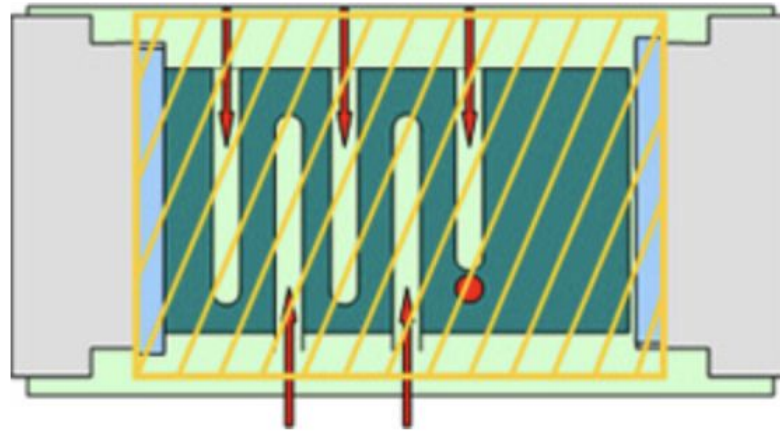


High Resolution Digitally Trimmable Resistor

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



Trimming (conceptual drawing)

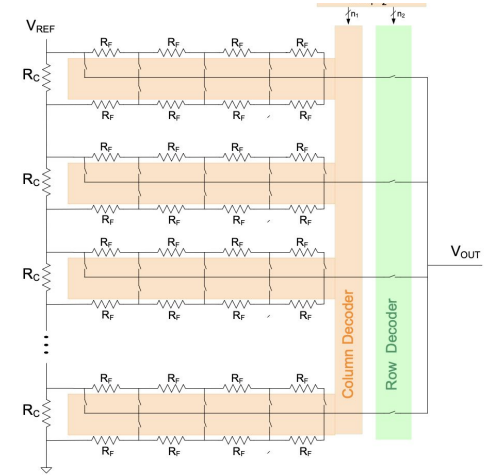
Project Description

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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
- $\pm 1\%$ 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

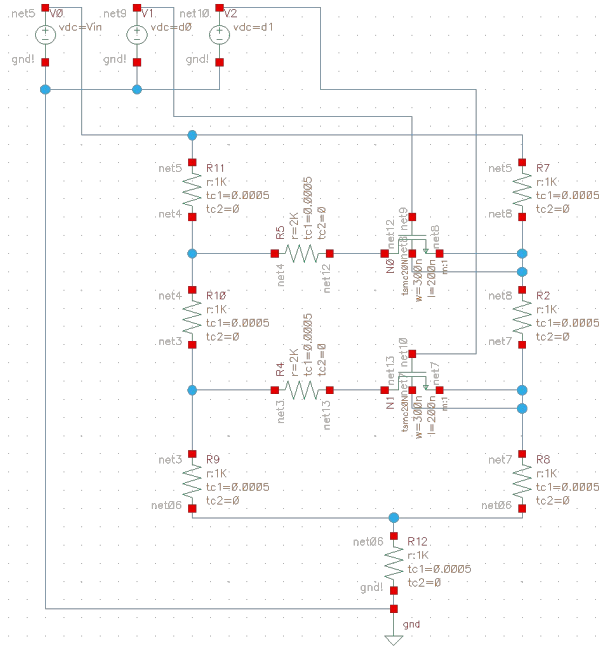
- Standardization:
 - 1500 ppm/°C TCR resistors
 - 300n x 200n size transistors
 - 10k Ohm Resistor
 - $V_{input} = 1V$, $V_g = 5V$
- Comparing temperature effects on the voltage(TCV) due to the resistor ratio
- Still looking at the effective TCR of resistor structure
- Comparing total resistance value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

Ladder structure

Theory:

