Thermodynamics for computing engines

- During an adiabatic process no loss or gain of heat occurs
- Relationship between information and energy
  1. Bits can be adiabatically generated
  2. Bits can be adiabatically copied
  3. Bits cannot be adiabatically erased
- To minimize the impact of erasure, the dissipation can be postponed by copying the information instead of erasing it

Adiabatic line driver circuit

- f = 1 MHz, C_{load} = 8×100 pF ⇒
- $P_{total} = 0.15\ P_{conventional}$
  - $P_{aldc} = 0.5\ P_{total}$
  - $P_{FET} = 0.3\ P_{total}$
  - $P_{FET\_gate} = 0.2\ P_{total}$

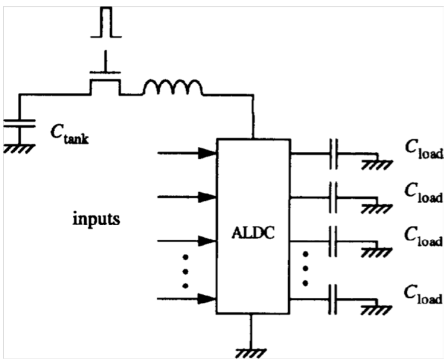


Fig. 3 Test set up

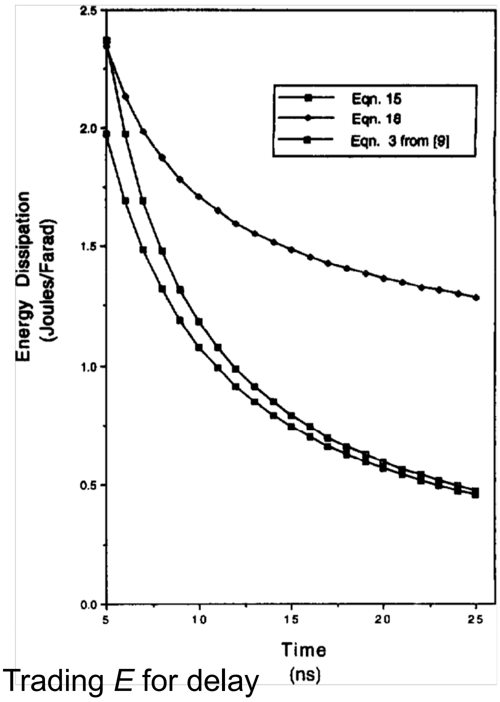


Fig. 4 Trading E for delay

Adiabatic logic pipeline

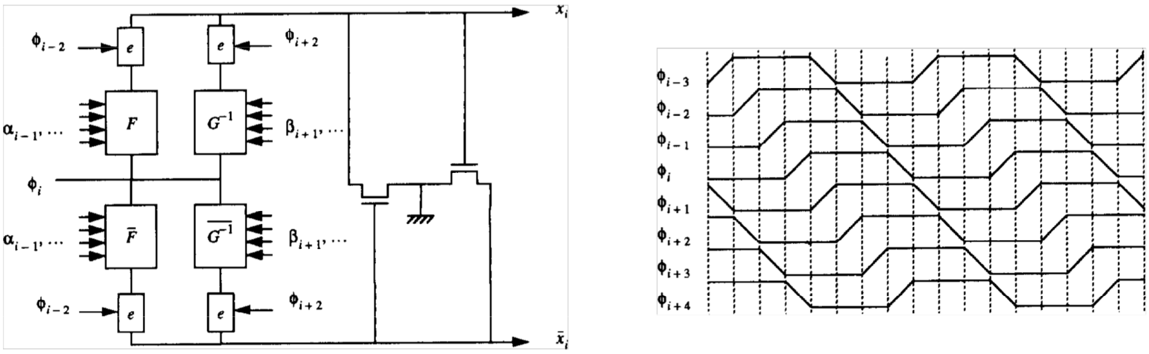


Fig. 8. Dual-rail logic and its 8-phase adiabatic clock signals

Energy sources

Light	Outdoor	10 000 μW/cm^2
	Office	100 μW/cm^2
	Indoor	10 μW/cm^2
RF	GSM	1-20 μW/cm^2
	WiFi	1 μW/cm^2
Thermoelectric	Machine	10 000 μW/cm^2
	Human	25-60 μW/cm^2
Vibration	Machine	800 μW/cm^3
	Human	4 μW/cm^3

