Flexible switching sensors for passive shape monitoring

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Toward shape aware flexible surfaces

- Goal: a passive wireless sticker that can monitor the shape of deployable structures in aerospace applications.
- Threshold-based "digital" sensors match RF-power constraints
- Geometric frustration is the key to a simple, "digital" shape sensor element
- We can microfabricate these devices

What can be done with shape-aware flexible surfaces?

- Thin, flexible materials that report their own 3-dimensional shape.
- Track the unfolding of inflatable structures or the changing shapes of body parts.
- Make a soft robot skin that recognizes the shape of objects it contacts.

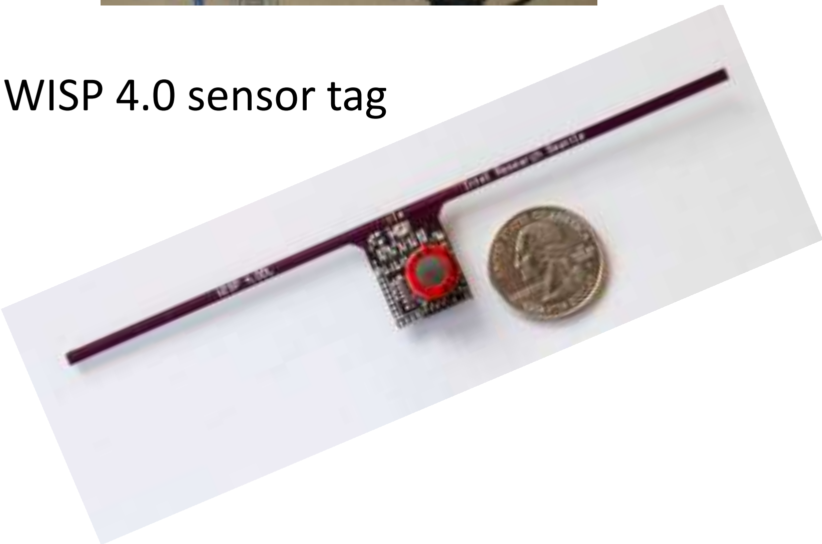
These systems can be made with fiber optics or strain gauge arrays, but what about the power requirements of passive wireless?

Look at power constraints of one reprogrammable RFID tag

- WISP: Wireless Integrated Sensing Platform
- Open source microcontroller board powered and read by commercial UHF RFID readers
- Started at Intel, now at University of Washington. Mainly academic users
- Wisp.wikispaces.com
- Typical power budget: 1 mW for 1 ms. No battery but uses a capacitor

commercial UHF RFID reader

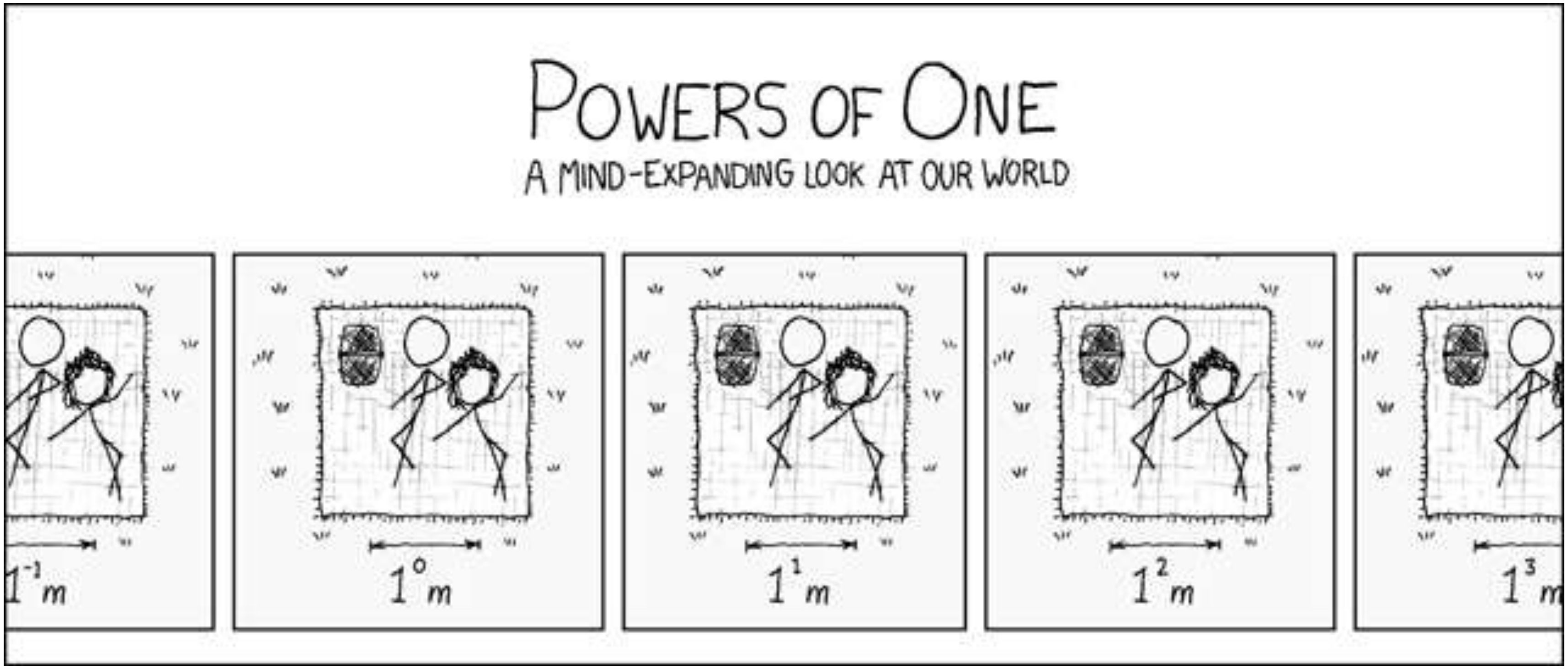
WISP 4.0 sensor tag



Sensors with discrete on/off states are good for low-power systems

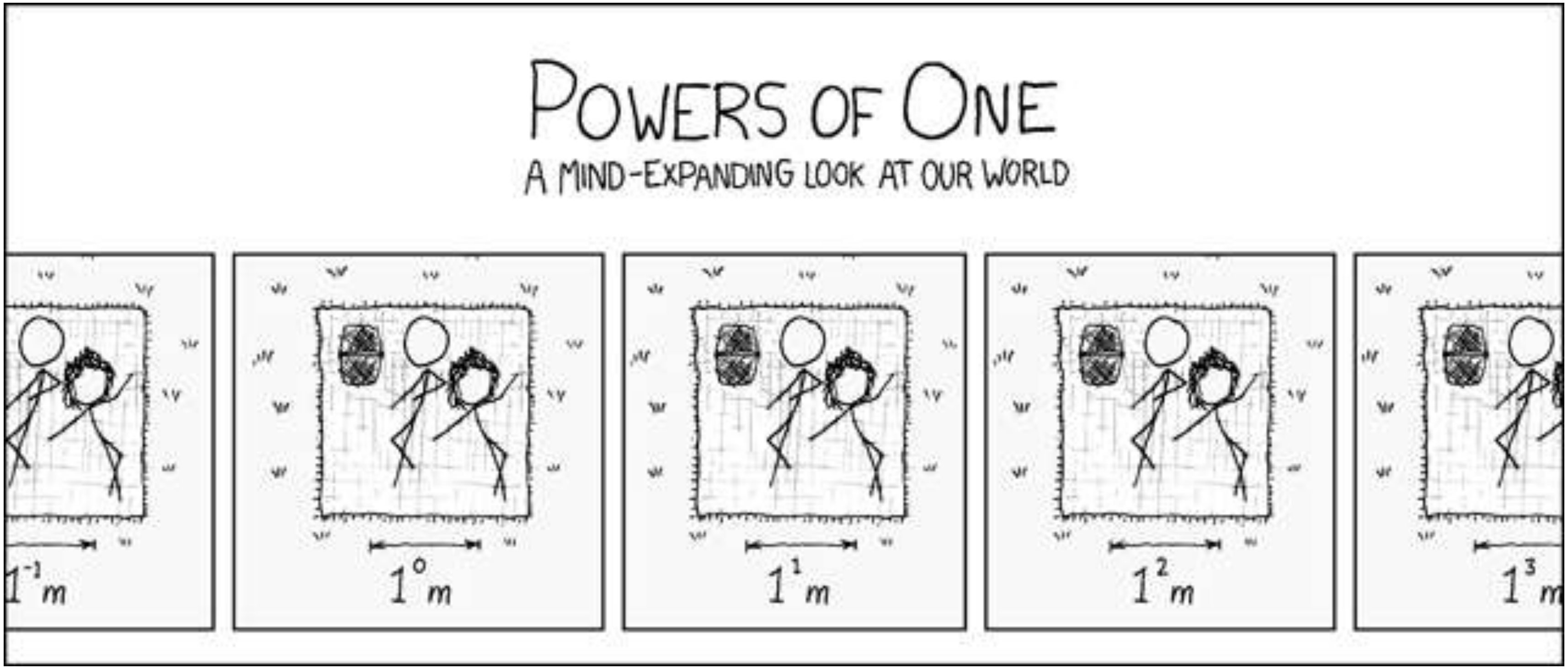
- No amplification of a small analog signal
- No analog-to-digital conversion needed.
- But there’s not much bit depth (1 bit).

