Energy Conversion for Micro Integration

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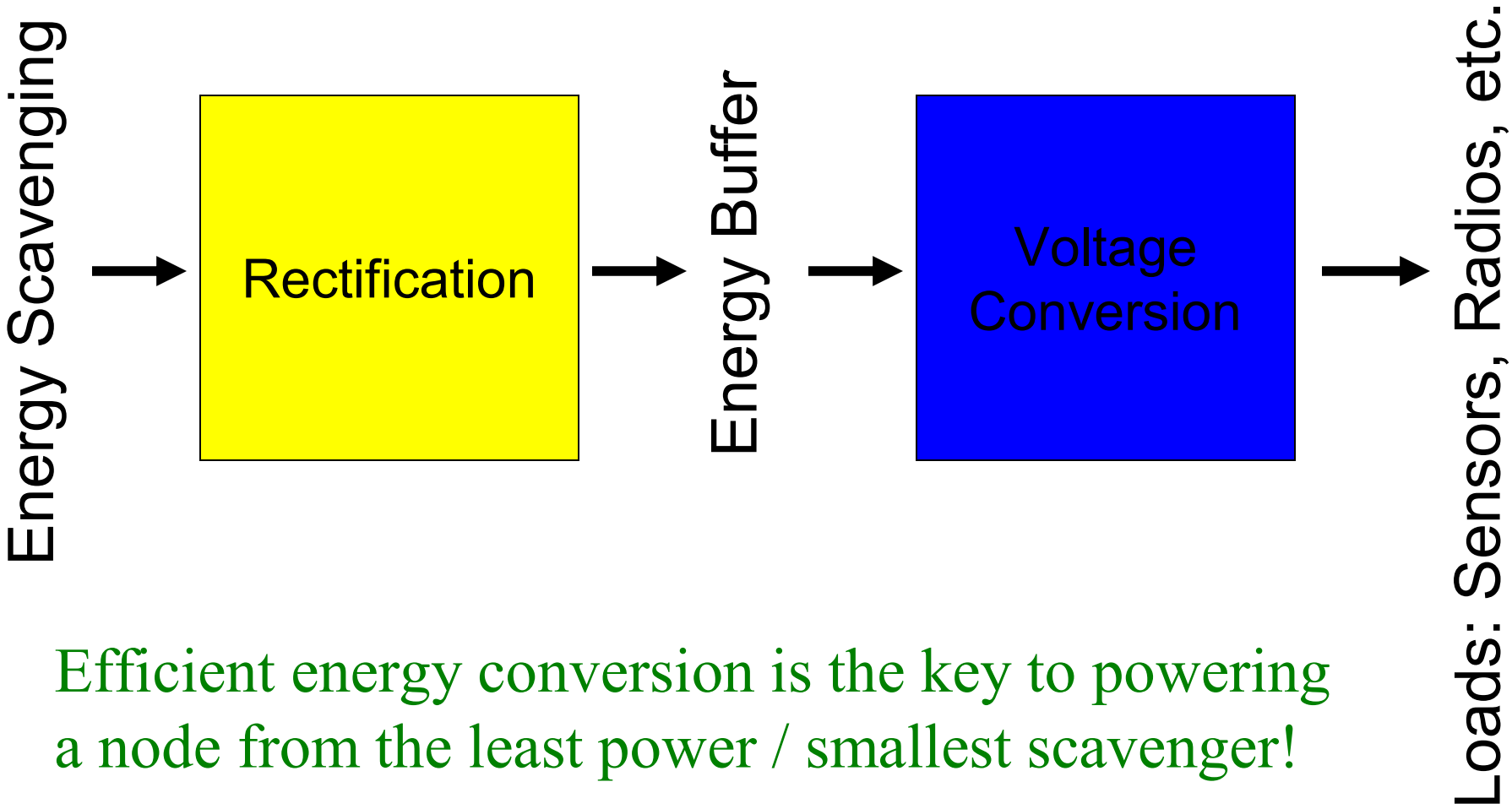
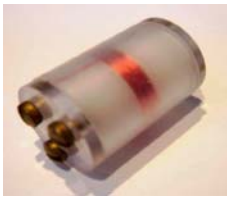
Energy Conservation Key!



Efficient energy conversion is the key to powering a node from the least power / smallest scavenger!

