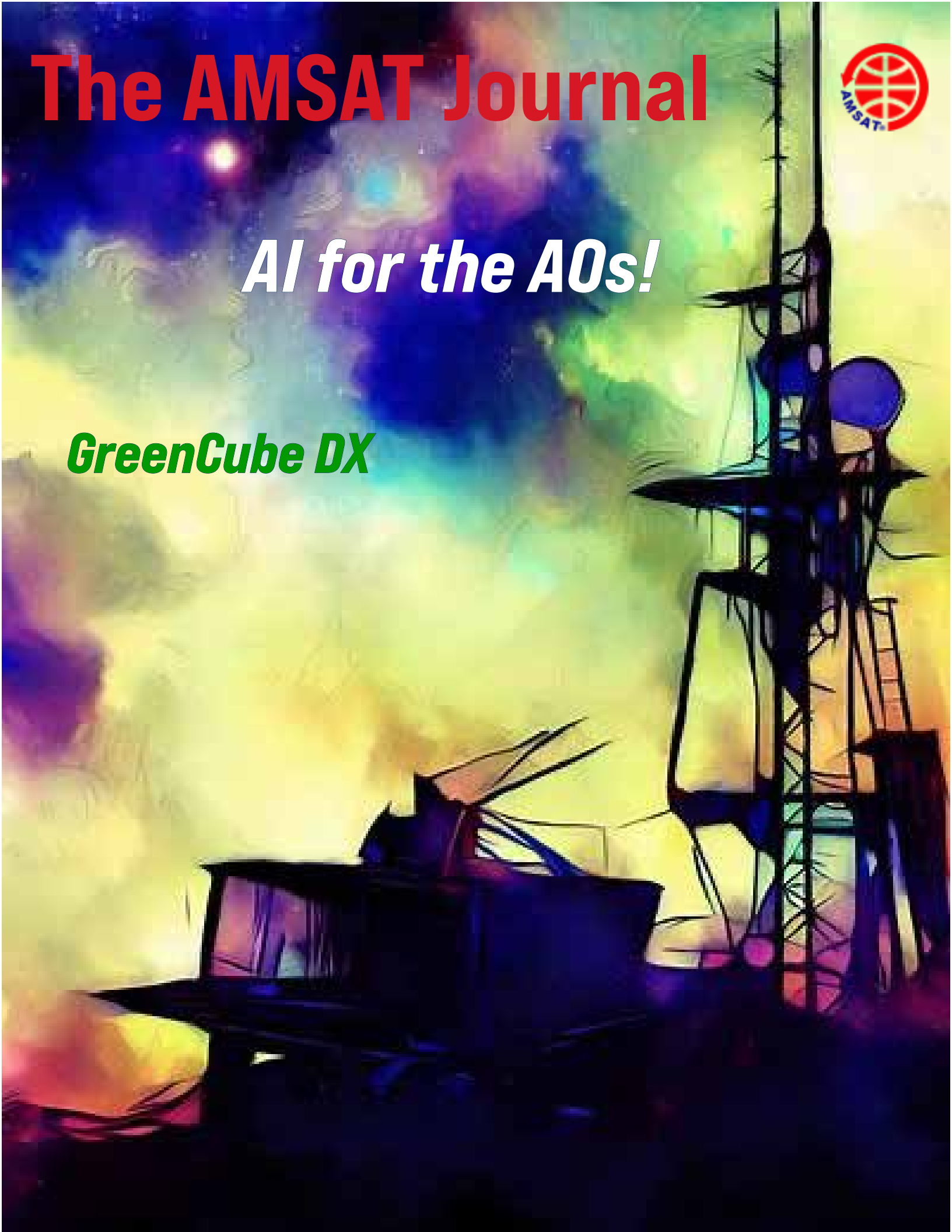


# The AMSAT Journal



*AI for the AOs!*

*GreenCube DX*





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*\*See our review, QST March 2016 page 60.*

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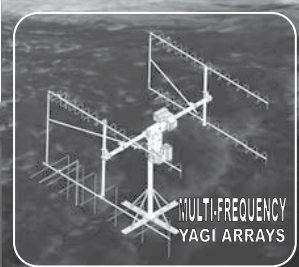
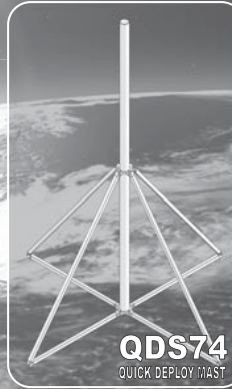
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Editor-in-Chief

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**Douglas Quagliana,**  
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**Paul Graveline, KIYUB**  
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AMSAT Websites: [www.amsat.org](http://www.amsat.org),  
[launch.amsat.org](http://launch.amsat.org) (Member Portal)

#### The AMSAT Journal Staff

Editor-in-Chief: Joe Kornowski, KB6IGK,  
[kb6igk@amsat.org](mailto:kb6igk@amsat.org)  
Assistant Editors:  
Douglas Quagliana, KA2UPW/5  
Bernhard Jatzbeck, VA6BMJ  
Paul Graveline, K1YUB

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submissions to: [journal@amsat.org](mailto:journal@amsat.org),

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AMSAT Journal* based on suitability of content and space  
considerations.

## Apogee View

### Robert Bankston, KE4AL President



#### Hamvention – Here We Come!

It is that time of year again – when we all pilgrimage to Ohio to join our friends and fellow hobbyists to celebrate all things amateur radio. I am excited about the opportunity to all get together again and share our passion for amateur radio in space at Hamvention. Innovation is this year's theme for Hamvention – a concept integral to AMSAT's many successes over the past 54 years. While we are certainly proud of our many accomplishments, our future success depends on our ability to overcome barriers, solve the impossible, and advance the art and science of amateur radio in space.

The 2023 Hamvention will be held May 19 – 21 at the Greene County Fairgrounds and Expo Center in Xenia, Ohio:

- Friday, May 19th, 9:00 am – 5:00 pm
- Saturday, May 20th, 9:00 am – 5:00 pm
- Sunday, May 21st, 9:00 am – 1:00 pm

AMSAT Engineering, Education, Youth Initiative, Member Services, Getting Started, and, of course, the popular AMSAT Store will be located in Building 1, booths 1007-1010 and 1107-11100. In addition, AMSAT will be hosting live satellite communication demonstrations just outside our booths, as satellite passes allow.

I will host a forum on Saturday, May 20th, from 1:10 to 2:10 pm, in Room 2, sharing AMSAT's vision, mission, and plan to make it happen. In addition, AMSAT Engineering, Education, and Youth Initiative will provide updates on their programs.


In addition, AMSAT will be hosting an informal social event on Thursday evening and co-hosting the AMSAT/TAPR Banquet on Friday night:

- Please join us for an informal get-together at Tickets Pub & Eatery, located at 7 W. Main St, Fairborn, OH, on Thursday night, May 19th, 6-8 pm.
- We are happy to once again partner with our friends at Tucson Amateur Radio Packet Radio on the 13th annual AMSAT/TAPR Banquet, to be held in conjunction with Hamvention. This year's AMSAT/TAPR banquet will be held at the Kohler Presidential Banquet Center on Friday, May 19th, at 18:30 EDT. This year's banquet speaker will be announced in the coming weeks. The Kohler Presidential Banquet Center address is 4548 Presidential Way, Kettering, Ohio — about 20 minutes from the Greene County Fairgrounds.

Tickets (\$60 each) may be purchased from the AMSAT store. The banquet ticket purchase deadline is Friday, May 12th. Banquet tickets must be purchased in advance and will not be sold at the AMSAT booth. Additionally, there will be no tickets to pick up at the AMSAT booth. Tickets purchased online will be maintained on a list, with check-in at the door of the banquet center.

Seating is limited to the number of meals reserved with the Kohler caterers based on the number of tickets sold by the deadline. For more information, to view the menu options and purchase your tickets, please visit [www.amsat.org/product/amsat-tapr-joint-hamvention-banquet-registration/](http://www.amsat.org/product/amsat-tapr-joint-hamvention-banquet-registration/). We look forward to seeing you at Hamvention.

#### Help Wanted

Although AMSAT is a small organization, we have big dreams. To bring those dreams to reality, we, as an all-volunteer organization, need your help. Engineering expertise is always a top priority, but our volunteer needs span the entire gamut, from administrative to program management, education to website development, and public relations to finance. Please consider donating your time and expertise to help us continue on our path Onward & Upward! 



## Educational Relations Update

**Alan Johnston, Ph.D., KU2Y**

In this issue of *The AMSAT Journal*, I have an article describing the design of the Second Version of the CubeSatSim, a beta release. Over the next few months, we will gather more feedback on the design and work towards an official V2 release in late 2023 or 2024. See the article for all the details. The new board stack appears in Figure 1.

You can see *it* at Hamvention this year. I hope to see *you* there!

The CubeSat Simulator was displayed at Hamcation earlier this year. Figure 2 shows the demonstration setup by Dennis Veselka, KI4KNC. The CubeSatSim is one he built himself, as shown in Figure 3.

Here's what he says about the project:

This project took me almost two years due to Covid supply chain issues getting some of the parts. I used the 1.1 version of the boards, which will date how long I had them. The main supply issues were the Pi Zero and the INA219 boards. Kevin Zari, KK4YEL, did the 3D printing for me.

The CubeSatSim looks great!

I see more and more hams on Mastodon these days, including many of my friends from Twitter.

You can find me there at [@ku2y@mastodon.radio](mailto:ku2y@mastodon.radio) along with ARISS [@ARISS\\_Intl@mastodon.hams.social](mailto:ARISS_Intl@mastodon.hams.social). Please get in touch with me if you make the move so I can follow you!

If you are interested in doing a demo for a group or school, I can ship you a loaner. Contact me via email at [ku2y@arrl.net](mailto:ku2y@arrl.net).

I'm always interested in your CubeSatSim projects – feel free to share them via email or social media. 🌐

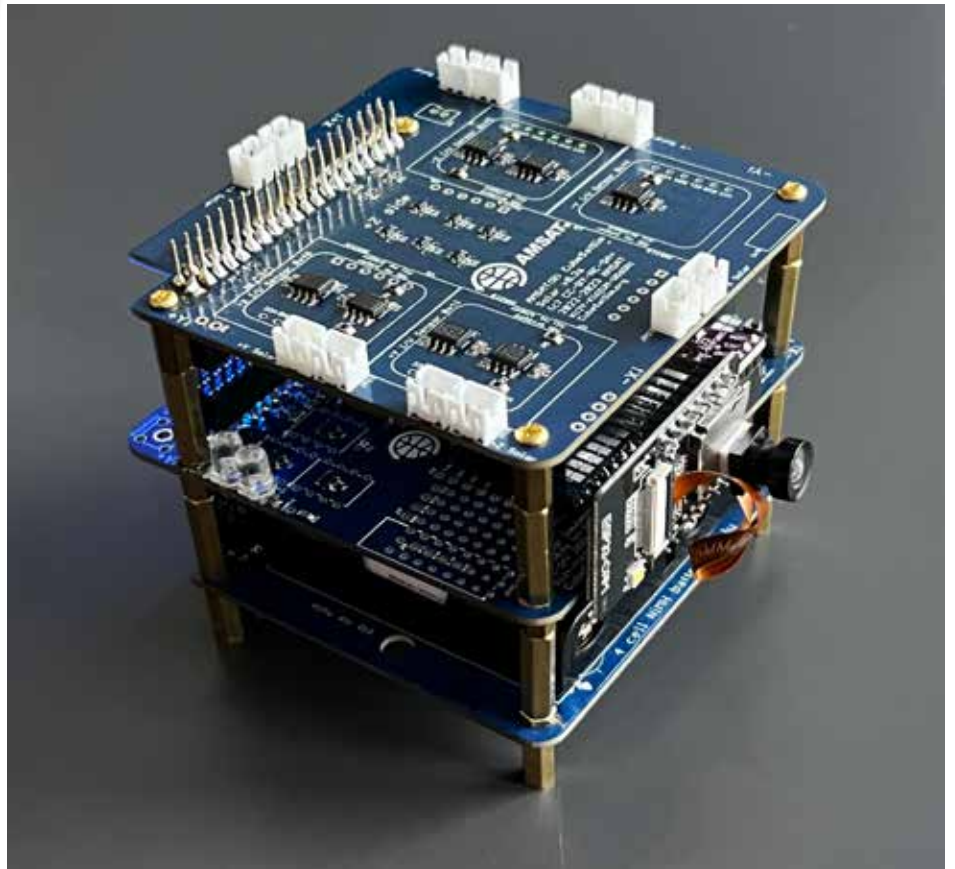


Figure 1 — AMSAT CubeSatSim V2 Beta Board Stack.



Figure 2 — CubeSat Simulator Demonstration at Hamcation 2023. Photo courtesy of Dennis Veselka, KI4KNC.



Figure 3 — CubeSat Simulator Built by Dennis Veselka, KI4KNC. Photo courtesy of Dennis Veselka.

## eBay Sellers Donate to AMSAT

Are you an eBay seller? One item, ten items, or a full-time business you can donate a percentage of your winning bid to AMSAT.

To do so, do not list your item with the basic listing tool, select advanced tools. eBay will give you a warning message that it is for large volume sellers, however this is where the eBay for Charity tool is found.

You can “select another nonprofit you love” and search for either AMSAT or Radio Amateur Satellite Corporation. Choose the percentage amount of the sale you would like to donate to AMSAT, and boom!

When your item sells and the winning bidder pays, eBay will deduct the percentage from your take and forward it to AMSAT.

Please consider giving a piece of the pie to a new satellite and choose AMSAT for your eBay Charity.

## Call for Nominations – 2023 AMSAT Board of Directors Election

AMSAT solicits nominations for the 2023 AMSAT Board of Directors election, to be held in the third quarter of the year. The seats of the following four incumbent Directors expire in 2023 and will be filled by this year’s election:

- Jerry Buxton, N0JY
- Joseph J. Armbruster, KJ4JIO
- Robert Bankston, KE4AL
- Zach Metzinger, N0ZGO

Further, up to two Alternate Directors may be elected for one-year terms. A valid nomination for Director must be written and requires either one Member Society or five current individual members in good standing to nominate an AMSAT member. Written nominations, with the nominee’s name, call sign, and contact information, as well as the nominators’ names, call signs, and contact information, should be sent to the AMSAT Secretary:

Jeff Davis, KE9V  
PO Box 11  
Yorktown, IN 47396

AMSAT bylaws require that the nomination be written and in the form specified by the Secretary who has elected to accept written nomination materials via mail or in electronic form, including email or electronic image of a paper document. Fax transmissions cannot be accepted.

Email nominations may be sent to [jdavis@amsat.org](mailto:jdavis@amsat.org).

No matter what means are used, petitions MUST be received by the Secretary no later than June 15th. The Secretary will verify the qualifications of candidates and nominating members or Member Societies as petitions are received, and will notify candidates whether their nominations are in order by the end of June.

