Ground station Hardware

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Chapter 1

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In this chapter, the hardware used for the ground station will be explained. First with an overview of the total ground stations hardware, and following that an explanation of the individual parts.

1.1 Overview

The goal of the ground station, is to be able to communicate with the satellite, without human interference. This means that the ground station is to be able to receive data from the satellite, and send predetermined commands, and and other data to the satellite. To be able to do this a minimum amount of hardware is necessary. This minimum hardware is (see fig 1.1):
An antenna for receiving and transmitting the electro magnetic waves.
A radio transceiver to receive and transmit data.
A computer for data handling, and for decision making.

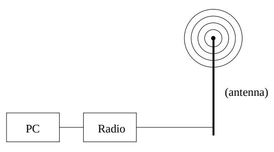

Figure 1.1: An overview of a minimum ground station

Apart from the minimum equipment shown above, further components are needed to fulfill the requirements of a well working satellite ground station. The final equipment setup can be seen in figure 1.2

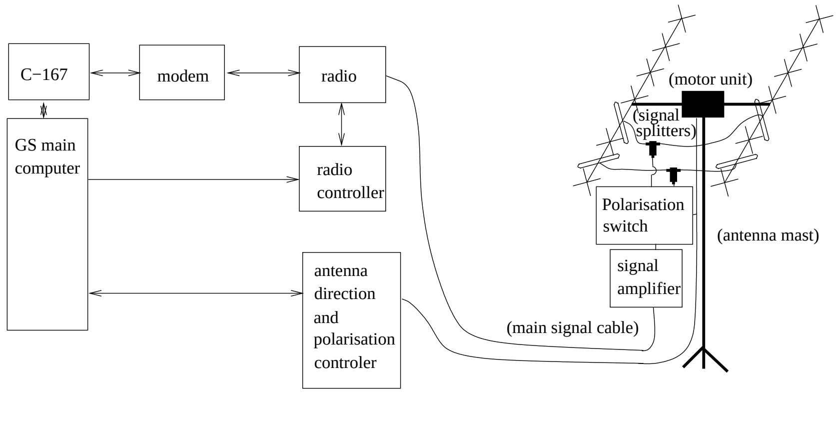

Figure 1.2: An overview of the chosen ground station hardware configuration

1.1.1 Location

In the following it is important to know whether different components will in doors or out door, and how far they will be placed from each other. Our chosen location for the antenna is on the roof of a building. The site is partly shadowed by a 4 meter high tower, so to avoid the shadowing effect of this tower, the antenna must be raised above its height. Together with the antenna, the mast, the signal splitter, polarisation switch and the signal amplifier will be positioned on the roof. All other electronic equipment will be located in a room below, which will be kept at normal room temperature, and humidity. The parts on the roof, will be connected to the rest through a set of 15 meter cables which is the minimum cable length between the top of the mast (at 4 meters height) and the equipment in the room below.

1.2 Antenna

When choosing the antenna, several things must be taken into consideration. First of all the antenna must be able to operate within the chosen frequency band of the radios. Secondly the antenna is to have as good receiving qualities as possible. Third the antenna must be able to withstand the weather conditions at the location of the ground station.

With the radio band determined to be in the amateur band (433 - 438), an antenna is needed that can operate with signals in this band. An estimate of the necessary gain of the antenna is around 15 dB.

When receiving a signal from a crossed dipole, as is the case with the satellite , the signal will be circularly polarised in the direction dictated by the crossed dipole antenna. To receive the full signal strength, a ground station antenna must be circularly polarised in the opposite direction of the satellites crossed dipole.

