University Alliance

SUMMiT V

Design Review Changes

Albuquerque Technical Vocational Institute

Advanced MEMS Co-op

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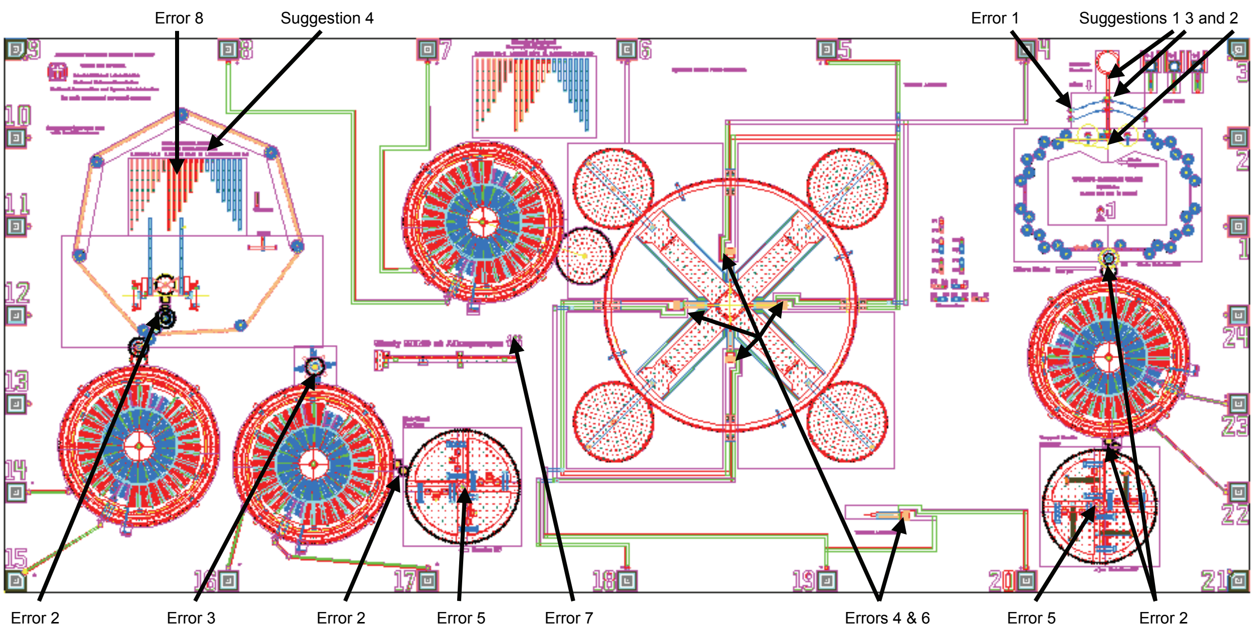
Forward

The following paper is an addendum to the University Alliance SUMMiT V Design Competition submission from the Albuquerque Technical Vocational Institute (TVI). TVI was awarded as the winner in the Novel Design Category. Subsequently, the design was reviewed by Sandia National Laboratories (SNL). Their corrections and suggestions are dealt with in this paper. *Italicized* text indicates quotes from the SNL review ("TVI-Review.doc"). All graphics represent the updated design.

Layout



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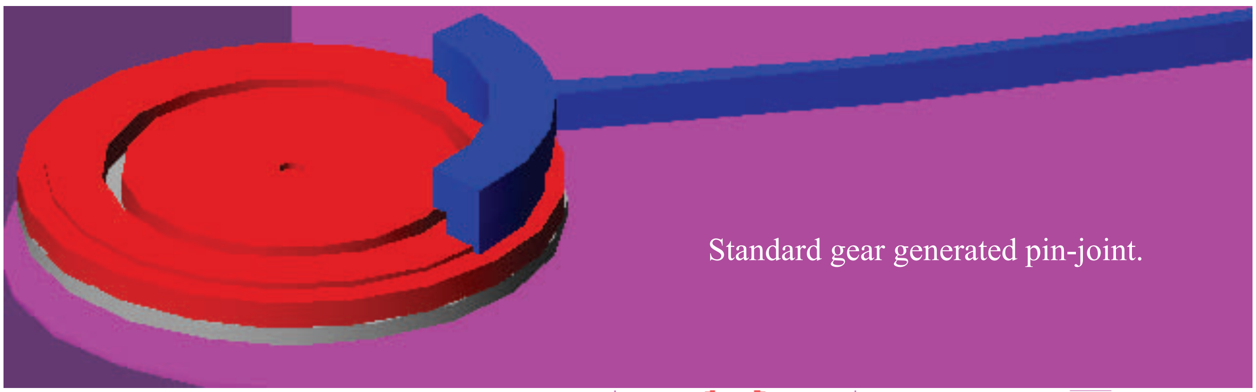
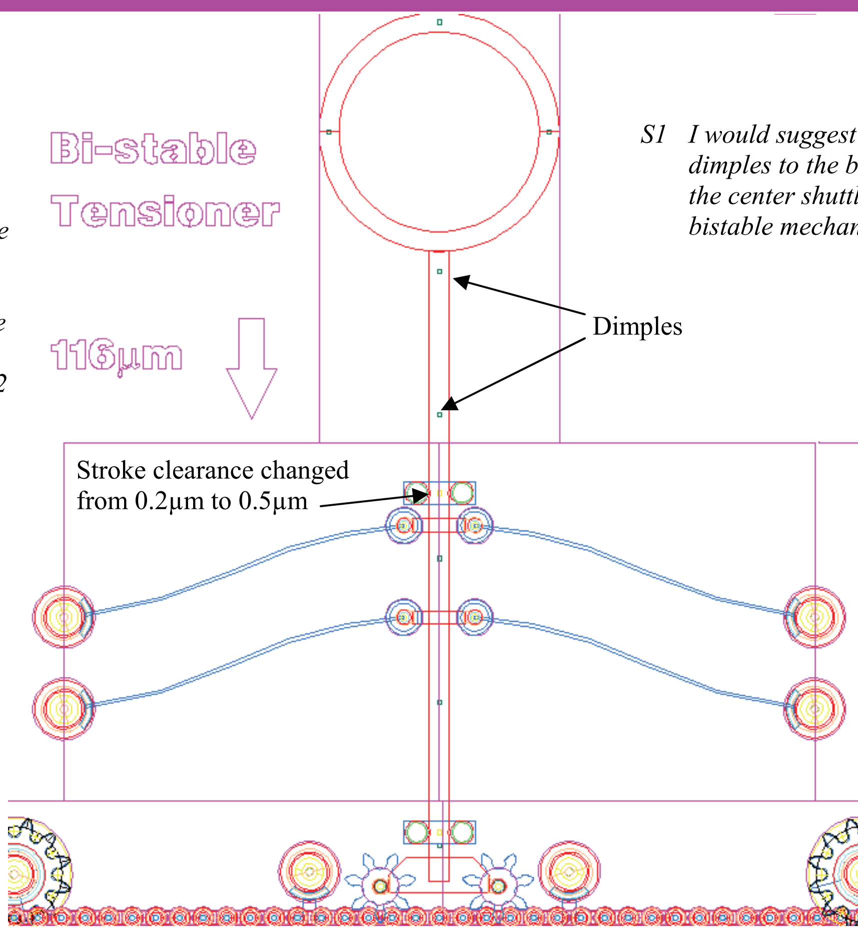
Error 1 and Suggestions 1 and 3

