The AMSAT® Journal

Volume 44, Number 2 | March/April 2021

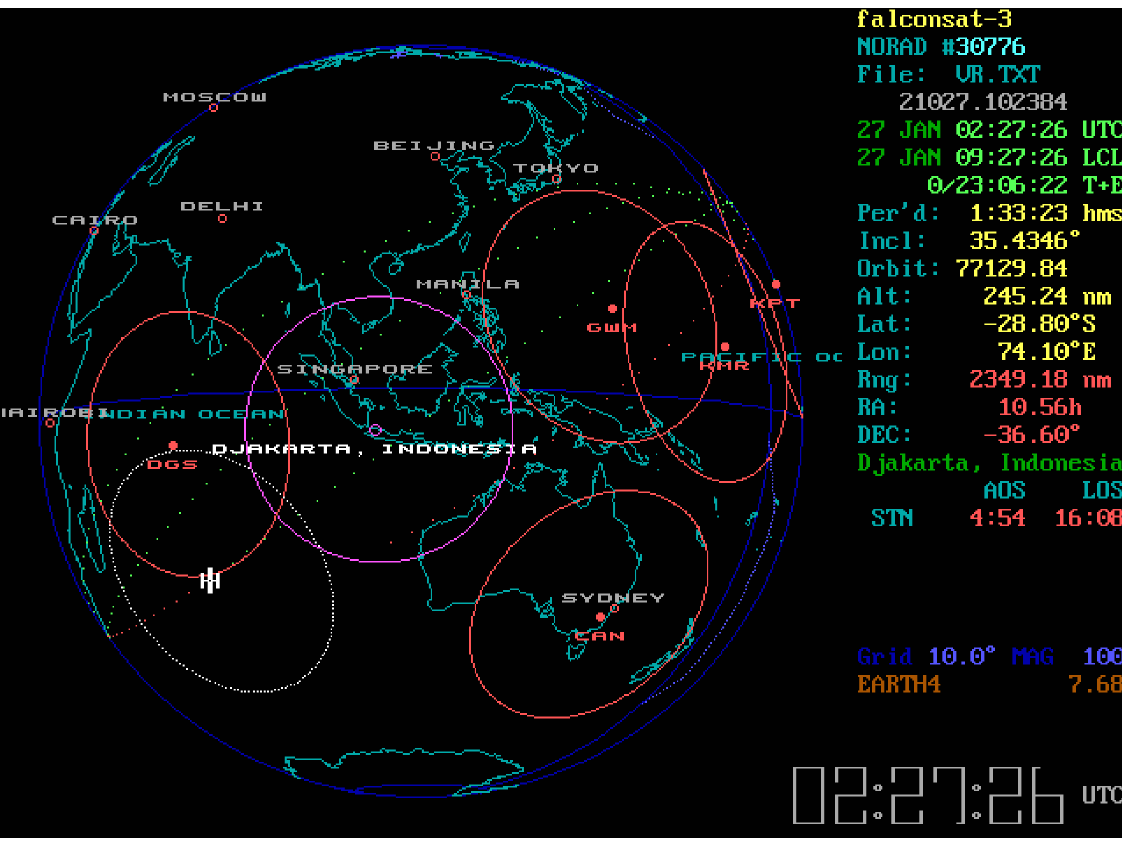
Editor-in-Chief
Joe Kornowski, KB6IGK

Assistant Editors
Bernhard Jatzeck, VA6BMJ
Douglas Quagliana, KA2UPW/5
Paul Graveline, K1YUB