Scavengers and Rectification

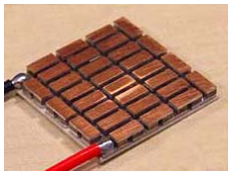


Magnetic Shaker

Synchronous rectifier and impedance matching by source tuning

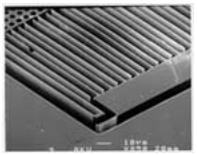
Solar Cell

Doubler or other fixed-ratio switched-cap DC-DC converter



Thermoelectric

Step-up switched-cap converter and ultra-low-voltage operation



Micro-scale Bender

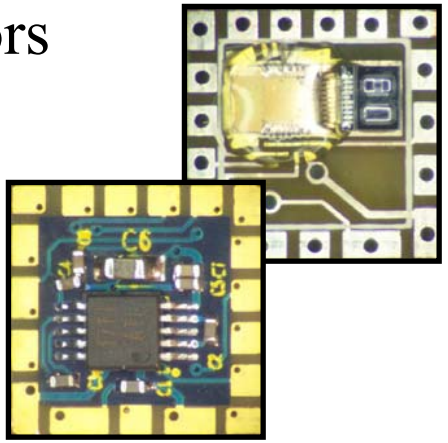
Series connection, then rectifier and a variable-ratio S.C. converter

DC-DC Conversion for Loads

Energy Buffer
(battery/cap)

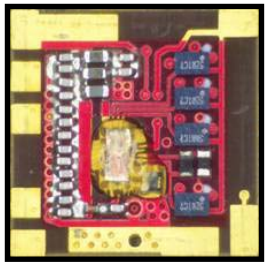
1:2 step-up

Microcontroller
Sensors
Etc.