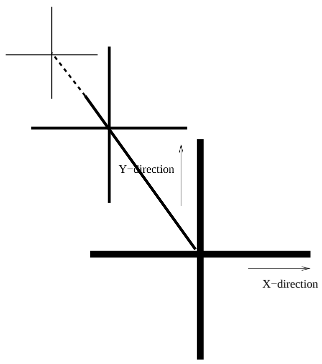

Figure 1.3: Ground station antenna dipole in X (horizontal) and Y (vertical) direction

This is done by delaying or lagging the signal between the X-directed dipole and the Y-directed dipole (see figure 1.3) by 90 degrees. This can be done by placing one antenna 1/4 wavelength closer to the satellite then the other, or by letting the signal from one dipole travel 1/4 wavelength longer through the cable before connecting the signals from the two dipoles. It must be remembered that 1/4 wavelength of the signal is not the same in a cable as in air. Which dipole must lag compared to the other is defined by what way the circular polarisation is wanted, and therefore by the satellite antenna. If the wrong polarisation is achieved, the signal received in one dipole will be nullified by the signal received by the other dipole, it is therefore crucial that the direction of the polarisation be correct compared to the polarisation of the satellite antennas. Finally the antenna must be able to withstand the local climate. This includes temperatures from -20 C to + 40 C and wind speeds of up til 45 m/s.

From these requirements an antenna of the type WX-706 from RF-connections was chosen. This is a 2X18 element crossed yagi directional antenna, with a gain of 14 dB. Since this is to small a gain to uphold the requirements of 15 dB, two of them where acquired and set up in a parallel configuration, as can be seen in figure 1.4, and thereby raising the gain with 3 dB and ending up with a total gain of 17 dB.

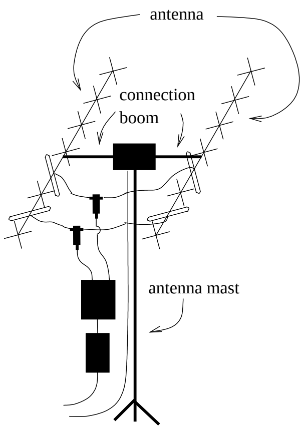

Figure 1.4: The antenna configuration

1.2.1 Signal splitter

Since the chosen antenna array has 4 individual feeders, the single signal from the radio to the antenna array must be split into the 4 feeders. Likewise the signal received from the individual feeders must be merged into one signal to the radio. This is done through two signal splitters. The chosen splitters are 2 - 1 splitter from RF-connection, as these splitter fit the chosen frequency, and supports the same cable size as the antenna and the radio.

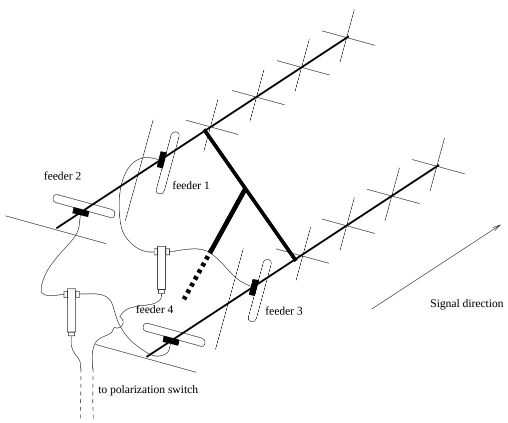

Figure 1.5: Setup of the signal splitter on the GS antenna

As can be seen in fig 1.5, the splitters are connected to the individual antenna feeders through 4 cables, and to the polarisation switch through two more. The cables to the individual feeders must be of a certain length compared to each other to ensure that the signals from the individual feeders are in phase when arriving at the splitters. The feeders that are parallel to each other must have cables of the same length and are connected to the same splitter. Two feeders that are perpendicular to each other must have a length difference in the cables so that the there will be a 90 degree phase shift of the received signal of one of the feeders compared to the other. Which feeder is to be shifted is dependent on whether a right handed or a left handed circular polarisation if wanted. On the chosen antenna array, there is a 24 cm distance between the feeders that are vertically polarised and the horizontally polarised feeders (see figure 1.6).

This distance will, because it is in the signal direction, give a phase shift between the signal received at the vertically polarised feeders and the horizontally polarised feeders. This shift must be taken into account when calculating the cable length to the individual feeders.

