Distributed Microsystems Lab

Dissertation Defense
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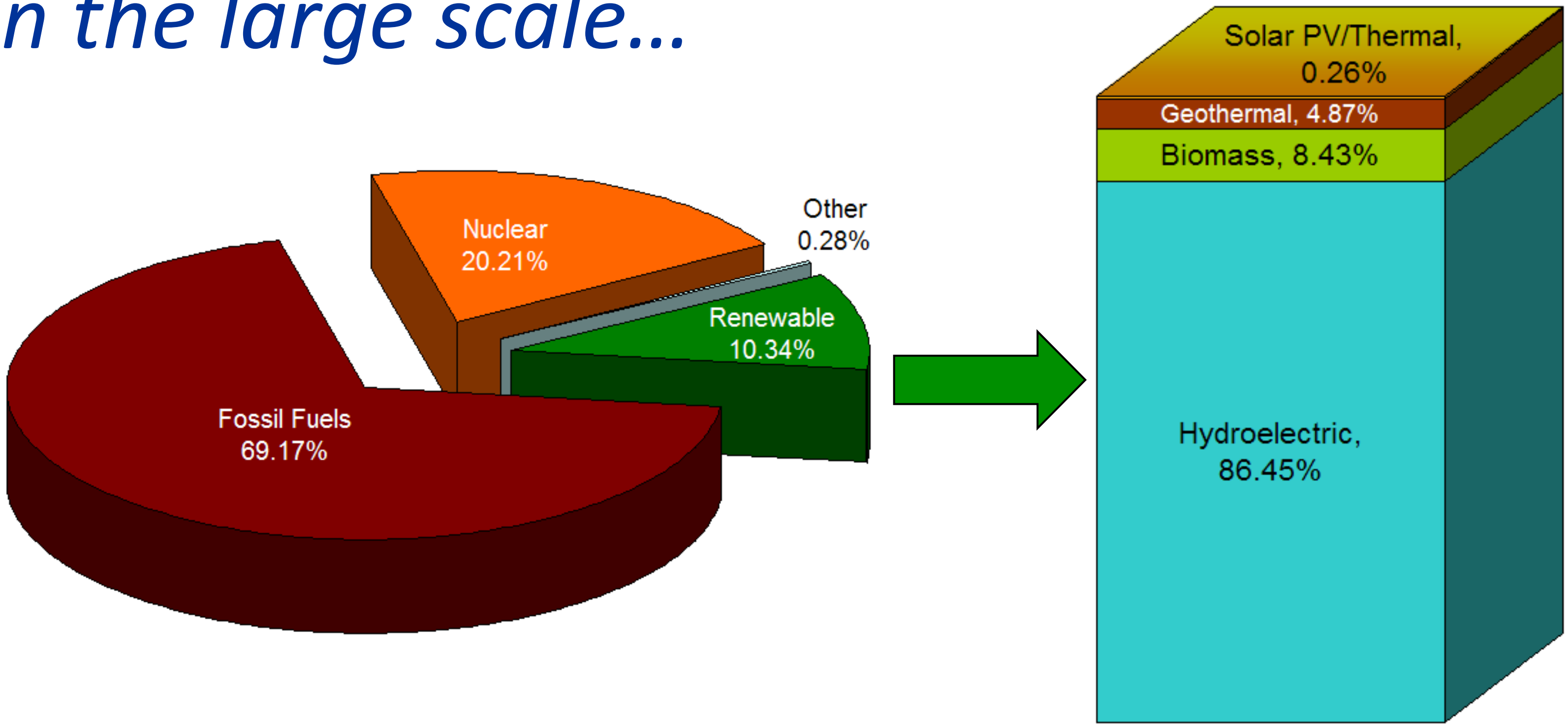
14th December 2010

Efficient micro-Power Conditioning for Solar Cells with Time Domain Array Reconfiguration

