Robust, low-cost, auditable random number generation for embedded system security

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All secure systems depend on random numbers

10 AM

DO YOU KNOW WHERE YOUR RANDOM NUMBERS COME FROM?

All secure systems depend on random numbers

Embedded systems face unique challenges

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Embedded systems face unique challenges

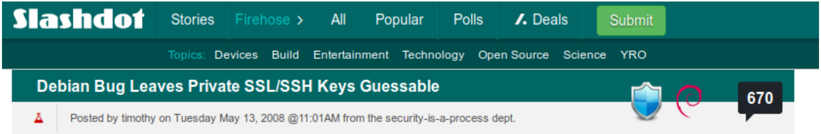
We present a hardware/software system for random number generation tailored to embedded devices:

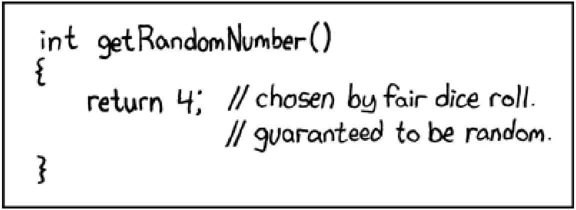
- hardware costs ≈$1.50, 1.5 cm^2 board area
- run once at boot, takes 25 ms to initialize
- energy cost equivalent to 10 ZigBee packets

Debian Bug Leaves Private SSL/SSH Keys Guessable

670

Posted by timothy on Tuesday May 13, 2008 @11:01AM from the security-is-a-process dept.





http://xkcd.com/221/ CC BY-NC 2.5

A deterministic “random” number generator?

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Idea: add a secret!

Cryptographically secure pseudorandom number generator

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Figure of merit: *entropy*
informally: the number of bits in k that an adversary does not know

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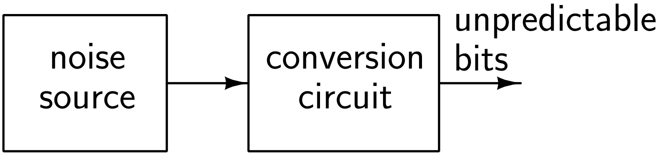
  ✗ Embedded processors may not have RNG
  ✗ Integrated RNG is opaque, not auditable
    - Becker et al. [CHES '13] showed that integrated hardware RNGs can be stealthily backdoored

Wish list

- Inexpensive
- Small
- Low power
- Insensitive to environmental factors (e.g., temperature, RF interference)
- Easy to detect failure: simple and auditable
- Generates a CSPRNG key quickly

Generating unpredictable bits: two easy pieces



Noise source: a device exhibiting
an unpredictable physical phenomenon

Conversion circuit: detects state of device,
produces corresponding bits

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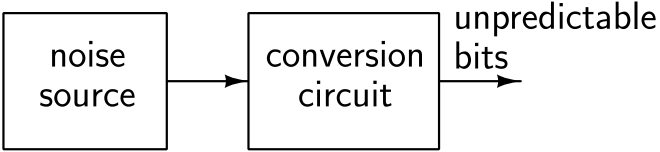

Example noise sources:

- Radioactive decay
- Beam splitting
- Photoelectric effect
- Circuit noise
  - thermal noise (all electronic devices)
  - shot noise, flicker noise (diodes and transistors)
  - Zener noise, avalanche noise (diodes)

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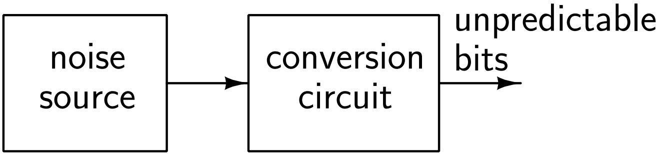