[*The AMSAT Journal* thanks Jeff Davis, KE9V, AMSAT Secretary for the above information.]



# Generative AI and Amateur Radio in Space: A Chatbot Conversation

**Joe Kornowski, KB6IGK**  
**Editor**  
**Microsoft Bing, Microsoft Corporation**

Humanity suddenly finds itself at a historic inflection point — existential, social, business/economic, health, STEM — precipitated by AI, "predictive" (forward-looking) and "generative" (based on existing data). Both forms will likely touch almost every aspect of our lives, perhaps as much as humanity's harnessing of fire or electricity.

Stepping back from my intrusive moments of imagination-on-fire thinking, I'm delving deeper into my new personal AI journey. As part of that adventure, I've wondered how AI might affect my interest and experience in amateur radio in space.

I decided the best place to start looking for answers\* would be my accessible AI "expert," Microsoft Bing ... which I affectionately refer to as "my buddy, Bot-o'-Bing." Who better to ask about AI than, well, ... AI?

*[\* Note: According to Microsoft's Bing Conversational Experiences and Image Creator ["Online Services"] Terms, "These Online Services are intended to delight, inspire, and enhance human creativity.... The Online Services are for entertainment purposes; the Online Services are not error-free, may not work as expected and may generate incorrect information. You should not rely on the Online Services and you should not use the Online Services for advice of any kind. Your use of the Online Services is at your own risk."]*

With those caveats and disclaimers out of the way, I'll pick up my smartphone and ask my buddy, Bot-o'-Bing, a few questions. My questions (Microsoft calls them "Prompts") and Bing's answers (in MS-speak, "Text Creations") or images ("Image Creations") appear verbatim below "to delight, inspire, and enhance human creativity."

## The Demo

### How can AI advance the hobby of amateur radio using satellites?

AI can advance the hobby of amateur radio using satellites by using \*\*machine learning\*\* and \*\*deep learning\*\* techniques to enhance

and enable various aspects of the radio communication and operation, such as:

- \*\*Signal processing and modulation\*\* such as using AI algorithms to improve the quality and reliability of the radio signals, reduce noise, interference, distortion, and fading effects, increase the bandwidth and efficiency of the data transmission, adapt to dynamic and complex environments, etc<sup>2</sup>.
- \*\*Data analysis and visualization\*\* such as using AI algorithms to process and analyze the data collected by the satellites, such as telemetry, images, audio, etc., and generate and display useful insights and products for the amateur radio operators<sup>13</sup>.
- \*\*Natural language processing and generation\*\* such as using AI algorithms to enable natural language communication between amateur radio operators and satellites, such as voice commands, speech recognition, text-to-speech, etc.
- \*\*Orbit determination and control\*\* such as using AI algorithms to estimate and adjust the orbits and trajectories of the satellites, avoid collisions, perform orbital maneuvers, etc<sup>13</sup>.

AI can also enable new applications and innovations in amateur radio using satellites that are not possible with traditional methods.

Source: Conversation with Bing, 5/13/2023  
(1) Amateur radio satellite - Wikipedia. [https://en.wikipedia.org/wiki/Amateur\\_radio\\_satellite](https://en.wikipedia.org/wiki/Amateur_radio_satellite).  
(2) AMSAT – The Radio Amateur Satellite Corporation. <https://www.amsat.org/>.  
(3) Orbiting Satellites Carrying Amateur Radio – AMSAT. <https://www.amsat.org/orbiting-satellites-carrying-amateur-radio/>.

### How can AI be used to improve the tracking of amateur radio satellites?

AI can be used to improve the tracking of amateur radio satellites by providing:

- \*\*Orbital prediction\*\* algorithms that can calculate the position and velocity of satellites based on their orbital elements (such as TLEs) and account for perturbations such as atmospheric drag, solar radiation pressure, and gravitational forces.
- \*\*Signal processing\*\* algorithms that can extract useful information from the satellite signals, such as telemetry, beacon, or image data, and correct for noise, distortion, and Doppler shift.
- \*\*Antenna control\*\* algorithms that can automatically steer the antenna rotators to point at the satellite and optimize the antenna gain and polarization for maximum

signal strength and quality.

- \*\*Spectrum management\*\* algorithms that can monitor the frequency bands used by amateur radio satellites and avoid interference with other users or sources of noise.
- \*\*User interface\*\* algorithms that can display the satellite tracking information in an intuitive and user-friendly way, such as maps, charts, graphs, or tables, and allow the user to interact with the satellite tracking software through voice, touch, or gesture commands.

Source: Conversation with Bing, 5/13/2023  
(1) Tracking Satellites: The Nitty Gritty Details | Hackaday. <https://hackaday.com/2020/12/16/tracking-satellites-the-nitty-gritty-details/>.  
(2) Ham radio programs for satellite tracking - The DXZone. [https://www.dxzone.com/catalog/Software/Satellite\\_tracking/](https://www.dxzone.com/catalog/Software/Satellite_tracking/).  
(3) Ham Radio Deluxe Satellite App for Amateur Radio Operators. <https://www.hamradiodeluxe.com/features/sattrack/>.

### How can AI be used to improve radio digipeating through CubeSats?

AI can be used to improve radio digipeating through CubeSats by using \*\*machine learning\*\* and \*\*deep learning\*\* techniques to process and optimize radio signals and data transmission between satellites and ground stations. Some examples of how AI can improve radio digipeating through CubeSats are:

- \*\*Enhancing the quality and reliability of radio communications\*\* by using AI algorithms to reduce noise, interference, distortion, and fading effects on the radio signals<sup>46</sup>.
- \*\*Increasing the bandwidth and efficiency of data transmission\*\* by using AI algorithms to compress, encode, modulate, and multiplex the data streams<sup>4</sup>.
- \*\*Adapting to dynamic and complex environments\*\* by using AI algorithms to adjust the frequency, power, direction, and polarization of the radio signals according to the changing conditions and requirements<sup>4</sup>.
- \*\*Enabling new applications and innovations in radio communications\*\* by using AI algorithms to generate and synthesize natural language, music, and other audio content for broadcasting<sup>5</sup>.

Source: Conversation with Bing, 5/13/2023  
(1) RadioGPT: 'World's first' AI-driven radio station is here. <https://interestingengineering.com/innovation/radiogpt-worlds-first-ai-radio-station>.  
(2) Solar Powered APRS Digipeater for



Amateur Radio. <https://www.instructables.com/Solar-Powered-APRS-Digipeater-for-Amateur-Radio/>.

(3) The World's First AI Radio Station Is Equipped to Write and Deliver .... <https://edm.com/gear-tech/worlds-first-ai-radio-station>.

(4) A Survey on CubeSat Missions and Their Antenna Designs - MDPI. <https://www.mdpi.com/2079-9292/11/13/2021/htm>.

(5) Nanosatellites Could Play Pivotal Role in Defense Against Enemy .... <https://www.defense.gov/News/News-Stories/Article/Article/2685840/nanosatellites-could-play-pivotal-role-in-defense-against-enemy-missiles/>.

(6) CubeSats Overview | NASA. [https://www.nasa.gov/mission\\_pages/cubesats/overview/](https://www.nasa.gov/mission_pages/cubesats/overview/).

### How might AI help enable amateur radio communication between radio stations on Earth and stations or digipeaters on the moon or Mars?

AI might help enable amateur radio communication between radio stations on Earth and stations or digipeaters on the moon or Mars by providing **signal processing**, **error correction**, **data compression**, **antenna control**, and **spectrum management** techniques. AI could also help with **predicting** and **optimizing** the best times and frequencies for communication based on the **orbital dynamics**, **atmospheric conditions**, and **interference sources**.

Amateur radio communication with the moon or Mars is not a new idea. In fact, some amateur radio operators have already used the moon as a passive reflector to communicate over great distances via a technique called **EME (Earth-Moon-Earth)** or **moonbounce**<sup>3</sup>. Amateur radio operators will also join a powerful international network tracking NASA's Orion spacecraft after it launches toward the moon this month as part of the Artemis 1 mission<sup>1</sup>. Most of the astronauts aboard the Artemis 2 mission, which will send a quartet of people around the moon in late 2024, are certified ham radio operators and there's high hopes in the community that they may call home from deep space<sup>2</sup>.

Source: Conversation with Bing, 5/13/2023

(1) Weak Signal -- (VHF-DX, Meteor Scatter, EME-Moonbounce) - ARRL. <https://www.arrl.org/weak-signal-vhf-dx-meteor-scatter-eme-moonbounce>.

(2) Amateur radio operators and more will track NASA's Artemis 1 moon mission. <https://www.space.com/artemis-1-tracking>

amateur-radio-operators.

(3) Artemis 2 astronauts flying to the moon could phone home with ham radio .... <https://www.space.com/nasa-artemis-2-moon-mission-ham-radio>.

### What are the challenges of amateur radio communication with Mars?

Some of the challenges of amateur radio communication with Mars are:

- The **distance** between Earth and Mars varies depending on their orbital positions, ranging from about 54 million kilometers to 401 million kilometers. This means that the **propagation delay** for radio signals can be anywhere from 3 minutes to 22 minutes one way, making real-time communication impossible.

- The **atmosphere** of Mars is much thinner than Earth's, which affects the **ionization** and **refraction** of radio waves. The Martian atmosphere also has **dust storms** that can interfere with radio signals.

- The **terrain** of Mars is rugged and uneven, which can block or scatter radio signals. The **rotation** of Mars also affects the visibility of Earth from different locations on the surface.

- The **solar activity** and **space weather** can affect the propagation of radio waves in both interplanetary and planetary environments. Solar flares, coronal mass ejections, and geomagnetic storms can cause **noise**, **distortion**, and **fading** of radio signals.

- The **legal and regulatory** aspects of amateur radio communication with Mars are not well defined. There are no international agreements or conventions that govern the use of radio frequencies or call signs for Mars communication. There are also potential issues of **interference**, **coordination**, and **licensing** with other users of the radio spectrum, such as NASA, ESA, and other space agencies or commercial entities.

To overcome these challenges, amateur radio communication with Mars would require advanced techniques such as:

- Using **high-gain antennas**, **high-power transmitters**, and **low-noise receivers** to improve the signal-to-noise ratio and overcome the attenuation caused by distance and atmosphere.

- Using **adaptive modulation**, **coding**, and **compression** schemes to optimize the data rate and error correction for different channel conditions and bandwidth constraints.

- Using **frequency hopping**, **spread**

**spectrum**, or **cognitive radio** techniques to avoid interference and exploit unused spectrum opportunities.

- Using **relay satellites**, **digipeaters**, or **mesh networks** to extend the coverage and connectivity of radio signals across Mars and Earth.

- Using AI to assist with **signal processing**, **routing**, **scheduling**, and **optimization** of radio communication based on the dynamic environment and user requirements. AI could also help with generating or interpreting natural language messages for human operators.

Source: Conversation with Bing, 5/13/2023

(1) Military Auxiliary Radio System - Wikipedia. [https://en.wikipedia.org/wiki/Military\\_Auxiliary\\_Radio\\_System](https://en.wikipedia.org/wiki/Military_Auxiliary_Radio_System).

(2) The Navy-Marine Corps Team Needs Amateur Radio Operators. <https://www.usni.org/magazines/proceedings/2022/september/navy-marine-corps-team-needs-amateur-radio-operators>.

(3) MARS-Amateur Radio Exercise an Overall Success - ARRL. <https://www.arrl.org/news/mars-amateur-radio-exercise-an-overall-success>.

### How can AI assist in enabling amateur radio satellites to advance the search for extraterrestrial intelligence (SETI)?

AI can assist in enabling amateur radio satellites to advance the search for extraterrestrial intelligence (SETI) by providing:

- **Signal detection** algorithms that can scan the radio spectrum for potential signals of artificial origin, such as narrowband carriers, pulses, or modulated signals, and filter out natural sources of noise or interference.

- **Signal analysis** algorithms that can extract features and parameters from the detected signals, such as frequency, bandwidth, polarization, modulation, coding, and information content, and compare them with known or expected characteristics of natural or human-made signals.

- **Signal classification** algorithms that can assign probabilities or scores to the detected signals based on their likelihood of being of extraterrestrial origin, and rank them according to their significance or interest for further investigation.

- **Signal confirmation** algorithms that can verify the detected signals by requesting observations from other amateur radio satellites or ground stations, and correlate the results to eliminate false positives or spurious detections.

- **Signal communication** algorithms



that can attempt to establish a two-way communication with the detected signals by sending appropriate responses or queries, and decoding or interpreting any replies or feedback.

Source: Conversation with Bing, 5/13/2023

(1) SETI at the Allen Telescope Array (ATA) - SETI Institute. <https://www.seti.org/seti-allen-telescope-array-ata>.

(2) AMSAT – The Radio Amateur Satellite Corporation. <https://www.amsat.org/>.

(3) Allen Telescope Array Overview. <https://www.seti.org/ata>.

### What are some examples of potential signals of artificial origin?

Some examples of potential signals of artificial origin are:

- **Narrowband signals** that occupy only a few frequency channels and have a high signal-to-noise ratio. These signals could indicate a deliberate transmission of information or a beacon signal to attract attention. Any signal less than about 300 Hz wide must be, as far as we know, artificially produced<sup>1</sup>.

- **Pulsed signals** that have a periodic or irregular pattern of on-off states. These signals could indicate a binary code or a modulation scheme that encodes information or identifies the source. Pulsed signals could also be used for radar or navigation purposes.

- **Modulated signals** that have a varying amplitude, frequency, phase, or polarization. These signals could indicate a complex communication system that uses different modulation techniques to transmit information or overcome noise and interference. Modulation could also be used to encode images or other types of data.

- **Coded signals** that have a structured or random sequence of symbols or bits. These signals could indicate an encryption or compression method that protects or optimizes the information content. Coded signals could also be used to identify the source or the recipient of the transmission.

- **Anomalous signals** that have unusual or unexpected characteristics that do not match any known natural or human-made sources. These signals could indicate a novel or advanced technology that uses different physical principles or operates in different domains. Anomalous signals could also be used to test or probe the environment or the receiver.

Source: Conversation with Bing, 5/13/2023

(1) What evidence would be needed to determine a signal was artificial in .... <https://space.stackexchange.com/questions/3276/>

what-evidence-would-be-needed-to-determine-a-signal-was-artificial-in-origin.

(2) Seti: alien hunters get a boost as AI helps identify promising signals .... <https://theconversation.com/seti-alien-hunters-get-a-boost-as-ai-helps-identify-promising-signals-from-space-198694>.

(3) If aliens were sending us signals, this is what they might look like. <https://phys.org/news/2022-04-aliens.html>.

(4) AI Has Found Potential Alien 'Technosignatures' Hidden in Radio Signals .... <https://www.vice.com/en/article/m7gz5v/ai-has-found-potential-alien-technosignatures-hidden-in-radio-signals-from-space>.