Multi-harvesting power chip

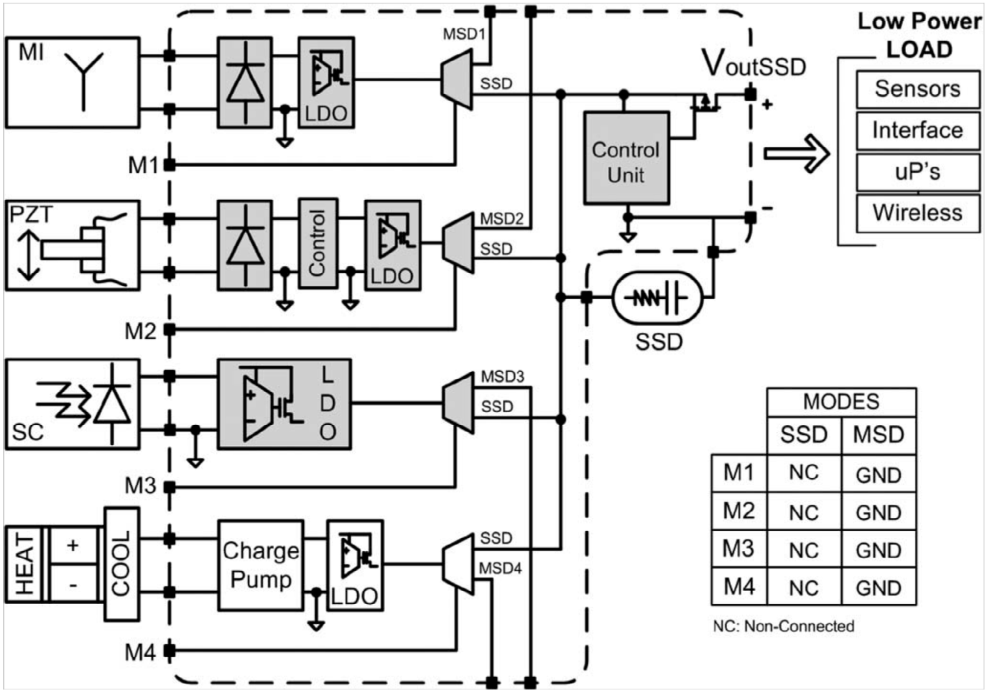


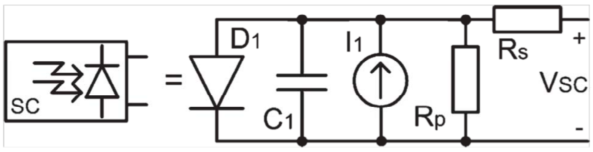
Fig. 1

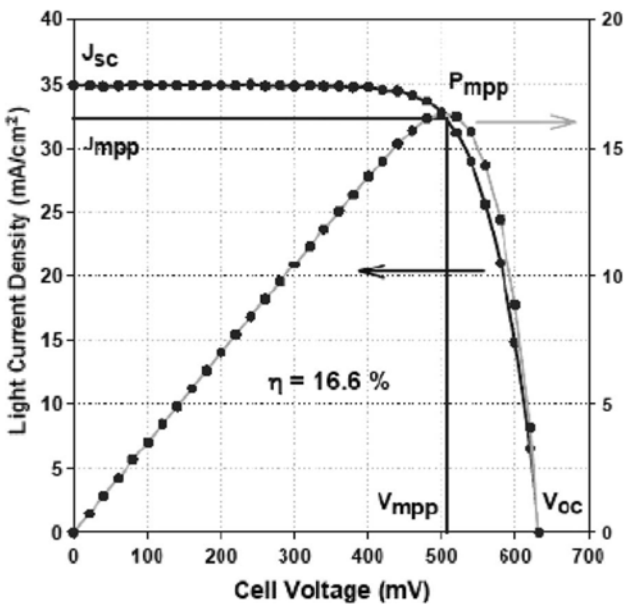
Solar cell (SC)

- Three solar cells per package
  - Total volume 22 x 7 x 1.6 mm^3

TABLE II
IXYS XOB17 ELECTRICAL CHARACTERISTICS

Symbol	Parameter	Value	Units
V_{OC}	open circuit voltage	1.89	V
I_{SC}	short circuit current	12.6	mA
V_{MPP}	voltage @ MPP	1.53	V
I_{MPP}	current @ MPP	11.7	mA





Figs. 2-3

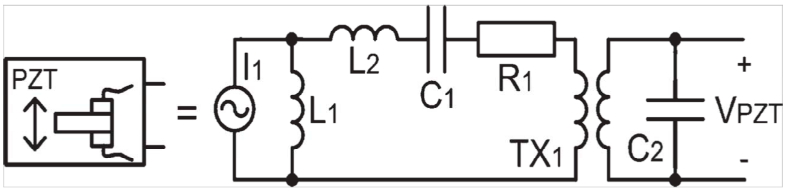
Piezoelectric generator (PZT)