E1. The pin-joint used to attach the bistable mechanism to the substrate is not designed correctly. There are three potential issues. First, the sacox2 feature is drawn to be exactly coincident with the poly2 edge (as defined by the mmpoly2_cut layer). As mask alignment is not perfect, this will likely cause a stringer to form at some location around the cut that attaches the poly2 down to the poly1, rendering the pin-joint inoperable. To visualize this, move the sacox2 feature by 0.2 microns in X and do a horizontal cross-section through the pin-joint. Second, there is a ring of poly2 around the base of the pin-joint that serves no purpose. It will not likely cause any harm, but should be removed. Third, there will be small dimple-like formations in the poly2 above the sacox1_cut features due to conformity of the poly1 in the oxide cut. If the oxide cut were drawn as a donut this would not cause any problems, but as it's drawn in four sections, the dimple may create interference when the pin-joint is rotated so that it is above the section without a sacox1_cut feature. My recommendation would be to just use the pin-joint found in the center of the standard gear as generated by the gear generator tool.





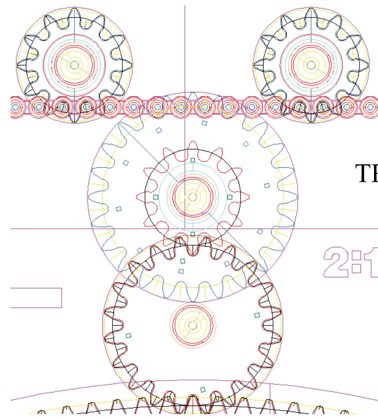
S1 I would suggest adding dimples to the bottom of the center shuttle of the bistable mechanism.

S3 The guides used on the bistable mechanism are a good idea and have been shown to be effective in past designs. However, 0.2 microns of clearance is a little tight, especially because tight tolerances are not critical at this particular location.

Error 2

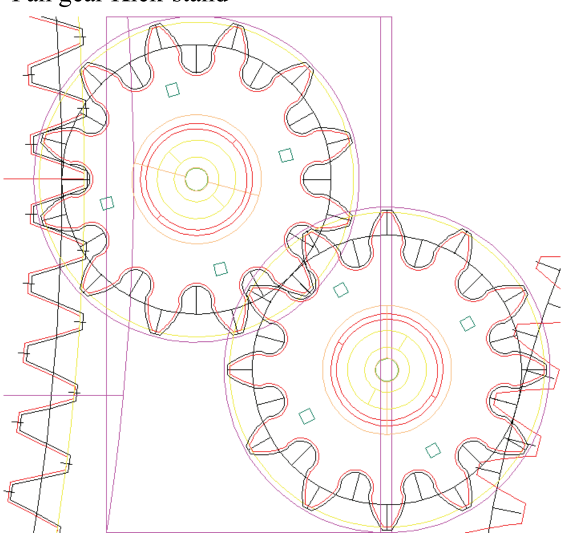
E2 In several places in this module there are gears that are not properly aligned. To mesh correctly, the pitch circles of the two meshing gears must be tangent to one another. This error was found at:

1. *the P12 gears connecting the TRA idler gear to the chain drive.*
2. *The P12 connection between the idler gear and the trapped SacOX Fan Gear.*
3. *The P12 connection between the idler gear and the kick-stand fan gear.*
4. *The P12 connection between two idler gears above the belt drive. This is at location 820,1412 in the drawing file.*

