



Initiation à la technique LoRa : *Long Range*

UBA LIEGE : ON5VL site Internet <https://on5vl.org>

Exposé présenté par ON4IJ le 15.10.2022

Projet *i-gate* LoRa ON0LG-10 et installation à Seraing



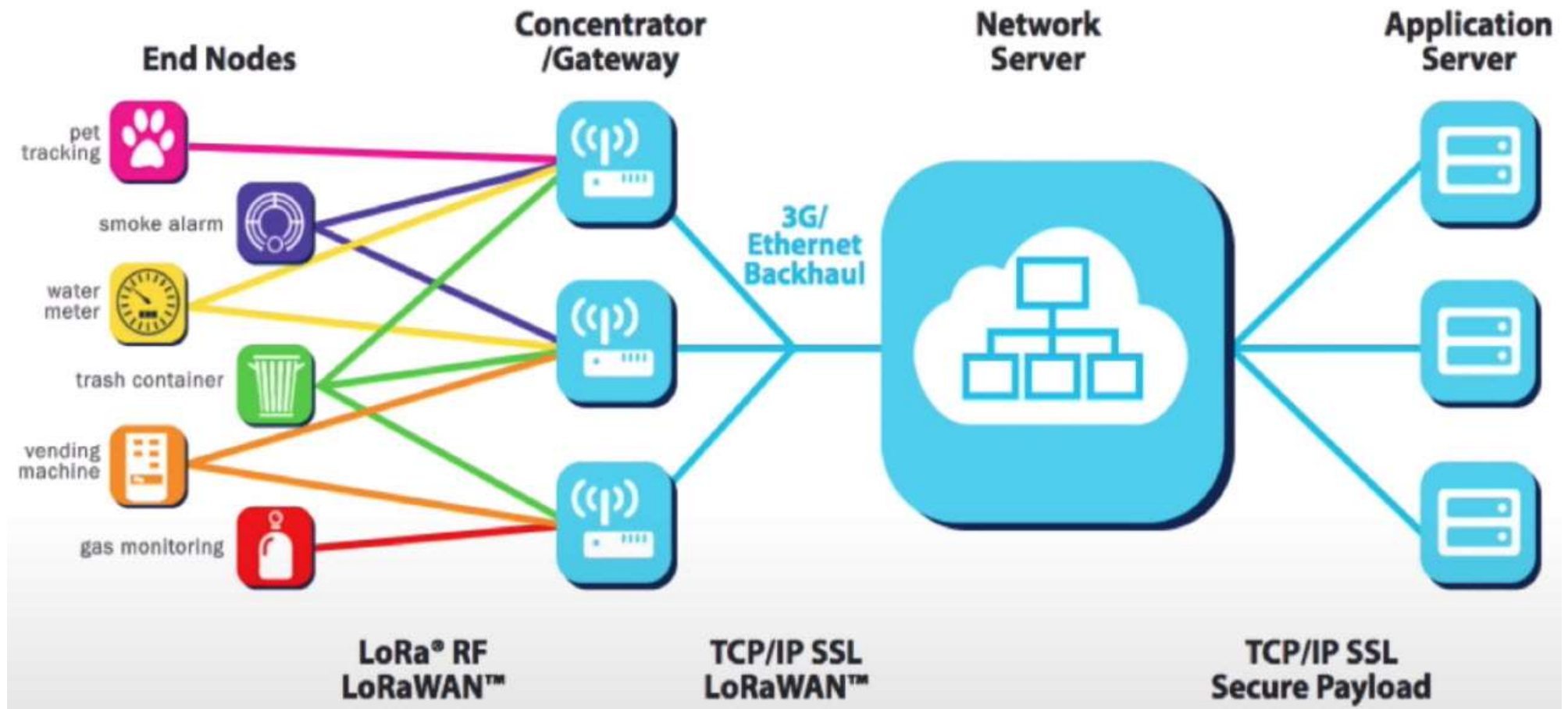
LoRa : qu'est-ce que c'est ?

- Système de communication sans fil, par radiofréquences ;
- Couche physique pour communications à longue distance ;
→ modulation : *Chirp Spread Spectrum* ; modulation à spectre étalé par sauts de glissements de fréquences (balayage en fréquences, rampes de fréquences, « piaulements ») ;
- Bande passante 125 kHz ; (ou 250 kHz ou 500 kHz) ;
- Faible consommation ; alimentation sur pile ;
- Faible puissance TX : +14 dBm (25 mW) ;
- (Bandes ISM) ; appellation SRD *Short Range Devices* ;
- Sans licence : EU 433 MHz ; EU/US 868 MHz ; US 918 MHz ;
- Taux d'utilisation : limitation du temps de présence sur l'air ;
- *Link Budget* (bilan de liaison TX-RX, gains et pertes) : 156 dB² ;

LoRaWAN : qu'est-ce que c'est ?

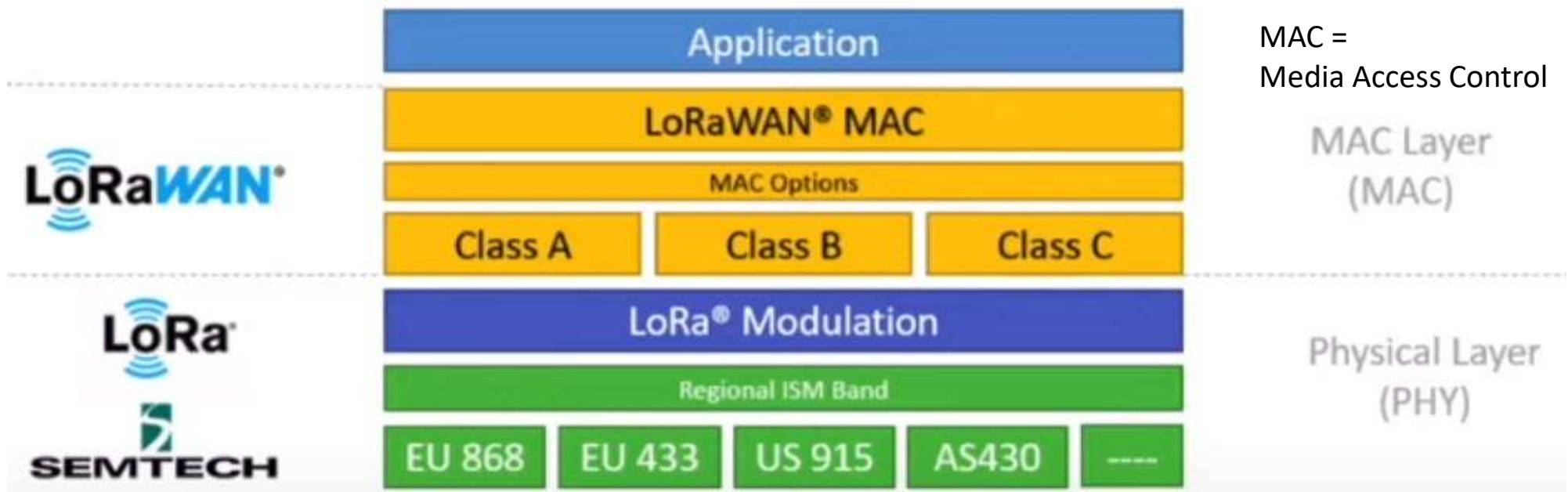
- Protocole de communication et architecture qui utilise la couche physique Lora ; Aloha (Hawaii 1970) ; TCP/IP ;
- Taux de transmission prédéfinis ; faibles *Data Rate* ;
 - → de 300 bps à 5,5 kbps ; APRS LoRa : 250 bps ;
- Liaisons par Internet vers des serveurs de réseaux ;
- Liaisons vers des serveurs d'applications ;
 - Exemple : APRS.fi ;
 - APRS 144,800 AFSK AX25 ≠ APRS LoRa 433,775 Chirp ;
- Permet :
 - Liaisons de communications bidirectionnelles sécurisées ;
 - Mobilité (IoT : *Internet of Things* ; objets connectés) ;
 - Localisation d'objets (APRS) ;

Architecture ou infrastructure LoRa et LoRaWAN



Sources : M. Dassari & S. Das : Wireless and Mobile Networks CSE570 Spring 2020 www3.cs.stoneybrook.edu ; nnnc.com.au ; LoRa Alliance.

Quelle différence entre LoRa et LoRaWAN ?



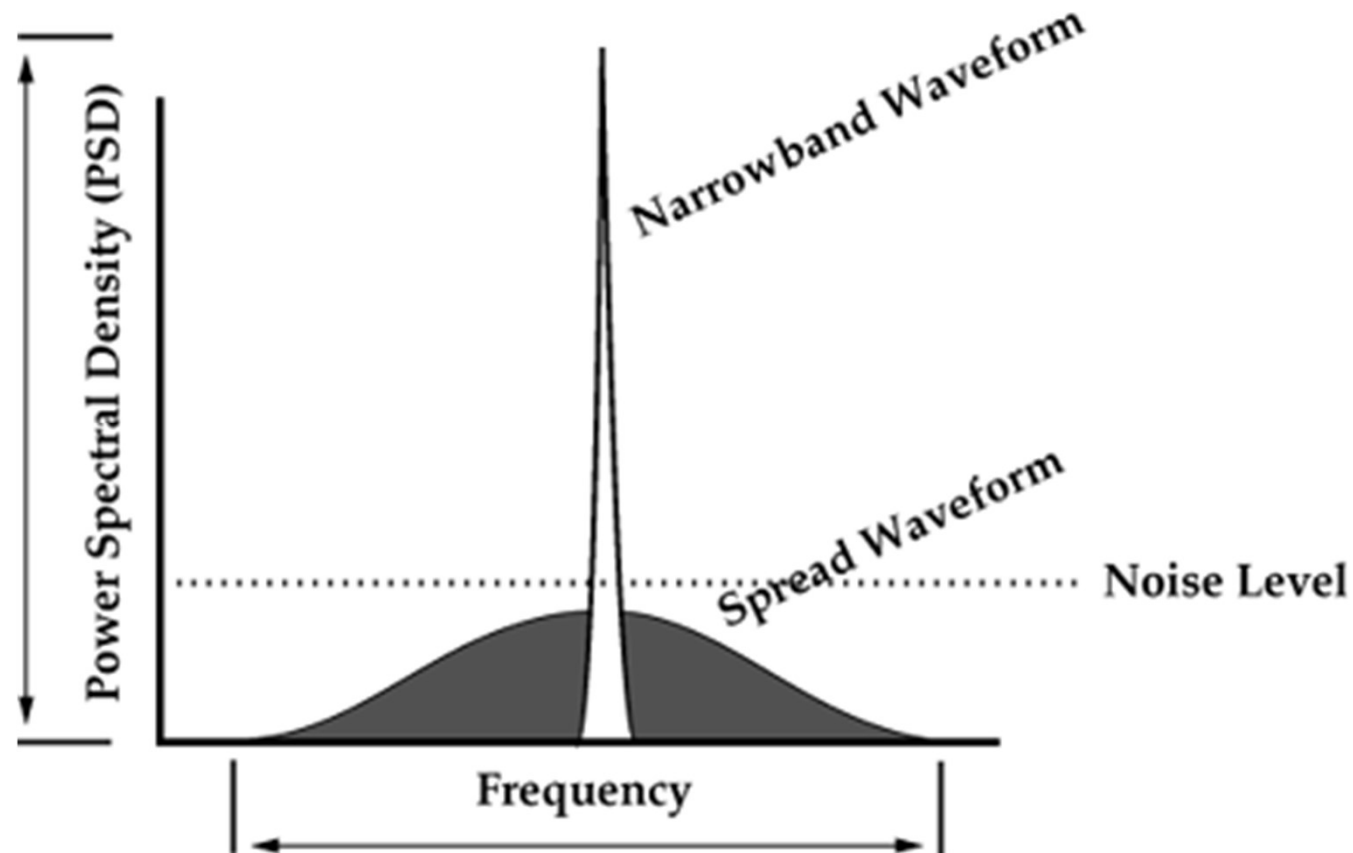
Source : Semtech Technical Paper (lora-developers.semtech.com) ; What are LoRa and LoRaWAN ?

Où se situe LoRa dans le paysage des télécommunications des objets connectés ?



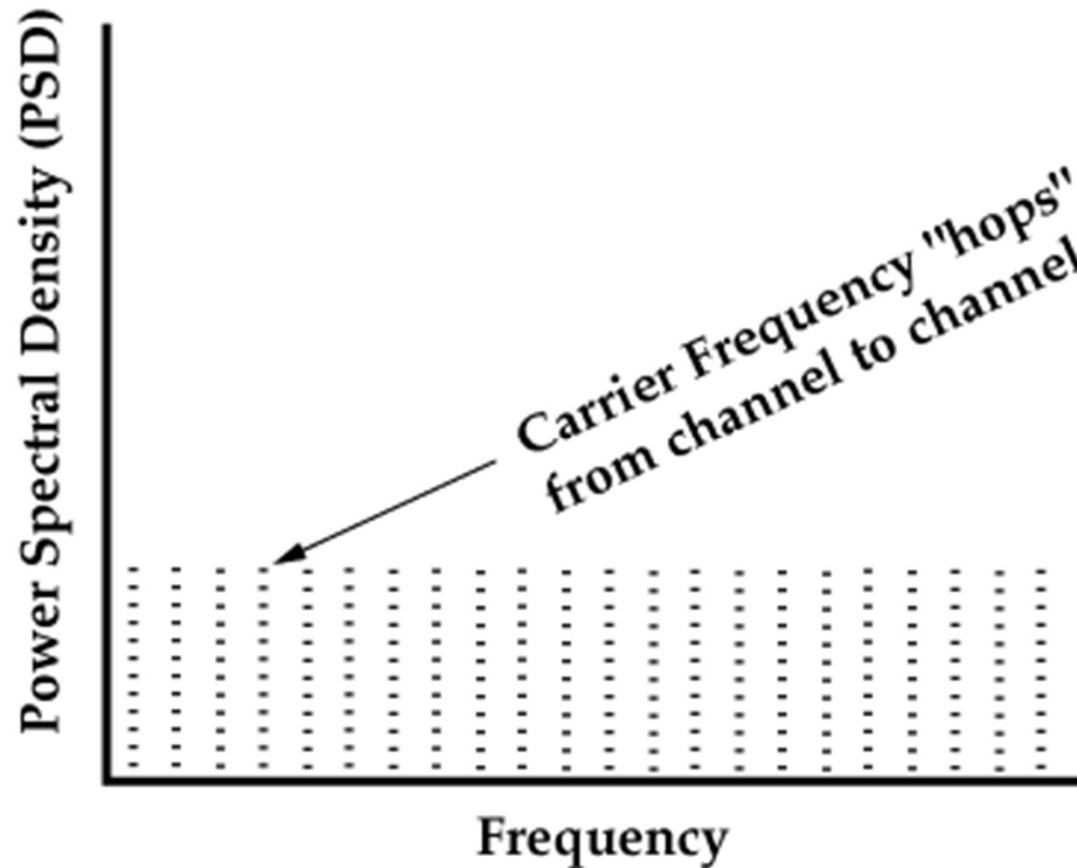
Source : Wireless and Mobile Network Courses ; IoT/Sensor Networks LoRa and LoRaWAN ; www3.cs.stonybrook.edu.

