(Please skip problems 8,9,10 since material needed to solve these problems will not be covered until Wednesday)

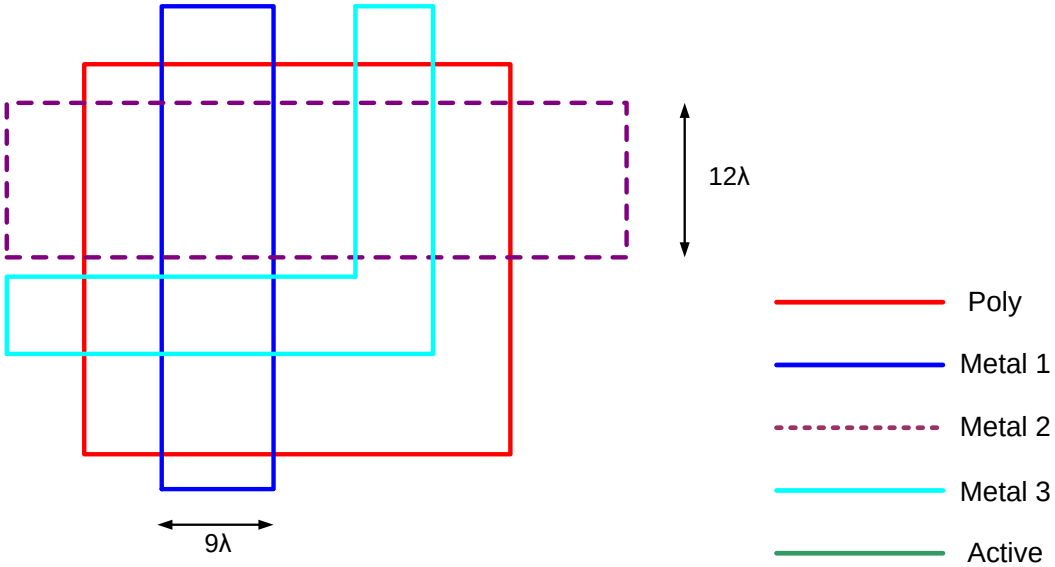
EE 330
Homework 5
Fall 2018 (This assignment is due Wednesday Sept 19 at 12:00 noon)

Assume the CMOS process is characterized by model parameters V_{TH}=1V and μC_{OX}=100µA/V^2. If any other model parameters are needed, use the measured parameters from the TSMC 0.18u process run that are attached. On those problems that involve the design of passive components, a sketch of the design is sufficient provided you indicate dimensions (i.e. it need not be done in Cadence).

Problem 1 Design a 3K resistor in the TSMC 0.18µ CMOS process. Use Poly 1 with a silicide block for the resistor. The width-length ratio of an imaginary box enclosing the resistor should have a W/L ratio of between 1:2 and 2:1. The layout of the resistor can be either sketched or come from a Cadence layout.

Problem 2 Design a 500fF capacitor in the TSMC 0.18µ CMOS process. Clearly specify which layers you are using for this capacitor. The layout of the capacitor can be either sketched or come from a Cadence layout.

Problem 3 Four non-contacting regions are shown. Identify the parasitic capacitances and their size if this is fabricated in the 0.18µ CMOS process. Don't forget that there is substrate below all layers. (assume this drawing is to scale)



Problem 4 Assume a resistor has a resistance of 4.534KΩ at T=250°K. If the TCR of this resistor is constant of value 1200 ppm/°C, what will be the resistance at T=320°K?

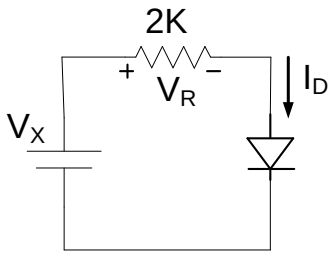
Problem 5 Consider an n+ diffused resistor that is 50u long and 2u wide. What is the nominal value of the resistance if it is doped with Arsenic and the doping density is 2E14/cm^3.

