JNXRFID

BUYER EDUCATION SERIES · TECHNICAL GUIDE TG-002 · THIRD EDITION

UHF RFID Printer-Encoders

A technical buyer's guide to the tag, the chip and the encoder — what the physics and the EPC Gen2 protocol actually permit, and how to specify and run a print-and-encode line without buying the wrong hardware twice.

Written for people who have to sign the purchase order.

DOCUMENT TYPE	Technical guide (buyer education). Not a product datasheet.
DOCUMENT ID	JNX-TG-002 · Third edition (V3.1)
RELEASE DATE	11 September 2026
SUPERSEDES	V3.0 (11 Sep 2026); V2.0 (11 Sep 2026); V1.0 (10 Sep 2026)
APPLIES TO	Passive UHF RFID systems operating in the 860–960 MHz band, encoded by thermal printer-encoders, desktop encoders or handhelds.
INTENDED AUDIENCE	Procurement, operations and project managers specifying RFID labelling; systems integrators; technical sales.
PREPARED BY	JNXRFID product marketing — compiled from the published engineering literature (see References, page 31).
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FRONT MATTER

About this guide

Why we wrote it

RFID projects rarely fail because the reader was too weak. They fail because an assumption made at specification time — about how far a tag reads, how thick a label can be, whether a phone can verify it, what a "VOID" label means — turns out to be wrong, and nobody discovers this until the line is running. The cost of that discovery is measured in wasted media, missed go-live dates and eroded internal trust in the technology.

This guide collects the assumptions we see most often, states them in the buyer's own words, then examines each one against the underlying physics and the EPC Gen2 protocol. It is deliberately technical. A guide that only lists "best practices" gives you nothing to defend a decision with; a guide that explains the mechanism lets you evaluate any claim you are handed, including ours.

Purpose and scope

In scope: passive UHF (860–960 MHz) transponders; the four Gen2 memory banks; tag form factors and their convertibility into printer media; chip selection criteria; the five classes of encoding equipment; the mechanics that decide whether a given inlay encodes reliably on a given printer; application difficulty ranking; and field troubleshooting.

Out of scope: high-frequency (13.56 MHz) design detail beyond the comparisons needed to prevent UHF/HF confusion; active and battery-assisted tags; reader network planning and portal layout; software architecture; and any specific commercial quotation.

> **READ THIS BEFORE QUOTING A RANGE**
> Every read-range figure in this guide is a physical ceiling measured under benign conditions. Regulatory limits, materials, geometry and interference all reduce it. No vendor, ours included, can promise a site-specific range without a site-specific test. Treat any number quoted without test conditions as marketing, not engineering.

Who this is for, and how to read it

The guide is written to be read in three different ways, depending on what you need today.

- **Evaluating a purchase (≈20 minutes).** Read §1 (the three physical facts), §3 (buying myths) and §2.6 (the decision path). This is enough to write a competent requirement.
- **Specifying media and hardware (≈50 minutes).** Add §2 in full, which covers the tag × chip × encoder system, the geometry that governs reliable encoding, and the difficulty of the application you are proposing.
- **Running the line.** Go straight to §7 (field reference) and Appendix A, then use §4–§6 to understand any symptom you cannot clear.

Conventions used in this guide

- **Units.** Radio power in dBm (0 dBm = 1 mW); gain and loss in dB. A 3 dB change is a doubling or halving of power. Sensitivity figures for chips are negative dBm, and a *more negative* number means a *more* *sensitive* chip.

- **Currency of standards.** "Gen2" means EPCglobal Class-1 Generation-2, standardised as ISO/IEC 18000-63. "ISO 18000-6C" is the older, equivalent designation still common in product literature.
- **Admonitions.** A block with a coloured rule and a label is a caution drawn from field experience, not a legal warning. The only mandatory legal statement is in Document control, on the last page.
- **Cross-references.** "§4.2" means section 4.2. References to the numbered tables and figures use the caption numbers on this page's Contents listing.
- **Anonymity.** Where a failure pattern is documented in printer-manufacturer support literature, it is cited as such rather than attributed to a named competitor. Chip vendors are named, because a chip is a component you must specify by part number.

Revision history

EDITION	DATE	CHANGE
V3.1	2026-09-11	Added the manufacturing chain behind a tag (antenna, bonding, converting, data and print) and a new §2.7 on why two rolls of the same inlay part number can perform differently: bonding spread, yield culling, converting variance, and what third-party inlay programmes do and do not certify. Expanded §1.3 with the current Chinese allocation (920–925 MHz since 1 November 2024) and a regional allocation table, now Table 1; the remaining tables were renumbered. Added a seventh operating rule on writing read-rate acceptance criteria as repetitions rather than 100 %. Updated the NXP row in the chip table with the current sensitivity benchmark. Checklist extended with placement-guideline, batch-record and acceptance-criterion items.
V3.0	2026-09-11	Document restructured to guide convention (purpose, scope, audience, conventions, revision history, numbered contents with page numbers, terminology, numbered tables and figures, references, document control). Visual identity reworked. Technical review performed against the cited literature: corrected the conductivity ranking of antenna metals; corrected the maximum media thickness claim for on-metal printer-encoders; tightened figures for polarisation loss, material attenuation, VOID rates and VOID causes; added the "already compliant media needs no RFID calibration" rule from published inlay-placement guidelines; added media storage and print-over-chip guidance.
V2.0	2026-09-11	Added "The Tag × Chip × Encoder System": tag form-factor ladder, chip family comparison, five encoder classes, compatibility mechanics (a/x/y geometry, profiling, firmware chip lists, thickness classes), application difficulty ladder, and the five-question decision path.
V1.0	2026-09-10	Initial release: three physical facts, fifteen misconceptions in four levels, cheat sheet and troubleshooting matrix.

FRONT MATTER

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FRONT MATTER

Terminology and abbreviations

Terms are defined here as they are used in this guide. Where industry usage is loose, the tighter definition is given and the looseness is noted.

Backscatter

The mechanism by which a passive tag replies: it switches the impedance of its own antenna between two states, changing how much of the reader's incoming wave is reflected. The tag does not transmit; it modulates a reflection.

Chip / IC / die

The silicon integrated circuit carrying the memory and the Gen2 state machine. "Inlay" is not a synonym: the inlay is the chip plus its antenna and substrate.

Dry inlay / wet inlay

A dry inlay is chip + antenna + carrier, with no adhesive and no liner. A wet inlay adds pressure-sensitive adhesive and a release liner. Radio performance is identical; only convertibility differs.

EPC (Electronic Product Code)

Bank 1 of Gen2 memory: the writable identity presented during inventory. Typically 96 bits, extensible to 496 bits on some silicon. Must be written as valid hexadecimal.

Encoder

Any device that writes data to a transponder. It is a radio, not a printer. A printer-encoder is one class of encoder that also prints.

Inlay pitch (y)

The distance from the leading edge of one inlay antenna to the leading edge of the next, along the feed direction. If pitch is too small, the encoder couples with two inlays at once and can write the same EPC into both.

Printer-encoder

A thermal printer containing an RFID reader module and a near-field encoding antenna, with a write–verify loop: write, read back, compare, print. Failure is marked on the label (typically "VOID") rather than silently shipped.

Profiling / RFID calibration

A routine in which the printer determines and stores the parameters needed to encode a specific converted media: chip type, program position, read and write power, and memory-bank sizes.

Q (and the Q algorithm)

The Gen2 anti-collision parameter. The reader announces a Q value; each tag that wishes to reply selects one of 2^Q slots. Q is adjusted as the population estimate changes.

Region / region mask

The regulatory channel plan in force at the site. Radiated power, channel count and channel spacing differ by jurisdiction, and a printer moved between regions must be re-validated, not merely re-labelled.

Sensitivity (read / write)

Expressed in negative dBm: the weakest signal at which the chip will respond (read) or accept a write. More negative is better. Write sensitivity is always worse than read sensitivity, and on an encoding line it is the figure that matters.

TID (Tag Identifier)

Bank 2: factory-programmed, read-only identity, unique per chip. Its leading bytes encode the silicon vendor and model, which makes TID a practical incoming-inspection tool.