- Two generators per device with total volume 51 x 38 x 0.8 mm^3

TABLE III
QP20W ELECTRICAL CHARACTERISTICS

Acceleration	Voltage	Current	R_{LOAD}
$7 m/s^2$ @ 82 Hz	1.2 V	75µA	10kΩ

Fig. 4



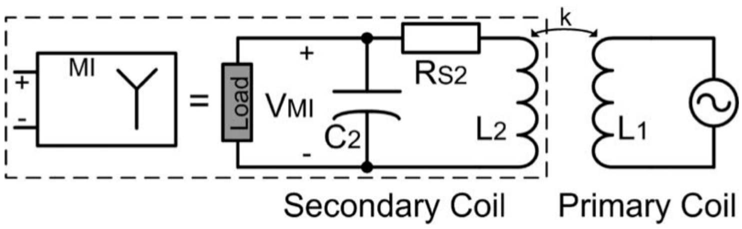
Magnetic induction power link (MI)

- RFID 200 mW transmitter
  - Receiver coil on PCB
  - Area 30 x 15 mm^2

TABLE IV
RECTANGULAR COIL CHARACTERISTICS

Symbol	Parameter	Value	Units
L_2	secondary coil	220	nH
C_2	parallel capacitor	620	pF
R_{S2}	secondary series resistance	310	mΩ
f	Resonance frequency	13.56	MHz
N	number of turns	3	-
CW	Conductor width	1	mm
SUB	type of substrate	FR4	-
L x W	dimensions	30 x 15	mm

Fig. 5



Rectifier

- PMOS is more efficient than NMOS but larger

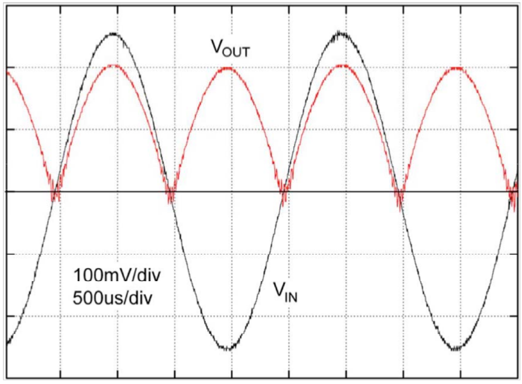
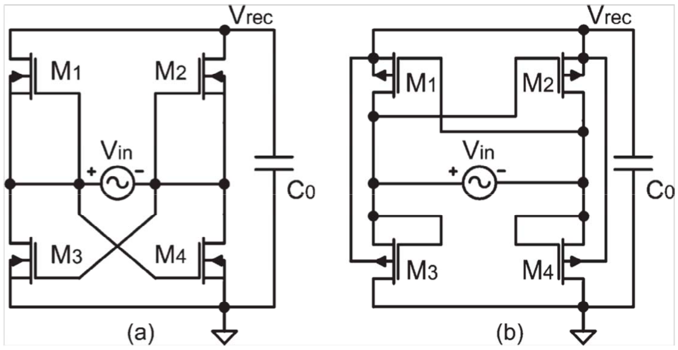


Fig. 6

TABLE V
NMOS FULL-WAVE RECTIFIER CHARACTERISTICS

Symbol	Parameter	Min	Max	Units
V_{IN}	nominal input voltage	0.3	2.5	Vp
V_{drop}	drop voltage	0.2	0.67	V
I_{out}	output current	-	20m	A
Freq	working frequency	-	16M	Hz
η	efficiency	52	85	%
$I_{leakage}$	leakage current	-	1.4m	A
W	width of each transistor	3000μ		m
L	length of each transistor	0.28μ		m



Low drop-out regulator (LDO)

- Large off-chip C_L is used for stability

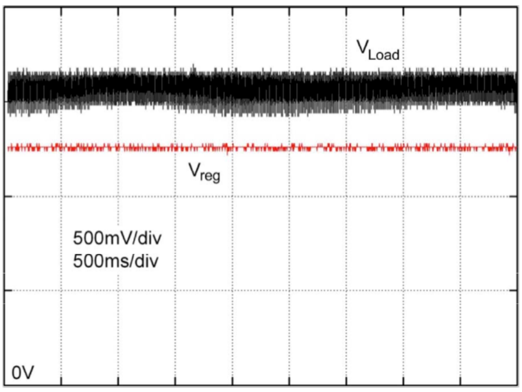


Fig. 14

TABLE VI
LDO ELECTRICAL CHARACTERISTICS

Symbol	Parameter	Min	Max	Units
V_{IN}	input voltage	1.3	2.5	V
V_{Reg}	regulated outputvoltage	1.189	1.22	V
I_{Reg}	output current	20μ	10m	A
I_{CC}	current consumption	23μ	27μ	A
P_{CC}	power consumption	29 μ	67 μ	W
Λ_{Load}	load regulation*	13m	34m	V
Λ_{Line}	line regulation**	7m	18m	V
Λ_{DC}	DC gain	63	72	dB
P_M	phase margin	58	65	°
PSSR	supply rejection ratio	28.7	39.4	dB

