LoRa-APRS via QO-100

Mobile operation over the geostationary Satellite Es'hail-2

1. Beginnings and link budget

On February 14th 2019 the first geostationary satellite with amateur radio payload was officially opened to the public. Two days before the transponders were opened for experimental operation. The evening on the very next day I was QRV on the narrowband transponder as one of the first Austrian amateur radio stations. At this moment the setup of my uplink station was very experimental. My FT-817 connected to an attenuator, output signal fed to a mixer to which a frequency generator was delivering the L.O. signal. The 2.4 GHz output was connected to a bandpass filter and then the signal amplified to be fed to the Uplink antenna (WLAN-grid dish) and I was ready for the first QSOs. Right from the start I was impressed how great the transponder was performing. A CW signal was readable, even if I used just 1 watt effective radiated power in linear polarisation. As the receiving antenna at the satellite is circular polarized, with a circular antenna at the ground station only 0.5 Watts would have been needed. At the above stated grid dish the input power was only 13 milliwatts. At this point is was foreseeable, that this bird will be very interesting for low power operation.

A bit later, at a flea-market where Om Wolfgang, OE3WHU gave me the idea, I got the ambition to build my own 13cm band transverter. A few months were passing by with conception, redesign, doing experiments and redesigns again, getting materials at flea-markets and on the internet, so finally in November my home-built transverter was finished.

Picture 1: Transverter from 70cm Band to 13cm Band

Parallel to the development and construction of the transverter I was asking myself if it would be possible to do mobile operation via QO-100 with just 20 Watts of RF power. I was especially interested in the question, if it would be possible to use LoRa-APRS via satellite to get whole European coverage (and of course much more than that) in addition to the terrestrial LoRa-APRS network.

Basis for this consideration was a roughly estimated link budget. I've made therefore some measurements. With about 600 W effective radiated uplink power (EIRP), I've got an SNR of 18 dB in a resolution bandwidth of 1 kHz. Considering the LoRa bandwidth of 125 kHz (actually used configuration for LoRa-APRS) and the associated increase in noise level of about 21 dB, as well as the LoRa sensitivity limit of -20 dB SNR, again considering the actual LoRa-APRS configuration, it would result in a minimum uplink power of 12 Watts. Assuming an antenna gain of about 0 dBi in 34 degrees elevation (I did not expect more from a dipole before the simulation with EZNEC was done, which will be described later), 20W output power with not too much cable attenuation would be just sufficient for my LoRa-APRS transmissions to be readable via QO-100.