VOID

A label the encoder refused to release because the write-verify comparison failed. It is a quality gate operating, not necessarily a fault.

Anti-metal / on-metal tag

A construction engineered to work with a conductive surface directly behind it, using a spacer or ferrite layer. It is a matched component: on a non-metal surface it usually performs worse than an ordinary inlay.

PART ONE · FOUNDATIONS

1. Introduction: three physical facts

Nearly every misconception in this guide is a downstream consequence of one of three facts. An hour spent on these pages is worth more than a week of vendor brochures, because they let you predict failure instead of discovering it.

1.1 A passive tag is a mirror, not a radio

A passive UHF tag contains no transmitter and no battery. It harvests a small amount of energy from the reader's field, powers up its logic, and answers by switching the impedance of its own antenna between two states. That switching changes how much of the incoming wave is reflected back, and the reader detects the change and decodes it. The mechanism is called *backscatter*, and it has one consequence that governs everything else: the reader always speaks first, and the tag's reply is powered by whatever energy the tag managed to harvest.

Two practical results follow. Anything that reduces the energy reaching the tag — distance, orientation, a conductive surface nearby, a lossy material in the path — also weakens the reply, because the same field does both jobs. And the reply is extraordinarily weak: a backscattered signal arriving at the reader is commonly in the picowatt to nanowatt range. That is why the return link, not the transmitter, is usually the limiting factor in a real installation.

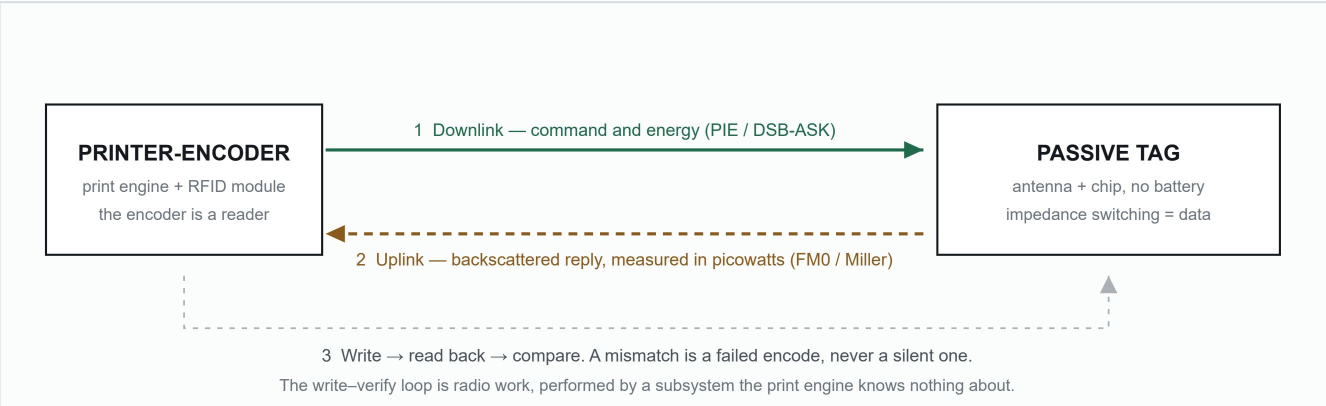


FIGURE 1 The backscatter link and the write–verify loop. See §1.1 and §4.1.

1.2 Range follows the Friis equation — and it is a fourth-root law

Radio power spreads as it travels. The power density arriving at a tag falls with the *square* of distance, and the tag's backscattered reply makes the same journey back, losing power with the square of distance a second time. For the reader to hear anything, the round trip has to close, so the signal the reader receives from a given tag falls roughly with the *fourth power* of distance. Invert that and you get the rule that governs every range argument you will ever have with a supplier: read range scales only with the **fourth root** of transmit power.

Numbers make it concrete. Doubling reader power (+3 dB) buys about 19 % more range, not double. A tenfold increase (+10 dB) buys about 78 %. An improvement of the same size in the tag's own sensitivity is worth the same percentage, because the chip's wake-up threshold and the reader's transmit power act on the same link equation. This is why chip generation matters more than reader wattage, and why "we will turn the power up" is almost never the answer to a range problem.

> **NOTE — THE ASYMMETRY THAT DECIDES PROJECTS**
> The tag's reply is far weaker than the reader's transmission, so the return link usually fails first. A tag that is comfortably energised may still be inaudible. When diagnosing, establish which link is failing: if the tag cannot power up it will not reply at all, and if it powers up but is not heard, the problem is the return path and additional forward power will not fix it.

1.3 The air interface is a shared, regulated channel

A reader does not talk to tags one at a time. It announces a collision parameter, Q, and every tag in range picks one of 2^Q reply slots at random, so that the population sorts itself out without central coordination. Q is then adjusted as the reader refines its estimate of how many tags are present. The rule of thumb is that Q should be set so that 2^Q is close to the number of tags in the field: too low produces collisions, too high wastes time on empty slots. Dense populations — a full pallet, a packed tote — are therefore a *protocol* problem before they are a hardware problem.

The band itself is regulated, and the regulations differ. UHF RFID shares a single harmonised window, 860–960 MHz, but each administration carves its own sub-band out of it and sets its own radiated-power and channel rules. A unit that worked in one region is not automatically valid in another, and the difference does not announce itself: it appears as intermittent encode failures in production.

The Chinese allocation is the one most often quoted out of date. For years China permitted two segments, 840–845 MHz and 920–925 MHz; the current regulation, in force since 1 November 2024, keeps only **920–925 MHz** and no longer accepts type-approval applications for 840–845 MHz equipment. Equipment already approved in the withdrawn segment may be sold and used until it is scrapped, which means both configurations remain visible in the market at the same time. Under the same regulation, RFID equipment is managed like a terrestrial public mobile terminal: type approval is required, a radio station licence is not.

TABLE 1 Common UHF RFID allocations — the region plan must match the country of installation

REGION	ALLOCATION	WHAT IT MEANS AT THE LINE
China	920–925 MHz	Single segment since 1 November 2024; 840–845 MHz withdrawn. Verify the region plan of any unit bought before that date.
North America	902–928 MHz	Widest allocation and the highest permitted power; hopping over 50 channels.
Europe	865–868 MHz	Narrowest of the three, with listen-before-talk; four channels, lower power.
Japan	916–924 MHz	Separate approval regime; a Japanese unit is not a European or Chinese unit.
Elsewhere	varies within 860–960 MHz	Confirm locally before the order, not after the machine lands.

> **WHY THIS IS A PURCHASING QUESTION, NOT A LEGAL FOOTNOTE**
>
> Region is set in firmware, and in most machines it can be changed — but the antenna, the power table and sometimes the supported channel plan are region-specific. A machine bought for one market and re-pointed at another may run outside its type approval, and the failure mode is not a warning message: it is a tag population that encodes reliably in the workshop and not on site. Decide the country of installation first, then buy.

Two consequences follow for a print-and-encode line. First, the label is a passive device with no region of its own; the same inlay is legal everywhere, while the machine writing it is not. Second, when a project spans several countries, treat the encoder fleet as a per-country asset with its own configuration record, not as interchangeable stock.

PART TWO · THE SYSTEM

2. The tag × chip × encoder system

Most problems described as "printer problems" are mismatches between three separate things: the physical construction of the label, the silicon inside it, and the machine doing the encoding. This chapter establishes the vocabulary, then ranks real applications by difficulty so that you know what you are committing to before you promise a date.

2.1 Tag form factors: one chip, six bodies

"RFID tag" is not a product; it is a construction system. Every passive tag begins as the same three-layer core: a silicon **die**, bonded through a conductive **strap** to a printed **antenna** — usually aluminium, copper or silver, where silver offers the highest conductivity and the highest cost, and aluminium the cheapest workable compromise — all carried on a thin **PET substrate**. That core is the **inlay**. Everything after it is conversion: adding adhesive, liner, facestock, housing or encapsulation so that the inlay survives in a particular place.