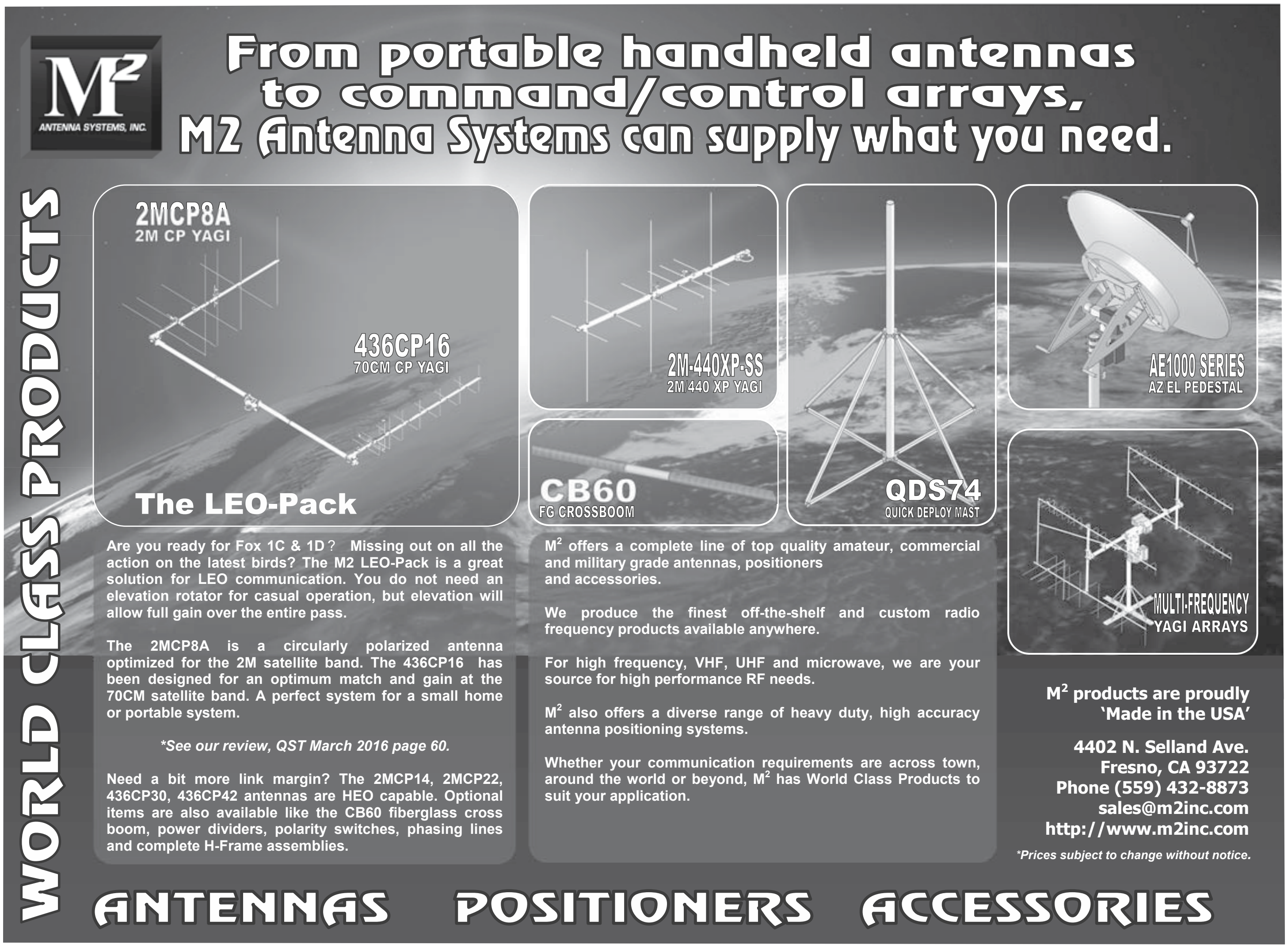
2021 AMSAT Field Day Rules

WD9EWK at DM34/DM44 in Arizona

N6UTC at DM06/DM16 in California
(578km WNW of WD9EWK QTH)



In this issue —



AMSAT Announcements

The AMSAT Journal Needs Your Words and Wisdom

The AMSAT Journal is looking for interesting articles, experiences and photos to share with other AMSAT members. Writing for the *Journal* is an excellent way both to give back to the AMSAT community and to help others learn and grow in this most fascinating aspect of the amateur radio avocation.

Find a quiet place, sit yourself down, get out your laptop or pick up a pen, and …

1. *Launch* your inner writer;
2. *Downlink* your knowledge and experiences to others by:
   -- Sharing your adventures in the "On the Grids" column or
   -- Describing your AMSAT career in "Member Footprints;"
3. *Transmit* lessons learned from operational and technical projects;
4. *Log* some of your more interesting passes across the sky; and
5. *Boost* others to a higher orbit of know-how and experience.

