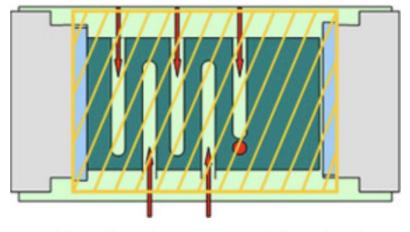
# High Resolution Digitally Trimmable Resistor

Presented by: Alek Benson, Clark Reimers, Pierce Nablo, Oluwatosin Oyenekan

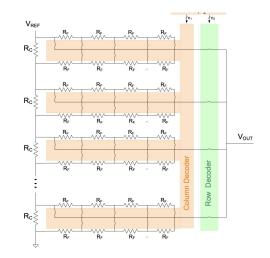


Trimming (conceptual drawing)

### **Project Description**

Team: sddec20-08

Team Email: sddec20-08@iastate.edu



#### **Project Statement:**

To design a high resolution digitally trimmable resistor. It should be capable of adjusting its resistance value by  $\pm 1\%$ , should be re-trimmable infinitely many times.

### **Project Goals**

- Conduct additional research targeted towards resistor structures.
- Refine simulation environment to improve precision of data.
- Expand on selected resistor structure schematics.
  - Refine existing schematics
  - Scale up designs to simulate more realistic scenarios
- Conduct more in-depth evaluations of resistor structures.
  - Consider scalability of designs
  - Consider TCR management of all logic states
- Repeatedly trimmable
- ±1% resolution
- Low temperature dependencies

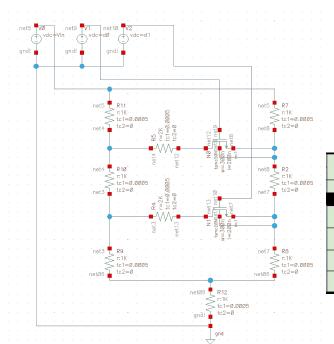
#### **Previous Technical Challenges**

- Mitigating temperature effects when designing the circuit structure
  - Limit amount of current through the switches
  - Maintain a somewhat small form factor
- Simulation issues with setting up proper settings
  - Reltol, abstol, simulation arithmetic rounding rules
- Determining a good TCR value for comparing structures between one another
  1500 ppm/°C

#### **Test Bench**

- Standardization:
  - 1500 ppm/°C TCR resistors
  - 300n x 200n size transistors
  - 10k Ohm Resistor
  - Vinput = 1V, Vg = 5V
- Comparing temperature effects on the voltage(TCV) due to the resistor ratio
- Still looking at the effective TCR of resistor structure
- Comparing total resistance value
  - Contributes to the overall size of component
- Comparing precision of trimming values

#### Ladder structure



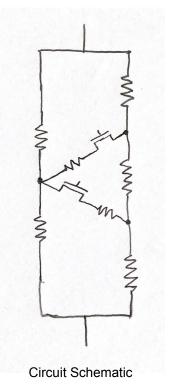
Theory:

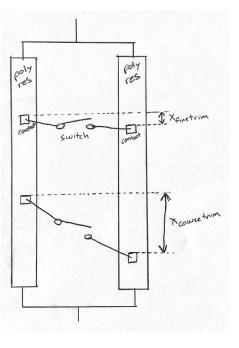
• Combination of Series and parallel structure.

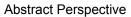
#### Data:

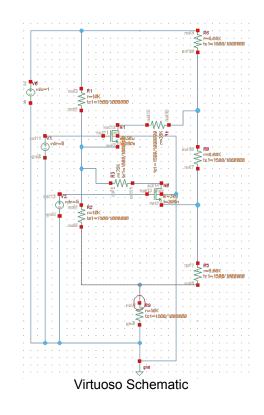
		Sim	ulate		Calcul	ate	Performance				
	State	Temp	V	I	Resistance	Trim	TCR	TCV	% Trim		
	OFF OFF	27.00	0.499999999996	0.00005000000	10,000.00	0.00	1500.0000	0.0000	0.00%		
	OFF OFF	28.00	0.499999999995	0.00004992511	10,015.00						
Ì	ON OFF	27.00	0.50085048695	0.00005008505	9,966.04	33.96	1502.1674	-1.0803	0.34%		
	ON OFF	28.00	0.50084994591	0.00005000998	9,981.01						
I	OFF ON	27.00	0.50242772187	0.00005024277	9,903.36	96.64	1500.2210	-0.1098	0.97%		
	OFF ON	28.00	0.50242766671	0.00005016752	9,918.22						
Î	ON ON	27.00	0.50252778869	0.00005025278	9,899.40	100.60	1500.2089	-0.1038	1.01%		
	ON ON	28.00	0.50252773655	0.00005017751	9,914.25						
-											