The distinction that catches buyers is between the two unconverted forms. A **dry inlay** has no adhesive and no liner; a **wet inlay** adds pressure-sensitive adhesive and a release liner. Their radio performance is *identical*, because the antenna and the chip are untouched. What differs is convertibility, and that single fact produces one of the most expensive misunderstandings in the industry: a printer-encoder consumes **converted label rolls**. Raw dry inlays cannot be fed through any printer on the market, however willing the salesperson.

Where the inlay you buy actually comes from

An inlay is not made in one step, and knowing the sequence explains most of the variance you will later measure. Four operations stand between a wafer and the roll in your machine.

1. **Antenna.** The antenna is printed or cut from a conductive layer on a carrier film. For UHF the shape is a half-wave dipole: at 860–960 MHz the wavelength is about 30 cm, so the half-wave element is roughly 15 cm — which is why a UHF label is a long, narrow strip rather than a square patch. **Aluminium** is the material of nearly all volume production: its conductivity is more than adequate, it etches and die-cuts cleanly, and it is cheap. **Copper** conducts better but its material cost keeps it to a small set of performance-critical products. **Silver** conducts best of the three and is correspondingly the most expensive — the metal ranking and the price ranking run in the same direction, which is the opposite of what most buyers assume.
2. **Bonding.** The die is attached to the antenna. The dominant process is **flip chip**: a conductive adhesive is dispensed between die and antenna and cured under heat and pressure, which suits flexible substrates and high volume. The alternative, **COB** (chip-on-board), wires the die with gold thread and encapsulates it — slower and dearer, but mechanically tougher, which is why reusable credentials such as identity and payment cards still use it. This is the stage that produces the inlay.
3. **Converting.** The inlay is laminated between facestock, adhesive and liner, and die-cut into the label format you can actually buy. Converting capacity in the industry generally exceeds bonding capacity, and this is the step most exposed to price competition.

4. **Data and print.** Only now does a printer-encoder write an identity and print a face. Everything the buyer sees happens last; everything that determines whether the write succeeds happens first.

> **THE CONSEQUENCE FOR SPECIFICATION**
>
> Three of the four operations happen before your media supplier ships anything, and none of them is visible in the delivered product. That is why §2.7 asks you to specify the *process* evidence you want — a placement guideline, a batch record, a sample trial — rather than trusting a part number to be self-describing.

TABLE 2 Tag form factors and their compatibility with printer-encoders

FORM FACTOR	CONSTRUCTION	TYPICAL USE	PASSES THROUGH A PRINTER-ENCODER?
Dry inlay	Chip, antenna and carrier only. No adhesive, no liner.	Raw material for label converters; embedding in cards and packaging.	**No — must be converted into a label roll first**
Wet inlay	Dry inlay plus pressure-sensitive adhesive and release liner.	Direct application; the converter's input for smart labels.	**Yes, once converted into rolls**
Smart label	Wet inlay plus printable facestock (paper or PET).	Cartons, retail items, logistics. The standard printer media.	**Yes — the default choice**
Hard tag	ABS or PC housing, screwed, riveted or cable-tied on.	Tools, machinery, returnable containers, outdoor assets.	**No — commissioned with a reader or desktop encoder**
On-metal label or tag	Spacer or ferrite layer between antenna and a conductive surface; the metal becomes part of the antenna system.	Metal assets, IT equipment, racks, machinery.	**Flexible label forms only, and only within the printer's media-thickness rating**
Laundry / textile tag	Silicone, PPS or TPU encapsulation, sewn or heat-sealed in.	Uniforms, linen rental, textiles passing through wet processing.	**Usually commissioned by a desktop encoder before issue**

> **THE COMPATIBILITY HEADLINE**
>
> Two rules explain most media surprises. A printer consumes converted label rolls, so the conversion — not the chip — is what the machine is actually handling. And if a converter changes the conversion (inlay position, pitch or facestock), the printer must be re-calibrated for what is nominally the same label, because the geometry the encoder relies on has moved.

2.2 Chip families: how to read a chip datasheet

All Gen2 chips speak the same protocol, which tempts buyers to treat them as interchangeable. They are not. Three properties decide what your application can actually do, and all three are in the datasheet once you know where to look.

Rule 1 — there are four memory banks, and one of them is often missing

Gen2 defines **Reserved** (kill and access passwords), **EPC** (the writable identity used in inventory), **TID** (factory-burned, read-only, unique per chip) and an optional **User** bank. Many of the most popular chips — including Impinj M730 and M830, and NXP UCODE 9 — ship with **zero user memory**. A requirement that says "write our batch number onto the tag" will therefore fail quietly against a perfectly functional chip, unless you choose silicon with a user bank or hold that data in your back-end instead.

Rule 2 — sensitivity is a negative dBm, and write sensitivity is the one that matters

A chip specified at −25 dBm wakes up on a weaker field than one specified at −20 dBm, which converts directly into range and into reliability in cluttered environments. The relationship is linear in decibels and logarithmic in distance: a 1.5 dB improvement in sensitivity is worth roughly 19 % more range, and 3 dB is worth roughly 41 %. On an encoding line, however, read sensitivity is not the number to buy on. Writing costs the chip more energy than reading, so **write sensitivity sets the usable encoding distance**, and it is always the worse of the two figures.

Rule 3 — the TID prefix identifies what you actually received

The leading bytes of TID are assigned by the silicon vendor and cannot be rewritten, which makes them an incoming-inspection tool rather than a curiosity. `E280 1191` identifies an Impinj M730; `E280 6995` identifies an NXP UCODE 9. Label vendors sell visually identical labels built on different silicon at different prices, and the printed label tells you nothing. Reading a sample TID on receipt is the cheapest way to confirm that the chip you specified is the chip you were shipped.

TABLE 3 UHF chip families at a glance — representative values, not a purchasing specification

FAMILY	REPRESENTATIVE ICS	EPC BITS	USER BITS	READ SENS.	CHARACTER
Impinj M700 / M800	M730, M750, M770, M830, M850	96–128	0–32	−24 to −25.5 dBm	Sensitivity leader; the M800 pair sits at the bottom of that range. AutoTune retuning sustains performance when tags are stacked or detuned by nearby material.
NXP UCODE	UCODE 8, 9, 9xe, 9xm, X, DNA	96–224	0–3072	−23 to −26.2 dBm	Broadest memory ladder. UCODE X currently sets the sensitivity benchmark at −26.2 dBm read, which is what allows a usable read range from a physically smaller antenna. UCODE DNA adds AES-128 authentication for anti-counterfeiting work.
Alien Higgs	Higgs-3, Higgs-4, Higgs-9, Higgs-EC	96–496	128–688	−18 to −22.5 dBm	Memory leader: Higgs-9 carries a 688-bit user bank, enough to keep asset history on the tag itself.
EM Microelectronic	EM4124, EM4325, EM4423	96–224	up to 720	−18 to −30 dBm	Specialists rather than generalists. EM4325 adds on-chip temperature sensing; EM4423 is a dual-interface chip carrying UHF and NFC on one die.
Fudan Micro / Quanray	FM13 series, QS200–QS800	96–496	0–1024	−18 to −24 dBm	Cost-optimised domestic silicon with widening international acceptance; verify firmware support before committing to volume.
Axzon Magnus	Magnus-S3 (M3D / M3E)	96	sensor registers	not comparable	Passive temperature and moisture sensing in the chip itself. Purchase on the sensing specification, not on EPC memory.

THE LIMIT THAT CATCHES PEOPLE OUT

Chip selection is bounded by your encoder. A printer-encoder supports a published chip and inlay list held in firmware, and the newest silicon is not on it until the vendor ships an update. Choosing the best chip on the market before checking that list is a reliable way to buy a roll of labels your machine will refuse to write.

2.3 Encoder types: five ways to write a chip

Encoding is radio work. A printer is only one of the machines that can do it, and it is the most constrained one. The five classes below differ less in capability than in where the bottlenecks sit, and choosing the wrong class is a common way to pay for throughput you cannot use.