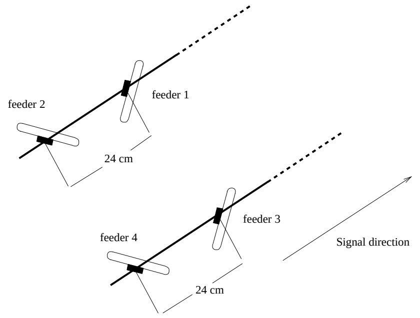

Figure 1.6: Physical distance between the feeders in the signal direction

1.2.2 Polarisation switch

If the direction the satellite will be pointing was known to be the planned, the chosen circular polarisation of the signal would be known and the right phase shifting could be done on the ground station antenna. Unfortunately if the satellite is pointing as planned, that is that the antenna side of the satellite is pointing towards earth, the polarisation will be in one direction (see figure 1.7 a), but if the satellite is turned 180 degrees the polarisation will be opposite (see figure 1.7 b).

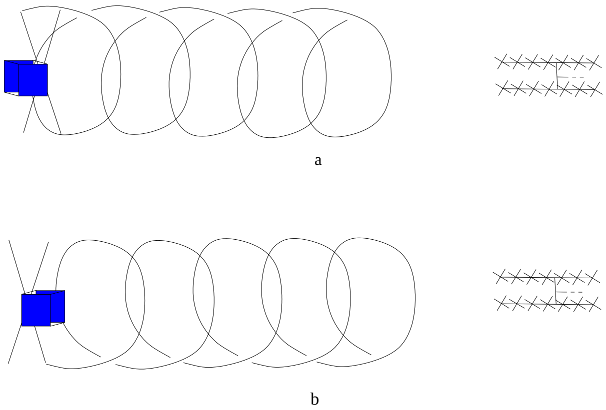

Figure 1.7: (a)The right hand or clockwise polarisation, (b) the left hand or counter clockwise polarisation

This means that the polarisation of the ground station antenna must be changeable. This is done by using a polarisation switch. This switch must be able to switch between right hand circular polarisation and left hand circular polarisation. The chosen switch is a remote polarisation switch from Wimo.

The two input signals from the splitters must be in phase at the switch, so the 24 cm distance between the feeders must be compensated for in the cable lengths from the splitters. This distance results in a phase shift given by equation 1.1

$$\begin{aligned} \lambda &= \frac{c}{f} \\ ps &= \frac{d}{\lambda} * 360^0 \end{aligned} \qquad (1.1)$$

Where:
λ is the wavelength of the radio signal travelling through air.
c is the velocity of electromagnetic waves through vacuum.
f is the frequency of the radio signal
d is the distance between the feeders.
ps is the phase shift caused by this distance.

With a frequency of 437 MHz and the distance between the feeders being 24 cm, or 0.24 m, equation 1.1 becomes:

$$\lambda = \frac{3 * 10^8 m/s}{437 * 10^6 Hz} = 0.69m \tag{1.2}$$

$$ps = \frac{0.24m}{0.69m} * 360^0 = 125^0 \tag{1.3}$$

The appropriate cable length to compensate the 125^0 phase shift can be found as follows (see equation 1.4 and 1.5)

$$\lambda_c = \frac{c * f_v}{f} \tag{1.4}$$

Where:
λ_c is the wavelength of the radio signal travelling through the cable.
f_v is the velocity factor between the radio propagation in vacuum and through the cable.

