Objectives

- Title is to capture notions of
- How RFID systems have evolved under constraints
- How they might evolve under research
- If desired, some details of research at Adelaide
Topics

- RFID regulations
- Antenna issues
- Propagation studies
- Protocol issues
- Higher functionality tags
- Signalling waveform design
- Security and authentication
RFID regulations

- Regulators
  - ITU Regions
  - FCC, EN, Other national bodies
- Usage of radio spectrum and bands
- Regulatory standards
  - ISO ETSI
- Australia experimental licence
- Listen before talk regulations
- Synchronisation
Antenna issues

- Electromagnetic theory
- Coupling calculations
- Bode Fano Limit
- Antennas for dual frequencies
- Antenna size and frequency constraints
- Antennas in or near metal
- A small antenna example.
Propagation studies

- Electromagnetic theory
- Near and Far fields
- Near and far field coupling theories
- Some fundamental constraints
- Dense RFID reader studies.
Protocol issues

- Concept of a protocol
- Tag talks first and reader talks first protocols
- Constraints on protocols
  - UHF signalling
  - HF signalling
- Adaptive round concepts
- EPCglobal C1G2 protocol
- Approaches to advanced HF protocols
  - Can HF sustain heavy signalling?
  - Ways it might
Higher functionality tags

- Autonomously networking tags
- Merging of EAS and data tags
- Trigger circuits for battery tags
  - Low power approach
    - Issues and experiments
  - Zero power approach
    - Application to theft detection
Security and Authentication

• Methods for providing security
• Levels of security
• Burdens on chip design
• Burdens on signalling systems
Overview of Adelaide research

- Personnel
- Classification of projects
- Detector research
- Data logging reader research
- Dense reader environment research
- Privacy and security research
- Trigger circuit research
- Publications
Antenna Issues

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Outline

• Electromagnetic theory
• How antennas work (approximately)
• Near and far fields
• Near and far field coupling theories
• Significant conclusions about performance
• Bode-Fano limit for efficiency
• Some simple tag designs
Laws in differential form

\[ \nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \]

\[ \nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t} \]

\[ \nabla \cdot \mathbf{D} = \rho \]

\[ \nabla \cdot \mathbf{B} = 0 \]
Boundary Condition: electric field
Boundary Condition: magnetic field

Magnetic field

Current or displacement current

Conducting plane
The basic laws: how they work

- **Gauss’s law**
  - Electric flux deposits charge
  - Electric field cannot just go past a conductor, it must turn and meet it at right angles

- **Faraday’s law**
  - Oscillating magnetic flux induces voltage in a loop that it links
Fields of a Magnetic Dipole
(oh dear)

\[ H_r = \frac{j\beta^3 M}{4\pi} \left( \frac{2}{\beta^2 r^2} - \frac{2j}{\beta^3 r^3} \right) e^{-j\beta r} \cos \theta \]

\[ H_\theta = \frac{j\beta^3 M}{4\pi} \left( j \frac{1}{\beta r} + \frac{1}{\beta^2 r^2} - \frac{j}{\beta^3 r^3} \right) e^{-j\beta r} \sin \theta \]

\[ E_\phi = \frac{j\beta^3 M}{4\pi} \left( \frac{j}{\beta r} + \frac{1}{\beta^2 r^2} \right) e^{-j\beta r} \sin \theta \]
Near and far field coupling theories

• Common feature: a label driving field is created, how much signal can be extracted?

• In the near field of the interrogator, the driving field is mostly energy storage, and the amount radiated does not affect the coupling, but does affect the EMC regulator.

• Various techniques to create energy storage without radiating are then applicable.

• Some theorems on optimum antenna size are of interest.

• In the far field of the interrogator, the relation between what is coupled to and what is regulated is more direct, and such techniques are not applicable.
Far field coupling theory

\[ P_r = A_{er} \times \text{Power flow per unit area} \]

Power flow per unit area = \( \frac{g_t P_t}{4\pi r^2} \)

\[ A_{er} = \frac{g_r \lambda^2}{4\pi} \]

\[ P_r = S_r A_e = \frac{g\lambda^2}{4\pi} S_r \]

\[ \frac{P_r}{P_t} = g_r g_t \left( \frac{\lambda}{4\pi r} \right)^2 \]
\[
V_c = \frac{\text{Reactive power flowing in the untuned label coil when it is short circuited}}{\text{Volume density of reactive power created by the interrogator at the label position}}
\]

\[
V_d = \frac{\text{Reactive power flowing in the inductor of the interrogator field creation coil}}{\text{Volume density of reactive power created by the interrogator at the label position}}
\]

\[
\frac{P_2}{P_1} = \frac{V_c}{V_d} \frac{Q_1 Q_2}{Q_1 Q_2}
\]
In the far field

\[ W_v = \beta S_r \]
Significant conclusions

• Coupling volumes for well shaped planar electric and magnetic field labels are size dependent and similar

\[
\text{Magnetic } V_c = \frac{L^3}{2} \quad \text{Electric } V_c = \frac{2L^3}{3}
\]