#### **Truss Structure**

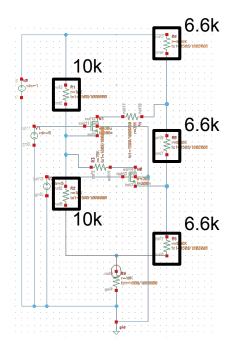






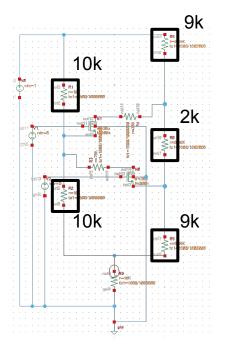


#### Truss Structure - Constant resistor ratio



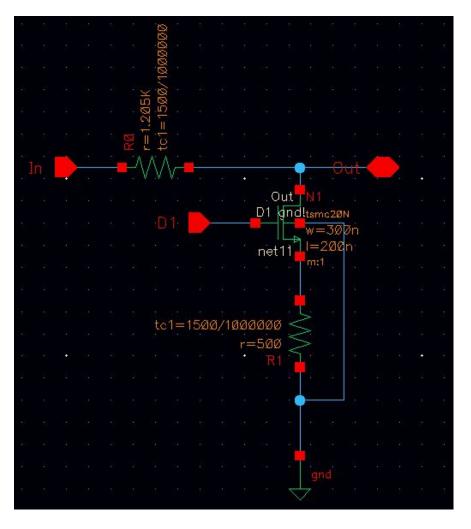
		R	esistor (	Configu	uration		Simulate				Calculate Performance				
Run		Left Res	Switch	1 size	Trim Res	<b>Right Res</b>		3111	ulate		Calct	liate		renormance	
	Level	(Ohms)	W (n)	L (n)	(Ohms)	(Ohms)	State	Temp	v	I	Resistance	Trim	TCR	тсу	% Trim
	1					6,660	OFF OFF	27.00	0.50012509390	0.00005000000	9,997.50	2.50	2004.0082	-0.0002	0.03%
	2	10,000	30,000	200	55,000		OFF OFF	28.00	0.50012509380	0.00004990000	10,017.53				
	3					6,660	ON OFF	27.00	0.50119944890	0.00005010000	9,956.10	43.90	1999.9974	0.0026	0.44%
1	4	10,000	30,000	200	55,000		ON OFF	28.00	0.50119945020	0.00005000000	9,976.01				
· 1	5					6,660	OFF ON	27.00	0.50119945160	0.00005010000	9,956.10	43.90	1999.9974	0.0026	0.44%
	6						OFF ON	28.00	0.50119945290	0.00005000000	9,976.01				
	7						ON ON	27.00	0.50253830750	0.00005030000	9,889.89	110.11	1992.0254	0.0064	1.10%
	8						ON ON	28.00	0.50253831070	0.00005020000	9,909.60				
	1					6,660	OFF OFF	27.00	0.50012509390	0.00005000000	9,997.50	2.50	2004.0082	-0.0002	0.03%
	2	10,000	30,000	200	35,000		OFF OFF	28.00	0.50012509380	0.00004990000	10,017.53				
	3					6,660	ON OFF	27.00	0.50094548200	0.00005010000	9,961.17	38.83	1999.9986	0.0014	0.39%
2	4	10,000	30,000	200	75,000		ON OFF	28.00	0.50094548270	0.00005000000	9,981.09				
-	5					6,660	OFF ON	27.00	0.50168116440	0.00005020000	9,926.67	73.33	1996.0026	0.0054	0.73%
	6						OFF ON	28.00	0.50168116710	0.00005010000	9,946.48				
	7						ON ON	27.00	0.50279753250	0.00005030000	9,884.74	115.26	1992.0232	0.0086	1.15%
	8						ON ON	28.00	0.50279753680	0.00005020000	9,904.43				