(5) SETI scientists spot 72 signals 'from alien galaxy' 3bn light years .... <https://news.sky.com/story/seti-scientists-spot-72-signals-from-alien-galaxy-using-ai-algorithm-11495075>.

### Can you generate a hopeful poem about the future of amateur radio in space?

Sure, I can generate a hopeful poem about the future of amateur radio in space. Here is one possible poem:

#### A Poem for Amateur Radio in Space

The sky is not the limit for the radio enthusiasts

Who explore the wonders of the cosmos with their transceivers

They send and receive signals from satellites and stations

And share their passion and knowledge with other believers

They are not deterred by the challenges of space and time

They are always eager to learn and innovate

They use artificial intelligence and machine learning to optimize

And create new applications and solutions to communicate

They are not just hobbyists, they are pioneers and visionaries

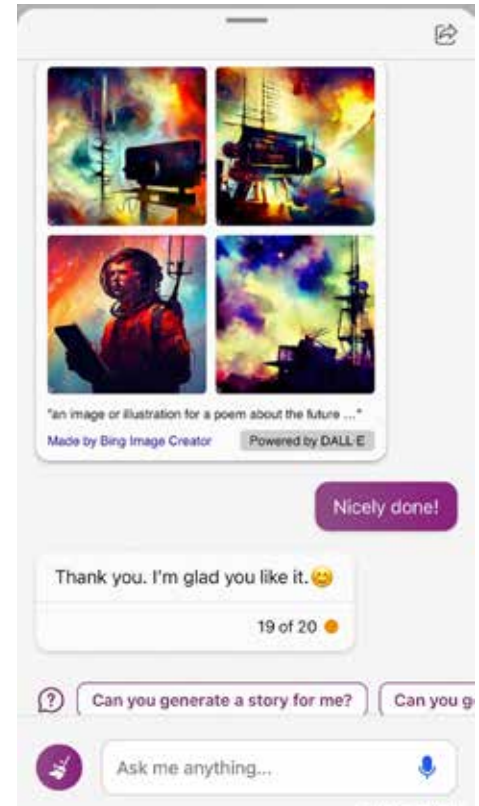
They contribute to science and society with their skills and expertise

They inspire and educate the next generation of space explorers

And foster a global community of peace and harmony"

### That's great! Can you generate an image or illustration for that poem?

Sure, I can generate an image or illustration for that poem. Here is one possible image:



### Creations to Applications

Besides what I have shared in this article, I've used Bing's creations to help me design a new magazine cover for this issue. For the cover image, I used one of the four that Bing provided based on the poem I requested it to create.

In a separate conversation with Bing that I did not show here, I asked Bing, "What font would you choose for the title of a new magazine related to innovative space communications?" I used the words "new" and "innovative," and omitted "amateur radio," to push Bot-o'-Bing towards something more artistic, futuristic and unexpected than what currently exists.

Bing provided five potential suggestions, a mix of serif and sans serif, classic and modern, while hedging its "creations" response with "it depends on ...." The one I chose was one of two that Bing characterized as sans serif modern, Bebas Neue Pro.

All of that is to say that the "new cover" of this issue of the *Journal* is a co-creation of my question to Bing and its responsive





"creations." I'll sit with both the font and the image for a while to determine if they "have legs." My sense is the font will; the image, ... *meb*. I personally like the radio starman better.

I've also snuck in a few additional Bing "image creations" related to the articles and labeled them accordingly.

### An Invitation

This gives you a feel for ways we can begin to use generative AI chatbots like Microsoft Bing, Google Bard and Open AI Chat GPT to explore aspects of amateur radio in space. I invite you to play with chatbots as part of your amateur radio satellite adventures.

Whether related to your operating, your station, DIY projects or experiments, or roving events, begin incorporating generative AI to problem-solve, learn something new, find shortcuts, or generate ideas. And then write an article about it.

For those who have struggled with writing or finding the time and energy to write, your struggles are over. So I invite you to set aside an hour occasionally when you find yourself mulling over an idea, problem or question about amateur radio in space to strike up a conversation with a chatbot buddy.

When your conversation ends, cut and paste the relevant text and images from your chatbot conversation into a notes app or MS Word. Elaborate, modify, rearrange, and otherwise edit until you make it yours. Add salt to taste. Plate it up, and serve it to [journal@amsat.org](mailto:journal@amsat.org).

Gotta run... "Mrs. Davis" is calling! 🌐

# AMSAT CubeSatSim Version 2 Design

**Alan Johnston, Ph.D., KU2Y**  
**Vice President, Educational Relations, AMSAT**  
**Associate Teaching Professor, Villanova University**  
[ku2y@arri.net](mailto:ku2y@arri.net)

### Abstract

The AMSAT CubeSatSim is a small, low-cost, spacecraft simulator that serves as a tool for academic education, public demonstrations, and theory and design disciplines. CubeSatSim use cases include a classroom, lab, or training setting to introduce satellite operations basics or teach STEM exercises. This article describes a redesign of the hardware and software for the second version, with an overview of prior CubeSatSim designs.

A CubeSat is a nanosatellite designed for low-cost educational space missions, defined by the CubeSat Design Specification (CDS) [www.cubesat.org](http://www.cubesat.org). The AMSAT CubeSatSim, the CubeSat Simulator, is a functional 1U form factor CubeSat model that transmits real radio telemetry and runs on rechargeable batteries and solar panels.

The ARRL ETP CubeSat Simulator was designed and built by Mark Spencer, WA8SME, and the subject of an article in *The AMSAT Journal* (September/October 2009) [www.arrl.org/files/file/ETP/CubeSat/CubeSat-Pt1-SepOct09.pdf](http://www.arrl.org/files/file/ETP/CubeSat/CubeSat-Pt1-SepOct09.pdf).

When I became AMSAT's VP of Engineering five years ago, everyone mentioned this educational resource and suggested I lead the effort to design and build one for AMSAT. The AMSAT CubeSatSim was intended to be low-cost and easy to build. The project is also open source software (GPL license) and hardware (creative commons license).

Instead of dedicated hardware, we used a Raspberry Pi Zero Single Board Computer (SBC) to take advantage of software and software-defined radio. We developed the first beta version with a transmitter Pi HAT based on the AX5043 called the Digital Transceiver Board for the Raspberry Pi (DigitalTxRxRPi) [github.com/BrandenburgTech/DigitalTxRxRPi](https://github.com/BrandenburgTech/DigitalTxRxRPi). The beta version offered two telemetry modes: APRS (Automatic Packet Reporting System using Audio Frequency Shift Keying, AFSK, with FM modulation) and CW (Continuous Wave - Morse code). An off-the-shelf battery charger board (MoPower UPS v2) supplied 5 V to the Pi, a nickel metal hydride (NiMH) rechargeable 9 V battery, and low-cost solar panels. The unit's custom PCB had INA219 voltage and current sensors for the solar panel charging circuit, along with a boost converter to provide the 12 V charging voltage. We published the design in *The AMSAT Journal* (November/December 2018): [cubesatsim.org/content/CubeSatSimPaper1.pdf](http://cubesatsim.org/content/CubeSatSimPaper1.pdf). See the block diagram shown in Figure 1.

Having experienced building and using this version in the classroom, I determined that the CubeSatSim Version 1 (V1) released in 2020 eventually had three custom PCBs (printed circuit boards): Main, Battery, and and

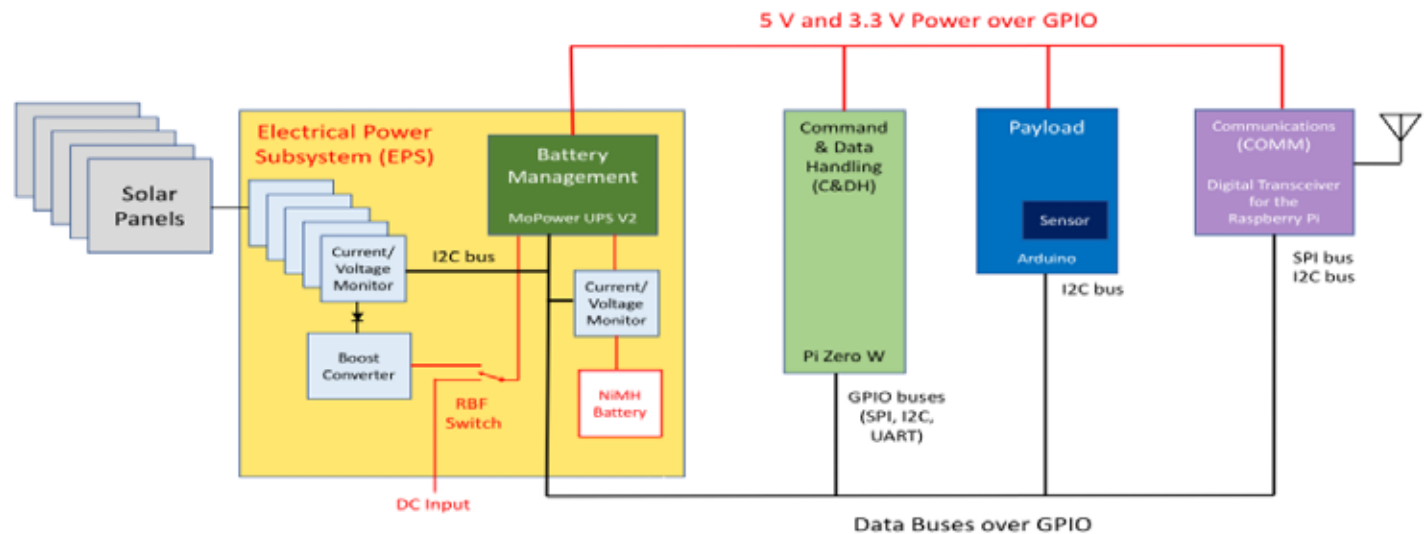


Figure 1 — AMSAT CubeSatSim Beta Block Diagram.



STEM Payload boards. We replaced the transmitter Pi HAT with the rpitx software library [4] that modulated the Raspberry Pi clock pin to generate telemetry in five modes: APRS, Frequency Shift Keying Data Under Voice (FSK DUUV, used by AMSAT Fox-1 FM CubeSats), Binary Phase Shift Keying (BPSK), Slow Scan TV (SSTV), and Continuous Wave (CW). Instead of the 9 V NiMH battery, we installed a battery pack of three AA NiMH cells to make a 4 V battery pack, which supplied power to the Pi with a 5 V boost converter. The battery charging circuit used an integrated circuit module based on the CN3085. We described that design in *The AMSAT Journal* (March/April 2020): [cubesatsim.org/content/CubeSatSimPaper5.pdf](https://cubesatsim.org/content/CubeSatSimPaper5.pdf). See the block diagram shown in Figure 2.

The AMSAT Store has CubeSatSim PCB sets available (the Main, Battery, and STEM Payload boards). The boards are blank except for a few surface mount technology (SMT) components. A bill of materials for the parts needed is available, along with step-by-step Wiki instructions and videos.

A CubeSatSim Lite beta version, a pHAT with the same form factor as a Pi Zero, only had LEDs, pushbuttons, and a low pass filter. However, the beta version transmitted simulated telemetry in the same five modes. In addition, some fully assembled beta boards were made available.

This version worked quite well. However, the rpitx library had some advantages and disadvantages. The advantages were that it was flexible and only needed a simple low pass filter (LPF) with no other hardware to

generate so many modulation modes. The library's disadvantages were very low power output (< 1 mW) and a frequency offset randomly set at initialization.

Also, some of us experimented with flying the CubeSatSim Lite on high-altitude balloons (HABs). The results had been mixed, due to the low power and frequency offsets. In addition, the design used mainly through-hole components and relied on some circuit modules. This was good for kit building but unsuitable for fully assembled boards.

Starting in 2020, Raspberry Pis became more difficult to purchase due to global supply chain disruptions. In 2021, the availability of Raspberry Pi Zeros essentially went to zero, and the few purchased models had a price tag of almost ten times the list price. As a result, it became clear to us that we needed to redesign the hardware to use a different processor.

The processor we decided upon was the Raspberry Pi Pico [www.raspberrypi.com/products/raspberry-pi-pico/](http://www.raspberrypi.com/products/raspberry-pi-pico/), a microcontroller based on the RP2040 processor. It can be programmed with the simple Arduino Integrated Development Environment (IDE) software [www.arduino.cc/en/software](http://www.arduino.cc/en/software). This processor is available and cheaper than the Pi Zero (\$5 for the cheapest). Unfortunately, we could no longer use the rpitx library, as it is specific to the Broadcom chipset used in the Raspberry Pi SBCs. So we needed to redesign the transmitter. We also decided to take advantage of the redesign to make improvements over the V1 hardware, including:

- A more powerful transmitter
- Surface Mount Technology (SMT) option to make getting fully assembled boards easier and cheaper
- Moving away from circuit modules that might be discontinued in the future
- Simplify the charging and power circuits
- Making the parts, including the solar panels, easier to purchase
- Creating the design more like a real CubeSat.

As a result, we are announcing the beta hardware and software release of the CubeSatSim V2. This new version does not currently implement any new features over the V1 hardware - its goal was to replicate existing features. Note that the Pro Micro microcontroller on the STEM Payload Board in the V1 hardware is now replaced by the Raspberry Pi Pico. The block diagram appears in Figure 3.

In redesigning the transmitter, we tried to minimize the hardware needed. Our early testing tried to use Pulse Width Modulation (PWM) pins on the Pico to generate the RF. We had partial success, since the Pico has very high frequency PWM signals. However, the power level was very low at these higher frequencies, and we had to use high harmonics (such as 5th or 7th) to get the 70 cm frequency we wanted, reducing the signal power. Eventually, we switched to using a Si5351 clock generator. We initially experimented using the Adafruit module ([learn.adafruit.com/adafruit-si5351-clock-generator-breakout/](http://learn.adafruit.com/adafruit-si5351-clock-generator-breakout/)) and added the SMT IC along with a crystal.

