

Modelling for Optimisation of Self-Powered Wireless Sensor Nodes

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Introduction

- Self-powered sensors are an enabling technology for body-sensor networks
- We need a generator, power electronics, sensor and radio
- Off-the-shelf components cannot meet the power and size constraints
- Aim for 1 cm³ device, 1 kbps, over 1 m
- Scaling size and power tends to reduce efficiency (parasitics, bias currents...)
- We need power used \leq power generated

System Modelling is Challenging

- Non-negligible parasitic effects require detailed modelling
- Many design variables and many design trade-offs
- Trade-offs involve multi-domain parameters (e.g. electrical and mechanical)
- Analytical closed-form solutions do not exist for much of system
- How do we get an optimal design?

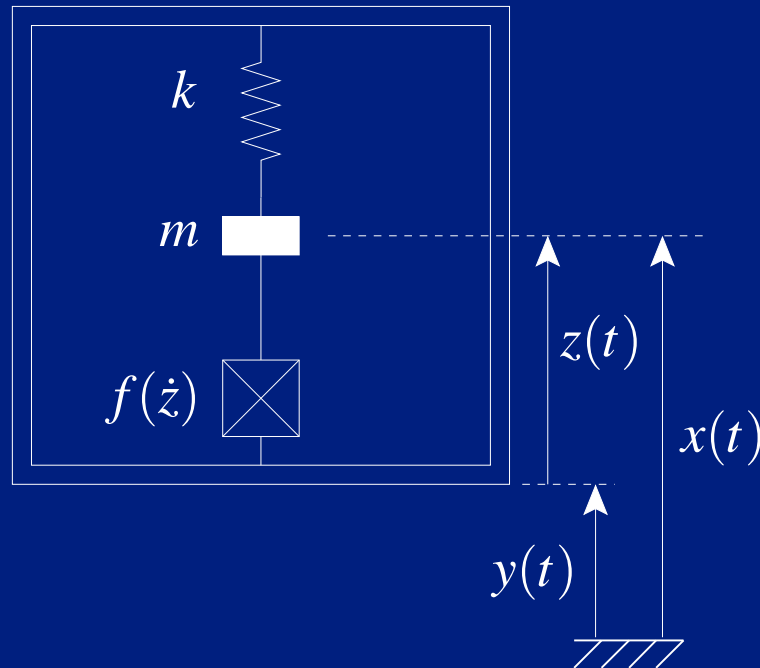
Our Approach to Modelling

Split model at power supply output - optimise power generation and load separately.

- Find the generator power output as a function of rail voltage
- Find the power usage of the load as a function of rail voltage
- Operate at the rail voltage which gives highest value of:
(power generated)/(power used)