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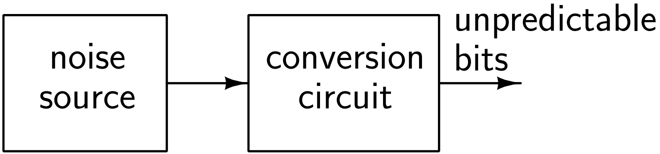

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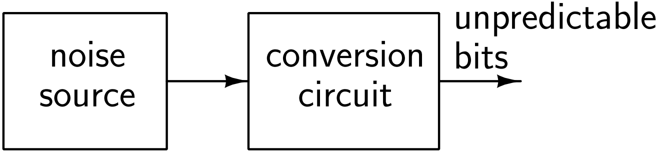

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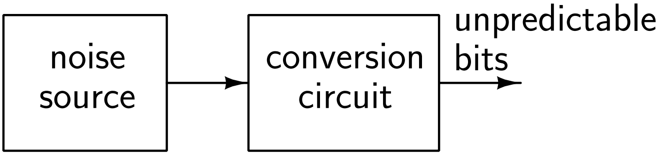

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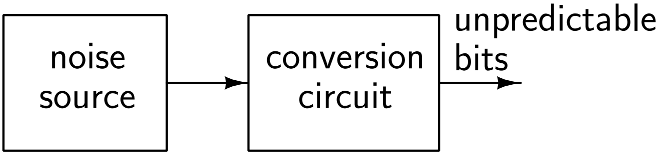

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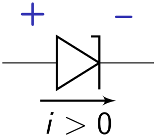
Diodes, reverse breakdown, and avalanche

Voltage applied in forward direction: current can flow



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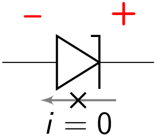

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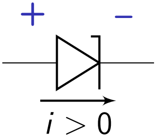

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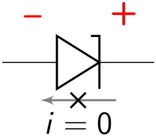

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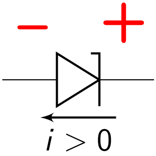

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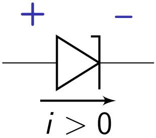

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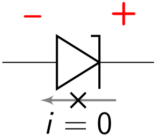

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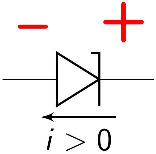
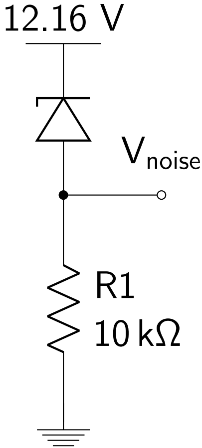
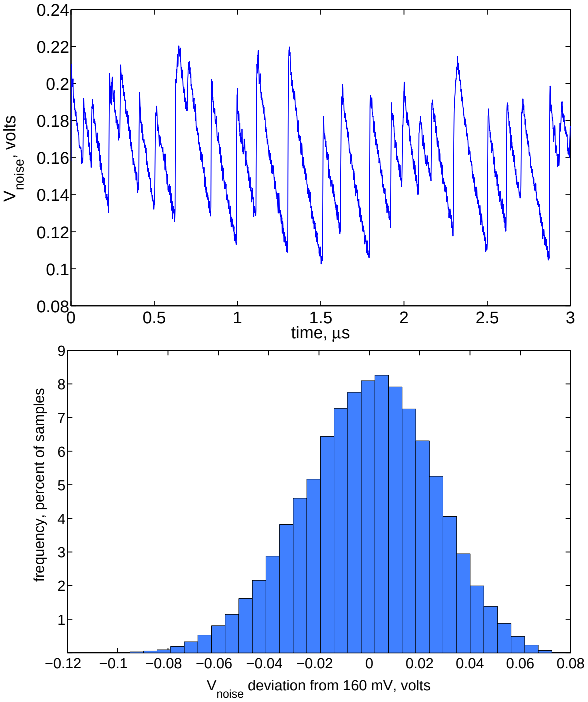


Avalanche current:

