AUTO-ID LABS

Evolution of RFID Systems

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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

AUTO-ID LABS

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

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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

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

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

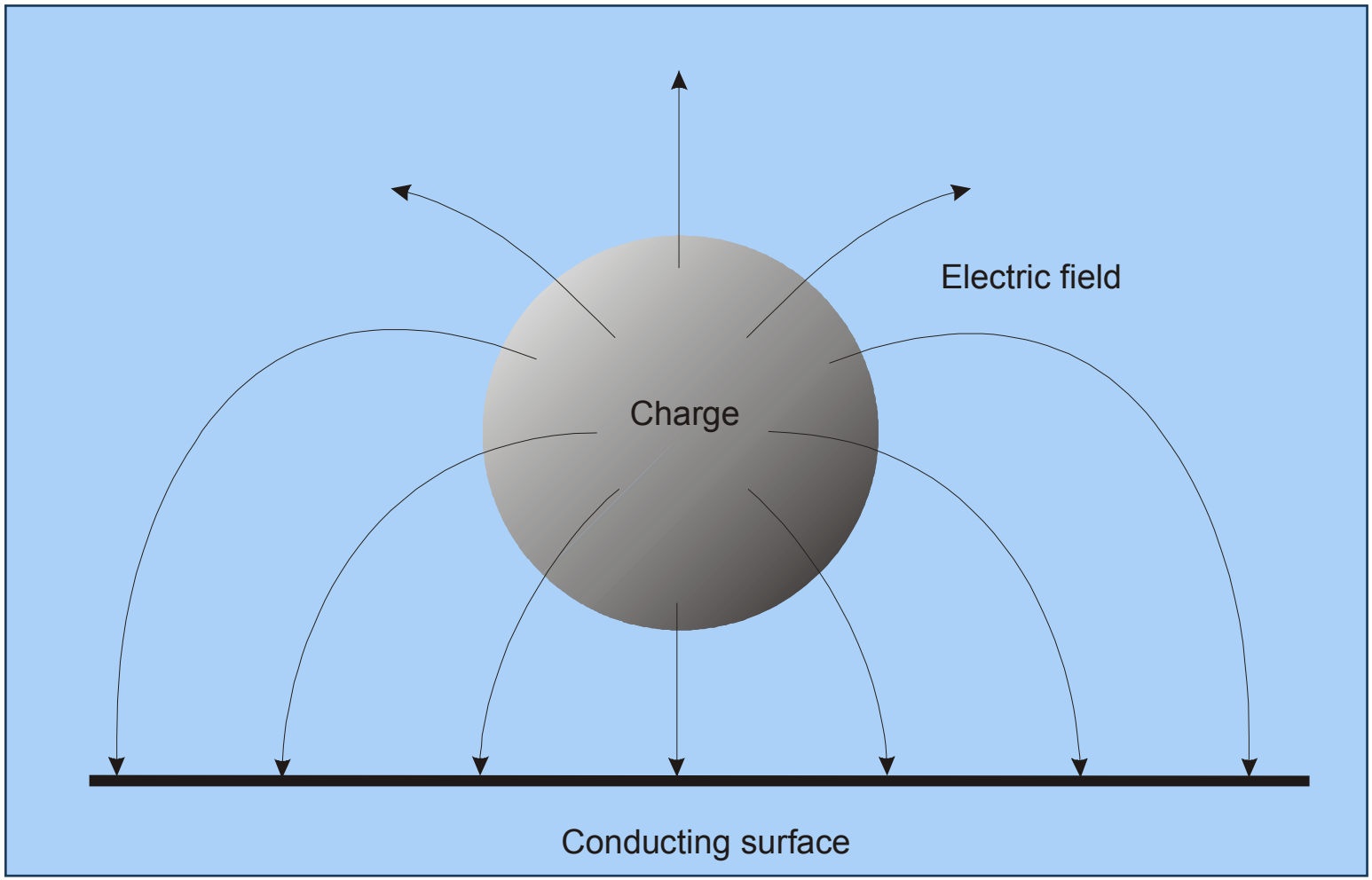
Vortex

$$\nabla \cdot \mathbf{D} = \rho$$

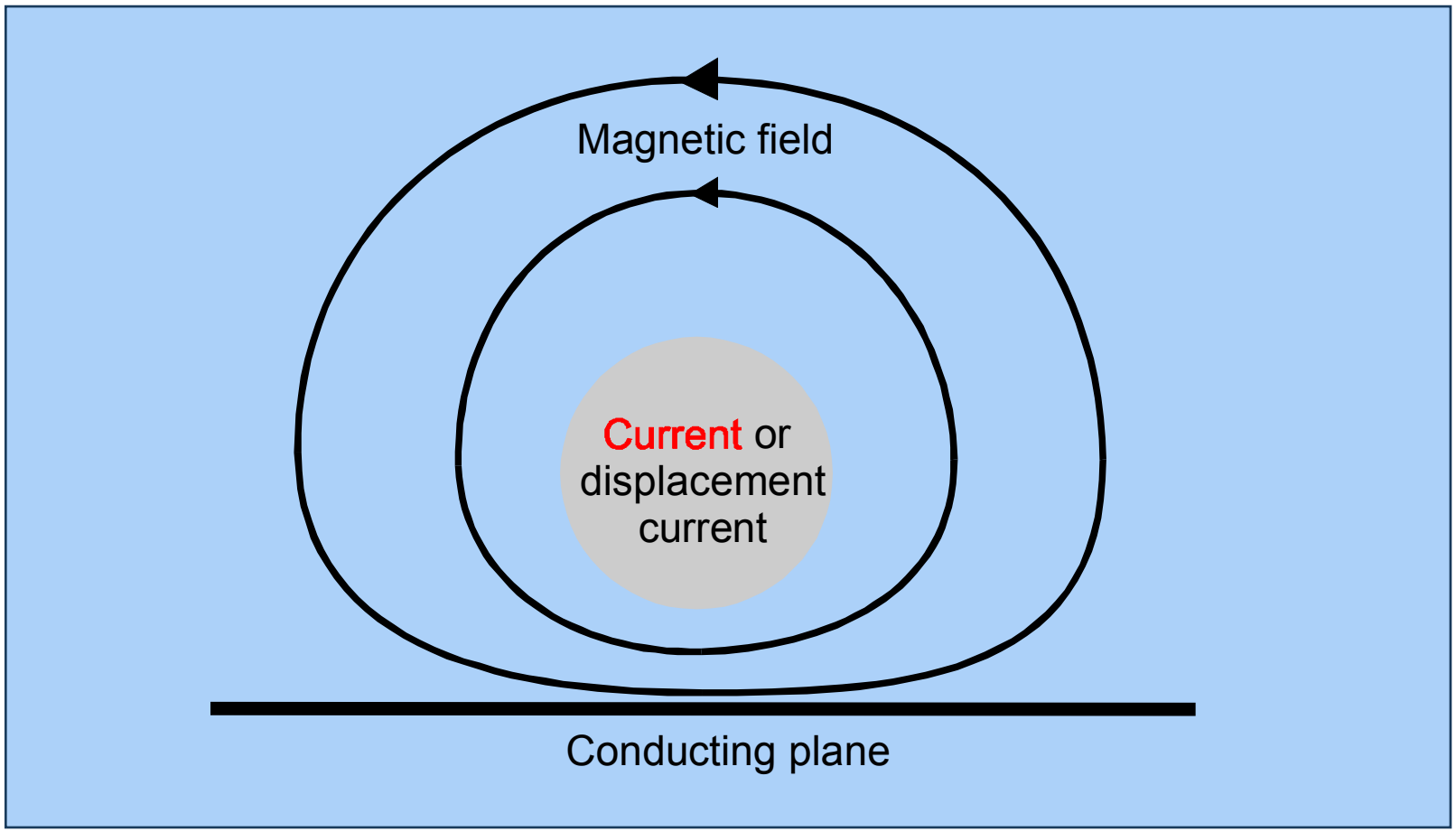
$$\nabla \cdot \mathbf{B} = 0$$

Source

Boundary Condition: electric field

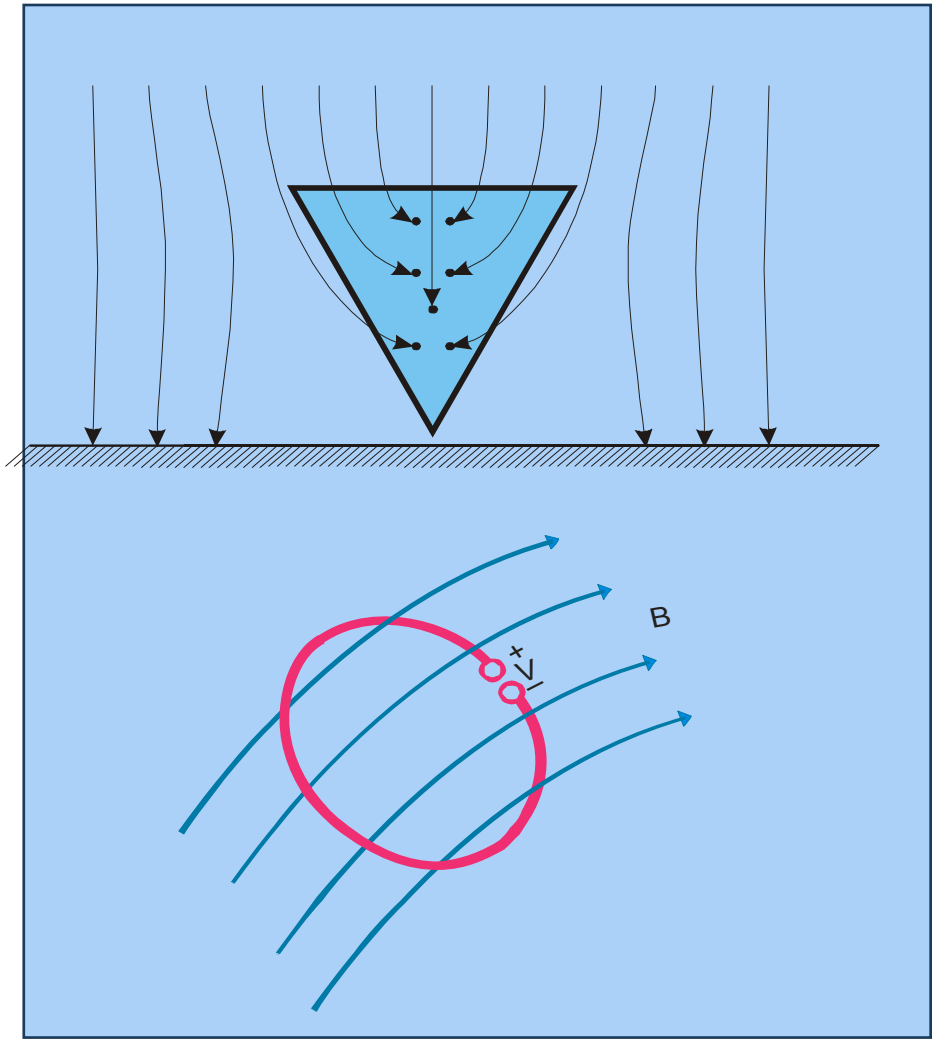


Boundary Condition: magnetic field



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)