Mechanical Modelling

An inertial generator is the most versatile and practical for BSN node

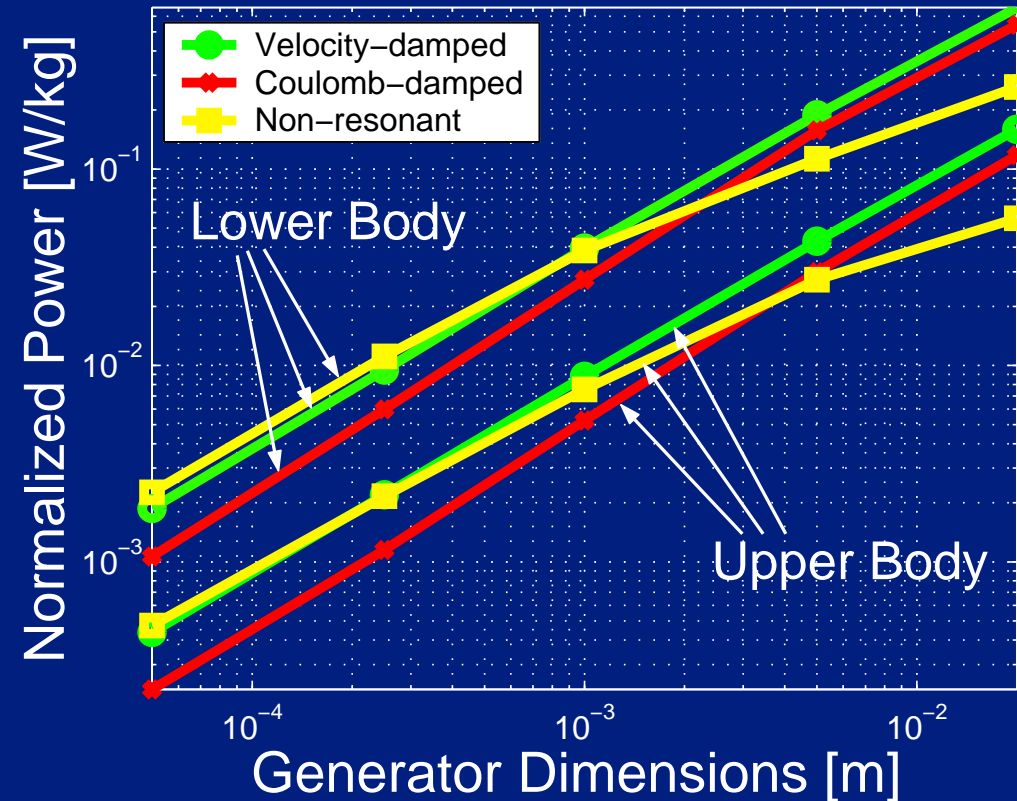
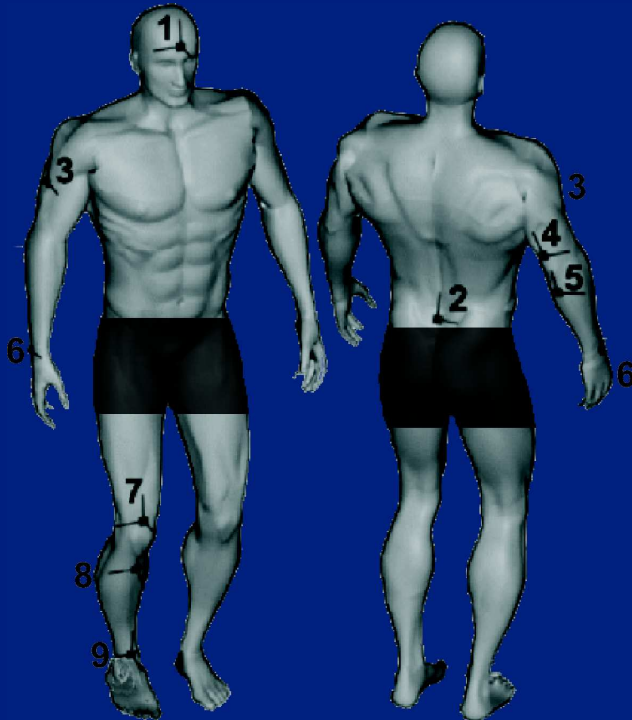


Energy per cycle:

$$E = 2 \times \int_{-Z_0}^{Z_0} f(\dot{z}(t)) dz$$

- The damper is the energy conversion mechanism - from mechanical to electrical

Human Powered Generators



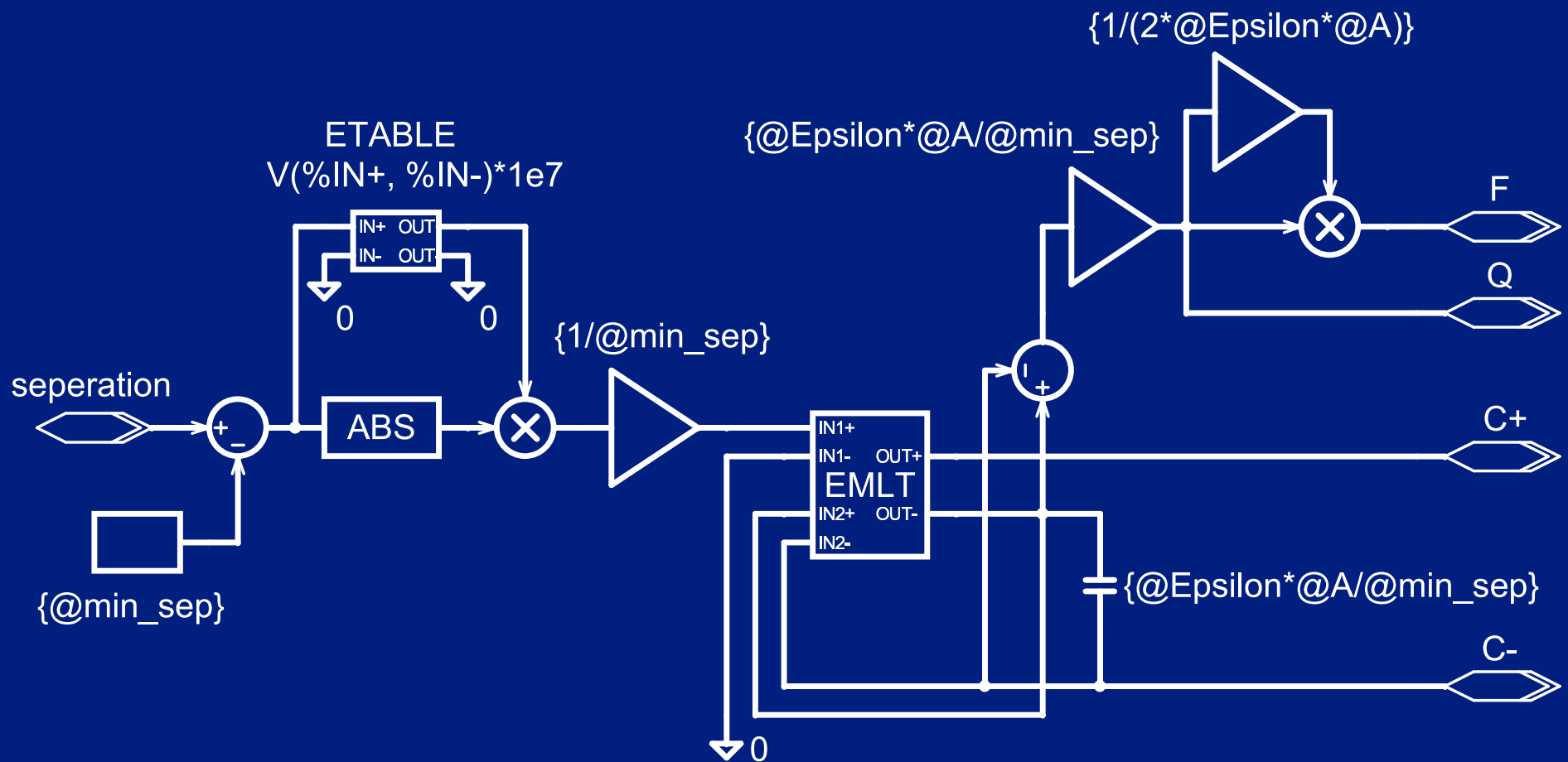
This work was in collaboration with T. von Büren at ETH Zurich

Generator Implementation

- Best way of implementing the non-resonant generator in MEMS is electrostatically with a variable capacitor
- Raw electrical output of generator needs processing
- Mechanical efficiency of generator and power electronics are mutually dependent
- Increasing power processing efficiency decreases mechanical generator efficiency