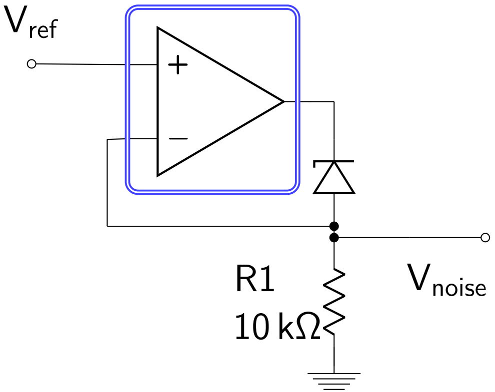
electron collisions cause an "avalanche" of charge carriers

Avalanche current

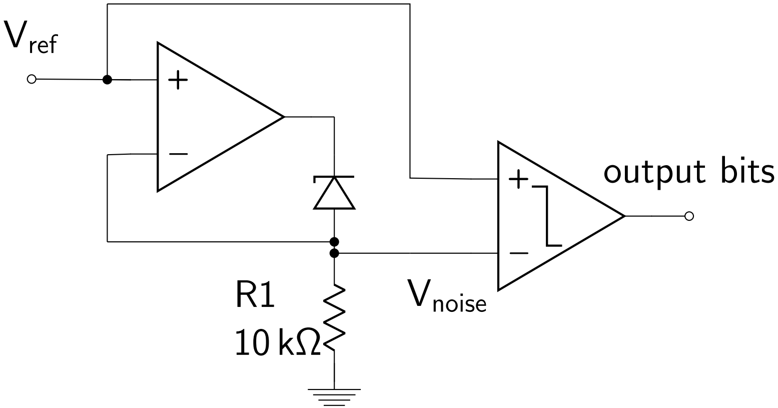




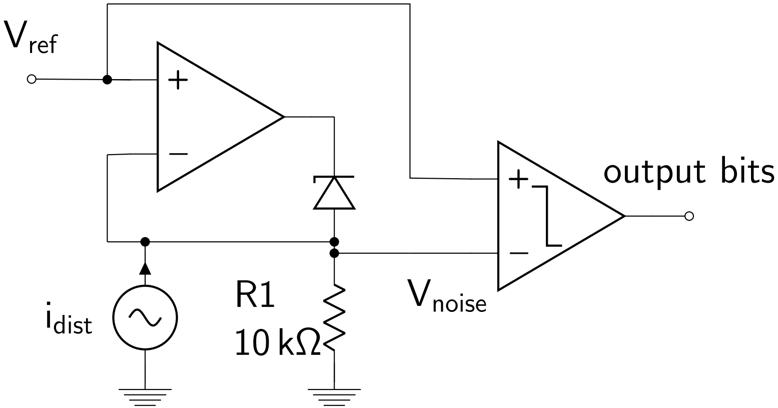
Overcoming manufacturing variations



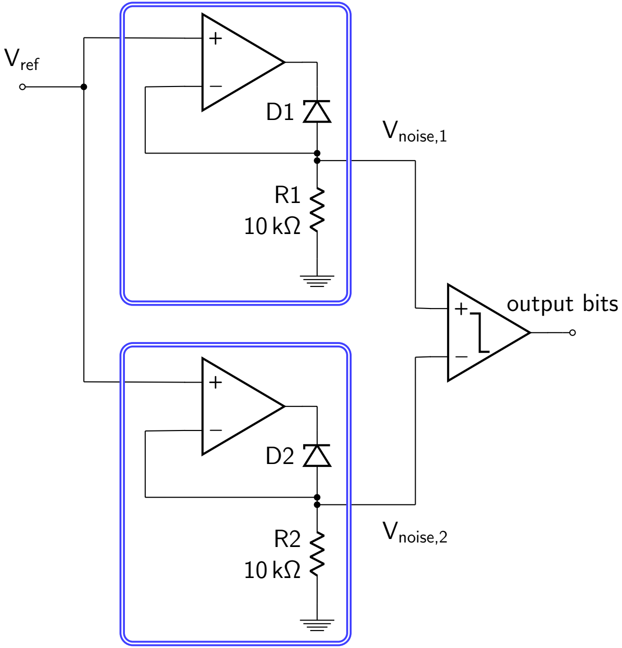
Converting V_{noise} to bits



Issue: outside disturbances



