Ultra-Wideband Antenna Simulations

Stanley Wang
Prof. Robert W. Brodersen
January 8, 2002
Outline

• Antenna Basics
• Traditional Antenna Design
• UWB Antenna Design
  – Challenges
  – Tool: Electromagnetic Simulator
  – Looking for a Suitable UWB Antenna
• Antenna/Circuit Co-Design for UWB Transmitter
• Conclusion
Antenna & Radiation

• Radiation happens when a charge is accelerated

\[ E = \frac{q}{4\pi \varepsilon_0} \left[ \frac{1}{c^2 k^3 r} \left( \hat{r} \times \left( \hat{r} - \frac{v}{c} \right) \times a \right) \right] \]

In an infinitely short conductor, \( I = \frac{dQ}{dt} = n \frac{dq}{dt} \)

\[ E \propto \frac{dI}{dt} \]

• Radiated E-field from an antenna

\[ |\overrightarrow{E}| \propto \sum_i \frac{1}{r_i} \frac{dI_i(t - r_i / c)}{dt} \]
Antenna Parameters

• Things people care about
  – Directivity
  – Radiation efficiency
  – Radiation bandwidth
  – Polarization

\[ E = f(I_{ant}) \]
Antenna in Communication Systems

- **At Transmitter**
  - Antenna is modeled as a passive circuit component; real part in it determines the radiated power (if $\sigma=\infty$)
  - Current distribution in the antenna determines $E_{\text{rad}}$
- **At Receiver**
  - E-field at the Rx is translated to a voltage source
  - By reciprocity theorem, $Z_{\text{ant,rx}}=Z_{\text{ant,tx}}$
Traditional Antenna Design

- Designed for narrowband systems
- Assume time-harmonic (steady-state sinusoidal)
  - Phasor is applied \( (d/dt=j\omega) \), Maxwell’s equations become more friendly
  - Drive the antenna by \( \cos(\omega t) \), radiate \( \cos(\omega t+\theta_1) \), and receive \( \cos(\omega t+\theta_2) \)
  - Matching is trivial \( \rightarrow \) make it resonate
Challenges in UWB Antenna Design

UWB means very broad bandwidth (DC~2GHz)

• Phasor can no more be applied
  – Maxwell’s equations can’t be simplified
• Waveform dispersion
  – Redefine directivity
• Ultra-wideband matching
  – Ringing might happen
  – High radiation efficiency is hard to achieve
• Flat frequency response
Tool: EM Simulator

- Remcom XFDTD – Finite-Difference Time-Domain
- Transform Maxwell's equations (differential equations) into difference equations

Ex. In Free-space

\[
\frac{\partial H_x}{\partial t} = \frac{1}{\mu_0} \left( \frac{\partial E_y}{\partial z} - \frac{\partial E_z}{\partial y} \right)
\]

\[
\frac{H_{x}^{n+\frac{1}{2}} - H_{x}^{n-\frac{1}{2}}}{\Delta t} = \frac{1}{\mu_0} \left( \frac{\Delta E_y^n}{\Delta z} - \frac{\Delta E_z^n}{\Delta y} \right)
\]
Simulation in XFDTD

- Define the geometry & source → Run!
- Derive input voltage/current, input impedance, near/far zone transient fields, s-parameters, animation of the currents/fields/power flow, etc.
Frequency Response: $s_{11}$ of Monopole

- The smaller the $s_{11}$, the larger the radiation
- Resonant at $f = c/(0.25\lambda)$, which leads to freq. hump
- Two ways to avoid ringing & flatten the freq. response
  - Make the conductive wire more resistive
  - Shorten the monopole

\[ \text{s11 for 6cm monopole} \quad \text{s11 for 2cm monopole} \]
Far-zone Electric Fields of the Monopole

- When $L$ is much smaller than $\lambda/4$, no ringing happens
- Radiated energy is decreased, but it’s ok
  - Undetectable UWB system transmits at noise level
Short Monopole: Input V/I Characteristics

• The input V/I behavior resembles that as driving a capacitor → Quasi-static condition
• Modeling a 2cm monopole by a 0.315pF capacitor
• Given the same $V_s$ & $R_s$, $I_s$ in two cases overlap perfectly
**Short Monopole: Radiation**

- The radiated field is the time-derivative of the INPUT current
  - The dimension is small. Phase difference between $I(z)$ at each part is ignorable → **One-point Radiation**
Antenna/Circuit Co-design

• Model the monopole/dipole as a capacitor in Spectre
  – According to the simulation in XFDTD, the capacitances of the small antennas are 0.1~1.5pF
  – Need the driving circuit to have variable driving capability to test different antennas
    → Inverters in parallel with Enable signals

• Radiated fields determined by the time-derivative of the current through the capacitor
  – Expect to radiate a symmetric monocycle pulse
  – Design by observing the shape of it in Spectre
Driver Circuit Schematic

- Inverter chain sharpens the edge of the input signal
  - Eliminate the effect of input waveforms
- Pre-driver NAND/NOR circuits skew the signals
  - Enable/Disable the driver
  - Avoid short-circuit current
  - Shape the output waveform

[Diagram of driver circuit]
Driver Circuit Layout

- STMicroelectronics 0.13um CMOS process
- Chip area: 0.49mm²
- 1.2V Vdd
- 2 drivers with enables → Can either drive a monopole or dipole
- Each driver with 16 levels of driving capabilities
- Put the driver close to the output pins
Conclusion

• Antenna characteristics have been investigated by EM simulator XFDTD
• In small monopole/dipole antenna quasi-static assumption stands, so the antenna can be modeled as a capacitor
• Radiation from a small monopole/dipole can be thought of as one-point radiation
• By using small antenna, antenna design is transformed to circuit design
• UWB antenna/circuit co-design for transmitter has been done