Digital Voice on Amateur Satellites: Experiences with LilacSat-OSCAR 90

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While narrowband digital text modes like PSK31, JT65, and FT8 have swept HF, and digital voice modes such as DMR, D-STAR, and C4FM have proven quite popular for terrestrial VHF and UHF repeaters, digital voice modes have not come into common use either on HF or amateur satellites. This paper will discuss ideas for the future use of digital voice modes on amateur satellites by exploring the author's experiences with LilacSat-OSCAR 90, an amateur satellite featuring a transponder with an FM uplink and a Codec2 downlink.

About LilacSat-OSCAR 90 (LO-90)

LilacSat-1 is a 3U CubeSat that was constructed at the Harbin Institute of Technology in Harbin, China as part of the QB50 mission to study the lower thermosphere. The satellite was deployed from the International Space Station on May 25, 2017. The satellite's primary payload is an ion and neutral particle mass spectrometer developed by the University of London.[1] The satellite's amateur radio capabilities include a transponder with a 145.985 MHz FM uplink and a 9600 bps BPSK downlink at 436.510 MHz. Downlink power is 200 or 500 mW. Amateur operators may also operate the satellite's onboard camera by sending a 1000 bps AFSK AX.25 UI command.[2] The downlink accommodates telemetry, camera, and voice in the same stream. A 7 byte 1300 bps Codec2 frame encoding 40 ms of the FM uplink audio is included in each 120-byte packet. The remaining space in each packet is used for telemetry and camera data (sent in JPEG format). More details about the downlink format can be found at **destevez.net/2017/05/low-latency-decoder-for-lilacsat-1/**.

LilacSat-1 was designated LilacSat-OSCAR 90 or LO-90 by AMSAT on June 20, 2017. Unfortunately, as it was deployed from the ISS, its remaining lifetime is limited. As of this writing, LO-90 is in an orbit of 301 km x 298 km with an inclination of 51.6 degrees. Calculations by Mike Rupprecht, DK3WN, predict a decay date of March 25, 2019.[3]

About Codec2

Most amateur radio digital voice modes utilize a proprietary codec from a family known as AMBE (Advanced Multiband Excitation). DMR, D-STAR, and C4FM all use versions of AMBE. Codec2, on the other hand, is a fully open source speech codec designed for low-bitrate digital voice communications. Bitrates of between 700 and 3200 bps are available. Most amateur radio use of Codec2 is in the form of FreeDV, a digital voice software package utilizing the Codec2 voice codec, FDMDV modem, and forward-error correction. FreeDV allows amateur radio operators to easily use digital voice on standard HF SSB transceivers using the same equipment used for soundcard digital modes, such as FT8 and PSK31, on HF (though an additional soundcard is generally necessary). FreeDV is robust – the 700D version outperforms SSB in poor conditions.[4]

Operating through LO-90

Utilizing LO-90's FM to Codec2 transponder requires nothing more than a 2 meter FM transceiver (a 5 watt HT is sufficient), a modern computer (most laptop or desktop computers from the last decade should suffice), an adequate antenna (a handheld Arrow Antenna works well), and a software-defined radio receiver (a $22 RTL-SDR.com USB dongle is sufficient, a FUNcube Dongle or AirSpy will provide better results). The challenge in receiving the downlink is on the software side. The available decoders are GNU Radio flowgraphs available only for Linux systems. Although it may technically be possible to compile these decoders for MacOS or Windows systems, it would require significant effort. Fortunately, M6SIG produced a live ISO image containing the necessary tools that can be downloaded and imaged to a USB stick.[5] This image is based on Ubuntu and will boot and run on most modern systems. The other option is to install these decoders on an existing Linux system. However, successful installation does require moderate Linux experience. Installation steps vary by distribution.

The decoders provided by the Harbin Institute of Technology, gr-lilacsat, work well but have a significant handicap. These decoders wait until an entire frame is received before passing the voice data to the Codec2 decoder. This introduces 200 ms of latency. Daniel Estévez, EA4GPZ, includes a low-latency decoder that passes the voice data to the Codec2 decoder as soon as it is received in his gr-satellites package.[6]

Once the software is up and running, the operating experience is similar to any FM satellite. FM transmissions with a 67.0 Hz tone are encoded in the satellite, then transmitted, and received and decoded by the software. The audio produced is clearly digital, though with good signals, it can be quite pleasant.

