

Abstract

This paper details the architecture of a high-density hybrid smart card capable of housing three distinct independent transponders within a standard ISO 7810 form factor. The system utilizes a Dual-Zone Architecture to mitigate cross-talk between high-security and general-purpose applications. Zone A (Left) houses a standalone EMV-compliant payment module. Zone B (Right) houses a vertically stacked pair of NTAG215 transponders separated by a high-permeability ferrite flux diverter. This configuration allows for "Sidedness", activating specific transponders based on the physical orientation of the card, driven by a combination of magnetic flux shielding and the physical layer "Capture Effect."

System Architecture: The Dual-Zone Layout

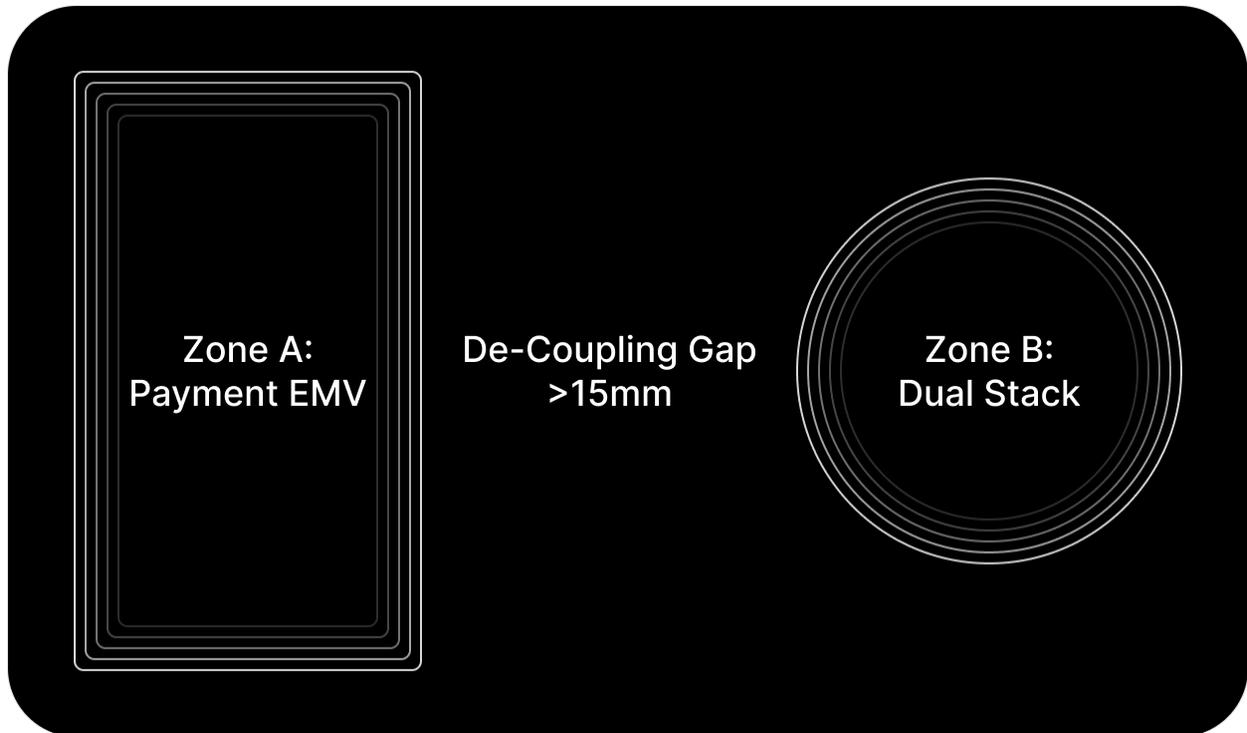
Unlike traditional smart cards which utilize a single large perimeter antenna, this device utilizes a Spatially Diverse Loop Array to separate functions physically.

Zone A: The Payment Sector (Left Quadrant)

- **Function:** Secure EMV Financial Transactions.
- **Location:** Left-hand side (0mm to ~40mm from left edge).
- **Antenna Topology:** Rectangular Planar Loop.
- **Isolation Strategy:** Spatial Separation. By confining the payment coil to the left, it maintains a physical distance ($d > 20\text{mm}$) from the data stack on the right. Due to the rapid attenuation of the magnetic field ($H \propto 1/d^3$), the coupling coefficient (k) between the Payment Coil and the Data Stack is negligible ($k < 0.05$).