TABLE 4 Five classes of encoder, and where each one breaks down

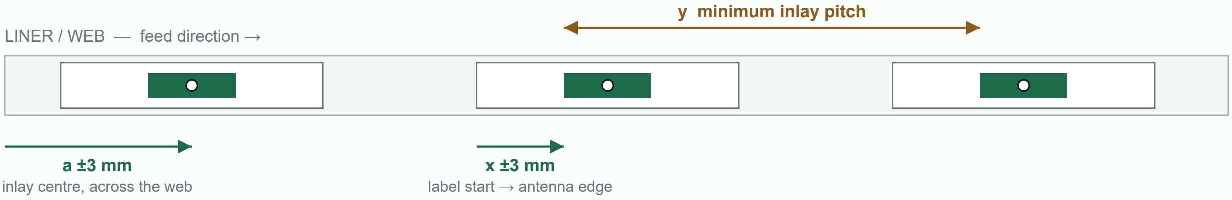
CLASS	WHAT IT DOES	BEST FOR	WHERE IT BREAKS DOWN
1. Printer-encoder desktop or industrial	Prints the visual layer, writes the chip, reads it back to verify, in a single pass.	Item-level programmes from roughly 500 to 20,000+ labels a day.	The most compatibility-sensitive class: media conversion, firmware chip list and media thickness all bind it.
2. Desktop reader as encoder	USB reader with vendor software; one tag at a time at a commissioning station.	Low volume, asset commissioning, pilots, re-encoding hard tags.	Manual and slow, though hardware-cheap and close to failure-proof.
3. Handheld or sled	Field encoding and re-tagging; scan, then write, on the spot.	Maintenance crews, re-labelling, mobile commissioning.	Throughput depends entirely on the operator; battery and ergonomics dominate the outcome.
4. Fixed reader or portal	Inline batch initialisation on a conveyor or through a tunnel.	High volume where no visual print is required.	Densely spaced inlays couple with each other; power and Q must be tuned, and crosstalk is a live risk (§4.1).
5. OEM encoder module	Reader module plus antenna designed into your own equipment.	Machine builders embedding encoding into a print-and-apply or kiosk line.	The antenna design and RF validation become your engineering problem, not the supplier's.

ARCHITECTURAL INSIGHT

Encode where it is cheapest and most reliable, not where it is most convenient to draw on an organisation chart. If the printed image and the EPC originate from the same record, a printer-encoder earning both in one pass is hard to beat. If the visual layer is pre-printed or unnecessary, a desktop commissioning station encodes at a fraction of the equipment cost and is simply slower. Mature programmes often split the work deliberately: printer-encoders for label rolls, a desktop station for hard tags and re-commissioning.

2.4 Compatibility: the a / x / y geometry

Here is a situation worth understanding before it happens to you. The same label roll, the same software, two printers: one encodes every label, the other rejects three in ten. Nothing is broken. Encoding a converted label is a three-way negotiation between the conversion geometry, the printer's media path, and the RF coupling between a fixed antenna and a moving inlay. Printer manufacturers publish that geometry as three dimensions, and the tolerances are tight.



a — inlay centre.
Horizontal position of the inlay across the web. Coupling changes along this axis, and many printers allow the antenna coupler to be moved to match.

x — inlay position.
Distance from the start of the label to the leading edge of the inlay antenna. A displacement can be compensated by a program-position command, but only within that comm

y — inlay pitch.
Leading edge to leading edge. Space inlays too closely and the encoder couples with two at once, writing one EPC into two chips. The published minimum pitch for printer-e

FIGURE 2 The three dimensions of converted RFID media. Tolerances are typically ±3 mm. See §2.4.

Four mechanics that decide whether media will encode

1. **Profiling — and when it is not needed.** A calibration routine reads out the chip type, program position, read power, write power and memory-bank sizes, and stores them as an inlay profile. Media converted to a published placement guideline needs no RFID calibration at all. Media that deviates from the guideline does, and so does any change of inlay family, conversion, batch or even roll diameter.
2. **Chip support is a firmware list, not a promise.** Vendors certify specific chips and inlays and revise the list as new silicon appears. Check the list and your firmware version before ordering media, not after.
3. **Media thickness is a mechanical limit.** The encoder antenna sits a fixed distance from the media path, and the media has to fit through the gap. Ordinary thermal media runs from about 0.06 mm to 0.25 mm; printer-encoders rated for on-metal labels accept up to roughly 1.5 mm, which is the order of thickness of the flexible on-metal constructions the industry actually uses. A rigid tag will not pass the antenna gap, and no firmware setting changes that.
4. **Region changes the geometry, not only the channel.** Placement and power guidance is published per regulatory region because permitted antenna power differs. Moving a printer between regions requires re-validation, not just a change of region setting.

TABLE 5 What RFID calibration actually determines and stores

PARAMETER	WHAT THE PRINTER IS MEASURING	WHAT INVALIDATES IT
Inlay family and chip type	Which silicon and antenna geometry is present in the media.	Any change of chip or inlay part number.
Program position	Where the inlay must sit relative to the print line for the write to succeed.	A change of conversion (§2.4), or a different label length.
Read and write power	The minimum field strength that reliably reads and writes this inlay.	Region change, firmware update, or a change in roll geometry.
Memory-bank sizes	How many EPC and user bits the chip exposes, and how they are addressed.	A different chip family, or a firmware default reset.

2.5 Application difficulty ladder

Not all RFID applications are equally hard, and the difference is physical rather than commercial. The ladder below ranks common applications from hardest to easiest, states the mechanism that makes each one difficult, and names the single question that most reliably exposes an unrealistic proposal.

TABLE 6 Application difficulty ladder, hardest first

APPLICATION	RATING	THE MECHANISM THAT MAKES IT HARD	THE QUESTION TO ASK BEFORE YOU COMMIT
On-metal assets	★★★★★	Metal reflects the incident wave almost completely and detunes the tag antenna, moving its resonance out of band. Interference between the incident and reflected waves produces nulls that can reach −30 dB, so a standard label can lose most of its range or fall silent.	"What is the maximum media thickness your encoder accepts, and has the tag been validated on the real asset?" Rigid tags are commissioned outside the printer; only flexible on-metal labels belong in one.
Liquids, cosmetics, pharma	★★★☆☆	Water has high dielectric loss at UHF, converting field energy into heat. Attenuation through 10 cm of water is in the order of 15–25 dB, and a soaked carton can be worse still.	"Was this tag tested on the *filled* and *stacked* product?" Open-air results are meaningless here, and this is a tag-design problem rather than a reader-power problem.
Laundry, textile, high temperature	★★★☆☆	Repeated industrial washing, detergents, drying at 85–130 °C and mechanical stress destroy ordinary constructions, and read performance degrades progressively with wash cycles.	"How many cycles was the rating actually tested to, and what happens to read range after them?" Buy range headroom rather than a bare pass.
Dense stacking — backroom and pallet	★★☆☆☆	Tags detune each other when packed together, and the anti-collision algorithm has to arbitrate a large population within the Q setting it is given.	"What read rate do you guarantee at pallet density?" A single-tag, in-air figure predicts nothing about a full pallet.
Curved and flexible packaging	★★☆☆☆	Bending the tag changes the antenna geometry; an inlay optimised for a flat surface detunes around a small radius.	"What minimum bend radius is this inlay rated for?" Then test on the real container diameter, not on a sample tube.
Cartons, apparel, general goods	★☆☆☆☆	Paper, cardboard and dry textiles are RF-friendly. The mechanism is not the obstacle; discipline is.	"What is the cost per label at volume, and what is the lead time?" This is a procurement decision, not an engineering one.

2.6 The five-question decision path

The whole chapter compresses into five questions. Each answer eliminates options, and the order matters, because the first question is the one that cannot be engineered around later.

TABLE 7 Decision path: five questions in sequence

QUESTION	CONSEQUENCE
1. What surface does the tag live on?	Metal leads to an on-metal construction, and the encoder's thickness rating must be checked. Liquids lead to placement engineering or an HF strategy. Everything else leads to a standard smart label.
2. Batch read at distance, or tap to verify?	Distance and inventory lead to UHF silicon and UHF encoders. Tap and authentication lead to HF/NFC — a different chip, a different tag and a different encoder. Dual-interface silicon such as EM4423 bridges both on one tag.
3. How many labels a day?	Under 500: a desktop printer-encoder or a commissioning station. 500 to 5,000: mid-class. Above 5,000: industrial class, with the media-thickness range that implies.