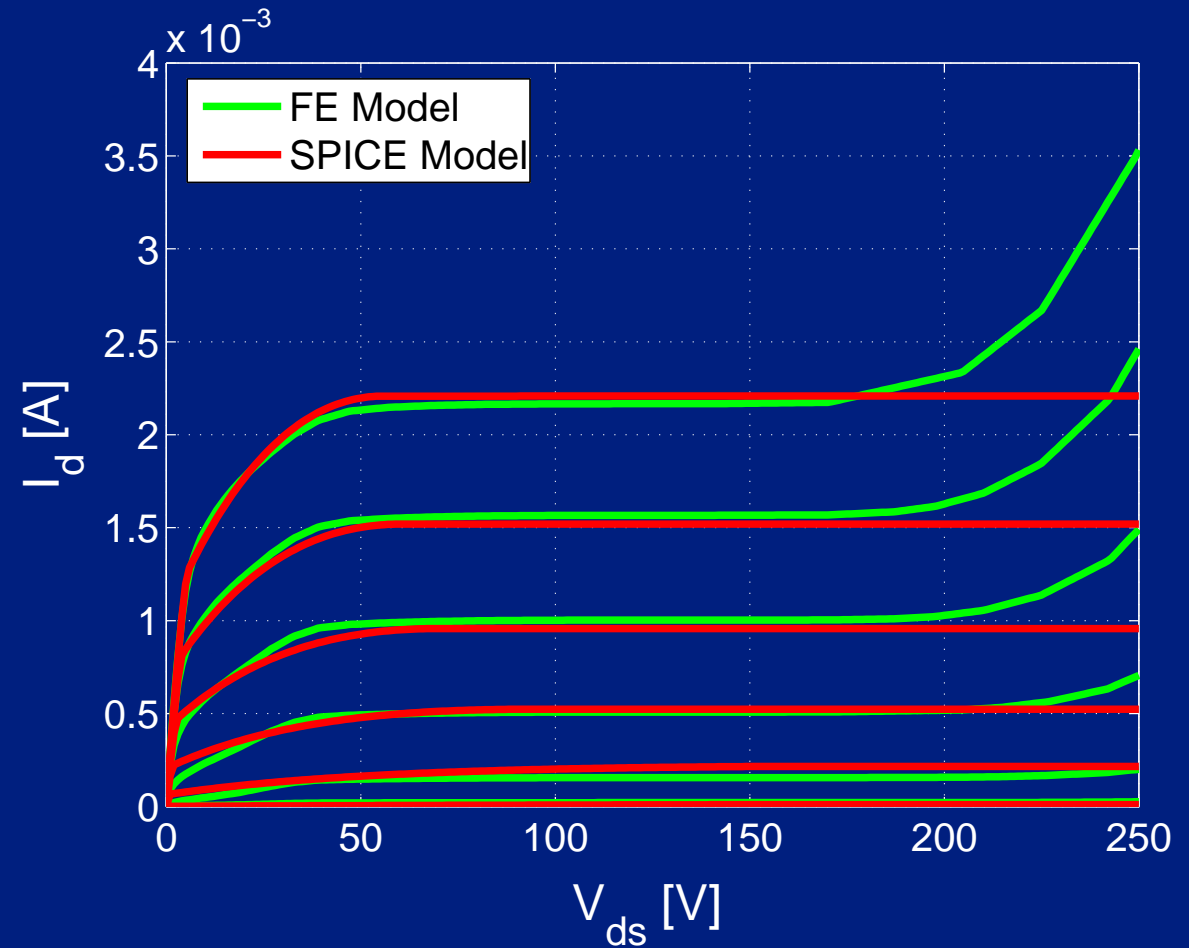
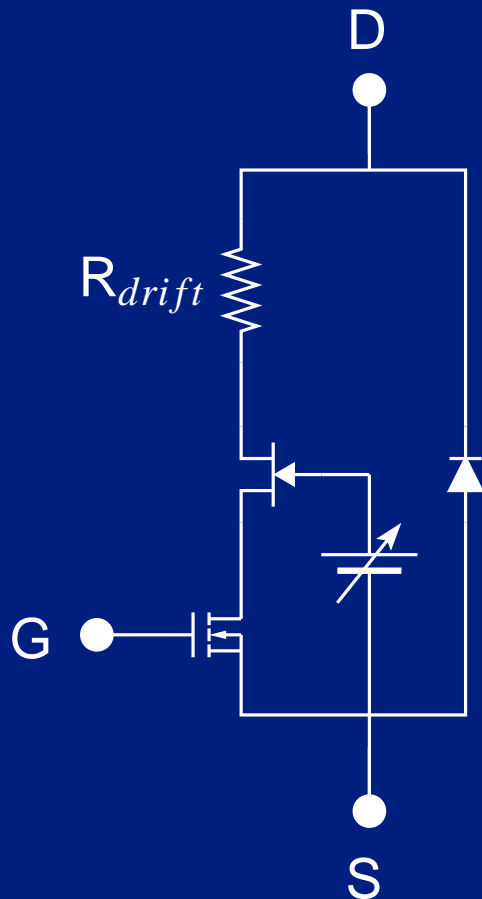
Numerical System Modelling

Use SPICE to model a mixed electro-mechanical system - allows good semiconductor models.