After your article lands in members' mailboxes, and the kudos start arriving for your narrative payload, you can enjoy the satisfaction of knowing you've elevated the collective wisdom of AMSAT to a higher trajectory. Send your manuscripts and photos, or story ideas, to: **journal@amsat.org**.

Our editors are standing by!

AMSAT's Mission

AMSAT is a non-profit volunteer organization which designs, builds and operates experimental satellites and promotes space education. We work in partnership with government, industry, educational institutions and fellow Amateur Radio societies. We encourage technical and scientific innovation, and promote the training and development of skilled satellite and ground system designers and operators.

AMSAT's Vision

Our Vision is to deploy satellite systems with the goal of providing wide-area and continuous coverage. AMSAT will continue active participation in human space missions and support a stream of LEO satellites developed in cooperation with the educational community and other amateur satellite groups.

Radio Amateur Satellite Corporation (AMSAT)
P.O. Box 27, Washington, D.C. 20044
Telephone: 888-322-6728
AMSAT Club Callsign: W3ZM
AMSAT Websites: www.amsat.org, launch.amsat.org (Member Portal)

The AMSAT Journal Staff
Editor-in-Chief: Joe Kornowski, KB6IGK, kb6igk@amsat.org
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Douglas Quagliana, KA2UPW/5
Bernhard Jatzeck, VA6BMJ
Paul Graveline, K1YUB

Editorial Office: Joe Kornowski KB6IGK, 3310 W. Braker Ln., Suite 300-322, Austin, TX 78758. Please e-mail *Journal* submissions to: journal@amsat.org,

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The AMSAT Journal staff is always interested in article submissions. Whenever possible, submissions should be sent via e-mail to journal@amsat.org using plain text or word processor files; photos or figures in TIF, GIF or JPG formats. Kindly do not embed graphics or photos in your manuscript. We prefer receiving those as separate files. AMSAT reserves the right to select material for *The AMSAT Journal* based on suitability of content and space considerations.

Apogee View

Robert Bankston, KE4AL, President

It has been six months since I was elected president of AMSAT, so I thought this would be an excellent time to bring you up-to-date on what we have been working on and what we have accomplished.

In my initial address to the board of directors, I laid out my plan to lead AMSAT forward and place it in a better position to accept the challenges and take advantage of the opportunities ahead. Within this plan, I laid out both a list of goals and a timeline to accomplish them. I am happy to share that we are on track and, thanks to a lot of hard work from our volunteers, making significant progress.

Virtual Office Transition

Our biggest challenge has been transitioning from a centralized, brick-and-mortar office in Kensington, Maryland, to a virtual office spread across multiple time zones. Undoing 50-plus years of manual processing habits is no easy feat, and it has certainly not gone off without a hitch. While a few loose ends remain, we are fully functional and in a better position than we were several months ago.

In addition to improving our efficiencies, switching to a virtual office has allowed us to significantly reduce our overhead costs. The fiscal year 2021 budget I presented to our board of directors included over $150,000 in cost savings over the prior year and represents one of the first budgets in many years where our projected revenues exceeded our projected expenses.

Member Portal One Year Anniversary

Part of this virtual office transition started a year ago as we launched our online member manage system – the AMSAT Member Portal (launch.amsat.org), on May 1, 2020. Providing our members with the opportunity to access their membership account and member benefits in real-time is a vast improvement over the manual system we used in the past. To this day, I still receive compliments from our members on our member portal and the improved quality of our member services.

Bylaws Amendment

The Bylaws of the Radio Amateur Satellite Corporation were last amended in 1989 – 32 years ago. As such, certain provisions have become outdated, especially concerning communication methods. In March 2020, then-president Clayton Coleman, W5PFG, requested that a committee review the bylaws and recommend changes. Through the committee's efforts (see their report elsewhere in this issue of The AMSAT Journal), the AMSAT Board of Directors approved a Bylaws Amendment on March 2, 2021.