2. Construction of the transmitting equipment

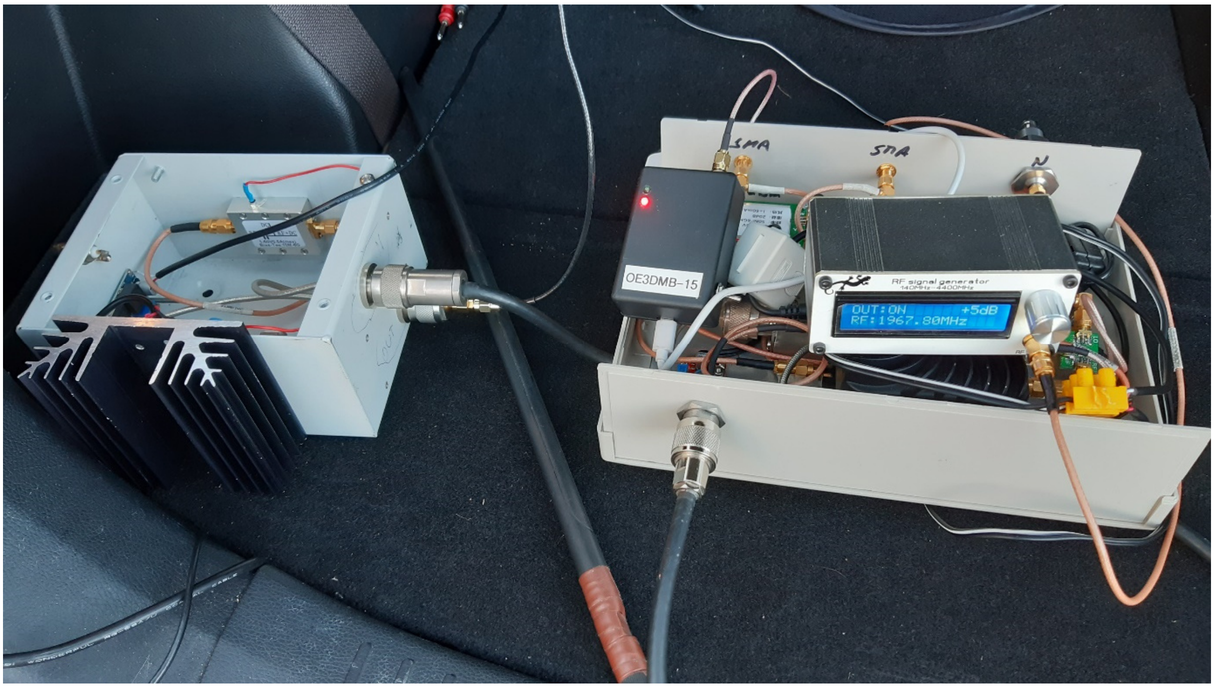
For the purpose of approving these considerations, the transverter was given a low-level input to get maximum output power from approx. 10dBm, additional to the radio connection, on which up to 1 W input power can be used on 70 cm. Since the transverter itself can only deliver a maximum of 4 W output power and considering the link budget, this power seemed to be too low to actually transmit the signal via satellite with a simple omnidirectional antenna. Therefore I bought the 13 cm power amplifier from sg- labs, which delivers an output power of 20 W with 0.5 W input power.

The finished transverter box now consists of a connection for the 70 cm radio, which works in both the transmit and receive direction (for terrestrial operation, for example in contests or via the 13 cm repeater at Wienerberg OE1XKU), a connection for a transmitter with low power below 10 mW, a local oscillator input and the 2.4 GHz output.

Components inside the transverter: A circulator (Flea market goods, serves as an attenuator in the transmit direction and lets the received signal pass through), a combiner for the radio- and Low-Level inputs, transmit mixer, SAW-Filter, amplifier stages and WLAN-power amplifier are the components used in the transmit chain. For the receive chain I've modified the WLAN-PA to get the received signal out through a second SMA connector, which is then fed to the receive mixer, who's output is connected to the circulator feeding the signal back to the 70cm TRX. The L.O. is connected to a buffer-amplifier and then to a splitter, feeding the signal to the transmit and receive mixers.

In addition to the already described modification of the WLAN power amplifier with its own RX output, I also modified the PTT switching, i.e. slowed it down so that a clear SSB signal can be transmitted and I also coupled the PTT signal with high impedance to the RF output, so the power amplifier can be switched remotely via the coaxial line.

The configuration for the mobile LoRa-APRS transmitter was now completed:



Picture 2: LoRa-APRS Equipment for transmissions on 2.4 GHz

Explanation of the picture: In the left box the power amplifier module is hidden behind the heat sink, a DC / DC step-up converter provides 28 V from the 12 V vehicle electrical system and Bias-T provides the control voltage for PTT switching by the transverter via the coaxial cable. On the top of the transverter box on the right in the picture, there is the LoRa-APRS tracker on the left and on the right the RF signal generator which generates the L.O. frequency for converting up to 2.4 GHz.

3. Antenna system

Before I went into satellite mode, I first proofed the concept terrestrially at 2.4 GHz. To do this, I used the rather long omnidirectional antenna, which according to internet information should have a gain of 12 dBi, which is located in the photo in the middle between the transverter and the power amplifier, on a magnetic mount (everything from the area of the WiFi community) to transmit my signals. At home I converted the signals back to 70 cm with a second 2.4 GHz transverter and fed it to my LoRa receiving gateway. The receiving antenna at home in this case was a panel antenna, which is aligned with the 13 cm FM repeater at Wienerberg, which I also care for. This enabled me to receive my signals from the southern border of Vienna at home in Münchendorf, about 15 km away.