Direct Sequence Spread Spectrum : Modulation à spectre étalé à séquence directe



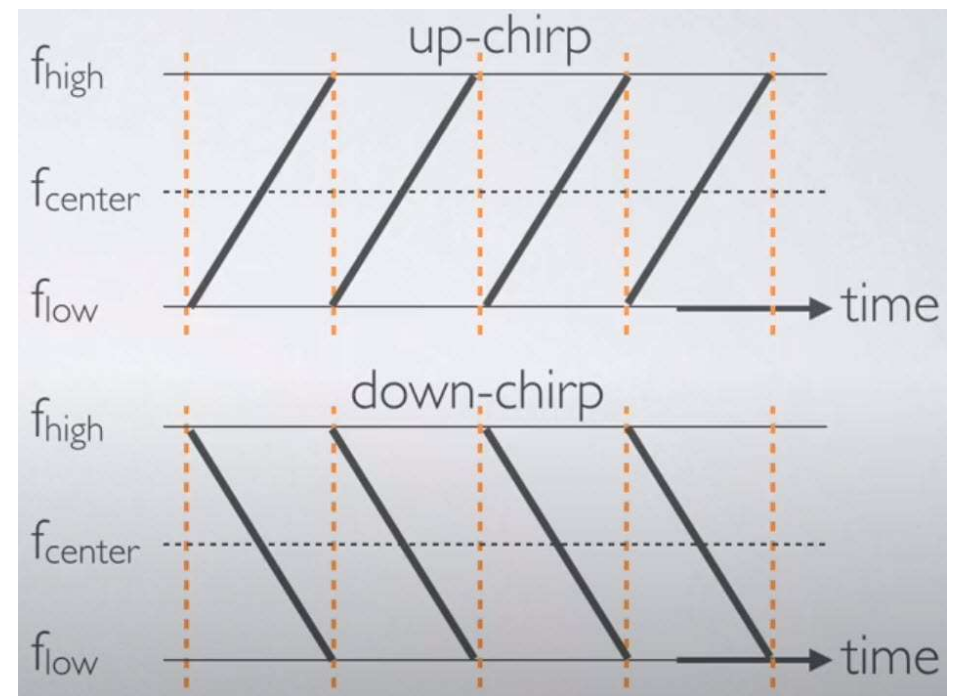
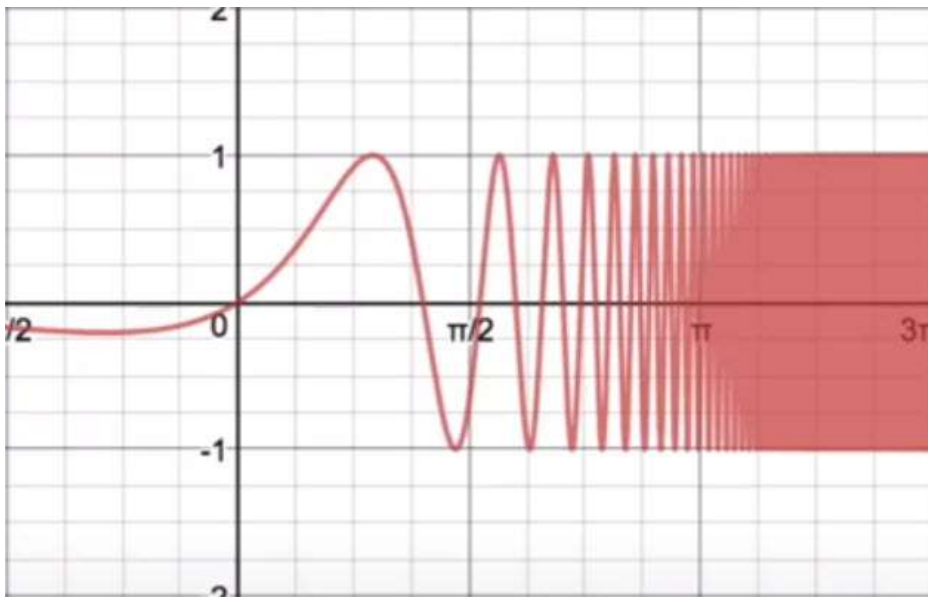
Source : Steve Bible N7HPR QSL,net ; Harold E. Price NK6K QEX 1995.

Frequency hopping Spread Spectrum :
Modulation à spectre étalé à sauts de fréquences



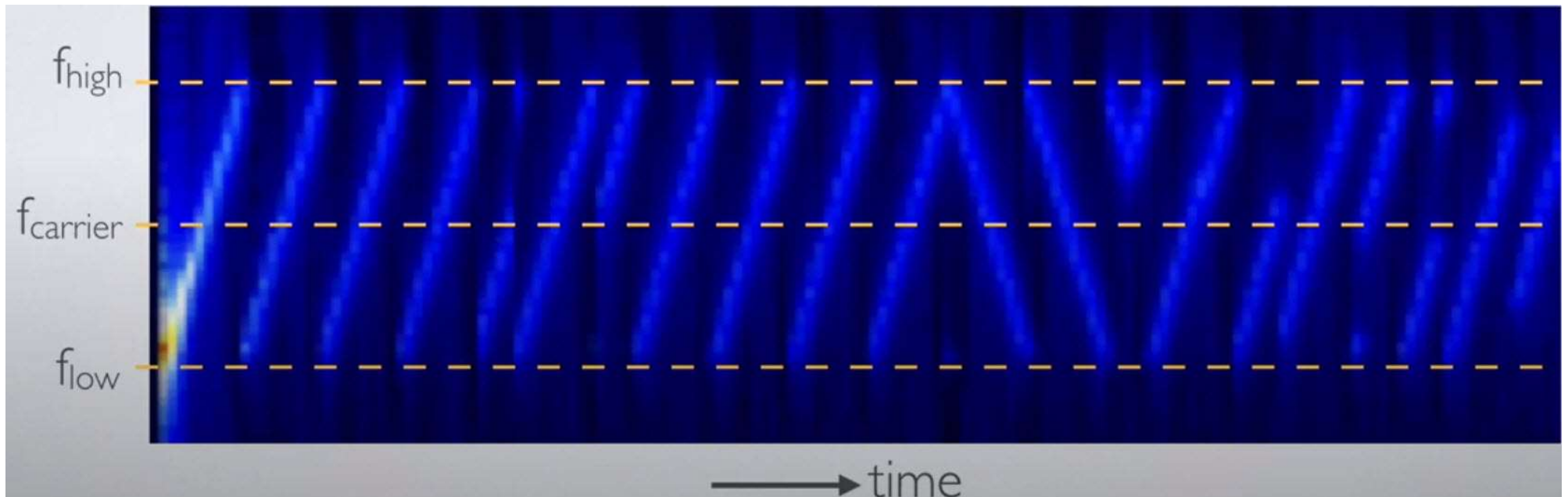
Source : Steve Bible N7HPR QSL,net ; Harold E. Price NK6K QEX 1995.

Chirp Spread Spectrum : Modulation à spectre étalé par glissements (rampes) de fréquences, balayages de fréquences, « piaulements »



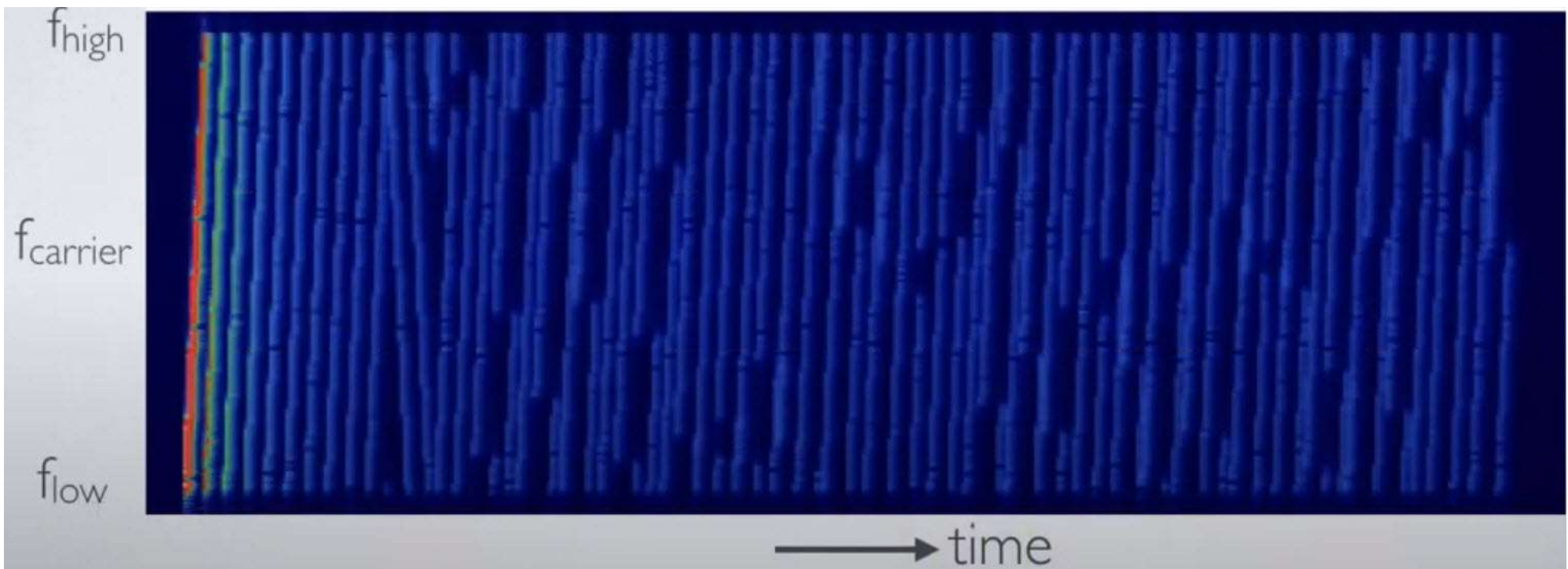
Source : Mobilefish.com ; Youtube Tutoriel LoRa LoRaWAN 12.

Modulation à spectre étalé par sauts de glissements de fréquences (préambule, synchro et transmission de symboles)



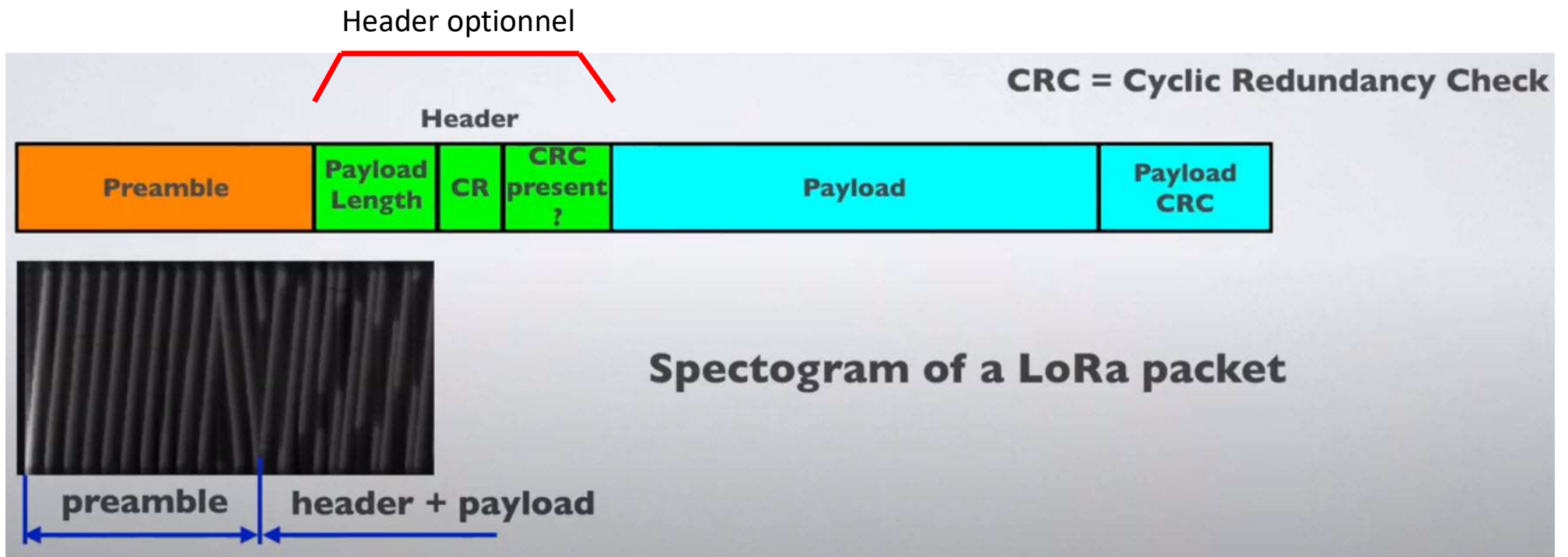
Source : Mobilefish.com ; Youtube Tutoriel LoRa LoRaWAN 12.

