

# Digital communication exam

J.-M Friedt, April 2, 2026 (+1.5 points/answer, -2 for stupidly copying chatbot replies)

Since November 2025, we have been recording from the ENSMM location the signals broadcast by radiosondes (Fig. 1), a radiofrequency emitter fitted to weather sounding balloons launched every day to assess the wind speed and direction, temperature and possibly ozone concentration in the atmosphere. Weather balloons will typically rise to an altitude of 30 km before bursting and letting the radiofrequency emitter free-fall.

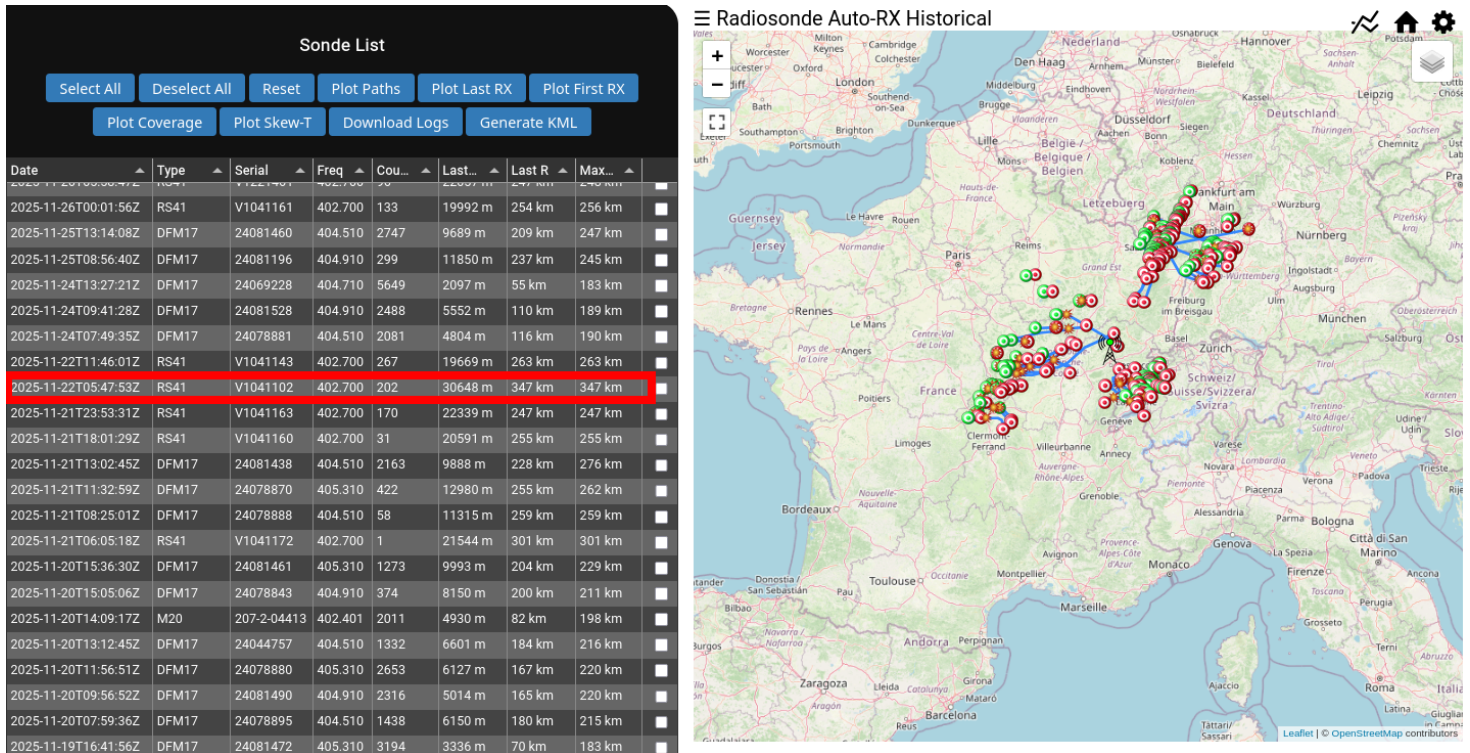


Figure 1: Screenshot of the history of received radiosondes, with the statistics on the left and the map of the weather balloons trajectories broadcast by the attached radiosonde. The largest communication range has been highlighted in red.

We are interested in analyzing the signal broadcast by one of the radiosondes, the Vaisala RS41 whose signal was recorded and shared at <https://www.sdrangel.org/iq-files/>. The archive is available, with some additional files, at [http://jmfriedt.free.fr/examL3\\_2026\\_TI.tar.gz](http://jmfriedt.free.fr/examL3_2026_TI.tar.gz).

1. Considering that the recording of the signal carried by a 402.7 MHz radiofrequency carrier is interleaved I and Q samples, each sample encoded as a 16-bit integer, and sampled at 31250 Hz, how can you estimate the duration of the recording from the file size, considering that there is no compression in the WAV file format?
2. Analyze the spectrum of the recording using your favorite digital signal processing tool. If using GNU Radio, notice that the WAV file format is supported through the WAV File Source set with *two outputs*, one for the I component and the other for the Q component, which can be assembled as a complex quantity through the Float to Complex block. What is the bandwidth used by the modulated signal?
3. We are told at <https://www.sdrangel.org/iq-files/> that the recording is offset by 10300 Hz: how do you center the signal on the baseband 0 Hz? Display the resulting spectrum.
4. We are unsure of the type of modulation used to broadcast the information. Try demodulating AM or FM and check which one is the most probable. You might get a hint from the shape of the modulated signal spectrum. Which modulation is most probable? Justify your decision.