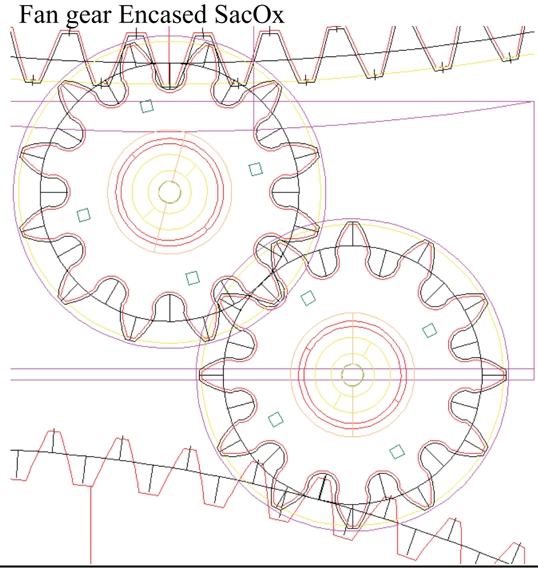


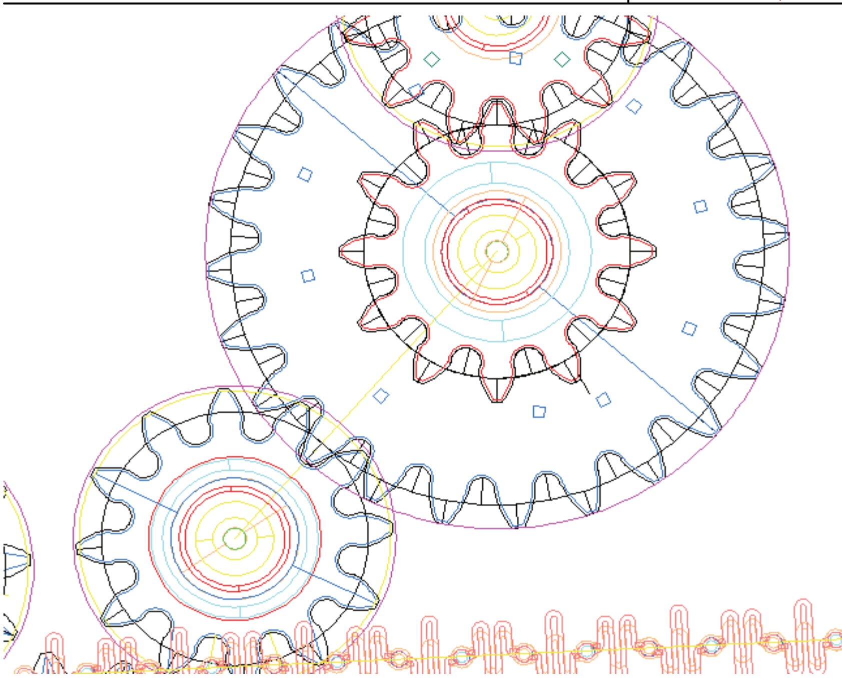
TRA to Chain

Fan gear Kick-stand



Fan gear Encased SacOx



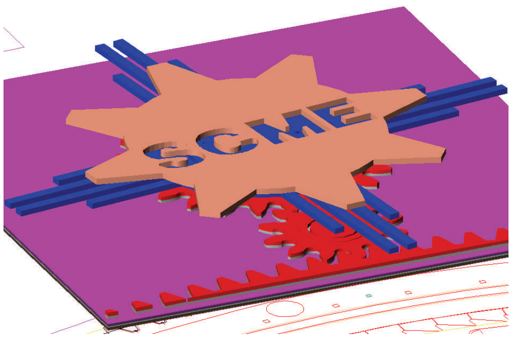


Gear inside Belt

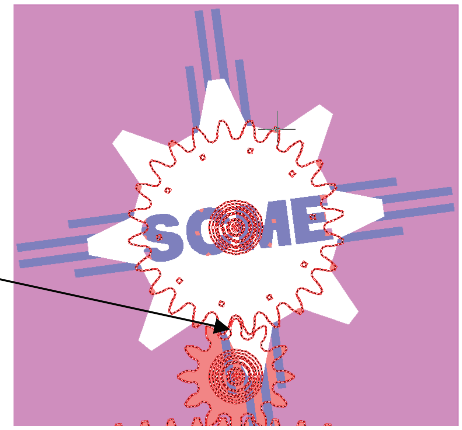
Errors 3, 5 and 7

E3 There is a gear with an SCME logo in P3 and P4 attached to the TRA used to drive the kick-stand fan gear. This SCME logo idler gear is not properly aligned with the TRA, and is in fact overlapping such that the TRA will not function.

SCME TRA connection

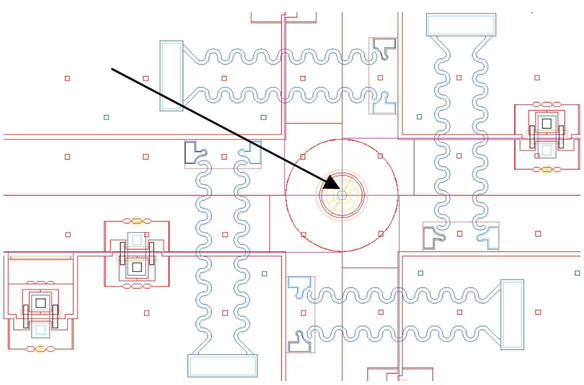


Proper Gearing

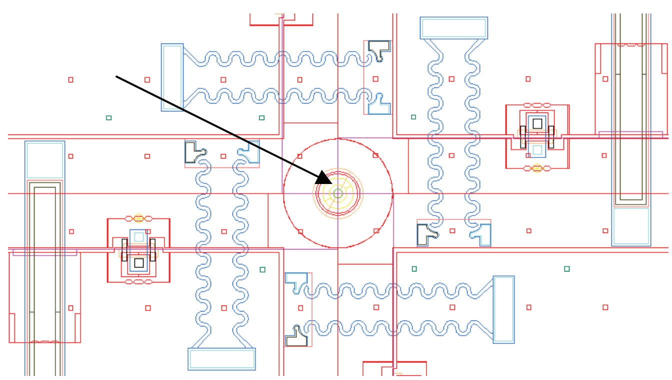


E5 Both Fan Gears are not anchored. Two gears in the belt drive structures are not anchored. These will float away during release.

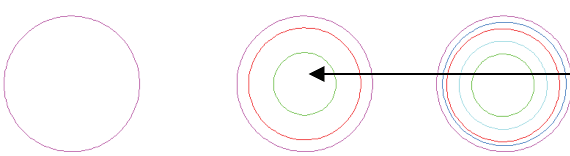
SacOx1_Cut Fan Gears connection to substrate



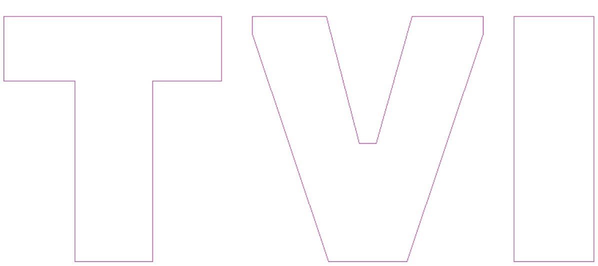
Kick-stand



Encased SacOx



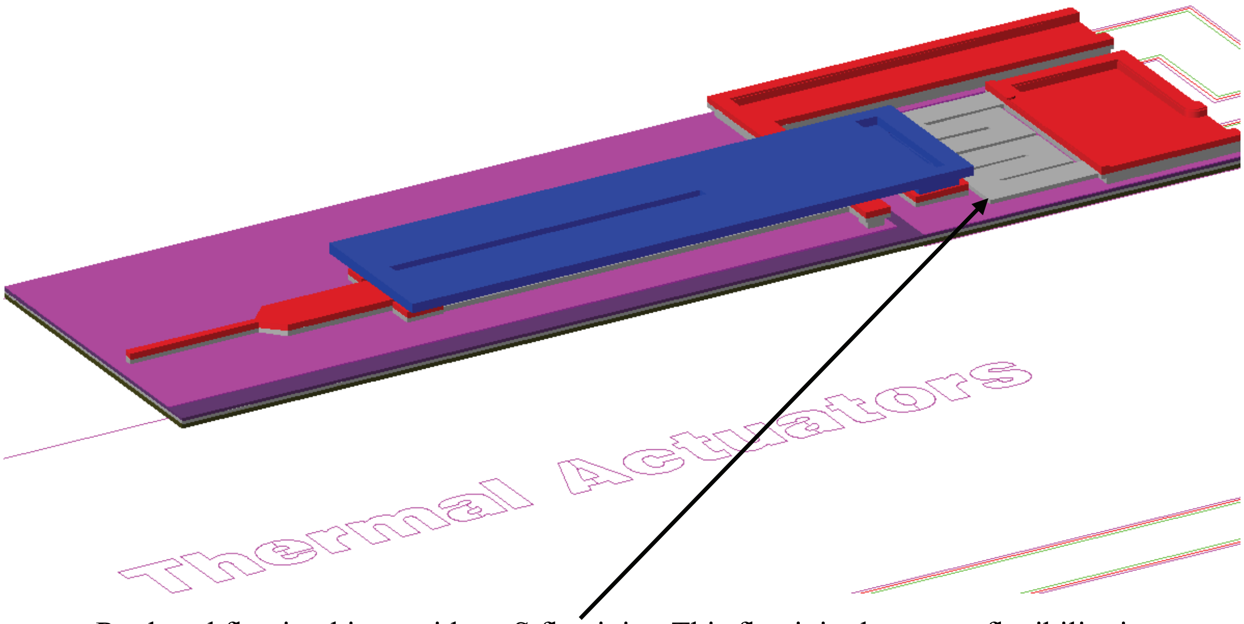
TVI Dot with SacOx1_Cut properly connected to substrate



E7 Poly2 Floater over the "V" in TVI Logo. Need to anchor P2.