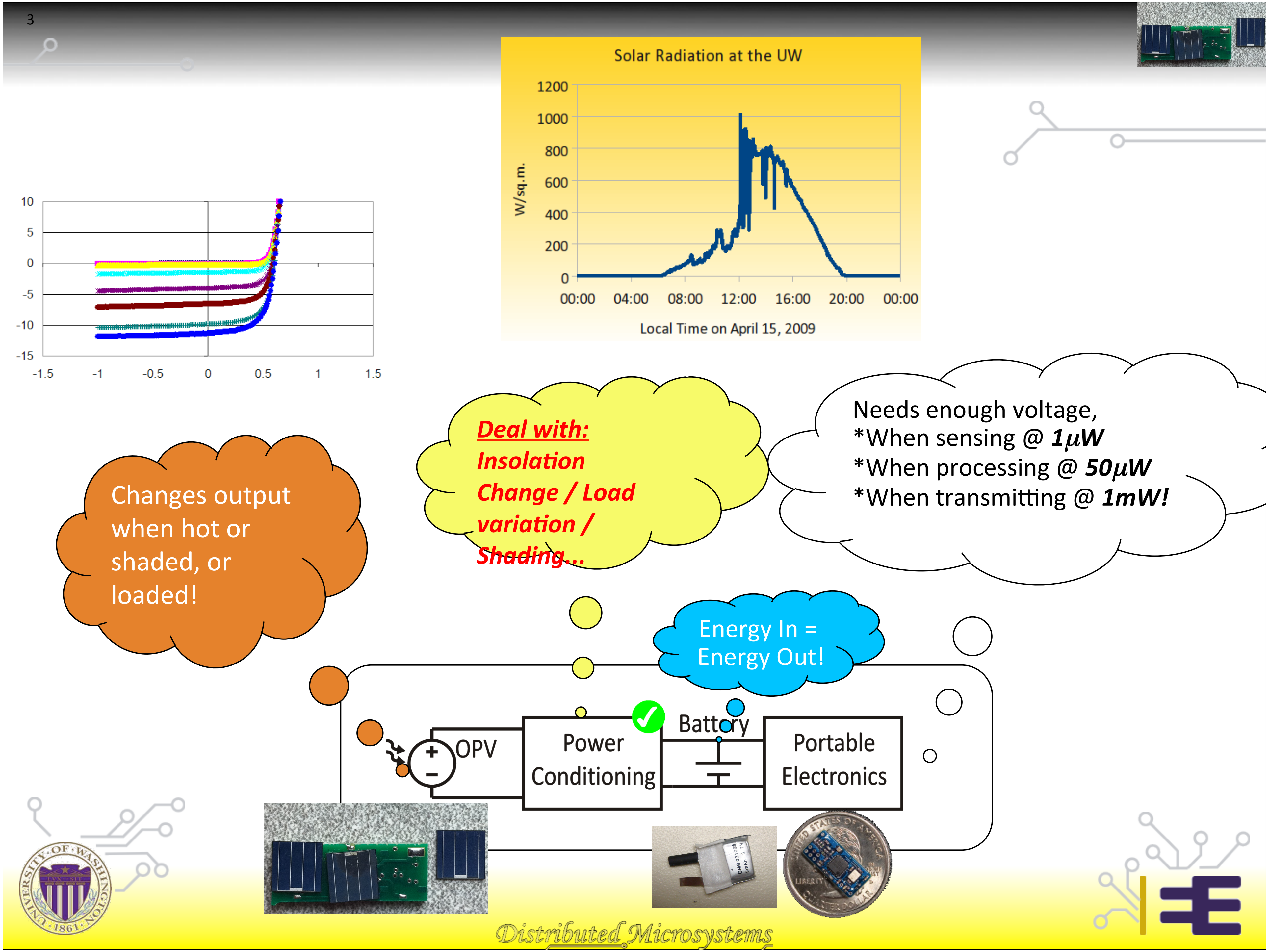
UNIVERSITY OF WASHINGTON
ELECTRICAL ENGINEERING

Harnessing the Sun

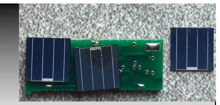
on the large scale…



Total Energy Demand of the World: **12** TeraWatts
Average Solar Energy Received on Earth: **84** TeraWatts

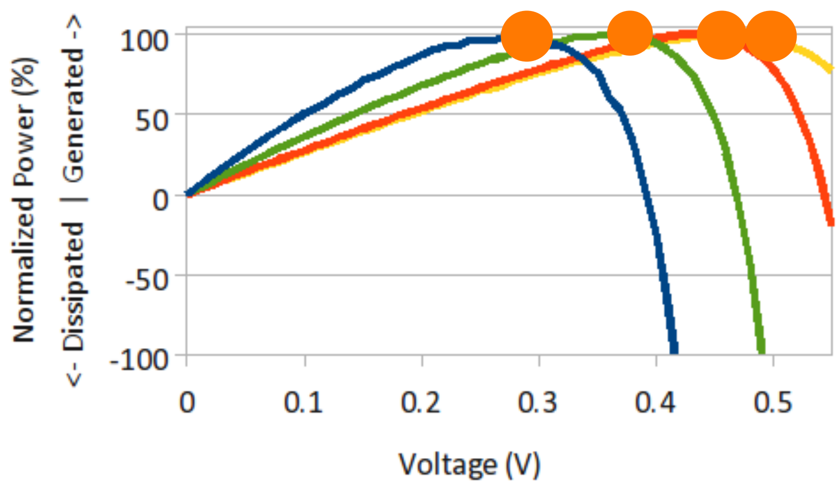


Solar Radiation at the UW
W/sq.m.
1200
1000
800
600
400
200
0
00:00
04:00
08:00
12:00
16:00
20:00
00:00
Local Time on April 15, 2009
10
5
0
-5
-10
-15
-1.5
-1
-0.5
0
0.5
1
1.5
Changes output when hot or shaded, or loaded!
Deal with:
Insolation Change / Load variation / Shading...
Needs enough voltage,
*When sensing @ 1µW
*When processing @ 50µW
*When transmitting @ 1mW!
Energy In = Energy Out!
OPV
Power Conditioning
Battery
Portable Electronics
Distributed Microsystems