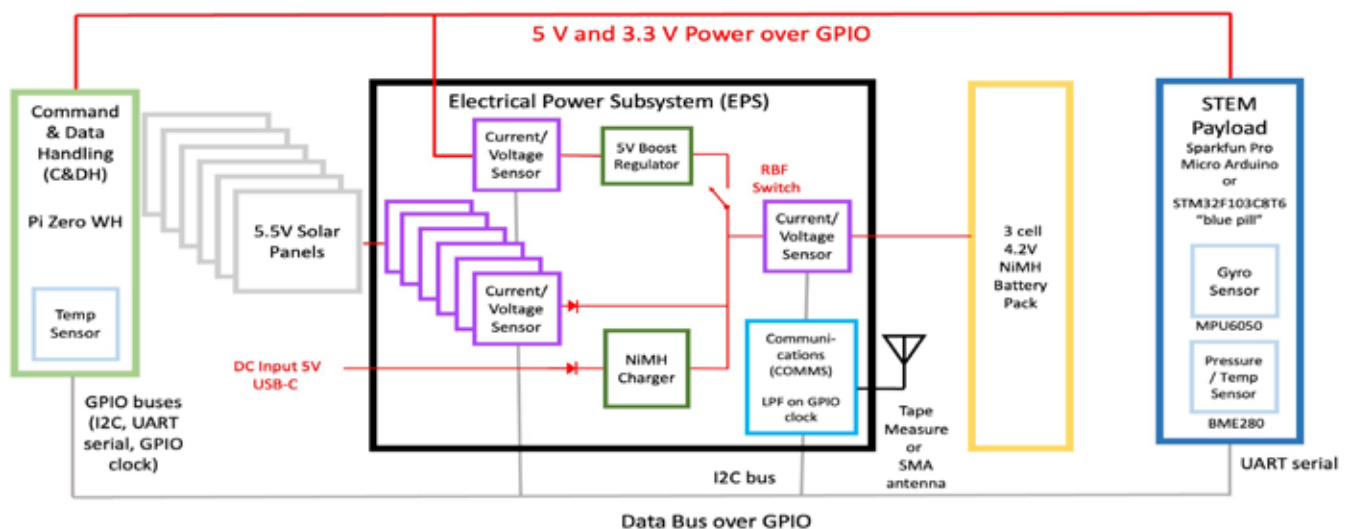


Figure 2 — AMSAT CubeSatSim V2 Block Diagram.

# CubeSatSim Block Diagram v2 Hardware

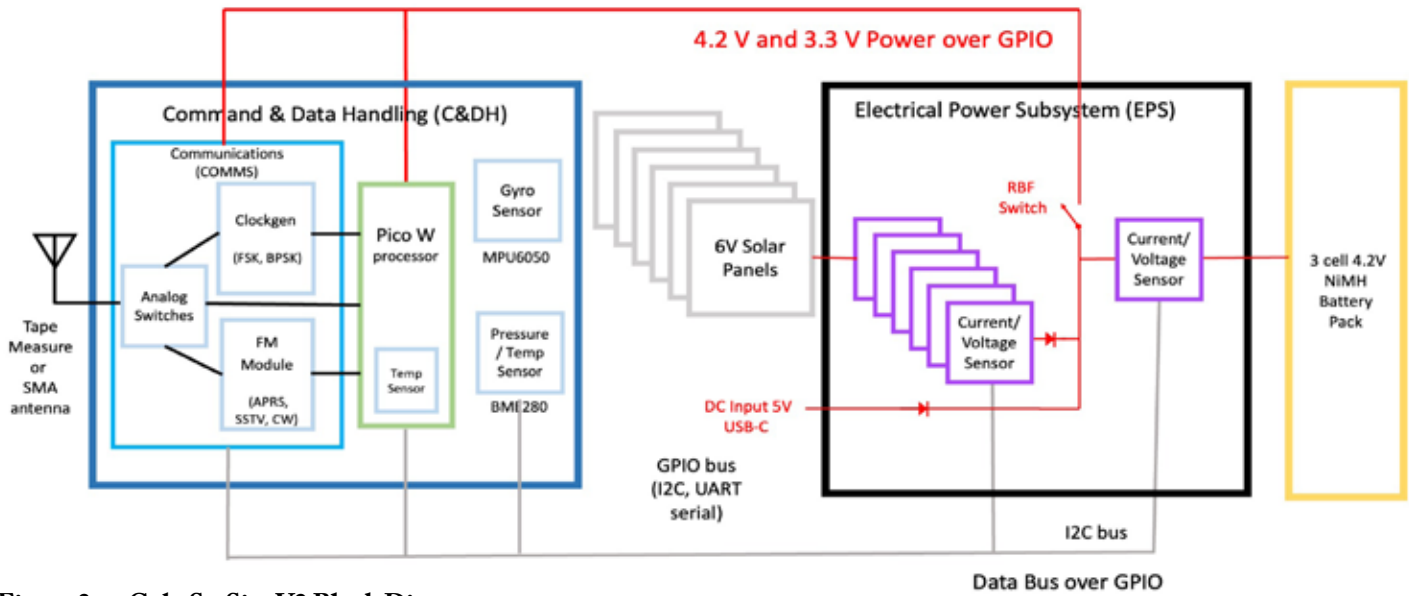


Figure 3 — CubeSatSim V2 Block Diagram.

A clock generator chip such as this, combined with a bandpass filter, can generate different modulations such as FSK and BPSK. For the Fox-1 FSK DUV modulation, we needed to switch between two clocks slightly shifted in frequency from each other. For the Fox-1E and GOLF BPSK modulation, we needed to switch between two clocks of the same frequency but shifted by 180 degrees (inverted). We found that the I2C commands to enable and disable the clocks were not fast enough or consistent enough, so we had to add two analog switches controlled by GPIO (General Purpose Input Output) pins. This way the switching for 1's and 0's was much faster and consistent. We use the 3rd harmonic of the clockgen output, and filter the resulting signal with a 433 MHz SAW bandpass filter to eliminate the fundamental and higher harmonics for our 434.9 MHz.

The clockgen approach needed a way to do the FM modulation needed for the APRS, SSTV, and CW telemetry modes. So we used a ShenZhen Sunrise Electronics CO, Ltd SR\_FRS\_0W5U FM transmitter module: [www.sunrisedigit.com/product/23-en.html](http://www.sunrisedigit.com/product/23-en.html). This module is relatively cheap (\$7.50) and simple to configure and control using a serial interface. However, the 500 mW power output is too much for the classroom but reasonable for HAB payload. We solved this with an attenuator circuit, so the power to the antenna is around 10 mW. Finally, we needed to add another analog switch to allow the clockgen and the FM module to share the transmit antenna.

We couldn't use the excellent and low-cost Pi Camera without a Pi Zero. We needed a low cost camera with a serial output that could send images to the Pico for SSTV encoding. We use the popular ESP32-CAM, an ESP32 processor interfaced with the imaging element. We program the ESP32-CAM to take a JPEG photo then send it over the serial interface. This camera works, although the image quality is much lower than the Pi Camera. Also, the device has some reliability issues that we have yet to be able to fully address so far.

Speaking of software, the Pico, like the Pi Zero, can be programmed in C language and Python, which the V1 software was written in. However, the libraries we used on the Pi Zero had to be ported to the Pico or alternatives found. The biggest headaches were the APRS library and the SSTV library. Also, the Pico does not have an audio out, so we needed to use PWM audio which required a low pass filter circuit to clean up the square wave signal.

Just porting the CubeSatSim software to the Pico proved to be a challenge. Software development on a microcontroller like the Pico is much more challenging than an SBC like Pi Zero. Very little flash storage and few CPU cycles are available to take care of everything. As each new feature was ported and made to work, some other features would stop working due to timing, hardware, or software interaction.

We also reduced the complexity of the

charging and power circuits. Instead of producing exactly 5 V for the Pi Zero, the Pico can run with a 1.8 - 5.25 V and produce a regulated 3.3 V output for other devices. We charge the three-cell NiMH battery pack directly from the USB-C 5 V or 6 V solar panels. With this simplified charging circuit, we no longer have trickle charging capability. However, this means the USB-C charger should be kept connected for an hour for a charged battery and four hours for a discharged battery. Without the Pi Zero, we could also redefine some pins on the GPIO header. This allowed us to supply power from the Battery Board to the other boards using



Figure 4 — CubeSatSim V2 showing new solar panels.



the GPIO header instead of having to have an external JST cable.

For the solar panels, we found a good supply of low-cost small solar panels, 6 V of size 75 mm x 45 mm. Unfortunately, this requires two panels per side, which is how many CubeSats are designed. This necessitated a redesign of the 3D-printed frame to handle the smaller panels. This also allowed us to move the switches and LEDs from the frame's bottom (or top) to the middle, which is also similar to real CubeSats. The CubeSatSim V2 frame with the new solar panels appears in Figure 4. We have had good results with the new solar panels and we like the new look!

One great new feature of the V2 software is the ease of installing and updating software. Installing the software on the Pi Zero required a lengthy script install while connected to the internet via WiFi or Ethernet over USB. Likewise, updating the Pi Zero software required connecting it to the internet, then running an updating script that took a long time to complete. In contrast, the Pico can act as a flash drive and mount on your computer. To install or update the software, you download a UF2 binary file, plug the Pico into your computer and drag the UF2 file to the Pico flash drive. In a few seconds, the Pico is programmed and automatically reboots and runs the software. This is a lovely feature!

On the V1 hardware, we used eight INA219 voltage and current sensor boards mounted on the top and bottom of the PCB. We initially used the smaller purple boards, but during the pandemic, these boards became hard to find, expensive, and unreliable as many sellers were shipping defective boards to make up orders. With some work, the larger blue INA219 boards could be used instead. On the V2 hardware, we can use the blue or purple INA219 boards, but we also optionally support the INA219 SMT Integrated Circuit, so the whole board can be built without relying on other modules.

Currently, the CubeSatSim V2 hardware and software are in beta. You can find information about the following:

- Hardware — [github.com/alanbjohnston/CubeSatSim/tree/pico/hardware/v2beta](https://github.com/alanbjohnston/CubeSatSim/tree/pico/hardware/v2beta)
- Software in [github.com/alanbjohnston/CubeSatSim/tree/pico](https://github.com/alanbjohnston/CubeSatSim/tree/pico)
- Software releases in [github.com/alanbjohnston/CubeSatSim/releases](https://github.com/alanbjohnston/CubeSatSim/releases) labeled “Pico Beta”

- Wiki building instructions in [github.com/alanbjohnston/CubeSatSim/wiki/V2-Home](https://github.com/alanbjohnston/CubeSatSim/wiki/V2-Home)

Later in 2023, this will be officially released as the V2 CubeSatSim.

### Acknowledgments

I want to thank all the CubeSatSim Project team volunteers:

Jim McLaughlin, KI6ZUM  
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Jim Nagle, KF4OD  
Virginia Smith, NV5F  
Chris Thompson, G0KLA/AC2CZ  
Christine Mehner, MD, PhD, KO4EWG  
Kai Ji, AC3EN  
Melissa Pore, Km4CZ  
Lindsay White, KI6LZN  
Randy Standke, KQ6RS

Thanks to Mark Spencer, WA8SME, for his trailblazing work on CubeSat simulators and to Bob Bruninga, WB4APR (SK), for ideas and inspiration from his undergrad "LabSat" developments. Pat Kilroy, N8PK, was instrumental in getting the CubeSat Simulator project going again.

I would also like to acknowledge all the open-source hardware and software that is a part of the AMSAT CubeSatSim.

Finally, I acknowledge the support of the AMSAT Board of Directors and the members of AMSAT for their support and encouragement of this project. 🌐

### AMSAT Awards 2/21/23 through 4/20/23

AMSAT Satellite Communication Achievement Award  
G4NMD

GridMaster  
KF6JOQ, #55

AMSAT Rover Award  
LU5ILA, #73  
VK5DG, #74

## Operating Low Elevation DX via GreenCube

Dave Fisher, KG0D

I've enjoyed the LEO (low earth orbit) satellites for a few years. With a base station and portable rig (K8YSE-inspired; Figure 1), I always look for ways to make those DX (long-distance) contacts at low elevations! GreenCube, now called IO-117, with a footprint of about 13,041 Km, has dramatically increased the number of countries and operators we can connect with. However, it has also brought new challenges: packet radio operation and signal fading. Signal fading happens right after I finally get a successful digipeat! UZ7HO solved the packet radio part with his SoundModem and Digipeater software. I've recently been using the OZ9AAR Terminal program with the UZ7HO SoundModem.



Courtesy of Joe Kornowski, KB6IGK, and Microsoft Bing.

Signal fading has been a different story. Other hams had theories on this fading: clouds, rain, snow, cosmic dust, satellite elevation, antennas, and polarity. So I started gathering pass data to see what trends I might identify. DK3WN software (telemetry decoder and GetKISS+ 1.4.2 are also beneficial tools. These count packet decodes, telemetry decodes and includes a Unique Calls counter. It also forwards data to SatNOGS.

We first conducted tests with the base station, which consists of an IC-9700, SAT controller, M2LeoPack 8+8 RHCP UHF Yagis, Yaesu G-5500DC rotator and an ULNA from JG HiTechnology. Early test results looked interesting, and I headed down the path of comparing “decodes” and





Figure 1.

"decodes per minute." However, very quiet flight paths out over the Pacific Ocean showed me this was not a good comparator. We gathered thirty data passes with the base station at various elevations over several months (Figure 2).

IO-117 transmits telemetry about every 45 seconds, which appears on the SatNOGS GreenCube Telemetry data graph. I gathered telemetry time stamp data (DK3WN Decoder timestamps) and analyzed it in a spreadsheet. An occasional pause puts the telemetry data being transmitted about every 49 (48.9) seconds on average. Logging the start/end of each pass data decodes gave me the decode minutes. Next, I calculated the expected number of telemetry decodes versus what was received/counted. I call that the Reception Quality percentage.

I arranged this data into three groups (FIG 3) to compare pass info: 0 to 30 degrees, 31 to 60 degrees, and 61 to 90 degrees. It shows better Reception Quality at higher elevations. That could be because, at 87 degrees, EL IO-117 is 5,842 km (3,630 miles) away, while at approximately 0 deg EL, the satellite is 10,437 km (6,485 miles) away.

I then turned my attention to the antennas. I previously built a group of WA5VJB "Cheap" Yagis" (Figure 4). I chose the 11-element UHF Yagi for the first January 5, 2023 test. I alerted folks about this test on Twitter. It was a very low Max EL pass of just 1.3 degrees, so I wasn't expecting any significant results. Surprisingly, we captured 188 decodes in 19 minutes, with 17 telemetry packets sent to SatNOGS. The icing on the cake was the ST2NH connection (12,535 km) during this pass. The Yagi was supported by a tripod on the back deck (Figure 5) nearest the radio in the house. I could adjust it for vertical, horizontal, or anywhere between for maximum radio volume/signal. While this was great fun, I proceeded to more testing at other elevations. At this point, I needed remote antenna control.

Meanwhile, I was building another 11-element Yagi to experiment with a phased array vertically or horizontally and with LHCP and RHCP. I began sharing this project on my Twitter page on December 25, 2022. I learned about quarter-wave phasing/matching with coax plus LHCP and RHCP with help from these websites: [www.dg7ybn.de](http://www.dg7ybn.de) <https://k7mem.com> and <https://qsl.net/sv1bsx/antenna-pol/polarizations.html>

The added Yagi let me pair 11-element Yagis to test vertically, horizontally, or

IO-117 pass decode count data by KG0D							
Ver 1.2							
May 11, 2023		Single M2 LeoPack 8+8 RHCP Yagi ONLY					
CN88ka		IC-9700, 24 dB ULNA, LeoPack 8+8 RHCP Yagi					
		SORT		DK3WN			
Date	Max EL	GetKISS+ Decodes Count	Unique Calls Count	Telemetry Frames to SatNogs	Minutes (First to Last decode)	Decodes/Minute	Reception Quality Percentage
<b>Three Elevation Group Review</b>							
	1-30	2,926	386	250	301	9.7	67.8%
	31-60	5,618	382	458	490	11.5	76.3%
	61-90	7,740	527	650	635	12.2	83.6%

Figure 2.