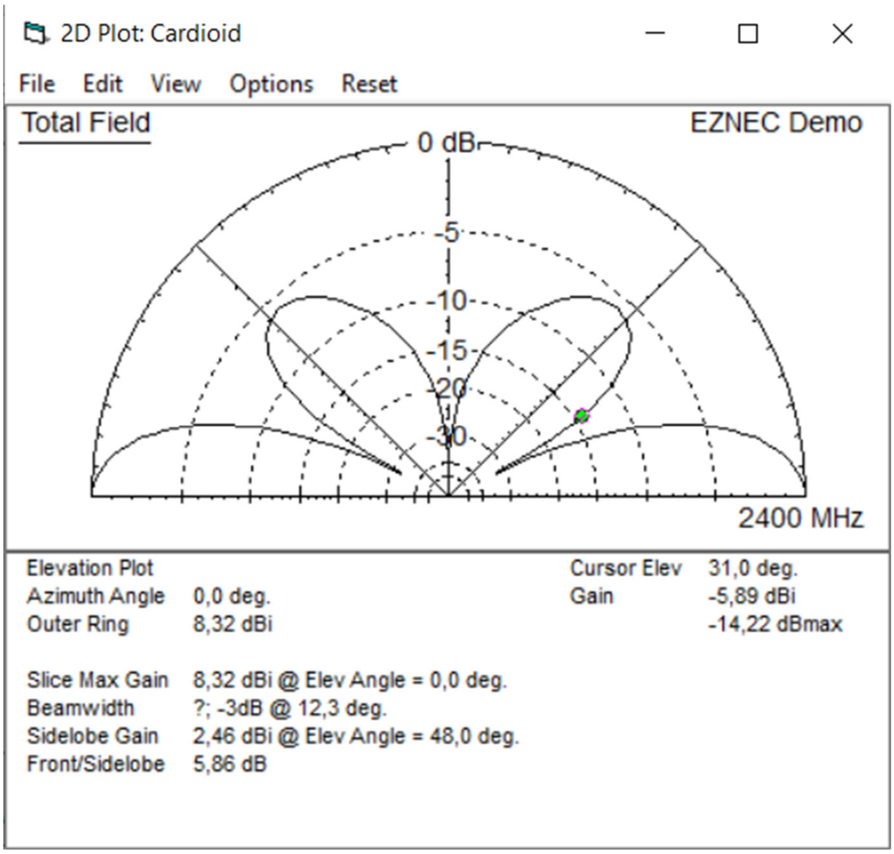
LoRa on 2.4 GHz was a success. Now it was time to realize satellite operation. Of course, a completely different antenna is required for this purpose than for terrestrial operation. While I used an antenna that was deliberately concentrated in the plane for terrestrial operation in order to bring as much effective radiated power as possible from the transmitter to the receiver without elevation, the antenna for satellite operation must of course radiate upwards rather than in the plane. In our latitudes, the elevation angle to QO-100 is about 34 degrees. A simple dipole antenna above a large ground surface (car roof) radiates a not inconsiderable portion relatively steeply and seemed to be a good solution. Again, I found what I was looking for in the WLAN area and so I screwed this small WLAN antenna onto the magnetic mount instead of the long vertical antenna, as can be seen in the photo on the following page.

So now I was able to start. I made my first attempts on the narrowband transponder, because it delivers higher signal levels and signal-to-noise ratios, at least on my relatively small 60cm offset dish antenna. The first attempts showed a quite interesting behaviour. It is not easy to see in the photo, but the antenna on the magnetic mount is not in the middle of the car roof. This is due to the fairly short coaxial cable, which I deliberately took in order not to bring excessive cable loss into my transmission system. The approx. 1.5 m long cable already has 3 dB attenuation, so only half of the generated power actually comes to the antenna anyway.

Picture 3: small WLAN Antenna on the magnetic mount on the car roof

It turned out that the signals arrived much stronger when I was travelling north or west than when I was driving south or east. Since the antenna is placed on the left, rear part of the car roof, so there is significantly more ground area in the direction of radiation when I drive south or east, I expected better results in those directions. But it was exactly the other way around. Travelling north or west, I achieved LoRa-SNR values of about -15dB. However, in the other directions the SNR values were rarely above -20 dB or packets were often no longer decoded at all, since the SNR was too low. Since a car roof is of course never completely flat, the antenna also had a tilt angle of about 3 degrees to the left and to the rear due to its non-roof-centered position. In these directions, the elevation from the antenna was about 6 degrees higher than in the opposite directions. Again, I was surprised that the radiation was better at higher elevation angles than at lower elevation angles.