Overcoming disturbances using a differential circuit



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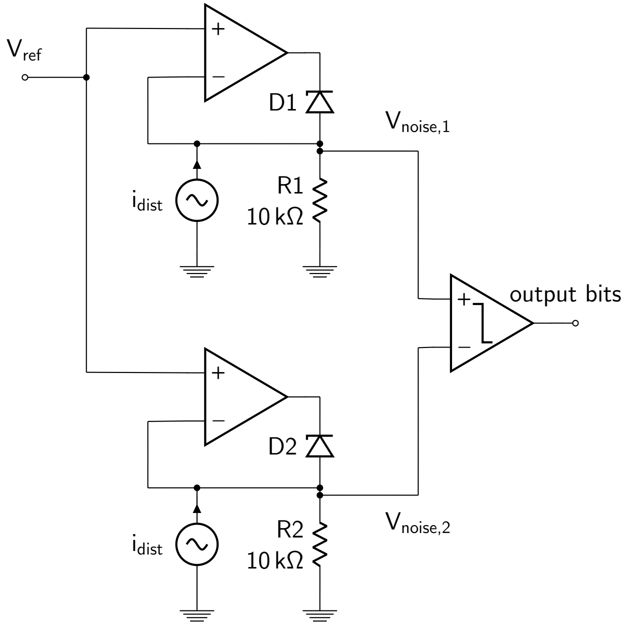

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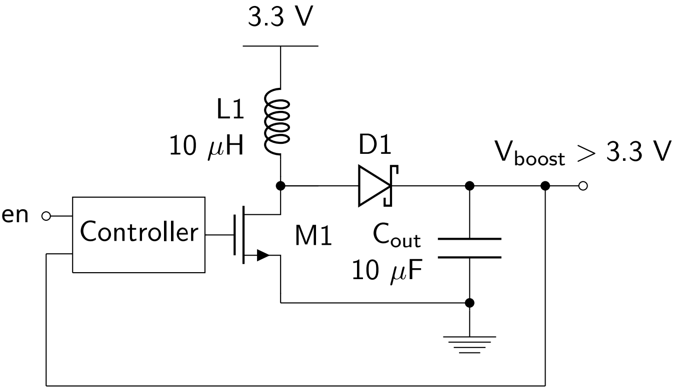

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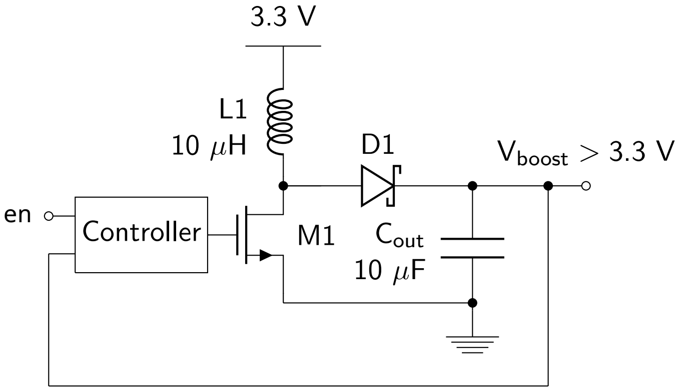