With a velocity factor of 66 % the above gives a wavelength in the cable of 45 cm or 0.45 m. This means that 0.45 meters of cable would give a phase shift of 360^0. This can then be used to find the required phase shift in the cable. This cable length can be found with equation 1.5

$$d_c = \frac{ps_c * \lambda_c}{360^0} \tag{1.5}$$

With d_c being the difference in cable length between the front feeders and the rear feeders, the above becomes:

$$d_c = \frac{125^0 * 0.45}{360^0} = 15.6cm \tag{1.6}$$

1.3 Antenna mast

The function of the antenna mast is to clear the antenna of any obstacles so that it will have a clear view of the satellite. It must also assure free movement of the antenna, since it is a directional antenna, and therefore must be pointed at the satellite when transmitting and receiving. At the chosen location the antenna must be lifted to a hight of 4 meters to have a clear view of the satellite. The antenna must of course be able to withstand the weight of the antenna array, and the wind pressure the wind causes on the antenna. This maximum wind pressure for the chosen antenna is 88N at 45 m/s wind speeds ([rf conections, 2002]). Since we are going to have two of these antennas in the array, the maximum wind load will be 176N at 45 m/s. To be on the safe side, the mast requirement is set to 200 N horizontal pressure on the top of the mast. Likewise the total weight of the antenna array will be 2 X 3.1 kg ([rf conections, 2002]) + the weight of the boom connecting the two antennas. We therefore set the requirements to 10 kg or approximately 100 N of vertical pressure on the top of the mast.

For the sake of future use after this project, it has been chosen to build a modular antenna. This antenna is a series of modular joints, that fit to normal water pipes, or any other pipe or rod of the appropriate diameter. In this way, one only has to cut the pipes to the appropriate lengths, and the antenna mast can be assembled on site. This also has the advantage of being able to fit the antenna precisely to the site. Figure 1.8 shows the individual modules used for our antenna mast.

Both the centre pole and the four support poles are of galvanized iron and have an outer diameter of 48 mm and a thickness of the iron of 4 mm. These are standard water pipes.

The fully assembled antenna mast can be seen in figure 1.9.

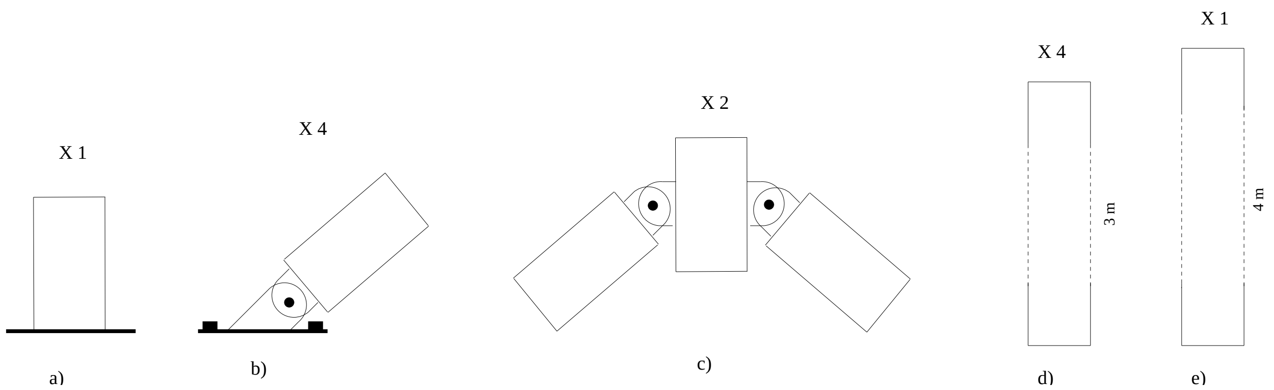

Figure 1.8: The individual antenna parts: a) centre support b) support foot c) support beam joint d) support poles e) centre pole

