PE1HVH

# From Text to Chirp

## How LoRa Encodes Data

*A step-by-step explanation from bits to radio signal*

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# 1. You Want to Send "Test"

Let’s start with something concrete: you want to send the word "Test" via LoRa. How does that become a radio signal?

## 1.1 Letters Become Bits

Each letter has an ASCII code, and that code is a number that we can write as bits:

| Letter | ASCII | Binary |
|---|---|---|
| T | 84 | 01010100 |
| e | 101 | 01100101 |
| s | 115 | 01110011 |
| t | 116 | 01110100 |

Together, "Test" is 32 bits.

# 2. Bits Become Symbols

Now the Spreading Factor (SF) comes into play. With SF12, we group bits into groups of 12.

## 2.1 Why 12 Bits?

SF12 means: each symbol carries 12 bits of information. Those 12 bits together form a number from 0 to 4095 (because $2^{12} = 4096$ possible values).

## 2.2 Splitting "Test" into Symbols

We take our 32 bits and divide them into groups of 12. The word "Test" thus becomes three symbols: 1350, 1395, and 1860.

# 3. Symbols Become Chirps

Now the crucial step: how does a number (for example, 1350) become a radio signal?

## 3.1 The Frequency Ladder

Imagine the 125 kHz bandwidth as a ladder with 4096 rungs. Each symbol number corresponds to a rung on that ladder:

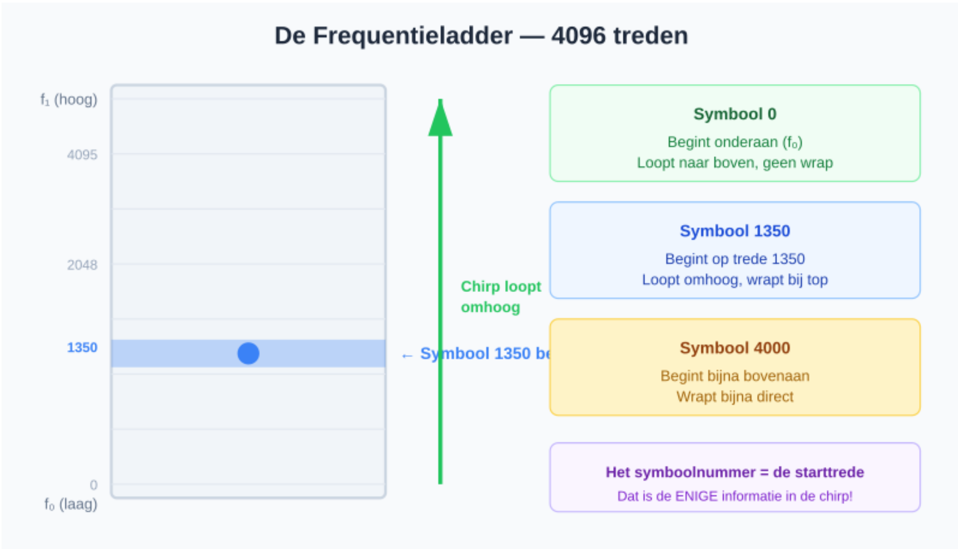


*Figure 1: The frequency ladder — the symbol number determines the starting rung*

## 3.2 The Chirp Climbs the Ladder

A chirp starts at its starting position and then climbs all the rungs, upward. At the top, it wraps to the bottom and continues until it reaches its starting point again. Each chirp always traverses ALL 4096 rungs.