Problem 6 Consider a 15K resistor that is made by the series connection of two resistors. One of the resistors is a n+ doped 5K polysilicon resistor with a TCR of -1400 ppm/^{o}C and the other is a p+ diffused silicon 10K resistor with a TCR of 900 ppm/^{o}C. What is the TCR of the series combination? How does this compare to the TCR that would be achieved if the 15K resistor were made entirely with n+ doped polysilicon?

Problem 7 Consider a Poly 1 (without silicide block) interconnect in the 0.18µ CMOS process that is 1µ wide and 100µ long. What is the resistance of this interconnect? What is the capacitance from this interconnect to the substrate? If Metal 1 is above this interconnect, what is the capacitance between this interconnect and Metal 1?

Problem 8 If the voltage of a forward-biased pn junction is varied between 0.5V and 0.6V, what is the range in the diode current. Assume the junction area of the diode is $50\mu^2$ and $J_S=10^{-15}A/\mu^2$.

Problem 9 Determine the current I_D (within ±5%) if $V_X=10V$ for the following circuit. Assume the area of the diode is $200\mu^2$ and $J_S=10^{-15}A/u^2$.



Problem 10 Repeat Problem 5 if $V_X=520mV$.

Problem 11 and 12 Use Modelsim create a one-bit Half Adder. For the inputs use two one-bit inputs. For the outputs, use a one-bit output and a carry out bit. Create a test bench for the code ad show the results and waveforms.

MOSIS WAFER ACCEPTANCE TESTS

RUN: T4BK (MM_NON-EPI_THK-MTL) VENDOR: TSMC
TECHNOLOGY: SCN018 FEATURE SIZE: 0.18 microns

INTRODUCTION: This report contains the lot average results obtained by MOSIS from measurements of MOSIS test structures on each wafer of this fabrication lot. SPICE parameters obtained from similar measurements on a selected wafer are also attached.

COMMENTS: DSCN6M018_TSMC

TRANSISTOR PARAMETERS	W/L	N-CHANNEL	P-CHANNEL	UNITS
MINIMUM	0.27/0.18			
Vth		0.50	-0.53	volts
SHORT	20.0/0.18			
Idss		571	-266	uA/um
Vth		0.51	-0.53	volts
Vpt		4.7	-5.5	volts
WIDE	20.0/0.18			
Ids0		22.0	-5.6	pA/um
LARGE	50/50			
Vth		0.42	-0.41	volts
Vjbkd		3.1	-4.1	volts
Ijlk		<50.0	<50.0	pA
K' (Uo*Cox/2)		171.8	-36.3	uA/V^2
Low-field Mobility		398.02	84.10	cm^2/V*s

COMMENTS: Poly bias varies with design technology. To account for mask bias use the appropriate value for the parameters XL and XW in your SPICE model card.

Design Technology	XL (um)	XW (um)
SCN6M_DEEP (lambda=0.09)	0.00	-0.01
thick oxide	0.00	-0.01
SCN6M_SUBM (lambda=0.10)	-0.02	0.00
thick oxide	-0.02	0.00

FOX TRANSISTORS	GATE	N+ACTIVE	P+ACTIVE	UNITS
Vth	Poly	>6.6	<-6.6	volts

PROCESS PARAMETERS	N+	P+	POLY	N+BLK	PLY+BLK	M1	M2	UNITS
Sheet Resistance	6.6	7.5	7.7	61.0	317.1	0.08	0.08	ohms/sq
Contact Resistance	10.1	10.6	9.3				4.18	ohms
Gate Oxide Thickness	40							angstrom

PROCESS PARAMETERS	M3	POLY_HRI	M4	M5	M6	N_W	UNITS
Sheet Resistance	0.08	991.5	0.08	0.08	0.01	941	ohms/sq
Contact Resistance	8.97		14.09	18.84	21.44		ohms

COMMENTS: BLK is silicide block.