IO-117 pass decode count data by KG0D							
Ver 1.2							
May 11, 2023		Single M2 LeoPack 8+8 RHCP Yagi ONLY					
CN88ka		IC-9700, 24 dB ULNA, LeoPack 8+8 RHCP Yagi					
SORT DK3WN							
Date	Max EL	GetKISS+ Decodes Count	Unique Calls Count	Telemetry Frames to SatNogs	Minutes (First to Last decode)	Decodes/Minute	Reception Quality Percentage
<b>Three Elevation Group Review</b>							
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	31-60	5,618	382	458	490	11.5	76.3%
	61-90	7,740	527	650	635	12.2	83.6%

Figure 3.

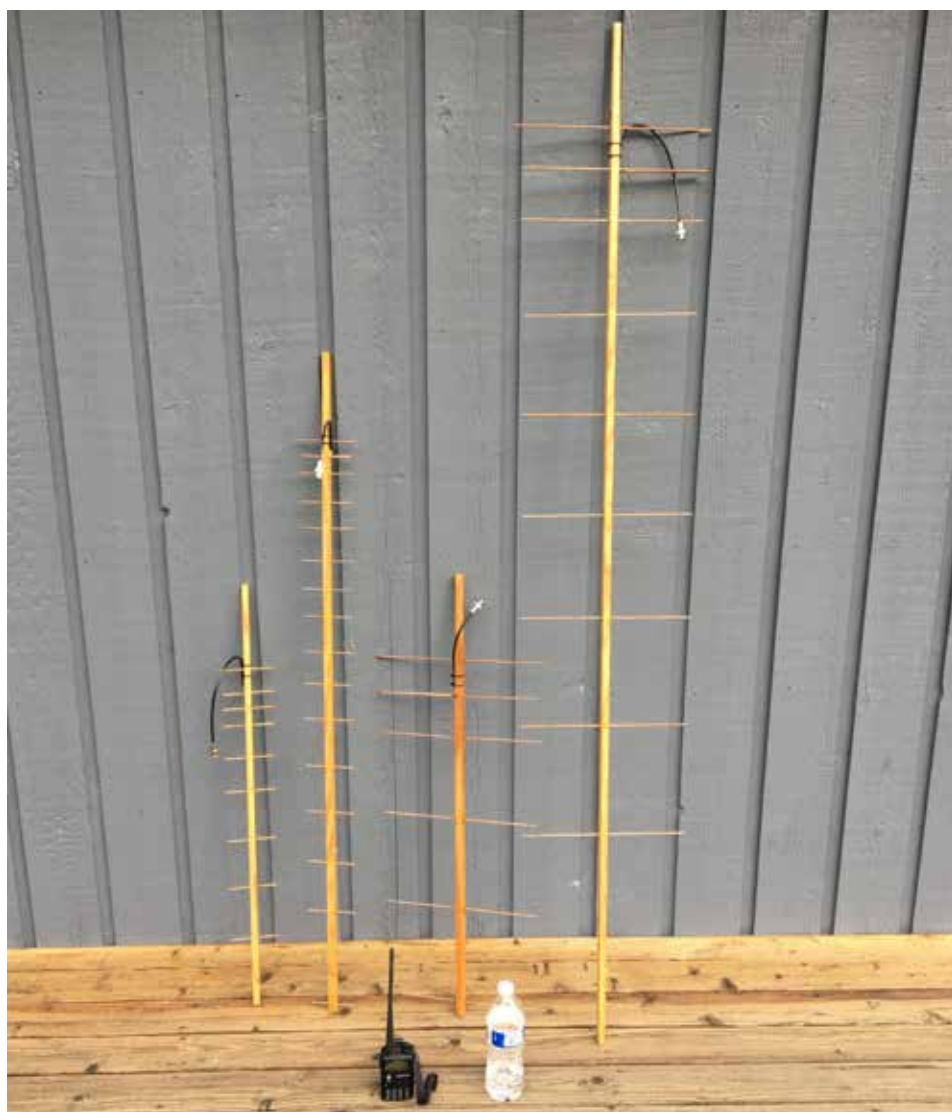


Figure 4.

anywhere between (Figures 6-7). The Yagi also added about 2.5 dB of gain. I completed three LHCP or RHCP passes with these 11-element Yagis (Figure 8). Taking care of antenna V/H orientation, the AZ/EL, radio operation, and note-taking was a lot of work while also trying to make a couple of contacts to prove these work both ways. So, I was considering fixed Yagis, one vertical and one horizontal. I switched using a coax relay (Figures 9-11) with the switch located by the radio. On Twitter, I noticed JI5USJ using a similar method. So, I researched, found and ordered the correct relay — more testing. I've completed several tests with this coax relay using a single 11-element Yagi. Later, I tested with a single 7-element Arrow Yagi. I added a 1N4004 flyback diode to the relay coil to eliminate the spike I could see when un-powering the relay.

JN2QCV shared a video on Twitter showing how he used a motor with printed gears to change the antenna V to H and back to V. I studied gear ratios and delivered torque math to select gears and a toothed belt needed, plus the correct RPM 12 VDC motor. Also, I found a small VFD along with a reversing switch. KC7JPC used his 3D plastic printer to create the blue part (Figure 12) needed for the rectangular Yagi boom to the inner round gear. I recently tested with a single 11-element Yagi (Figures 13-15). This xxx has the potential for dual motors and dual-phased Yagis. I designed this for a half rotation in four seconds. The higher speed is needed to adjust for those short packets. The VFD allows me to fine-tune that speed. VFD/Motor noise was high in one direction, but tolerable, and super quiet in the other direction. Wrapping that coax around the boom could be very easy, so further testing/thought is needed.

The short piece of wood clamped to the tripod has served as a great multi-antenna test platform. Research in the websites above gave me the 39" separation distance for the two 11-element Yagis. The PVC pipes allow manual axial rotation as needed. One of the Yagis I built used a bit longer boom so I could slide it forward a quarter wave for RHCP/LHCP operation. The same piece of wood also let me do additional testing with a pair of 7-element Arrow Yagis (FIG 16 17). I am lucky I didn't cut the extra bit off on the right side, which became my motor mounting area (Figures 6 and 14).

With 46 tests completed, I'm comparing the summary table to identify patterns (Figure 18). These have been sorted in the Reception Quality column. Luckily, the sorted RQ data put the antenna systems in the correct order from lowest to highest gain. Now it is a matter of what our antenna needs are. Simple/small for roving could be just the single 7-element Arrow, manually adjusted for vertical, horizontal, or anywhere between. We could get about 70% of the data and miss the other 30%. If that signal loss happens at the first/last two minutes of a pass, I could miss some good DX! So, I'm leaning toward the pair of 11-element Yagi's, one vertical and the other horizontal, fed with the remote-controlled coax switch. A couple of 15-element Diamond Yagis could be in my future, too. Alternatively, I could build the 20-element WA5VJB UHF Yagis. More testing is needed with the motorized version. One antenna would be much easier to work with than two. So many choices!

During this project, additional roving trips with this WA5VJB 11-element Yagi produced some great DX. I made memorable contacts with VU2LBW, A65BR, and ZL3TCM, plus others, at distances of 12,937 km, 11,841 km, and 11,961 km, respectively. The contact with VU2LBW held the distance record for a couple of weeks before being broken. The actual distance record for the pair of phased 11-element Yagis on the tripod was an EME contact with DL7APV in February 2023. Of course, his 128 Yagis did at least 99% of the heavy lifting (Figure 19).

In summary, increased gain from longer Yagis provides greater receive signal strength and reduces signal fading severity. This, in turn, provides more received packets and ensures a better chance of connecting with that rare DX at one-degree elevation. Therefore, we select the best tool for our needs, budget, base station or roving. 🌐



Figure 5.



Figure 6.

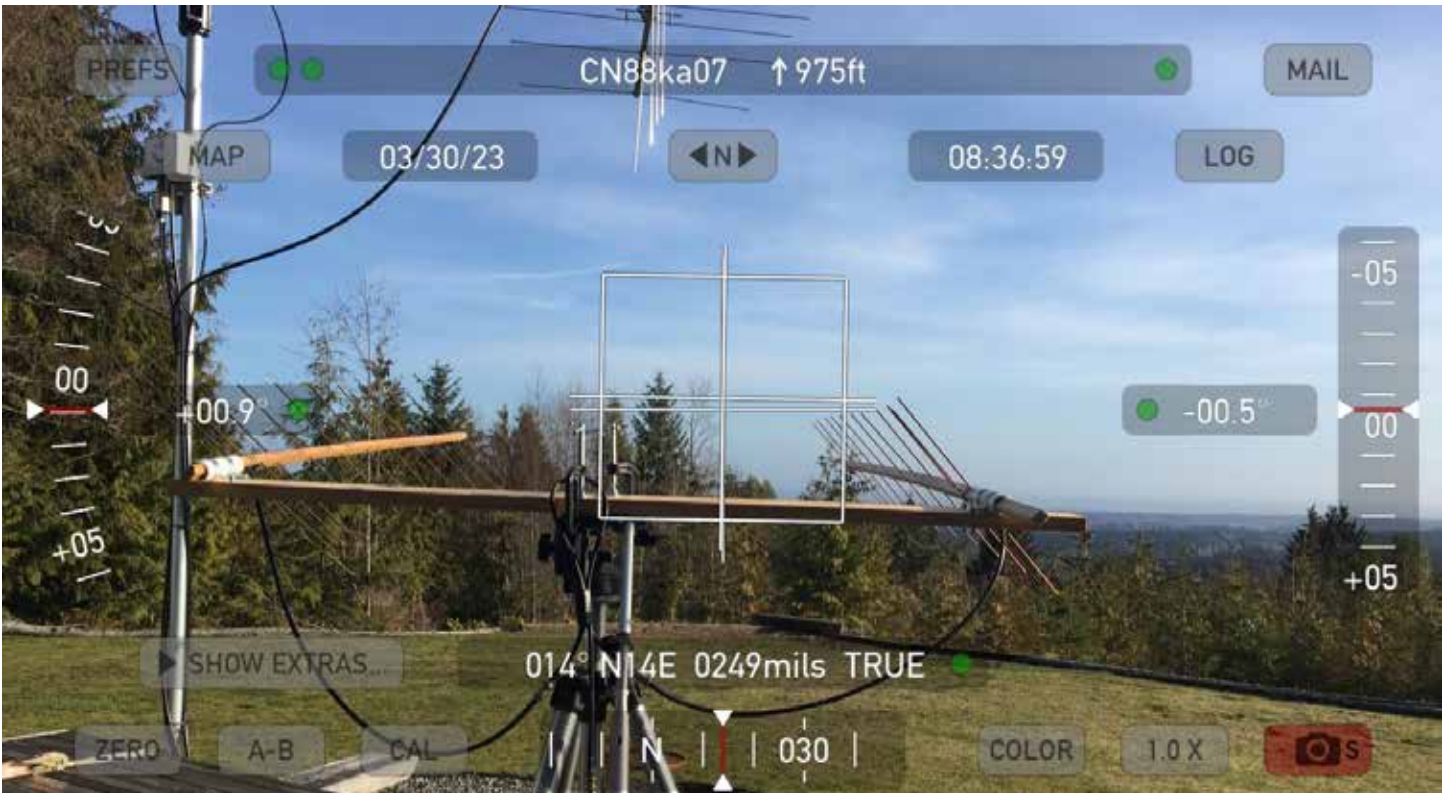


Figure 7.

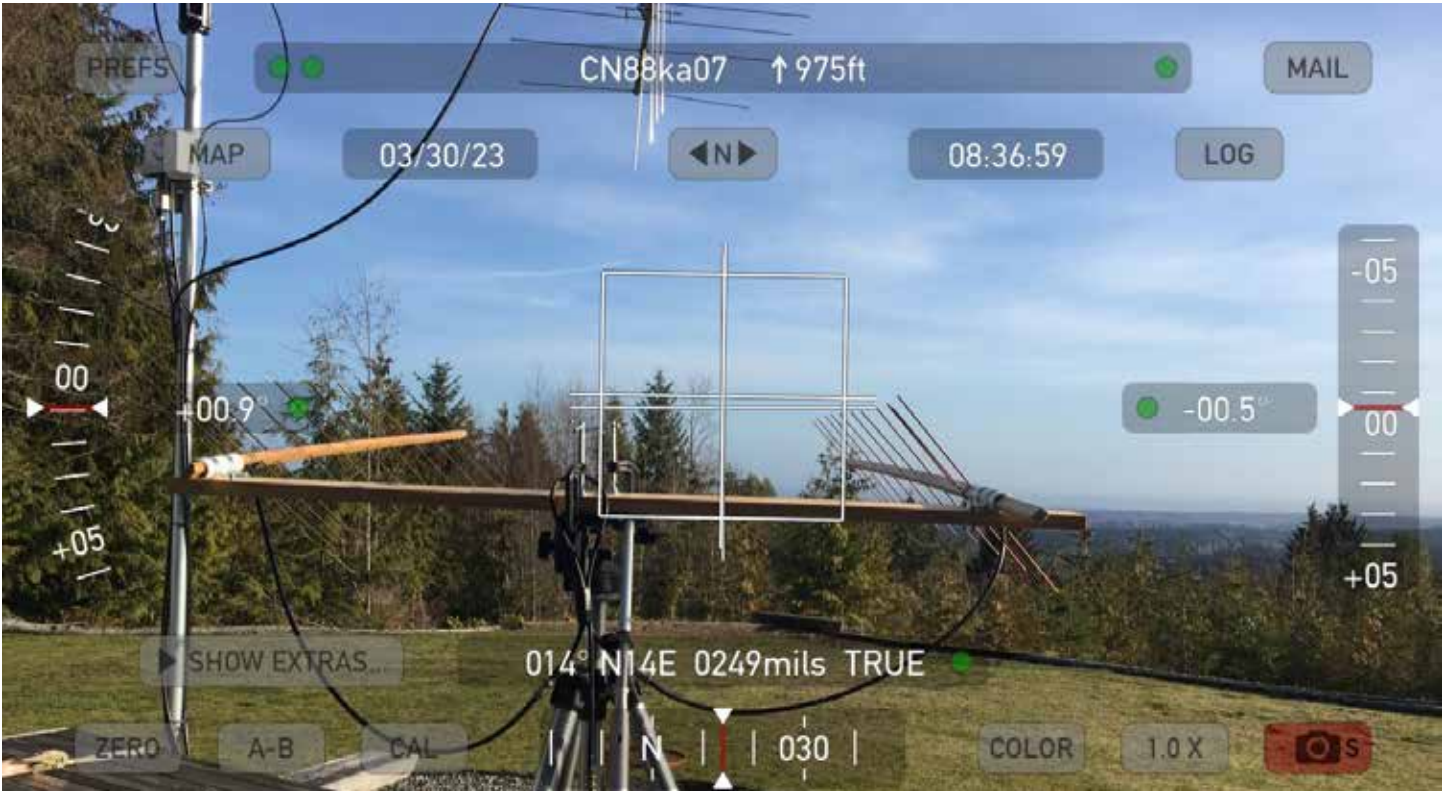


Figure 8.