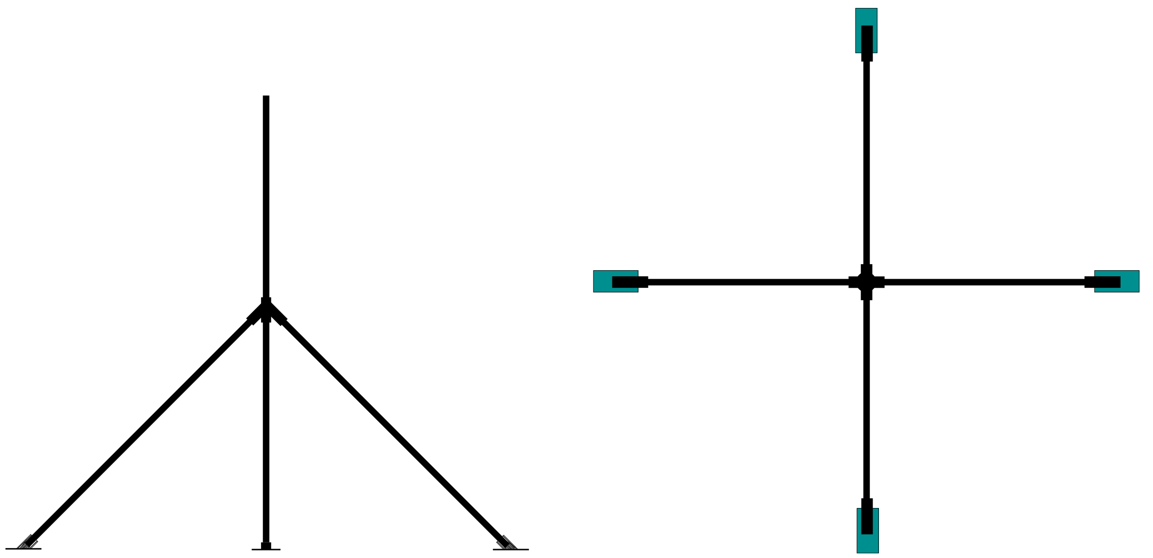

Figure 1.9: The fully assembled antenna mast, side view (left) and top view (right)

1.3.1 Antenna directional motor

To allow the antenna array to follow the satellite across the sky, a double antenna motor is mounted on the top of the antenna mast. The requirements for this motor are the same as mentioned for the antenna mast. It must withstand the wind pressure of 200 N from the antenna array and must be able to withstand the weight of 100 N from the array. More importantly it must also withstand the weather conditions mentioned earlier (see 1.2). The chosen double motor is the Yeasu G-5500, which fulfill the above mentioned requirements ([G-5500, 2002]).

Antenna motor control

To control the the antenna directional motor, a series of transistors are used to ground the appropriate control connections on the control box, and thereby turning the antenna in the wanted direction. The transistors are controlled by the I/O board on the ground station computer. The position of the motors, and thereby the antenna, is relayed directly to the I/O board as one voltage level for the elevation, and one for the azimuth. The setup can be seen on figure 1.10

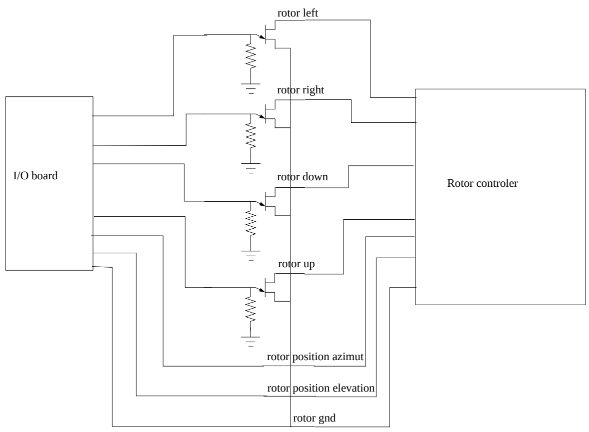

Figure 1.10: Setup of the motor control

Polarisation switch controller

To control the polarisation switch a 4 wire logical interface is needed and therefore the same I/O board which is used to control the antenna motors is used.

1.4 Radio

As mentioned earlier (see 1.2) the operating frequency band will be around 437 MHz. For this we need a radio transceiver that can operate in this band. An estimate of the needed transmitting capability is of min 50 Watts. Another requirement is that the radio must be controllable from the ground station main computer. Apart from that there are certain functions that could facilitate the work on the ground station. These are frequency scanning, automatic frequency control, and adjustable squelch level.