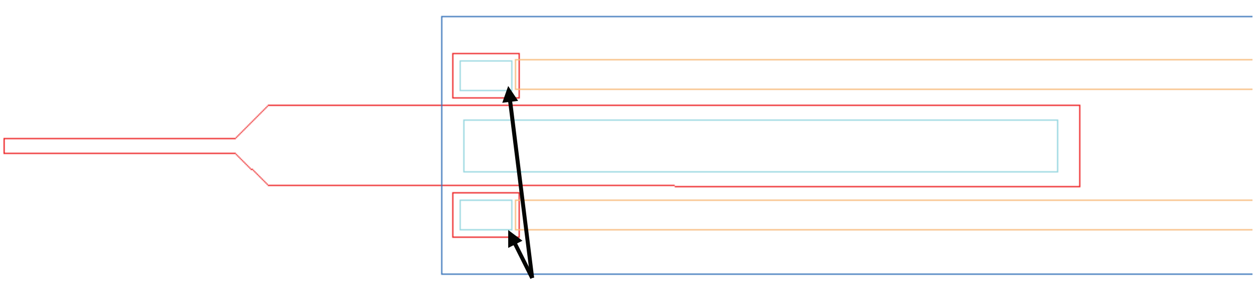
Errors 4 and 6

E4 The out-of-plane thermal actuators used to lift the symmetric-out-of-plane table will not function as currently designed because of the use of a hinge at the base of the wider "cold" arm. The AutoCAD layout that I received for review appears to be different from what is shown in the .pdf documentation. The documentation shows the wide arm anchored using P1, whereas the layout has an in-plane hinge. The hinge will not provide electrical continuity across the actuator, and will prevent any current from passing through the arms (poly on poly contact is very high resistance, very unreliable, and in this case not even guaranteed). In addition, the predicted actuator elongation at 500C is only 0.125 microns, much less than the 1 micron gap in the hinge design. The hinge should be replaced with a compliant flex joint, similar to what is shown in the documentation.



Replaced floating hinge with an S flex joint. This flex joint has more flexibility in the z– direction (straight up and down) but stiff in the x and y direction.

E6 It appears there is a floating structure on the thermal actuator using bond pads 18 & 19, defined with Poly2 and Poly1(sacox2)

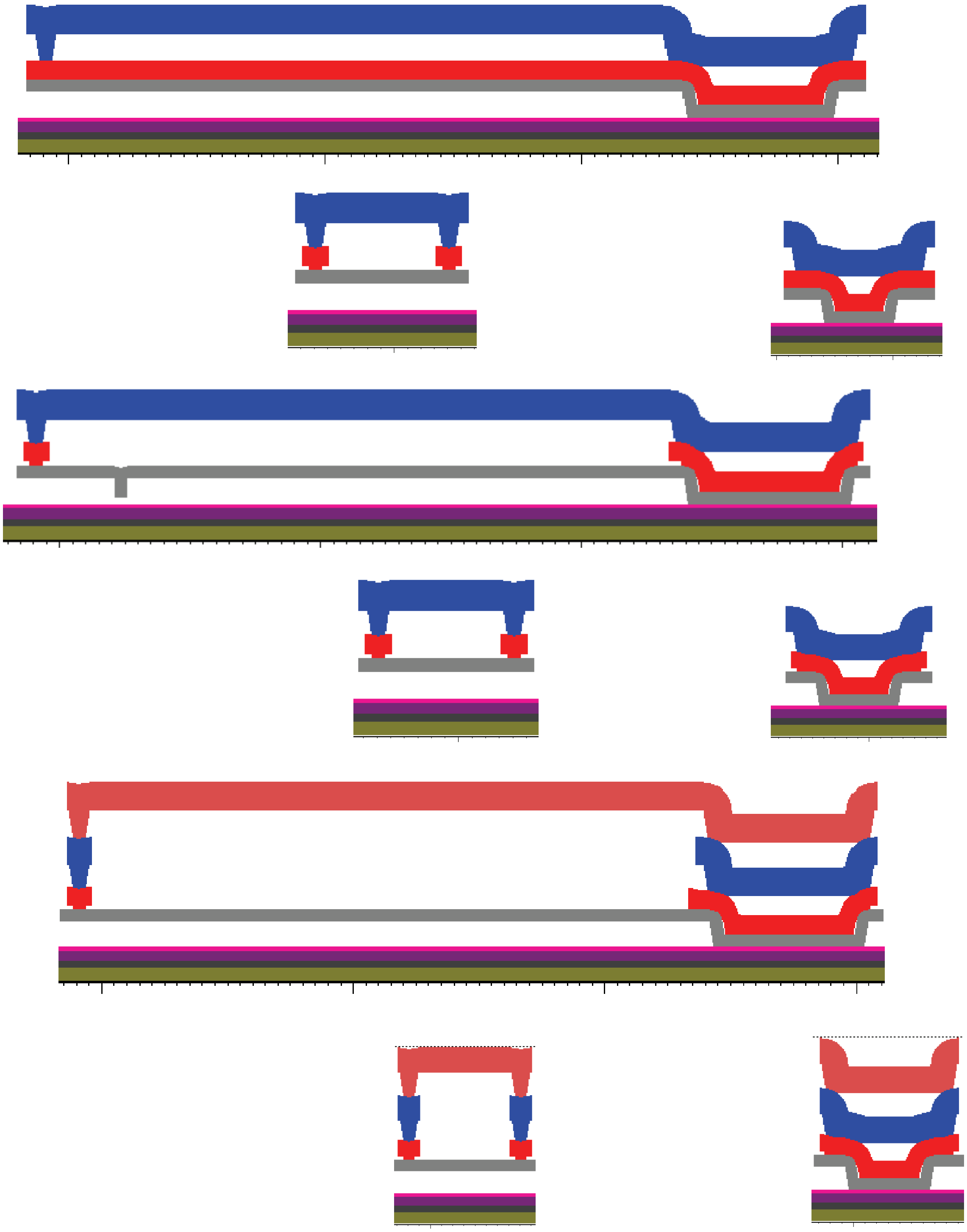


The original design had a missing SacOx3_cut layer which was causing an incomplete circuit. New design has a complete electrical connection.

Error 8

E8 Odd anchors in most of the trapped Oxide beams. This may not be what was originally intended. Do a 2D cross section through the SacOx1_Cut in the anchor region to see the space between the P1 and P2.

New anchored cantilevers were added and the old anchored cantilevers were kept in the design for comparison purposes. Cross sections are shown for the cantilever's beam and anchor for each of the 3 designs.