5. The RS41 datasheet<sup>1</sup> states that the local oscillator can vary up to  $\pm 2$  kHz. What impact of this local oscillator error on the output of the demodulated signal?

Once demodulated, we assume that the information has been digitally encoded and transmitted, most probably at a fixed datarate. A traditional way of identifying the datarate of a digital communication is a cyclostationarity analysis as described by Daniel Estévez<sup>2</sup>: this technique considers the Fourier transform of the result of multiplying each sample  $x_n$  with the complex conjugate of the neighbouring sample (one sample earlier  $x_{n-1}$  or one sample later):  $|FT(x_n \cdot x_{n-1}^*)|$  displays a peak at the frequency matching the datarate.

6. Perform the cyclostationarity analysis on the demodulated signal: what datarate do you find as most probable, considering it might be close to one of the RS232 asynchronous communication datarates?

According to <https://github.com/rs1729/RS/tree/master/rs41>, “If the signal quality is low and (default) zero-crossing-demod is used, a lowpass filter is recommended...”.

7. Based on the observed datarate, how do you tune the low-pass filter and its transition width? How do you adjust the resulting datarate to use at best the computational power available for subsequent processing?

When a continuous stream is received, we must often identify the beginning of each frame. Indeed, a continuous stream of bits must be assembled as bytes and then as frames, and the beginning of each frame is often identified with a unique Synchronization Word, or Header. We are told<sup>3</sup> that the synchronization word for the RS41 is the bit sequence

```
00001000011011010101001110001000010001000110100101001000000111111
```

This sequence has been encoded as a single-byte integer in the header `.sigmf-data` file provided in the archive.

8. Assuming the wind can blow the weather balloon to a speed of up to 150 km/h: what is the resulting Doppler frequency shift on the carrier? How does it compare with the local oscillator inaccuracy? How does it impact your digital signal decoding capability?
9. How do you convert the continuous sample stream to hard bit states with a single sample for each payload bit?
10. Demonstrate how you can search for this header pattern in the demodulated signal stream. What is the name of the signal processing operation you implemented?
11. How often do you detect the start of frame pattern? Does it match the datasheet description of the message transmission rate?

The weather balloons can rise up to 30 km in altitude.

12. What is the maximum communication range on Earth? What would be the maximum communication range if we were probing the atmosphere of Mars (remember that Mars is about half the size of the Earth)?

The datasheet informs that the power radiated by the RS41 radiosonde is 60 mW.

13. What is the received power at maximum range? Since the radiosonde can rotate in all directions during its ascent and since the wind might push the radiosonde in any direction, what kind of antenna would you fit on the emitter? on the receiver? what is the associated antenna gain? Justify.
14. Based on the bandwidth observed earlier, what is the noise floor? The SNR? Justify.
15. The datasheet claims a maximum communication range of 350 km: what factor is limiting this range? Based on the previous analysis, how could you extend the communication range beyond 350 km by modifying the receiver setup only?

---

<sup>1</sup><https://docs.vaisala.com/v/u/B211321EN-L/en-US>

<sup>2</sup><https://www.gnuradio.org/news/2016-11-04-reverse-engineering-outernet/>

<sup>3</sup><https://github.com/rs1729/RS/blob/master/rs41/rs41.c#L69C18-L69C82>

1.  $62597016/31250/2/2 = 500.78$  seconds with 62597016 the size of the recording, 31250 the sampling rate, IQ interleaved and 2 bytes/sample
2. 6 kHz
3. **Frequency Xlating** FIR filter to move from intermediate frequency to baseband, setting the local oscillator to 10300 Hz
4. from the datasheet the modulation is GFSK (Frequency Shift Keying), as verified with the **AM Demod** block (no output variation) v.s **WBFM Receive** which displays the two bit states. The spectrum did display two frequency peaks which could hint at two bit states.
5. Frequency offset in a FM demodulator leads to a DC offset.
6. The cyclostationarity analysis displays a peak close to 4800 Hz, the most probable datarate.
7. Low pass filter and decimate
8.  $150/3.6 \times (402.7 \cdot 10^6/3 \cdot 10^8) = 56$  Hz  $\ll$  2 kHz with no impact on the demodulation capability since FSK is insensitive to the frequency offset
9. **Symbol Synchronization** and **Theshold detection**
10. **Correlate Access Code** with the provided sequence, see [https://github.com/bazjo/RS41\\_Decoding](https://github.com/bazjo/RS41_Decoding)
11. 1 message every second
12.  $d = R_{Earth} \cdot \text{acos} \left( \frac{R_{Earth}}{R_{Earth}+h} \right)$  with  $R_{Earth} \simeq 6400$  km and  $h \simeq 30$  km  $\Rightarrow d \simeq 620$  km. On Mars,  $d = R_{Mars} \cdot \text{acos} \left( \frac{R_{Mars}}{R_{Mars}+h} \right) \simeq 450$  km with  $R_{Mars} \simeq 3390$  km
13.  $\text{FSPL} = 20 \log_{10}(f) + 20 \log_{10}(d) - 147.55 = 20 \log_{10}(402.7 \cdot 10^6) + 20 \log_{10}(620 \cdot 10^3) - 147.55 = 140$  dB so the received power is  $10 \cdot \log_{10}(60) - 140 = -123$  dBm. There is no antenna gain since the antennas should be isotropic.
14. about 10 kHz bandwidth so the noise floor is  $-174 + 10 \cdot \log_{10}(10^4) = -134$  dBm so the signal to noise ration  $\text{SNR} = 12$  dB.
15. the range is not limited by the curvature of the Earth, so it must be limited by the receiver sensitivity: improve the signal power at the receiver by using a directional antenna and hence benefit from antenna gain in the link budget.