Figure 9.



Figure 10.

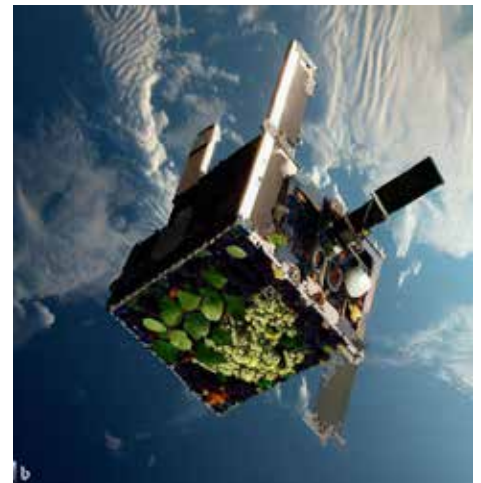


Figure 11.





Figure 12.



Courtesy of Joe Kornowski, KB6IGK, and Microsoft Bing.

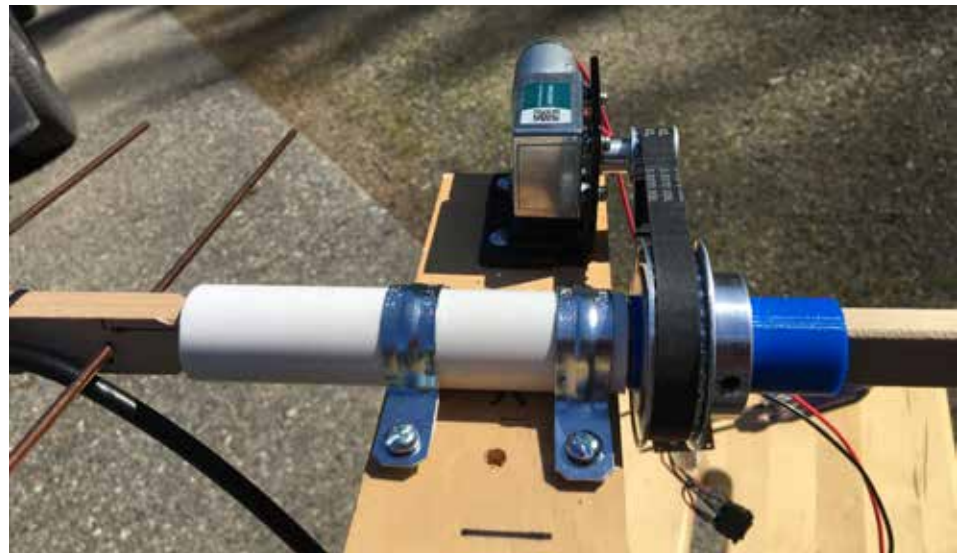


Figure 13.



Figure 14.





Figure 15.



Courtesy of Joe Kornowski, KB6IGK, and Microsoft Bing.



Figure 16.



Figure 17.



KG0D May 13, 2023 at CN88ka					SORT
Master Summary Greencube IO-117	Satellite	Total	Total	Decode	Reception
	Passes	Decodes	Telemetry	Minutes	Quality
		(GetKISS+)	to SatNOGs		Percentage
Portable IC-9700, Single Arrow 7 El Yagi V/H or Between (?? dBi), 20dB ULNA	1	49	49	58	69.0%
Portable IC-9700, Single Arrow 7 EL COAX RELAY V/H (?? dBi), 20 dB ULNA	1	428	56	60	76.2%
Base station IC-9700, M2 LeoPack 8+8 RHCP only (13.3 dBi), 24dB ULNA	30	16,284	1,358	1,426	77.8%
Portable IC-9700, Single Homebrew 11 EL AXIAL Motor (13.8 dBi), 20 dB ULNA	1	720	58	56	84.6%
Portable IC-9700, Single Homebrew 11 EL V/H or Between (13.8 dBi), 20 dB ULNA	4	2,108	205	190	88.1%
Portable IC-9700, Dual Homebrew 11 EL RHCP/LHCP (13.8-3.0 dBi), 20 dB ULNA	3	1,380	127	115	90.2%
Portable IC-9700, Single Homebrew 11 EL COAX RELAY V/H (13.8 dBi), 20 dB ULNA	2	1,263	182	164	90.6%
Portable IC-9700, Dual Homebrew 11 EL V/H or Between (13.8+2.5 dBi), 20 dB ULNA	3	1,893	172	144	97.5%
	45	24,125	2,207	2,213	

Figure 18.

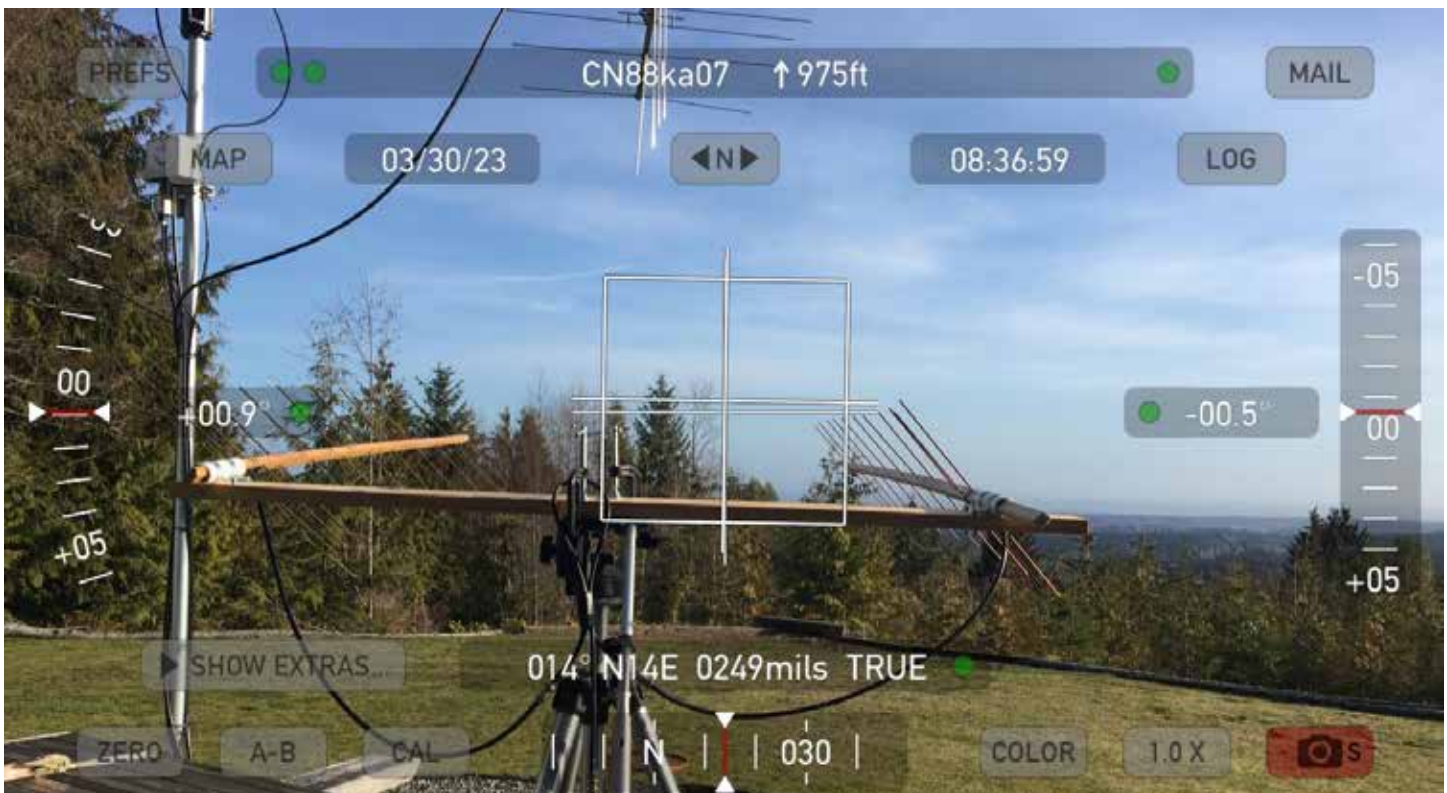


Figure 19.



**A GreenCube Haiku**  
*GreenCube in orbit*  
*Plants grow in microgravity*  
*A new frontier blooms*

— Joe Kornowski and Microsoft Bing

# Evaluating Antennas For LEO Satellites

Terry Osborne, ZL2BAC

The release of the EZNEC Pro [1] antenna modeling program has given us an excellent tool to evaluate various antennas and see how well they match the requirements for LEO Satellites.

In this paper, I have included the Vertical Radiation Pattern results of some popular antennas and have tabulated the results on a spreadsheet available on GitHub [2]. All the antennas are modeled three meters above real ground from EZNEC Pro.

The ideal antenna for LEO satellites should have maximum gain at the horizon and a smooth transition falling to about 10 dB minimum overhead (*The AMSAT Journal*, March/April 1990 [3]).

To confirm this, I found an online slant range calculator [4] to calculate the range for various elevations and satellites. From these figures, I calculated the Free Space Path Loss using the well-known formula:

$$PL = 32.4 + 20 \cdot \text{LOG}(\text{Range}) + 20 \cdot \text{LOG}(\text{Frequency}), \text{ where Range is}$$

measured in km and Frequency in MHz.

I then calculated the difference in path loss from 0 degrees to 90 degrees elevation (Gain at Elevation), as shown in Table 1 for an RS44 example.

The importance of coverage overhead is often exaggerated since the satellites spend little time at high elevation angles. For an XW2A example, see Figure 1 from Leovis and Note 1.

## Antenna Evaluation

Radiation at 0 degrees elevation is impossible due to ground absorption, and even NASA

considers an elevation of 5 degrees the minimum for a ground station.

### 1) Two-meter Quarter wave Ground plane (Figure 2 - 2 m QuarterWaveGP)

This is the simplest antenna and gives an almost acceptable radiation pattern. The overall gain is low, but installing a low-noise preamp can compensate for this. Note that the polarization of the received signal at low elevations usually is vertical, as confirmed by tests on AO-91 using a handheld yagi. Other vertical antennas give similar results, but increasing the gain at lower angles reduces gain at higher elevation angles.

Field	Type	Remarks
MsgID	2-byte value	This message has value 3
SatId	16-byte value	Unique for the satellite
UpdateNo	4-byte value	Update number
SegNo	4-byte value	Segment number sent
SegLen	4-byte value	Length of segment sent
Segment	2,048-bytes	The actual segment
Sign	256-byte value	Digital signature

Table 1.

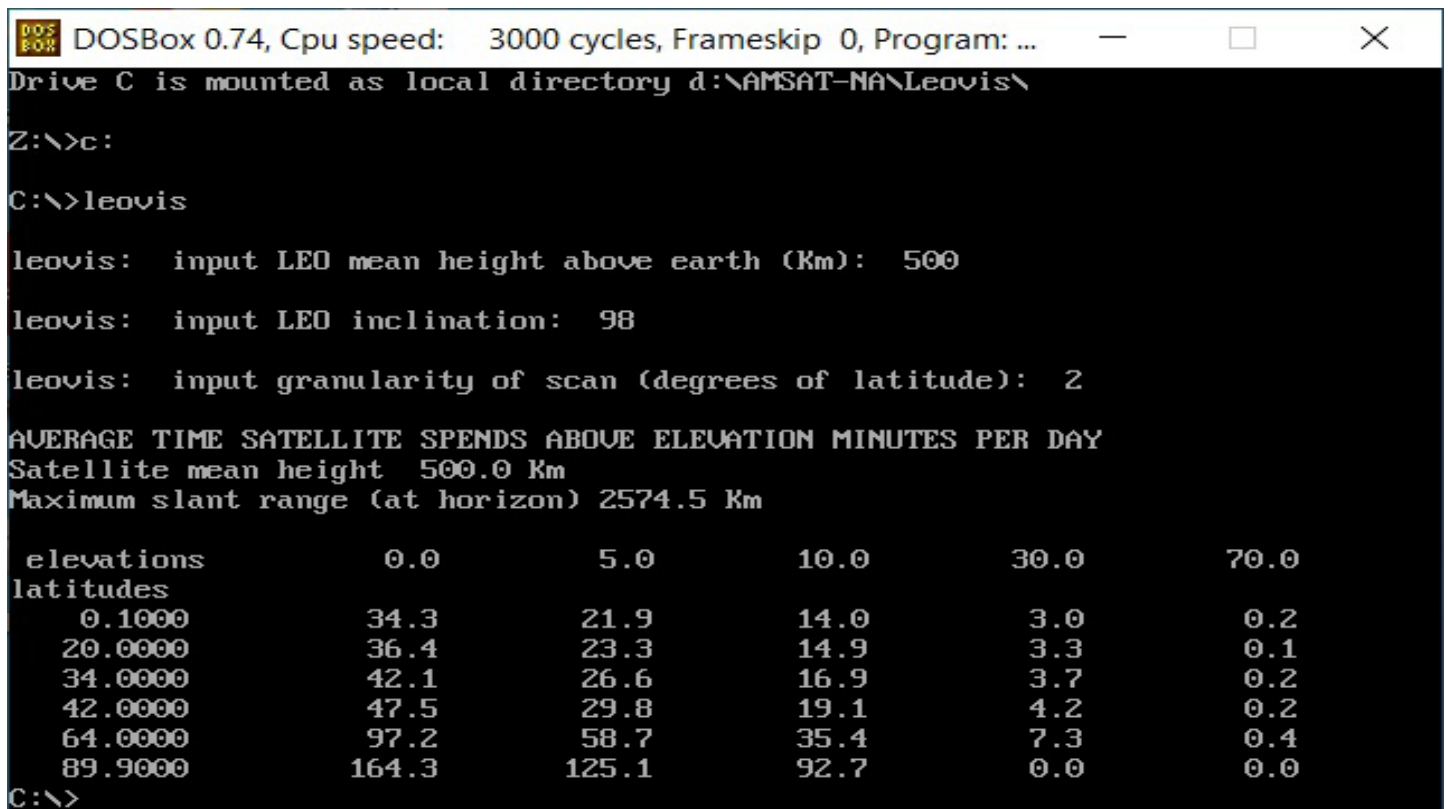


Figure 1.