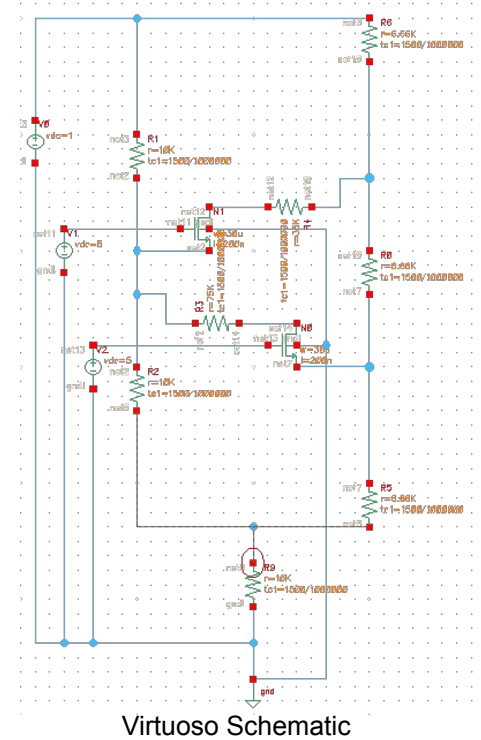
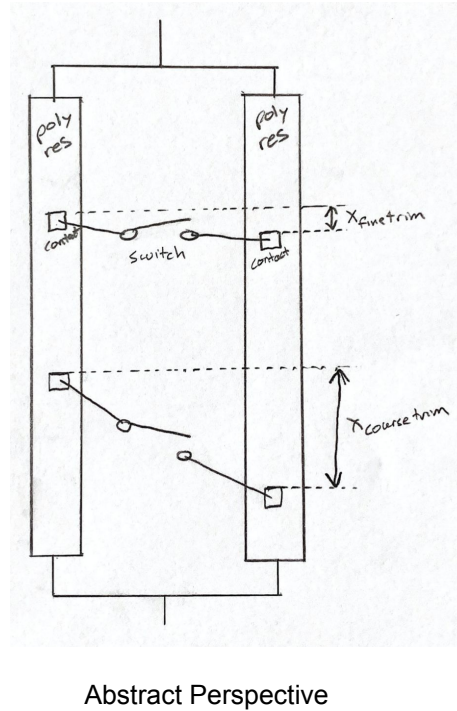
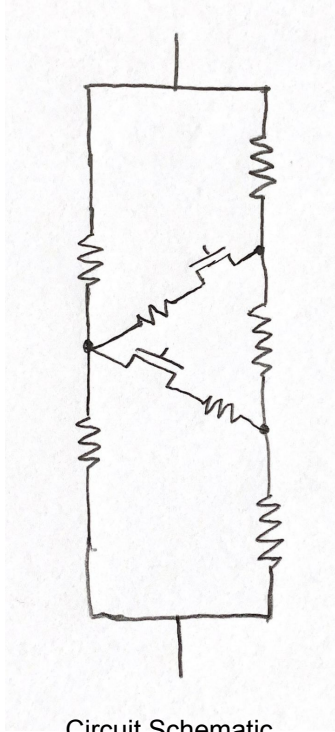
- Combination of Series and parallel structure.

Data:

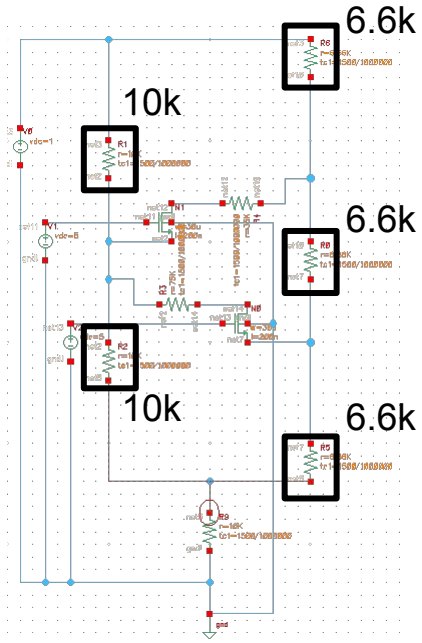


Simulate				Calculate		Performance		
State	Temp	V	I	Resistance	Trim	TCR	TCV	% Trim
OFF OFF	27.00	0.499999999996	0.000050000000	10,000.00	0.00	1500.0000	0.0000	0.00%
OFF OFF	28.00	0.499999999995	0.00004992511	10,015.00				
ON OFF	27.00	0.50085048695	0.00005008505	9,966.04	33.96	1502.1674	-1.0803	0.34%
ON OFF	28.00	0.50084994591	0.00005000998	9,981.01				
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				
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