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

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

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

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

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

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

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

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

$$\frac{P_r}{P_t} = g_r g_t \left(\frac{\lambda}{4\pi r} \right)^2$$

Near field coupling theory

$$V_c = \frac{[\text{Reactive power flowing in the untuned label coil when it is short circuited}]}{[\text{Volume density of reactive power created by the interrogator at the label position}]}$$

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

$$\frac{P_2}{P_1} = \frac{V_c}{V_d} Q_1 Q_2$$

Measures of exciting field

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**

$$\text{Magnetic } V_c = \frac{L^3}{2} \qquad \text{Electric } V_c = \frac{2L^3}{3}$$

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

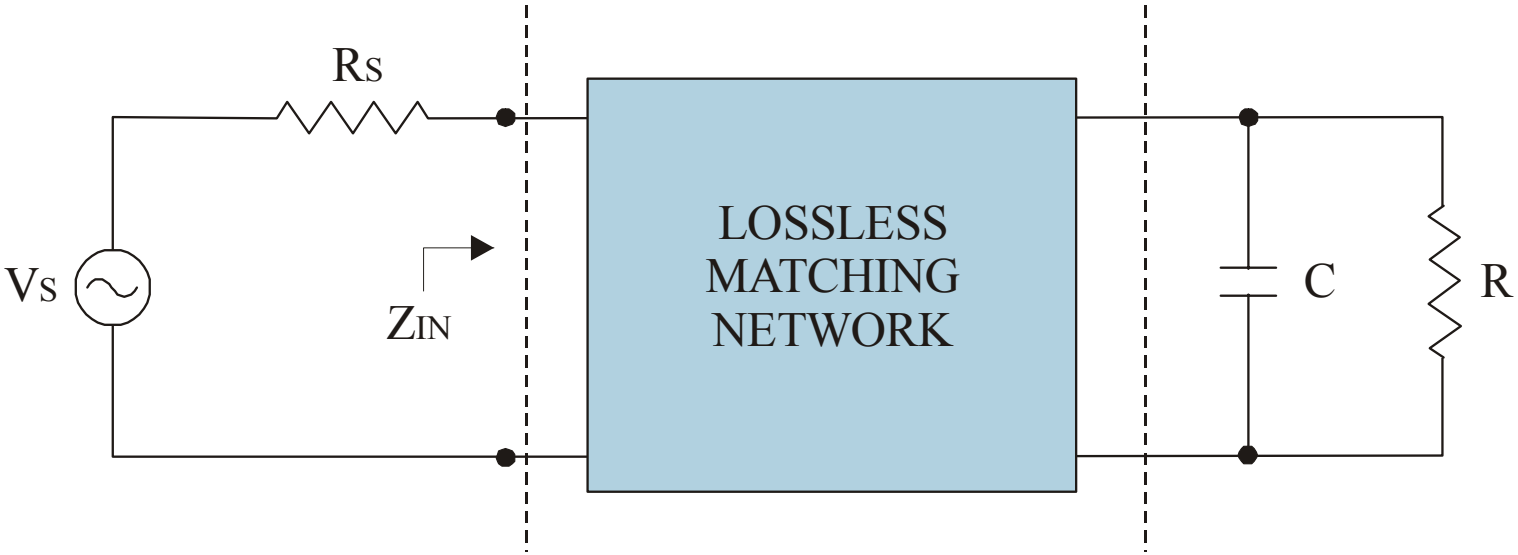
$$\text{Magnetic } Q_r = \frac{40}{(\beta L)^3} \qquad \text{Electric } Q_r = \frac{13}{(\beta L)^3}$$

- **These are calculated results for sensibly shaped antennas**

Optimum operating frequency

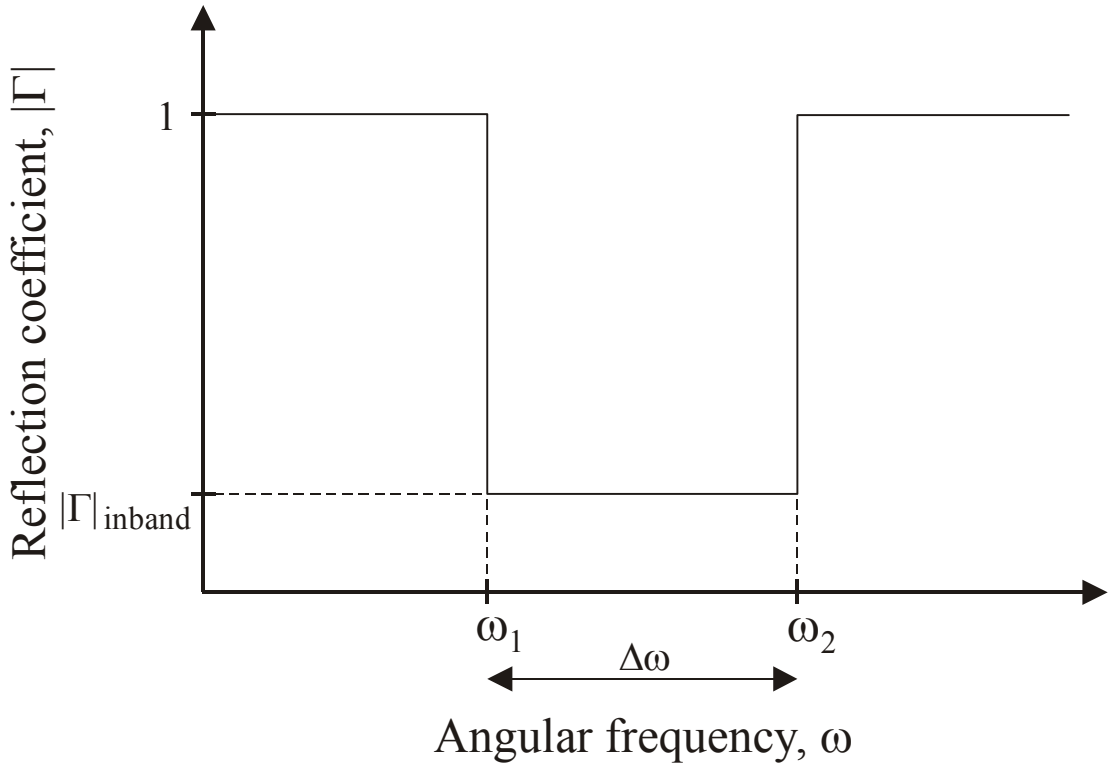
The optimum frequency for operation of an RFID system in the far field is the lowest frequency for which a reasonable match to the radiation resistance of the label antenna can be achieved, at the allowed size of label, without the label or matching element losses intruding.