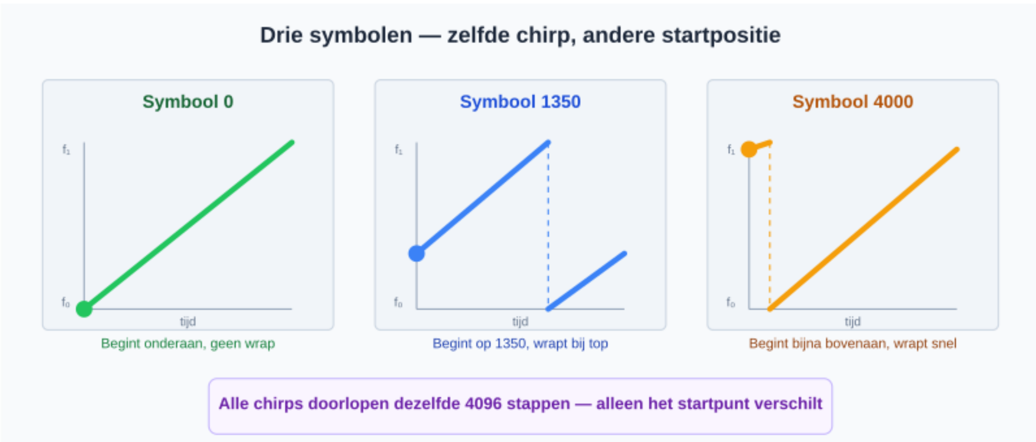


*Figure 2: Three symbols — same chirp shape, different starting position*

# 4. The Complete Chain

Let's combine everything into one overview:


*Figure 3: From "Test" to chirps — the complete encoding chain*

# 5. How Does the Receiver Know Which Symbol It Was?

The receiver performs a clever mathematical trick: it multiplies the received chirp with a locally generated inverted chirp (down-chirp).

Rising frequency × falling frequency = constant tone. The pitch of that tone depends on where the original chirp started!

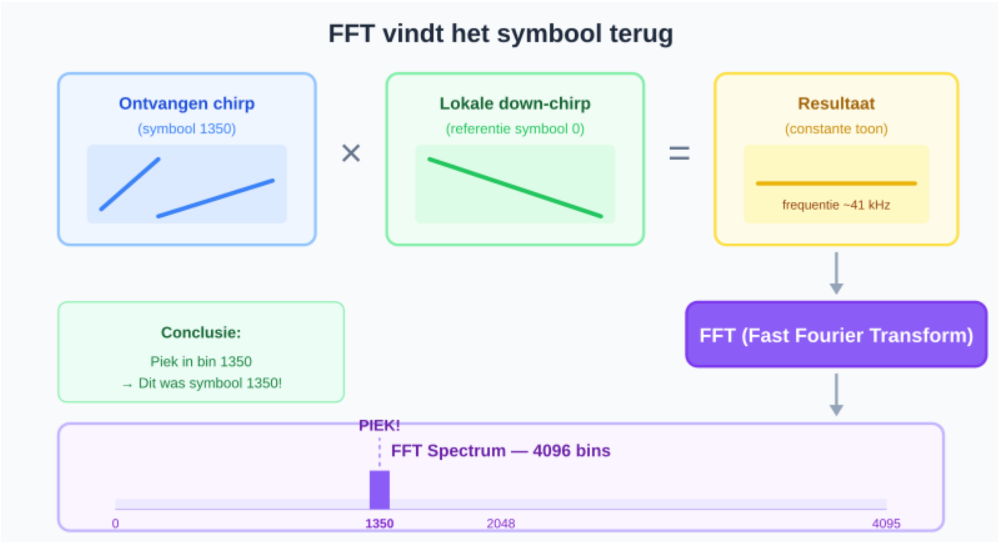


*Figure 4: FFT finds the symbol — the peak position IS the symbol number*

The FFT (Fast Fourier Transform) analyzes the tone and produces a spectrum with 4096 bins. The bin where the peak is located is directly the symbol number.

## 5.1 Why a Constant Tone?

The chirp itself is a sweep (frequency changes continuously), not a constant tone. But something special happens during the multiplication:

| Signal | Character |
|---|---|
| Received chirp | Sweep up (low → high) |
| Local down-chirp | Sweep down (high → low) |
| **Result** | **Constant tone** |

When you multiply a rising frequency with a falling frequency, the changes cancel each other out. The result is a constant tone — and the frequency of that tone depends on the phase difference between the two chirps.

**Mathematically:**

- Received: frequency rises by +X Hz per sample
- Local: frequency falls by -X Hz per sample
- Sum: +X + (-X) = 0 change → constant frequency

The pitch of that constant tone depends on where the received chirp started (the symbol number). Symbol 1350 produces a different constant tone than symbol 1351.