ARTICLE IV of the Bylaws of the Radio Amateur Satellite Corporation – Amendment of the Bylaws, provides:

> *Adoption of and amendments to these Bylaws shall require the written approval of two-thirds or more of the Directors. Notice of an adoption or amendment which has received such approval, including the text thereof, shall be mailed to all Members by the Secretary, or, at the Secretary's discretion, included in a publication of the corporation mailed to all Members. Such adoption or amendment shall be effective thirty days after the mailing of such notice or publication, unless written objection is received from at least ten percent of the Members in which case a vote shall be conducted by the Secretary in the manner specified for election of Directors. In any such vote, such amendment, to become effective, shall require a majority vote of those Members voting.*

Notices to all members were mailed on April 9, 2021, and, unless more than 10% of our members object, the amendment shall be effective on May 9, 2021.

The most significant changes relate to modernizing how we communicate with our membership. Prior to this amendment, all communications had to be by mail. If you have had to buy stamps lately, you know how quickly this adds up when you must communicate with over 4,000 members. In addition, our committees recommended we take this opportunity to answer recent questions relating to membership and the election process. Ambiguity leads to interpretation, which leads to inconsistent application. The changes not only ensure fairness but enhance our transparency.

I would like to thank the board for taking the initiative to take on this challenge and the members of the Bylaws Committees for their time and insightful input.

JAMSAT Symposium

On March 20, I had the opportunity to

attend the Japan AMSAT (JAMSAT) Virtual Symposium. JAMSAT did an excellent job of hosting its symposium online, which provided a greater opportunity for the entire amateur satellite service community to participate and share ideas. Our Vice-President of Engineering, Jerry Buxton N0JY, provided an excellent presentation. If you missed it, the recordings are still available at youtube.com/channel/UCnOhGHA_WWIc2IUPoncf0iQ.

During the symposium, JAMSAT selected a new president, H4PHW, Shiro Sakai san. We congratulate him and look forward to a strong friendship and cooperation. Outgoing President JA3GEP, Mikio Mouri san, announced his retirement after 20 years of commendable service. We thank him for the many years of support and friendship.

Golf-Tee Manifested

In the exciting news category, AMSAT's GOLF-TEE CubeSat has been manifested for launch on NASA's ELaNa-46 mission. GOLF-TEE is a critical first step in our return to HEO.

The TEE in GOLF-TEE stands for "Technology Exploration Environment," reflecting GOLF-TEE's mission testing two primary systems needed for higher orbits. First, an Attitude Determination and Control (ADAC) system will be tested to allow active pointing of the satellite antennas, which will provide significant gain. The other primary goal of GOLF-TEE is to provide initial orbit and space radiation exposure for radiation event-induced fault tolerant systems designed using COTS components. GOLF-TEE will carry an Integrated Housekeeping Unit (IHU) / command transceiver designed using the Hercules line of ARM architecture-based microcontrollers.

GOLF-TEE will also evaluate a low-cost, deployable, fixed attitude solar panel array design as part of AMSAT Engineering's exploration of fixed panel arrays that allow for outfitting a variable number of "wings" to best match the power requirements of various CubeSat missions.

GOLF-TEE will carry a modified commercial software-defined radio (SDR), the Ettus E310, as an experimental package to test high-speed data downlink in the 10 GHz band, as well as a fully-functional LEO VHF/UHF amateur satellite carrying conventional backup systems, including a linear transponder.

CubeSat Developers Workshop

On April 27-29, AMSAT hosted a virtual booth at the 2021 CubeSat Developers Workshop (CDW). CDW is an annual conference hosted by the Cal Poly CubeSat Laboratory at Cal Poly, San Luis Obispo, with over 500 industry professionals, small satellite developers and students. This year's Workshop venue was held virtually due to COVID-19 response policies. I want to thank Vice-President of Engineering, Jerry Buxton N0JY, Vice-President of Operations, Drew Glasbrenner KO4MA, Vice-President of Development, Frank Karnauskas N1UW, and Executive Vice-President Paul Stoetzer for representing AMSAT and sharing our mission with the CubeSat community.

ARISS-USA

I would like to congratulate our friends and partners, ARISS-USA, in obtaining its 501(c)(3) charitable tax-exempt status. This is a monumental accomplishment and represents years of hard work and dedication by Frank Bauer, KA3HDO, and all of the ARISS volunteers. The ARISS program has grown so much since its inception and has inspired so many students worldwide. We are proud to be a part of it and wish them success in all their future endeavors.