One-bit sensors…?



xkcd.com/271

One-bit sensors…?



xkcd.com/271

Arrays of 1 bit switches are still interesting for shape sensing, feedback, and control.

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Discrete shape sensors: applications

- “Rolatube” bistable mast has a discrete shape change that matches well with threshold sensors.
- Put shape-sensing stickers periodically along the tube. Is it flat or curved? Use passive wireless to poll the switches.

- What about other shapes?

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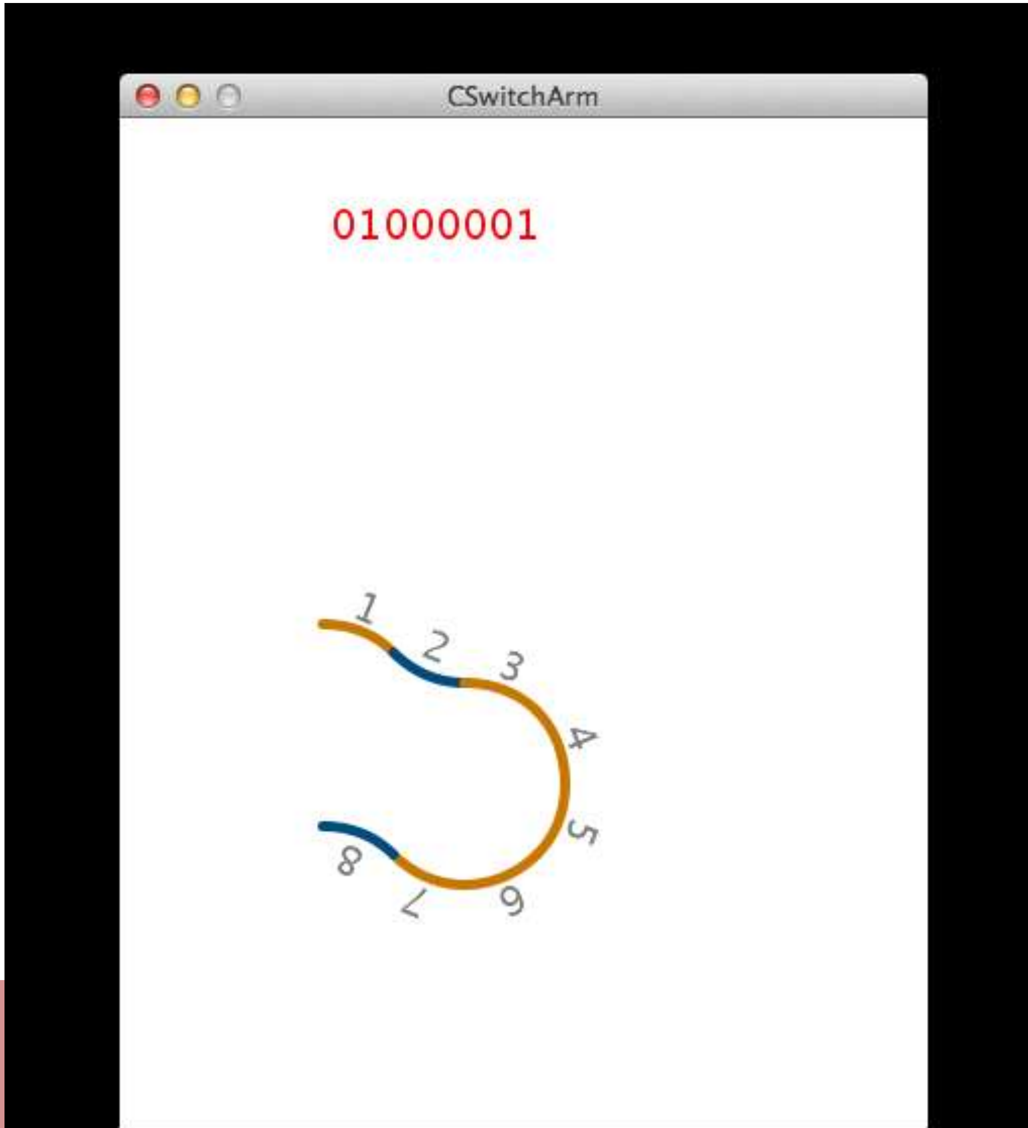
Convert a curve to 1-bit digital by making a sequence of "macaroni" arcs

- A sequence of up-or-down orientations for identical arcs will produce a curve.
- Rotate to an accumulated angle, translate the new arc to the latest endpoint, and repeat.
- Here's a byte of macaroni



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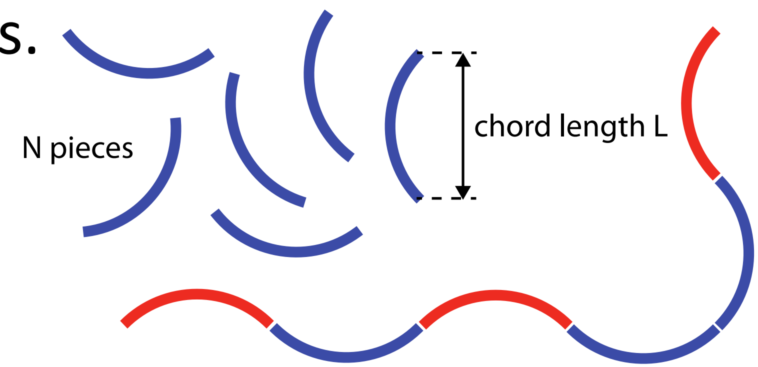
Describing a shape with bits

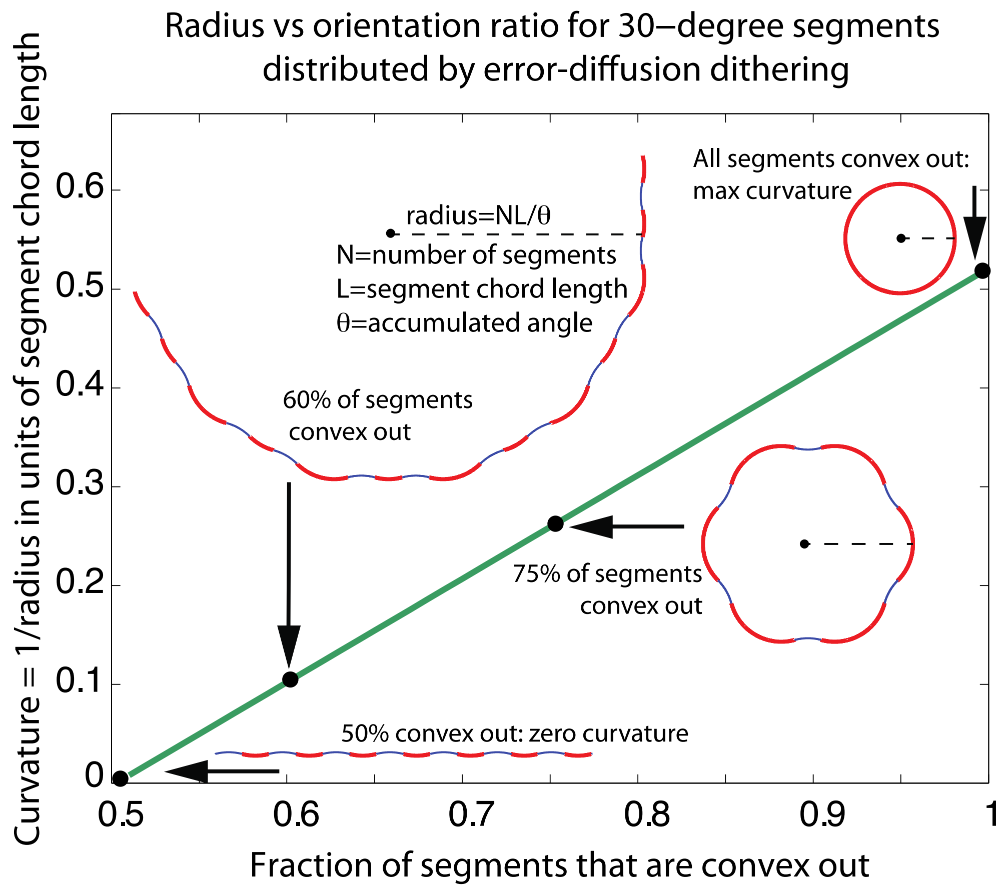
- Important: the tangent is continuous between neighbors. This coupling makes the global shape depend on local conditions.