Bode-Fano Limit



$$\int_0^{\infty} \ln \frac{1}{|\Gamma|}\, d\omega \;\leq\; \frac{\pi}{RC}$$

Bode-Fano Limit (cont)



$$|\Gamma|_{inband} \geq e^{-\frac{1}{2\Delta f RC}}$$

Bode-Fano Limit (cont)

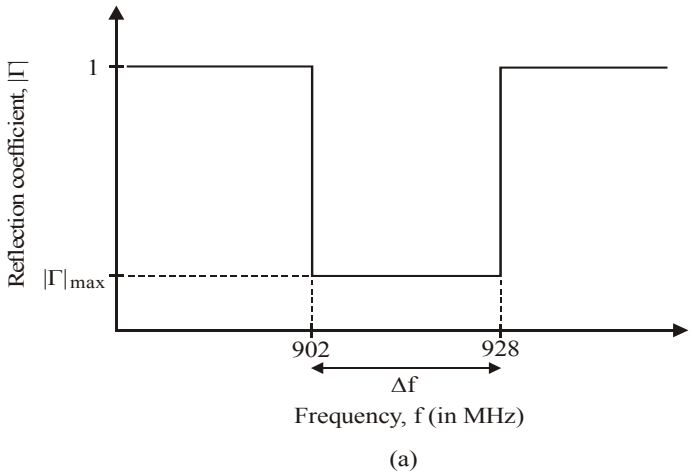
- **Allocated bandwidths for RFID:**

Country	Frequency in MHz		Bandwidth in MHz
	Begin	End	
European countries	865	868	3
USA	902	928	26
Japan	950	956	6

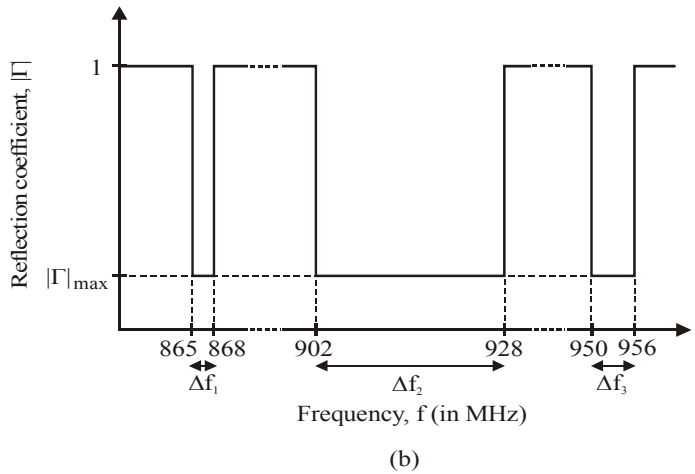
- **Others:**
  China: **917 – 922 MHz (Temporary license can be applied)**
  Australia: **918 – 926 MHz**

Bode-Fano Limit (cont)

- **3 different cases considered:**



(a)



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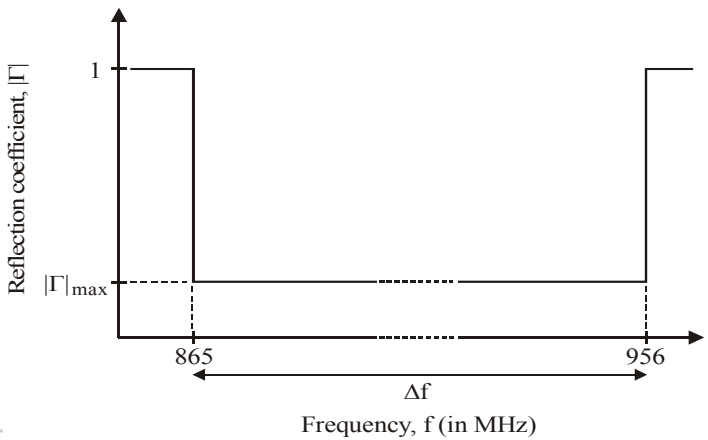


(c)

Bode-Fano Limit (cont)