QUESTION	CONSEQUENCE
4. Who encodes, and where?	In-house printer-encoder for label rolls; a desktop station for hard tags; or pre-encoded media from your converter, convenient for pilots and urgent SKUs but paid for in lead time and flexibility.
5. What data must live on the tag?	A unique identifier only: 96- to 128-bit EPC silicon is enough, and it usually carries no user bank. Batch, expiry or history on the tag: choose silicon with at least 256 bits of user memory. Cryptographic authentication: choose AES-capable silicon.

> **THE ONE-SENTENCE VERSION**
> Choose the form factor from the surface, the chip from the data and the density, and the encoder from the volume and the form factor — then buy one test roll, run a hundred-label encode-and-verify trial, and only then scale.

2.7 Why two rolls of the same inlay can behave differently

Sooner or later a project buys the same inlay part number twice and gets two different results: the first roll encodes at a comfortable distance, the second needs the power turned up, or throws more VOIDs in one section. Buyers usually read this as a defective batch, a counterfeit part, or a printer fault. It is more often the ordinary spread of a three-stage manufacturing chain, and knowing which stage moves tells you who to ask and what evidence to request.

Stage 1 — Bonding sets the electrical joint

The die is held to the antenna by a conductive adhesive that has to be cured under heat and pressure, and that cure takes seconds per unit — which is why bonding, not printing, is the throughput bottleneck of the whole industry, and why bonders are built with several heads working in parallel. The quality of that joint is invisible: there is nothing to see on the finished inlay. It surfaces as **sensitivity spread** across a roll — most units at the designed figure, a tail of units a dB or two worse. That tail is what your encoder meets on a bad day.

Stage 2 — Yield culling is a control, not a scandal

Every high-volume line produces some proportion of units that fail end-of-line testing; they are removed and replaced, by hand or by machine. A small, stable reject rate is evidence that testing exists. What matters to a buyer is not the presence of culling but its **stability**: a rate that steps up on a delivery is a signal about that delivery, and it is only visible to you if VOID rate per roll is logged.

Stage 3 — Converting decides what your printer actually handles

Converting capacity in the industry generally runs ahead of bonding capacity, which makes converting the most competitive and most fragmented step: many suppliers, thin margins, wide variation in equipment and process control. Two converters can laminate the same inlay and deliver two different products at the point of use, because facestock, adhesive, die-cut tolerance, liner and — above all — the placement geometry (the a, x and y dimensions of §2.4) are all set here. The chip was never the variable; the conversion was.

WHAT A CERTIFICATE DOES AND DOES NOT COVER

Third-party inlay programmes in the retail supply chain — the ARC programme run by Auburn University's RFID Lab is the best known — certify two things: that a specific inlay *model* meets defined sensitivity and read-range requirements, and that the *inlay manufacturer's* quality system can reproduce that performance at volume. Both concern the inlay and its maker. Neither extends to the converted label or to the converter. A certificate on the inlay therefore does not transfer to the roll you receive, and for constructions that fall outside those programmes altogether — on-metal and other specialty media — there may be no certificate to ask for at all. In that case the converter's placement guideline and your own acceptance test *are* the quality system.

The four things to ask for instead

- A **placement guideline** for the media, giving the inlay centre, position and pitch with tolerances — the same document the printer's calibration relies on. (§2.4)
- A **batch record** per delivery: inlay lot, converter and conversion date. Without it, a variance cannot be traced to anything.
- A **sample encode-and-verify run per batch**, not once at qualification. Ten labels from the middle of the roll will find what a visual inspection never will.
- **Re-qualification when the converter changes.** A change of converting site is a change of product, however identical the inlay part number.

PART THREE · MISCONCEPTIONS, IN FOUR LEVELS

3. Buying myths

Four beliefs that produce the most expensive wrong purchases. Each entry follows the same structure: the belief as a buyer states it, the mechanism that contradicts it, and what to do instead.

3.1 "It is just a printer. Any thermal printer can handle RFID labels."

> *"We already own label printers. We will load RFID media and switch the software into encode mode."*

WHAT BUYERS BELIEVE

Encoding is a software feature. Buy the media, install a driver, done.

WHY THE PHYSICS DISAGREES

A standard thermal printer contains no RF front end: no reader module, no encoding antenna, no Gen2 protocol stack. It will overprint a smart label indefinitely while the chip inside stays silent and blank. Writing requires the machine to power the chip, issue Gen2 write commands, and then read the data back and compare it before the visual layer is printed. That write–verify loop is radio engineering, and it lives in a hardware subsystem the print engine has no part in.

HOW TO DO IT RIGHT

- Buy a printer-**encoder** class device, and read the frequency band and the supported chip families out of the datasheet rather than the brochure.
- Require write-then-verify operation with automatic marking of failed labels.
- Test with your actual inlay before committing to media volume. Encoder and inlay are a matched pair, and the match is not guaranteed by either part alone.

REF Finkenzeller, *RFID Handbook*, 3rd ed. — reader architecture; ISO/IEC 18000-63 command set.

3.2 "One RFID printer covers UHF, HF and NFC."

> *"RFID is RFID. We will pick the tag type later."*

WHAT BUYERS BELIEVE

A printer carrying an RFID logo handles any tag with a chip in it.

WHY THE PHYSICS DISAGREES

UHF at 860–960 MHz and HF/NFC at 13.56 MHz are not two settings on one machine; they are two different physical systems. UHF is **far-field backscatter**: a propagating electromagnetic wave, metres of range, hundreds of tags resolved per second. HF is **near-field inductive coupling**: a magnetic field linking two coils, useful to about a metre, one tag at a time. They require different RF modules, different antenna designs, different modulation and different protocol stacks. No firmware switch converts one into the other.

HOW TO DO IT RIGHT

- Choose the frequency from the application, not the other way round. Bulk inventory and portals point to UHF; tap-to-authenticate and consumer phone interaction point to HF/NFC.
- Then buy the encoder class that matches. Many operations legitimately operate one of each, for different workflows.

REF Finkenzeller, ch. 3–4 (coupling mechanisms); ISO/IEC 18000-63 compared with ISO/IEC 14443 and 15693.

3.3 "I will verify the tags with my phone."

> *"Everyone has a smartphone. Of course it can read the label."*

WHAT BUYERS BELIEVE

A phone is a universal RFID reader, and an app can unlock any tag.

WHY THE PHYSICS DISAGREES

Phones carry a 13.56 MHz NFC radio and nothing else. A UHF tag operating at 860–960 MHz is invisible to that hardware whichever app is installed, because there is no software remedy for a missing antenna and RF front end. UHF verification requires a dedicated handheld reader or a Bluetooth sled.

HOW TO DO IT RIGHT

- Budget a handheld UHF reader for incoming-goods checks and finished-label sampling.
- Use the printer's own verify mode as the first gate and a separate handheld as the independent second gate; a single gate that reports its own work is not verification.
- Phones remain useful for HF/NFC consumer touchpoints. They are not a UHF test instrument.

REF NFC as an ISO/IEC 14443 subset at 13.56 MHz; UHF hardware requirements per ISO/IEC 18000-63.

3.4 "The datasheet says ten metres, so I get ten metres."

> *"The vendor promised eight metres. We are getting three. The hardware must be defective."*

WHAT BUYERS BELIEVE

Read range is a fixed property of a tag, like its weight.

WHY THE PHYSICS DISAGREES

Datasheet ranges are measured under benign conditions: correct orientation, no metal, tuned antenna, often in an anechoic chamber. A warehouse adds metal racking, lift trucks, liquids and people, producing **multipath** — reflected waves that alternately reinforce and cancel, so that a tag readable at three metres can disappear at four and return at five. Reflection nulls can reach −30 dB. And because of the fourth-root relationship in §1.2, no legal increase in power buys back metres lost to physics.