- We can easily recreate a curve from a given bit sequence as you just saw.

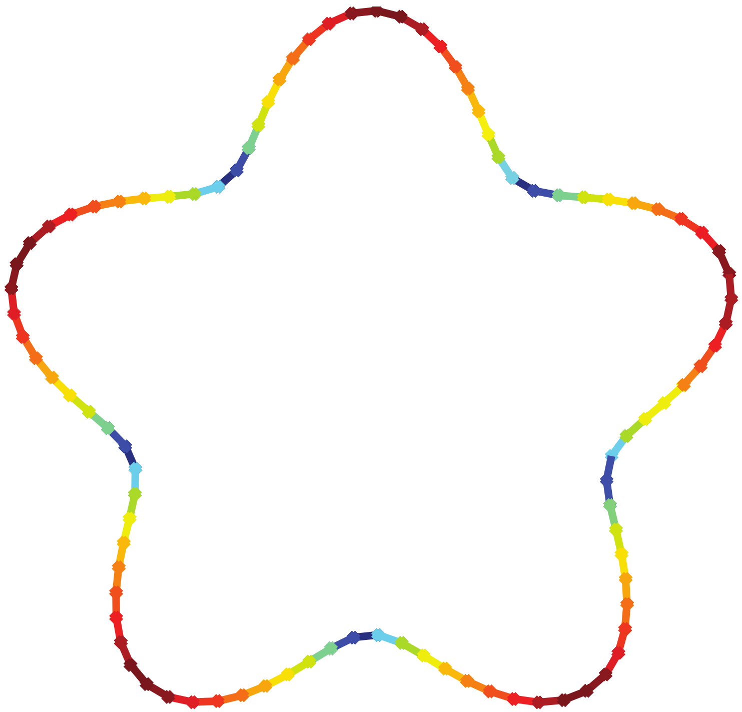


Inverse problem: How can we come up with a bit sequence to describe a known shape?

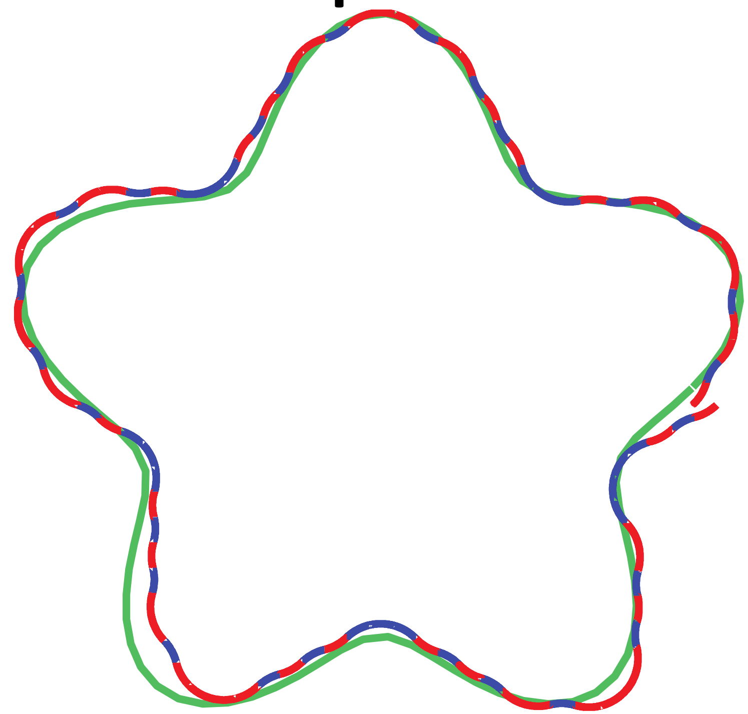
Local curvature depends on local bit distribution



Matching curvature to bit patterns: here is a 1-bit, length 96 sequence to match a test shape



Shape with varying curvature

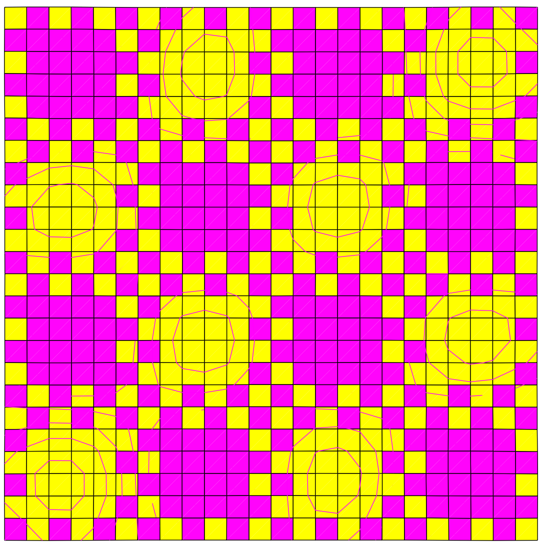


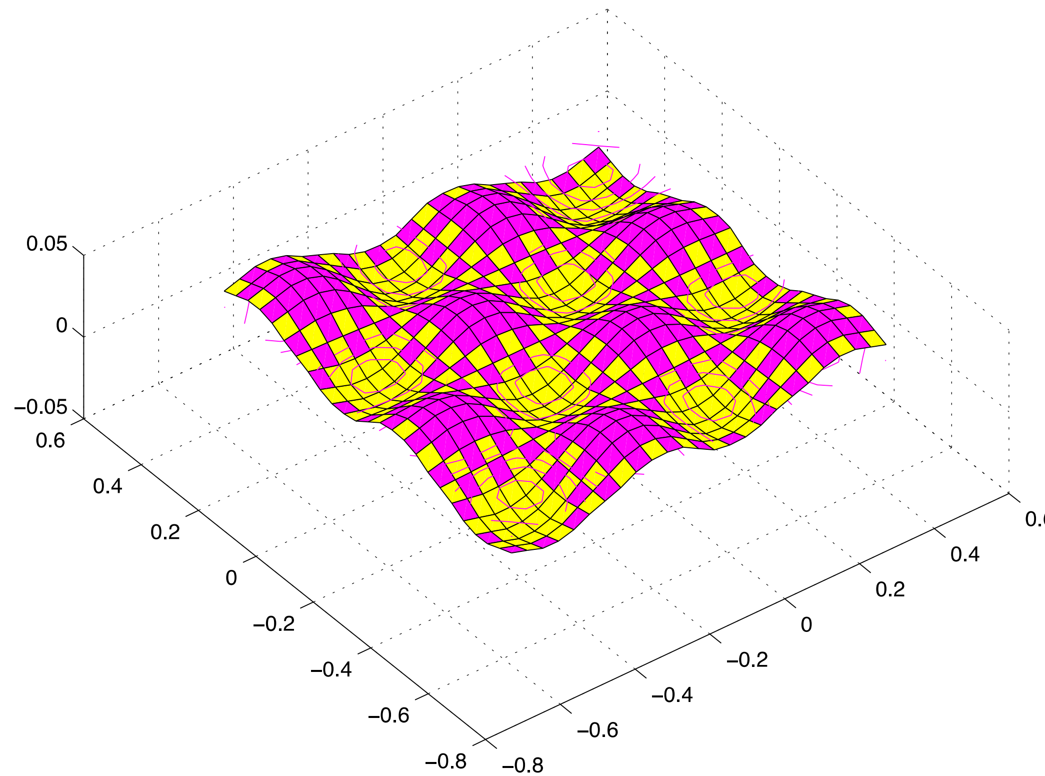
96 30-degree macaroni oriented using error-diffusion dithering to match curvature

Can we recreate a 3D shape from a 2D array of switch states?

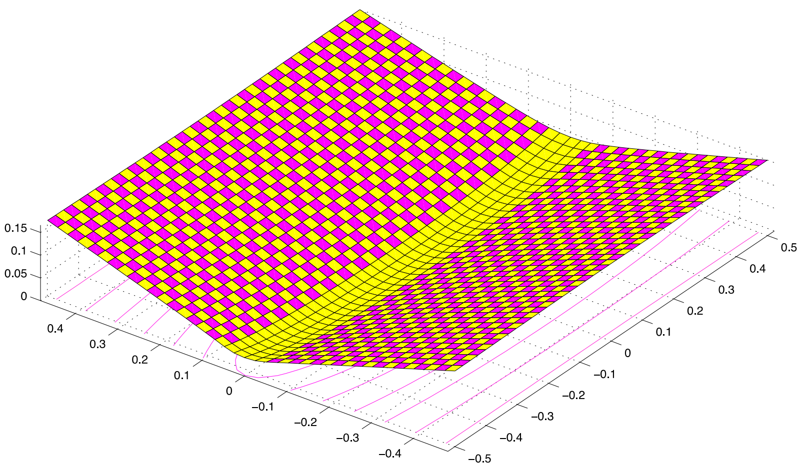
- Instead of arcs, we have dimpled tiles in an array. It's still a 1-bit depth system with dimples facing up or down.
- A binary array of tile orientations is used to generate a shape. It's a curvature map like the macaroni sequence.
- Recovering a shape from a 2D bit array is not as straightforward as 1D because of constraints. You need to evolve a surface where each tile satisfies boundary conditions with its neighbor on each of 4 sides.