Zone B: The Programmable Stack (Right Quadrant)

- **Function:** Dual-Application Data Storage (e.g., Access Control / Social Sharing).
- **Location:** Right-hand side.
- **Configuration:** Vertical Z-Axis Stacking (Sandwich Assembly).
- **Components:**
 1. **Transponder 1 (Face A):** NTAG215 (13.56 MHz).
 2. **Isolation Layer:** Sintered Ferrite Sheet ($\mu^I \approx 130$).
 3. **Transponder 2 (Face B):** NTAG215 (13.56 MHz).



Physics of Operation: Zone B (The Stack)

The innovation lies in the "Right Side" stack, where two chips share the same X-Y coordinates but function independently based on card flip (Z-axis orientation). This is achieved through two mechanisms: **Flux Diversion** and the **Capture Effect**.

Mechanism A: Ferrite Flux Diversion

Standard PVC allows magnetic fields to pass through the card transparently. To create "Sidedness," a ferrite layer is introduced.

- **Permeability:** The ferrite material has high magnetic permeability ($\mu_r \gg 1$), creating a path of low magnetic reluctance (R_m).
- **Operation:** When the reader interrogates **Face A**, the magnetic flux enters the Face A antenna, inducing current. Upon reaching the ferrite layer, the flux is conducted laterally through the shield rather than penetrating to **Face B**.
- **Attenuation:** The field reaching the rear antenna is attenuated by approximately -15dB to -20dB, rendering it insufficient to power the rear chip's voltage rectifier.

Coil A



Coil B

Mechanism B: The "Capture Effect"

In scenarios where the ferrite shield is saturated or imperfect, the field may leak to the rear chip. The system relies on the **Capture Effect** as a fail-safe.

Because both chips are NTAG215s, they have identical modulation characteristics. However, the chip physically touching the reader dominates the signal.

The Physics of the Capture:

The induced voltage (V_{ind}) in the loop is a function of the change in magnetic flux (Φ_B):

$$V_{ind} = - \frac{d\Phi_B}{dt} \approx \omega \cdot B \cdot A$$

Since the magnetic field B degrades via the inverse cube law in the near field:

$$B(z) = \frac{\mu_0 I \tau^2}{2(\tau^2 + z^2)^{3/2}}$$

Even a minimal separation distance (z) of 0.6mm (the thickness of the top chip + ferrite) results in a significant differential in induced voltage.

- **Front Chip:** High V_{ind} fast boot time, strong load modulation.
- **Rear Chip:** Lower V_{ind} slower boot time, weak load modulation.

The reader's demodulator "locks" onto the stronger signal (Front Chip) during the initial ISO 14443 start-up frame, effectively ignoring the rear chip as background noise.

Electromagnetics: Mutual Inductance & Detuning

Ridum Labs

A critical engineering hurdle in the Zone B stack is the **Detuning Effect**. Placing two resonant LC circuits in close proximity alters their electrical characteristics.

Mutual Inductance (M)

The two stacked coils are strongly coupled. The Mutual Inductance is defined as:

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

Where k is the coupling coefficient (approaching 0.8 in this stack).