## 5.2 Fault Tolerance: Processing Gain

What if a portion of the chirp is lost due to interference or noise? Suppose: of the 4096 samples, you miss 100 at the beginning.

Because the FFT doesn't measure the chirp itself, but the constant tone that results after the multiplication:

- You still have 3996 samples of the same constant tone
- The FFT analyzes that tone and finds the same peak
- The peak is slightly weaker (less energy), but is at exactly the same position

Het is alsof je een liedje herkent, ook al heb je de eerste seconde gemist. De melodie is hetzelfde, je hebt alleen iets minder "bewijs" gehoord. De positie van de FFT-piek is dus inherent robuust tegen partieel signaalverlies — dit noemen we **Processing Gain**or **Spreading Gain**.

## 5.3 The Role of the Preamble in Synchronization

But how does the receiver actually know where those first 100 samples should have been? This is where the preamble becomes crucial.

**The synchronization process:**

1. **Preamble detection** — The receiver first sees 8 identical symbol-0 chirps
2. **Timing lock** — Through these repeated, identical chirps, the receiver knows exactly when each chirp period starts and ends
3. **Expectation window** — For each subsequent data symbol, the receiver knows: "the chirp runs from sample X to sample X+4096"

The preamble thus functions as a clock signal. Without that synchronization, the receiver wouldn't even know where a chirp begins or ends. With synchronization, it knows exactly which samples belong to which chirp — even if some samples are corrupted.

If the first 100 samples of a chirp are corrupted by noise, the receiver knows through preamble synchronization that those 100 samples should have been there. It simply analyzes the 3996 samples it did receive correctly, and the FFT still finds the same constant tone at the same position. The corrupted samples don't shift the symbol number — they only weaken the peak.

## 6. Why Symbol 0 Is Special

Symbol 0 is the reference — a chirp that starts at the lowest frequency and neatly ends at the highest, without wrap. This symbol is used in the preamble for synchronization.

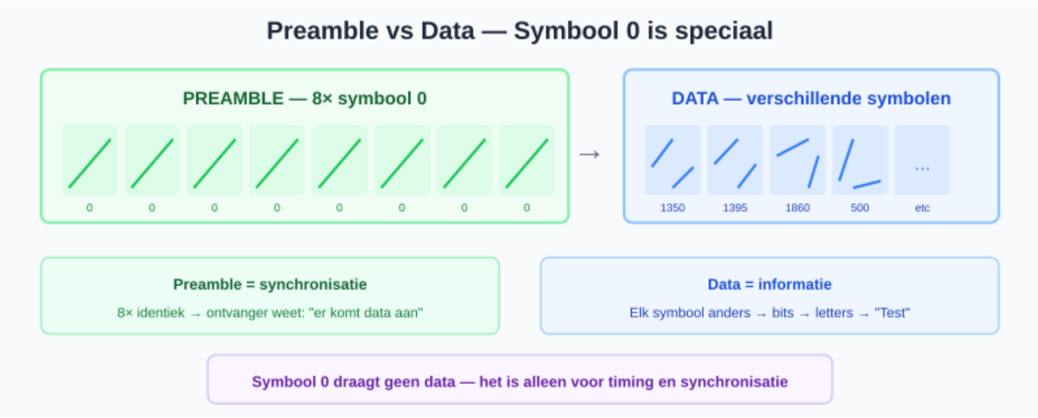


*Figure 5: Preamble (8× symbol 0) vs Data (different symbols)*

The receiver sees 8 identical chirps and knows: "data is coming, I am synchronized." After that come the data symbols, each with a different starting position.

## 7. Summary

The core of LoRa modulation:

- Text becomes bits, bits are grouped into symbols (12 bits with SF12)
- Each symbol is a number from 0-4095
- That number determines where the chirp starts in the frequency sweep
- The receiver finds the symbol via FFT

It doesn't matter if the symbol is 0, 1350, or 4000 — the chirp always traverses all 4096 steps. Only the starting point differs, and that starting point IS the data.

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