To better understand this effect, I tried to simulate the antenna configuration with EZNEC. My EZNEC model was a very simple half-wave dipole with a length of 6 cm and the phase centre 7 cm above an infinite ground plane. The simulation brought the following result:



Picture 4: Elevation plot simulated with EZNEC

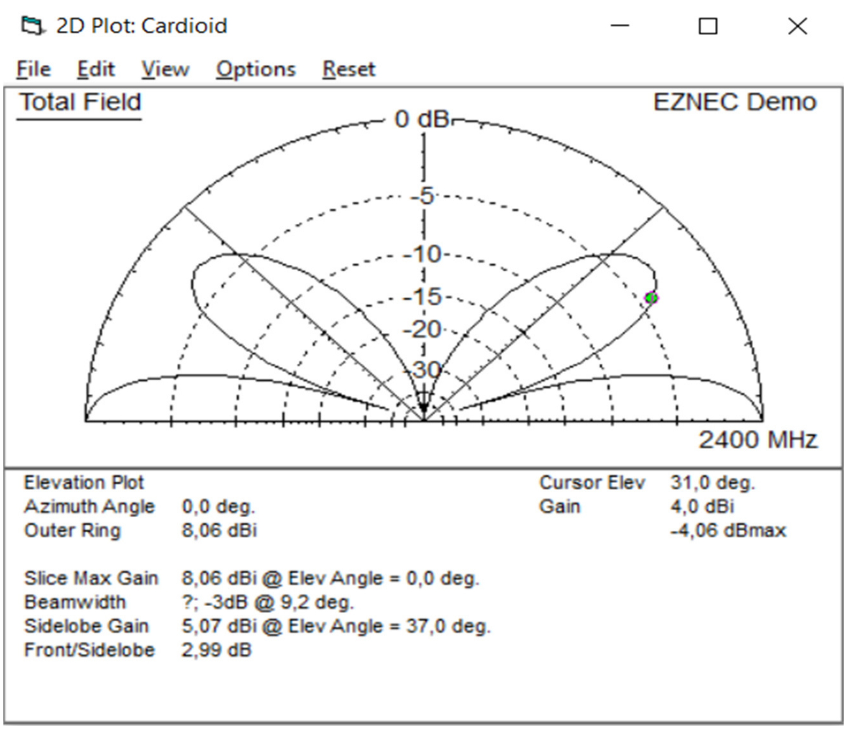
In picture 4 the marker is set at 31 degrees elevation. This corresponds to the radiation above the larger ground area with the antenna tilted backwards by 3 degrees. Here you can see that the radiation is much better at higher elevation angles. The marker at 31 degrees is approx. 5 dB lower than the gain at 37 degrees elevation. This corresponds very closely to the practical result that I described earlier.

Now I started changing the antenna configuration in EZNEC to achieve better characteristics in the required elevation angles. The diagram above shows the highest gain (apart from the radiation in the plane) at a bit more than 45 degrees. You would need this elevation in southern Italy, but not here in Austria. As already described above, the elevation for my area is about 34 degrees. As expected, the elevation angle for the best radiation decreases with increasing antenna height above the ground plane. The simulation showed that a 3 cm increase in antenna mounting would provide the best results.

Now I was looking for ways to increase the antenna height above the car roof. The easiest way seemed to me to screw two adapters between the antenna and the magnetic mount. The result was an antenna that was “raised” by 2.5 cm. While car drivers like to lower their vehicles, I do the opposite with my antenna hi.

Picture 5: Antenna raised by 2.5 cm with 2 adapters

2.5 cm increase is close to the optimal configuration, but I wanted to know it exactly and I simulated this new configuration again with EZNEC.