Unfortunately, LO-90 has not seen widespread use, likely due to a general unfamiliarity with Linux among most amateur radio operators. Only 10 stations in North America are known to have completed a QSO via LO-90 as of this writing:

K0FFY
N6RFM
K4KDR
N8HM
KB1PVH
NB3T
KC4LE
VE7CEW
KE8FZT
W2RTV.

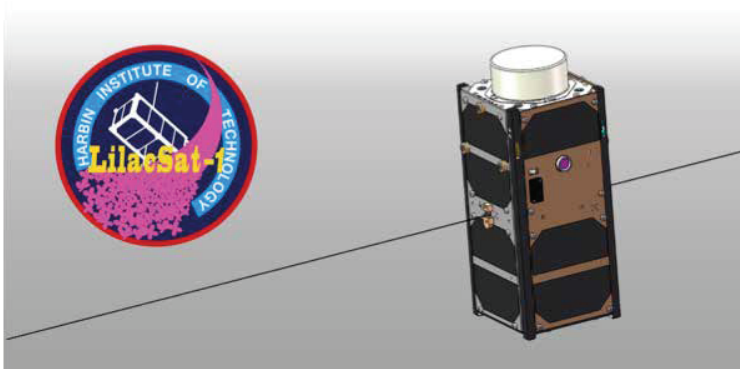Below are screenshots of various setups used by several different stations.
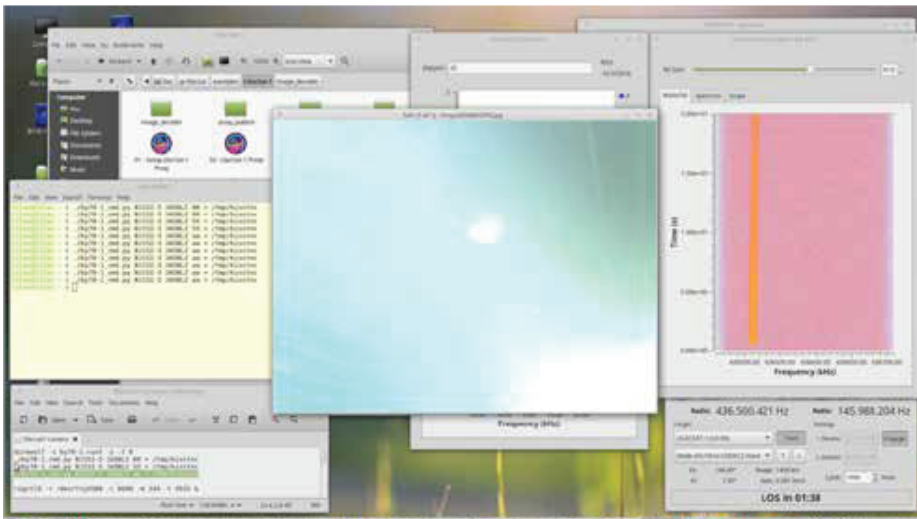

Figure 1 – LilacSat-1.

Figure 2 – A screenshot from JA5BLZ using the gr-lilacsat tools and commanding the camera on Linux Mint.
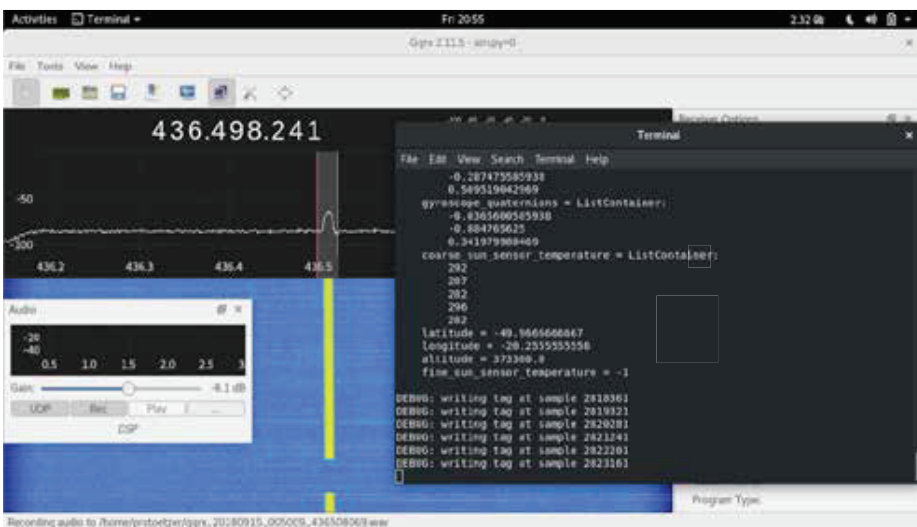