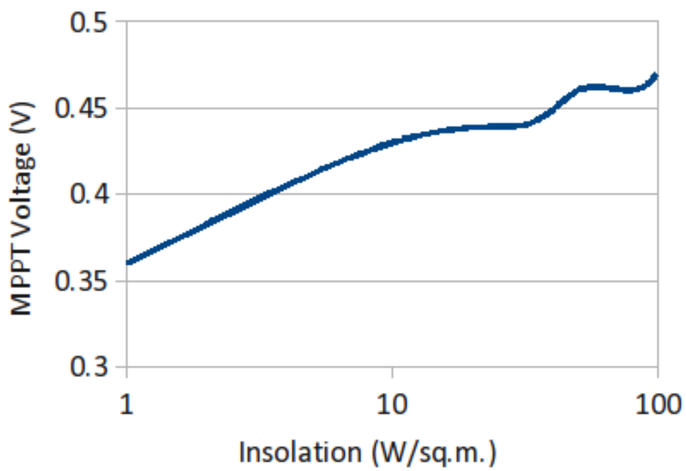


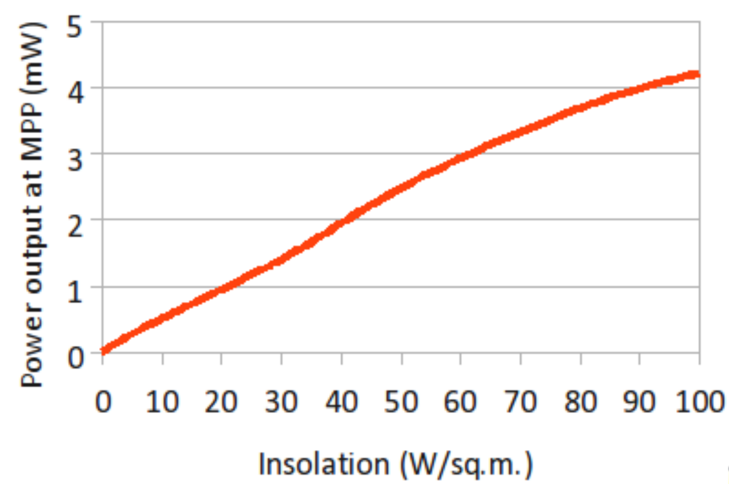
Chasing Maximum Power

OPV Characteristics v/s Insolation
Left to Right: 0.1, 1, 10 and 100 W/sq.m.



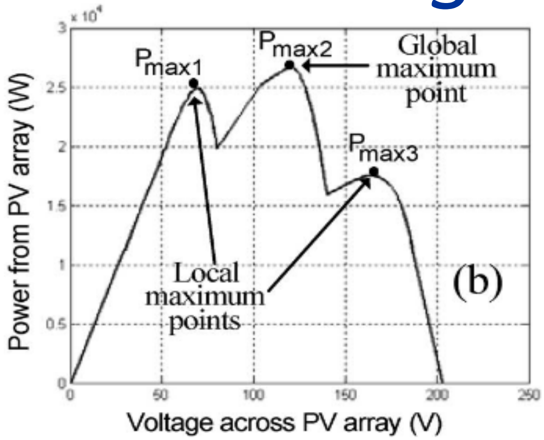
Maximum Power Point! (**MPP**)



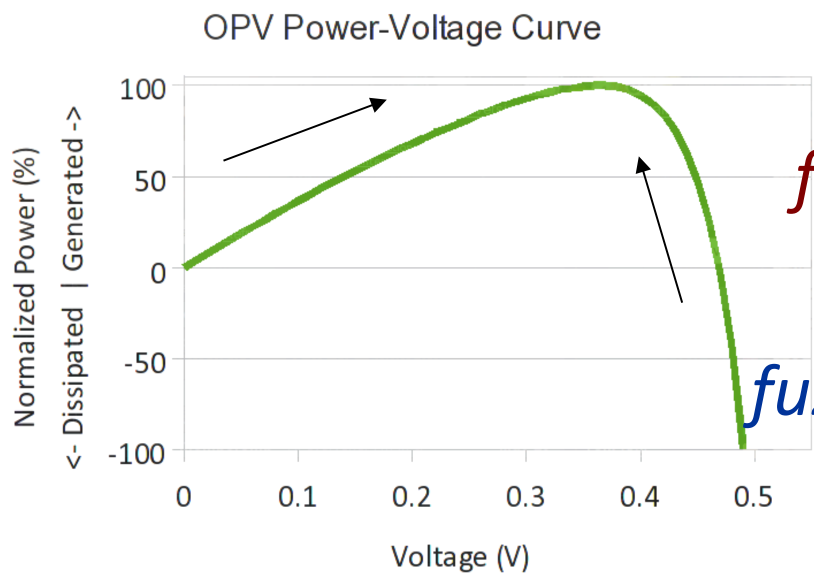


Chasing Maximum Power

hill climbing…



Ref: *H. Patel and V. Agarwal, Energy Conversion, IEEE Transaction on, vol. 23, 2008, pp. 302-310*