HOW TO DO IT RIGHT

- Treat a datasheet range as a ceiling rather than a specification, and run a site pilot with your own products, packaging and racking.
- Design read zones from measured results, recording position *and* orientation rather than a single best-case number.
- Ask any supplier for the test conditions behind a quoted figure. A serious supplier will tell you them; a brochure will not.

REF Friis transmission equation and multipath fading — standard antenna-theory treatment (Balanis); RAIN Alliance deployment guidance.

4. Operating myths

Where most support tickets originate. Every item in this section is a case of a machine behaving correctly being read as a machine behaving badly.

4.1 "Turn the RF power to maximum and everything encodes."

> *"If some labels fail, more power must be the answer. Set it to maximum."*

WHAT BUYERS BELIEVE

Encoding failures mean the field is too weak, and power is a volume knob for success.

WHY THE PHYSICS DISAGREES

An encoder is designed to illuminate **exactly one inlay** at the programming position. Excess power radiates beyond it, and the classic failure is **crosstalk**: the same EPC is written into the neighbouring labels still on the roll, where it is discovered much later as duplicate serials in the field. Over-power also provokes multiple-tag errors, and per §1.2 it barely touches the real bottleneck, which is the weak return link.

HOW TO DO IT RIGHT

- Run RFID calibration for each inlay, and set read and write power just above the reliable threshold.
- Keep verify-on-write enabled so that a mis-write is caught at the printer rather than in the warehouse.
- Guarantee that only one label sits over the antenna at a time. That is what the pitch dimension exists for.

REF Gen2 write and lock command behaviour, ISO/IEC 18000-63; encoder crosstalk documented across printer-encoder support literature.

4.2 "A VOID label means my printer is broken."

> *"Five VOIDs in this roll. Service the machine before we lose another shift."*

WHAT BUYERS BELIEVE

Every failed label is a machine fault. A perfect printer prints perfect labels.

WHY THE PHYSICS DISAGREES

Some chips arrive dead or marginal, and some antennas are damaged during converting, storage or handling. A VOID is the **safety net working exactly as designed**: the encoder attempted the write, verified it, found a mismatch, and refused to release an unencoded label into your supply chain. A well-set printer on certified media typically runs below one per cent; a low single-digit rate on ordinary media is a media-quality signal, not a fault. What matters is the pattern. Isolated failures scattered through a roll are normal. Failures clustered at the same roll position, or a rate that steps up after a media change, point to a systematic cause.

HOW TO DO IT RIGHT

- Enable automatic re-try so that a transient failure is re-attempted before the label is marked VOID.
- Escalate on patterns rather than on singles: a rate above a few per cent, failures at a repeatable position, or clustering after a media change.
- Log VOID rate per roll. It is a media-quality metric as much as a printer metric, and it is your evidence when you talk to a converter.

REF Inlay yield and VOID handling in printer-encoder vendor support literature; verify-read loop per Gen2.

4.3 "Calibrate once and the printer is set for life."

> *"It was calibrated at installation. It is calibrated. Move on."*

WHAT BUYERS BELIEVE

Calibration is a commissioning step with an end date.

WHY THE PHYSICS DISAGREES

Calibration binds together media pitch and length, inlay position, antenna position and RF power, all against a **specific inlay profile**. Change to a different inlay — a new chip family, a different antenna geometry, a different pitch — and the encode point shifts without any visible symptom, because the label still prints. Move the printer to another country and the regulatory region may no longer match, the "region mask" problem that surfaces as intermittent tag-not-found in production. Firmware updates can reset RF defaults. None of this is visible from outside the machine.

HOW TO DO IT RIGHT

- Make it standard practice: on every roll change, run media and RFID calibration, then print the built-in test label and confirm both the encode and the verify result.
- After any site move or firmware update, re-check region and inlay profile before returning to production.
- Hold driver and printer RFID settings under an administrative profile so that operators cannot drift them, and version-control label templates as you would code.

REF Region-specific channel plans: ETSI EN 302 208 (EU), FCC Part 15.247 (US); the inlay-profile concept in printer-encoder documentation.

4.4 "It printed, so it is encoded."

> *"The label looks perfect — barcode, text, everything. Ship it."*

WHAT BUYERS BELIEVE

Visual output is proof of data integrity.

WHY THE PHYSICS DISAGREES

Printing and encoding are independent layers. A label template can omit the RFID write command entirely, and the printer will faithfully produce beautiful labels with blank chips. A dead chip looks exactly like a working one, and the verify loop proves nothing to the human eye: only an RF read-back does. Sampling the first and last label of a roll misses the middle, which is precisely where tension and inlay-batch problems concentrate.

HOW TO DO IT RIGHT

- Enable verification mode and require the verify result in the job log, so that "encoded" is a logged fact rather than an assumption.
- Sample-read each batch with a handheld reader, including labels taken from the middle of the roll.
- Treat "prints but does not encode" as a template or driver problem first: check the encode flag and the EPC format before blaming hardware.

REF Gen2 read-verify flow; template-override failure patterns documented in printer support case literature.

5. Placement and environment myths

The tag is an antenna. Its surroundings are part of its circuit, and the two most common materials in industry are the two that matter most.

5.1 "RFID reads through anything. That is the whole point."

> *"It is radio. It goes through boxes, walls, whatever."*

WHAT BUYERS BELIEVE

UHF penetrates, and materials do not matter.

WHY THE PHYSICS DISAGREES

UHF propagates as an electromagnetic wave, and two materials dominate field failures. **Metal reflects.** Near a conductive surface the incident and reflected waves interfere, and at 180° of phase difference the field cancels into a null that can reach −30 dB; contact with metal also detunes the tag antenna, shifting its resonance out of the operating band. **Water absorbs.** At 860–960 MHz water has high dielectric loss and converts field energy into heat; attenuation through 10 cm of water is in the order of 15–25 dB, and a soaked carton can be worse. Liquid-filled goods are the hardest tagging category in the industry for exactly this reason.

HOW TO DO IT RIGHT

- Tag the outside of packaging, and keep labels away from metal ribs, hinges, frames and liquid surfaces.
- Place labels on top of shrink wrap, never underneath it, and keep strapping from crossing the label.
- Match the tag class to the material: on-metal inlays for metal, liquid-tolerant inlays and tested placement for fluids. This is a tag-selection decision before it is ever a reader decision.

REF Finkenzeller ch. 4 (propagation); antenna detuning literature; RAIN Alliance material guidance.

5.2 "I bought anti-metal tags, so I will use them on everything."

> *"Anti-metal is the premium product. On plastic it must be even better."*

WHAT BUYERS BELIEVE

On-metal inlays are a strictly better tag.

WHY THE PHYSICS DISAGREES

An on-metal inlay carries a spacer or ferrite layer engineered around one assumption: a conductive surface directly behind the antenna, acting as a ground plane. Put that inlay on plastic or cardboard and the assumption fails, so it frequently reads *shorter* than an ordinary inlay on the same surface. It is a matched component, not a superior one. The same logic applies in reverse to a standard inlay on metal, where the surface detunes the antenna and can reduce range to a fraction of its free-air value.

HOW TO DO IT RIGHT

- Match tag class to substrate: standard inlays for cardboard and plastic, on-metal for metal, liquid-rated for fluids.
- If one label must serve mixed materials, validate it on *every* one of them, or split the SKUs by material.
- Validate on production-representative surfaces and after the adhesive has settled, not on a desk in free air.

REF On-metal tag design (spacer and ground-plane principle); antenna-engineering literature on detuning.

5.3 "Orientation does not matter. Radio goes everywhere."

> *"We placed the labels whichever way the operators found convenient. It should be fine."*

WHAT BUYERS BELIEVE

Read zones are spheres, and the tag merely has to be inside one.

WHY THE PHYSICS DISAGREES

A passive UHF tag is a dipole antenna. Against a **linearly polarised** reader antenna, a tag rotated 90° out of the polarisation plane can lose 10 dB or more, which is most of its signal. Multipath adds spatial nulls on top of that, so the same physical location can read at eight metres from one angle and fail from another. "It reads somewhere in this zone" and "it reads reliably everywhere in this zone" are different engineering targets, and only the second one survives an audit.