Figure 3 – A screenshot of the author operating through LO-90, using EA4GPZ's gr-satellites decoder on Fedora 28.
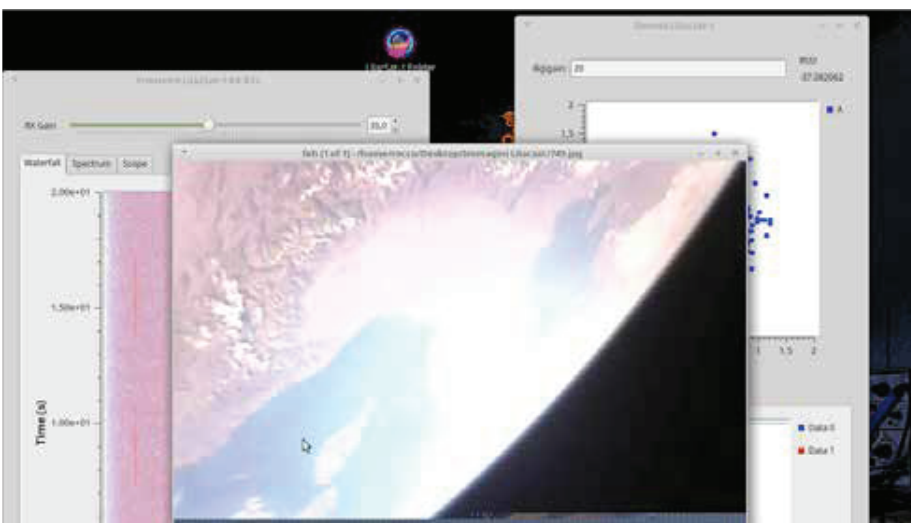

Figure 4 – IK8XLD receives most of an excellent Earth image with gr-lilacsat.

The Author's Portable LO-90 Station

I currently live in an apartment building in Southwest Washington, DC. This requires me to operate fully portable and often to move around the building during a pass. This requires an entirely portable solution that can be used and carried around during the pass. In August 2018, I acquired a GPD Win. This is a handheld computer designed as a portable computer for playing PC games on the go (there is an integrated game controller pad). This computer features an Intel Atom X7-Z8750 processor capable of operating at up to 2.56 GHz, 4 GB of RAM, and 64 GB of eMMC storage. While these are low-end specifications, it is plenty of power for narrowband SDR applications. Immediately upon receipt, I wiped the pre-installed version of Windows 10 Home in favor of Linux. While my preferred distribution is Arch Linux, the GPD Win contains some odd hardware quirks, and I could not get it working, so I installed my second-favorite distribution, Fedora. All hardware worked out of the box on Fedora with just a minor tweak required to get the system's WiFi working. After installing Linux, my first goal was to get this working for use decoding the LO-90 downlink. Although it took the better part of a day, I was finally able to get EA4GPZ's gr-satellites up and running on the machine (attaching an external keyboard, monitor, and mouse would have sped up the process). After waiting for the next pass, I was able to confirm that everything worked as intended. I was now able to use LO-90 with a very small, portable setup as seen below.

To carry the equipment around, I use a Connect-A-Desk. This product is designed as a harness for a laptop computer. In practice, I find it difficult to use with a full-size laptop, especially when also carrying an Arrow Antenna. The GPD Win, on the other hand, is relatively convenient to use while being carried around this way.