Modulation à spectre étalé par sauts de glissements de fréquences (préambule, synchro et transmission de symboles)



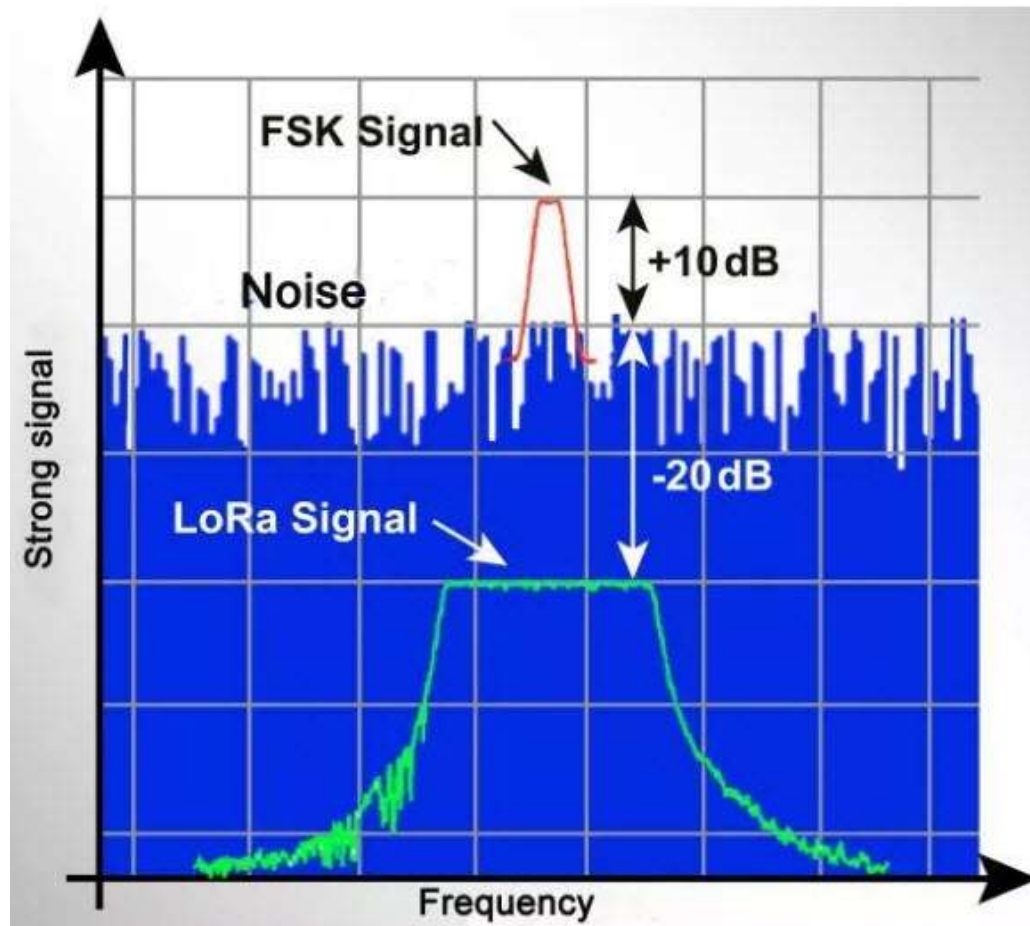
Source : Mobilefish.com ; Youtube Tutoriel LoRa LoRaWAN 12.

Constitution d'une trame de données LoRa



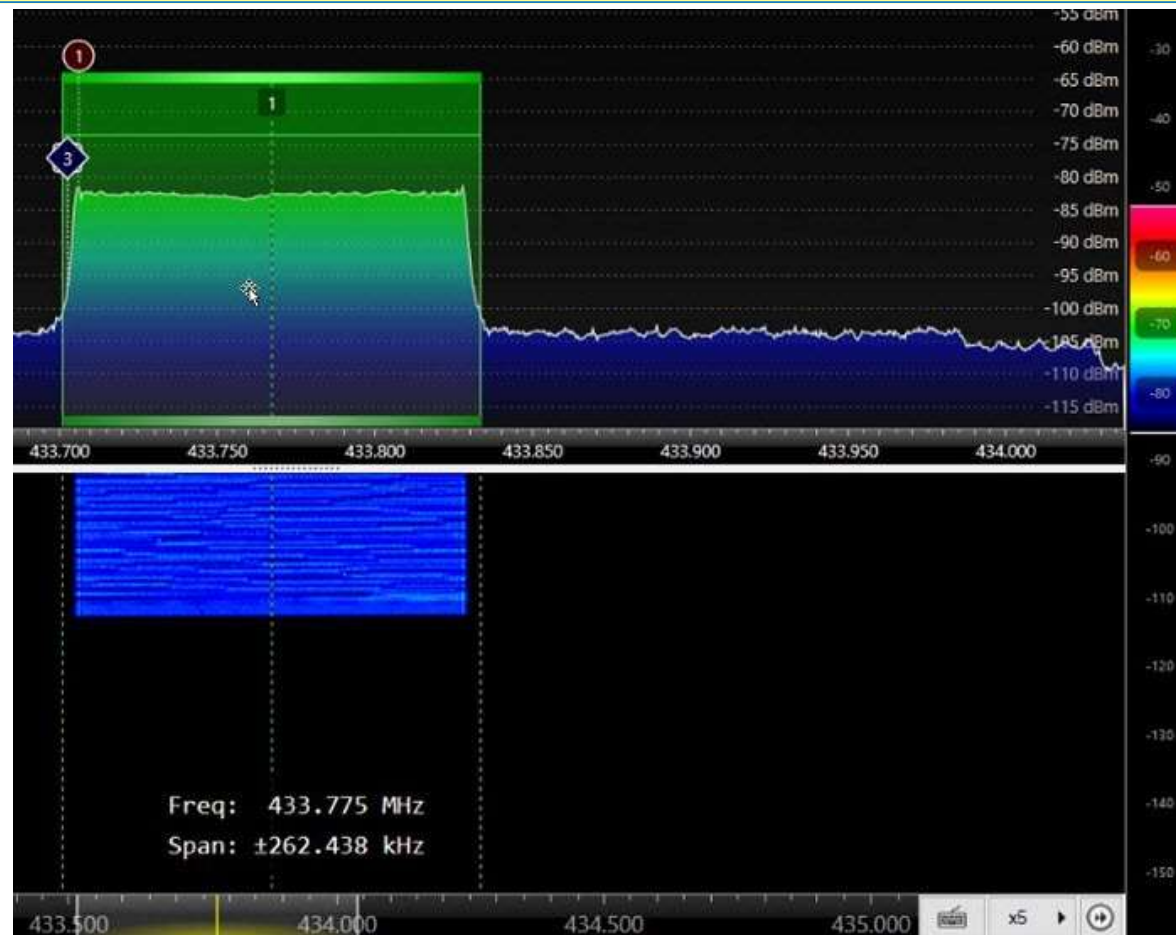
Source : Mobilefish.com ; Youtube Tutoriel LoRa LoRaWAN 53.

Spectre étalé d'une modulation LoRa



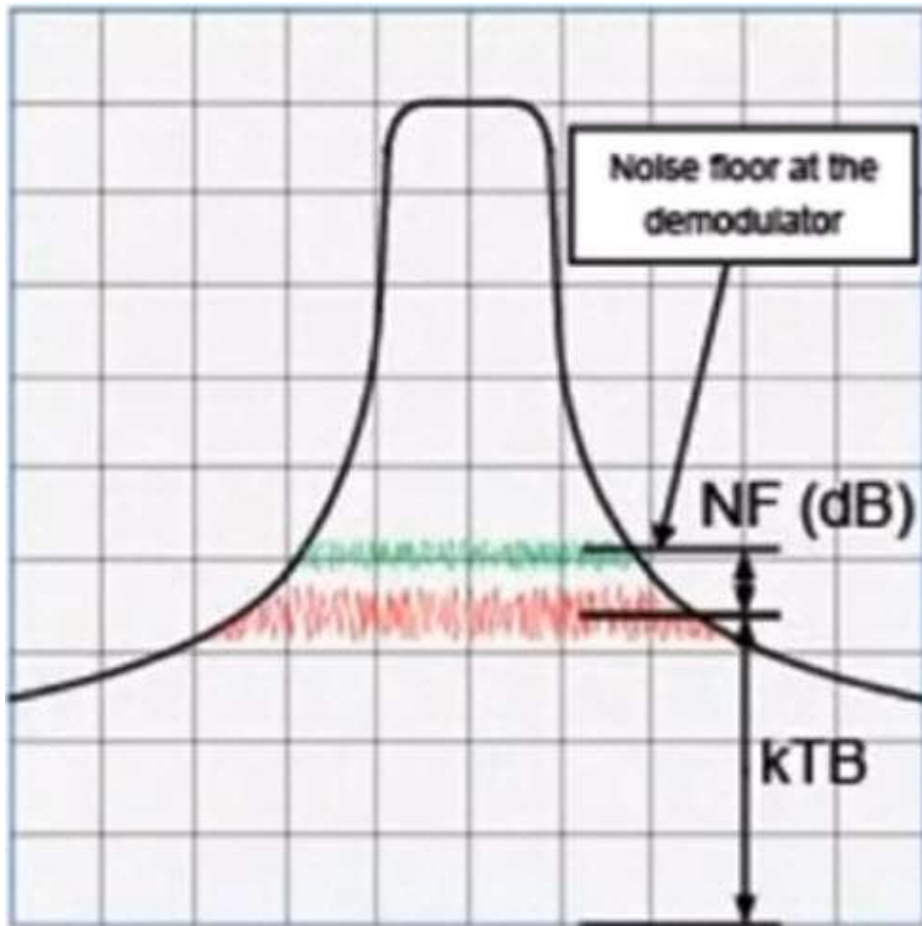
Source : mokosmart.com ; lora-frequency.com.

Spectre étalé d'une modulation LoRa



Source : Thierry F4EWI ; F5KMY.fr.

Plancher du niveau du bruit ; sensibilité d'un récepteur



MDS = *Minimum Discernable Signal* : sensibilité du récepteur pour une bande passante donnée et pour un rapport signal sur bruit donné.

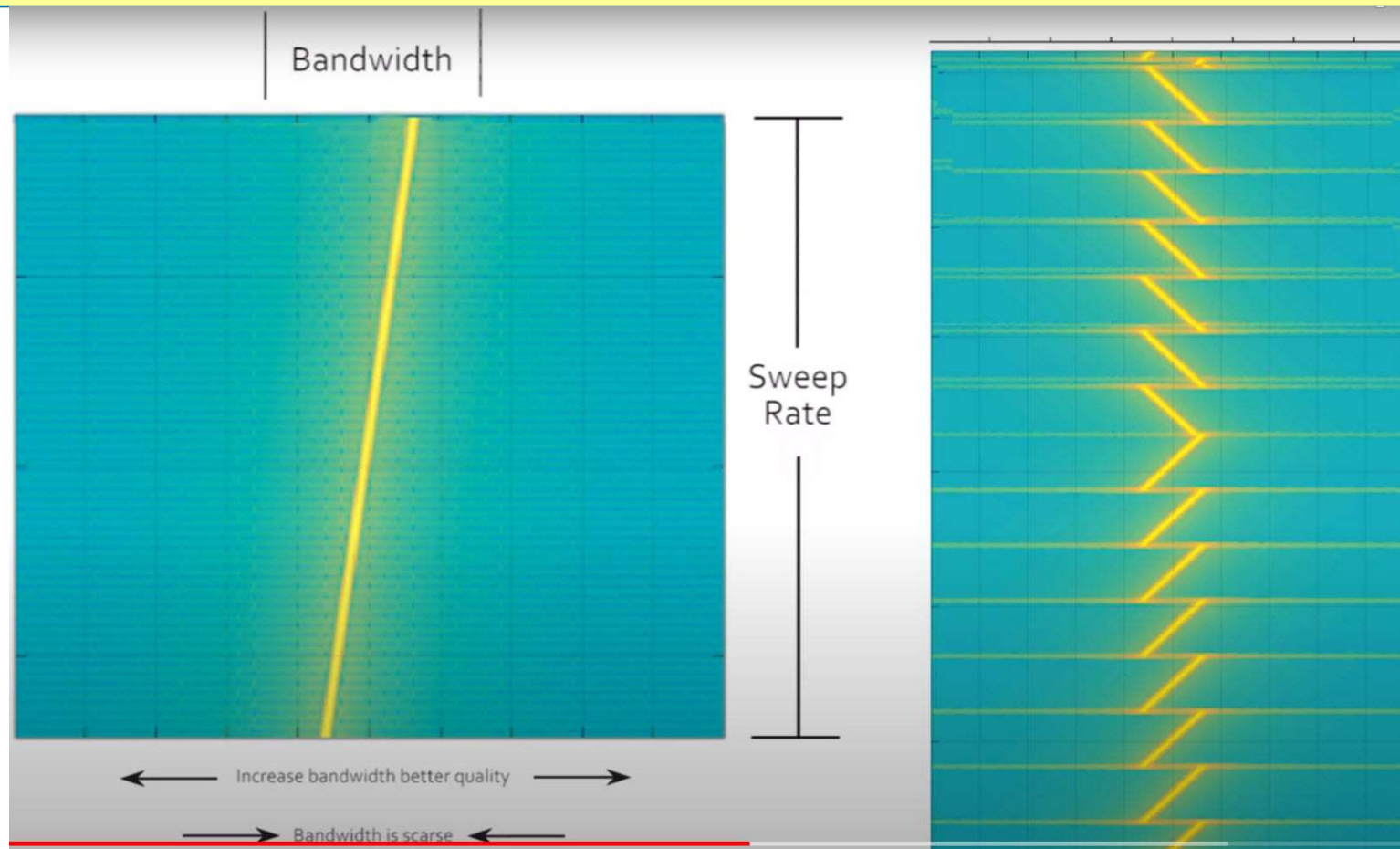
SNR = *Signal to Noise Ratio* : rapport signal sur bruit du récepteur.