Issue: the boost converter causes large disturbances

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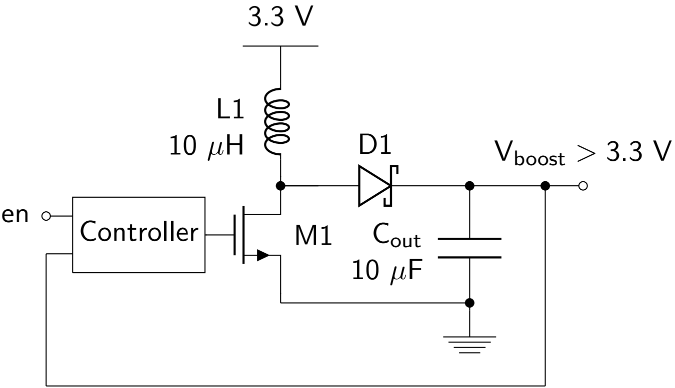
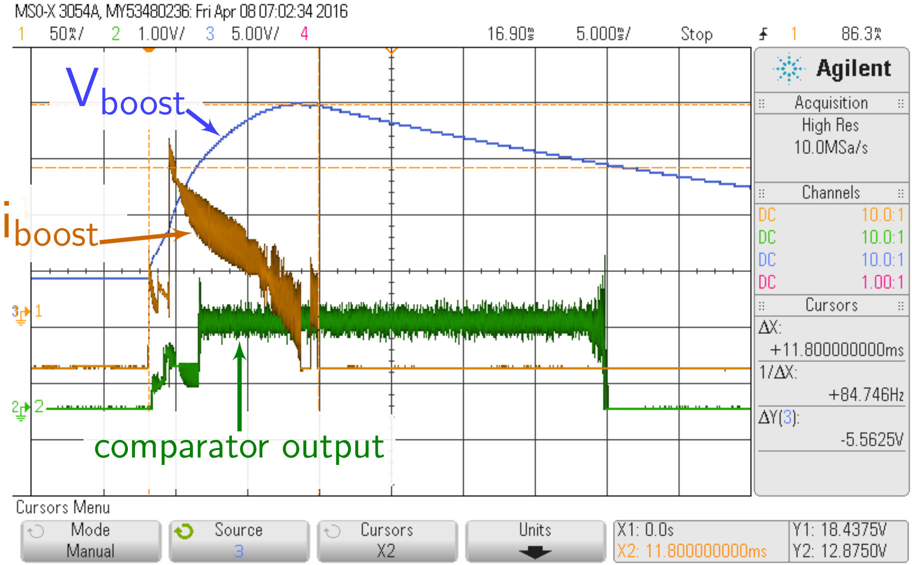


Issue: the boost converter causes large disturbances

Solution: interleave boost and output sampling

Interleaved boost operation



Putting it all together

- At boot:
  1. run circuit to gather 1024 bits, b_{raw}
  2. compute $k = \text{SHA256}\left(b_{\text{raw}}\right)$
  3. initialize global counter $c = 0$

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- To generate a random number:
  1. increment counter c
  2. use AES to encrypt c under key k
  3. return resulting ciphertext

Testing and monitoring

In the paper, we define methods for:

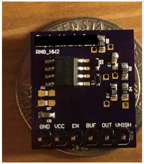
Acceptance testing:
after assembly and before deployment, each device should be checked for proper operation

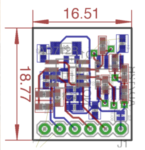
Online auditing:
for systems requiring high assurance, further online testing in the field