Unfortunately, after just a few passes, I broke the USB connector off my FUNcube Dongle Pro+ while carrying it around dangling by the USB cable and coax. I replaced it with an AirSpy Mini. I also tested a $22 RTL-SDR. com dongle with adequate results.

One important note when operating this way – the third harmonic of the 2-meter transmitter significantly harms reception while transmitting. This can be cured with a diplexer or low-pass filter on the output of the 2-meter transmitter. Depending on the SDR, you may also encounter front end overload, requiring a filter on the input of
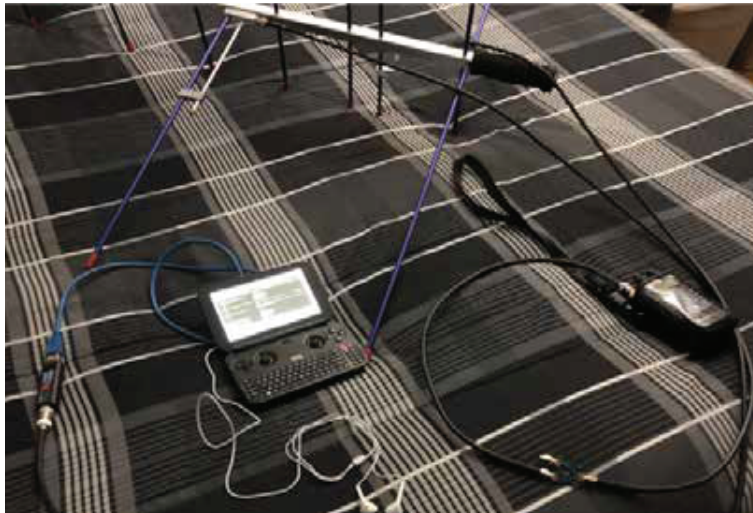
Figure 5 – The "World's Smallest LO-90 Station" - A GPD Win handheld PC, a FUNcube Dongle Pro+, an Alinco DJ-G7T HT, and an Arrow Antenna.

Figure 6 – The author's Connect-A-Desk with the GPD Win and an AirSpy Mini.

Figure 7 – LO-90 QSL Card.

the SDR.

Although this is not exactly a "grab and go" setup like an HT and Arrow Antenna for an FM satellite or even two FT-817s and an Arrow for linear transponders, it is a very portable setup and a good proof of concept for what is possible to do while portable.

Future Satellites Utilizing Codec2

Taurus-1, a 2U CubeSat developed by the AeroSpace System Engineering Research Institute of Shanghai plans to incorporate a VHF/UHF FM-to-Codec2 digital transponder similar to LO-90. According to the IARU coordination request, a February 2018 launch was planned.[7] However, no further information on the status of this project is available at the time of this writing.

Conclusion - The Future of Digital Voice on Amateur Satellites

As of this writing, LO-90 is the only satellite to have successfully demonstrated a digital voice mode in orbit. D-STAR ONE from German Orbital Systems was launched in 2018 but was not successful. Two other satellites, Oufti-1 and TableSat-Aurora, also included D-STAR systems but were not successful. D-STAR was successfully used through the AO-27 satellite in 2007, but this was simply using the satellite as a bent-pipe. A few attempts to make a FreeDV QSO on FO-29 have also been made. German Orbital Systems does plan another attempt at a D-STAR satellite and, as noted above, there is potentially another FM-to-Codec2 satellite in the works, but what about some other ideas for future projects?

Digital voice offers several advantages. The first major advantage is bandwidth. For example, AO-92 and Fox-1Cliff, the two AMSAT Fox-1 satellites with a camera, can not transmit images and voice at the same time. When the camera is operating, the transponder does not. In nearly the same bandwidth, LO-90 transmits telemetry, camera data, and voice data simultaneously. Activating the camera does not require the transponder to be deactivated.

Expanding upon this concept, perhaps a future satellite could include multiple channels of digital voice. LO-90 uses 1300 bps Codec2. Utilizing 700 bps Codec2, possibly two channels of voice could operate simultaneously with the camera and telemetry data. 700 bps Codec2 would also be ideal for amateur CubeSats in HEO where a low SNR is expected. In LEO, a satellite with a high date rate microwave downlink could have many channels of voice

and other data, perhaps including store-and-forward messaging and real-time text messaging.