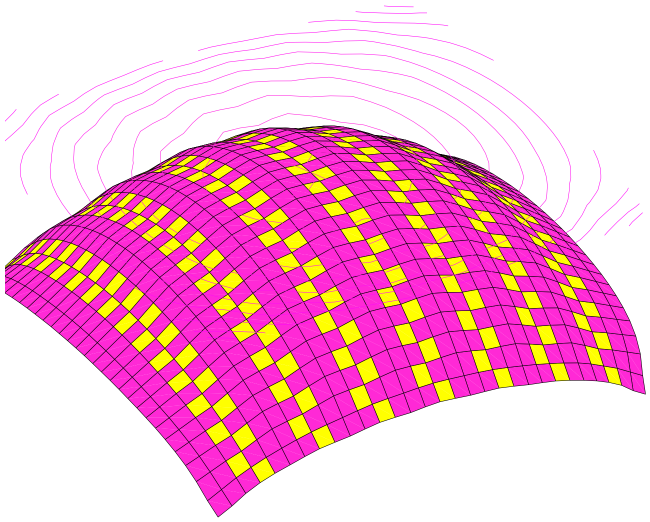
Our 2D solver generates some self-consistent shapes from bit arrays

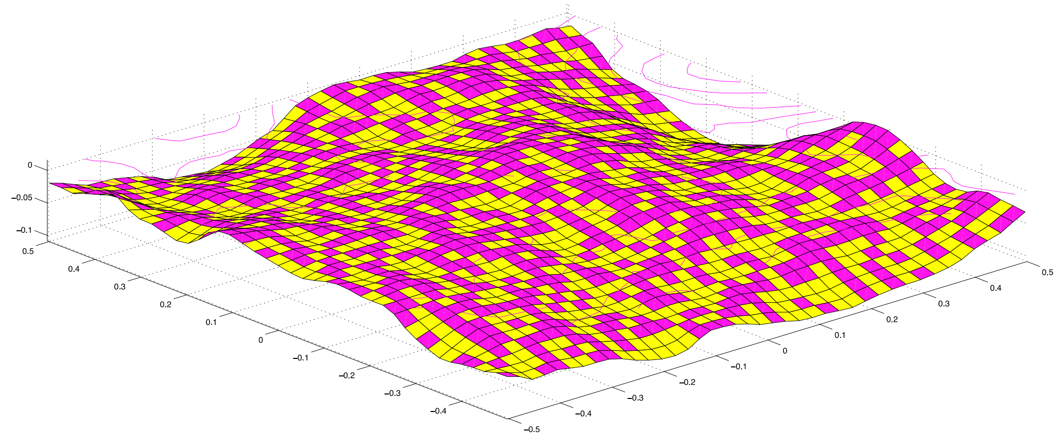




More folded tile arrays

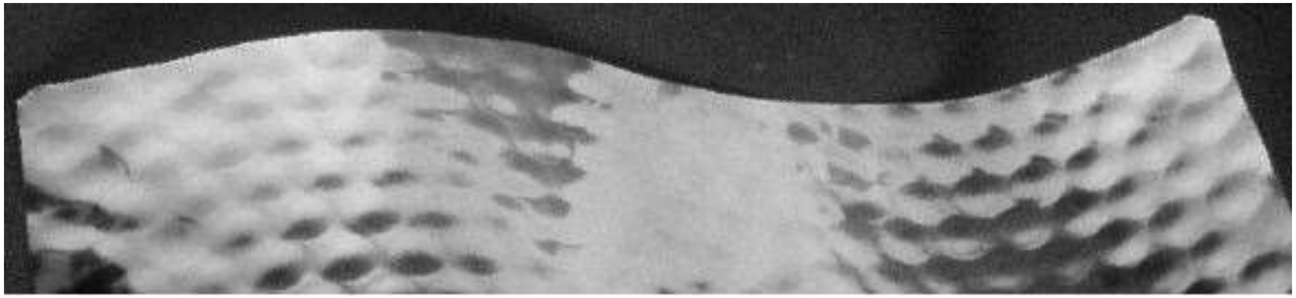






Are these things real?

YES, multistable structures have been made from spring steel sheets



http://home.earthlink.net/~barkingpo/bistabledome.html

- There are also 3D printed multi-stable structures
- Let's apply concept to a wider range of materials and over a larger range of size scales.

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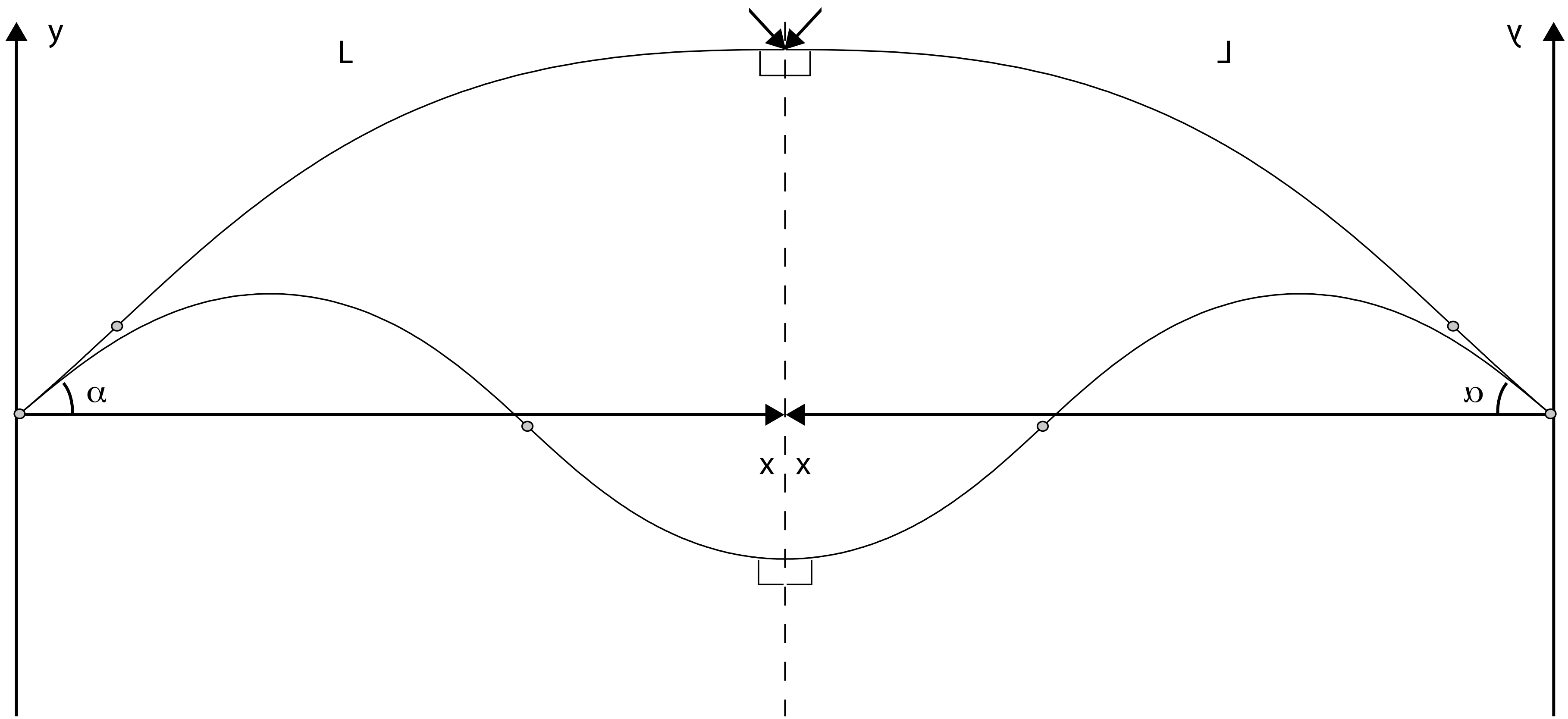
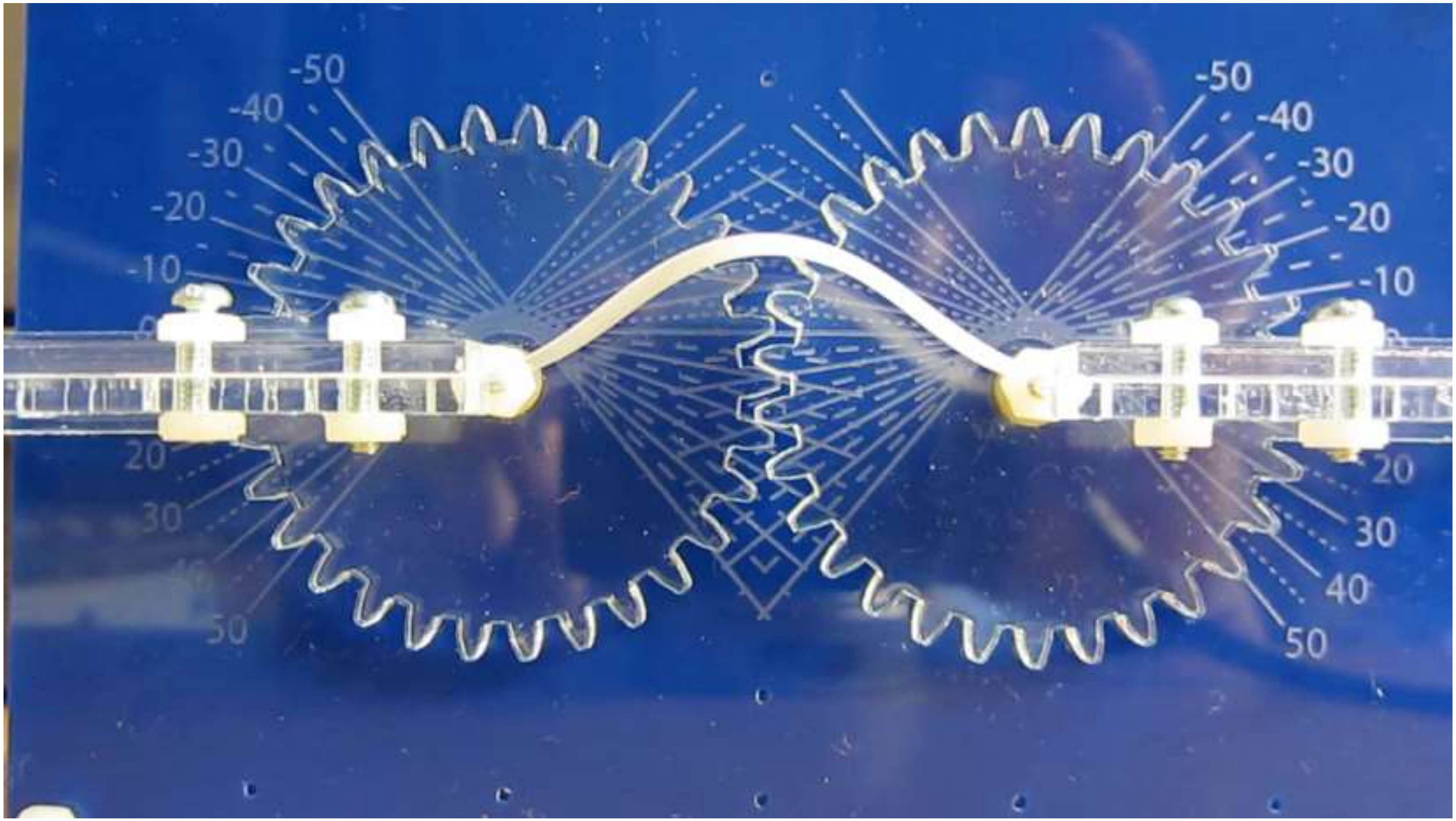
“Geometrical frustration” key to making a multi-stable structure