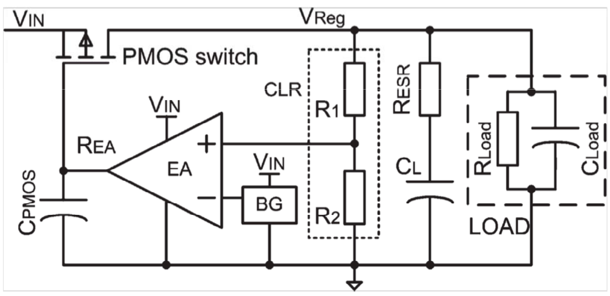


Fig. 12

Power consumption of the components

- Low-dropout regulator (LDO)
  - P = 30 μW per LDO
- Control module
  - P = 70 μW
- Combination of the three power sources
  - P = 60 μW

Multi-harvesting power chip

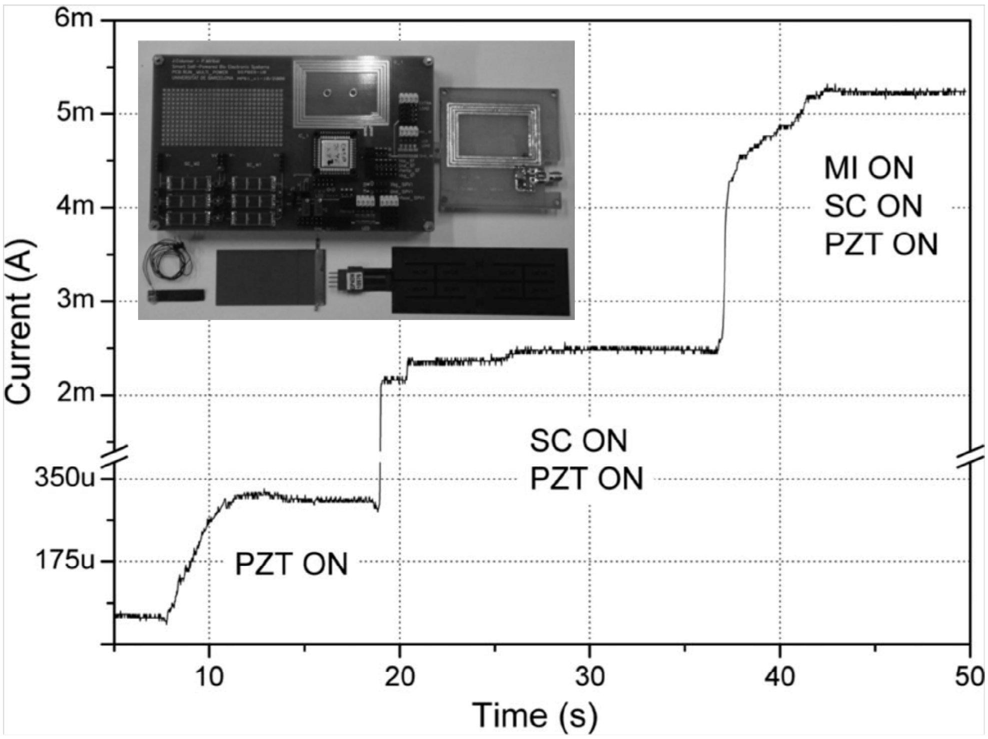


Fig. 18

Some experimental applications

- [79]: Ultrasonic powering
  - *P* = 21 nW
- [91]: Temperature measurement and transmission every 5 s
  - *P* = 10 µW
- [92]: Pulse oximeter sensor
  - *P* = 90 µW
- [93]: Average sensor node measuring and transmitting 200 kb/s
  - *P* = 200 µW

References

15.pdf **Low-power digital systems based on adiabatic-switching principles**

W.C. Athas, L.J. Svensson, J.G. Koller, N. Tzartzanis, and E. Ying-Chin Chou

IEEE Transactions on Very Large Scale Integration (VLSI) Systems, volume 2, issue 4, Dec. 1994, pages 398-407

16.pdf **A multiharvested self-powered system in a low-voltage low-power technology**

J. Colomer-Farrarons, P. Miribel-Catala, A. Saiz-Vela, and J. Samitier

IEEE Transactions on Industrial Electronics, volume 58, issue 9, Sept. 2011, pages 4250-4263