Picture 6: Simulation of the 2.5cm raised antenna

The simulation showed now the maximum gain at 37 degrees elevation, but at 31 degrees only about 1 dB lower gain. In absolute terms, the gain of the higher antenna in the simulation is now at 37 degrees about 4 dB higher than in the original configuration, at 31 degrees even almost 9 dB higher than before.

In practice, it turned out that these values were not reached exactly, the car roof is not an infinitely large ground plane. However, travelling north and west I got now -12 dB SNR, i.e. 3 dB more than before the antenna was raised and in directions east and south only about 1 to 2 dB less than in the opposite direction. All in all, the simulation went very well with practice and changing the antenna height was a complete success.

4. Results in practical operation

As the narrowband transponder, as the name suggests, is not intended for wideband applications and also during busy times (e.g. Saturday in the afternoon) the radio signal strength indicator (RSSI) of my receiving station increased due to the busy transponder and thus my SNR decreased, so the next step was to switch to the wideband transponder.

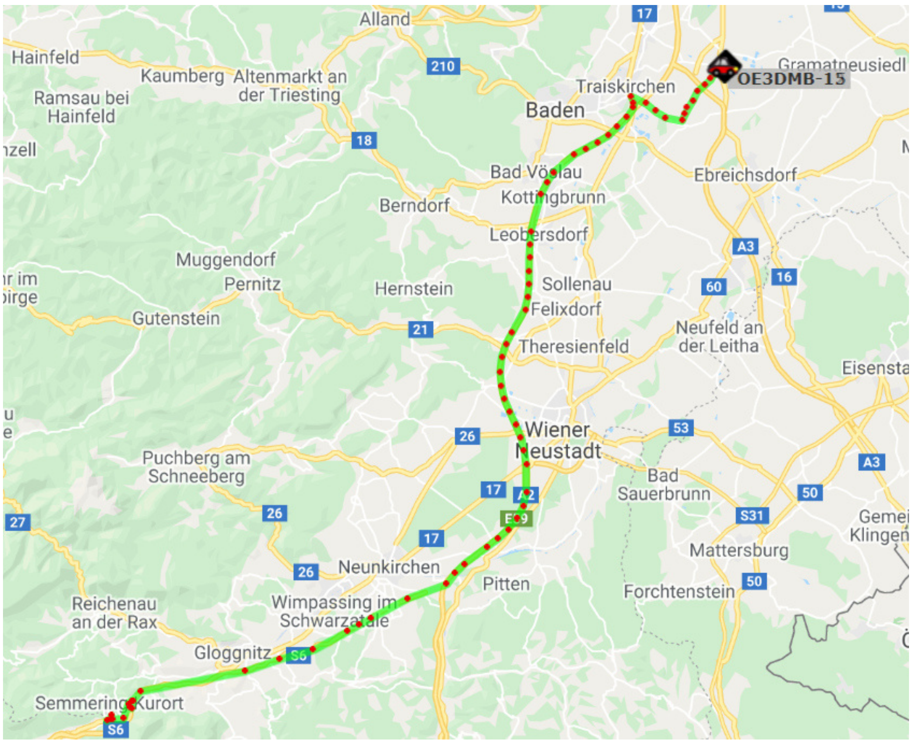
I chose the uplink frequency as follows:

433,775 MHz (LoRa-APRS 70cm frequency) + 1967,800 MHz (Local oscillator) = 2401,575 MHz.

The downlink frequency at the wideband transponder therefore was 10491,075 MHz.