CAPACITANCE PARAMETERS

	N+	P+	POLY	M1	M2	M3	M4	M5	M6	R_W	D_N_W	M5P	N_W	UNITS
Area (substrate)	998	1152	103	39	19	13	9	8	3		129		127	aF/um^2
Area (N+active)			8566	54	21	14	11	10	9					aF/um^2
Area (P+active)			8324											aF/um^2
Area (poly)				64	18	10	7	6	5					aF/um^2
Area (metal1)					44	16	10	7	5					aF/um^2
Area (metal2)						38	15	9	7					aF/um^2
Area (metal3)							40	15	9					aF/um^2
Area (metal4)								37	14					aF/um^2
Area (metal5)									36			1003		aF/um^2
Area (r well)	987													aF/um^2
Area (d well)										574				aF/um^2
Area (no well)	139													aF/um^2
Fringe (substrate)	244	201		18	61	55	43	25						aF/um
Fringe (poly)				69	39	29	24	21	19					aF/um
Fringe (metal1)					61	35		23	21					aF/um
Fringe (metal2)						54	37	27	24					aF/um
Fringe (metal3)							56	34	31					aF/um
Fringe (metal4)								58	40					aF/um
Fringe (metal5)									61					aF/um
Overlap (P+active)			652											aF/um

CIRCUIT PARAMETERS			UNITS
Inverters	K		
Vinv	1.0	0.74	volts
Vinv	1.5	0.78	volts
Vol (100 uA)	2.0	0.08	volts
Voh (100 uA)	2.0	1.63	volts
Vinv	2.0	0.82	volts
Gain	2.0	-23.33	
Ring Oscillator Freq.			
D1024_THK (31-stg,3.3V)		338.22	MHz
DIV1024 (31-stg,1.8V)		402.84	MHz
Ring Oscillator Power			
D1024_THK (31-stg,3.3V)		0.07	uW/MHz/gate
DIV1024 (31-stg,1.8V)		0.02	uW/MHz/gate