- **Assume R = 1 kΩ, C = 1 pF**

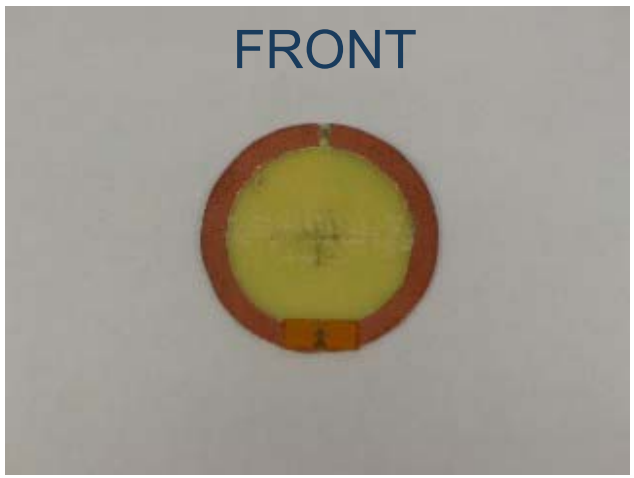
Case	Minimum achievable reflection coefficient, $\|\Gamma\|_{inband}$
1	4.45×10^{-9}
2	6.25×10^{-7}
3	4.11×10^{-3}

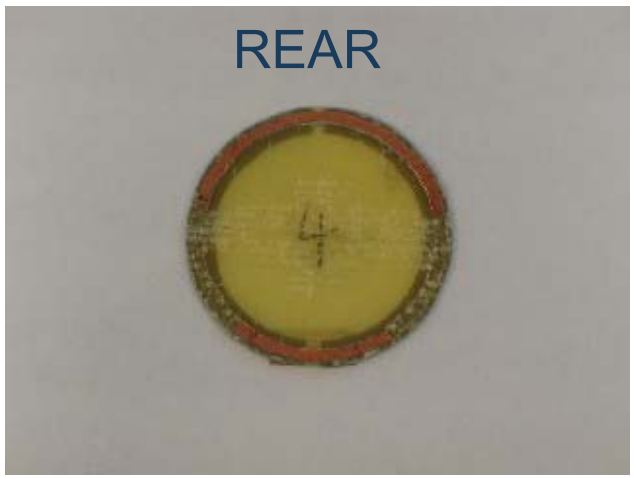
- **R = 10 kΩ, C = 1 pF (for less power consuming tag chip in practice)**

Case	Minimum achievable reflection coefficient, $\|\Gamma\|_{inband}$
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**





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Higher Functionality Tags

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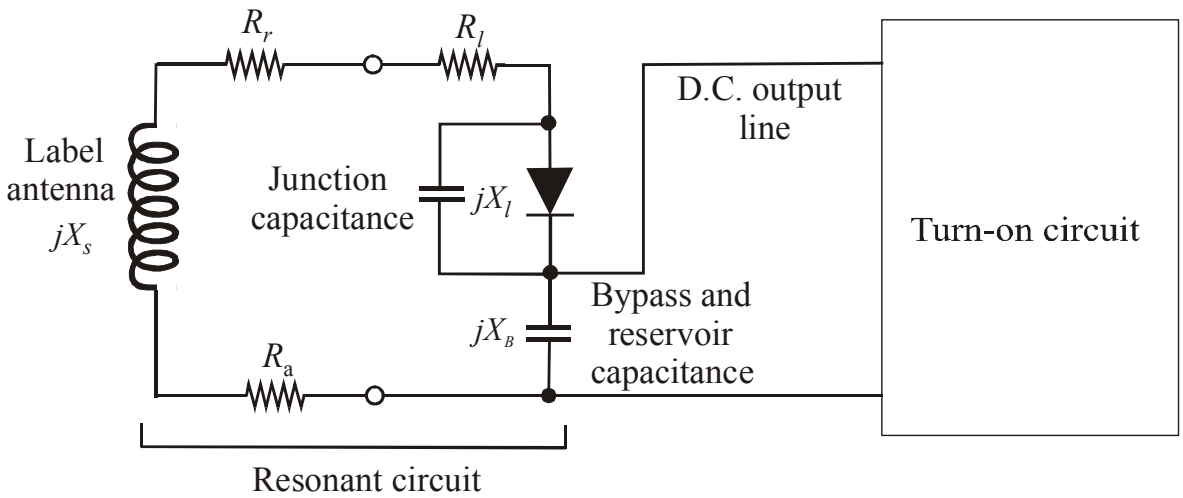
Interesting questions

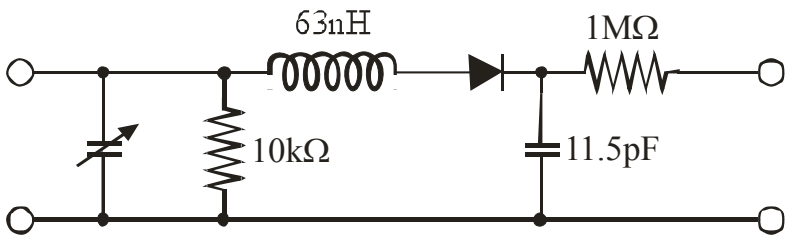
- **Merging of EAS and Data tags**
- **Turning on battery operated tags**
  - Low power consumption
  - Zero power consumption