NF = Noise Figure : figure de bruit du récepteur.

kTB = bruit thermique pour une température et bande passante donnée.

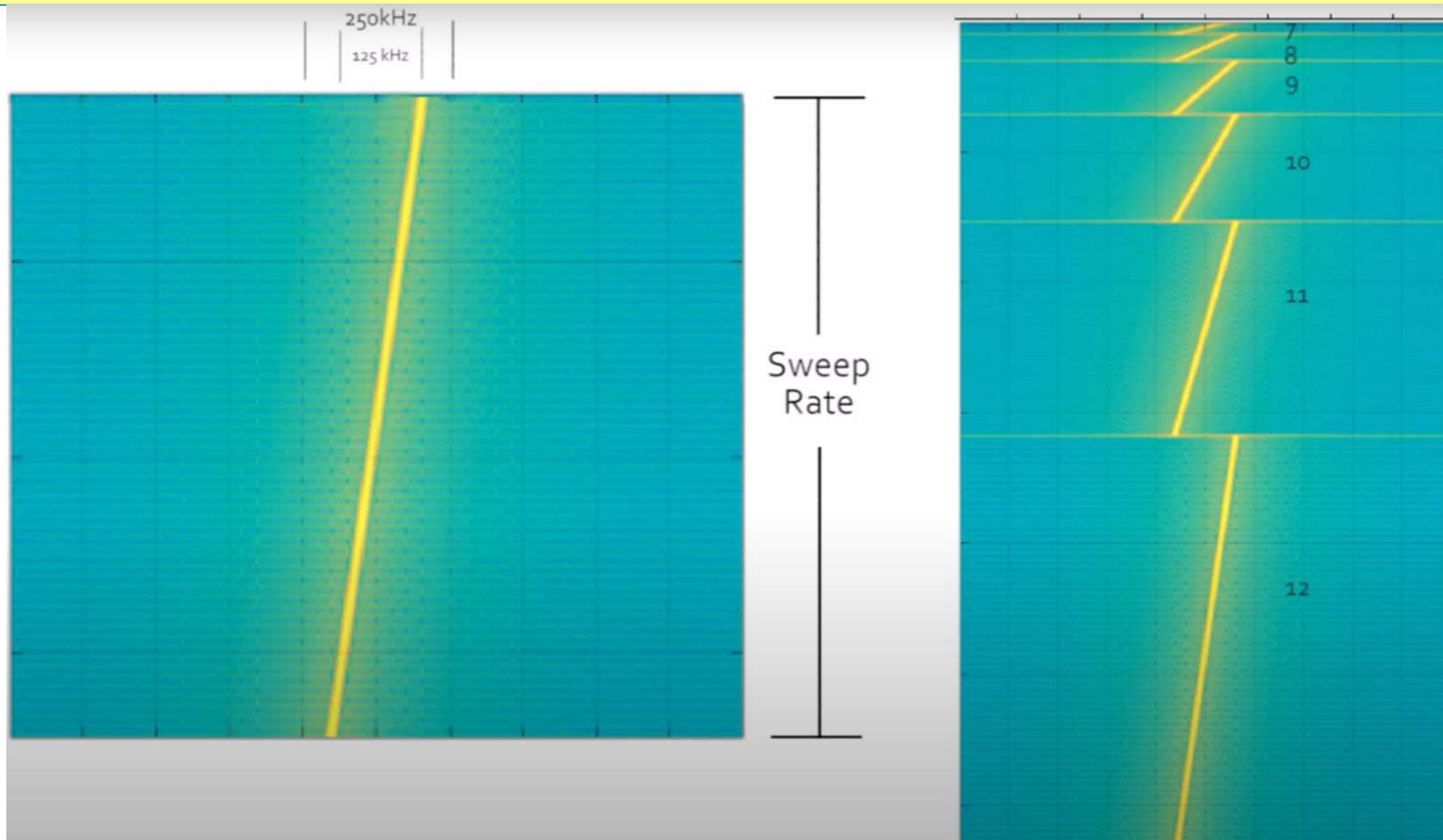
Source : Thomas Telkamp ; Youtube LoRa Crash Course.

SF Spreading Factor : facteur d'étalement, bande passante, *Data Rate*



Source : Richard Wenner ; Youtube LoRa CHIRP ; animation Mathlab sghoslya.com.

SF Spreading Factor : facteur d'étalement, bande passante, *Data Rate*



Source : Richard Wenner ; Youtube LoRa CHIRP ; animation Mathlab sghoslya.com.

SF Spreading Factor : facteur d'étalement, sensibilité du récepteur

Spreading factor	Receiver sensitivity for bandwidth fixed at 125 kHz
SF7	-123 dBm
SF8	-126 dBm
SF9	-129 dBm
SF10	-132 dBm
SF11	-134.5 dBm
SF12	-137 dBm

Source : The Things Network ; Docs ; LoRaWAN ; Spreading Factor.

SF Spreading Factor, Bit Rate, Range, Time on Air (Dwell Time)

Spreading Factor (For UL at 125 KHz)	Bit Rate	Range (Depends on Terrain)	Time on Air for an 11-byte payload
SF10	980 bps	8 km	371 ms
SF9	1760 bps	6 km	185 ms
SF8	3125 bps	4 km	103 ms
SF7	5470 bps	2 km	61 ms

Faible facteur d'étalement



Distance de liaison plus courte



Moins de temps sur l'air



Plus faible consommation d'énergie



Data Rate (taux de transmission) plus élevé

Frequency plan	EU	US
Duty cycle	0.1%-10%	No limit
Dwell time	No limit	400ms for channels 0-63

	10 bytes	51 bytes
SF7	62 mc	118 ms
SF8	113 ms	206 ms
SF9	206 ms	390 ms
SF10	371 ms	697 ms
SF11	823 ms	1561 ms
SF12	1483 ms	2794 ms

Source : Johan Stokking ; The Things Industries ; Everything you need to know about LoRaWAN in 60 minutes.

Sensibilité du récepteur et bilan de liaison en fonction du facteur d'étalement (*SF Spreading Factor*) → limite du SNR



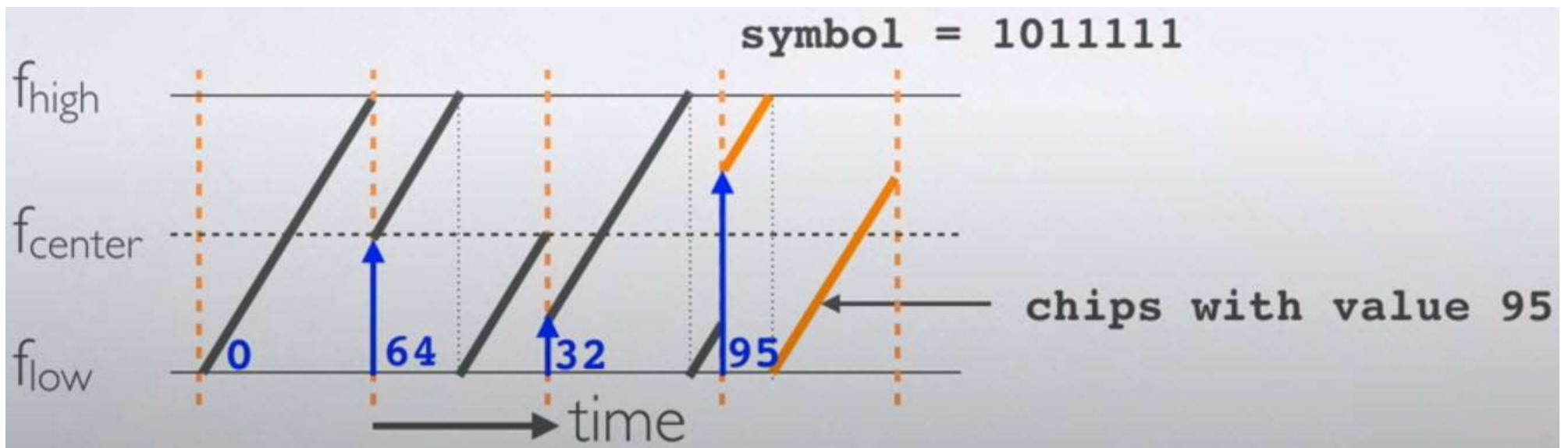
	Tx Power (dBm)	Rx Sensitivity (dBm)	Link Budget (dB)
Wi-Fi	20.5	-75	95.5
LoRa	14	-137	151
NB-IoT	23	-129	152

SF	SNR limit (dB)
7	-7.5
8	-10
9	-12.5
10	-15
11	-17.5
12	-20

Source : Johan Stokking ; The Things Industries ; Everything you need to know about LoRaWAN in 60 minutes.

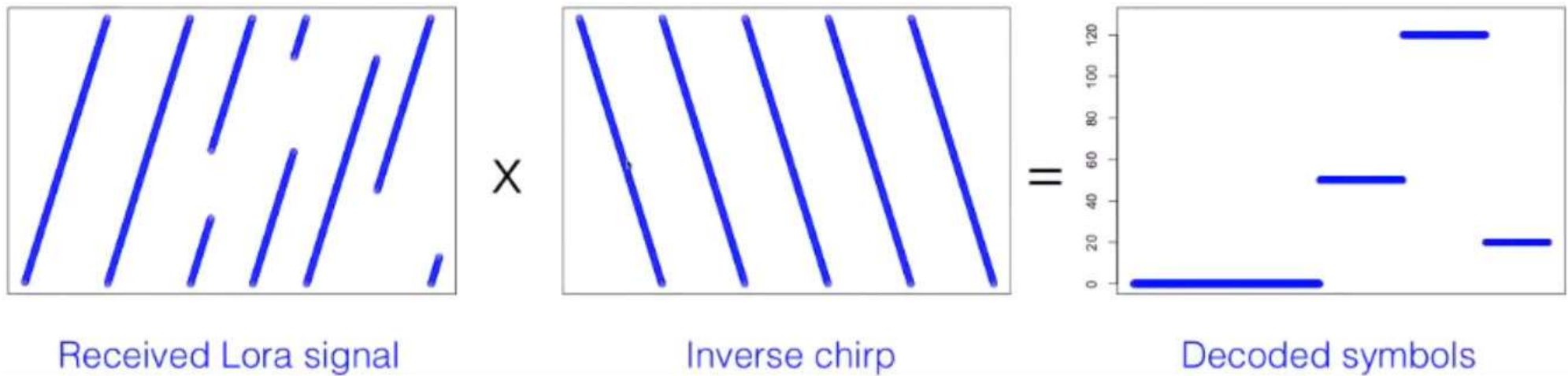
SF Spreading Factor : facteur d'étalement,
nombre de symboles, *Steps* ou *Chips*

Glissement du signal (balayage en fréquences) divisé en *Steps*
(des pas) ou *Chips* (des tranches) ;
nombre de symboles = 2^{SF} *Chips*



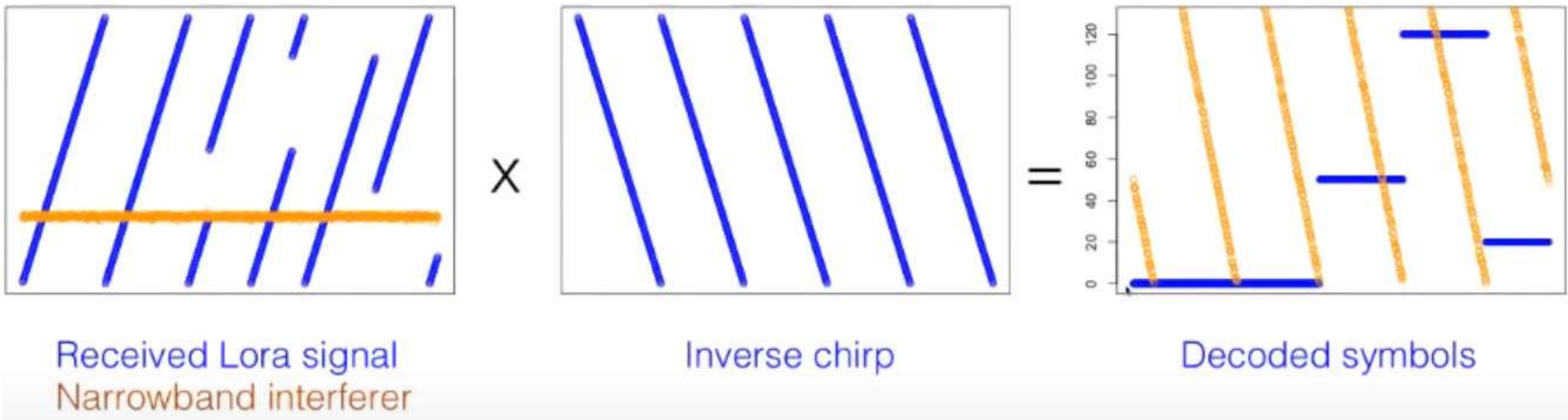
Source : Mobilefish.com ; Youtube Tutoriel LoRa LoRaWAN 13.