- It costs energy to bend or compress a sheet
- Geometrical frustration: not all parts of the material can be at the minimum energy state, because moving one part messes up another part that’s attached to it.
- Geometrical frustration can happen if parts of the sheet are tied together. The material responds by bending out of plane
- Examples can be found at all different scales

Geometrical frustration creates two stable states for an inclined, doubly clamped compressed beam



Bistability is lost at a critical angle



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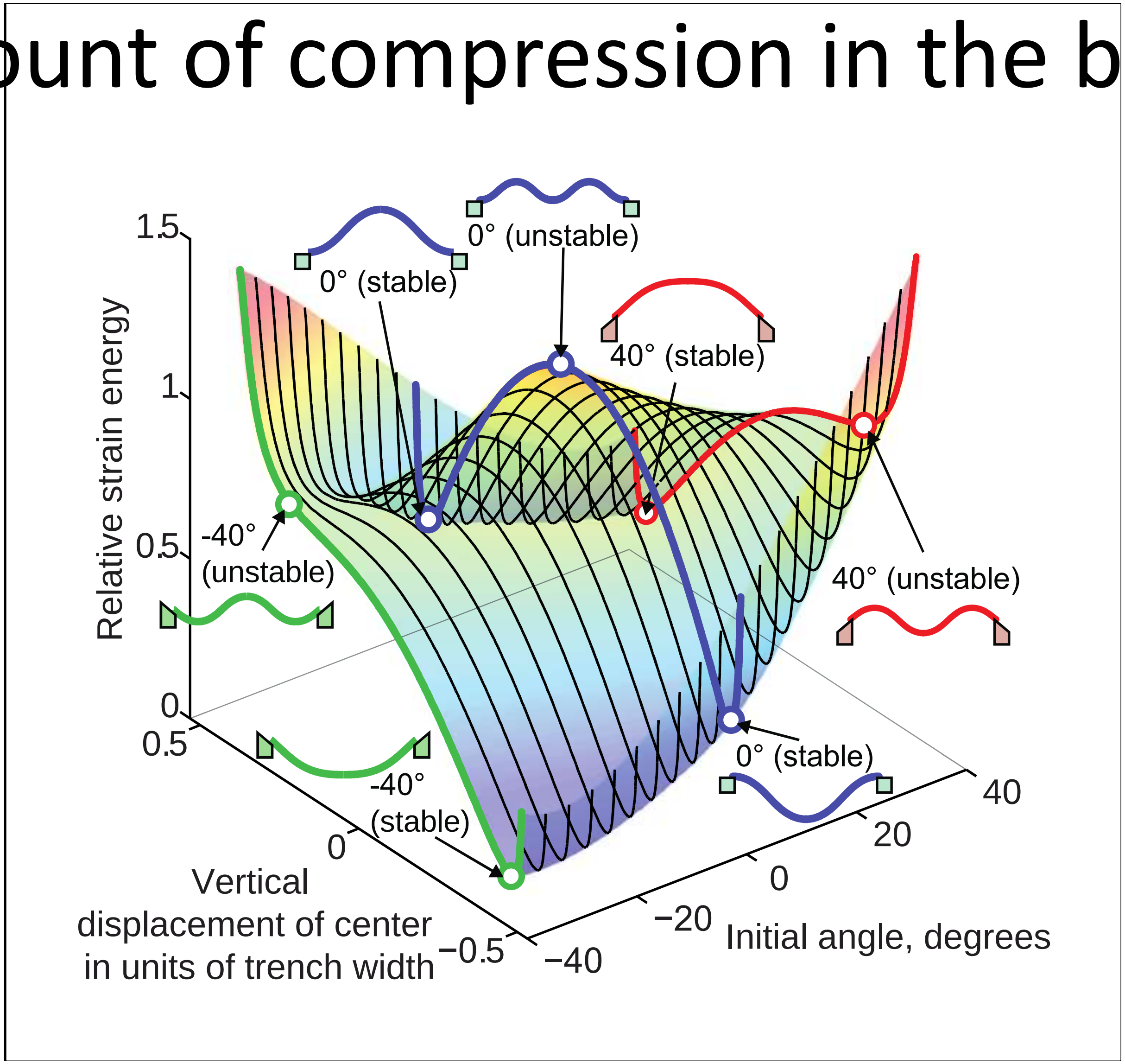
The critical angle is controlled by the amount of compression in the beam.



