13.2545u  from=   1.0000n     to= 170.0000n
```

برای محاسبه توان ایستا به ازای ورودی‌های A,B,C هشت حالت 000, 001, 010, 011, 100, 101, 110, 111 را به ترتیب به مدار اعمال کرده و در هر حالت توان را حساب میکنیم.

```
*//\/\/\//\/\/\/\/\//\/\/\/\\/\/\/\///\\/\/\/\//\\//\/\/\/\//\/\/\/\\\//\/\//\/\\/\/\/\\/\\/\\/\/\/\\/\\/\
*nnnnnnnnnnnnnnnnnnnnnnnnnnnnnnn*
*       ==> INPUTS              *
*uuuuuuuuuuuuuuuuuuuuuuuuuuuuuuu*

Vina    A       0       PWL     0n      0       , '10n-t'       0,      10n     vdd

Vinb    B       0       PWL     0n      0       , '5n-t'0,      5n      vdd,
+       '10n-t' vdd,    10n     0,      '15n-t' 0,      15n     vdd

Vinc    C       0       PWL     0n      0,      '2.5n-t'0,      2.5n    vdd,
+       '5n-t'  vdd,    5n      0,      '7.5n-t'0,      7.5n    vdd,
+       '10n-t' vdd,    10n     0,      '12.5n-t'       0,      12.5n   vdd,
+       '15n-t' vdd,    15n     0,      '17.5n-t'       0,      17.5n   vdd

*//\/\/\//\/\/\/\/\//\/\/\/\\/\/\/\///\\/\/\/\//\\//\/\/\/\//\/\/\/\\\//\/\//\/\\/\/\/\\/\\/\\/\/\/\\/\\/\
*nnnnnnnnnnnnnnnnnnnnnnnnnnnnnnn*
*       ==> SIMULATIONS         *
*uuuuuuuuuuuuuuuuuuuuuuuuuuuuuuu*
.option post=2
.TRAN   1p      20n

*//\/\/\//\/\/\/\/\//\/\/\/\\/\/\/\///\\/\/\/\//\\//\/\/\/\//\/\/\/\\\//\/\//\/\\/\/\/\\/\\/\\/\/\/\\/\\/\
*nnnnnnnnnnnnnnnnnnnnnnnnnnnnnnn*
*       ==> MEASUREMENTS *
*uuuuuuuuuuuuuuuuuuuuuuuuuuuuuuu*

*====================================================================================================
****************************** STATIC POWER **********************************
******************************************************************************
.measuretran    static_power_1  AVG     power   from = 0ns      to = 2.5ns
.measuretran    static_power_2  AVG     power   from = 2.5ns    to = 5ns
.measuretran    static_power_3  AVG     power   from = 5ns      to = 7.5ns
.measuretran    static_power_4  AVG     power   from = 7.5ns    to = 10ns
.measuretran    static_power_5  AVG     power   from = 10ns     to = 12.5ns
.measuretran    static_power_6  AVG     power   from = 12.5ns   to = 15ns
.measuretran    static_power_7  AVG     power   from = 15ns     to = 17.5ns
.measuretran    static_power_8  AVG     power   from = 17.5ns   to = 20ns
```

نتیجه شبیه‌سازی برای محاسبه توان ایستا بصورت زیر خواهد بود.

```
****** transient analysis tnom=  25.000 temp=  25.000 ******
 static_power_1= 875.5234n  from=   0.         to=   2.5000n
 static_power_2=  16.8370u  from=   2.5000n    to=   5.0000n
 static_power_3=   4.1274u  from=   5.0000n    to=   7.5000n
 static_power_4=  20.1386u  from=   7.5000n    to=  10.0000n
 static_power_5=  21.9501u  from=  10.0000n    to=  12.5000n
 static_power_6=  24.2993u  from=  12.5000n    to=  15.0000n
 static_power_7=   5.6427u  from=  15.0000n    to=  17.5000n
 static_power_8=  11.5726u  from=  17.5000n    to=  20.0000n
```

میانگین هشت حالت بدست آمده، توان ایستای متوسط خواهد بود.

P_{STATIC_AWG} = 13.1804 uW

ج) بررسی تأثیر دما :

در این بخش مجددا پارامترهای تأخیر، توان پویای متوسط و توان ایستا را در دما 0 و 100 درجه شبیه‌سازی میکنیم. انتظار داریم افزایش دما، سبب افزایش تأخیر سیستم و توان مصرفی شود.