AMSAT Symposium

Let me take a few moments to talk about the 2021 AMSAT Symposium. Last year, COVID-19 restrictions forced us to host the event virtually; however, it looks like this year's symposium will be in person in Bloomington, Minnesota. More information will be forthcoming as soon as it's available.

Finally, I want to thank every one of you for being a part of AMSAT. This is a great organization with a noble mission to advance amateur radio in space. There is also no better time to serve at the helm as your president. I am deeply honored. Until the next time, Onward and Upward!

Share Your Experiences as an AMSAT Member

The AMSAT Journal is looking for you to share your satellite radio experiences, likes and dislikes, how you work the birds, and what you like about *The AMSAT Journal*. We'll publish a selection of responses in upcoming issues of the Journal under a column we're calling "Members Footprints." Photos are strongly encouraged! Thanks!

Please send the information requested below to journal@amsat.org --

- Your Name
- Call Signs Held
- Primary Grid Square
- Favorite Satellite Contact
- First Satellite Contact
- First Satellite Ground Station Description
- Current Satellite Ground Station Description
- Reasons You Are an AMSAT Member
- Favorite AMSAT Memory (a satellite contact, symposium, engineering project, event that would never have happened without AMSAT, etc.)
- Favorite Topics Appearing in The AMSAT Journal (could include things like building a homebrew antenna, assembling a ground station, using tablets and smartphones, news of upcoming launches, portable operations, ARISS, etc.

Please Provide a Hi-Resolution Photograph (see www.amsat.org/?page_id=1709).

Smile for AMSAT at Amazon.com

When making purchases from Amazon, you can select a charity and Amazon will donate .5% of a qualified purchase towards that charity. Select smile.amazon.com when making your Amazon purchases and make Radio Amateur Satellite Corporation (AMSAT) your chosen charity.

Having selected a charity, when you go to amazon.com, you will be prompted to go to smile.amazon.com. However, you can put everything you want in your cart at the original amazon.com site, then leave the site and go to smile.amazon.com and all your items will still be in your cart.

Educational Relations Update

Alan Johnston, Ph.D., KU2Y
V.P. Educational Relations

With schools slowly starting to open, the AMSAT CubeSat Simulator loaners are beginning to be used again. I recently shipped the first one with the new CubeSatSim hardware to Melissa Pore, KM4CZN, at Bishop Denis J. O'Connell High School in Arlington, VA. The new loaners (Figure 1) include the turntable, LED lamp, and ready-to-launch CubeSatSim in the shipping case (with AMSAT luggage tags!).