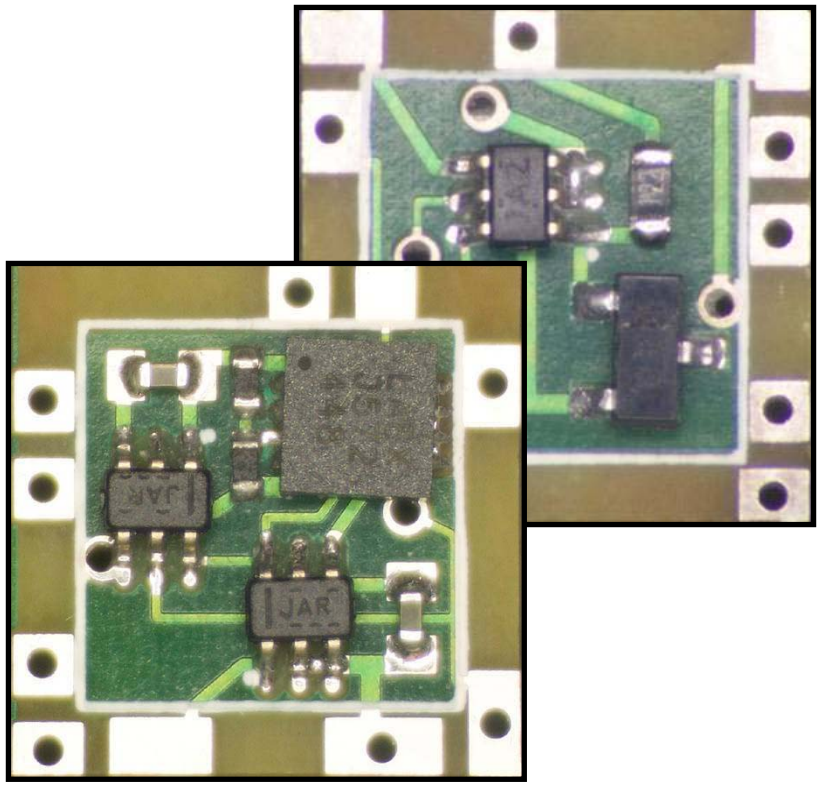


1:0.66 step-down

PicoRadio
Other low-voltage stuff



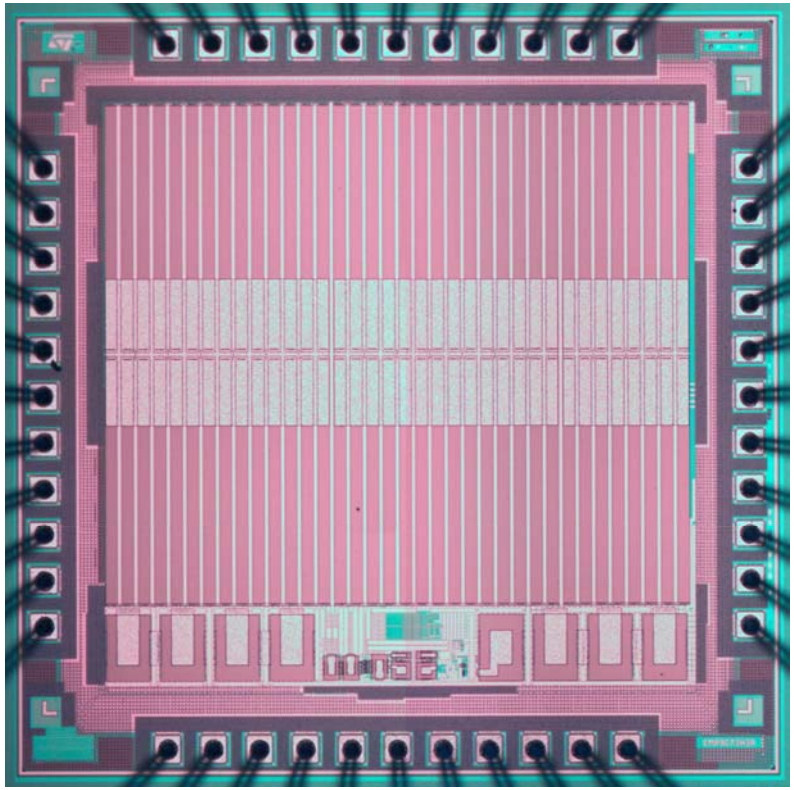
Discrete Power Electronics



- 1:2 switched-capacitor converter
  - External caps
- 2 linear regulators
- Diode Rectifier

Discretes take up a lot of space and are inefficient!

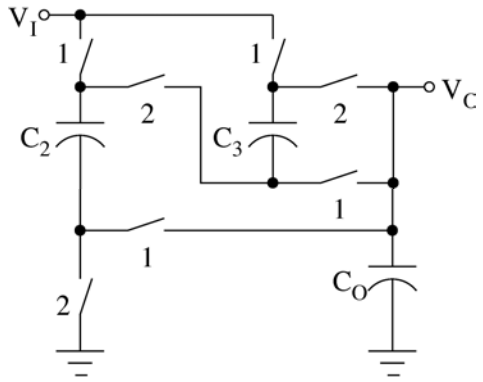
Integrated Power Electronics



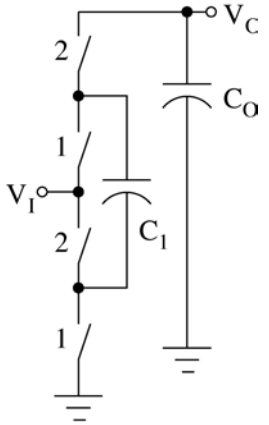
- **All power electronics on a single chip!**
  - 2 S.C. Converters
  - Synchronous Rectifier
  - Linear Regulators
- **Shrinks size**
- **Improves efficiency**
- **Ver. 2 back Oct '07**

Converter Designs

3:2 Converter (0.7V)