```
****** transient analysis tnom=  25.000 temp=   0.000 ******
 t_rise_sum_1=  53.0132p  targ=   2.6320n   trig=   2.5790n
 t_rise_sum_2=  40.4945p  targ=   7.5845n   trig=   7.5440n
 t_rise_sum_3=  54.7455p  targ=  15.1415n   trig=  15.0868n
 t_rise_sum_4=  57.6874p  targ=  25.1529n   trig=  25.0952n
 t_rise_sum_5=  66.1377p  targ=  32.7872n   trig=  32.7210n
 t_rise_sum_6=  49.3124p  targ=  42.7430n   trig=  42.6937n
 t_rise_sum_7=  35.4069p  targ=  55.0640n   trig=  55.0285n
 t_rise_sum_8=  44.5192p  targ=  57.6768n   trig=  57.6323n
 t_rise_sum_9=  50.1854p  targ=  62.7616n   trig=  62.7115n
 t_rise_sum_10=  57.8475p  targ=  80.1488n   trig=  80.0910n
 t_rise_sum_11=  53.0560p  targ=  95.2861n   trig=  95.2330n
 t_rise_sum_12=  49.7027p  targ= 105.2992n   trig= 105.2495n
 t_rise_sum_13=  66.1402p  targ= 127.7589n   trig= 127.6928n
 t_rise_sum_14=  55.5514p  targ= 145.2663n   trig= 145.2107n
 t_rise_sum_15=  50.1558p  targ= 150.2621n   trig= 150.2120n

 t_fall_sum_1=  45.3896p  targ=   5.1708n   trig=   5.1254n
 t_fall_sum_2=  42.8402p  targ=  12.6022n   trig=  12.5594n
 t_fall_sum_3=  38.8979p  targ=  20.2130n   trig=  20.1741n
 t_fall_sum_4=  38.1761p  targ=  30.1179n   trig=  30.0797n
 t_fall_sum_5=  47.4418p  targ=  35.1535n   trig=  35.1060n
 t_fall_sum_6=  45.8516p  targ=  45.2065n   trig=  45.1607n
 t_fall_sum_7=  38.2413p  targ=  57.5916n   trig=  57.5534n
 t_fall_sum_8=  41.4011p  targ=  60.2586n   trig=  60.2172n
 t_fall_sum_9=  46.1595p  targ=  77.7806n   trig=  77.7345n
 t_fall_sum_10=  41.3483p  targ=  90.2207n   trig=  90.1794n
 t_fall_sum_11=  48.0685p  targ= 100.1538n   trig= 100.1057n
 t_fall_sum_12=  42.1278p  targ= 112.7178n   trig= 112.6757n
 t_fall_sum_13=  46.5480p  targ= 140.2357n   trig= 140.1892n
 t_fall_sum_14=  42.3588p  targ= 147.7171n   trig= 147.6747n

 t_rise_cout_1=  49.4811p  targ=  20.1392n   trig=  20.0897n
 t_rise_cout_2=  47.1954p  targ=  37.6109n   trig=  37.5637n
 t_rise_cout_3=  48.8023p  targ=  45.1198n   trig=  45.0710n
 t_rise_cout_4=  47.1496p  targ=  50.1441n   trig=  50.0970n
 t_rise_cout_5=  35.8211p  targ=  55.0790n   trig=  55.0432n
 t_rise_cout_6=  66.1669p  targ=  60.2068n   trig=  60.1406n
 t_rise_cout_7=  49.1008p  targ=  77.6257n   trig=  77.5766n
 t_rise_cout_8=  68.9281p  targ=  90.1816n   trig=  90.1126n
 t_rise_cout_9=  35.6824p  targ=  97.5775n   trig=  97.5418n
 t_rise_cout_10=  35.5708p  targ= 107.5784n   trig= 107.5428n
 t_rise_cout_11=  69.1769p  targ= 112.6839n   trig= 112.6147n
 t_rise_cout_12=  54.9513p  targ= 117.6925n   trig= 117.6376n
 t_rise_cout_13=  49.8880p  targ= 140.1116n   trig= 140.0617n
 t_rise_cout_14=  53.6446p  targ= 147.6401n   trig= 147.5865n
 t_rise_cout_15=  35.7410p  targ= 152.5782n   trig= 152.5425n