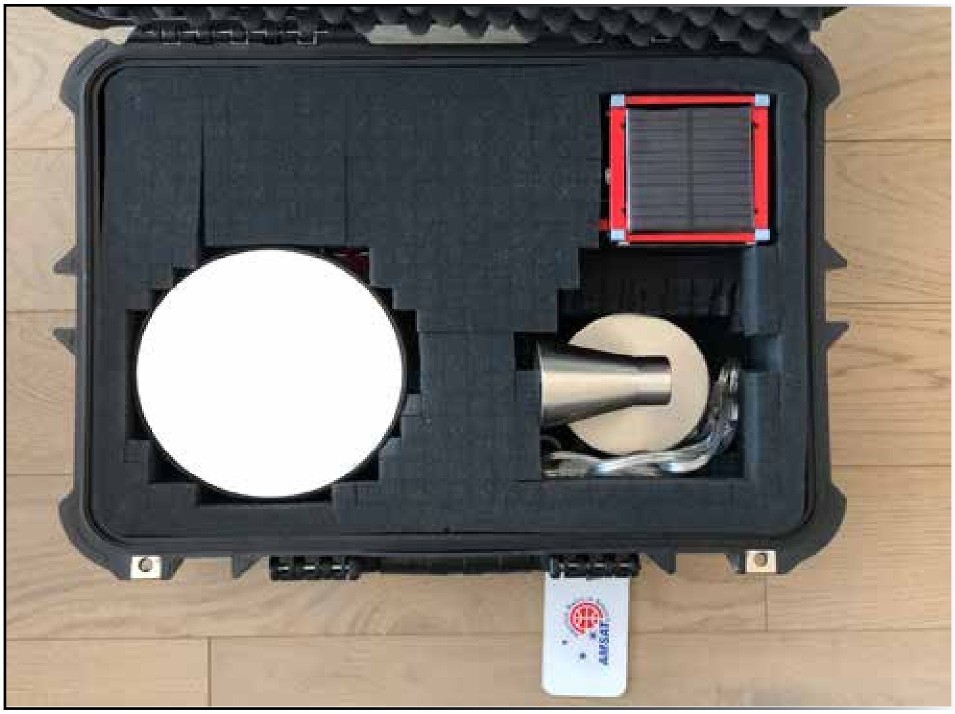

Figure 1 — AMSAT CubeSatSim Loaners are ready for your next event!

Her students in the Denis J. O'Connell Amateur Radio Club had used the original simulator last year and were excited to get the new hardware. I was able to join their first in-person meeting in a long time via Zoom the other week. Having used both versions, they appreciated the new features, including:

- LED lamp which does not run as hot as the old halogen lamp;
- FoxTelem automatic telemetry decoding and real-time graphing so you can see results in just seconds;
- STEM Payload Board with its gyroscope, temperature, pressure, humidity, and altitude sensors, all automatically decoded in FoxTelem;
- Raspberry Pi ground station with all software pre-installed, based on the ARISS Radio Pi image (see **github.com/alanbjohnston/CubeSatSim/wiki/Radio-Pi** for more info about this project)

We are building more CubeSatSim loaners, so we will have plenty available to ship to you and your event this spring and summer!

In other CubeSatSim news, we now have the first release version 1.0 printed circuit boards (PCBs) available on the AMSAT store for a donation. Instead of having to get your own circuit boards made, which often has minimum quantities, you can get one complete set of blank boards shown in Figure 2 - Main board, Battery board, and STEM Payload board (**www.amsat.org/product/amsat-cubesatsim-pcb/).** In addition, the mainboard comes with the SMD surface mount components for the bandpass filter (BPF) pre-installed. All the rest of the components are through-hole, making it an easy soldering project. For information on building your own CubeSatSim, see the Wiki **CubeSatSim.org/wiki**. Besides your blank printed circuit boards, you will need the components listed here on the bill of materials **CubeSatSim.org/bom**.

For the latest CubeSat Simulator news, follow our dedicated Twitter account **@CubeSatSim**. If you are interested in doing a demo for a group or school, I can ship you a loaner. Contact me via email **ku2y@amsat.org** or on Twitter **@alanbjohnston**.