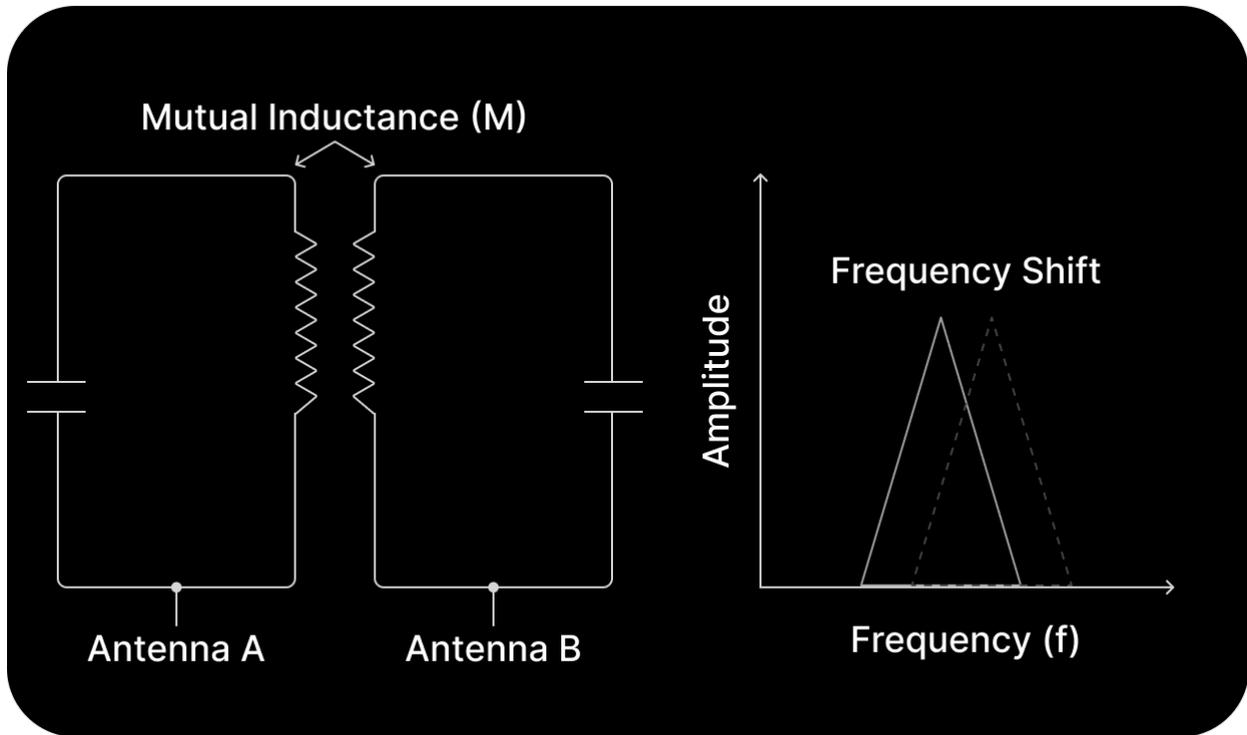
Reflected Impedance (Z_{ref})

The rear tag (even if unpowered) acts as a parasitic load on the front tag. The impedance seen by the front tag (Z_1) is modified by the rear tag (Z_2):

$$Z_{total} = Z_1 \frac{(\omega M)^2}{Z_2}$$

Consequence: The term $\frac{(\omega M)^2}{Z_2}$ represents energy loss and a shift in the resonant frequency (f_{res}).

- **Symptom:** The effective read range of the stacked chips is reduced by ~20% compared to the standalone Payment chip on the left.
- **Compensation:** The antennae in the stack must be tuned to a slightly higher "free air" frequency (e.g., 14.2 MHz) so that the coupling pulls them down to the operational 13.56 MHz center frequency.



User Experience & Operational Logic

The physical architecture creates a predictable User Interface (UI) based on "Tap Zones."

Interaction	Zone Activated	Chip Triggered	Mechanism
Tap Left Side	Zone A	Payment	Spatial Isolation (Zone B is out of range).
Tap Right Side (Front)	Zone B	NTAG 1	Ferrite Shielding + Capture Effect (NTAG 2 is blocked/weak).
Tap Right Side (Back)	Zone B	NTAG 2	Ferrite Shielding + Capture Effect (NTAG 1 is blocked/weak).

Conclusion

The prototype successfully demonstrates that a **Tri-Transponder Smart Card** is feasible by abandoning the traditional single-coil layout in favor of a **Zoned, Shielded, and Stacked** architecture. By leveraging the physical drop-off of magnetic fields (Spatial Diversity) for the payment sector, and High-Permeability Ferrite Shielding for the data sector, the device resolves the "Collision" problems inherent in multi-chip environments. This allows for a singular device to securely handle EMV payments while simultaneously offering two user-programmable interfaces for access control or data sharing.

Supervisor: Sz. Abel