Despreading : démodulation des signaux LoRa



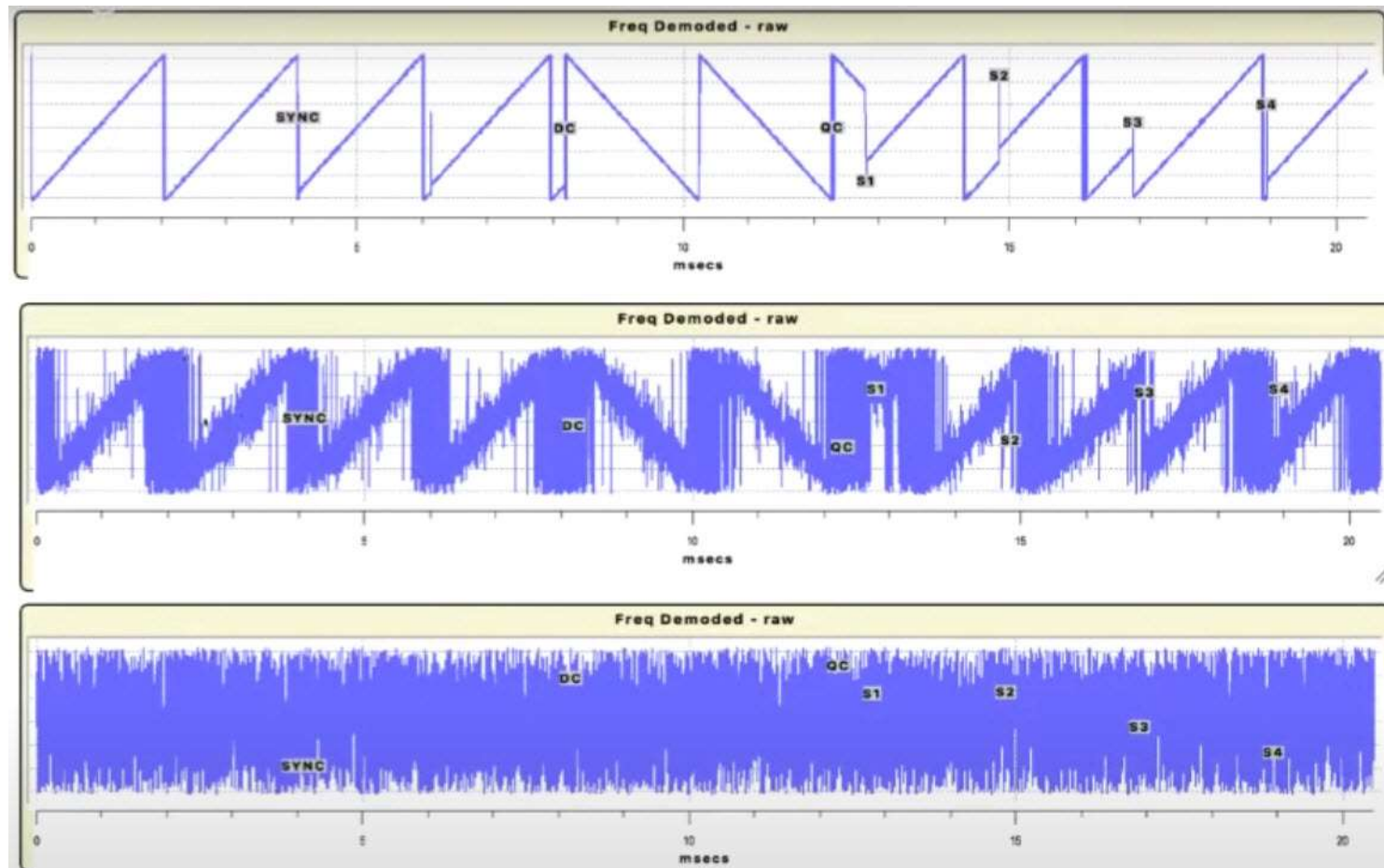
Source : Thomas Telkamp ; Youtube LoRa Crash Course.

*Despreading : immunité aux signaux **Narrow Band***



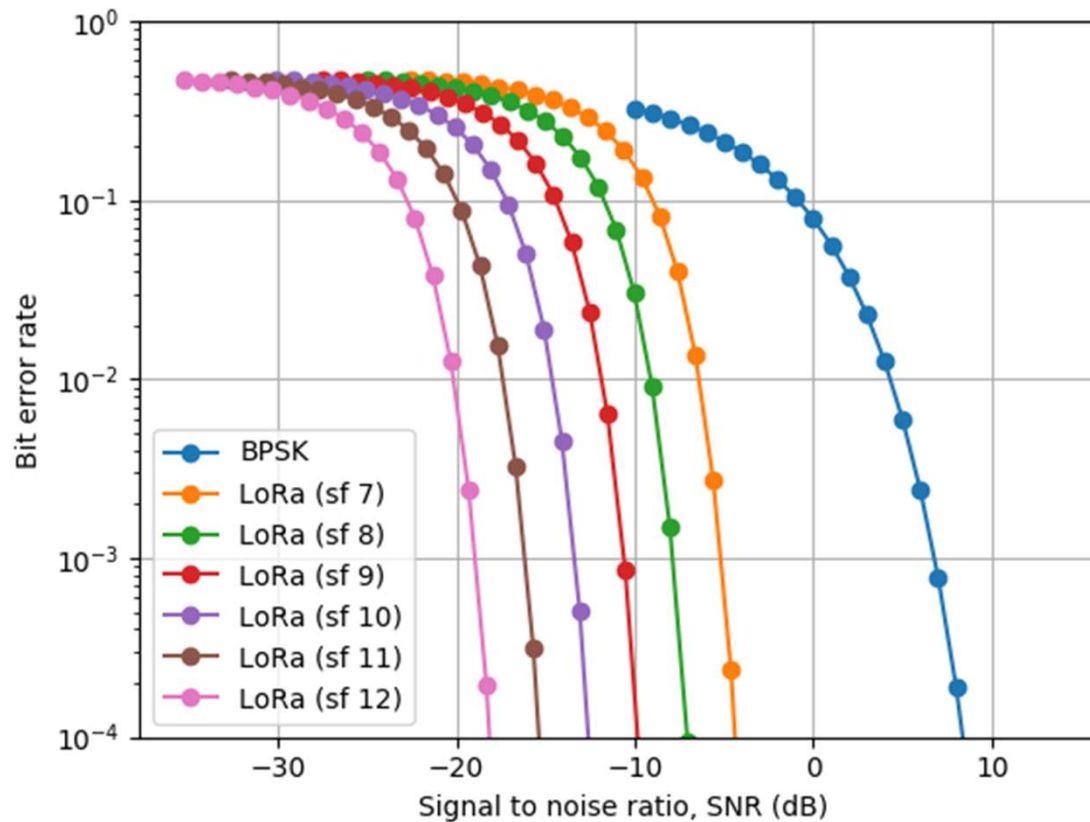
Source : Thomas Telkamp ; Youtube LoRa Crash Course.

Despreading : immunité au bruit



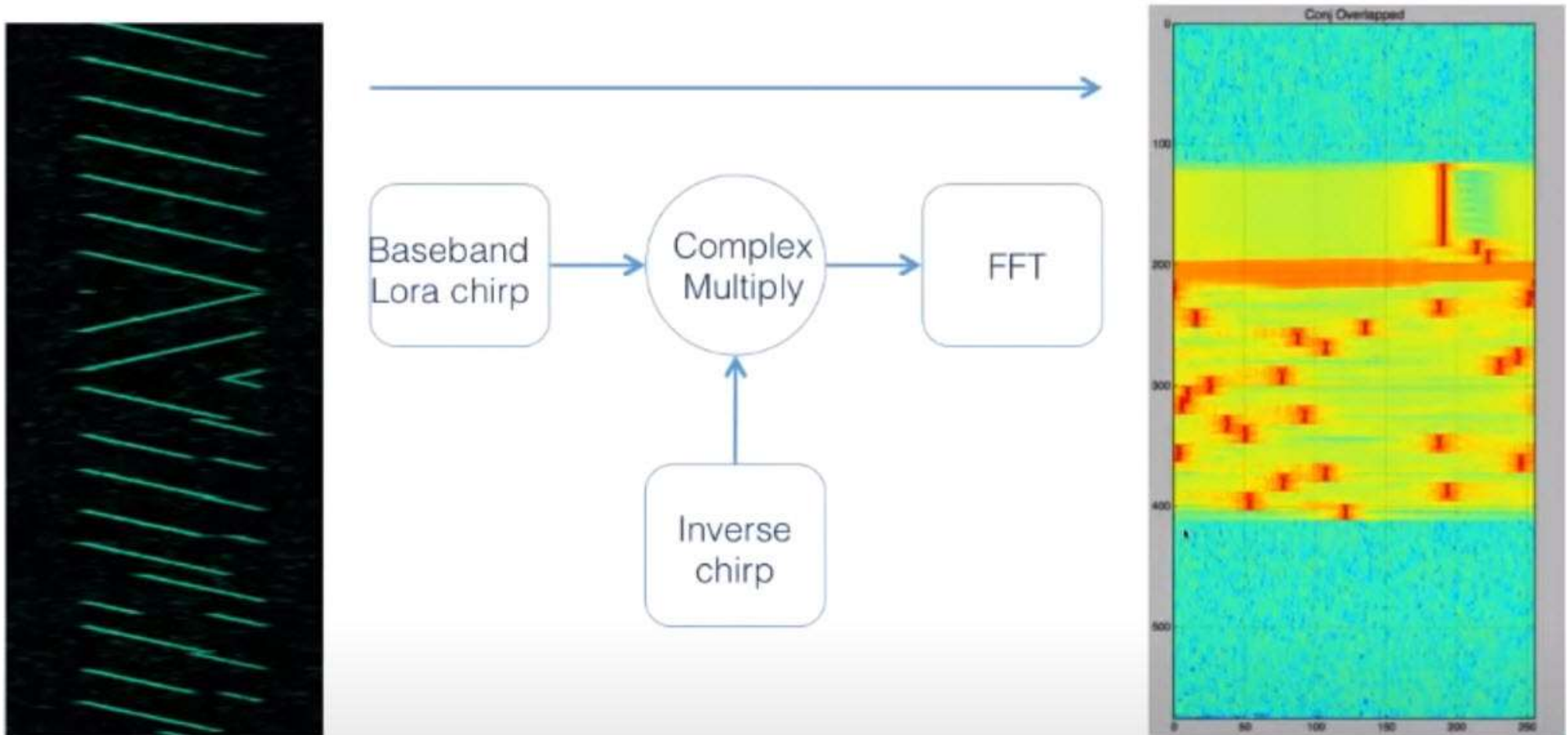
Source : Thomas Telkamp ; Youtube LoRa Crash Course ; The Things Network.

BER (*Bit Error Rate*) en fonction du SNR (rapport signal/bruit) pour différents SF (*Spreading Factor*)



Source : Digital Signal Processing Stack Exchange.

Despreading : démodulation des signaux LoRa



Source : Matt Knight ; Bastille Networks; Thomas Telkamp ; Youtube LoRa Crash Course.

Démodulation des signaux LoRa → beaucoup de math sup !!! pour 0,1 % des radioamateurs

Frequency Shift Chirp Modulation: The LoRa Modulation

Lorenzo Vangelista¹, Member, IEEE

Abstract—Low power wide area networks (LPWAN) are emerging as a new paradigm, especially in the field of Internet of Things (IoT) connectivity. LoRa is one of the LPWAN and it is gaining quite a bit of commercial traction. The modulation underlying LoRa is patented and has never been described theoretically. The aim of this letter is to give the first rigorous mathematical signal processing description of the modulation and demodulation processes. We provide as well a theoretical derivation of the optimum receiver entailing a low-complexity demodulation process, resorting to the Fast Fourier Transform. We compare then the performance of the LoRa modulation and the frequency-shift keying modulation both in an additive white gaussian noise channel and a frequency selective channel, showing the superiority of the LoRa modulation in the frequency selective channel. The results of this letter will enable a further assessment of the LoRa based networks, much more rigorous than what has been done until now.

Index Terms—Chirp modulation, frequency shift chirp modulation (FSCM), Internet of Things (IoT), LoRa, low power wide area networks (LPWAN).

I. INTRODUCTION

LOW power wide area networks (LPWAN) are emerging as a new paradigm, especially in the field of Internet of Things connectivity [1]–[3].

LoRa is one of the LPWAN (see [3]) and it is gaining quite a lot of commercial traction. Strictly speaking, LoRa is the physical layer of the LoRaWAN system, whose specification is maintained by the LoRa Alliance¹. The LoRa modulation is patented and has never been described theoretically. The patent [4], indeed, does not provide the details, in term of equations and signal processing. Paper [5] gives a high level description of the LoRa modulation, providing some basic equations and relying on the intuition of the reader for the decoding process. Papers [6] and [7] get more in detail with the signal, modulation and demodulation description, but still lack a mathematical, signal theory based definition of the modulation and demodulation processes, partly because the analysis is limited to the analog domain. For example, in [7] it is said that “For a spreading

factor S , $\log_2(S)$ bits define f_0 ,” i.e., the initial frequency shift, but there is no explanation of how this is done.

Actually the LoRa modulation is often referred to as a “chirp modulation” [8]–[10]. A close inspection of LoRa reveals that the information bearing element is the frequency shift at the beginning of the symbol and the chirp is similar to a kind of a carrier. For this reason, in our opinion, LoRa is better described as a Frequency Shift Chirp Modulation (FSCM).

The rest of the paper is organised as follows. In Section II, we provide a description of the modulation process and identify the orthogonal signals basis characterising the modulation; in Section III, we provide a description of the optimum demodulator and an efficient implementation of it making use of the Fast Fourier Transform; in Section IV, we provide the results of some computer simulations experiments on the link level performances, comparing as well the FSCM modulation with an frequency-shift keying (FSK) modulation with the same cardinality. Finally in Section V, we draw the conclusions of the paper.

II. FREQUENCY SHIFT CHIRP MODULATION

Let us suppose that the bandwidth of the channel we use for the transmission is B so we transmit a sample every $T = \frac{1}{B}$.

A symbol $s(nT_s)$ is sent at the input of the modulator every $T_s = 2^{SF} \cdot T$. The symbol $s(nT_s)$ is a real number formed using a vector $w(nT_s)$ of SF binary digits, with SF an integer parameter called, in the context of LoRa, *Spreading Factor* (usually taking values in $\{7, 8, 9, 10, 11, 12\}$) i.e.,

$$s(nT_s) = \sum_{k=0}^{SF-1} w(nT_s)_k \cdot 2^k. \quad (1)$$

We can see that $s(nT_s)$ takes values in $\{0, 1, 2, \dots, 2^{SF} - 1\}$.