 t_fall_cout_1=  41.5813p  targ=  32.6058n   trig=  32.5643n
 t_fall_cout_2=  65.3862p  targ=  42.6713n   trig=  42.6059n
 t_fall_cout_3=  29.3986p  targ=  47.5738n   trig=  47.5444n
 t_fall_cout_4=  28.9940p  targ=  52.5851n   trig=  52.5561n
 t_fall_cout_5=  37.0811p  targ=  57.6125n   trig=  57.5754n
 t_fall_cout_6=  65.2555p  targ=  62.6918n   trig=  62.6265n
 t_fall_cout_7=  35.8195p  targ=  87.5787n   trig=  87.5429n
 t_fall_cout_8=  46.1838p  targ=  95.1142n   trig=  95.0680n
 t_fall_cout_9=  65.9004p  targ= 105.2168n   trig= 105.1509n
 t_fall_cout_10=  57.6148p  targ= 110.1582n   trig= 110.1006n
 t_fall_cout_11=  29.9993p  targ= 115.0849n   trig= 115.0549n
 t_fall_cout_12=  37.5955p  targ= 127.5797n   trig= 127.5421n
 t_fall_cout_13=  42.7774p  targ= 145.1314n   trig= 145.0886n
 t_fall_cout_14=  41.2297p  targ= 150.1243n   trig= 150.0830n
 t_fall_cout_15=  60.3050p  targ= 155.1593n   trig= 155.0990n

 pow=  13.0862u  from=   1.0000n     to= 170.0000n
```

```
****** transient analysis tnom=  25.000 temp= 100.000 ******
 t_rise_sum_1=  66.9687p  targ=   2.6665n   trig=   2.5996n
 t_rise_sum_2=  49.6327p  targ=   7.6017n   trig=   7.5521n
 t_rise_sum_3=  66.6984p  targ=  15.1787n   trig=  15.1120n
 t_rise_sum_4=  67.1380p  targ=  25.1991n   trig=  25.1319n
 t_rise_sum_5=  84.2479p  targ=  32.8473n   trig=  32.7630n
 t_rise_sum_6=  54.3629p  targ=  42.7745n   trig=  42.7201n
 t_rise_sum_7=  43.1970p  targ=  55.0780n   trig=  55.0348n
 t_rise_sum_8=  60.6464p  targ=  57.7135n   trig=  57.6528n
 t_rise_sum_9=  53.6675p  targ=  62.7964n   trig=  62.7428n
 t_rise_sum_10=  67.3373p  targ=  80.1932n   trig=  80.1259n
 t_rise_sum_11=  87.2973p  targ=  95.3539n   trig=  95.2666n
 t_rise_sum_12=  62.5150p  targ= 105.3420n   trig= 105.2795n
 t_rise_sum_13=  85.7365p  targ= 127.8027n   trig= 127.7170n
 t_rise_sum_14=  66.6782p  targ= 145.3129n   trig= 145.2462n
 t_rise_sum_15=  68.3848p  targ= 150.3085n   trig= 150.2401n

 t_fall_sum_1=  56.9145p  targ=   5.1911n   trig=   5.1342n
 t_fall_sum_2=  52.7061p  targ=  12.6163n   trig=  12.5636n
 t_fall_sum_3=  46.4994p  targ=  20.2520n   trig=  20.2055n
 t_fall_sum_4=  44.6740p  targ=  30.1339n   trig=  30.0893n
 t_fall_sum_5=  57.1478p  targ=  35.1699n   trig=  35.1127n
 t_fall_sum_6=  55.0890p  targ=  45.2461n   trig=  45.1910n
 t_fall_sum_7=  45.8303p  targ=  57.6019n   trig=  57.5560n
 t_fall_sum_8=  56.0418p  targ=  60.3185n   trig=  60.2625n
 t_fall_sum_9=  56.8747p  targ=  77.8276n   trig=  77.7708n
 t_fall_sum_10=  55.3344p  targ=  90.2759n   trig=  90.2206n
 t_fall_sum_11=  57.0818p  targ= 100.1702n   trig= 100.1132n
 t_fall_sum_12=  53.8162p  targ= 112.7716n   trig= 112.7178n
 t_fall_sum_13=  54.9475p  targ= 140.2770n   trig= 140.2220n
 t_fall_sum_14=  48.4811p  targ= 147.7512n   trig= 147.7028n