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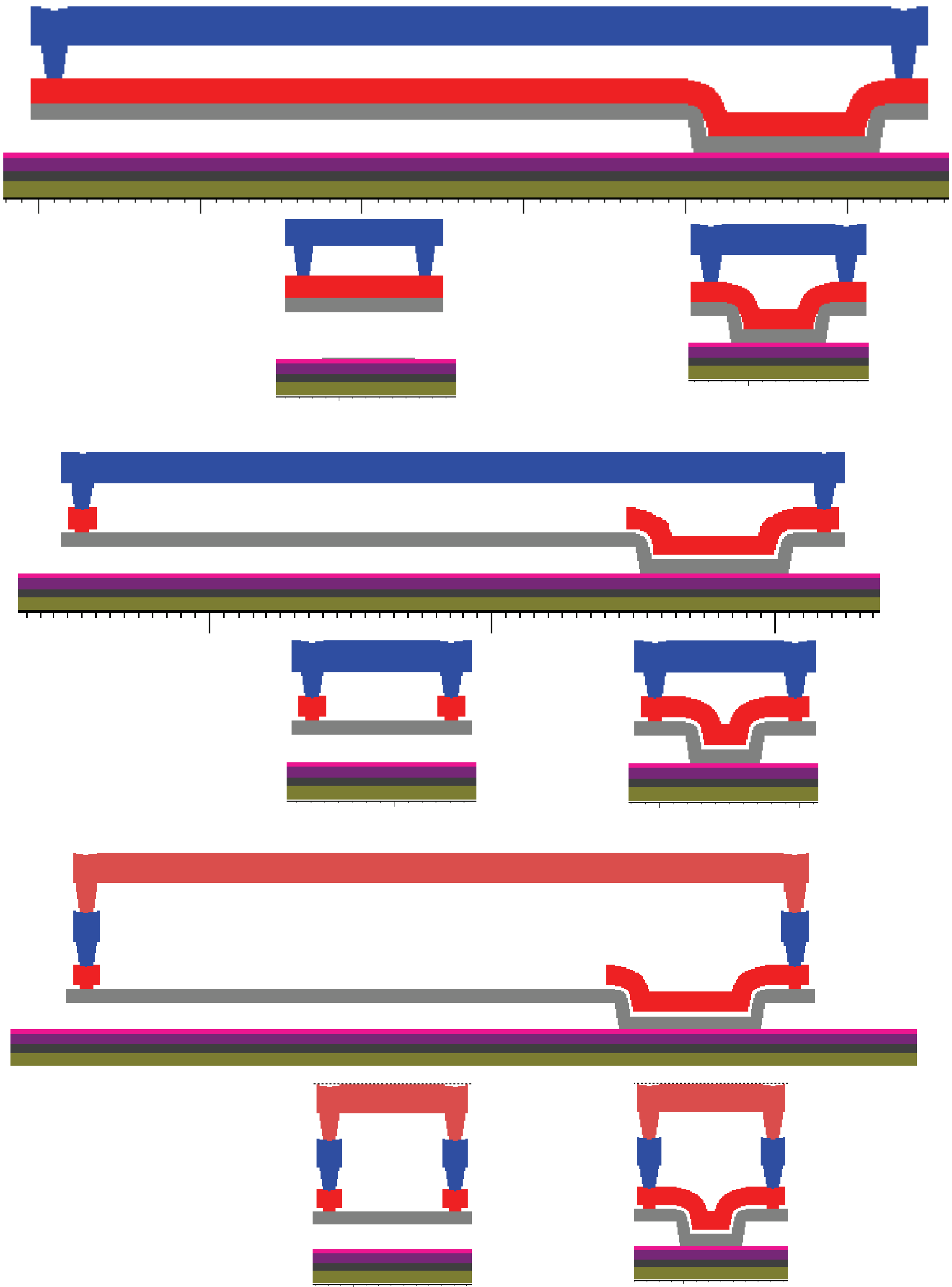
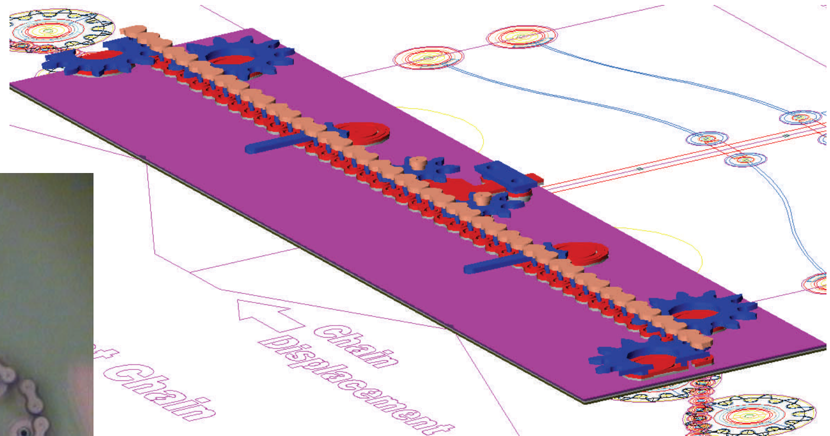
Error 8 continued

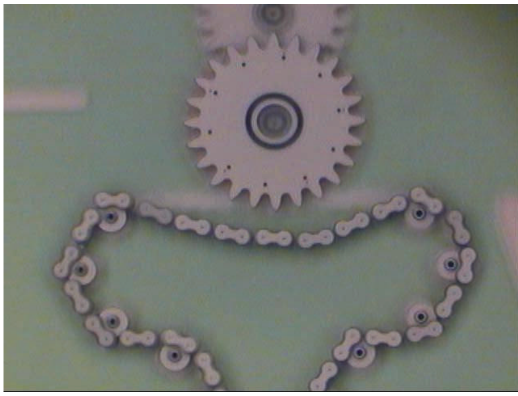
The unorthodox anchors were kept because additional residual stress may be produced within the anchors.