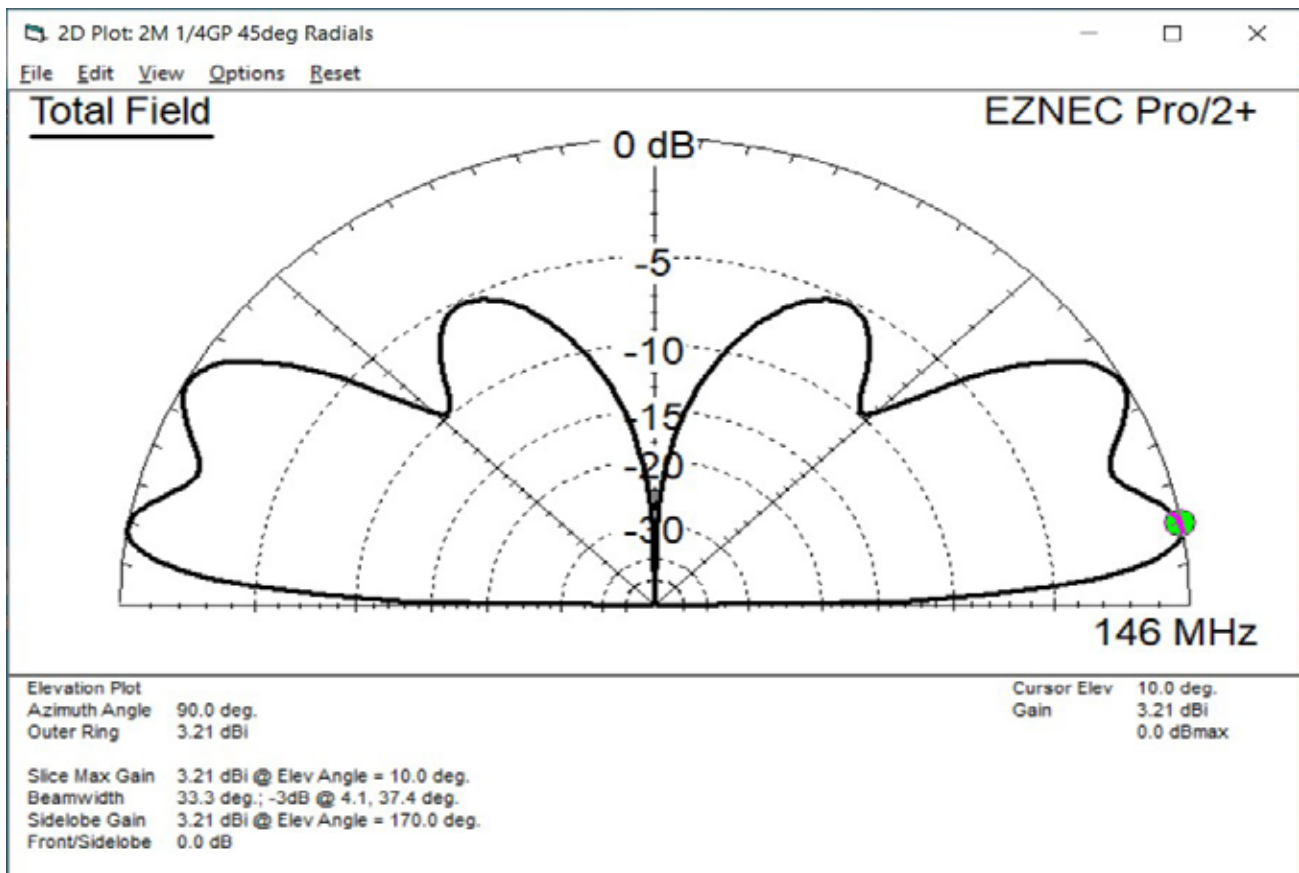


Figure 2.

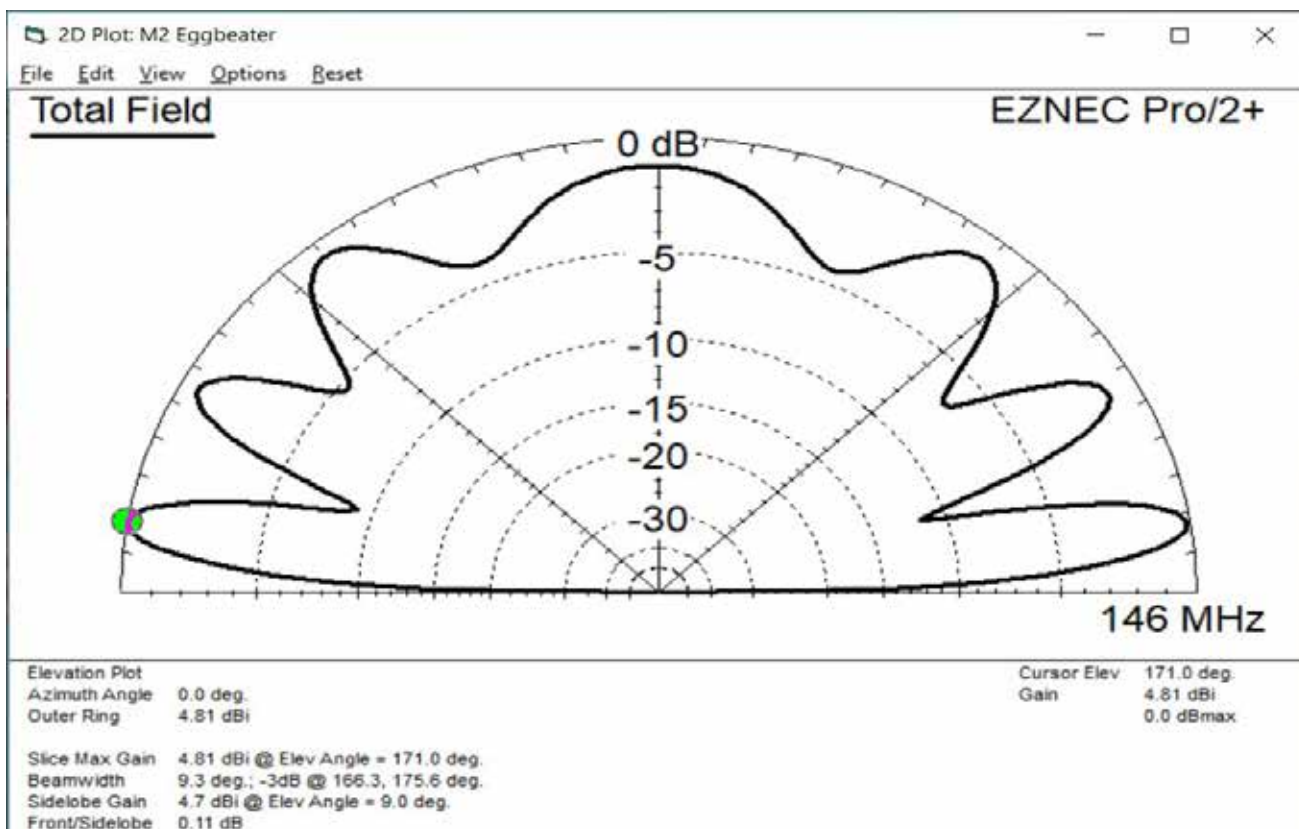


Figure 3.

## 2) Turnstiles

All variations of turnstiles give similar results, and I have included the two-meter eggbeater (Figure 3 — M2 Eggbeater 2 m).

This popular antenna is horizontally polarized at low angles and circular at higher angles. Note that a deep null at about 17 degrees elevation results from ground reflection. The angle and depth of the null vary with antenna height and are responsible for the varying effects that users of this antenna report. It will give good results above 20 degrees elevation.

The best results with a minimum null are from an eggbeater with square loops (see GitHub [2]).

Note that increasing the gain at low elevations creates a deeper null just above the angle of maximum gain.

## 3) Lindenblad (Figure 4 — 2 m Lindenblad)

This is probably the best of the omnidirectional antennas. It is the only one that is circularly polarised over the whole pattern. It does have a null at higher elevation angles, but this may be fine, as outlined above.

## 4) 2 m Moxon Loop Turnstile

This antenna was initially described by L.B. Cebik, W4RNL (SK), and the details appear in QST August 2001. This antenna has a minimal earth reflection null due to the low back lobe of the Moxon Loop design. As a result, it has good gain characteristics and should perform better than the eggbeater antennas (see GitHub [2]).

## 5) 2 m Quadrifila Helix

This antenna proved challenging, but I developed a model that used four straight wires for each helix. This antenna is effective, with maximum gain at higher angles (see GitHub [2]).

## 6) 2 m 3-Element Yagi (Figure 5 — 3 El Yagi @ 25 Deg Elev)

This antenna has the highest gain of the 2 m antennas modeled and is typical of the Arrow and similar antennas. This one is modeled at 25 degrees elevation, which would be used in a fixed station with a small azimuth rotator. The high gain and good pattern back up the results observed by operators using handheld antennas and portable stations.

## 7) 70 cm Eggbeater (M2).

At 70 cm, a problem of multiple ground reflections occurs, and you have an antenna that will suffer from fading and loss of signal

(Figure 6 — 70 cm M2 Eggbeater).

## 8) 70 cm 7-Element Yagi.

This works much better than the eggbeater (Figure 7 — 70 cm 7El Yagi).

I have also modeled several antenna designs not included here. The plots of these are in GitHub [2].

I have also made a spreadsheet to compare the performance of the popular antennas on five typical satellites Results (Results screenshot of spreadsheet) and GitHub [2].

The satellites are AO-7, RS-44, ISS Cross band repeater, AO-91 and XW2A. Only downlinks have been considered because the ground station can compensate for extra losses by increasing its transmit power.

The EIRP values for each satellite are taken from the published data as far as possible. Receiver Noise floors are based on calculations and are: -138 dBm for SSB with a 6 dB noise figure, -145 dBm for SSB with a 1dB noise figure preamp, -126 dBm for FM with a 6 dB noise figure, and -130dBm for FM with a 1 dB noise figure preamp. Feeder loss has not been considered.

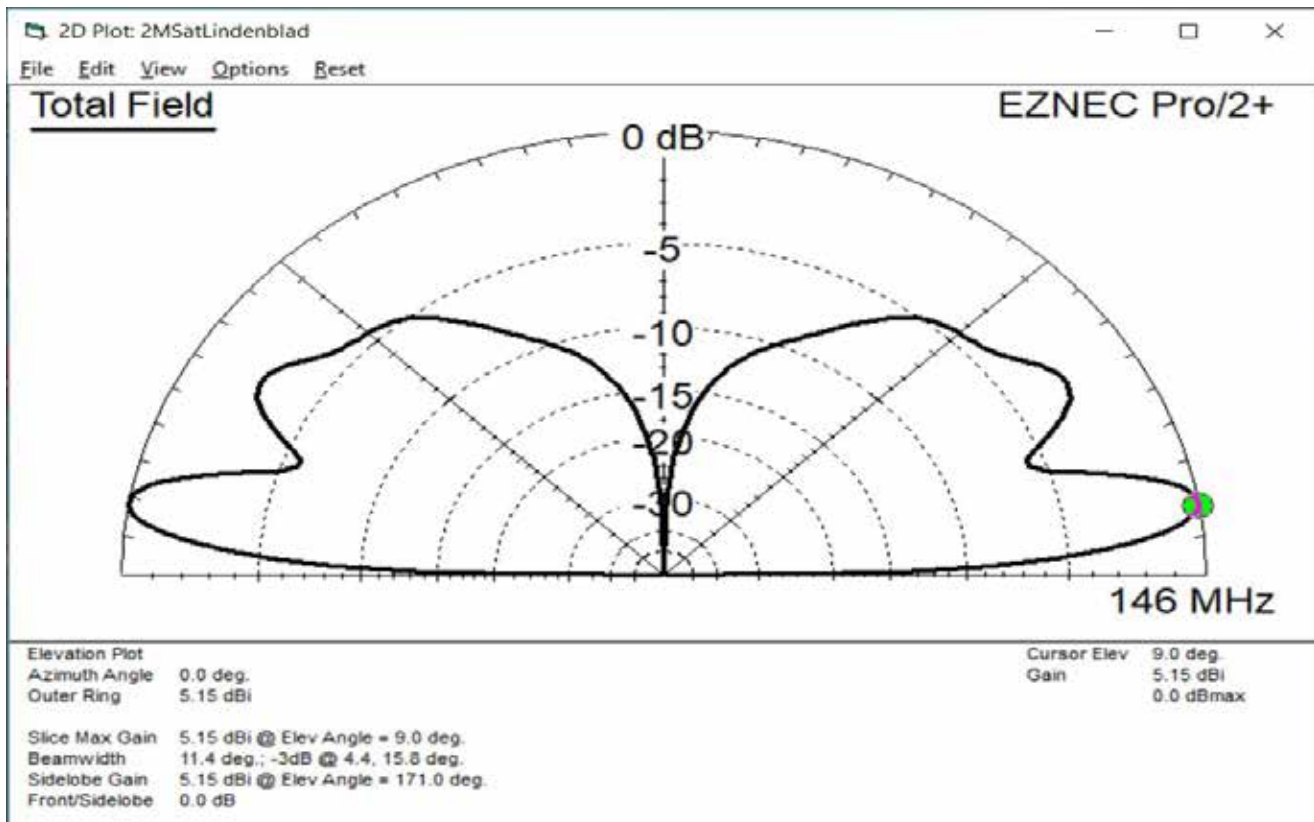


Figure 4.