 t_rise_cout_1=  70.8458p  targ=  20.1693n   trig=  20.0985n
 t_rise_cout_2=  57.9901p  targ=  37.6337n   trig=  37.5757n
 t_rise_cout_3=  64.2845p  targ=  45.1452n   trig=  45.0810n
 t_rise_cout_4=  56.8995p  targ=  50.1683n   trig=  50.1114n
 t_rise_cout_5=  40.9162p  targ=  55.0910n   trig=  55.0501n
 t_rise_cout_6=  92.4316p  targ=  60.2603n   trig=  60.1679n
 t_rise_cout_7=  64.3109p  targ=  77.6535n   trig=  77.5892n
 t_rise_cout_8=  83.6404p  targ=  90.2367n   trig=  90.1531n
 t_rise_cout_9=  43.5330p  targ=  97.5923n   trig=  97.5487n
 t_rise_cout_10=  43.6673p  targ= 107.5932n   trig= 107.5495n
 t_rise_cout_11=  82.8450p  targ= 112.7394n   trig= 112.6565n
 t_rise_cout_12=  75.7527p  targ= 117.7436n   trig= 117.6679n
 t_rise_cout_13=  59.6469p  targ= 140.1329n   trig= 140.0732n
 t_rise_cout_14=  60.0305p  targ= 147.6670n   trig= 147.6070n
 t_rise_cout_15=  44.1748p  targ= 152.5938n   trig= 152.5496n

 t_fall_cout_1=  52.9887p  targ=  32.6250n   trig=  32.5720n
 t_fall_cout_2=  76.5095p  targ=  42.6867n   trig=  42.6102n
 t_fall_cout_3=  34.7647p  targ=  47.5829n   trig=  47.5482n
 t_fall_cout_4=  35.8040p  targ=  52.5982n   trig=  52.5624n
 t_fall_cout_5=  44.4441p  targ=  57.6300n   trig=  57.5856n
 t_fall_cout_6=  80.8752p  targ=  62.7139n   trig=  62.6330n
 t_fall_cout_7=  41.7686p  targ=  87.5935n   trig=  87.5517n
 t_fall_cout_8=  59.1102p  targ=  95.1340n   trig=  95.0749n
 t_fall_cout_9=  80.4111p  targ= 105.2478n   trig= 105.1674n
 t_fall_cout_10=  72.7504p  targ= 110.1824n   trig= 110.1097n
 t_fall_cout_11=  35.0873p  targ= 115.0968n   trig= 115.0617n
 t_fall_cout_12=  43.2369p  targ= 127.5897n   trig= 127.5464n
 t_fall_cout_13=  48.9350p  targ= 145.1470n   trig= 145.0981n
 t_fall_cout_14=  48.5500p  targ= 150.1419n   trig= 150.0933n
 t_fall_cout_15=  72.8817p  targ= 155.1827n   trig= 155.1098n

 pow=  13.5667u  from=   1.0000n     to= 170.0000n


****** transient analysis tnom=  25.000 temp=   0.000 ******
 static_power_1= 845.4677n  from=   0.          to=   2.5000n
 static_power_2=  16.6562u  from=   2.5000n     to=   5.0000n
 static_power_3=   4.0241u  from=   5.0000n     to=   7.5000n
 static_power_4=  19.9207u  from=   7.5000n     to=  10.0000n
 static_power_5=  21.7680u  from=  10.0000n     to=  12.5000n
```

```
 static_power_6=  23.9067u  from=  12.5000n     to=  15.0000n
 static_power_7=   5.6293u  from=  15.0000n     to=  17.5000n
 static_power_8=  11.4024u  from=  17.5000n     to=  20.0000n

****** transient analysis tnom=  25.000 temp= 100.000 ******
 static_power_1= 818.0188n  from=   0.          to=   2.5000n
 static_power_2=  17.2474u  from=   2.5000n     to=   5.0000n
 static_power_3=   4.3233u  from=   5.0000n     to=   7.5000n
 static_power_4=  20.9875u  from=   7.5000n     to=  10.0000n
 static_power_5=  22.4476u  from=  10.0000n     to=  12.5000n
 static_power_6=  25.4120u  from=  12.5000n     to=  15.0000n
 static_power_7=   5.7687u  from=  15.0000n     to=  17.5000n
 static_power_8=  11.9261u  from=  17.5000n     to=  20.0000n
```

Parameters	0°C	25°C	100°C
T_{Rise}(SUM)	66.1402 ps	67.3805 ps	87.2973 ps
T_{FALL}(SUM)	48.0685 ps	51.4411 ps	57.1478 ps
T_{Rise}(C_{out})	69.1769 ps	75.0937 ps	92.4316 ps
T_{FALL}(C_{out})	65.9004 ps	70.0932 ps	80.8752 ps
Dynamic Power	13.0862 uW	13.2545 uW	13.5667 uW
Static Power	13.0191 uW	13.1804 uW	13.6163 uW

همانطور که مشاهده میشود، با افزایش دما، تأخیر سیستم و توان مصرفی افزایش میابد.