HOW TO DO IT RIGHT

- For random-orientation flows such as portals and tote lines, specify circularly polarised antennas and accept the 3 dB split that costs across polarisation planes.
- For controlled flows, orient labels to the antenna plane and recover the range you would otherwise lose.
- Commission with a spatial heat map rather than a single best-distance figure, and revisit it after any change to racking or layout.

REF Polarisation mismatch and multipath nulls — standard antenna-theory treatment; field method per RAIN Alliance deployment guidance.

5.4 "Reads keep failing. Replace the reader and add power."

> *"Three reader swaps and the problem is still here. RFID is unreliable."*

WHAT BUYERS BELIEVE

Hardware is the only variable worth replacing.

WHY THE PHYSICS DISAGREES

The return link is dominated by the tag antenna, its environment, and everything between the reader and that antenna. A ten-metre run of thin coaxial cable can lose 5–9 dB, which roughly halves the range before the "failing" reader has transmitted anything at all. Field engineers routinely diagnose defective readers that turn out to be healthy units on lossy cable or mis-aimed antennas. Meanwhile, per §1.2, extra transmit power is the weakest lever available.

HOW TO DO IT RIGHT

- Debug in layers, in this order: placement and material, then antenna aim and isolation, then cable and connectors, then power. Power comes last.
- Compare one tag in one direction, indoors and on site, to separate the environment from the hardware.
- Keep radiated power inside regulatory limits, and remember that +3 dB is not double the range.

REF Friis link budget including cable loss; integrator field reports on antenna and cable attenuation.

6. Data and security myths

Where encoding meets the Gen2 memory architecture, and where silent data errors are born. These failures are the most expensive kind, because the label looks right and the data is wrong.

6.1 "TID, EPC — same thing. The serial is just text I type."

> *"Just write our part number on the tag. Hexadecimal? ASCII? Does it matter?"*

WHAT BUYERS BELIEVE

The chip is a black box with one writable string in it.

WHY THE PHYSICS DISAGREES

Gen2 defines four separate memory banks: **Reserved** (kill and access passwords), **EPC** (the writable identity used in inventory), **TID** (factory-fused and read-only, unique per chip) and an optional **User** bank. The EPC must be valid hexadecimal — the digits 0–9 and the letters A–F only — and it must match the declared bit length, for example 96 bits for an SGTIN-96. A wrong format aborts the job; a wrong length leaves the software and the printer disagreeing about what was written, which is worse, because the job completes.

HOW TO DO IT RIGHT

- Learn the four banks, because they map directly onto use cases: TID for chip-level authentication, EPC for identity, User for application data.
- Derive EPC values according to the GS1 EPC Tag Data Standard rather than typing serials by hand.
- Appoint one owner for the encoding template, and validate formats before the job reaches the printer.

REF Gen2 memory-bank architecture, ISO/IEC 18000-63; GS1 EPC Tag Data Standard.

6.2 "I can rewrite any tag whenever I want."

> *"It is RFID. Of course we can just overwrite the old data."*

WHAT BUYERS BELIEVE

All tag memory is freely rewritable, indefinitely.

WHY THE PHYSICS DISAGREES

Writable does not mean unprotected. Tag memory is EEPROM, typically rated for around 100,000 write cycles with data retention measured in decades, so endurance is rarely the practical limit. Protection is. The **lock** command can make a bank permanently read-only and the **kill** command can silence a tag for good, and locked or pre-encoded incoming media — common from tag converters — fails writes in a way that looks exactly like defective media. The real cause is usually an access password you were never given.

HOW TO DO IT RIGHT

- Ask suppliers whether incoming media is pre-encoded or locked, and obtain the access passwords if it is.
- Register lock and kill operations in your asset system. A killed tag is electronic waste, not a blank.
- Differentiate deliberately: lock what must never change, such as identity, and leave workflow data writable.

REF Gen2 Lock, Kill and Access commands, ISO/IEC 18000-63; EEPROM endurance and retention characteristics of tag ICs.

6.3 "My label software and the printer always agree."

> *"The printer settings are correct and the software sends the job. What could go wrong?"*

WHAT BUYERS BELIEVE

Settings flow one way: whatever the printer panel says, applies.

WHY THE PHYSICS DISAGREES

Label designers and drivers can **override printer-level RFID settings per job**: EPC length, verification mode, memory bank, even power. The signature symptom is unmistakable once you know it — the printer's own test label encodes perfectly, while only *certain* templates fail in production. That is a template-level override, not a hardware fault, and replacing hardware will not touch it.

HOW TO DO IT RIGHT

- Maintain a known-good baseline template. When failures appear, run it first to separate a format problem from a hardware problem.
- Lock driver RFID settings under an administrative profile, and version-control templates.
- After any software update, re-run the baseline test before releasing the line back to operators.

REF Driver and middle-layer override patterns in printer-encoder support case literature; Gen2 job-level parameters.

PART FOUR · IN THE FIELD

7. Field reference

The preceding chapters explain why. This one is meant to be printed, pinned next to the machine and used. It condenses the fifteen misconceptions into seven rules and eight symptom patterns.

7.1 Seven standard operating rules

1. **Calibrate on every roll change.** Run media calibration, then RFID calibration, then print the built-in test label and confirm the verify result. A new inlay batch is a new profile. See §4.3.
2. **Verify, always — and verify independently.** Leave verify-on-write enabled at the printer, and sample-read each batch with a handheld reader, including labels from the middle of the roll. See §4.4.
3. **Respect normal VOID rates, and act on patterns.** A scattered fraction of a per cent is media yield. Escalate on clusters, on repeatable positions, or on a rate that steps up after a media change. See §4.2.
4. **Set power to the threshold, not to the maximum.** Over-power causes crosstalk and duplicate EPCs that only surface months later. See §4.1.
5. **Match the tag class to the surface.** Metal takes on-metal, liquids take liquid-rated and tested placement, everything else takes a standard smart label. Validate on real production surfaces. See §5.1 and §5.2.
6. **Any change of site, firmware or template triggers a re-test.** Region, inlay profile and template overrides are invisible failure sources that survive every visual inspection. See §4.3 and §6.3.
7. **Write the acceptance criterion as a repetition, not as 100 %.** A passive system cannot guarantee a single-pass read of every tag in a population: air interface, orientation, material and density all act on the result, and every practitioner who promises 100 % is quoting a laboratory figure. Specify instead "N consecutive clean read cycles of the full population, plus a defined sample of the order read label by label" — a criterion that can be measured, disputed and met. See §3.3 and §5.2.

7.2 Troubleshooting matrix

Work down the table by symptom. The right-hand column gives the first move, not the only move; if the first move clears nothing, the "most likely layer" column tells you what to question next.

TABLE 8 Symptom, likely layer and first response

SYMPTOM	MOST LIKELY LAYER	FIRST MOVE
Prints perfectly, chip reads blank	Template or driver — encode flag, or EPC format	Run the baseline template; check the encode flag and the EPC bit length
"Tag not found" during encoding	Calibration, region, or inlay position	Run RFID calibration; confirm the regulatory region matches the site
Duplicate EPCs on different labels	Encoder over-power — crosstalk	Reduce write power one step, re-test, and audit the affected batch
VOIDs clustered in one section of a roll	Media — inlay batch or transport damage	Quarantine the section, log VOID rate per roll, notify the converter
Reads in air, dies on the product	Material detuning or absorption	Match tag class to surface, move the label, re-validate placement

SYMPTOM	MOST LIKELY LAYER	FIRST MOVE
Same zone reads well today, poorly tomorrow	Multipath, antenna aim, or a change in the environment	Heat-map the zone; check antenna aim, cable condition and any new racking
Works at head office, fails at an overseas plant	Regulatory region mismatch	Set the correct region plan before any other debugging
Only some label formats fail	Template-level RFID overrides	Compare the failing template against the baseline, setting by setting

APPENDIX

Appendix A. Pre-purchase checklist

Work through this before releasing a purchase order for RFID media or an encoder. Each line exists because the corresponding mistake appears repeatedly in the field; the cross-reference tells you where the reasoning is set out.