Evaluation questions

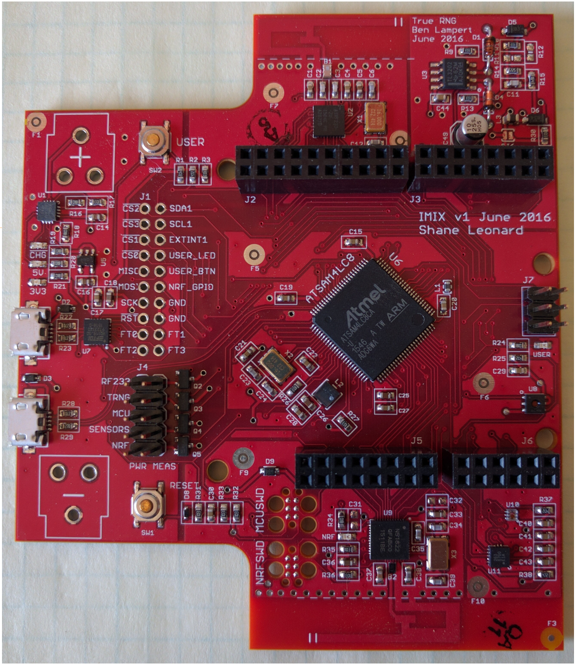
- How quickly should the system sample the bit generator's output?
- What are the statistical properties of the raw output versus time and temperature?
- What is the cost, in energy and time, of generating a CSPRNG key?