Device Models: FE to SPICE

Custom MOSFETs designed in FE, modelled in SPICE

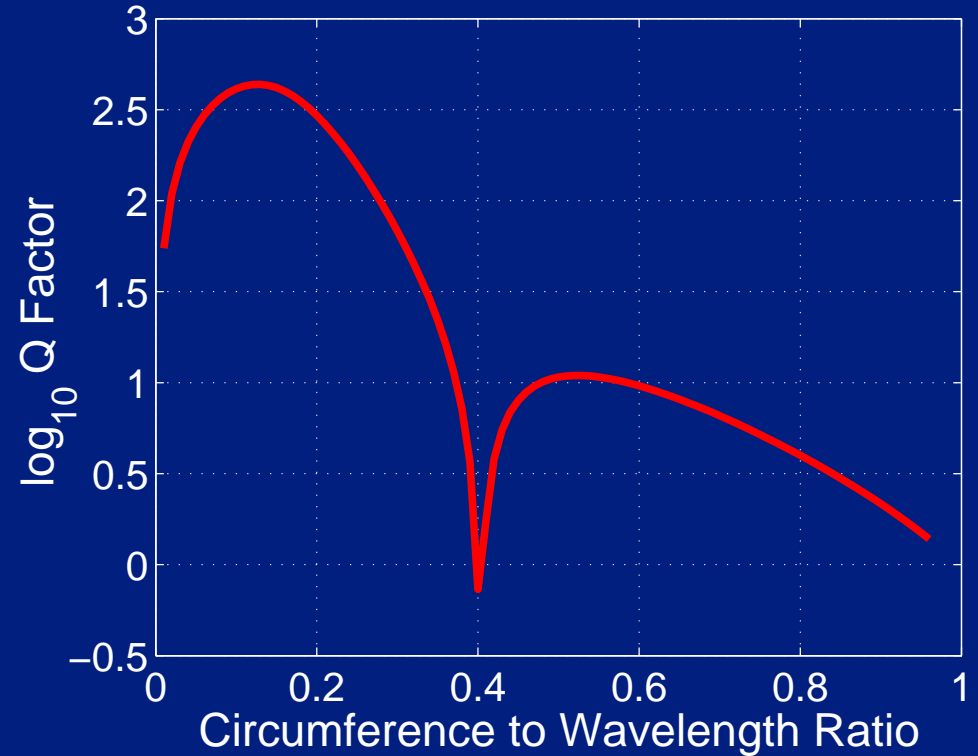
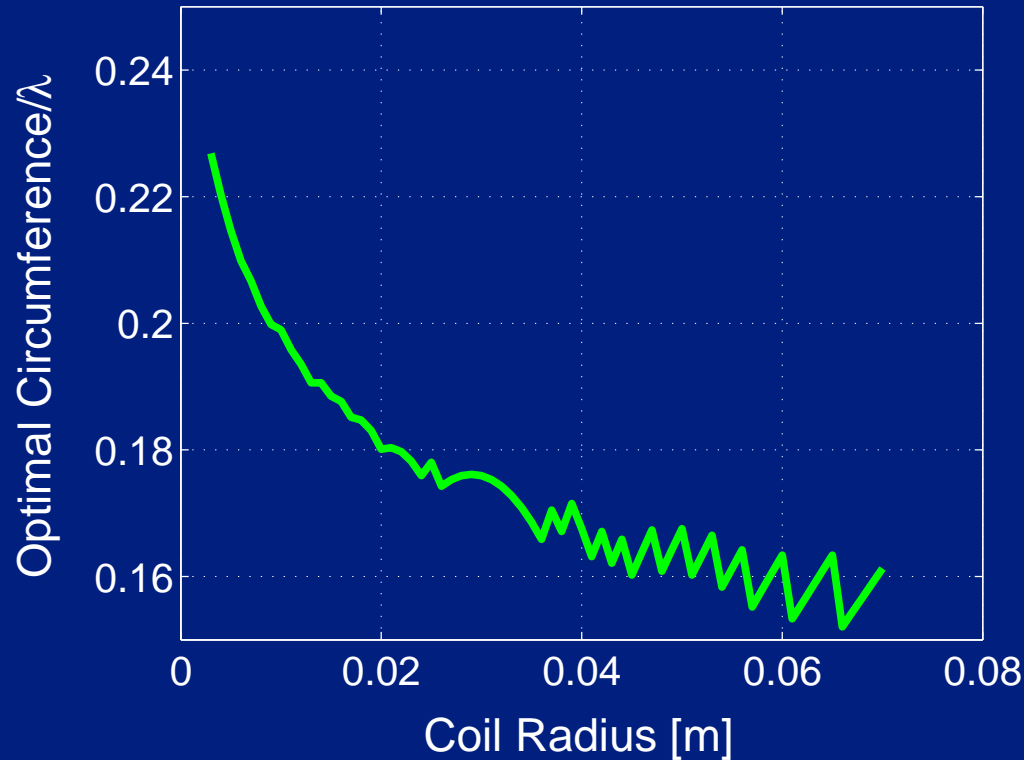


Radio Optimisation

Aim is to co-design the RF electronics and antenna to minimize power consumption

- Trade-off between antenna efficiency and circuit losses analysed
- Loop antenna simulated in MATLAB (analytical and numerical techniques)
- Modelling the current distribution of loop allows evaluation of antenna performance with size

Antenna Modelling Results



Antenna Q-factor is high for an electrical size at which the antenna also radiates efficiently