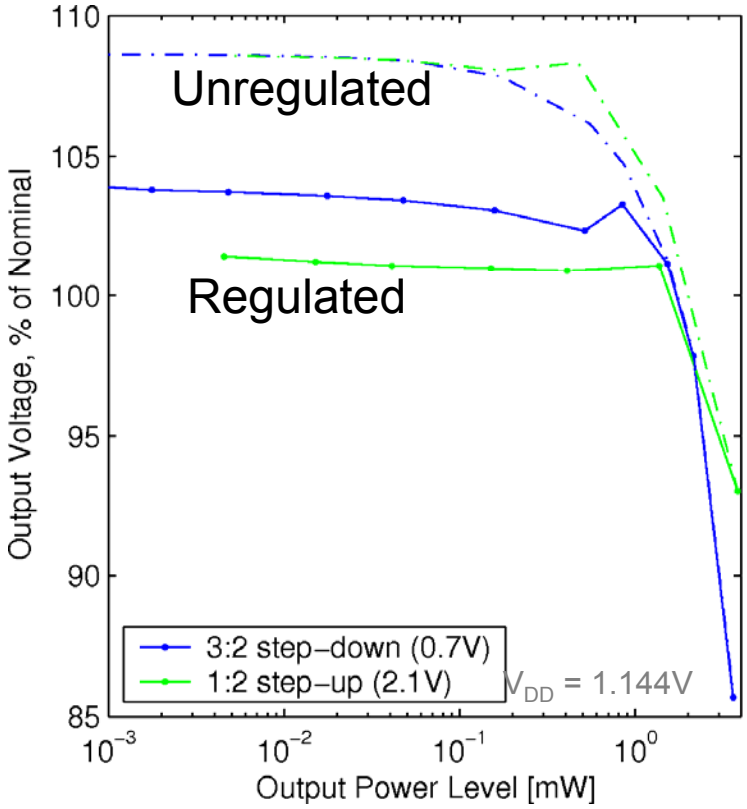


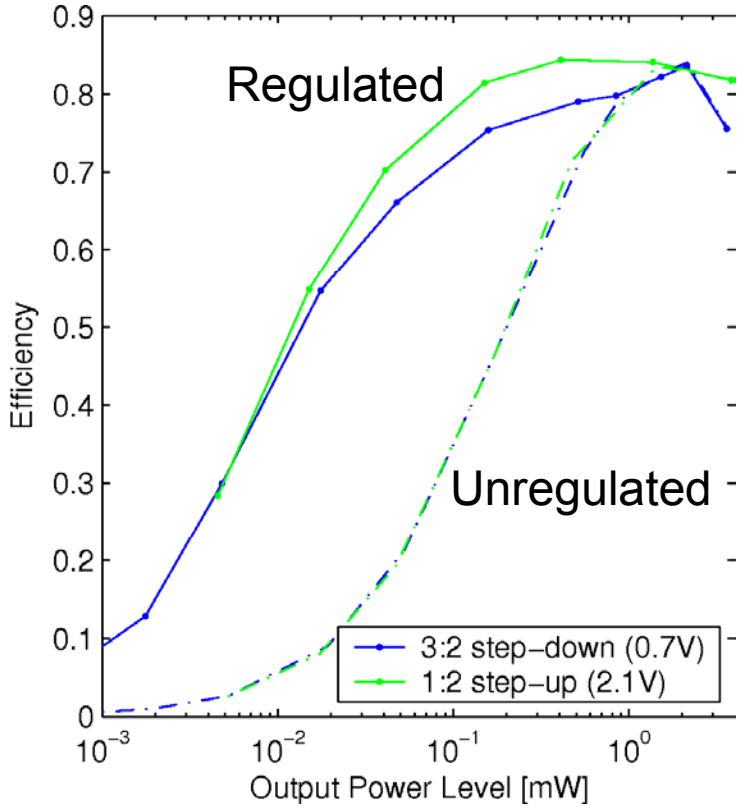
1:2 Converter (2.1V)



- Native 0.13µm NMOS devices used for high performance
- ~ 1 nF capacitors yield f_{sw} = 30 MHz
- Hysteretic feedback used to regulate converter switching frequency
- Novel gate drive structures used to drive triple-well devices