Frequency scanning is needed for finding the receiving frequency should the calculated frequency be off. This scanning could be implemented in the software of the ground station main computer, but it would be easier if it where an integrated part of the radio.

Automatic frequency control, is a function that once a signal is found, will scan the nearby frequency for the optimal reception of that signal. This function can be used for tracking the frequency as it shifts throughout the satellites over-flight over the ground station. This expected frequency shift is the one caused by the Doppler effect, and according to tests with satellites with similar communication frequencies, and similar orbits, the size of these shifts are just under + 10 kHz in the amateur band.

Adjustable squelch level will let us decide how strong a signal must be received before it will be acknowledged as an acceptable signal, and communication can commence.

To fulfill the above mentioned requirements, the ICOM IC-910H radio transceiver was acquired. This is a transceiver that can work in the 144 MHz band as well as the 430 - 440 MHz Band. In the required 433-438 MHz band the radio can transmit with a maximum effect of 75 Watts, which is well above the above mentioned required transmitting power. The wanted features are integrated in the radio, and remote controlling from the main computer is possible through a serial connection. This connection though is not at the same voltage level as th RS-232 serial port on the computer. Therefore a level converter is required for the radio control.

1.4.1 Radio control level converter

As the voltage levels on the RS-232 port are $0 - 5$ V and the voltage level on the radio end of the link is ± 12 V a level converter is needed. A official level converter can be purchased by the manufacturer of the radio, but at a HIGH price (over 100 $). This is a bit steep considering that all that is needed is a MAX 232 or similar IC and some 4 capacitors. Below are the schematics we used for our level converter 1.11.

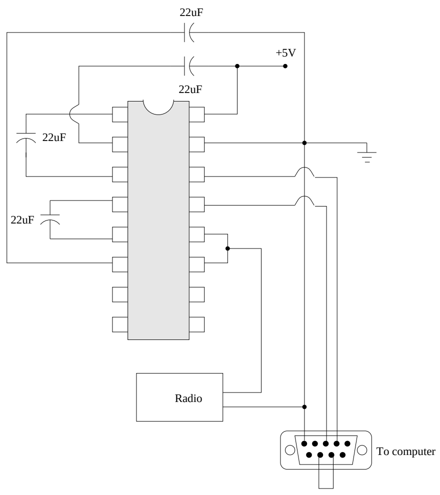

Figure 1.11: Schematics of the radio level converter

The above design is found from the net, and has been satisfactorily tested.

1.4.2 Radio power supply

The radio requires a 12-15 V 25 A power supply to run at its full potential. The manufacturers suggest the use of a car battery, since this gives a very stabile power supply. Of course the battery must be recharged, so a ordinary car battery charger is connected to the battery which again is connected to the power input of the radio. this is a cheap and reliable solution, but the out gassing of the battery during charging and discharging must be taken care of since this out gassing is both flammable and poisonous. Therefore the battery will be placed outside in a waterproof box.

1.4.3 Main signal cable

For the main signal cable, the radio manufacturer recommend a 1mm 50 Ω coaxial cable. The chosen cable has a dampening of 8 dB/100m. With a total of 15 meters of cable between the antenna and the radio, this gives a total signal dampening of 0.24 dB.To avoid loosing to much of the signal, the signal must be amplified before it is sent through the cable. For this a signal amplifier is needed.

1.4.4 Signal amplifier

From the connection on the antenna to the the location of the radio, the received signal will have to travel a minimum of 15 meter. This is done through the main data cable. This cable will dampen the already weak signal, and thereby worsen the signal to noise ratio. To avoid this, a low noise preamplifier will be set up as close to the signal splitter as possible. This will amplify the signal, before it is sent through the cable to be received by the radio and thereby ensure a strong signal to the radio. For this purpose, a SP-7000 from SSB-Electronic Gmbh, has been acquired. This model has a signal gain of 20 dB when receiving, and can withstand transmitting up to 300 Watts in the FM mode, which is plenty compared to the radio's 75 Watts. The amplifier is powered by the same supply as the radio.