Device and Circuit Modelling

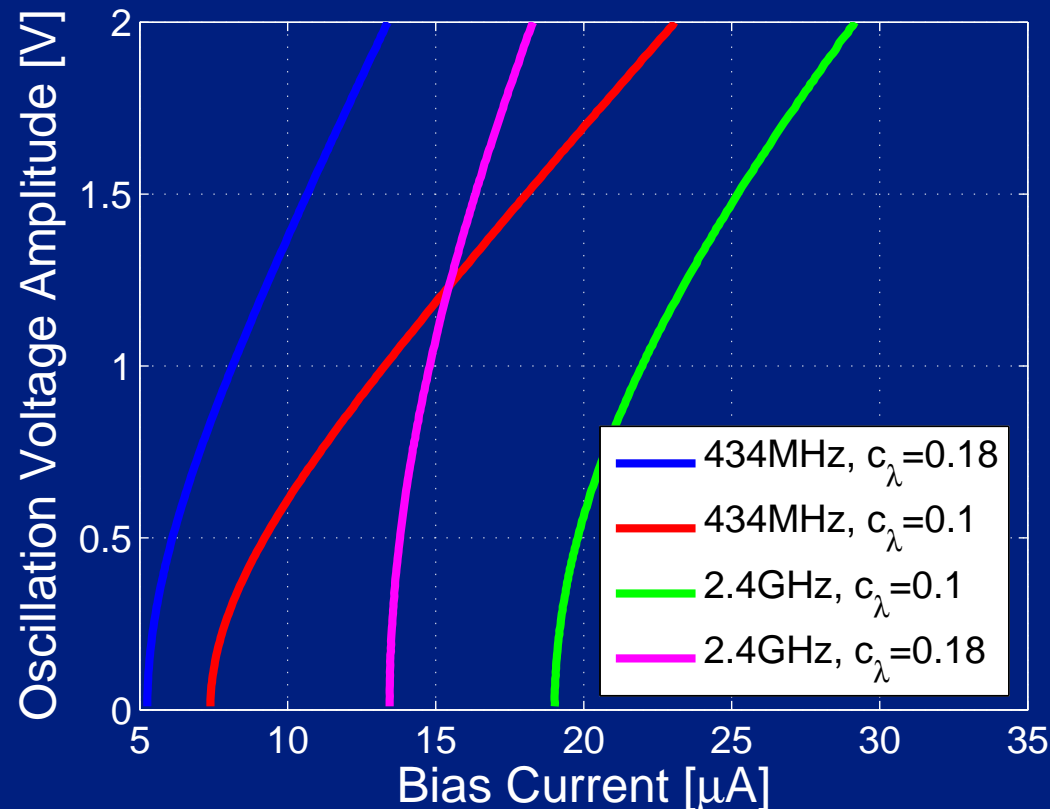
Difficult to use standard circuit simulators:

- Range and number of variables is large
- Each set of parameters requires separate transient, steady-state and noise analysis
- Simulations need tweaking by the user

Modelling in MATLAB (analytical and numerical techniques) - Compared with SPECTRE RF for specific operating points