fractional V_{oc}/I_{sc}

fuzzy logic control

array reconfiguration

perturb & observe…

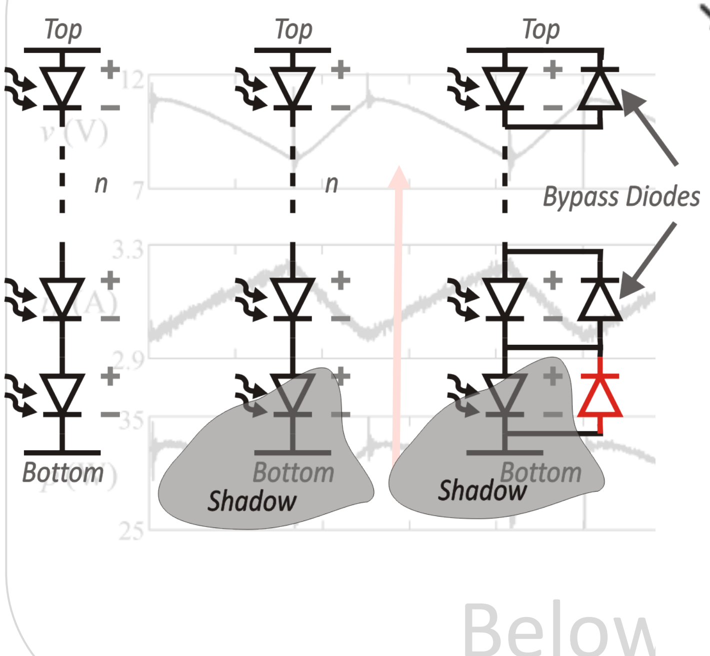
incremental conductance

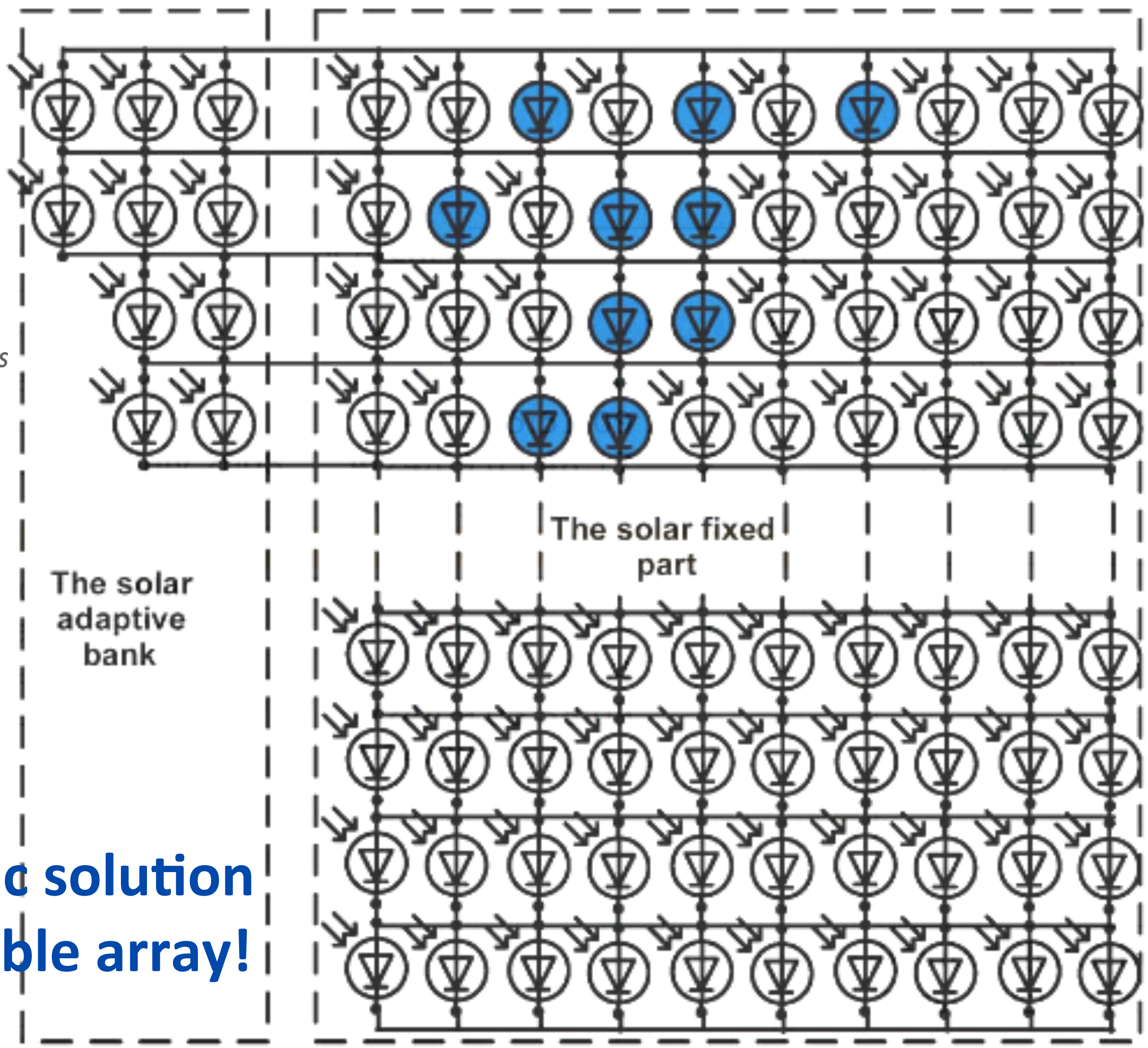
ripple correlation control

load I/V maximization

ripple correlation,
and array reconfiguration…

fixed solution
to partial shading





dynamic solution
=reconfigurable array!