The main lesson that can be learned from LO-90 is that for a system like this to be successful, multi-platform software support is crucial. Most amateur radio operators are not Linux enthusiasts and are not interested in booting to a different operating system to operate through a satellite. Any future digital voice satellite must have easy-to-use ground station software for Windows, MacOS, and Linux to be fully successful.

Notes

1. "LilacSat-1 CubeSat deployed from ISS." AMSAT-UK. **amsat-uk.org/2017/05/19/lilacsat-1-cubesat-iss/**. Accessed October 14, 2018.
2. "LilacSat-1 Radio Info." LilacSat. **lilacsat.hit.edu.cn/wp/?page_id=594**. Accessed October 14, 2018.
3. "Decay." DK3WN Satblog. **www.dk3wn.info/p/?page_id=43437.** Accessed February 5, 2019.
4. "Codec 2" Rowetel. **www.rowetel.com/?page_id=452**. Accessed October 14, 2018.
5. Links to the various software and articles about the technical characteristics of the LO-90 downlink are available at **lilacsat.hit.edu.cn/wp/?page_id=594**. However, M6SIG's live image is no longer available at that link. Please email the author for a link if you are interested in trying the live image.
6. "Low Latency Decoder for LilacSat-1." **destevez.net/2017/05/low-latency-decoder-for-lilacsat-1/**. Accessed October 14, 2018.
7. Taurus-1 Frequency Coordination. The International Amateur Radio Union. **www.amsatuk.me.uk/iaru/finished_detail.php?serialnum=568** Accessed October 14, 2018.

AMSAT on the Queen Mary

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In March 2016, I had the opportunity to work AO-7 from the Wireless Room on the RMS Queen Mary, W6RO, anchored at the Port of Long Beach in California. This was the last satellite activity from the W6RO station. After discussions during the summer and fall of 2018 about having more satellite activity from the Queen Mary, W6RO was heard once again on the satellites on December 15, 2018. In spite of the challenges in scheduling the event, and operating in an urban location full of RF, "AMSAT on the Queen Mary" was a success.

While I was in southern California for an event in August 2018, I asked Endaf Buckley, N6UTC — a Long Beach ham involved with the Associated Radio Amateurs of Long Beach (ARALB, the club that operates the W6RO station) — about the possibility of a satellite activity on the Queen Mary.

Endaf mentioned that the W6RO satellite station had been dismantled. I then suggested this activity could be done Field Day-style with portable equipment. Endaf took this suggestion to the ARALB's manager of the W6RO Wireless Room, David Akins, N6HHR, who then went to the management of the Queen Mary. The ship's management liked the idea, and the discussions focused on two points - when this would take place, and where on the ship we could conduct this activity. With holiday-related activities on the ship in December, including the installation of a small ice rink near the wireless room, the satellite activity needed to take place somewhere else on the ship. Endaf and David scouted the ship, and they along with the ship's management agreed on using the Verandah Deck, near the ship's stern. This allowed for a view of the eastern sky and a large open area where we could work around the rest of the ship for any passes to the west. After getting some options for the date of this event, all of us agreed on a Saturday, December 15, 2018, for the event.

Endaf and I brought our equipment to the Queen Mary on December 15. Endaf brought his trusty Yaesu FT-60R and Elk log periodic, and I also brought my Elk with a few radios (Kenwood TH-D72 and TH-D74, along with two Yaesu FT-817NDs). After clearing the Queen Mary security around 9 am (1700 UTC), we boarded the ship and went to the Verandah Deck. A table and chairs were waiting for us. We started to set up the table, with AMSAT flyers and 3D-printed models of CubeSats. We also hung an AMSAT banner. We were ready for the first pass as W6RO, an AO-92 pass, a half-hour after we boarded the ship.

The AO-92 pass was a 37-degree pass for us, giving us a footprint covering much of the continental U.S. We logged 14 contacts in the span of 5 minutes on this pass, which was an excellent start for the day. About 30 minutes after this pass, an ISS pass covered the western U.S. We logged one contact on this pass, making 15 QSOs for the first hour or so of the event. As we were starting out on the radio, a member of the Queen Mary's management visited our table to confirm we had everything needed for our event.