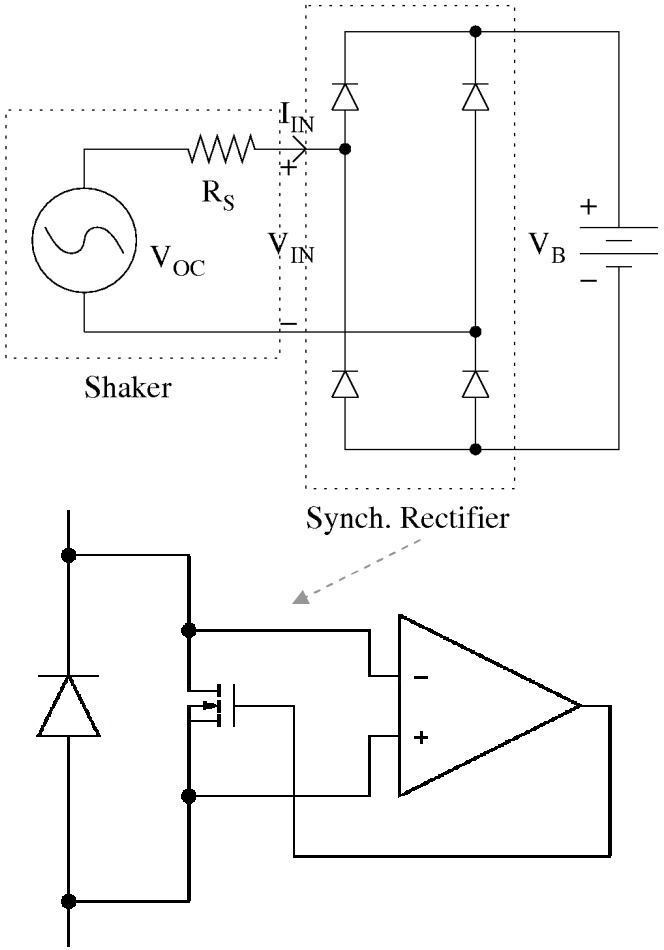
Converter Performance

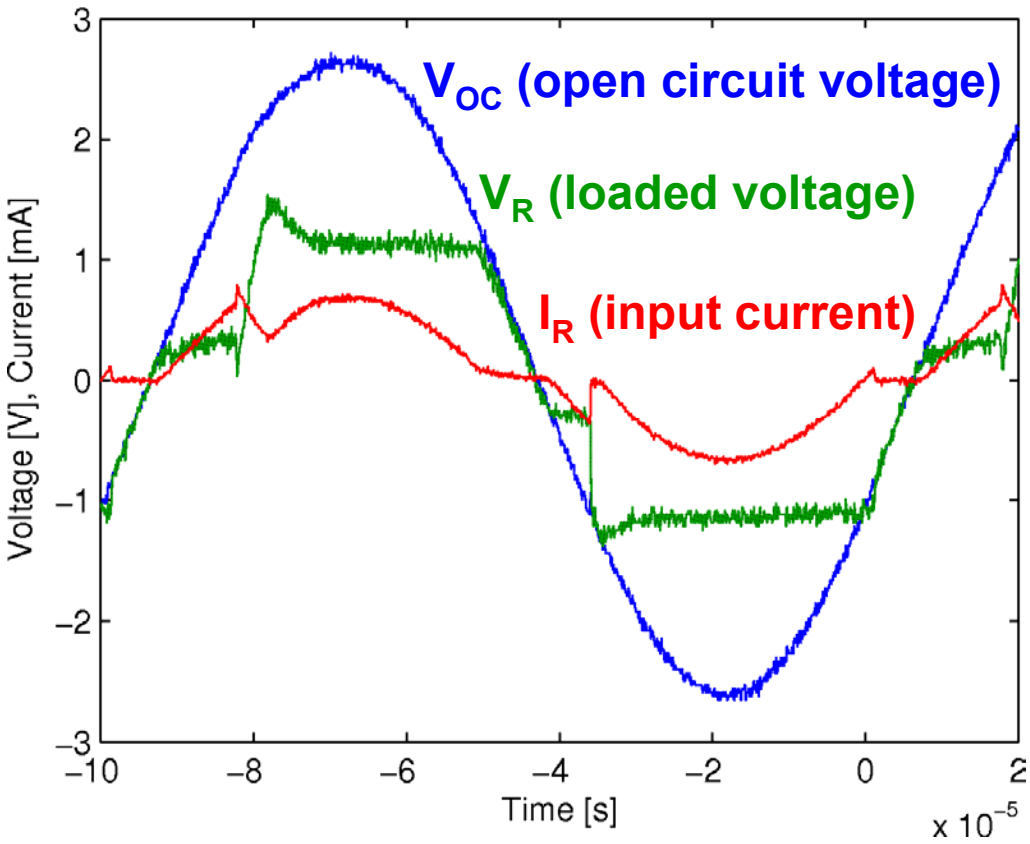




Regulation is effective at controlling output voltage and increasing efficiency at low power levels!