Figs Ref: *T. Esram et al., (Review Paper) Sept 2006,*
Nguyen et al., Transactions on Industrial Electronics 2008

Recap

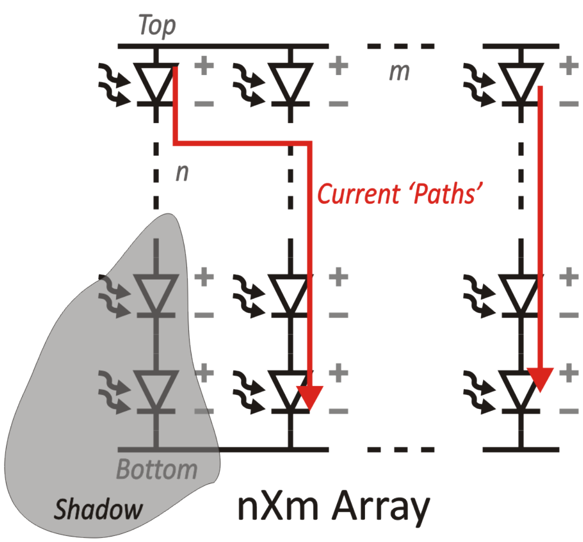
- Solar Energy – Abundant in large scale, key ‘application-enabler’ at small scale
- PV Cell management - maximum power point, power balancing between cells
- Array Reconfiguration is complex to implement, precluded from portable applications

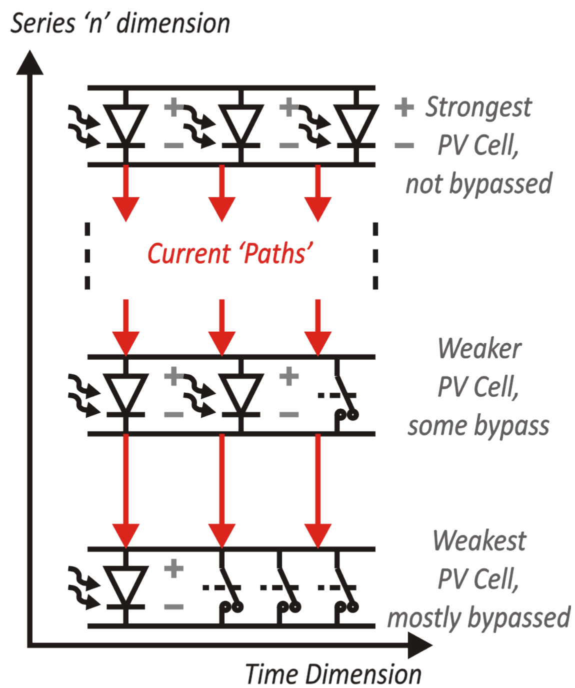
Can we have a simple and efficient system?

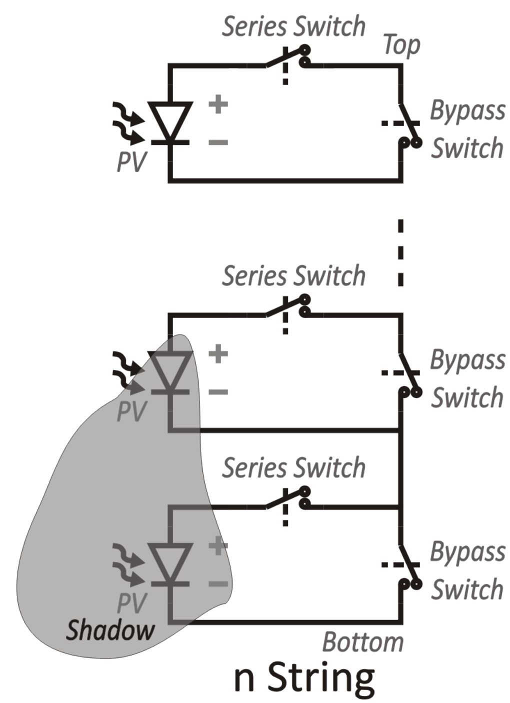
- Can we have array reconfiguration in a simple system?
- Can we use simple, automatic control loops?
- Can we do this in less than 100μW and under 1gram?

array reconfiguration… …in the ‘time domain’ ?