#### Truss Structure - Varying resistor ratio



_	Resistor Configuration						Simulate			Calculate		Performance			Total Trim Res		Equivalent Switch Resistance.			
un		Left Res						_	1	-								(all gates on)		
1	Level	(Ohms)	W (n)	L (n)	(Ohms)	(Ohms)	State	Temp	V	I	Resistance	Trim	TCR	TCV	% Trim	Switch Res	Total	Width (n)	Vs (v)	Length (n)
	1				_	9.000	OFF OFF	27.00	0.499999999990	0.00005000000	10.000.00	0.00	2004.0080	0.0000	0.00%					
	2	10.000	30,000	200	4,100	9,000	OFF OFF	28.00	0.499999999999		10.020.04	0.00	2004.0080	0.0000	0.00%	4.76	4,104.76	300	0.751237	1615,71685
	2	10,000	30,000	200	4,100	2,000	OFF OFF ON OFF	28.00	0.50044359580		9.991.13	8.87	-0.0050	0.0050	0.09%	4.70	4,104.76	300	0.751257	1015.71085
	4	10.000	30.000	200	4,100	2,000	ON OFF	27.00		0.00005000000	9,991.13	0.07	-0.0050	0.0050	0.09%	4.76	4,104,76	300	0.730814	1624.51916
1		10,000	30,000	200	4,100	9.000	OFF ON	28.00	0.50044359830		9,991.13	8.87	-0.0048	0.0048	0.09%	4.76	4,104.76	300	0.730814	1624.51916
	5					9,000	OFF ON	27.00	0.50044359430		9,991.13	6.67	-0.0048	0.0048	0.09%					
	7						OFF ON ON ON	28.00		0.00005020000	9,991.13	89.13	-0.0762	0.0754	0.89%	-				
	8						ON ON	28.00		0.00005020000	9,910.87	09.13	-0.0762	0.07.54	0.69%					
-	0		_				ON ON	28.00	0.50247455750	0.00003020000	9,910.87			_						
	1					9.000	OFF OFF	27.00	0.499999999990	0.00005000000	10.000.00	0.00	2004.0080	0.0000	0.00%	1				
	2	10,000	30,000	200	2,050	-,	OFF OFF	28.00		0.00004990000	10,020.04					4.76	2.054.76	300	0.755833	807.804030
	3	10,000	00,000	200	2,000	2,000	ON OFF	27.00		0.00005010000	9,969,68	30.32	1999.9932	0.0068	0.30%		2,001110			
	4	10.000	30.000	200	6.150	-,	ON OFF	28.00	0.50051913230	0.00005000000	9,989,62					4.76	6.154.76	300	0.726936	2438.3426
2	5				-,	9.000	OFF ON	27.00	0.50038724980		9,992.26	7.74	-0.0036	0.0036	0.08%		-,			
	6					-,	OFF ON	28.00	0.50038725160		9,992.25									
	7						ON ON	27.00	0.50256662200	0.00005030000	9.889.33	110.67	1991,9491	0.0818	1.11%					
	8						ON ON	28.00	0.50256666310	0.00005020000	9,909.03									
											.,									
	1			1		9,000	OFF OFF	27.00	0.499999999990	0.00005000000	10,000.00	0.00	2004.0080	0.0000	0.00%					
	2	10.000	30,000	200	6,150		OFF OFF	28.00	0.499999999990	0.00004990000	10.020.04					4.76	6.154.76	300	0.746733	2425.54879
	3					2.000	ON OFF	27.00	0.50038725090	0.00005000000	9,992.25	7.75	-0.0038	0.0038	0.08%					
	4	10.000	30,000	200	2,050		ON OFF	28.00	0.50038725280	0.00005000000	9,992.25					4.76	2,054.76	300	0.735127	812.271349
3	5					9,000	OFF ON	27.00	0.50051912680		9,969.68	30.32	1999.9932	0.0068	0.30%					
	6						OFF ON	28.00	0.50051913020	0.00005000000	9,989.62									
	7						ON ON	27.00	0.50256661790	0.00005030000	9,889.33	110.67	1991.9491	0.0818	1.11%					
	8						ON ON	28.00	0.50256665900	0.00005020000	9,909.03									

### Voltage divider



	VD all bits on								
	Temp	Vdd	Vout	Current	R	TCV	TCR		
	27	1	3.31E-01	3.31E-05	20,200.17	2.40E-04	1,500.00	7.94E-11	2.40E-04
	28	1	0.3311239927	3.31E-05	20,230.47	1			
	VD 1 bit on								
	Temp	Vdd	Vout	Current	R	TCV	TCR		
	27	1	0.3322263763	3.32E-05	20,099.96	-9.11E-03	1,500.01	-3.03E-09	-9.11E-03
	28	1	0.3322263733	3.32E-05	20,130.11				
	VD other bit on								
ľ	Temp	Vdd	Vout	Current	R	TCV	TCR		
	27	1	0.3322263443	3.32E-05	20,099.96	-9.39E-04	1,500.00	-3.12E-10	-9.39E-04
	28	1	0.332226344	3.32E-05	20,130.11				
	VD bits off								
2	Temp	Vdd	Vout	Current	R	TCV	TCR		
	27	1	0.3333333141	3.33E-05	20,000.00	-2.25E-03	1,500.00	-7.50E-10	-2.25E-03
	28	1	0.3333333134	3.33E-05	20,030.00	)			

### **Current Technical Challenges Overview**

Thermometer coded vs Binary weighted

#### Currently

Bits	Trim
00	0%
01	1%
10	1%
11	2%



Bits		Trim
	00	0%
	01	0.33%
	10	0.66%
	11	1%

## Questions?