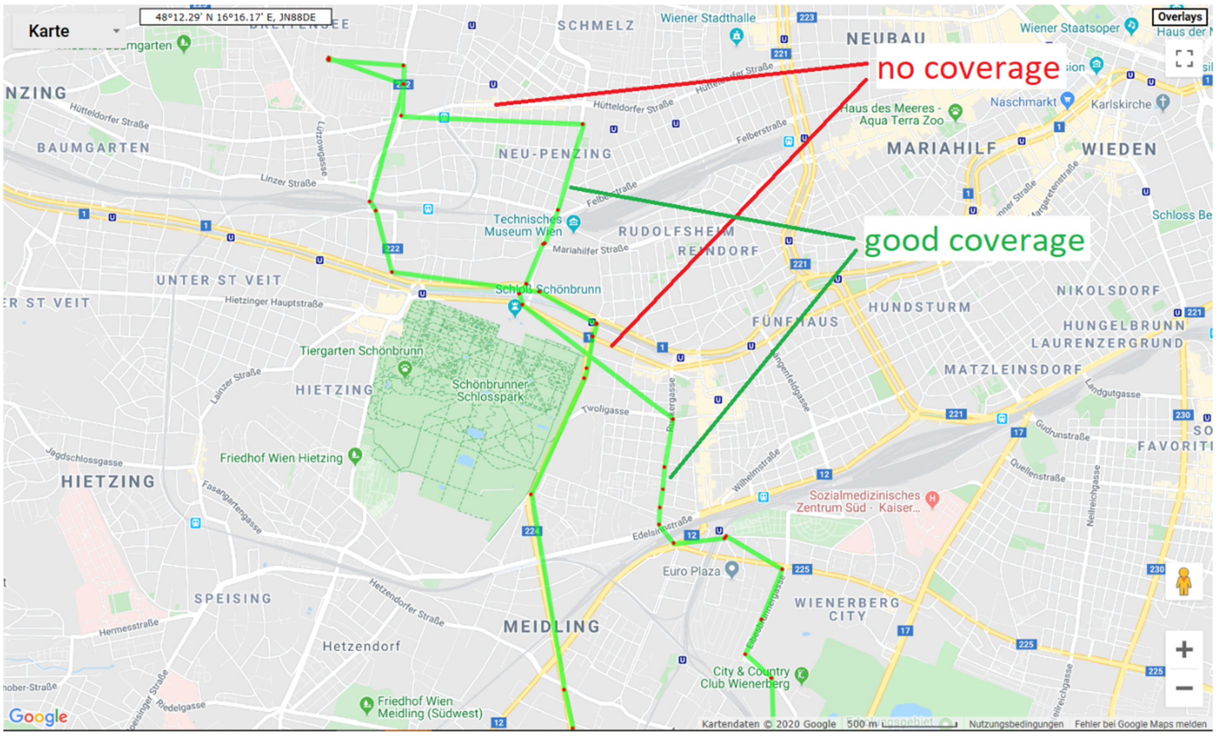
So I was at the bottom of the transponder passband and practically in the guard band of the 2 MS/s DVB-S2 DATV beacon of the satellite.

As expected, the results were around 3 dB worse SNR values, but still completely sufficient for practical use.



Picture 7: APRS track via QO-100 on the way home from Semmering to Münchendorf

With a clear view of the sky (highway or overland travel on flat terrain), almost every transmitted packet is received and displayed. On the S6 near Semmering, where you sometimes drive in the valley between striking elevations, you are often shaded to the south.



Picture 8: APRS track within the city of Vienna

The coverage is even useable in the inner city. It can be seen quite good, that on streets that are open to the south, the positions can be received reliably, while this is only very rarely the case with streets facing east-west, because you are of course shaded by buildings most of the time.

By the way, I did not miss the chance to connect my FT-817 to the second input of the transverter to try an SSB-QSO with the same antenna configuration over the narrowband transponder. In fact, I was able to have a QSO in this mobile setup with a German station. My signal was just a little bit above the noise floor and accordingly difficult to receive, but for mobile operation it was a really great result. In this case, I chose the WEB-SDR on the smartphone for receiving the downlink signal. The funny thing is, my transmission started at 2.4 GHz in the uplink to QO-100 (apart from the FT-817 at 70 cm, this signal was generated but not transmitted) and ended again at 2.4 GHz when transmitted from the smartphone to the Bluetooth speakers in the car.

5. Conclusions

All in all, my experiment showed that LoRa-APRS can be realized via QO-100 using relatively simple means. However, I would like to state that I do not plan to install a permanent ground station for reception, nor do I want to use my calculation example above to define a frequency for this application. Should my experiment actually result in a permanent use case (which I would be very happy about and proud of and I could imagine it as very useful for various situations where terrestrial network coverage is not feasible), this would of course have to be done in coordination with the satellite operator, so that a 125 kHz frequency segment could be reserved for this application.

With best 73's de Andreas, OE3DMB