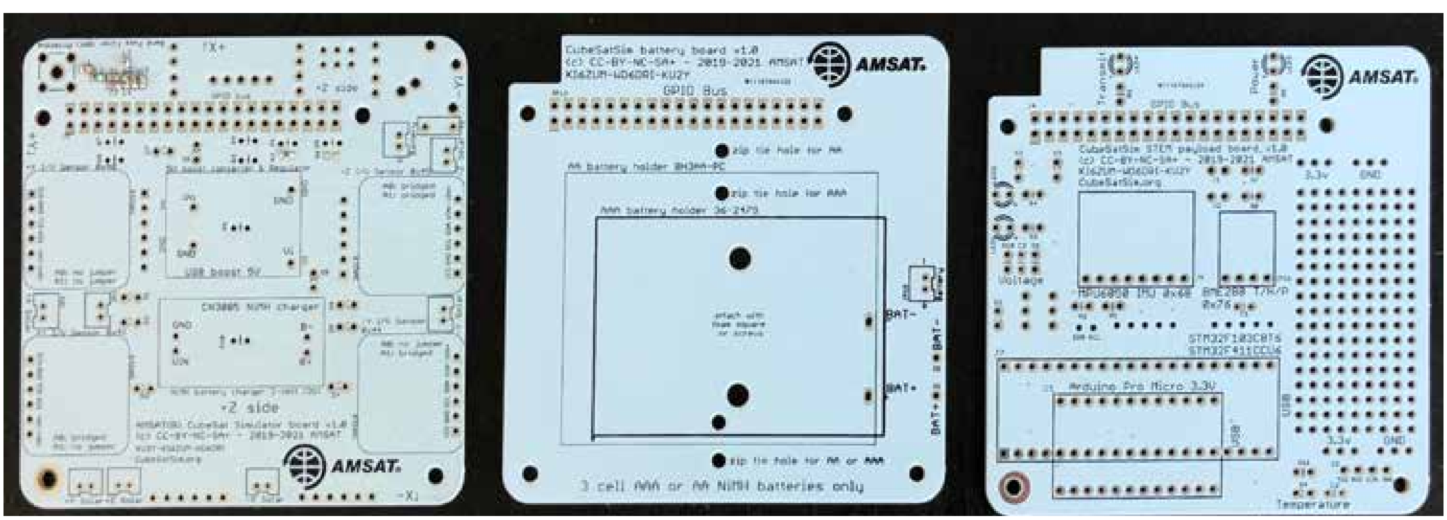

Figure 2 — AMSAT CubeSatSim PCB Set, showing (left to right) Main board, Battery board, and STEM Payload board.

2021 AMSAT Field Day

Bruce Paige, KK5DO
Director, Contests and Awards
AMSAT Board Member

It's that time of year again: summer and Field Day! Each year the American Radio Relay League (ARRL) sponsors Field Day as a "picnic, a campout, practice for emergencies, an informal contest and, most of all, FUN!" The event takes place during a 23-hour period on the fourth weekend of June. For 2021, the event occurs during a 27-hour period from 1800 UTC on Saturday, June 26 through 2100 UTC on Sunday, June 27. Those who set up before 1800 UTC on June 26 can operate only 24 hours. The Radio Amateur Satellite Corporation (AMSAT) promotes its own version of Field Day for operation via the amateur satellites, held concurrently with the ARRL event.

This year should be as easy as last year since we have more than 10 transponders and repeaters available. Users should check the AMSAT status page at **www.amsat.org/status/** and the pages at **www.amsat.org/two-way-satellites/** for what is available in the weeks leading up to field day. To reduce the amount of time to research each satellite, see the current FM satellite table at **www.amsat.org/fm-satellite-frequency-summary/** and the current linear satellite table at **www.amsat.org/linear-satellite-frequency-summary/.**

If you are considering ONLY the FM voice satellites, focus on SO-50, AO-91, AO-92 and possibly LilacSat. This year, it might be easier to make that one FM contact for the ARRL bonus points with so many FM birds. The congestion on FM LEO satellites is always so intense that we must limit their use to one QSO per FM satellite. This includes the International Space Station (ISS). You will be allowed one QSO if the ISS is operating voice.

It was suggested during past field days that a control station be allowed to coordinate contacts on the FM satellites. Nothing in the rules prohibits this. This is nothing more than a single station working multiple QSOs. If a station were to act as a control station and give QSOs to every other field day station, the control station would still only be allowed to turn in one QSO per FM satellite while the other station would be able to submit one QSO.

The format for the message exchange on the ISS or other digital packet satellite is an unproto packet to the other station (3-way exchange required) with all the same information as typically exchanged for ARRL Field Day, such as:

W6NWG de KK5DO 2A STX
KK5DO de W6NWG QSL 5A SDG
W6NWG de KK5DO QSL

If you have worked the satellites on Field Day in recent years, you may have noticed many good contacts can be made on some of the less-populated, low-earth-orbit satellites like FO-29, AO-7, EO-88 or the XW satellites. During Field Day, the transponders come alive like 20 meters on the weekend. The good news is that the transponders on these satellites will support multiple simultaneous contacts. The bad news is that you can't use FM, just low duty-cycle modes like SSB and CW.

2021 AMSAT FIELD DAY RULES

The AMSAT Field Day 2021 event is open to all Amateur Radio operators. Amateurs are to use the exchange as specified in ARRL rules for Field Day. The AMSAT competition is to encourage the use of all amateur satellites, both analog and digital. Note that no points will be credited for any contacts beyond the ONE allowed via each single-channel FM satellite. Operators are encouraged not to make any extra contacts via these satellites (e.g., SO-50). CW contacts and digital contacts are worth three points, as outlined below.