COMMENTS: DEEP_SUBMICRON

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SPICE 3f5 Level 8, Star-HSPICE Level 49, UTMOST Level 8
* DATE: Jan 21/05
* LOT: T4BK                  WAF: 3004
* Temperature_parameters=Default
.MODEL CMOSN NMOS (                                LEVEL   = 49
+VERSION = 3.1            TNOM    = 27             TOX     = 4E-9
+XJ      = 1E-7           NCH     = 2.3549E17      VTH0    = 0.3662648
+K1      = 0.5802748      K2      = 3.124029E-3    K3      = 1E-3
+K3B     = 3.3886871      W0      = 1E-7           NLX     = 1.766159E-7
+DVT0W   = 0              DVT1W   = 0              DVT2W   = 0
+DVT0    = 1.2312416      DVT1    = 0.3849841      DVT2    = 0.0161351
+U0      = 265.1889031    UA      = -1.506402E-9   UB      = 2.489393E-18
+UC      = 5.621884E-11   VSAT    = 1.017932E5     A0      = 2
+AGS     = 0.4543117      B0      = 3.433489E-7    B1      = 5E-6
+KETA    = -0.0127714     A1      = 1.158074E-3    A2      = 1
+RDSW    = 136.5582806    PRWG    = 0.5            PRWB    = -0.2
+WR      = 1              WINT    = 0              LINT    = 1.702415E-8
+XL      = 0              XW      = -1E-8          DWG     = -4.211574E-9
+DWB     = 1.107719E-8    VOFF    = -0.0948017     NFACTOR = 2.1860065
+CIT     = 0              CDSC    = 2.4E-4         CDSCD   = 0
+CDSCB   = 0              ETA0    = 3.335516E-3    ETAB    = 6.028975E-5
+DSUB    = 0.0214781      PCLM    = 0.6602119      PDIBLC1 = 0.1605325
+PDIBLC2 = 3.287142E-3    PDIBLCB = -0.1           DROUT   = 0.7917811
+PSCBE1  = 6.420235E9     PSCBE2  = 4.122516E-9    PVAG    = 0.0347169
+DELTA   = 0.01           RSH     = 6.6            MOBMOD  = 1
+PRT     = 0              UTE     = -1.5           KT1     = -0.11
+KT1L    = 0              KT2     = 0.022          UA1     = 4.31E-9
+UB1     = -7.61E-18      UC1     = -5.6E-11       AT      = 3.3E4
+WL      = 0              WLN     = 1              WW      = 0
+WWN     = 1              WWL     = 0              LL      = 0
+LLN     = 1              LW      = 0              LWN     = 1
+LWL     = 0              CAPMOD  = 2              XPART   = 0.5
+CGDO    = 8.06E-10       CGSO    = 8.06E-10       CGBO    = 1E-12
+CJ      = 9.895609E-4    PB      = 0.8            MJ      = 0.3736889
+CJSW    = 2.393608E-10   PBSW    = 0.8            MJSW    = 0.1537892
+CJSWG   = 3.3E-10        PBSWG   = 0.8            MJSWG   = 0.1537892
+CF      = 0              PVTH0   = -1.73163E-3    PRDSW   = -1.4173554
+PK2     = 1.600729E-3    WKETA   = 1.601517E-3    LKETA   = -3.255127E-3
+PU0     = 5.2024473      PUA     = 1.584315E-12   PUB     = 7.446142E-25
+PVSAT   = 1.686297E3     PETA0   = 1.001594E-4    PKETA   = -2.039532E-3
)
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.MODEL CMOSP PMOS (                                LEVEL   = 49
+VERSION = 3.1            TNOM    = 27             TOX     = 4E-9
+XJ      = 1E-7           NCH     = 4.1589E17      VTH0    = -0.3708038
+K1      = 0.5895473      K2      = 0.0235946      K3      = 0
+K3B     = 13.8642028     W0      = 1E-6           NLX     = 1.517201E-7
+DVT0W   = 0              DVT1W   = 0              DVT2W   = 0
+DVT0    = 0.7885088      DVT1    = 0.2564577      DVT2    = 0.1
+U0      = 103.0478426    UA      = 1.049312E-9    UB      = 2.545758E-21
+UC      = -1E-10         VSAT    = 1.645114E5     A0      = 1.627879
+AGS     = 0.3295499      B0      = 5.207699E-7    B1      = 1.370868E-6
+KETA    = 0.0296157      A1      = 0.4449009      A2      = 0.3
+RDSW    = 306.5789827    PRWG    = 0.5            PRWB    = 0.5
+WR      = 1              WINT    = 0              LINT    = 2.761033E-8
+XL      = 0              XW      = -1E-8          DWG     = -2.433889E-8
+DWB     = -9.34648E-11   VOFF    = -0.0867009     NFACTOR = 2
+CIT     = 0              CDSC    = 2.4E-4         CDSCD   = 0
+CDSCB   = 0              ETA0    = 1.018318E-3    ETAB    = -3.206319E-4
+DSUB    = 1.094521E-3    PCLM    = 1.3281073      PDIBLC1 = 2.394169E-3
+PDIBLC2 = -3.255915E-6   PDIBLCB = -1E-3          DROUT   = 0
+PSCBE1  = 4.881933E10    PSCBE2  = 5E-10          PVAG    = 2.0932623
+DELTA   = 0.01           RSH     = 7.5            MOBMOD  = 1
+PRT     = 0              UTE     = -1.5           KT1     = -0.11
+KT1L    = 0              KT2     = 0.022          UA1     = 4.31E-9
+UB1     = -7.61E-18      UC1     = -5.6E-11       AT      = 3.3E4
+WL      = 0              WLN     = 1              WW      = 0
+WWN     = 1              WWL     = 0              LL      = 0
+LLN     = 1              LW      = 0              LWN     = 1
+LWL     = 0              CAPMOD  = 2              XPART   = 0.5
+CGDO    = 6.52E-10       CGSO    = 6.52E-10       CGBO    = 1E-12
+CJ      = 1.157423E-3    PB      = 0.8444261      MJ      = 0.4063933
+CJSW    = 1.902456E-10   PBSW    = 0.8            MJSW    = 0.3550788
+CJSWG   = 4.22E-10       PBSWG   = 0.8            MJSWG   = 0.3550788
+CF      = 0              PVTH0   = 1.4398E-3      PRDSW   = 0.5073407
+PK2     = 2.190431E-3    WKETA   = 0.0442978      LKETA   = -2.936093E-3
+PU0     = -0.9769623     PUA     = -4.34529E-11   PUB     = 1E-21
+PVSAT   = -50            PETA0   = 1.002762E-4    PKETA   = -6.740436E-3
)
```