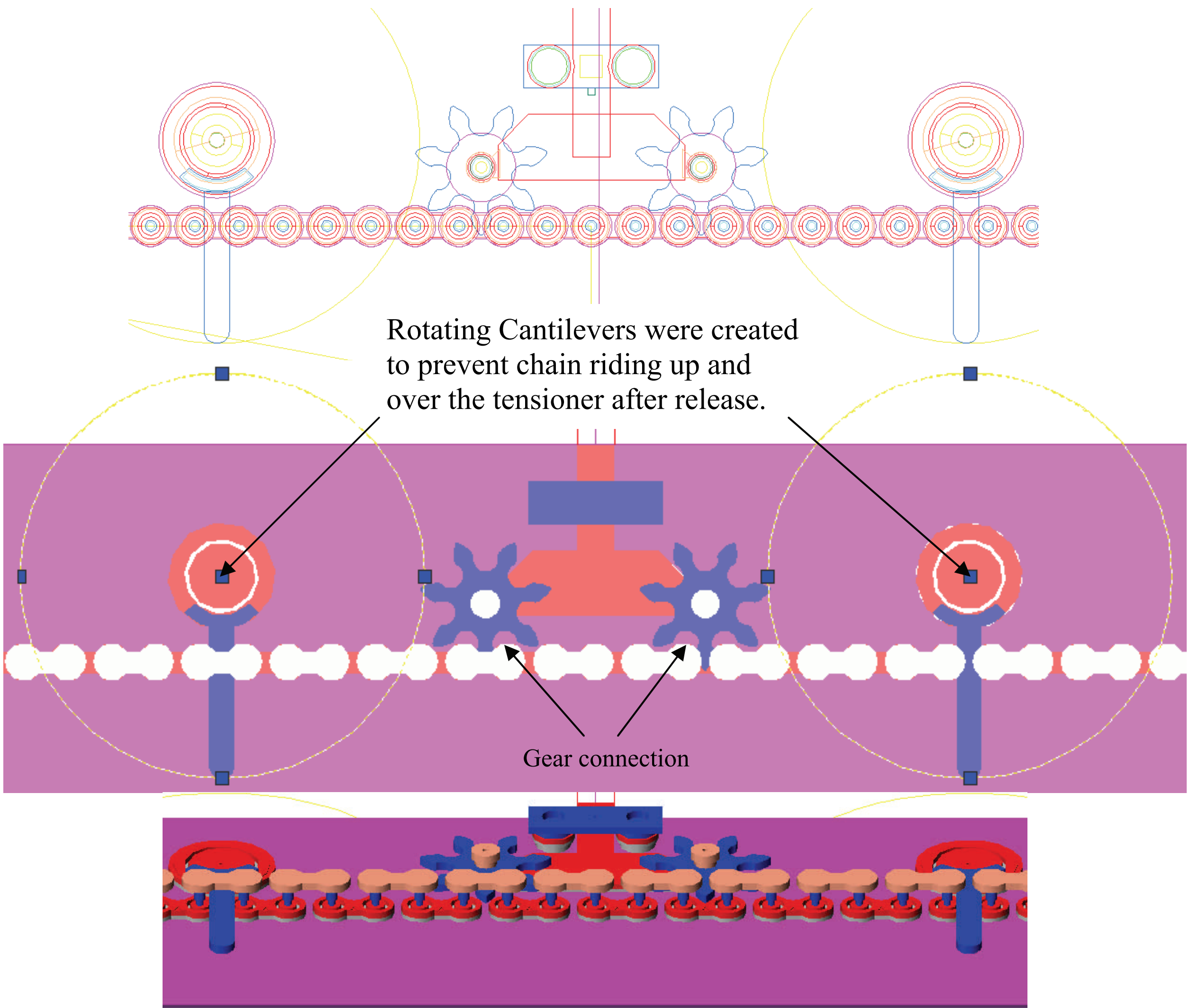


Suggestion 2

S2 While this may not be critical, you may want to consider using a gear on the end of the bistable mechanism instead of the current design with two free rollers. The gear (attached to the mechanism, not to the substrate) would engage with the chain preventing it from disengaging (riding up over the existing wheel system).







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Suggestion 2 continued

Tensioner Calculations.

Length from pin joint to pin joint = 11.8125µm
Amount of slope per link = ±0.2µm/link (SNL 2D Process Visualizer)

Number of links between gears at tensioner interface = 44
Slop between gears at tensioner interface = 8.8µm

Pre-release distance = 519.75µm

Chain w slop = 519.75µm + 8.8µm = 528.55µm

259.875µm per side
264.275µm per side

$$\sqrt{c^2 - a^2} = b$$

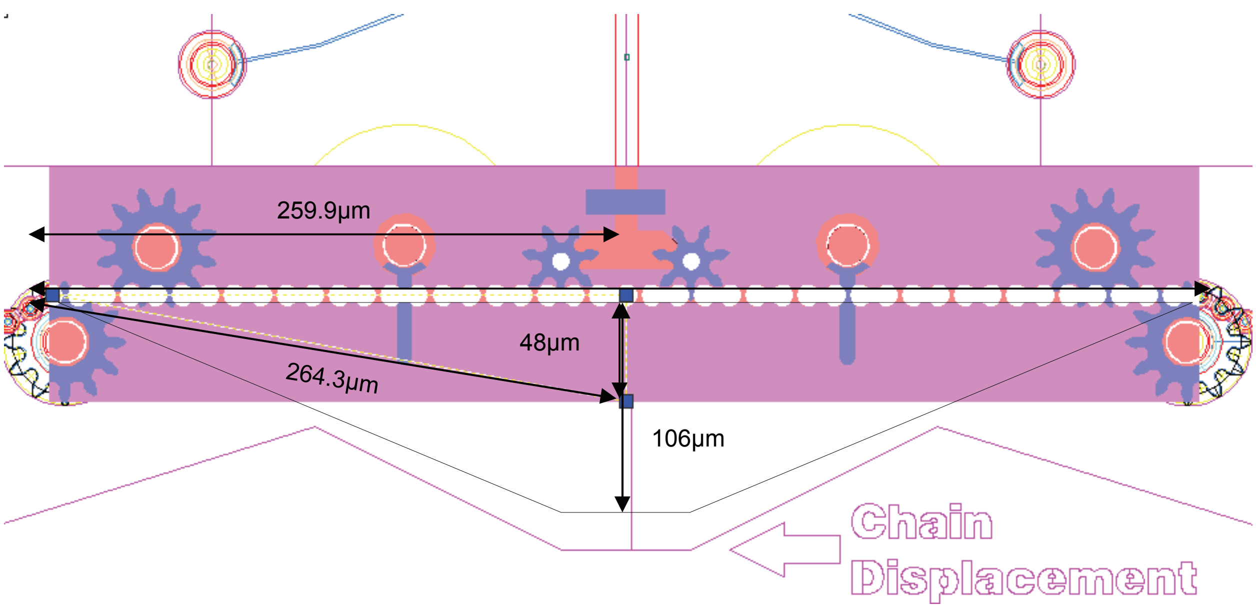
$$\sqrt{264.275^2 - 259.875^2} = 48.024\mu m$$

Number of links total = 208
Slop for entire chain = 41.6µm

259.875µm per side
280.675µm per side

$$\sqrt{c^2 - a^2} = b$$

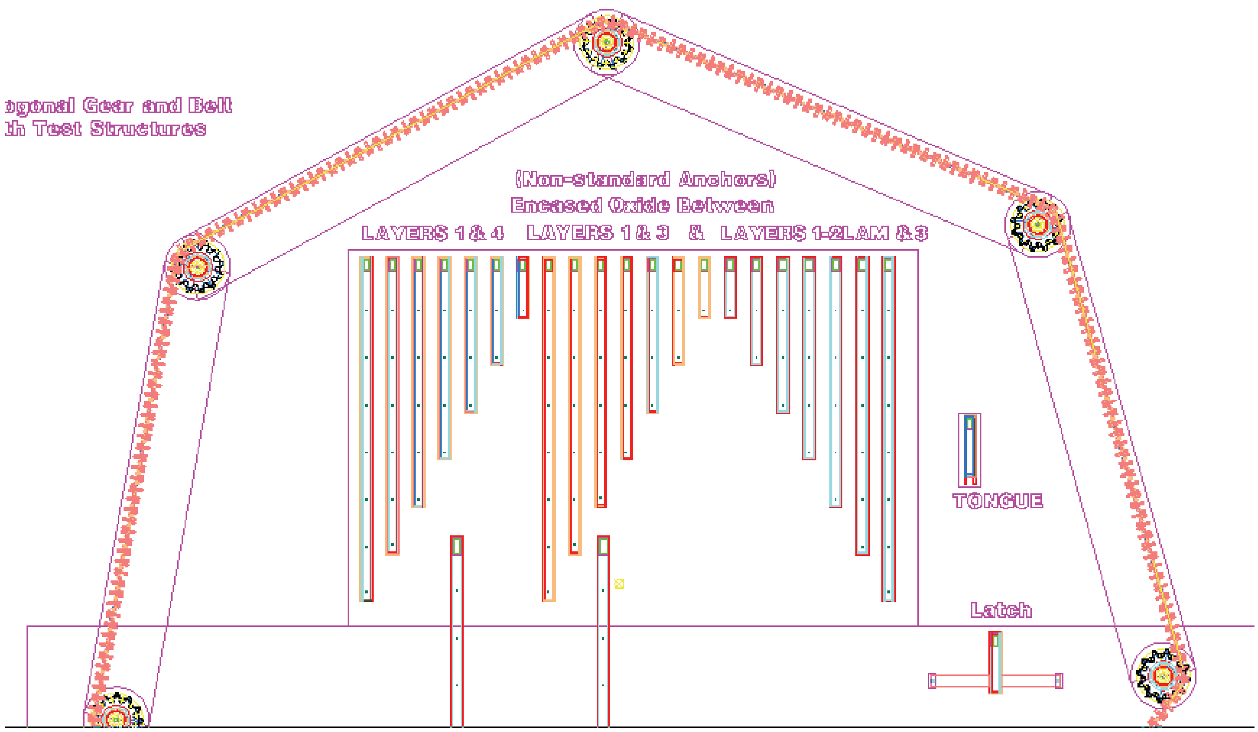
$$\sqrt{280.675^2 - 259.875^2} = 106.035\mu m$$