Transmitter operated systems

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

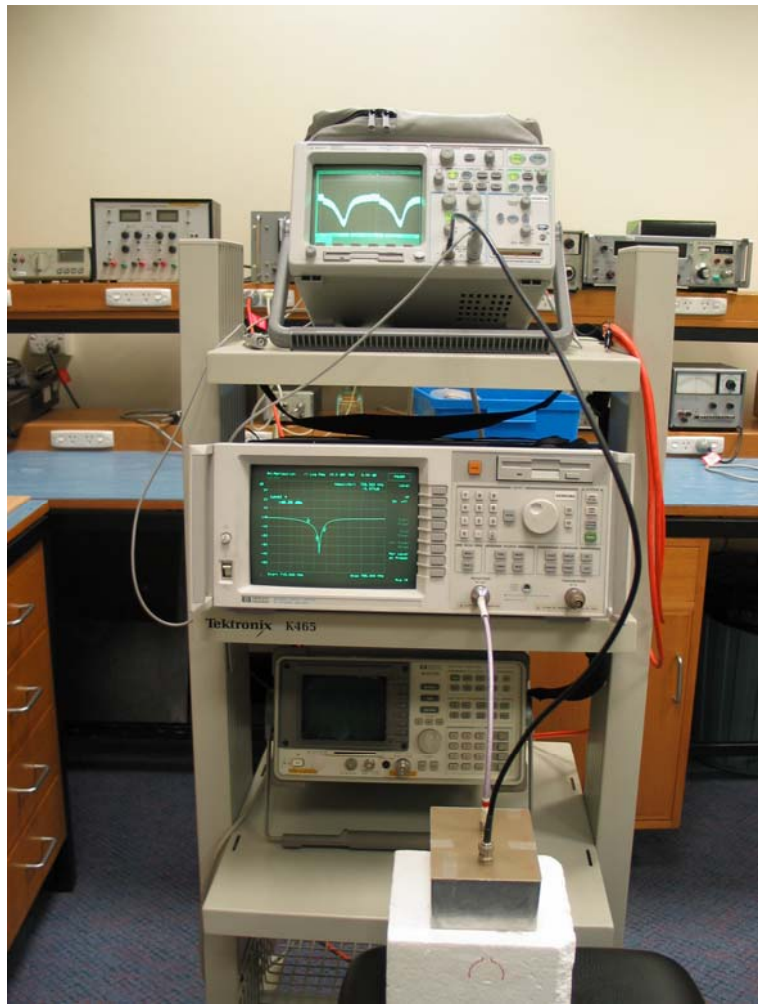


Experiments on detuning

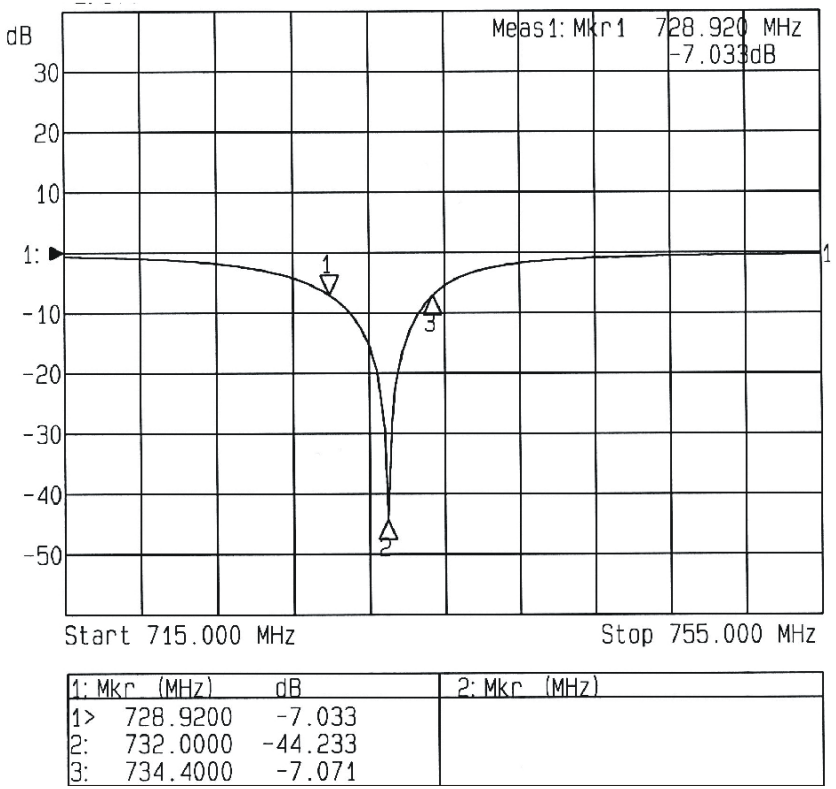


RF IN through an SMA connector

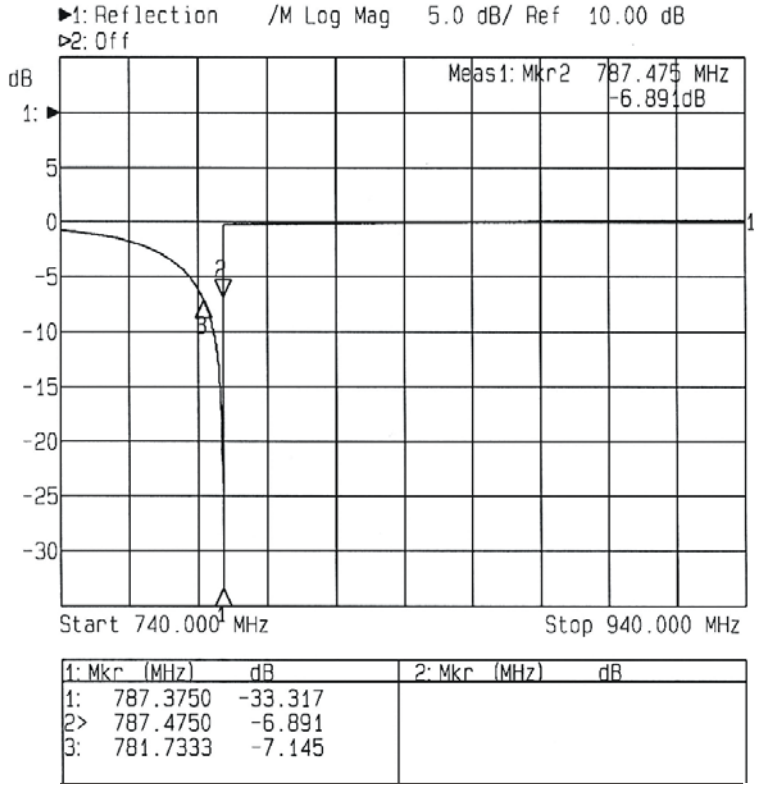
Rectified voltage to Oscilloscope using a BNC connector