The transmitted waveform, of duration T_s , for a certain $s(nT_s)$ is then

$$c(nT_s + kT) = \frac{1}{\sqrt{2^{SF}}} e^{j2\pi \left[\left(\frac{s(nT_s) + k}{2^{SF}} \right) \frac{B}{2} t^2 \right]} \quad (2)$$

$$= \frac{1}{\sqrt{2^{SF}}} e^{j2\pi \left[\left(\frac{s(nT_s) + k}{2^{SF}} \right) \frac{B}{2} t^2 \right]} \quad (3)$$

$$\text{for } k = 0, \dots, 2^{SF} - 1.$$

We can see that the modulated signal is a chirp waveform, as the frequency increases linearly with k , which is the time index; we note that each waveform differs from a base waveform having



AN1200.22
LoRa™ Modulation Basics

WIRELESS, SENSING & TIMING PRODUCTS

APPLICATION NOTE

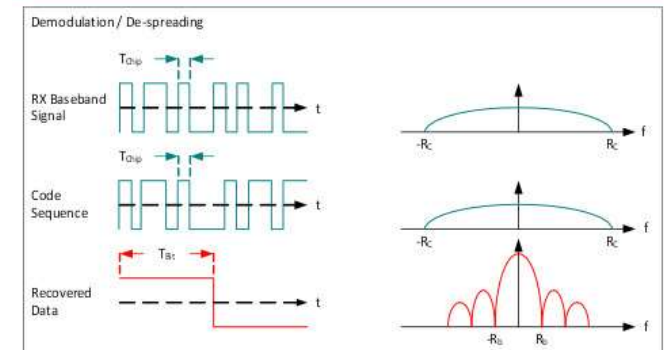


Figure 2: Demodulation / De-spreading Process

The amount of spreading, for direct sequence, is dependent on the ratio of “chips per bit” - the ratio of the chip sequence to the wanted data rate, is referred to as the processing gain (G_p), commonly expressed in dB.

$$G_p = 10 + \log_{10} \left(\frac{R_c}{R_b} \right) \text{ (dB)}$$

Where:

R_c = chip rate (Chips/second)
 R_b = bit-rate (bits/second)

As well as providing inherent processing gain for the wanted transmission (which enables the receiver to correctly recover the data signal even when the SNR of the channel is a negative value); interfering signals are also reduced by the process gain of the receiver. These are spread beyond the desired information bandwidth and can be easily removed by filtering.

DSSS is widely used in data communication applications. However, challenges exist for low-cost or power-constrained devices and networks.

Often, as is the case with GPS or the DSSS PHY of IEEE Standard 802.15.4k, the system will require a highly accurate and expensive reference clock source. In addition, the longer the spreading code or sequence, the longer the time required by the receiver to perform a correlation over the entire length of

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Sources : Lorenzo Vangelista IEEE Frequency Shift Chirp Modulation LoRa et Semtech Corporation AN 1200-22.

Démodulation des signaux LoRa → beaucoup de math sup !!!

Pour 0,1 % des radioamateurs

How LoRa Modulation really works - long range communication using chirps

Repeat for each basis symbol

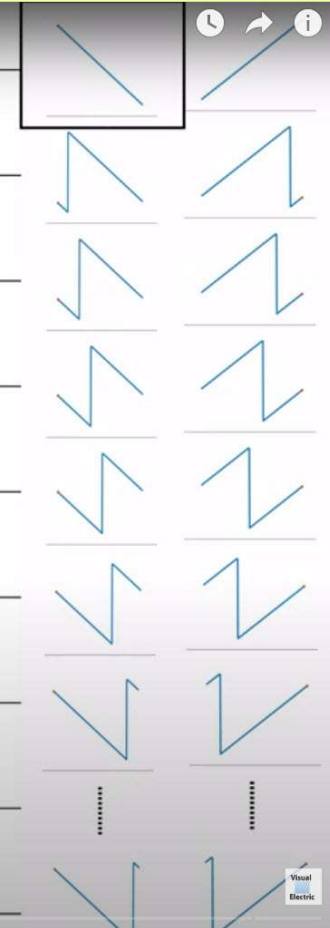
$$\sum_{k=0}^{2^{SF}-1} \text{Received signal } r(nT_s + kT) \cdot \text{Basis symbols } c^*(nT_s + kT)$$

$$c^*(nT_s + kT) = \frac{1}{\sqrt{2^{SF}}} e^{-j2\pi(s(nT_s) + k \bmod 2^{SF}) \frac{k}{2^{SF}}}$$

$$c^*(nT_s + kT) = \frac{1}{\sqrt{2^{SF}}} e^{-j2\pi(s(nT_s) + k \bmod 2^{SF}) \frac{k}{2^{SF}}}$$

$$= \frac{1}{\sqrt{2^{SF}}} \left(e^{-j2\pi \frac{k^2}{2^{SF}}} \right) e^{-j2\pi(s(nT_s) + k \bmod 2^{SF} - k) \frac{k}{2^{SF}}}$$

~~Base down chirp~~ a pure wave at frequency s



Sources : Visual Electric ; Youtube ; How LoRa Modulation really works – long range communication using chirps.

Pratique pour 99,9 % des radioamateurs → projet à ON5VL

i-gate

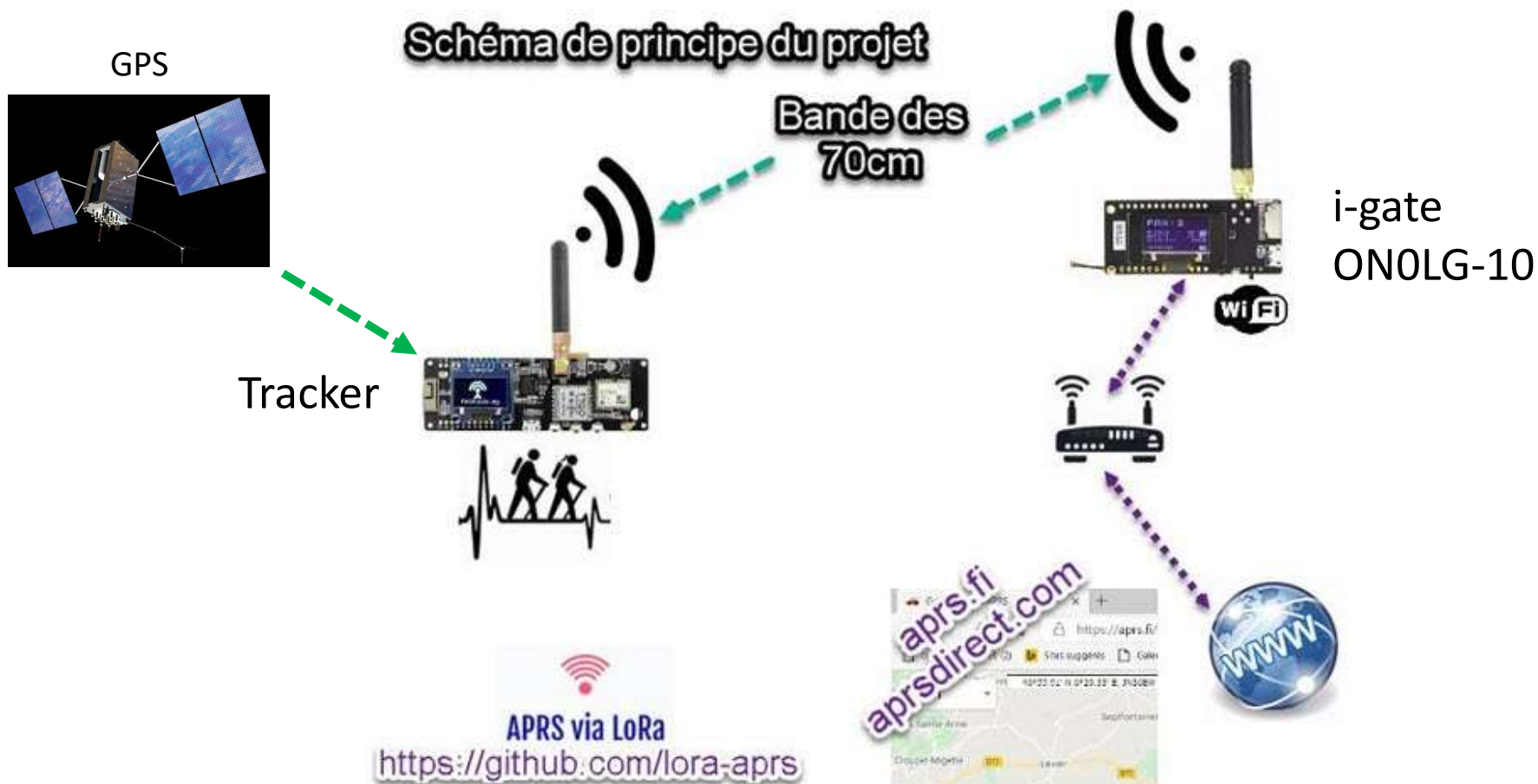


tracker



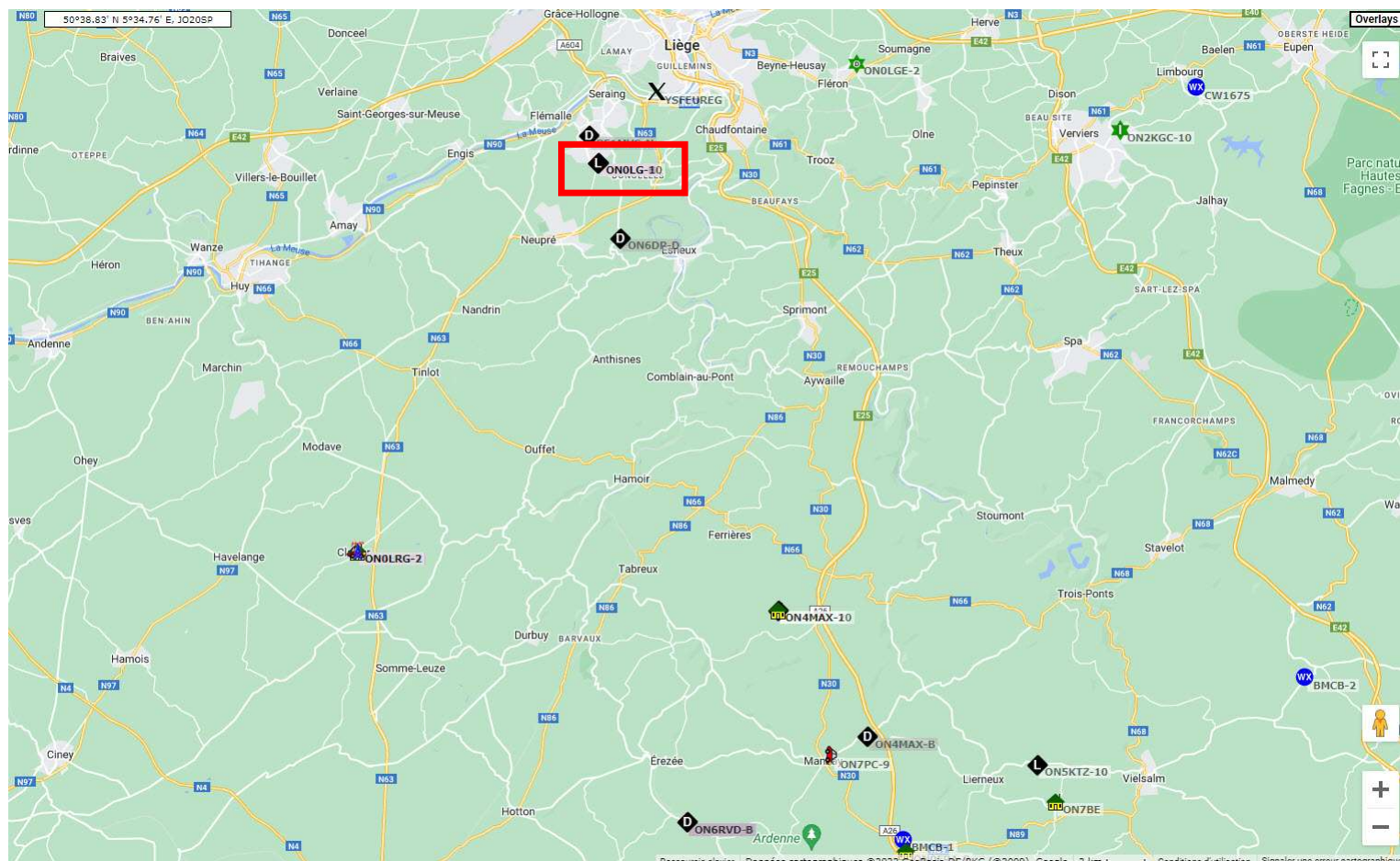
Source : LilyGo. Voir aussi le CQ-QSO de mai-juin 2022 ; Technical Info de Guy ON5FM et Rik ON7YD.