Media and conversion

- ☐ Is the media supplied as **converted label rolls**, not dry inlays? (§2.1)
- ☐ Is the inlay pitch at or above the printer's published minimum — commonly 16 mm? (§2.4)
- ☐ Are the a, x and y dimensions documented by the converter, with tolerances? (§2.4)
- ☐ Does the media thickness sit inside the printer's rating, with margin for on-metal constructions? (§2.4)
- ☐ Have you confirmed whether incoming media is pre-encoded or locked, and obtained access passwords if so? (§6.2)
- ☐ Is there a written placement guideline with tolerances, and a batch record per delivery naming the inlay lot and the converter? (§2.7)
- ☐ If the media relies on a third-party inlay programme, do you know what it certifies — and what it does not? (§2.7)

Chip and data

- ☐ Does the chip carry the user memory your application needs, or will that data live in the back-end? (§2.2)
- ☐ Is the chip family on the encoder's supported list, at your current firmware version? (§2.2, §2.4)
- ☐ Is the EPC format derived from a standard rather than typed by hand? (§6.1)
- ☐ Is there a documented procedure for reading a sample TID on receipt to confirm the chip you ordered? (§2.2)

Encoder and throughput

- ☐ Does the chosen encoder class match the daily label volume, with headroom? (§2.3, §2.6)
- ☐ Is write-then-verify with automatic failure marking a required feature of the specification? (§3.1)
- ☐ Is the region and channel plan correct for the country of installation, not the country of purchase? (§1.3, §4.3)
- ☐ Will VOID rate per roll be logged, and who receives that log? (§4.2)

Application validation

- ☐ Has the application been placed on the difficulty ladder, and its rating accepted by the project sponsor? (§2.5)
- ☐ Has one test roll been run through a 100-label encode-and-verify trial before the bulk order? (§2.6)
- ☐ Have reads been validated on the *filled*, *stacked* and production-representative product, not in free air? (§2.5, §5.1)
- ☐ Is a handheld UHF reader budgeted as an independent verification gate? (§3.3)
- ☐ Has a commissioning heat map been specified for any fixed read zone? (§5.3, §5.4)

- ☐ Is the acceptance criterion written as a repetition — N consecutive clean read cycles plus a defined label-by-label sample — rather than as 100 %? (§7.1)

References

Technical claims in this guide trace to the following sources. Where a figure is drawn from operational rather than academic literature, that is stated.

Standards and specifications

1. ISO/IEC 18000-63 — *Information technology — Radio frequency identification for item management — Part 63: Parameters for air interface communications at 860 MHz to 960 MHz*. The standardised form of EPCglobal Class-1 Generation-2. Memory banks, Q algorithm, Lock/Kill/Access commands, modulation and encoding.
2. GS1, *EPC Tag Data Standard* — EPC formats and encoding rules, including the SGTIN-96 structure referred to in §6.1.
3. ETSI EN 302 208 — European UHF RFID allocation, 865–868 MHz, including listen-before-talk requirements.
4. FCC Part 15.247 — United States allocation, 902–928 MHz, frequency-hopping spread spectrum.
5. ISO/IEC 14443 and ISO/IEC 15693 — the near-field 13.56 MHz families to which NFC belongs, referenced in §3.2 and §3.3.
6. Ministry of Industry and Information Technology of the People's Republic of China, *Provisions on Radio Management of Radio Frequency Identification (RFID) Equipment in the 900 MHz Band*, MIIT No. 76 [2024], issued 22 April 2024, in force 1 November 2024. Retains 920–925 MHz as the working frequency; no further type-approval applications for 840–845 MHz equipment; RFID equipment managed with reference to terrestrial public mobile terminals (type approval required, no radio station licence); 33 m protection distance from railway track centre lines. The basis of Table 1 and §1.3.

Engineering literature

8. K. Finkenzeller, *RFID Handbook: Fundamentals and Applications in Contactless Smart Cards, Radio Frequency Identification and Near-Field Communication*, 3rd ed., Wiley, 2010. Coupling mechanisms, propagation, reader architecture. The reference for §1.1 and §3.2.
9. C. A. Balanis, *Antenna Theory: Analysis and Design* — antenna theory, field regions, polarisation and the Friis transmission equation, applied in §1.2, §3.4 and §5.3.

Component data and vendor documentation

10. UHF tag IC datasheets and consolidated chip comparison tables from Impinj (M700 and M800 series), NXP (UCODE family), Alien Technology (Higgs family), EM Microelectronic, Fudan Microelectronics and Quanray (Qstar). The source of the memory sizes, sensitivity figures and TID prefixes in Table 3 and §2.2. Values are representative; the current vendor datasheet governs.
11. Printer-encoder manufacturers' media and inlay placement guidelines — the definitions of inlay centre (a), inlay position (x) and minimum inlay pitch (y), their typical ±3 mm tolerances, the 16 mm minimum pitch figure, per-region power and placement tables, media thickness ranges, the profiling procedure, and the rule that media converted to a published guideline does not require RFID calibration. The basis of §2.4, Figure 2 and Table 5.
12. On-metal printer-encoder and media specifications — the approximately 1.5 mm maximum media thickness for flexible on-metal labels quoted in §2.4 and Table 6, and the observation that print quality

degrades immediately around the chip location, which is why printed artwork should be designed around the inlay rather than over it.

13. Printer-encoder vendor support knowledge bases and integrator field reports — operational failure patterns: crosstalk from excessive write power, region-mask failures, VOID handling, template-level overrides, and the effect of media storage temperature and electrostatic discharge on label quality.
14. Inlay manufacturing and converting process documentation from inlay and label manufacturers — the antenna-bonding-converting sequence, flip-chip and COB bonding routes, adhesive curing as the throughput constraint of bonding, end-of-line culling and replacement of rejected units, and the relative capacity of bonding and converting. The basis of the manufacturing chain in §2.1 and the variance mechanisms in §2.7.

Deployment and material guidance

15. RAIN Alliance and ecosystem publications on deployment, material placement and item-level retail practice.
16. Application engineering guides for laundry and textile, liquid-product, and on-metal deployments — wash-cycle ratings, bend-radius limits and density test methodology. The source of the qualitative figures in Table 6.
17. Material attenuation measurements reported by integrators for metal, water and mixed loads at 860–960 MHz, the basis of the order-of-magnitude figures in §2.5, §5.1 and §5.2. Field measurements vary with geometry and product; treat these as ranges, not constants.
18. Third-party inlay performance and quality programmes in the retail supply chain, in particular the ARC programme administered by the Auburn University RFID Lab since 2009 — ARC Specs define the sensitivity and read-range requirements an inlay model must meet for a given deployment scenario, and ARC Quality Certification audits an inlay manufacturer's quality management system through a multi-stage review including site visits. Scope matters: both components address the inlay and its manufacturer, not the converted label or the converter. The basis of the scope note in §2.7.

Document control and legal notice

Document control

ITEM	DETAIL
Document ID	JNX-TG-002
Title	UHF RFID Printer-Encoders — A Buyer's Technical Guide
Edition and date	Third edition (V3.1), 11 September 2026
Owner	JNXRFID product marketing
Review cycle	Reviewed when a cited standard is revised, when chip families in Table 3 change materially, or annually, whichever comes first.
Change record	See the revision history on the About this guide page.
Feedback	Corrections and challenges are welcome and will be reflected in the next edition: support@jnxrfid.com

Notes on accuracy

Figures for chip memory, sensitivity and TID prefixes are representative values compiled from vendor documentation and consolidated comparison tables, and they change as silicon generations are released. The governing document for any specific part is the current vendor datasheet. Regulatory allocations are quoted as commonly applied in the applications discussed and are subject to change; confirm current national requirements before deployment. Read-range and attenuation figures are order-of-magnitude values measured under stated or typical conditions and are not guarantees for any particular site.

Legal notice

About JNXRFID

JNXRFID builds desktop and industrial UHF and HF RFID printer-encoders, and UHF RFID desktop readers. This guide is written to be media-agnostic: it applies to whatever inlay and conversion you buy from your label converter, because the constraints it describes are physical and belong to the system, not to any one supplier's catalogue. We wrote it because we answer these questions every week, and we would rather our customers never need the support ticket.

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