The amount of stroke is 116µm. The calculated distance is 106µm. An extra 10µm is added to compensate for tolerances found in the gear interface and the distance between the chain and the gear tensioner connection.

Suggestion 4

S4 The P0 text written on the inside of the belt drives will not be visible as it is surrounded by a large P0 area. This text would need to be changed to mmpoly0_cut for it to be visible. The poly0 issue mentioned above is repeated in the pull tab structures there are Poly features drawn inside other Poly0 features. (This may be intentional.) The lettering close to Bond Pad7 connection will not be produced for same issue.



Suggestion 5

S5 You should just be aware that the voltage required to power the thermal actuators used to lift the platform will be much higher than predicted in the .pdf documentation because of the significant trace resistance between the actuator and the bond pads.

Design of Thermal Actuators

The design of a vertical thermal Actuator involves the application of certain principles of electrical properties as well as thermal expansion. This design consists of using a hot arm made of 1µm thick MMpoly1 and a cold arm of MMPoly 3. There will be 2 hot arms per actuator, and they will both be 100µm long and 4µm wide. When a current is applied through the hot arm, the resistance caused by the small channel will make it heat up and expand. This expansion will lift the thermal actuator push rods in an upward direction.

Basic calculations would need to be made in order to determine what voltage and current are needed to drive the actuators. The first step is to determine the resistance of a bar of silicon 1µm thick, 4µm wide and 100µm long . The resistance is determined by using the intrinsic characteristics of polysilicon's resistivity and applying to *eq. 1*. All polysilicon layers are in n-type with a varying resistivity anywhere from 2-20Ω cm .[2]

R= ρ L/A *eq. 1*

Table 3 in the SUMMiT V design manual shows the electrical conductivity of each polysilicon layer in units of Ohm/Square.[2] By taking the length and dividing it by the width of the polysilicon layer one can get the # of squares (this number can be in decimal form) multiplying this by the Ohm/Square values in Table 3 will result in the resistance of that particular polysilicon layer. All the calculations for each Poly layer is shown in Appendix B.

For a Si beam 100µm long and a cross sectional area of $4\mu m^2$ a minimum current of 3.5 mA is required to generate an average temperature of 531C° to initiate buckling. [1]. Therefore by applying Ohm's law *eq.2* the minimum voltage needed to cause buckling would be 20.75V for thermal actuators 1 and 2, and 27.68V for thermal actuators 3 and 4. The voltages differ due to the significant difference in resistance caused by the length of the power lines from the bond pads to the thermal actuators. It is for this same reason that it is imperative that the resistance of the power lines going into each thermal actuator is equivalent to one another. This resulted in having to make modifications to the electrical power connections as shown in *figure 1* . This is accomplished by making the lengths equal. This guarantees an equal distribution of current to all thermal actuators. The calculations of V12 and V34 are shown on Appendix B.

V=IR *eq. 2*

V12 = IR12	V34 = IR34
V12 =(14mA) (1482Ω)	V34= (14mA) (1977Ω)
V12 =20.75V	V34=27.68V

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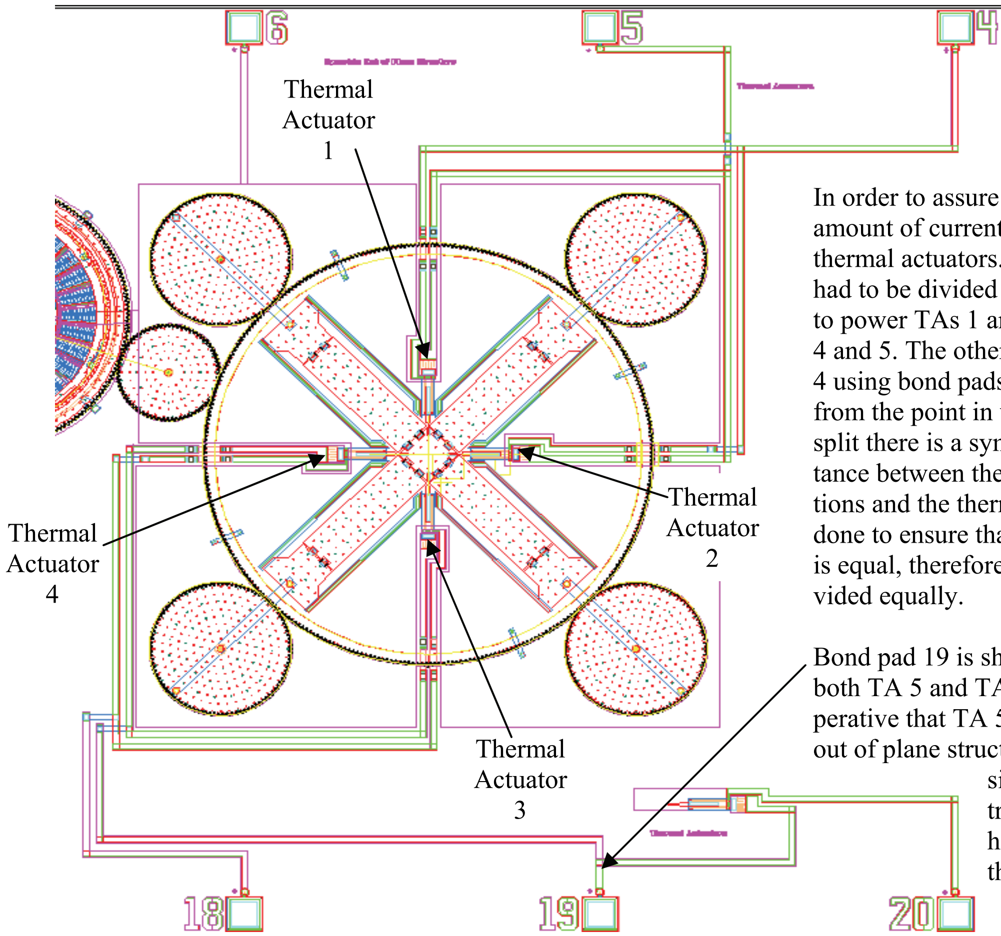
[1]. Mu Chiao and Liwei Lin " Self-Buckling of Micromachined Beams Under Resistive Heating" Journal of Microelectromechanical Systems, Vol 9, No. 1, March 2000, pp.146-151