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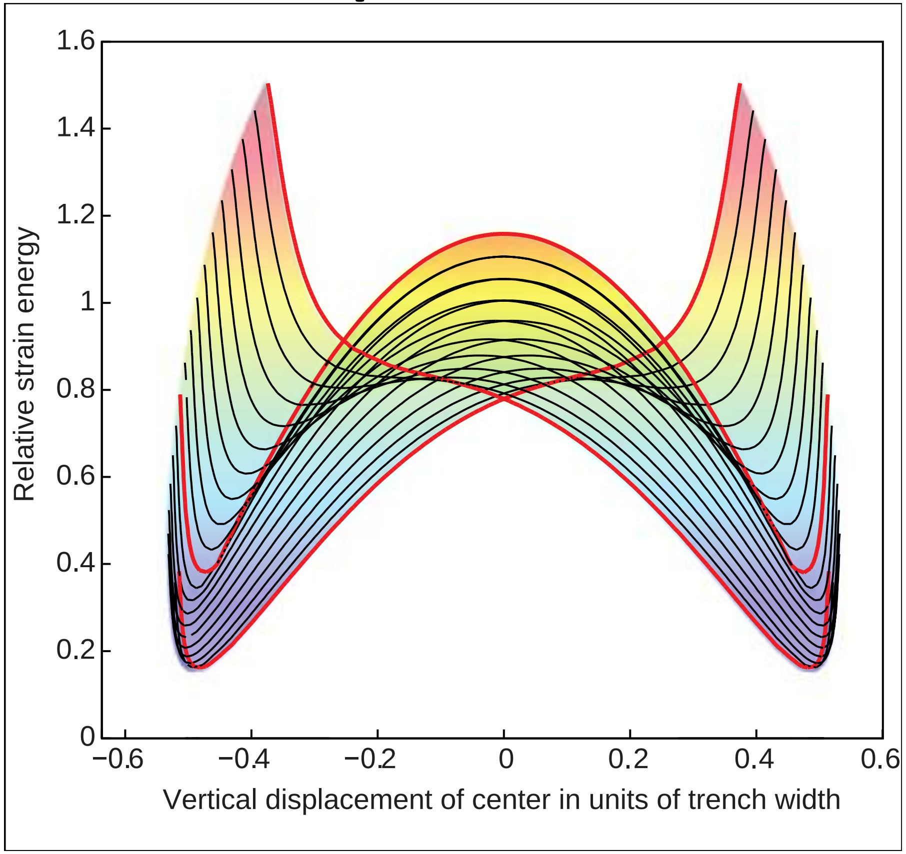
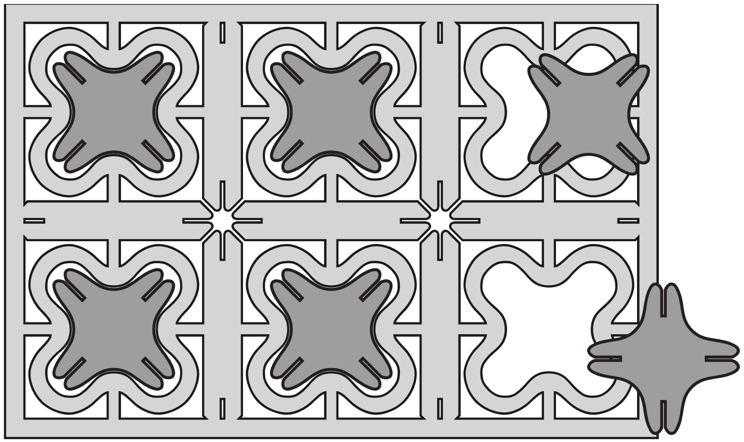
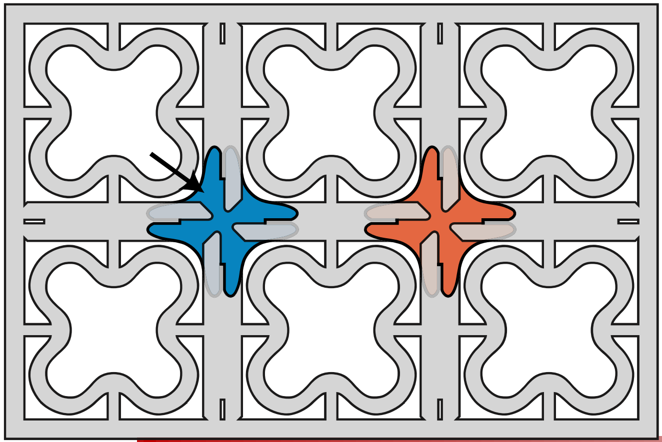


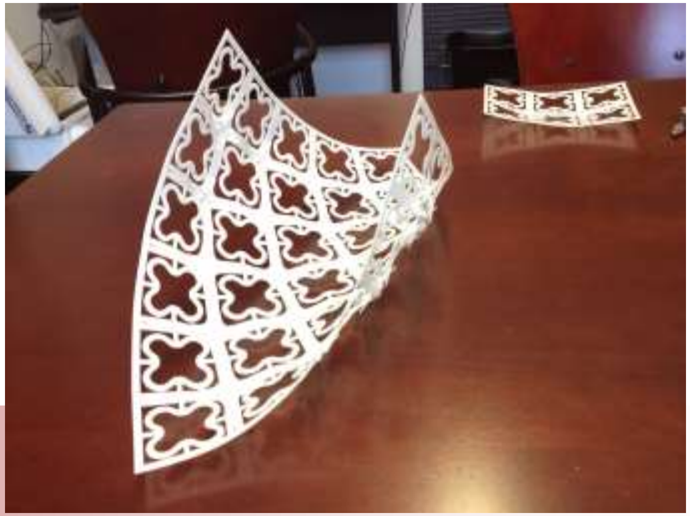
Front view of energy landscape
Each line is at a different substrate angle

1-D switch array with display

2-D arrays can be made using similar materials







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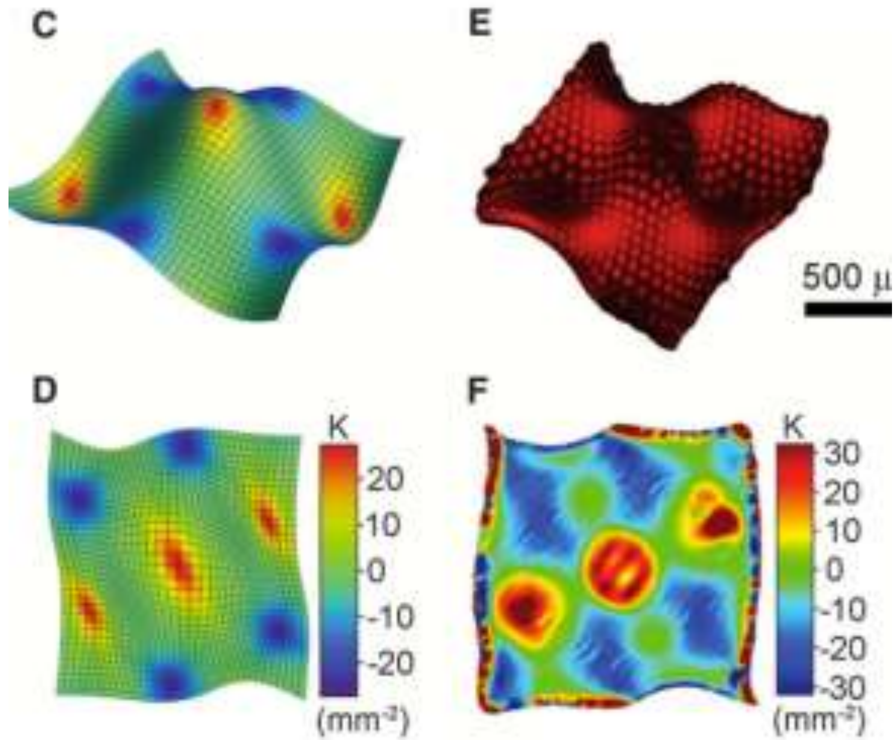
2-D array multi-stability

http://www.flickr.com/photos/46653815@N06/sets/72157630862667746/



Hydrogel sheet with patterned swelling
Kim et al., Science 335 p 1202 (2012)

