Energy Sources and Communication Protocols for Nano-Devices

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Outline

- Vision of wirelessly integrated nanosystems
- Case study: Nanotube radio
- Microchip RFID
- RF Nanotube antennae
- The future
Wirelessly interconnected nanosystems

Frequency -> channel -> interconnect

Long nanotube antennas, each resonant at a different frequency.

Integrated Nanosystem
(Nanowires, Nanotubes, Self-assembled DNA, etc.)

Peter J. Burke, Shengdong Li, Zhen Yu
"Quantitative theory of nanowire and nanotube antenna performance"
Case Study: Nanotube Radio


See also: J. Rogers, et al, preprint, UIUC, AM radio demonstration
Nanotube Radio
Protocols that will work

- AM
- FM
- Spread spectrum (CDMA, etc.)
- Protocol is not limiting factor
Energy source: “Rectenna”

Antenna

Diode

Low pass filter

DC source from RF power

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RFID Chips
Hitachi μ-chip

Mituo Usami, Hisao Tanaba, Akira Sato, Isao Sakama, Yukio Maki, Toshiaki Iwamatsu, Takashi Ipposhi, Yasuo Inoue, “A 0.05 x 0.05 mm² RFID Chip with Easily Scaled-Down ID-Memory”, ISSCC, 2007


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Small RFID Chip Trend

Mituo Usami, Hisao Tanaba, Akira Sato, Isao Sakama, Yukio Maki, Toshiaki Iwamatsu, Takashi Ipposhi, Yasuo Inoue, “A 0.05 x 0.05 mm² RFID Chip with Easily Scaled-Down ID-Memory”, ISSCC, 2007

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RFID On-chip Antenna (OCA)

1 mW available DC power for 1 W @ 2.45 GHz

Nano-RF Antennas?
Ideal antenna

- $Z_{\text{input}}$ close to 50 $\Omega$
- Resistive losses small
- Radiation pattern sharp
- Frequency well controlled and characterized
- Broad band
- Physically small
- Cheap
- Integratable with multiple systems
Impedances

\[ \frac{V_{dc}}{I_{dc}} = \text{???} \]

Resistance quantum

\[ R_Q \equiv \frac{h}{e^2} = 25 \text{ } k\Omega \]

Realm of ac integrated nanosystems

Characteristic impedance of free space

\[ Z_0 \equiv \sqrt{\frac{\mu_0}{\varepsilon_0}} = 377 \text{ } \Omega \]

\[ \alpha \equiv \frac{Z_0}{R_Q} = 2 \cdot \frac{1}{137} \]

\[ \frac{E_{RF}}{H_{RF}} = \text{???} \quad \frac{E_{\text{optical}}}{H_{\text{optical}}} = \text{???} \]
Nano-antenna vs. classical antenna

NT antenna

Wire antenna

λ / 2

λ / 2

λ

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Radiation Resistance

Classical short antenna of length \( l \):

\[
R_{rad} = 80\pi^2 \left( \frac{l}{\lambda} \right)^2
\]

\[
R_{rad} = 80\pi^2 (0.01)^2 = 0.08 \Omega
\]

Efficiency \( \sim R_{DC\ nanotube}/R_{\text{radiation}} \)

\( \Rightarrow \) -90 dB
Rigorous, self consistent theory

IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 53, NO. 11, NOVEMBER 2005

Fundamental Transmitting Properties of Carbon Nanotube Antennas

G. W. Hanson, Senior Member, IEEE

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Conclusions

- Power: Can come from external RF
- Protocol: Any can work
- Technology: Exists for microchips
- Antennas: Main challenge to miniaturize
- Integrated nanosystems: Still a dream, not yet reality

http://news.bbc.co.uk/2/hi/science/nature/7050477.stm