Built systems

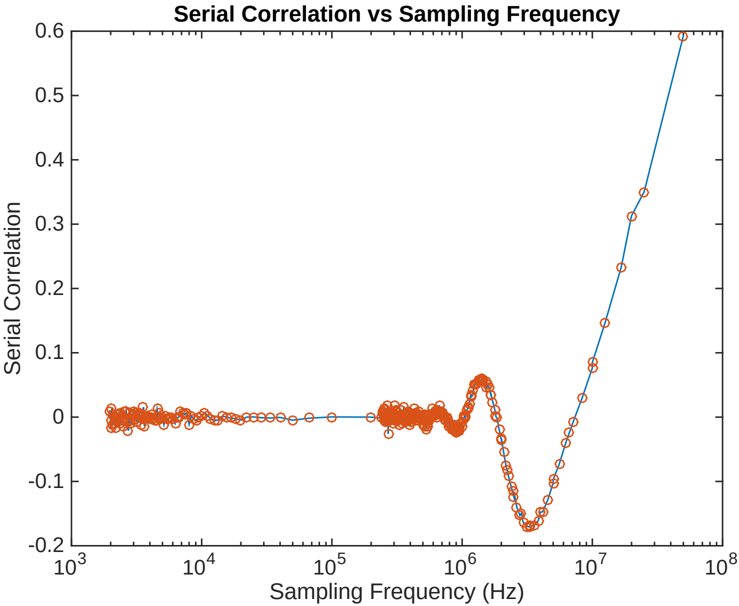




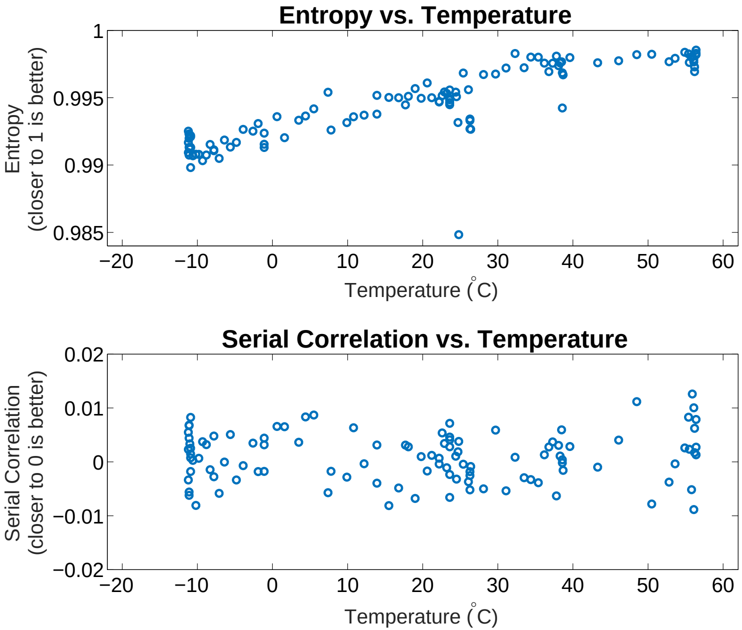
Cost ≈ $1.50



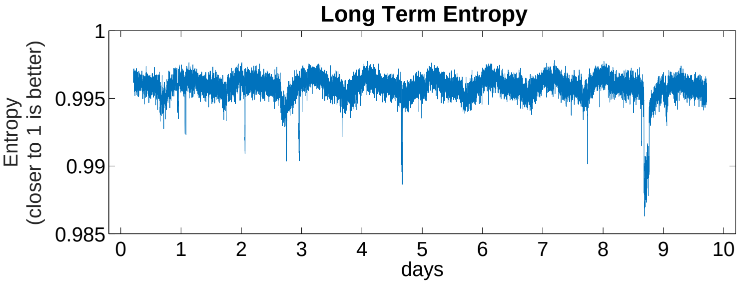
Determining the sample rate

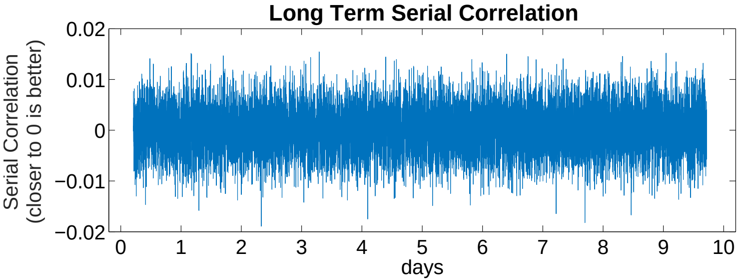


Statistical properties versus temperature



Statistical properties versus time





Time and energy costs to generate CSPRNG key

Time to gather 1024 bits:

$\approx$13 ms running dc/dc converter

$\approx$12 ms sampling output of bit generator

Energy to gather 1024 bits:

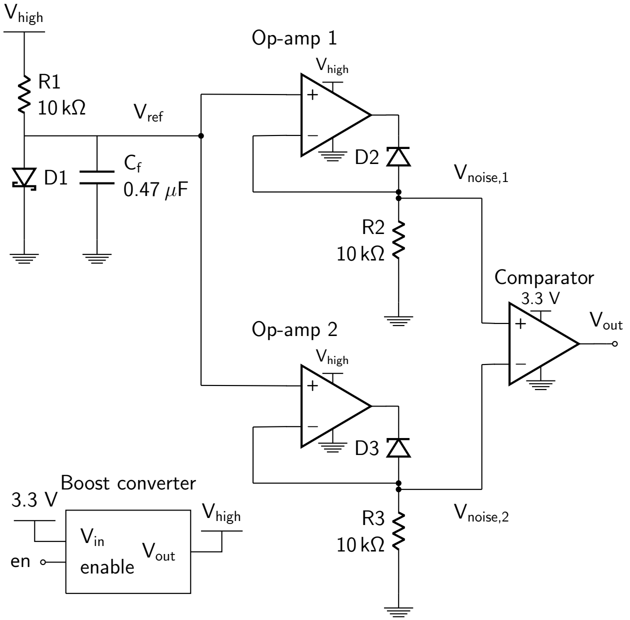
$\approx$3 μJ per bit

$\approx 10\times$ more energy per bit than a ZigBee radio, amortized over all CSPRNG outputs

Conclusions

- You should worry about your random numbers!
- A CSPRNG can generate secure, effectively limitless output given a hard-to-guess key...
- ...but in embedded systems, generating a CSPRNG key is challenging
- We have presented a design tailored to embedded systems for secure, inexpensive pseudorandomness
- Future work: smaller, cheaper, faster

`https://github.com/helena-project/imix`



V_{high}
R1
10 kΩ
V_{ref}
D1
C_f
0.47 μF
Op-amp 1
V_{high}
D2
$V_{noise,1}$
R2
10 kΩ
Comparator
3.3 V
V_{out}
Op-amp 2
V_{high}
D3
Boost converter
3.3 V
V_{in}
enable
V_{out}
V_{high}
en
R3
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