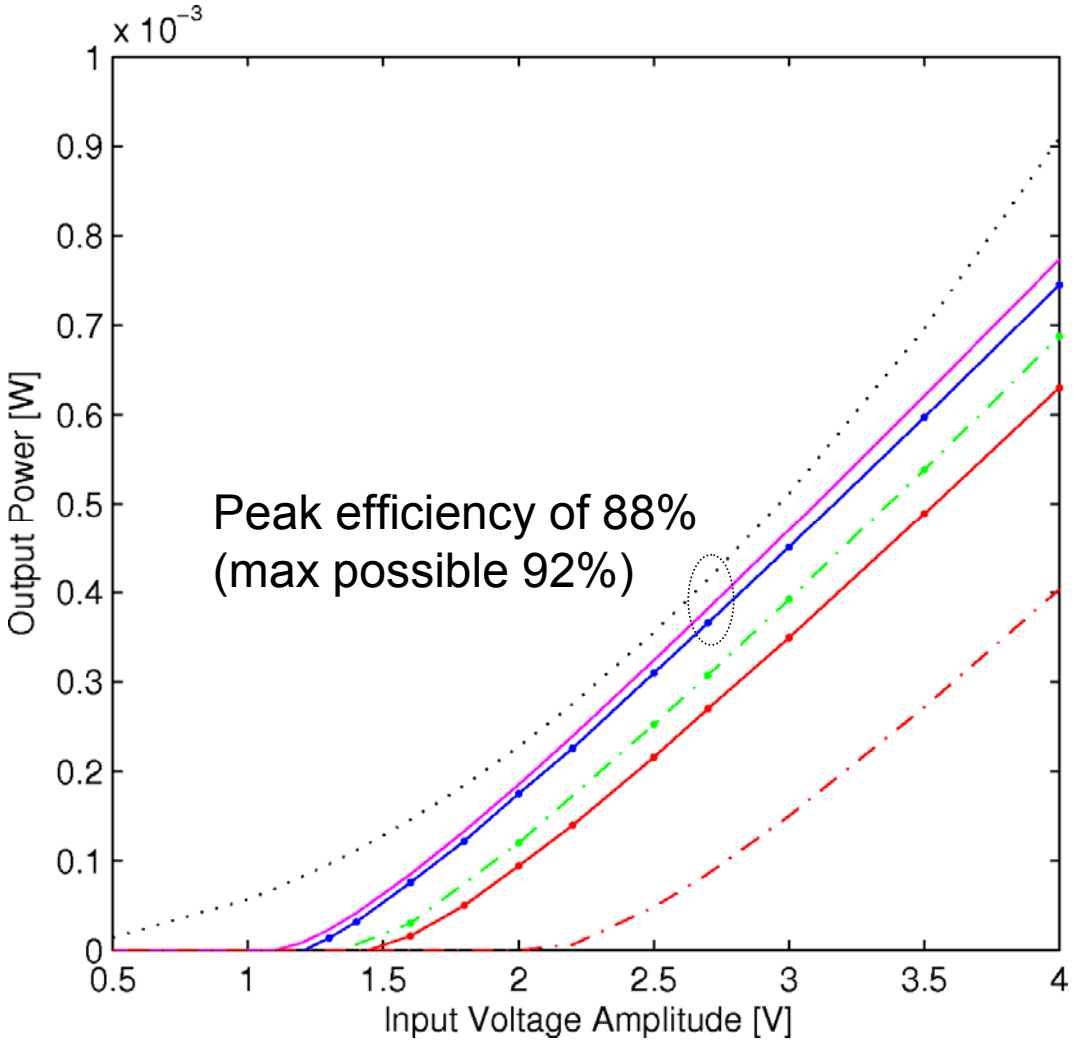
Synchronous Rectifier: Waveforms





10 kHz input, 2.2kΩ source impedance

Synchronous Rectifier: Efficiency



Matched Load $R_L = R_S$

Ideal diode rectifier (V_D=0)

This chip, ≤ 1 kHz input

This chip, 10 kHz (boosted)

This chip, 10 kHz input

V_D = 0.5V diode rectifier

V_{DD} = 1.1 V NiMH
2.2 kΩ source

Weighted Power Usage

Operation	Old Design	New Design	
	Efficiency	Input Power	Efficiency
Idle (5.86 s)	**N/A**	**8.6 µW**	**N/A**
Wakeup (4.5 ms)	**72 %**	**1.62 mW**	**84 %**
Sample (6 ms)	**58 %**	**480 µW**	**84 %**
Transmission (4 ms)	**69 %**	**4.17 mW**	**84%**
Weighted Averages	8.3 % (73.5 µW)	12.9 µW	47 %

Averaged power use decreased by 5x!

Conclusions

- Integrated power circuitry can improve performance and reduce size
- IC conversion required for advanced (integrated) energy scavenging
- More IC-based power conversion techniques to be developed to further shrink nodes