re-routing spatially…

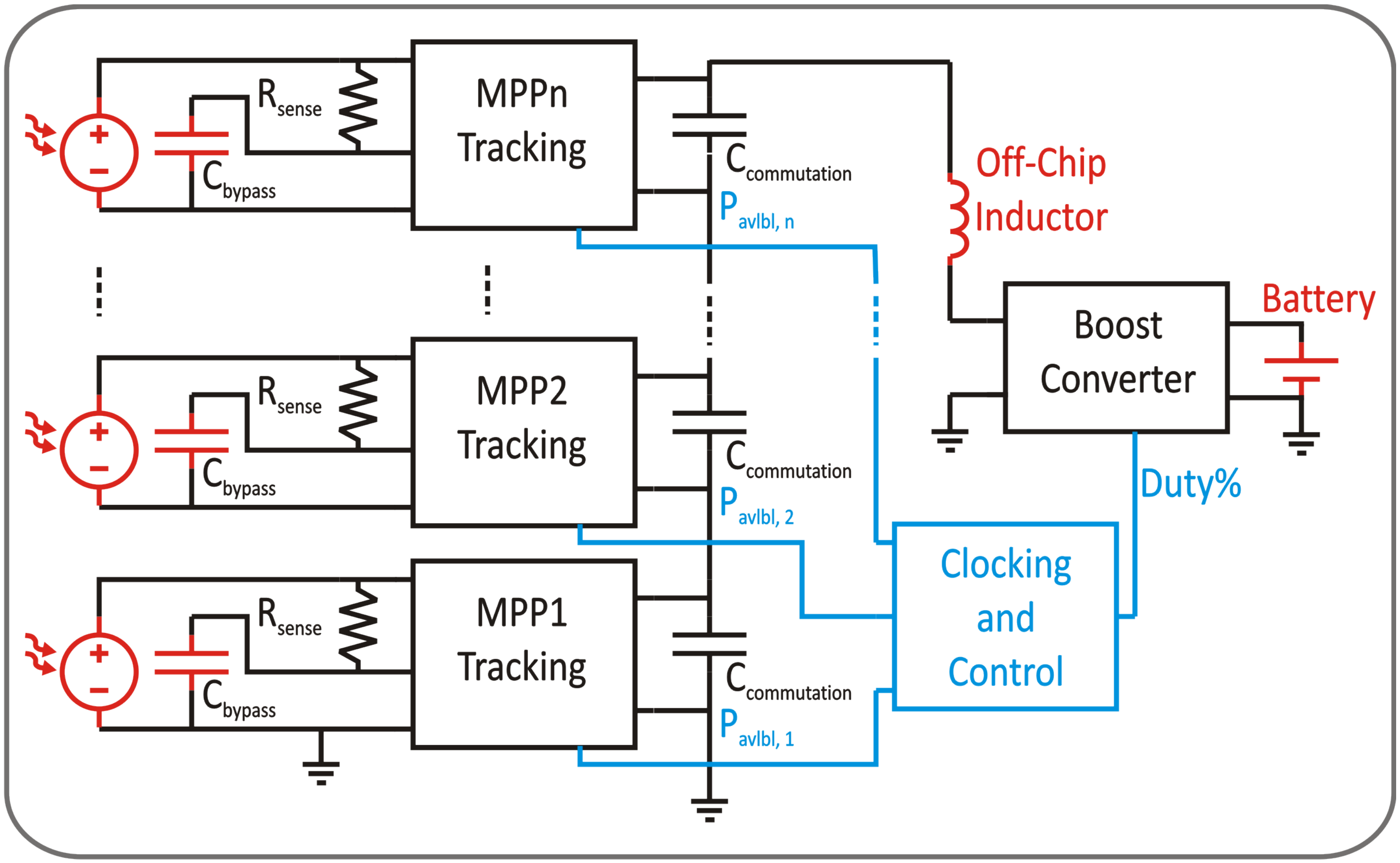






re-routing temporally…

The System


MPPn
Tracking
MPP2
Tracking
MPP1
Tracking
R sense
C bypass
C commutation
P avlbl, n
P avlbl, 2
P avlbl, 1
Off-Chip
Inductor
Boost
Converter
Battery
Duty%
Clocking
and
Control

Hmmm testing…

- Does TDAR Work?
- Are the switching losses prohibitive?
- Can the control loop be a small system?

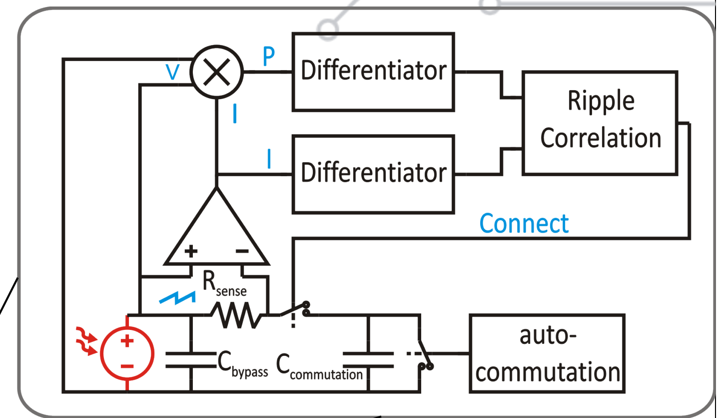
- Discrete TDAR system
  - off the shelf ICs that mirror chip control loop
- TDAR Chip
- 10mA and 40mA solar cells – 3-strings
- SMU's and Oscilloscopes!

