1 LoRa transmission from space

LoRa is a low power proprietary protocol for low bandwidth communication over the unlicensed ISM bands aimed at deploying the so called Intenet of Things (IoT) of distributed sensors. While the communication range is in the tens of kilometers on ground, it can reach hundreds of kilometers towards space links. A whole range of low-Earth orbiting (LEO) satellites – at altitudes from 500 to 2000 km – are being launched to be used as relays and broadcast sensor measurements.

A brief description of LoRa physical layer is provided in this $\longrightarrow$ excerpt of "Wireless Communication Based on Chirp Signals for LoRa IoT Devices" by V. Fialhoab & F. Azevedoa (i-ETC: ISEL Academic Journal of Electronics Telecommunications and Computers, **4**(1), p.6.)

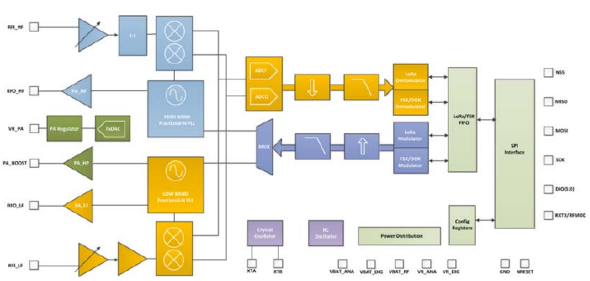
In Europe, the band allocated for LoRa communication is centered on 868 MHz.

1. What is the qualitative impact of emitting a LoRa signal from a low-Earth orbiting satellite when receiving from ground ?
2. What is the period of a satellite flying at an altitude of 500 km ? of 2000 km ? Justify. The third law of Kepler relating the period to the orbit with its semi-major axis (radius in case of a cicular orbit) might be used.
3. What is the range of velocities as seen from a ground-based receiver as the satellite rises over the horizon, at zenith and as the satellite sets below the horizon ? Basic trigonometry relating the position of this observer (at radius 6400 km from the center of the Earth) and the position of the satellite (at 6400+altitude) might be used.
4. Comment on the impact of the satellite motion with respect to the chirp bandwidth.
5. How can the motion of the satellite be compensated for on the ground based receiver ? What GNU Radio signal processing block implements such a functionality ?
6. LoRa aims at transmitting digital information over a wireless link. Why would they select a chirped modulation for such a task (what is the benefit of a chirp over a constant frequency pulse) ?
7. Based on the information collected so far, is a low-cost R820T2-based Digital Video Broadcast-Terrestrial (DVB-T) stick used as general purpose software defined radio receiver appropriate for collecting LoRa signals sent from space ? Justify.
8. While the maximum power transmitted by LoRa is 25 mW, we wish to save battery by only transmitting 10 mW and receive a signal at least 10 dB above noise floor of the receiver. According to the datasheet below, can this chip fitted with an omnidirectionnal antenna recover a signal transmitted from LEO satellites fitted with an omnidirectionnal antenna ?

SEMTECH LoRa™ **SX1276/77/78/79**

WIRELESS & SENSING PRODUCTS **DATASHEET**

SX1276/77/78/79 - 137 MHz to 1020 MHz Low Power Long Range Transceiver



GENERAL DESCRIPTION

The SX1276/77/78/79 transceivers feature the LoRa™ long range modem that provides ultra-long range spread spectrum communication and high interference immunity whilst minimising current consumption.

Using Semtech's patented LoRa™ modulation technique SX1276/77/78/79 can achieve a sensitivity of over -148dBm using a low cost crystal and bill of materials. The high sensitivity combined with the integrated +20 dBm power amplifier yields industry leading link budget making it optimal for any application requiring range or robustness. LoRa™ provides significant advantages in both blocking and selectivity over conventional modulation techniques, solving the traditional design compromise between range, interference immunity and energy consumption.

These devices also support high performance (G)FSK modes for systems including WMBus, IEEE802.15.4g. The SX1276/77/78/79 deliver exceptional phase noise, selectivity, receiver linearity and IIP3 for significantly lower

KEY PRODUCT FEATURES

- LoRa™ Modem
- 168 dB maximum link budget
- +20 dBm - 100 mW constant RF output vs. V supply
- +14 dBm high efficiency PA
- Programmable bit rate up to 300 kbps
- High sensitivity: down to -148 dBm
- Bullet-proof front end: IIP3 = -11 dBm
- Excellent blocking immunity
- Low RX current of 9.9 mA, 200 nA register retention
- Fully integrated synthesizer with a resolution of 61 Hz
- FSK, GFSK, MSK, GMSK, LoRa™and OOK modulation
- Built-in bit synchronizer for clock recovery
- Preamble detection

II. LORA CHIRP SPREADING SPECTRUM MODULATION

LoRa® wireless communication is based on chirp spread-spectrum (CSS) modulation scheme [5][6][7][8][9]. Chirp signal with in-phase (I) and quadrature (Q) is given by (1),

$$s(t) = e^{j(2\pi f_c t + 2\pi \frac{\beta}{2} t^2)} \quad (1)$$

where f_c is frequency carrier, β is frequency variation slope given by the ratio between bandwidth (BW) and time symbol (T_{symb}), as expressed by (2) [7][9]

$$\beta = \frac{BW}{T_{symb}}, \quad (2)$$

time symbol is given by (3)

$$T_{symb} = \frac{2^{SF}}{BW} . CR, \quad (3)$$

where SF is the spreading factor, e.g., number of bits per encoded symbol, and CR the code rate [7].