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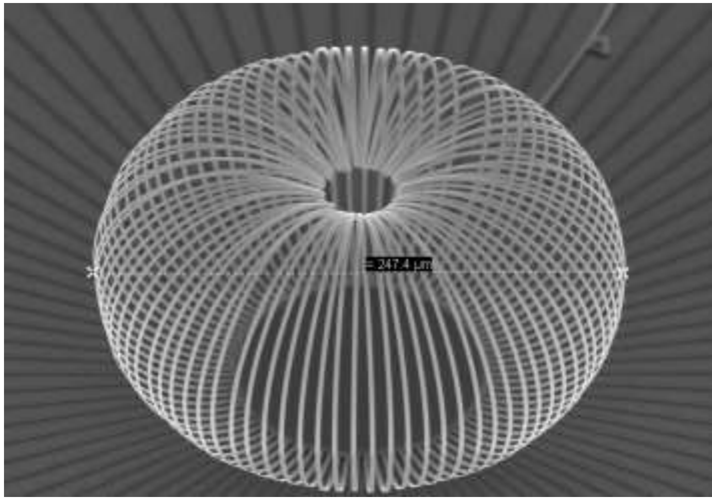
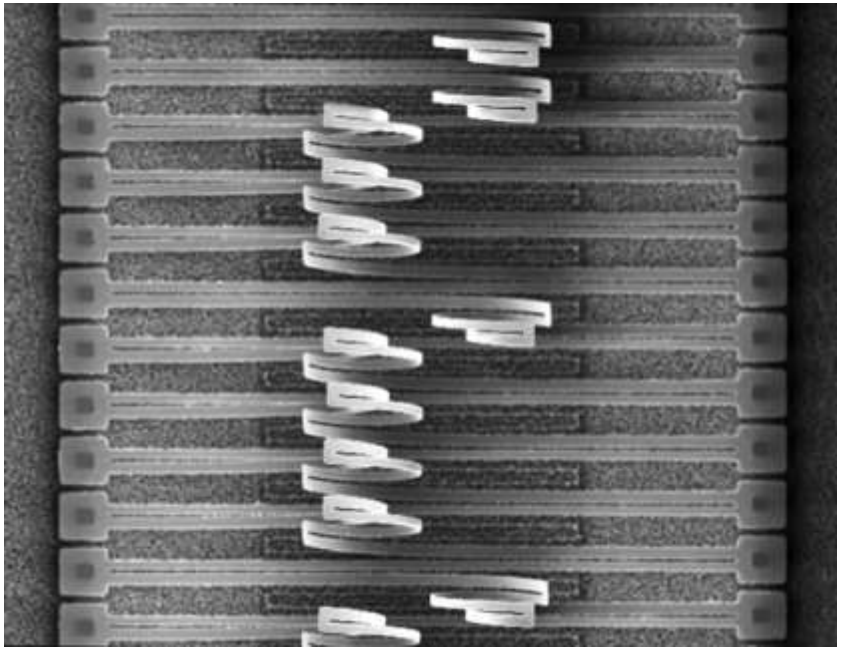
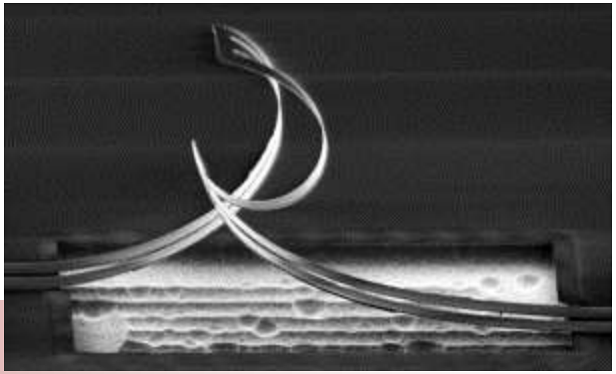
Geometrical Frustration: Microfabricated Structures



- Released bilayers have a preferred radius of curvature, about 200 microns shown here.



Serpentine layouts cannot all attain the preferred radius at the same time.



Goessling, et al. J. Micromech. Microeng. **21** 065030, 2011

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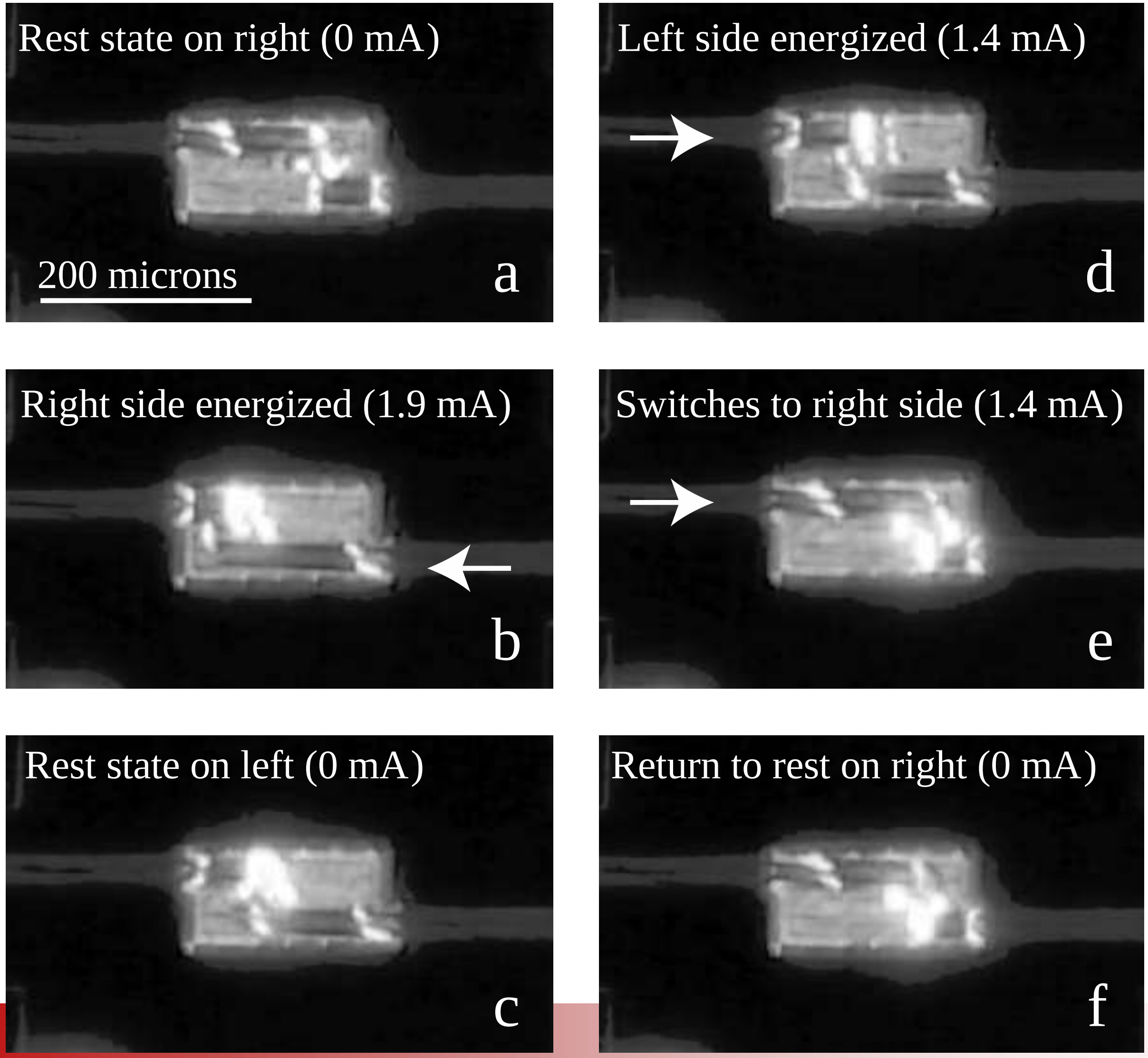
The serpentine structure is bistable