Low and high power sweeps



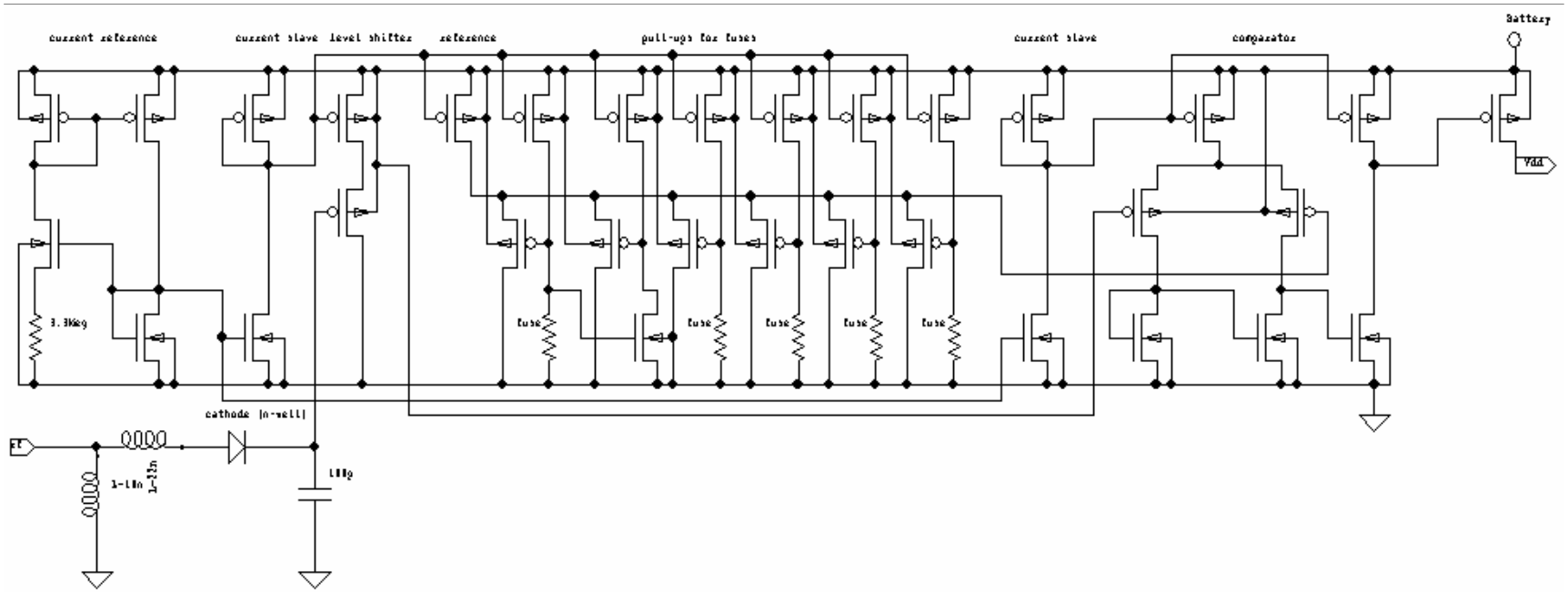
1: Mkr (MHz)	dB	2: Mkr (MHz)
1> 728.9200	-7.033	
2: 732.0000	-44.233	
3: 734.4000	-7.071	



1: Mkr (MHz)	dB	2: Mkr (MHz)	dB
1: 787.3750	-33.317		
2> 787.4750	-6.891		
3: 781.7333	-7.145		