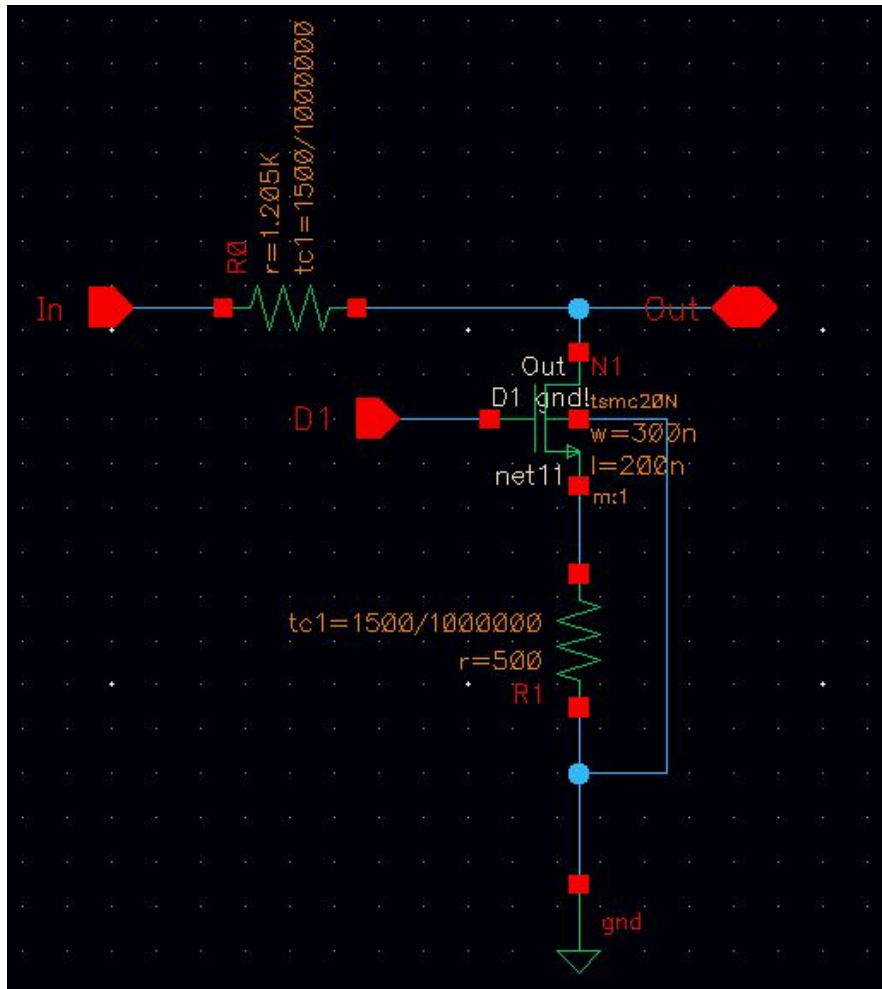


Truss Structure - Constant resistor ratio



Run	Resistor Configuration					Simulate				Calculate		Performance				
	Level	Left Res (Ohms)	Switch size W (n)	L (n)	Trim Res (Ohms)	Right Res (Ohms)	State	Temp	V	I	Resistance	Trim	TCR	TCV	% Trim	
	1						6,660	OFF OFF	27.00	0.50012509390	0.00005000000	9,997.50	2.50	2004.0082	-0.0002	0.03%
1	2	10,000	30,000	200	55,000	6,660	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%	
	4	10,000	30,000	200	55,000	6,660	ON OFF	28.00	0.50119945020	0.00005000000	9,976.01					
	5					6,660	OFF ON	27.00	0.50119945160	0.00005010000	9,956.10	43.90	1999.9974	0.0026	0.44%	
	6						6,660	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				
	2	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	6,660	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%	
4		10,000	30,000	200	75,000	6,660	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							6,660	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				

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					
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									
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									
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%

Goal

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

Questions?