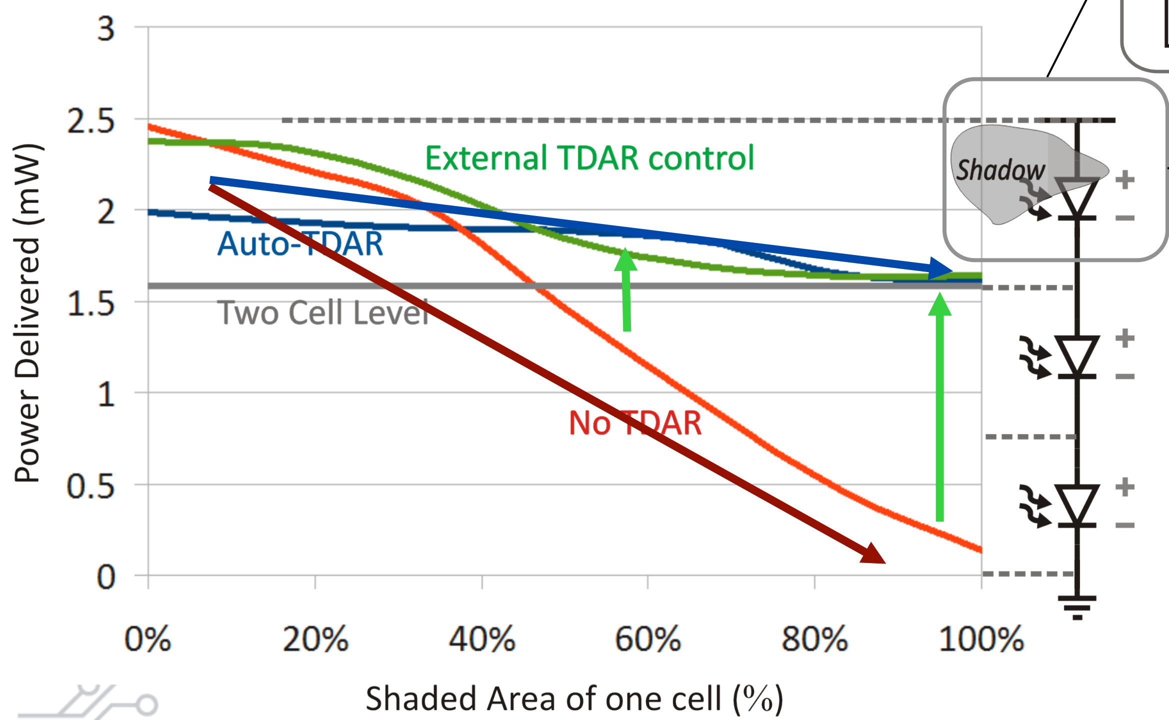
Does T.D.A.R. Work?