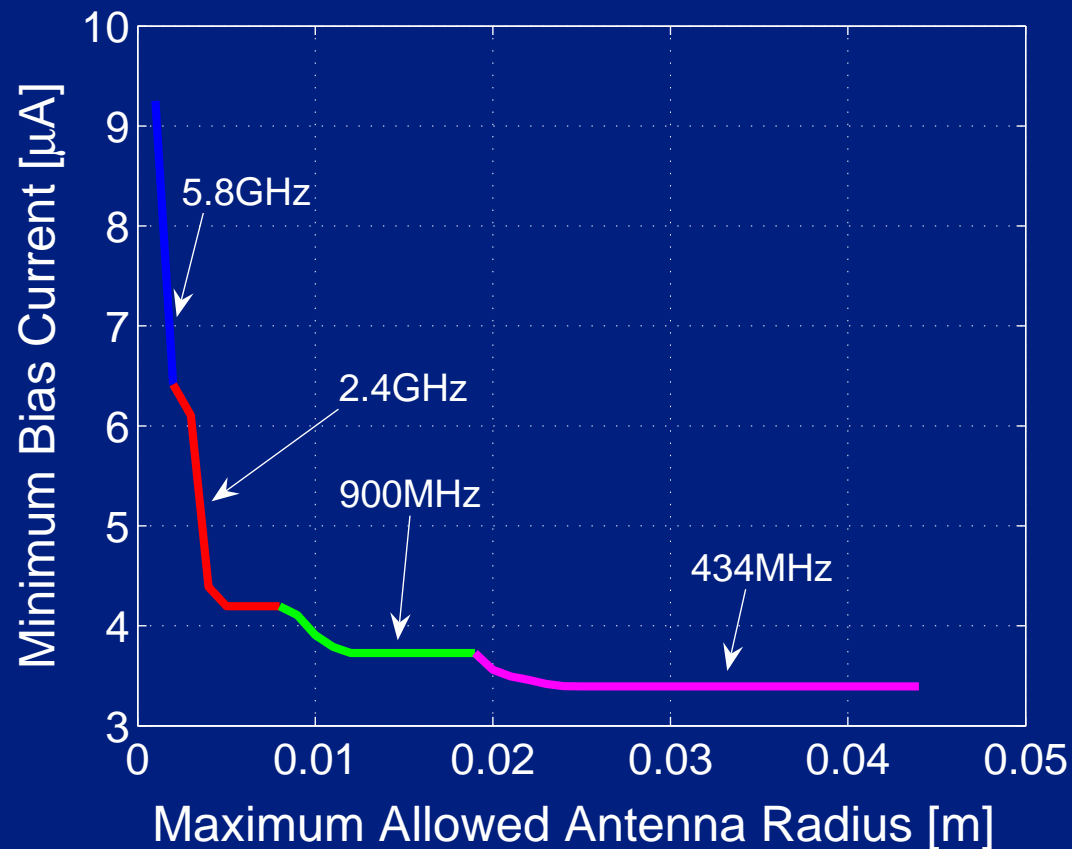
Bias Current versus Voltage

The EKV and a non-quasi-static model used with an energy conservation technique to evaluate required bias current for oscillation voltages