Projet à ON5VL : *Tracker* APRS (OM's) et *i-gate* ON0LG-10



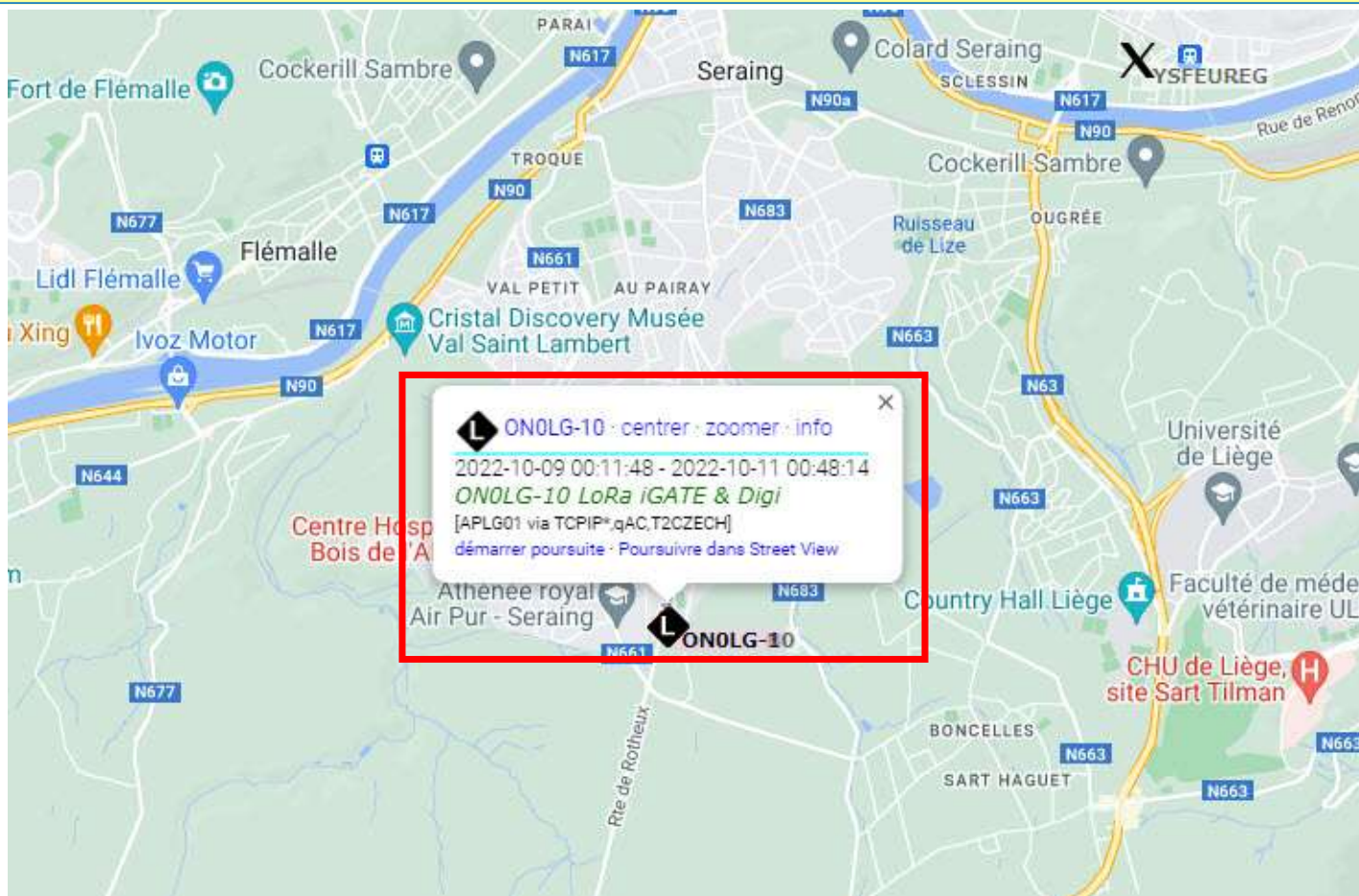
Source : Thierry F4EWI ; F5KMY.fr.

Projet à ON5VL : *Tracker APRS, i-gate ON0LG-10, APRS.fi*



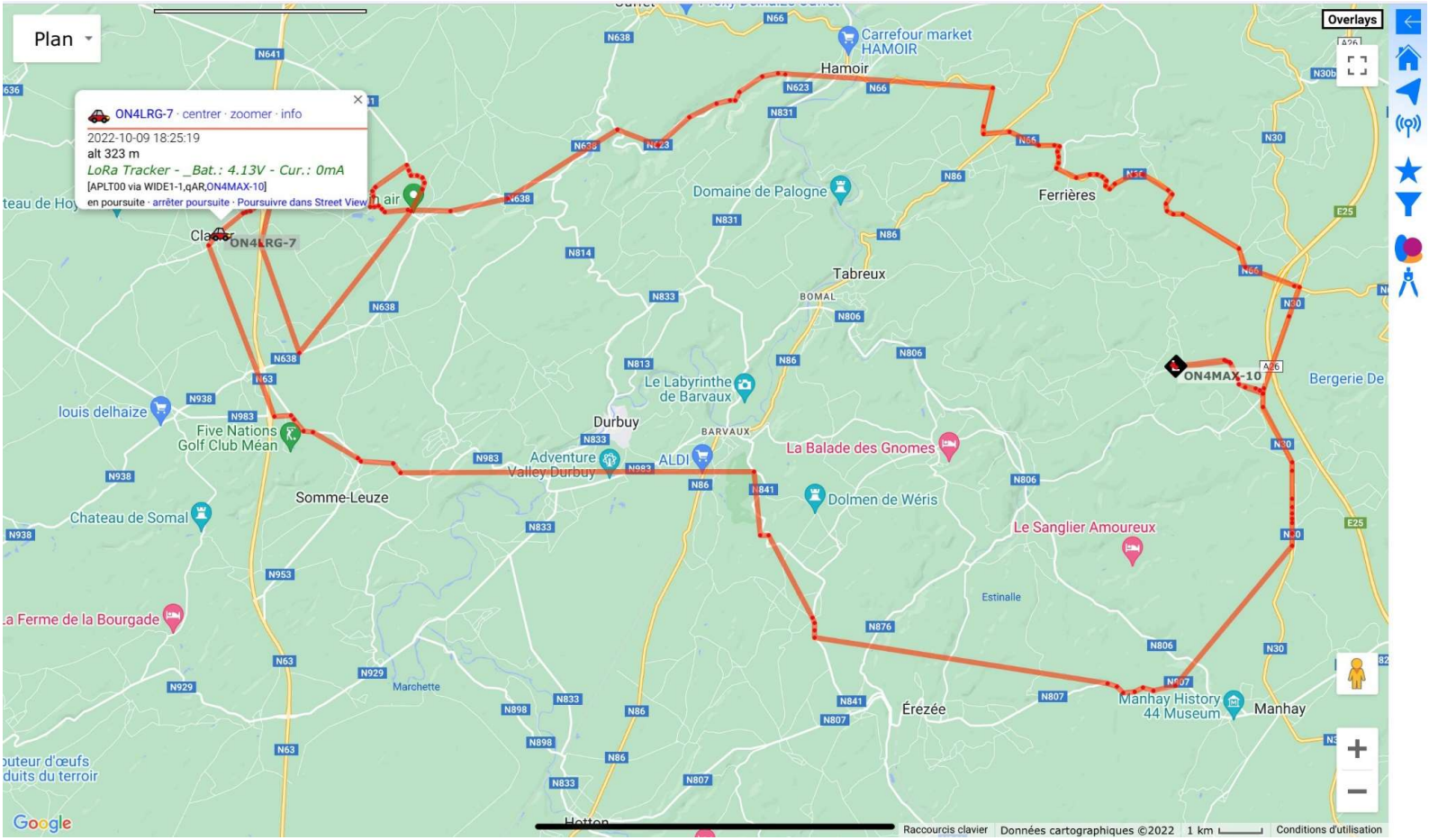
Source : APRS.fi.

Projet à ON5VL : *i-gate* ON0LG-10



Source : APRS.fi.

Projet à ON5VL : exemple d'un parcours avec *Tracker* ON4LRG-7



Source : ON4LRG.

Projet à ON5VL : *i-gate* ON0LG-10

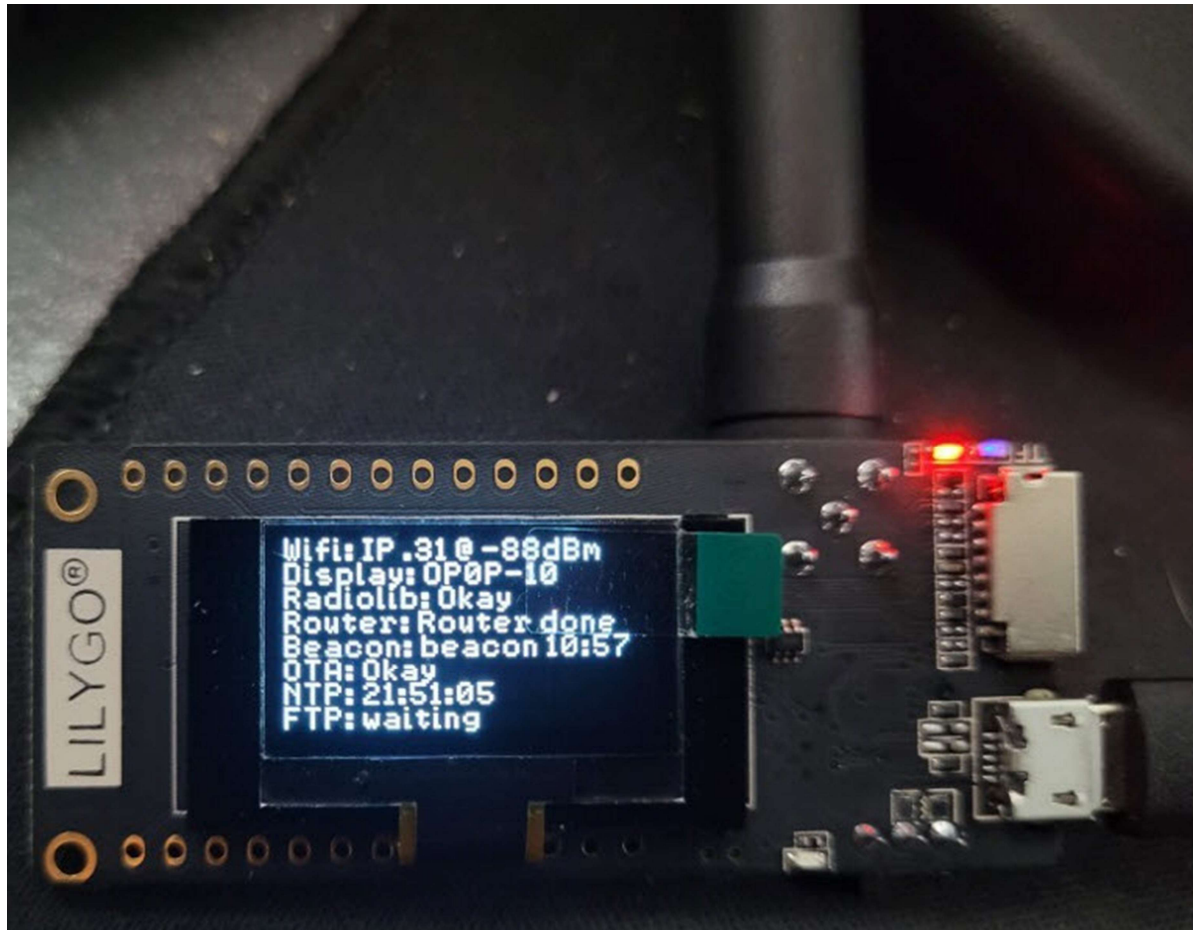


Photo : ON6DP.

Projet à ON5VL : exemple *Tracker* ON6DP-7 et *i-gate* ON0LG-10

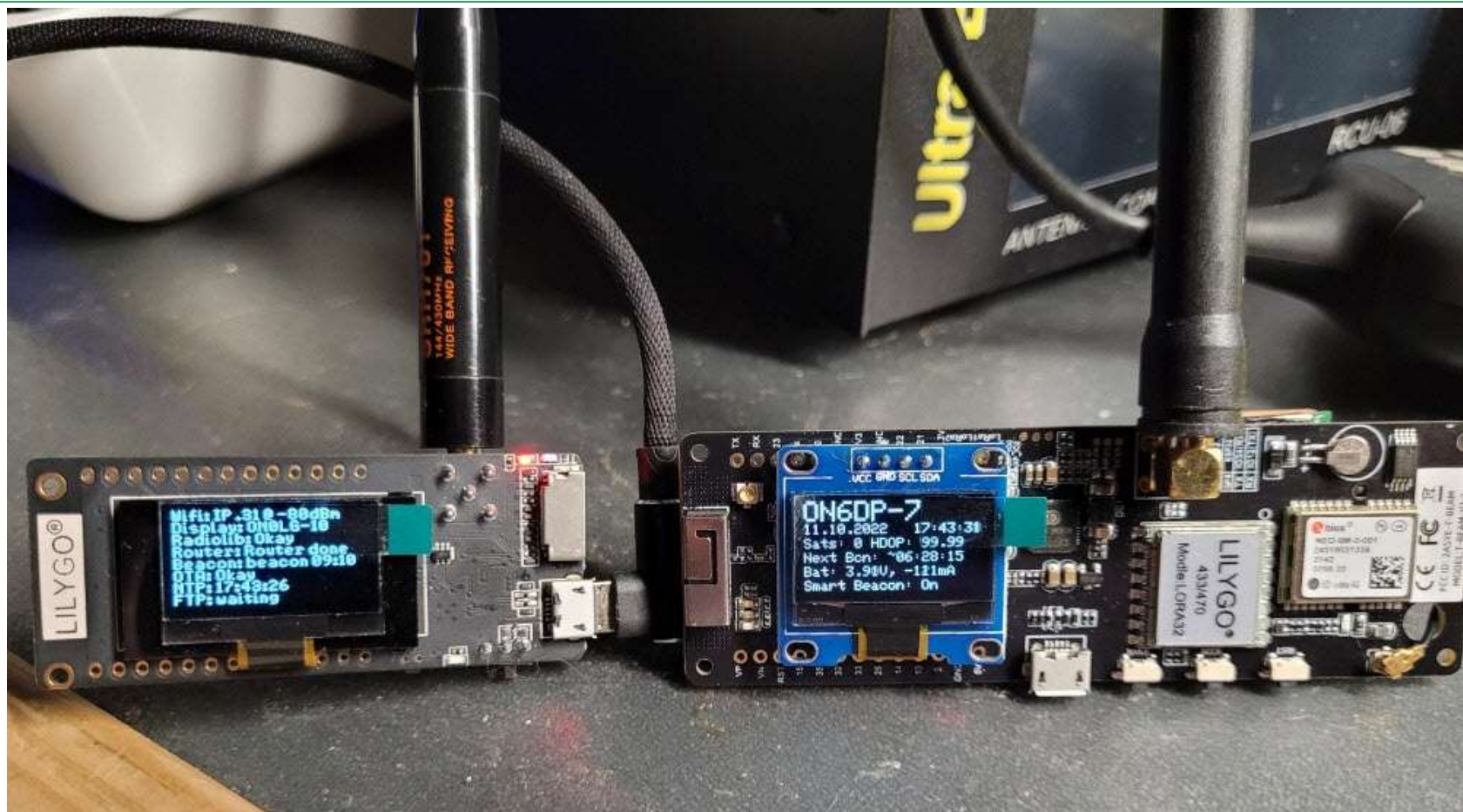
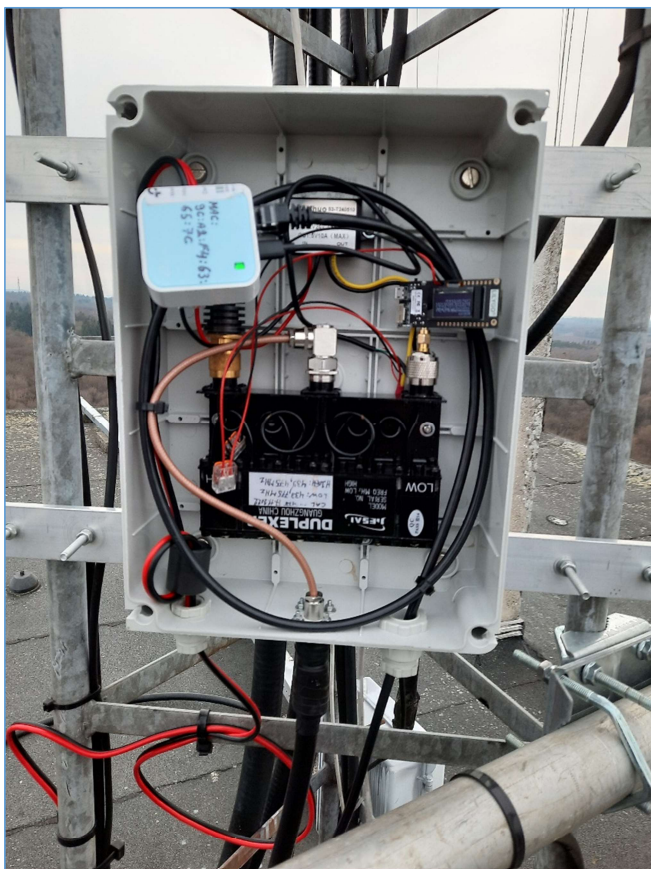