red- *drops below 2-cell level…*

green- optimal

blue- *duty cycle limited*



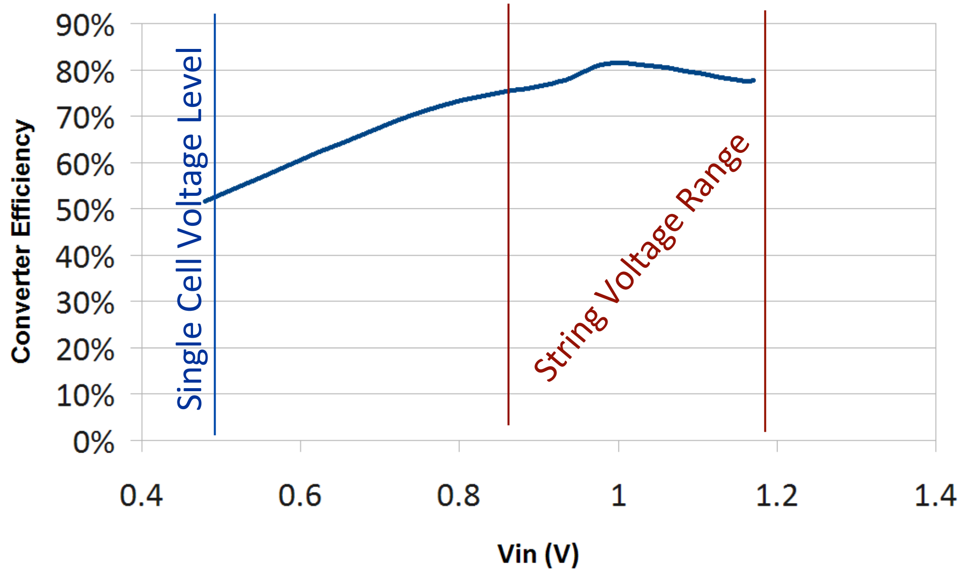


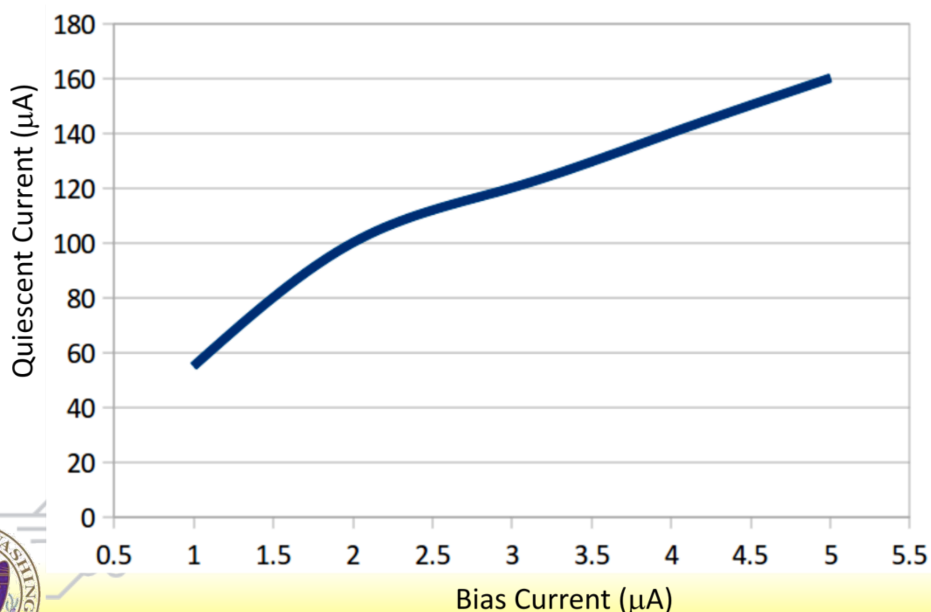
Inferences:

TDAR is only as good as:

- The control loop
- The power switches

Power consumption of Chip





Inferences:

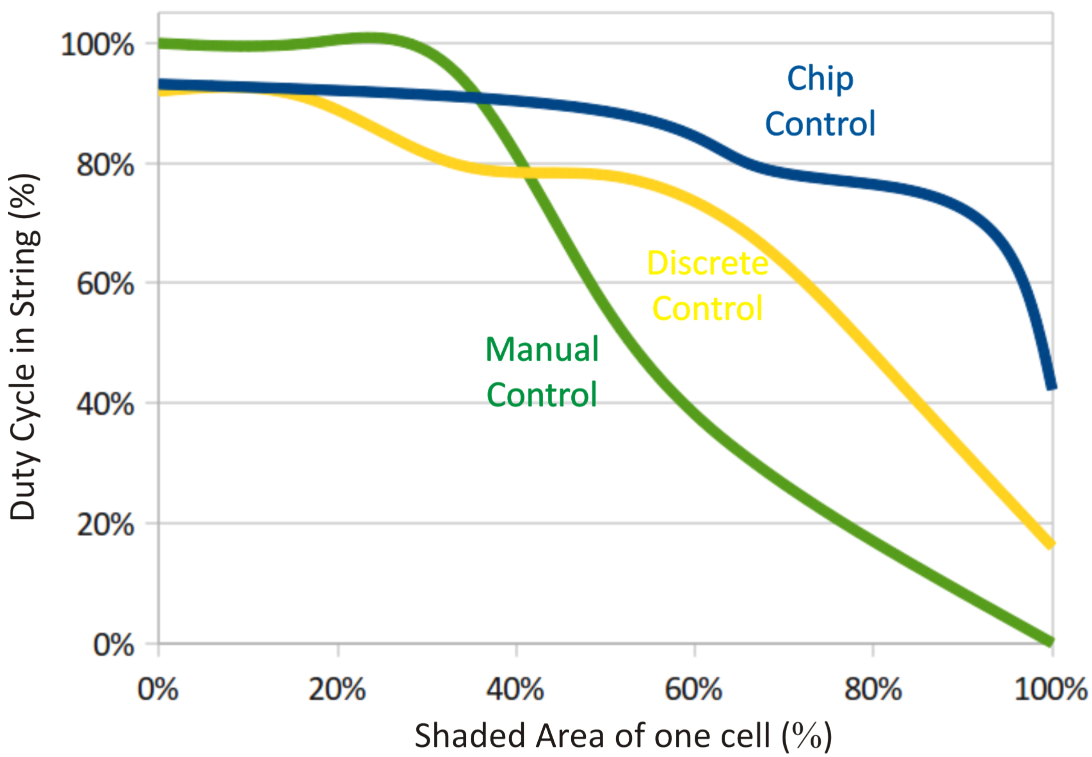
3 TDAR cells at 55µA total

Boost converter near 80% for 3-cell-string voltage range

Single-cell voltages see lower efficiency

=> TDAR can be more efficient!

Comparing control loops



Inferences:

On-chip control loop unstable at low duty-cycles

Other Notes:

Chip sensitive to light (!)

PV dynamic models can improve accuracy

SMU's can be faulty

Oscilloscopes can auto-calibrate

Conclusions…

- T.D.A.R. improves power availability under shading for any-sized array
- T.D.A.R. is a strong contender for low-power PV-string management
- Higher efficiencies with a PV string than a single cell for ultra-portable applications
- Scalable and Modular, but only as good as its control loop and power switches!

… the story continues!…