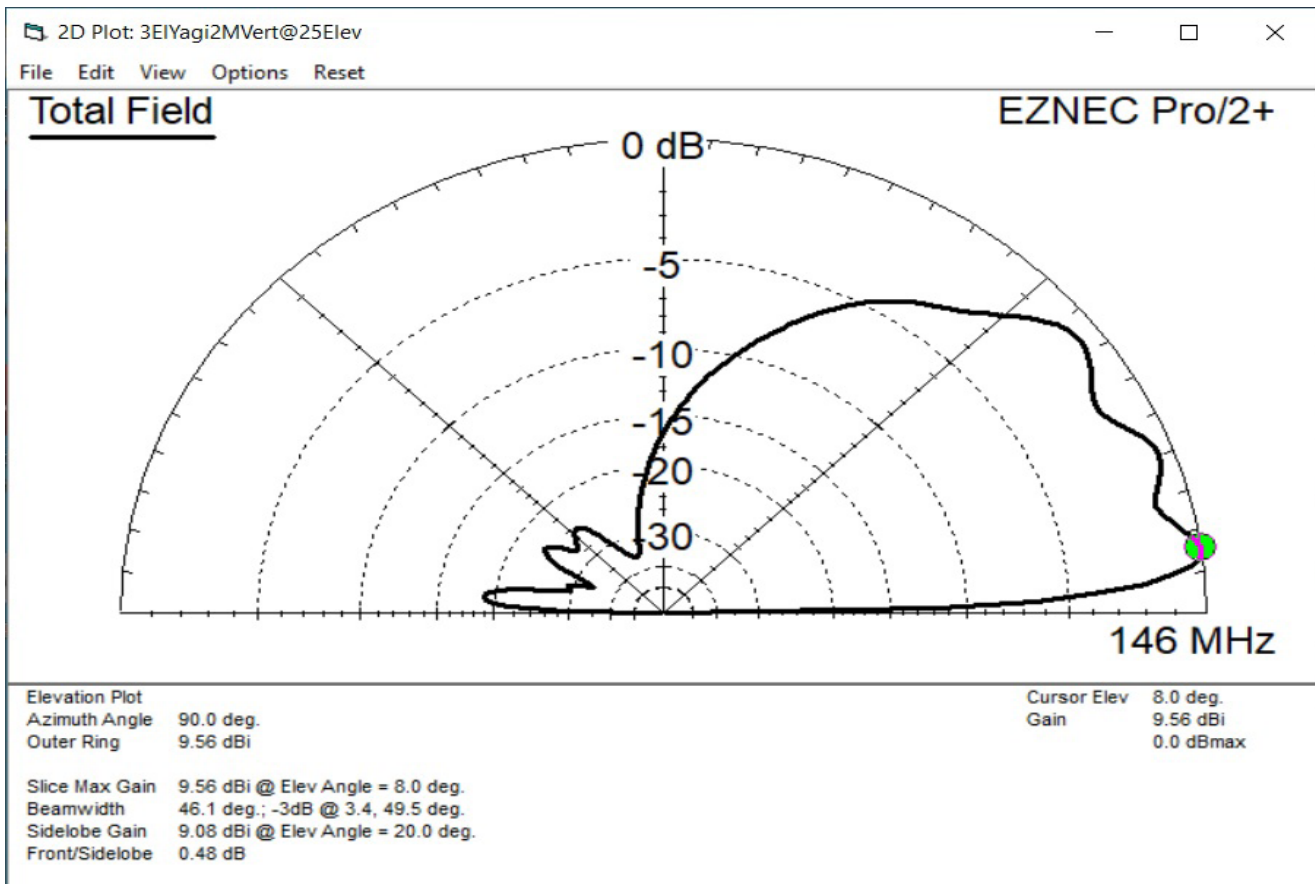


Figure 5.

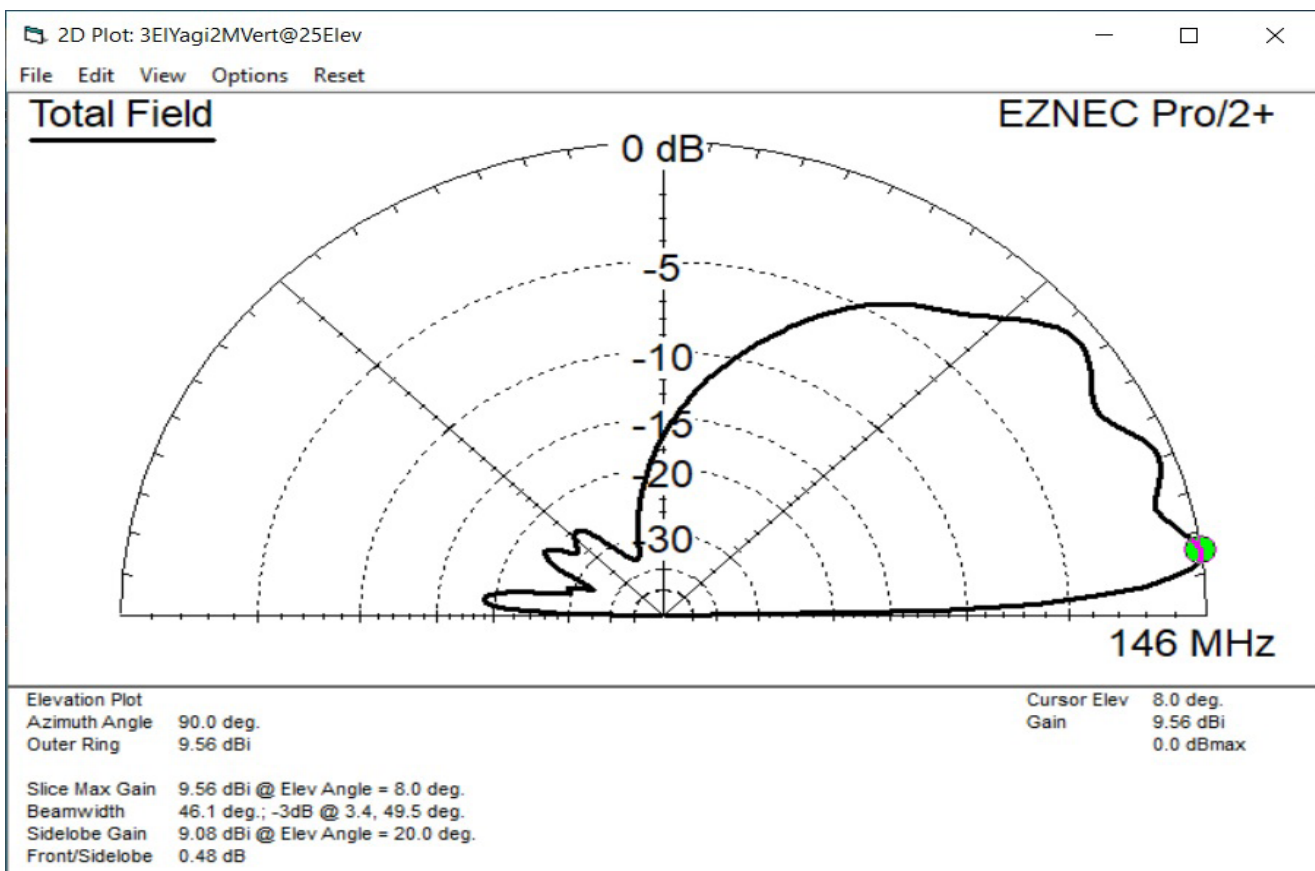


Figure 6.



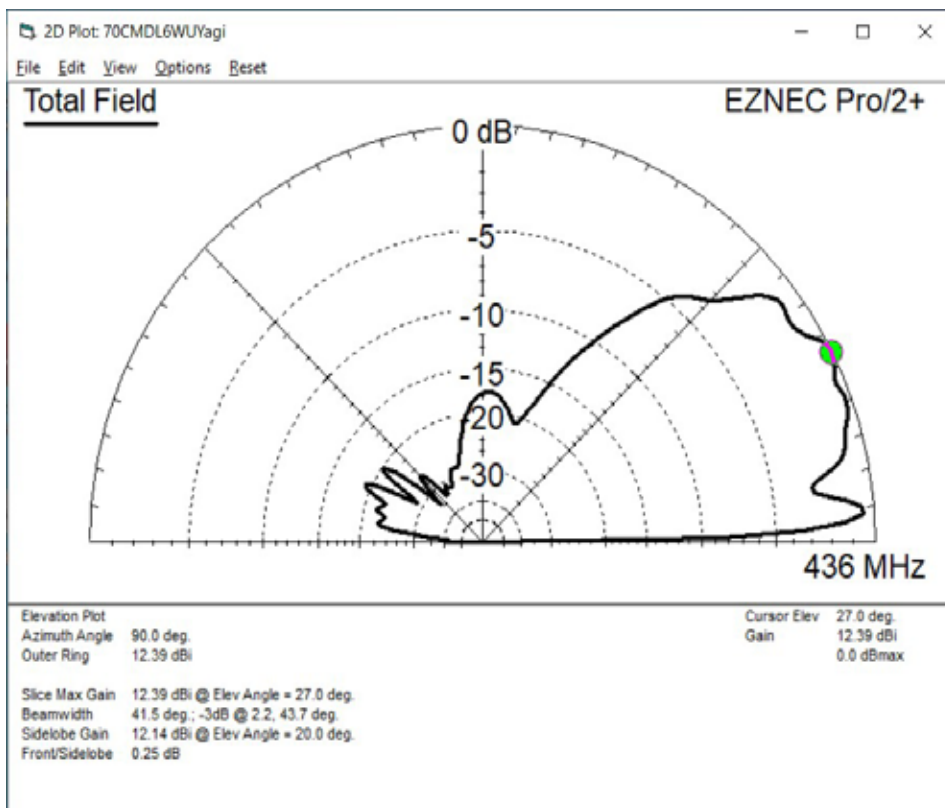


Figure 6.

	A	B	C	D	E	F	G	H	I	J	K	L	M
8 Antennas													
9 1/4 w G.P.													
10 Elevation	0.00	5.00	10.00	20.00	30.00	40.00	50.00	60.00	70.00	80.00	90.00		
11 Gain @ Elevation (dBi)	-50.00	2.15	3.15	1.00	1.00	-2.00	-4.00	-2.00	-4.00	-7.00	-30.00		
12 Rx Signal (dBm)	-170.62	-115.77	-112.31	-110.58	-107.84	-108.88	-109.46	-106.45	-107.77	-110.38	-133.26		
13 SNR TCVR 6dB NF	-44.62	10.23	13.69	15.42	18.16	17.12	16.54	19.55	18.23	15.62	-7.26		
14 Evaluation	Bad	Good	Good	Good	Good	Good	Good	Good	Good	Good	Bad		
15 SNR 1dB preamp	-40.62	14.23	17.69	19.42	22.16	21.12	20.54	23.55	22.23	19.62	-3.26		
16 Evaluation	Bad	Good	Good	Good	Good	Good	Good	Good	Good	Good	Bad		
17													
18 Egg Beater (M2)													
19 Elevation	0.00	5.00	10.00	20.00	30.00	40.00	50.00	60.00	70.00	80.00	90.00		
20 Gain @ Elevation (dBi)	-50	2.5	5.5	-6.5	3.5	-2.5	3.5	-0.5	1.5	1.5	2		
21 Rx Signal (dBm)	-170.62	-115.42	-109.95	-118.08	-105.34	-109.38	-101.96	-104.95	-102.27	-101.88	-101.26		
22 SNR TCVR 6dB NF	-44.62	10.58	16.04	7.92	20.66	16.62	24.04	21.05	23.73	24.12	24.74		
23 Evaluation	Bad	Good	Good	Bad	Good	Good	Good	Good	Good	Good	Good		
24 SNR 1dB preamp	-40.62	14.58	20.04	11.92	24.66	20.62	28.04	25.05	27.73	28.12	28.74		
25 Evaluation	Bad	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good		

Results.

Conclusions

Radio operators can work satellites with a two-meter downlink using most antennas. Even a simple 1/4 wave ground plane will give surprisingly good results. A 1dB noise figure or better preamp would be helpful but not essential.

Eggbeaters and other types of turnstiles will give varying results at low angles due to ground reflections but work well above 20 degrees elevation. Similar comments apply to the QFH antenna.

The best omnidirectional antenna is the Lindenblad. The overhead null should not be a problem.

The best antenna for 2M is a small Yagi. The modeled three-element version is far better than any other antenna. You can use vertical polarization, a fixed elevation of 25 degrees, and an azimuth rotator on a home station and obtain good results. However, circular polarization and an elevation rotator are overkill.

For 70 cm downlinks, the ISS can be worked with most antennas, but a yagi will be required for RS44, SO-50, and the upcoming GOLF satellites. Again vertical polarization, a fixed elevation, and an azimuth rotator will give good results.

Note 1: Figure 1 was produced with an old DOS program, "Leovis" by Duncan Courtenay N5BF. Many years ago, Courtney Duncan N5BF wrote a simple program to predict the time spent at various elevation angles. This program is available in the AMSAT archives as "Leovis" ([www.amsat.org/amsat/ftp/software/PC/tracking/leovis.zip](http://www.amsat.org/amsat/ftp/software/PC/tracking/leovis.zip)). Unfortunately, this old MS DOS program would not run on my Windows 10 box. However, Duncan included the source code in the distribution, and I was able to re-compile and run it.

References

- [1]: [www.eznec.com/](http://www.eznec.com/)
- [2]: [github.com/TerryOz/Evaluating-LEO-Antennas](https://github.com/TerryOz/Evaluating-LEO-Antennas)
- [3]: Dick Janson, WD4FAB, "Antennas for Microsat Ground Stations," *The Amsat Journal*, Vol 3 No 1, March 1990.
- [4]: [www.vcalc.com/wiki/KurtHeckman/Slant+Range](http://www.vcalc.com/wiki/KurtHeckman/Slant+Range)
- [5]: [www.dosbox.com/](http://www.dosbox.com/)

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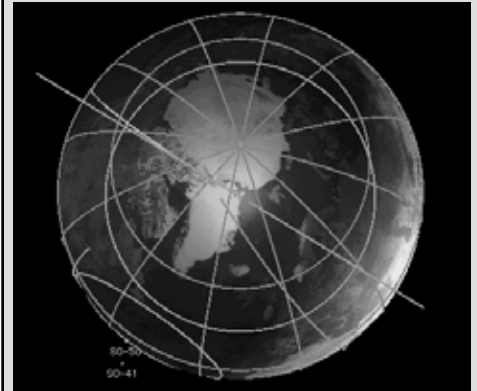
**AMSAT is the North American distributor of SatPC32, a tracking program for ham satellite applications. Version 12.8d features enhanced support for tuning multiple radios. Features include:**

1. The CAT commands of the IC-9100 have been extended again. The program now also controls the DV mode (DV for 'Digital Voice') of the radio. With the FT-817 the program now additionally supports the CWR mode.
2. All SatPC32 programs now process significantly larger Keplerian element source files. Especially because of the numerous new Cubesats, the number of data sets contained in the source files has increased significantly. For example the file Cubesat.txt currently contains data for nearly 400 satellites.
3. In all programs (SatPC32, SatPC32ISS, Wisat32, WinAOS and WinListen), the list of satellites contained in the source file ('Available' list in menu Satellites) is now displayed in alphabetical order to facilitate locating individual satellites.
4. The program SatPC32ISS now also allows the creation of up to 12 satellite groups. The new Cubesats have also increased the number of 'in-band' satellites. Originally, in-band operation in amateur radio was only available at the ISS.
5. In order to accelerate a change between the individual satellite groups, the 'Groups' window can now be called up by clicking on vacant areas of the main window, except in the Satellite menu. Such free positions are located on the right and left of the frequency window.
6. In the Satellites menu the data sets of the satellites contained in the active source file can now be displayed. When called, the data set of the currently selected satellite is displayed. The feature helps you to immediately know the identifier of the satellite.
7. The program has improved control of the sub-audible tone required by some satellites. The program can now automatically switch the sub tone on/off when switching between PL tone satellites and others, changing between u/v and v/u satellites, changing the group, closing the program, etc.

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