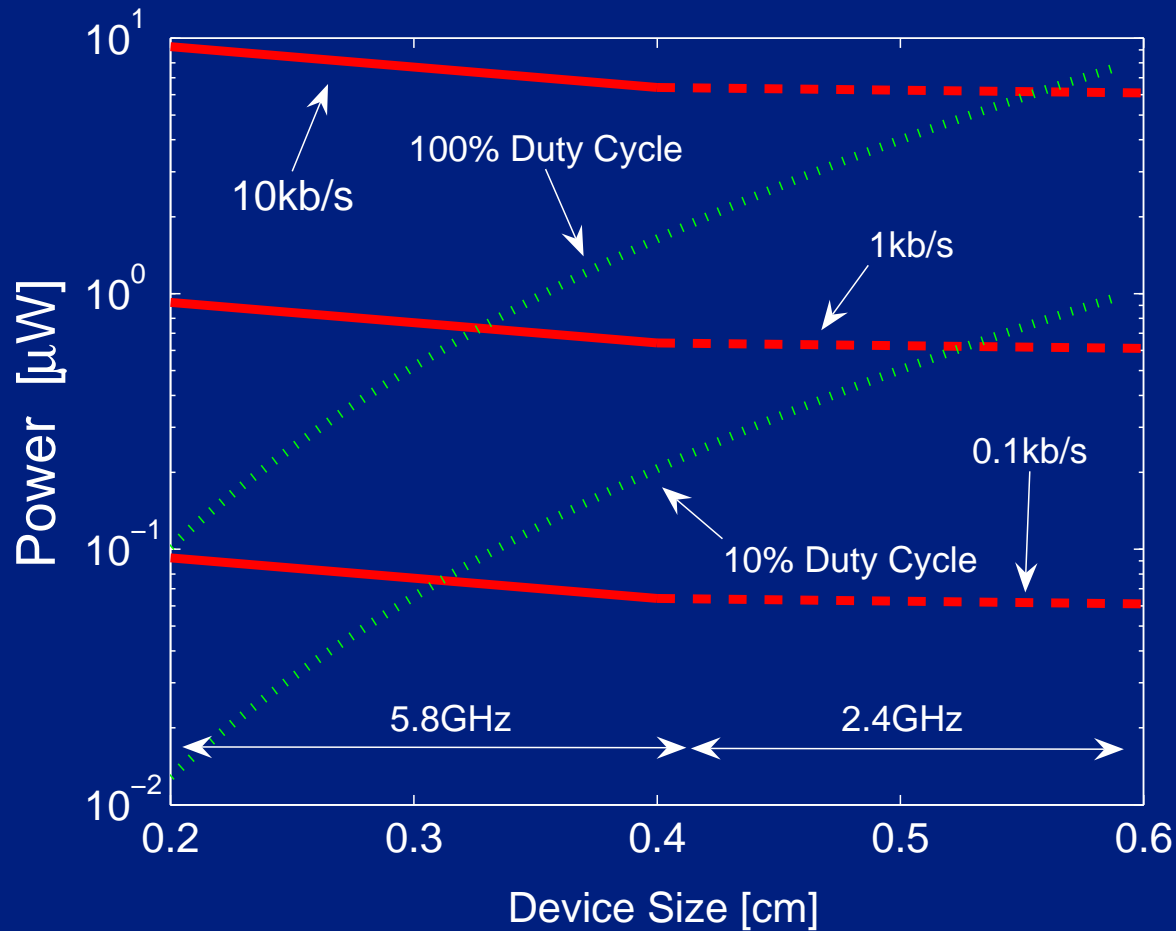
Combined Optimisation

The preferred carrier frequency from the standard ISM bands has been found for a given antenna size constraint



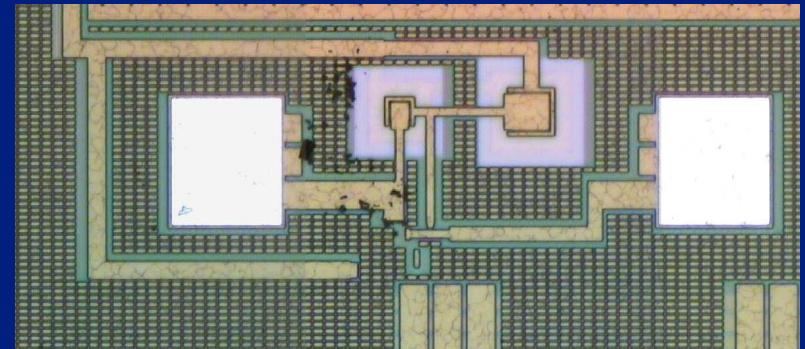
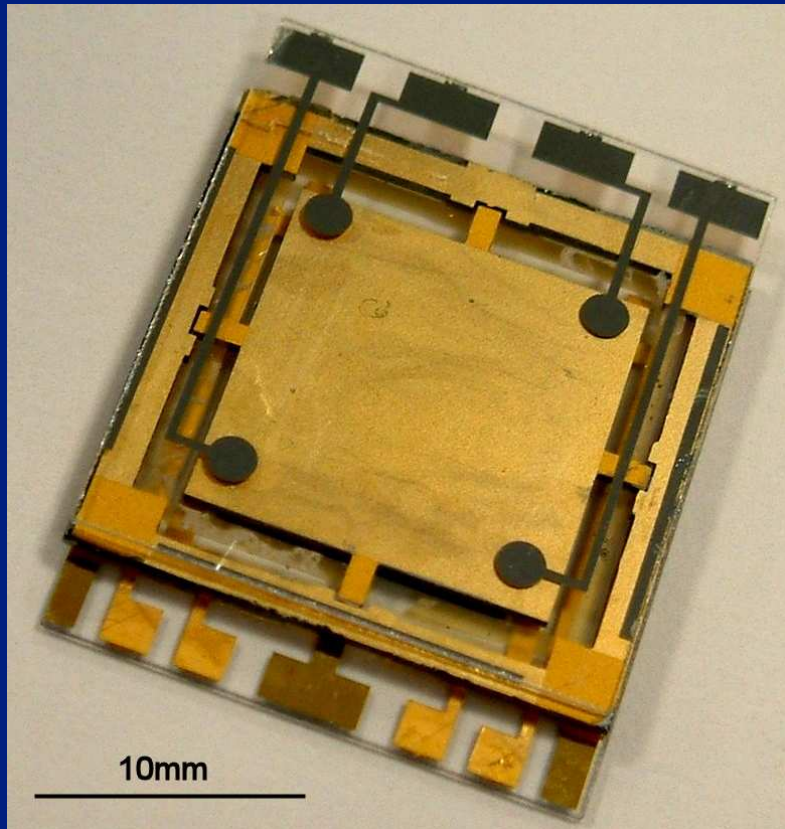
Global Optimisation

It is possible to achieve self-powering within our constraints...



Power generation (green) and usage (red)

Hardware Realisation



Prototype generator and transmitter