• Radiation quality factors for both types of label formed within a square of side L are size dependent and similar

\[
\text{Magnetic } Q_r = \frac{40}{(\beta L)^3} \quad \text{Electric } Q_r = \frac{13}{(\beta L)^3}
\]

• These are calculated results for sensibly shaped antennas
The optimum frequency for operation of an RFID system in the far field is the lowest frequency for which a reasonable match to the radiation resistance of the label antenna can be achieved, at the allowed size of label, without the label or matching element losses intruding.
Bode-Fano Limit

\[ \int_0^\infty \ln \left| \frac{1}{\Gamma} \right| \, d\omega \leq \frac{\pi}{RC} \]
Bode-Fano Limit (cont)

\[ |\Gamma|_{\text{inband}} \geq e^{-\frac{1}{2\Delta fRC}} \]
Allocated bandwidths for RFID:

<table>
<thead>
<tr>
<th>Country</th>
<th>Frequency in MHz</th>
<th>Bandwidth in MHz</th>
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<tbody>
<tr>
<td>European countries</td>
<td>865 – 868</td>
<td>3</td>
</tr>
<tr>
<td>USA</td>
<td>902 – 928</td>
<td>26</td>
</tr>
<tr>
<td>Japan</td>
<td>950 – 956</td>
<td>6</td>
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</tbody>
</table>

Others:
China: 917 – 922 MHz (Temporary license can be applied)
Australia: 918 – 926 MHz
• 3 different cases considered:

(a) Reflection coefficient, $|\Gamma|$ vs. Frequency, $f$ (in MHz)

(b) Reflection coefficient, $|\Gamma|$ vs. Frequency, $f$ (in MHz)

(c) Reflection coefficient, $|\Gamma|$ vs. Frequency, $f$ (in MHz)
**Bode-Fano Limit (cont)**

- **Assume** $R = 1 \, \text{k}\Omega$, $C = 1 \, \text{pF}$

| Case | Minimum achievable reflection coefficient, $|\Gamma|_{\text{inband}}$ |
|------|----------------------------------------------------------|
| 1    | $4.45 \times 10^{-9}$                                   |
| 2    | $6.25 \times 10^{-7}$                                   |
| 3    | $4.11 \times 10^{-3}$                                   |

- **$R = 10 \, \text{k}\Omega$, $C = 1 \, \text{pF}$ (for less power consuming tag chip in practice)**

| Case | Minimum achievable reflection coefficient, $|\Gamma|_{\text{inband}}$ |
|------|----------------------------------------------------------|
| 1    | 0.1462                                                   |
| 2    | 0.2397                                                   |
| 3    | 0.5773                                                   |
A Simple RFID Tag

- Consists of a circular loop antenna with a very simple matching network
Higher Functionality Tags

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Interesting questions

- Merging of EAS and Data tags

- Turning on battery operated tags
  - Low power consumption
  - Zero power consumption
Transmitter operated systems

- Some small voltage is generated form transmitted power
- A low power consumption circuit detects that event
- Quality factor issues arise
Experiments on detuning

RF IN through an SMA connector

Rectified voltage to Oscilloscope using a BNC connector
Low and high power sweeps

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<th>Mfr</th>
<th>Start 715.000 MHz</th>
<th>Stop 755.000 MHz</th>
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<tbody>
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<td>1</td>
<td>728.9200</td>
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<td>3</td>
<td>734.4000</td>
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<table>
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<td>2</td>
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<tr>
<td>3</td>
<td>781.7333</td>
<td>-7.145</td>
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</table>
A low voltage turn on circuit

- Sensitivity about 5 mV
- Power consumption few nA
Zero power turn on concept

- Low frequency magnetic field vibrates a magnet
- Piezoelectric converter generates about a volt
Electroacoustic conversion modelling

- **Variables are**
  - Torque and angular displacement,
  - charge and voltage

- **Electroacoustic parameters for substances known**

- **Parameters for structures are calculated therefrom**
Eletroacoustic conversion

- Structural parameters appear below

\[
\begin{bmatrix}
q \\
\theta
\end{bmatrix} = \begin{bmatrix}
C_{11P} & C_{12P} \\
C_{21P} & C_{22P}
\end{bmatrix}\begin{bmatrix}
\phi \\
\tau
\end{bmatrix}
\]
Structure analysed
Result

• **Turn-on voltage depends on**
  – Driving magnetic field
  – Electroacoustic parameters
  – Some resonance quality factors

\[
V_{TO} = \sqrt{\frac{k_{eff}^2 Q_m^2 (Mv\mu_0)^2 |H|^2 C_{22S}^2}{C_J C_{22eff}}} \cdot \frac{1}{C_J C_{22eff}}
\]