1.4.5 Modem

The modem used is the same as used on the satellite - a MX909 and to control is a C167 MCU from Infineon mounted on a MCB167 evaluation board from Keil. The data comes from the radio and is demodulated in the modem and then the MCB167 receives the data from the modem over a parallel connection. It them relays the data to the ground station pc via a serial connection. The modem setup is done accordingly to the datasheet [ltd., 2002].

The ICOM radio outputs the signal with an amplitude of 500mV which is them amplified to the required 1V level for the modem. The radio requires a 750mV amplitude of the input signal while the modem outputs 1V. Therefore the signal is dampened with a OP-AMP. The entire schematic for the modem setup are shown in figure 1.12.

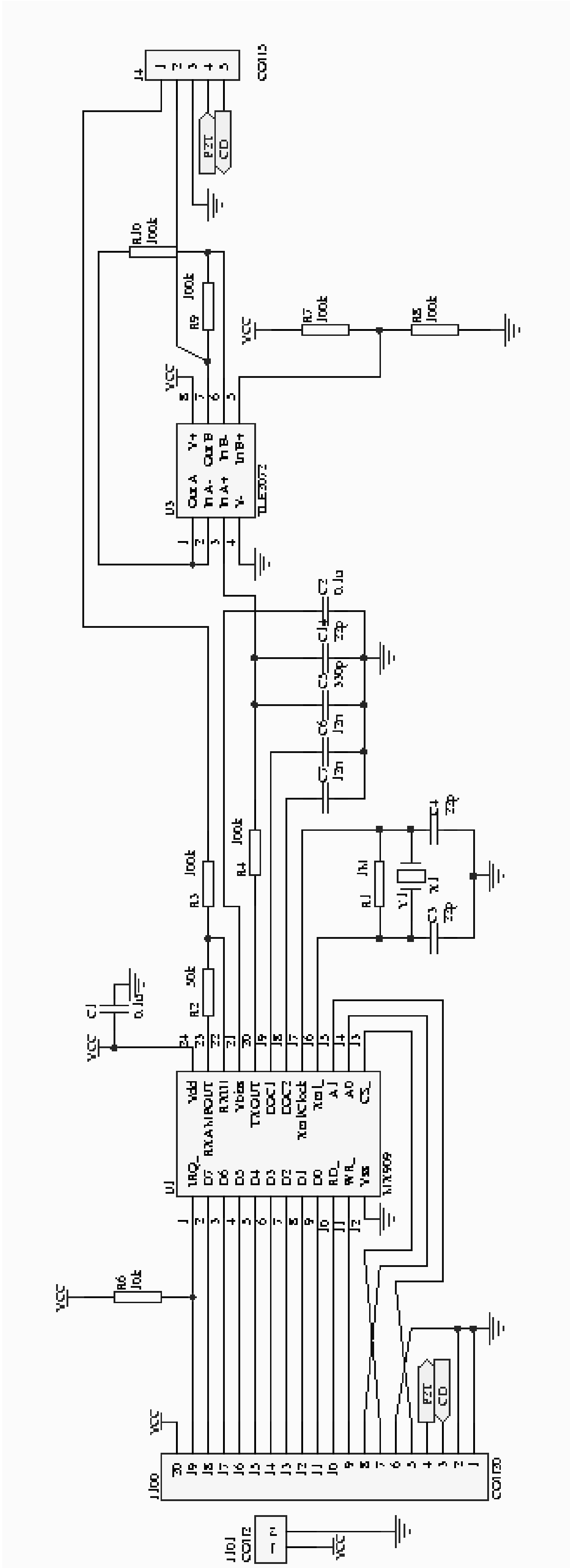

Figure 1.12: Schematics of the modem-print

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