Figure 2 presents two signals normalized to T_{symb}: up-chirp (β>0) and a down-chirp (β<0). Assuming BW=f_1-f_0 with f_1 > f_0 positive slope is obtained, otherwise slope is negative.

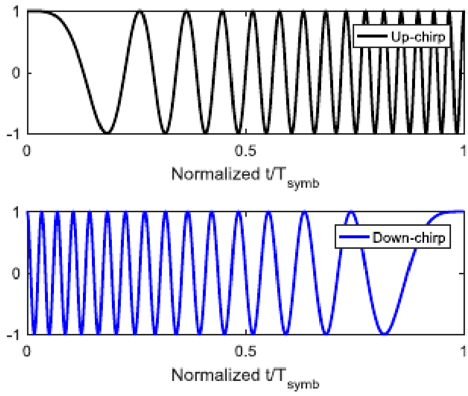


Fig. 2. Up and down chirp signals normalized to T_{symb}.

Chirp frequency variation can be represented as depicted in Figure 3. This graphical analysis allows T_{symb} estimation within a specific BW. It is also possible to infer the chirp slope.

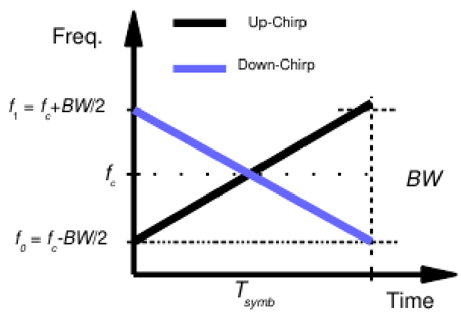


Fig. 3. Spectrogram representation: up-chirp and down-chirp.

According to LoRa® specification the BW, SF and CR may assume the values presented on Table I [7].

TABLE I

LORA® MODULATION MAIN PARAMETERS

Bandwidth (BW)	125 kHz to 500 kHz
Spreading Factor (SF)	7 to 12
Coding Rate (CR)	1 to 4

LoRa packet, presented in Figure 4, contains a preamble, composed by six up-chirps and two down-chirps configured with a specific SF and BW values. Data field contains optional header payload and payload cyclic redundancy check (CRC) value [6]. The CR value in this filed may change between the values presented in Table I.

9. If no, what solution might be used to improve the situation ? what might be the technical challenge of such a solution ? Justify the yes/no answer and argument for the challenge.
10. An amplitude modulated carrier of 868 MHz transmists a pure sine wave at 150 kHz. Draw the spectrum of the transmitted signal.
11. A R820T2 based receiver with 15 ppm frequency offset receives the signal sampled at 1 MS/s: draw the baseband signal as received by the DVB-T receiver.
12. The receiver decimates the dataflow by 5: draw the spectrum after decimation. Justify. If unsure, a GNU Radio simulation might be helpful.

1. Doppler induced frequency shift

2. $T^2/R^3 = cst$ with $R = (36000 + 6400)$ km for $T = 24$ h (geostationary orbit) $\Rightarrow T = \sqrt{\frac{(6400+500)^3}{(6400+36000)^3}} = 0.066$ days or 1.57 h ; $T = \sqrt{\frac{(6400+2000)^3}{(6400+36000)^3}} = 0.088$ days or 2.1 h.

3. tangential velocity is $2\pi(6400 + h)/T$ with $h = 500$ km for $T = 1.57$ h or $h = 2000$ km for $h = 2.1$ h so $v \in [25133 : 27614]$ km/h so that the project velocity towards the receiver is $v\frac{R}{R+h}$ with $R = 6400$ km the radius of the Earth, i.e. $v_{\|} \in [19148 : 25613]$ km/h= $[5319 : 7115]$ m/s. The frequency offset induced by the projected satellite velocity is positive when the satellite rises over the horizon, null at zenith, and negative when the satellite sets below the horizon.

4. Doppler shift: $df = f_c \times \frac{v_{\|}}{c} \in [15.4 : 20.6]$ kHz. The Doppler shift is small but not negligible with respect to the LoRa bandwidth

5. Doppler shift compensation might be needed for chirp pulse compression: the Xlating FIR Filter will take care of this operation (mixer + low pass filter)

6. the longer the pulse, the better the noise immunity (averaging) but the poorer the timing capability (bit rate). A chirp optimizes the tradeoff between timing accuracy (inverse of bandwidth B) and averaging duration T, as shown with the pulse compression ration $B \cdot T$

7. 500 kHz maximum chirp + $\pm$ 20.6 kHz frequency shift from the Doppler effect is much less than the 2.4 MHz sampling bandwidth of the DVB-T receiver, so yes the R820T2 based receiver can handle this signal.

8. 10 mW=10 dBm. Free Space Propagation loss at 868 MHz from 500 km to 2000 km: $20\log_{10}(d)+20\log_{10}(f)-147.55 =$ 145 to 157 dB. 10-145=-135 dBm while 10-157=-147 dBm. The 10 dB SNR is met with the lowest orbit satellite but not with the highest orbit.

9. directional antenna with some gain towards the Earth. However an antenna with gain is directional and must be steered as the satellite is flying overhead.

10. carrier+two sidebands at 868$\pm$0.15 MHz +

11. $868 \times 15 = 13.02$ kHz $\Rightarrow$ sidebands at -136980 and 163020 Hz.

12. decimate by 5 the 1 MS/s signal $\Rightarrow$ frequency range from -100 to +100 kHz $\Rightarrow$ aliasing. Carrier at 13.02 kHz and two sidebands at 63020 and -36980 Hz