[2] Sandia National Laboratories " SUMMiT V Five Level Surface Micromachining Technology Design Manual", Version 1.2- 11/01/2001, pp.7



In order to assure that there is an equal amount of current going through all 4 thermal actuators. The power supplied had to be divided into 2 sources. One to power TAs 1 and 2 using bond pads 4 and 5. The other to power TAs 3 and 4 using bond pads 18 and 19. Note that from the point in which the current is split there is a symmetry in the distance between the electrical connections and the thermal actuators. This is done to ensure that the total resistance is equal, therefore the current is divided equally.

Bond pad 19 is shared as a ground for both TA 5 and TAs 3 and 4. It is imperative that TA 5 is not used when the out of plane structure is in operation, since it can cause a tremendous amount of heat build-up around the bond pad 19.

figure 1

Signal Input Table

Bond Pad Number	Input Signal Label	Input Frequency	Input Voltage Pk to Pk	Waveform	Other
Vertical Thermal Actuators 1 and 2 (Symmetric Out-of-Plane Structure)					
5	Ground	0	0	N/A	
4	Input	DC or square	TBD	DC or square	
6	Earth Ground				
Torsional Ratchet Actuator (Symmetric Out-of-Plane Structure)					
7	Ground	0	0	N/A	
8	Input	< 30Hz	70-90V	Clipped Square	
Vertical Thermal Actuator 3 and 4 (Symmetric Out-of-Plane Structure)					
18	Input	DC or square	TBD	DC or square	
19	Ground	0	0	N/A	shared with TA 5
Vertical Thermal Actuator 5 (Independent Thermal Actuator)					
20	Input	DC or square	TBD	DC or square	
19	Ground	0	0	N/A	shared

Appendix B

	width	length	squares	Ohm/ square	Ohms	*Sectional Resistance
Power feed TAs 1 & 2						**358.9**
MMPoly0	20	912	45.6	28.4	1295.04	
MMPoly1_2 Laminate	18	912	50.66	9.8	496.5	
Ground lead TAs 1 & 2						**281.7**
MMPoly0	20	629	31.45	28.4	893.18	
MMPoly1_2 Laminate	18	629	34.94	9.8	342.45	
MMPoly3 Bridge	18	75	4.16	8.2	34.16	
Power feed TA 1						**446.45**
MMPoly0	20	1134.5	56.73	28.4	1611.13	
MMPoly1_2 Laminate	18	1134.5	63.02	9.8	617.6	
Ground lead TA 1						**400.35**
MMPoly0	20	1018	50.9	28.4	1445.56	
MMPoly1_2 Laminate	18	1018	56.5	9.8	553.7	
Power feed TA 2						**448.71**
MMPoly0	20	1043	52.15	28.4	1481.06	
MMPoly1_2 Laminate	18	1043	57.97	9.8	567.81	
MMPoly3 Bridge	18	84	4.66	8.2	38.26	
Ground lead TA 2						**412.8**
MMPoly0	20	1049	52.45	28.4	1489.5	
MMPoly1_2 Laminate	18	1049	58.27	9.8	571.04	
Power feed TAs 3 & 4						**429.09**
MMPoly0	20	992	49.6	28.4	1408.6	
MMPoly1_2 Laminate	18	992	55.11	9.8	540.08	
MMPoly3 Bridge	18	85	472	8.2	38.7	
Ground lead TAs 3 & 4						**712.04**
MMPoly0	20	1810	90.5	28.4	2570.2	
MMPoly1_2 Laminate	18	1810	100.5	9.8	984.9	
Power feed TA 3						**436.4**
MMPoly0	20	1109	55.45	28.4	1574.78	
MMPoly1_2 Laminate	18	1109	61.61	9.8	603.78	
Ground lead TA 3						**405.7**
MMPoly0	20	1031	51.55	28.4	1464.02	
MMPoly1_2 Laminate	18	1031	57.27	9.8	561.3	
Power feed TA 4						**437.99**
MMPoly0	20	1015	50.75	28.4	1441.3	
MMPoly1_2 Laminate	18	1015	56.39	9.8	552.61	
MMPoly3 Bridge	18	84.6	4.7	8.2	38.54	

Ground lead TA 4						**405.7**
MMPoly0	20	1031	51.55	28.4	1464.02	
MMPoly1_2 Laminate	18	1031	57.27	9.8	5671.25	
Thermal Actuator						**828.14**
MMPoly4 Bridge	18	106	5.88	8.7	51.23	
MMPoly0	20	402	20.1	28.4	570.84	
MMPoly1_2 Laminate	18	402	22.3	9.8	218	
MMPoly1 Hot arms	8	100	12.5	23.2	290	
MMPoly3 Cold Arm	35	133	3.8	8.2	31.16	
MMPoly1 flexure joint	14	81	5.79	23.2	134.2	
MMPoly0	20	286	14.3	28.4	406.12	
MMPoly1_2 Laminate	18	286	15.8	9.8	155.7	
MMPoly3 Bridge	18	84.6	4.7	8.2	38.54	

*All resistance in Ohms

	Ohms
Thermal Actuator TA 1	828.14
Power feed TA 1	446.45
Ground Lead TA 1	400.35
Total Resistance TA 1	**1674.9**
Thermal Actuator TA 2	828.14
Power feed TA 2	448.71
Ground Lead TA 2	412.8
Total Resistance TA 2	**1689.6**
Thermal Actuator TA 3	828.14
Power feed TA 3	436.4
Ground Lead TA 3	405.7
Total Resistance TA 3	**1670.2**
Thermal Actuator TA 4	828.14
Power feed TA 4	437.99
Ground Lead TA 4	405.7
Total Resistance TA 4	**1671.8**

TA 1 & TA 2 in Parallel	841.11
Power feed TAs 1 & 2	358.9
Ground lead TAs 1 & 2	281.7
Resistance R_{12}	**1481.71**
TA 3 & TA 4 in Parallel	835.5
Power feed TAs 3 & 4	429.09
Ground lead TAs 3 & 4	712.04
Resistance R_{34}	**1976.6**

Suggestion 6

S6 Just as a general design/layout suggestion, I'd recommend using AutoCAD blocks more frequently. For example, if you had blocked your thermal actuator design, then it could be fixed in the block and this fix would automatically appear in every copy of that block.

Additional Concerns Addressed

- *Deleted or reassigned to appropriate layers geometries located on layer 0*
- *Added TVI initials to block definition*
- *Removal of zero line width lines*