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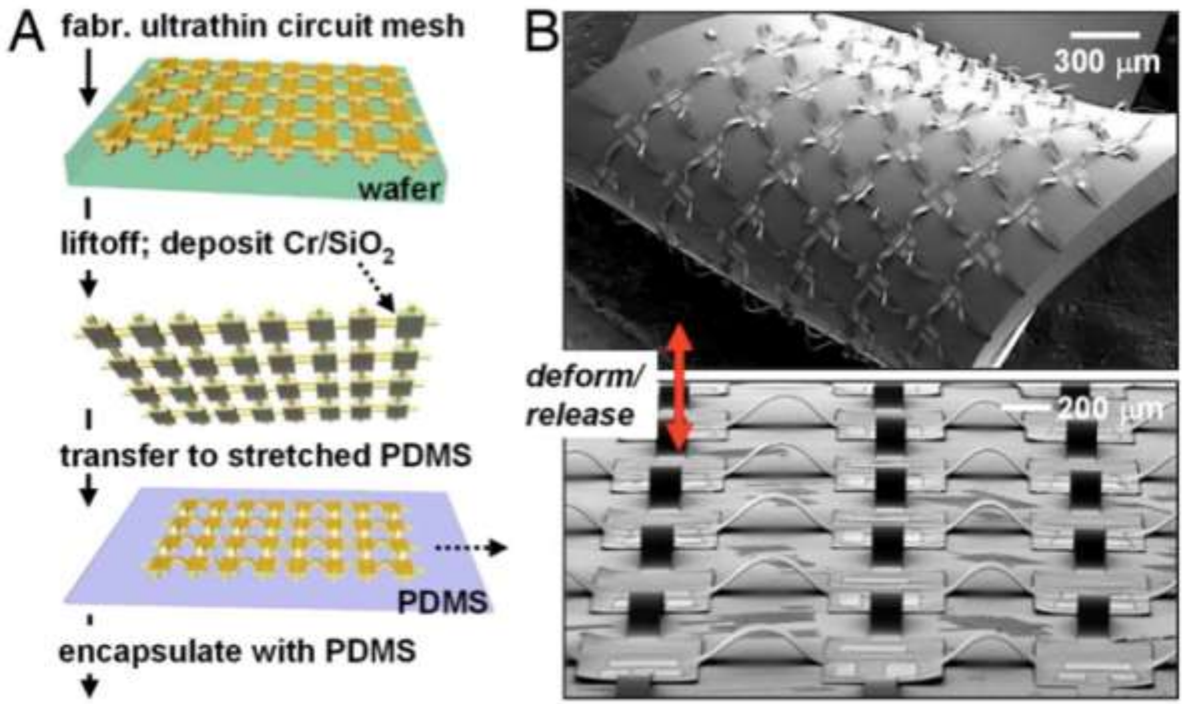
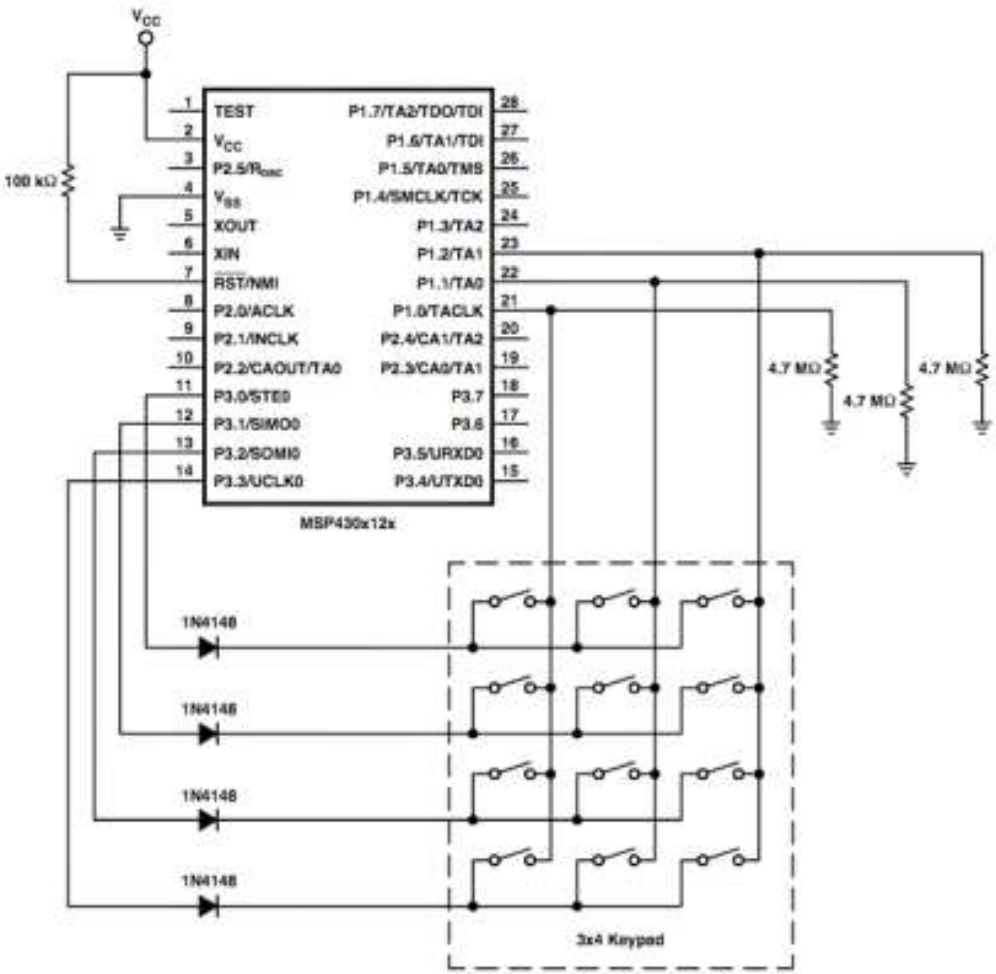
Will it bend?

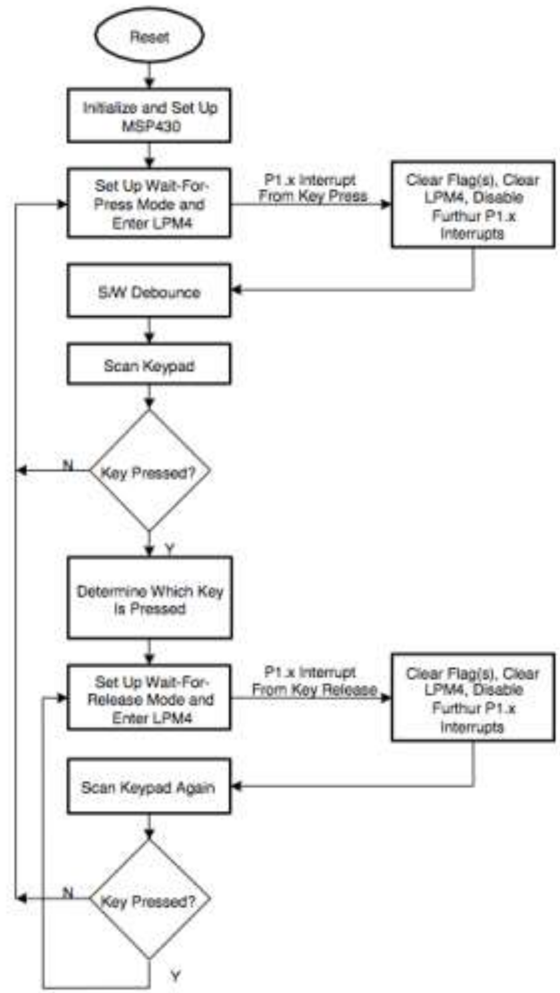
- Silicon, glass and other “brittle” materials can bend in thin-film form. Microelectronics on flexible substrates is a fast moving research area.



Kim et al.: Researchers have transferred functional semiconductor electronics onto silicone films. www.pnas.org/cgi/doi/10.1073/pnas.0807476105

LOTS of switches need to be read in a low-power manner. Software/hardware problem

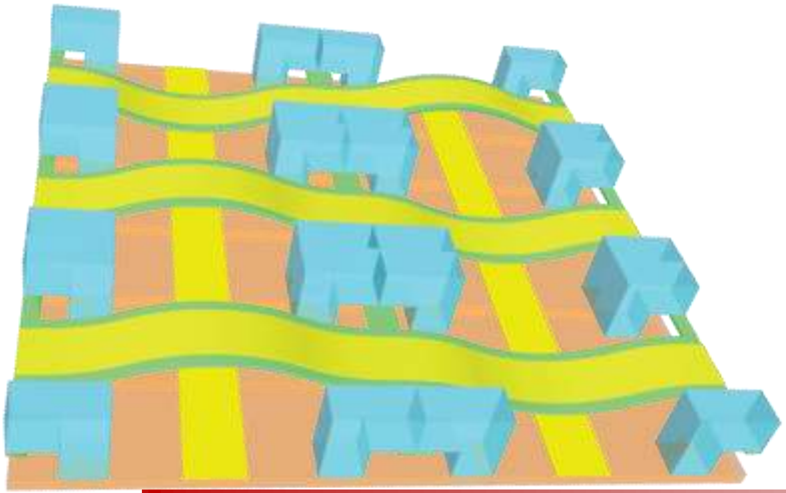


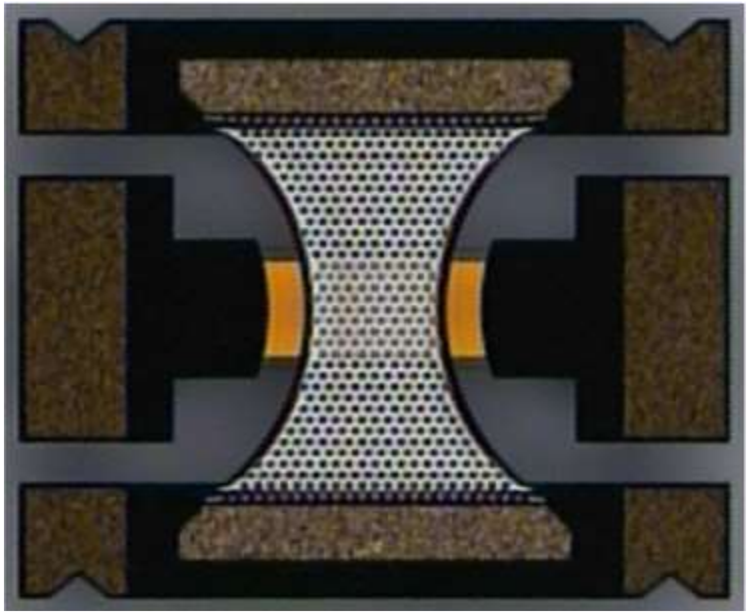


http://www.ti.com/litv/pdf/slaa139

But what about passive? Microswitches on silicon are well known from RF MEMS

- Ohmic contact switches are a RF MEMS device
- Another RF MEMS device, a variable capacitor AC switch, uses less power than an ohmic contact





RF MEMS capacitive switch, memtronics.com

Bringing it back to passive wireless

- Include switch array readers in the passive RF toolbox—whether analog or digital. People will use them for diverse applications
- Wireless switch readers/writers for large switch arrays have huge potential in flexible electronics and smart textiles.