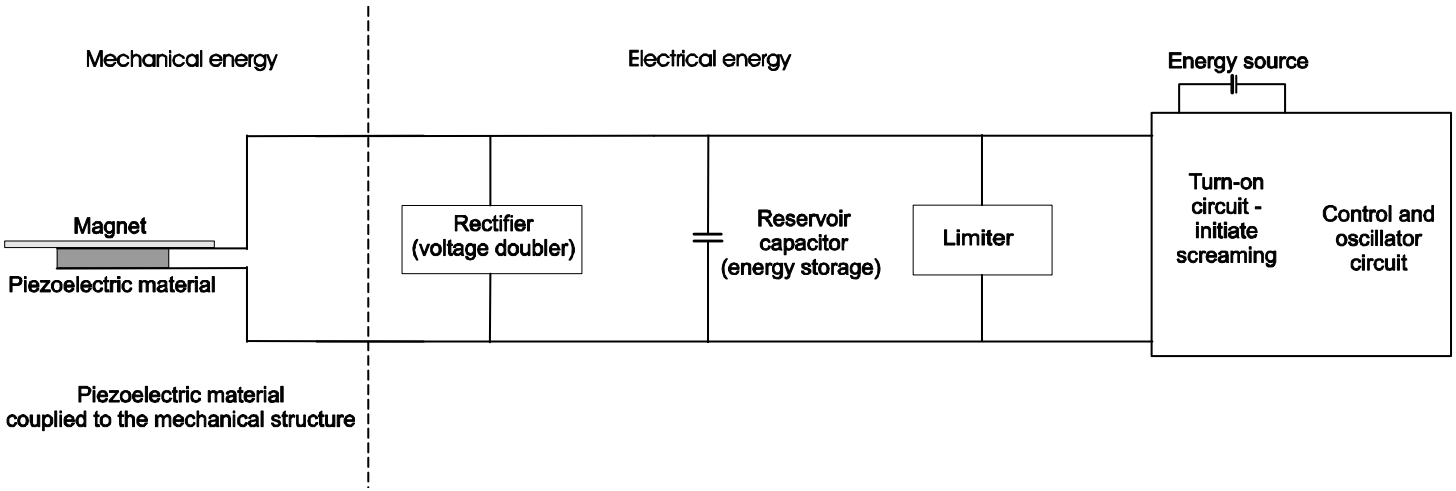
A low voltage turn on circuit

- **Sensitivity about 5 mV**
- **Power consumption few nA**



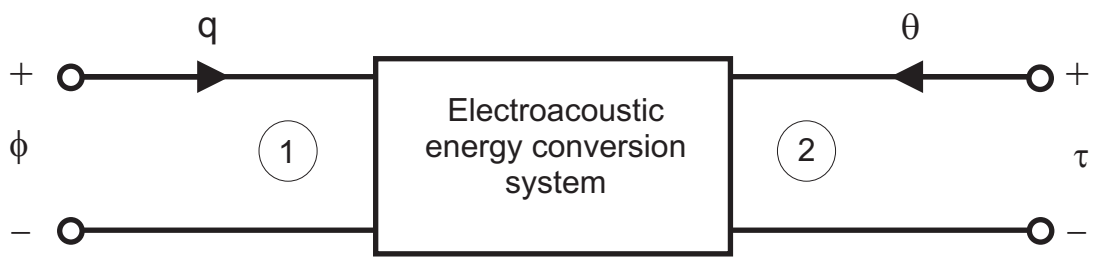
Zero power turn on concept

- 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**

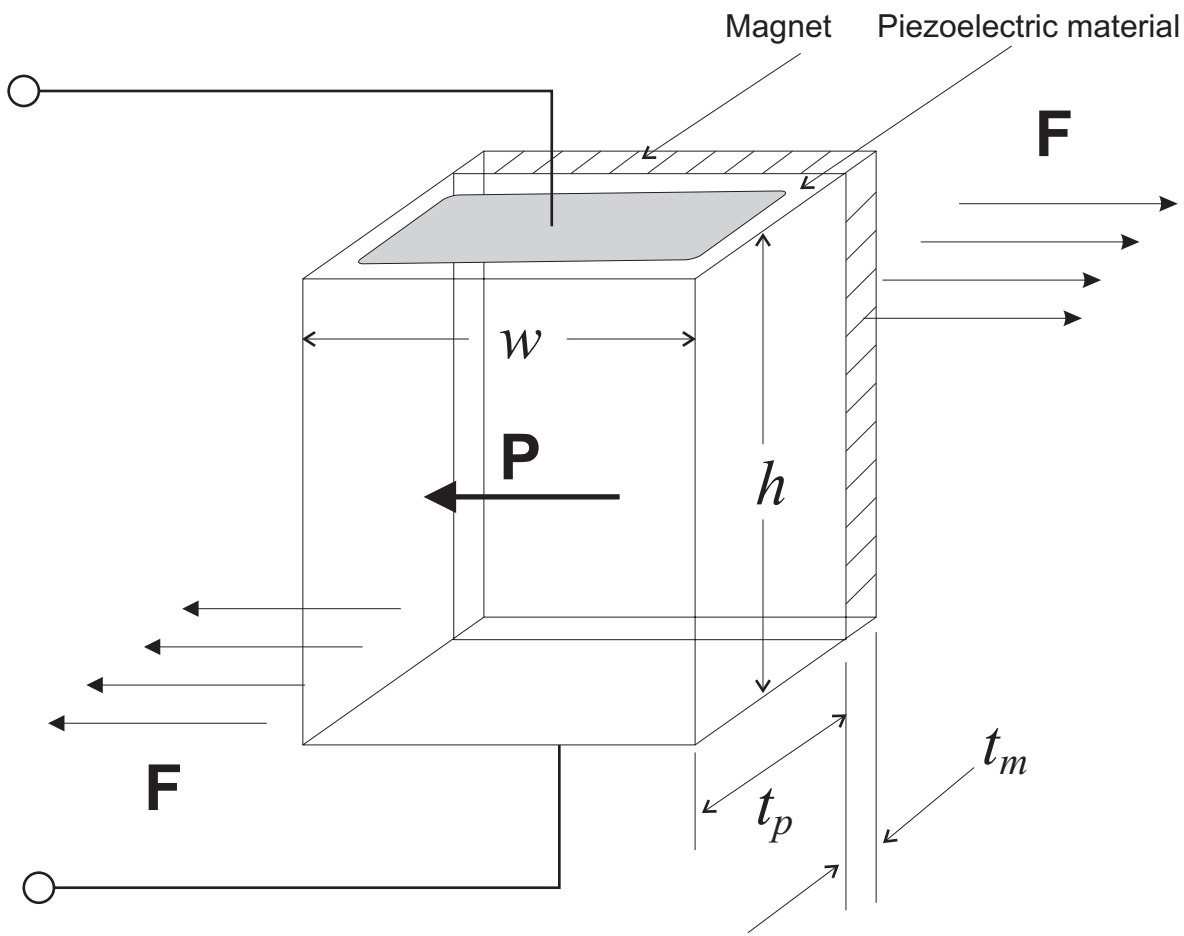


Eletroacoustic conversion

- **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

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