Photo : ON6DP.

Réalisation à ON5VL : installation d'un coffret *i-gate* ON0LG-10 et d'une antenne UHF verticale à Seraing

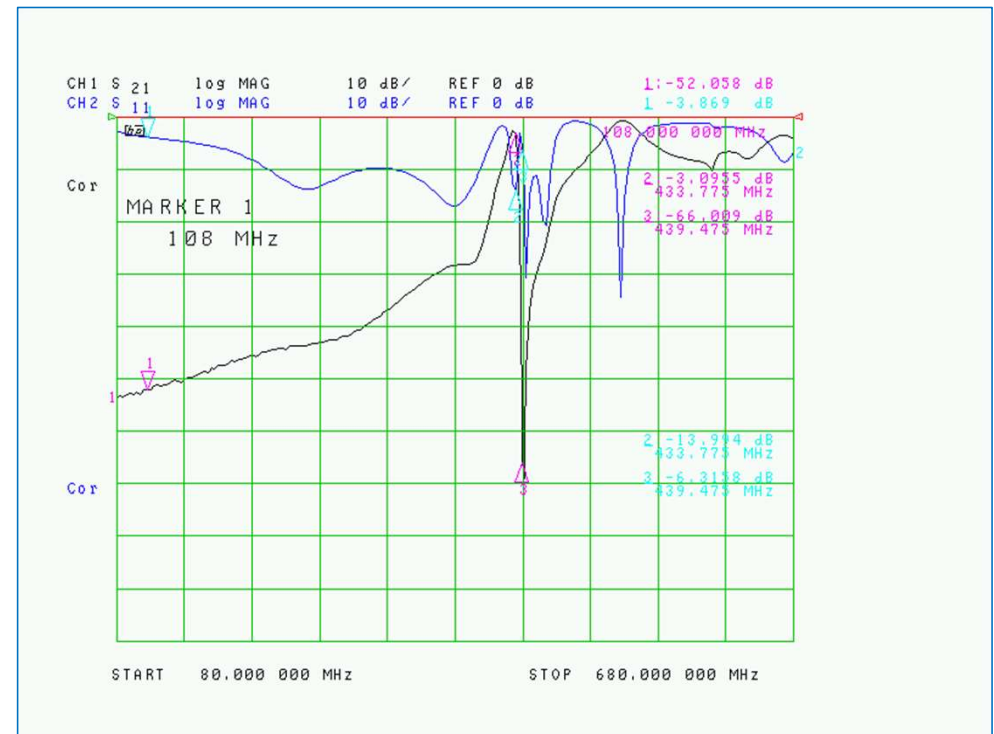
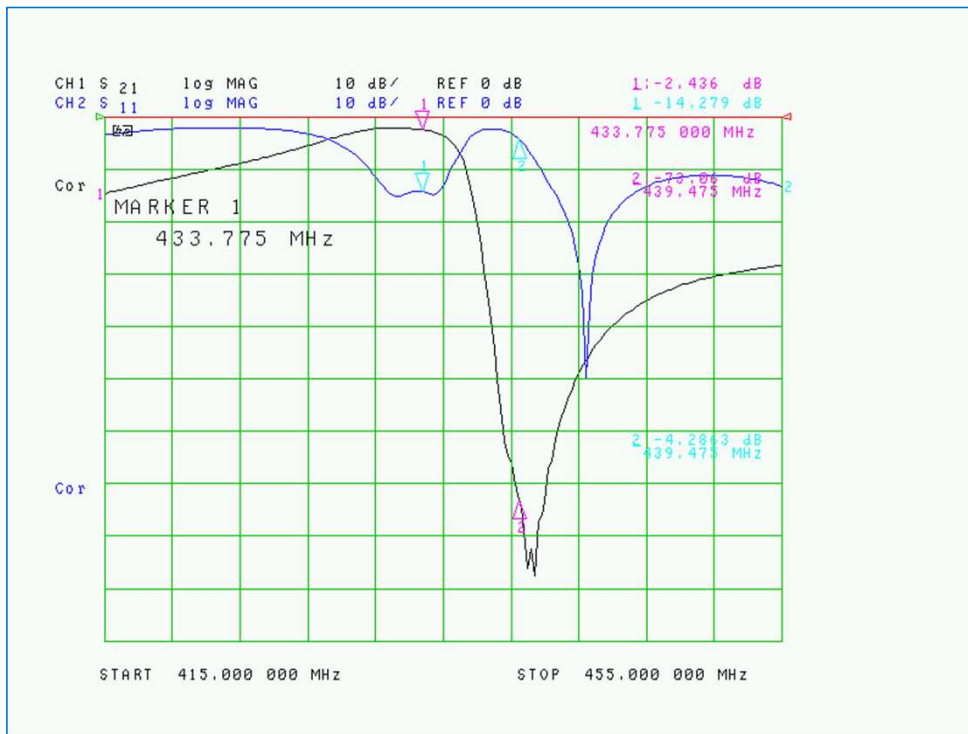


Photos : ON4IJ.

Utilisation atypique d'un duplexeur pour protection du *i-gate*

- Protection du RF *Front-End* RX (large bande) de l'*i-gate* :
 - *Damage level* +10 dBm !!! ; IIP3 : -11 dBm ;
- Vis-à-vis de l'émission du relais ON0LG UHF 439,475 MHz ;
- Vis-à-vis des émissions QRO *broadcast* FM 88-108 MHz ;
- Duplexeur utilisé sur une seule voie (*Low Freq. Out*) :
 - Filtre passe-bande (Bp) sur fréquence LoRa 433,775 MHz ;
 - Filtre *notch* (Br) sur fréquence ON0LG 439,475 MHz ;
 - Écart Bp et Br : 5,7 MHz $\approx$ compatible et proche d'un réglage avec *shift* usuel de 7,6 MHz d'un duplexeur UHF ;
 - Effet de filtre passe-haut pour atténuer l'émission de ON0LG VHF 145,650 MHz et les émissions QRO de la bande FM 88-108 MHz ;
 - Charge de 50 Ω sur la voie non utilisée (*High*) du duplexeur.

Réglages et mesures du duplexeur pour protection du *i-gate*



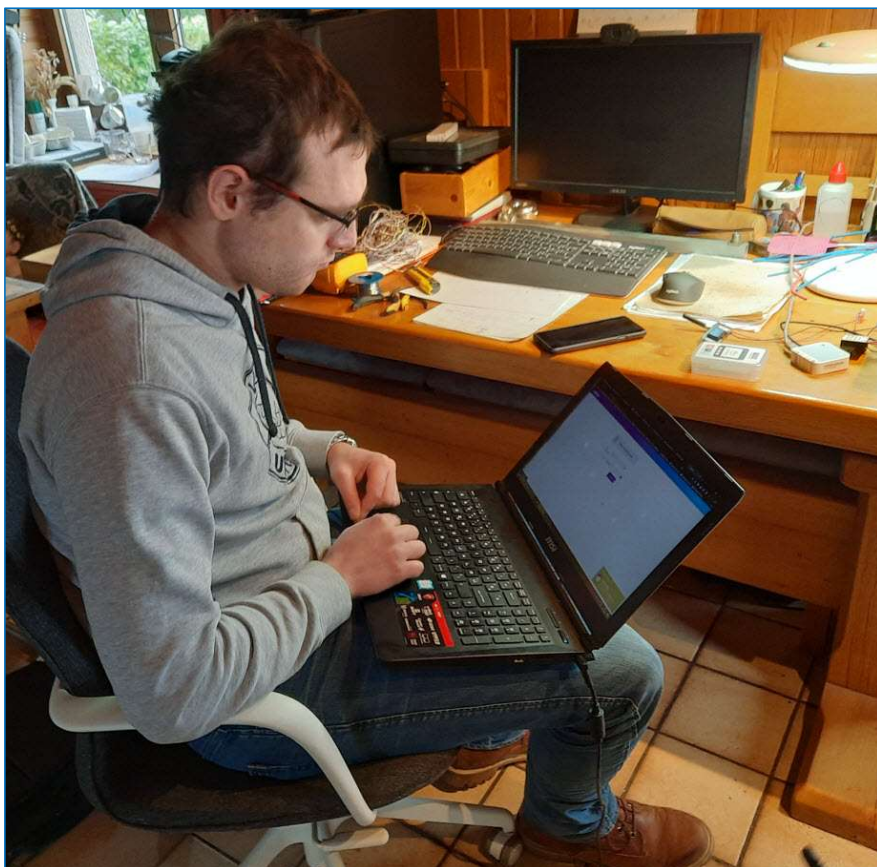
Clichés : ON4IJ.

Adjonction d'un *Access-Point* 2,4 GHz pour liaison vers Internet



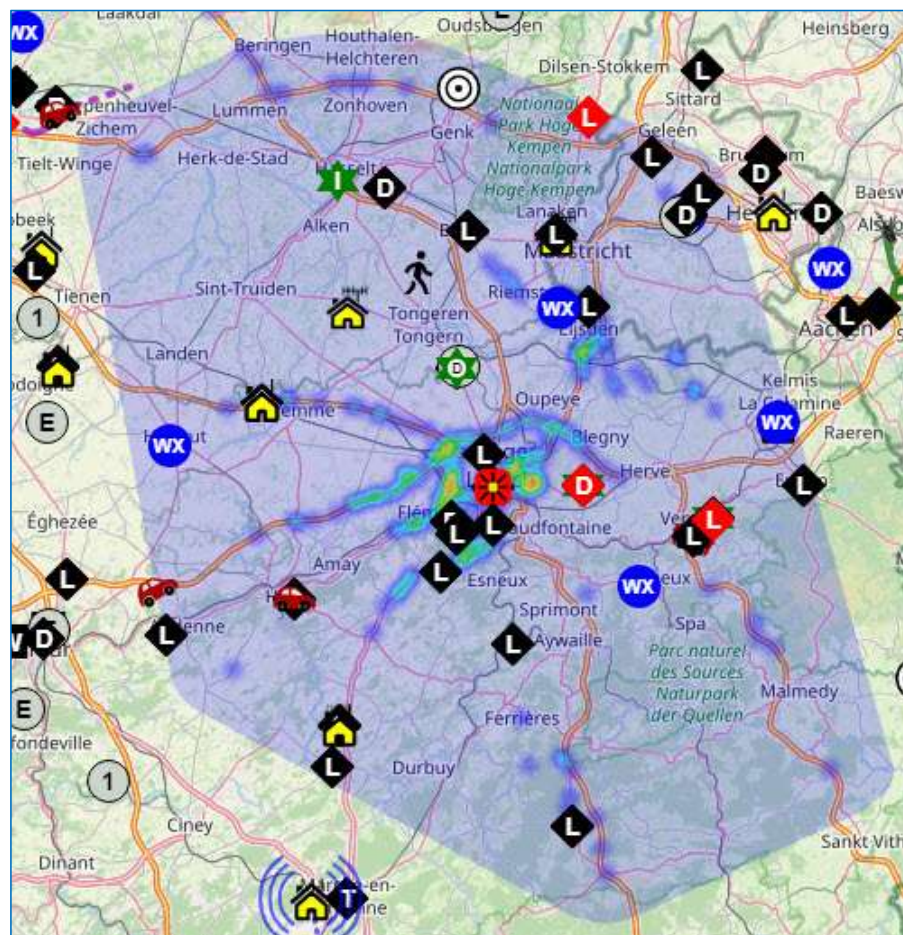
Photo : ON4IJ.

Paramétrages informatiques avec ON4MOD et ON6DP



Photos : ON4IJ.

Zone de couverture de ON0LG-10 (Aprsdirect.de)



Source : Aprsdirect.de

FIN

Questions - réponses

Merci pour votre attention.