Wireless Power and Data Transmission for *in vivo* Sensing

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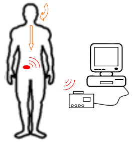
Motivation

Ingestible and implantable devices for *in vivo* sensing need wireless ***power*** and ***communication***.

Wireless power transmission reduces package volume required for on-board batteries and extends range of device.



Wireless transmission of sensor data permits condition monitoring (temperature, force, pH, etc.)

Given Imaging PillCam^{TM} for imaging the human GI tract

http://www.givenimaging.com/Cultures/en-US/given/english

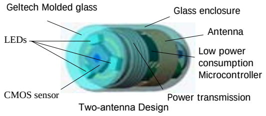
Digital Angel implantable tag for pet identification

http://www.digitalangelcorp.com/default.asp

System Design

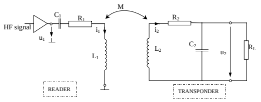
System Specifications:

1. 11 -15mm outside diameter, 26-40mm long
2. UV transparent "window"; minimum 50% transmittance at 300nm
3. 50mw continuous, 300mw peak at 20% duty cycle
4. 37°C maximum temperature
5. 42 dBµA/m at 10m maximum magnetic field strength (as per ETSI EN 300 330-1)
6. Non-interference frequency (selected 13.5 MHz)



Two-antenna Design

Wireless Power Coupling: Design of Transponder Coil



Supply voltage:

$$u_0 = k\cdot\sqrt{L_1\cdot L_2}\cdot\frac{i_1}{C_2\cdot R_2}$$
$$Z_i = \frac{R_2 + j\omega L_2}{j\omega C_2 R_2}$$
$$u_2 = u_0\cdot\frac{R_L}{Z_i + R_L}$$

Coupling coefficient:

$$k = \frac{M}{\sqrt{L_1 L_2}}$$

Where radius of reader coil is much larger than radius of transponder coil:

(x= reading distance)

$$k \cong \frac{r_R^2 r_T^2}{\sqrt{r_R r_T}\cdot\left(\sqrt{x^2 + r_R^2}\right)^3}$$

Coil resonant frequency:

$$\omega = 2\pi f = \frac{1}{\sqrt{LC}}$$

Define G as:

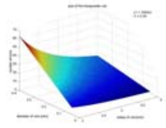
$$G = \frac{u_2}{i_1} = M\omega\frac{a\beta}{\sqrt{(\beta^2+\alpha)^2+\beta^2}}$$

$$\alpha = \frac{R_L}{R_2}$$

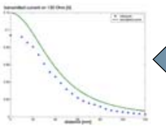
$$\beta = \frac{\omega L_2}{R_2}$$

Wireless Power Coupling: Modeling & Experiments

Find the transponder geometry knowing ω,k and L_1:



Good agreement between model & experiments. Achieved ~50 mW, 2.5V



Early experimental coils

Wireless Power Coupling: Design of Reader Antenna

For a loop antenna, induced voltage:

$$V = 2\pi fNAQB\sin\alpha$$

Inductance of infinitely long solenoid:

$$L = N^2\mu_0\pi\frac{r^2}{d}$$

f = frequency
N = # of turns
A = loop area
Q= quality
B= magnetic flux density

For constant *i*, transponder power proportional to V^2. Free parameters: N, A, B.

But: *A* limited by geometry, *N* coupled to *L*, *L* coupled to *C*, high *Q* limits tuning, therefore

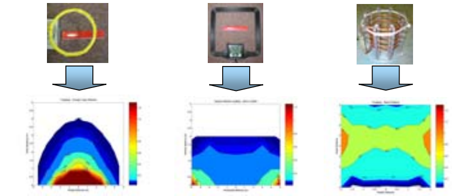
The reader antenna is the most critical part of power transmission system

For a round, planar antenna:

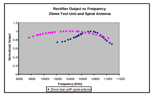
$$B = \frac{\mu_0 INr^2}{2\left(r^2+x^2\right)^{1.5}}$$

Wireless Power Coupling: Antenna Geometry Results

Power Coupling Results for various base station antenna geometries. Plots show normalized percentage of power induced in transponder in a cross section through the center of the antenna.

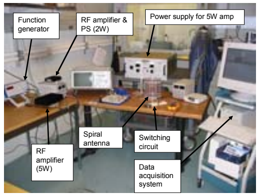


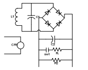
Improved frequency tuning (transponder/base) and antenna quality would improve power coupling



Wireless Power Coupling: Power Switching Results

Demonstrate 50 mW continuous power transmission with 300 mW peak load at 20% duty cycle.

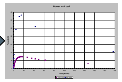


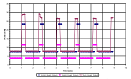


Load switching schematic

Load switching control

Power coupling significantly improves with higher power reader amplifier





Load switching data

Wireless Sensor Communication: Background

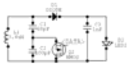
For data communication, we selected a single-antenna approach based on the concept of

PASSIVE BACKSCATTERING.

In passive backscattering, the base station and moving coils form the primary and secondary windings of a weakly coupled transformer. Serial data transmission is achieved by monitoring the voltage across the primary coil as the secondary coil characteristics are modulated.

Passive Backscattering System Block Diagram

Load modulation wastes energy – we selected capacitance modulation.



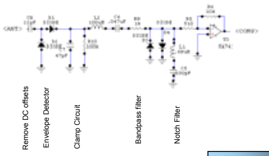
Transponder ("Pill") circuit using switched-capacitance Modulation

Resonant frequency shift decreases base station load.

Wireless Sensor Communication: Implementation

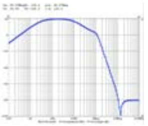
Similar to an RFID reader, a base station antenna circuit detects and decodes voltage changes caused by resonant frequency shifts.

Base Station Signal Flow Diagram

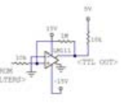


Base Station Filter Circuit

Filter Frequency Response



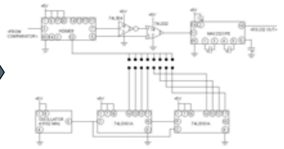
Wireless Sensor Communications: Implementation



Comparator Circuit

Comparator circuit converts sine wave to square wave for logic-level input to a microcontroller

Manchester decoder converts data to NRZ for transmission via RS232



Wireless Sensor Communications: Results

Wireless communication using passive backscattering demonstrated with ASCII data at 9600 Baud

Data integrity found to be highly ***independent*** *of transmitter orientation*

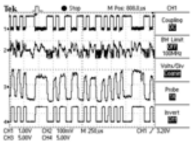
Spiral antenna used in power coupling and communications experiments

Manchester-encoded data input →

Output of passive filter stage →

Output of op-amp gain stage →

Output of comparator →



Prototype Decoder PCB

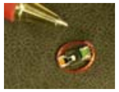
Oscilloscope traces demonstrating filters and comparator

Conclusions and Future Directions

Successfully demonstrated wireless power coupling and sensor communication.

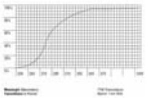
Future Goals:

1. Higher power with tuned antennas and higher power readers
2. UV transparent packaging
3. Conformable and human-dimensioned reader antennas



Implantable devices share similar requirements for wireless power and communication

Corning 7740 borosilicate glass: trans-mittance at 300nm approximately 70%



Human-scale readers or antenna arrays will be needed