1. Analog Transponders

ARRL rules apply, *except*:

- Each phone, CW, and digital segment ON EACH SATELLITE TRANSPONDER is considered a separate band.
- CW and digital (RTTY, PSK-31, etc.) contacts count THREE points each.
- Stations may only count one completed QSO on any single channel FM satellite. If a satellite has multiple modes such as V/u and L/s modes both turned on, one contact each is allowed. If the PBBS is on — see Pacsats below, ISS (one phone and one digital), Contacts with the ISS crew will count for one contact if they are active. PCSat (I, II, etc.) (one digital),
- The use of more than one transmitter simultaneously on a single satellite transponder is prohibited.

2. Digital Transponders

We have only APRS digipeaters and 10 m to 70 cm PSK transponders (see Bob Bruninga's article in the March/April 2016 issue of The AMSAT Journal).

Satellite digipeat QSOs and APRS short-message contacts are worth three points each but must be complete verified two-way exchanges. The one contact per FM satellite is not applied to digital transponders.

The use of terrestrial gateway stations or internet gateways (e.g., EchoLink, IRLP, etc.) to uplink/downlink is not allowed.

For the Pacsats (FalconSat-3) or "Store and Forward" hamsats, each satellite is considered a separate band. Do not post "CQ" messages. Simply upload ONE greeting message to each satellite and download as many greeting messages as possible from each satellite. The subject of the uploaded file should be posted as Field Day Greetings, addressed to ALL. The purpose of this portion of the competition is to demonstrate digital satellite communications to other Field Day participants and observers. Do not reply to the Field Day Greetings addressed to ALL.

The following uploads and downloads count as three-point digital contacts.

(a) Upload of a satellite Field Day Greetings file (one per satellite).
(b) Download of Satellite Field Day Greetings files posted by other stations. Downloads of non-Field Day files or messages not addressed to ALL are not counted for the event. Save DIR listings and message files for later "proof of contact."

Please note AMSAT uploaded messages do not count for QSO points under the ARRL rules.

Sample Satellite Field Day Greetings File:

"Greetings from W5MSQ Field Day Satellite station near Katy, Texas, EL-29, with 20 participants, operating class 2A, in the AMSAT-Houston group with the Houston Amateur Television Society and the Houston QRP club. All the best and 73!"

Note that the message stated the call, name of the group, operating class, where they were located (the grid square would be helpful) and how many operators were in attendance.

3. Operating Class

Stations operating portable and using emergency power (as per ARRL Field Day rules) are separate operating classes from those at home connected to commercial power. On the report form, simply check off Emergency or Commercial for the Power Source and be sure to specify your ARRL operating class (2A, 1C, etc.).

AND FINALLY...

The Satellite Summary Sheet should be used for submission of the AMSAT Field Day competition and be received by KK5DO (e-mail) by 11:59 P.M. CDT, Friday, July 16, 2021. This is earlier than the due date for the ARRL submissions. The only method for submitting your log is via e-mail to **kk5do@amsat.org** or **kk5do@arrl.net**. I have not had a mail-in entry in over five years, probably even longer than that.

Add photographs or other interesting information that can be used in an article for the *Journal*.

You will receive an e-mail back (within one or two days) when I receive your e-mail submission. If you do not receive a confirmation message, then I have not received your submission. Try sending it again or send it to my other e-mail address.

Certificates will be awarded for the first-place emergency power/portable station at the AMSAT General Meeting and Space Symposium in the fall of 2021. Certificates will also be awarded to the second and third place portable/emergency operation in addition to the first-place home station running on emergency power. A station submitting high, award-winning scores will be requested to send in dupe sheets for analog contacts and message listings for digital downloads.

You may have multiple rig difficulties, antenna failures, computer glitches, generator disasters, tropical storms, and there may even be satellite problems. Still, the goal is to test your ability to operate in an emergency situation. Try different gear. Demonstrate satellite operations to hams that don't even know the HAMSATS exist. Test your equipment. Avoid making more than ONE contact via the FM-only voice HAMSATS or the ISS, and enjoy the event!

AMSAT Satellite Summary Sheet - 2021

Satellite and number of Voice QSO's (1 point each)
SO-50 1 (example)

Satellite and number of CW/RTTY/PSK31 etc. QSO's (3 points each)
AO-07 5 (example)

Satellite and Up/Downloads (3 points each)
FalconSat3 3 (example)

Score Calculation
Total Voice QSO's 1 x 1 = 1
Total CW/RTTY/PSK31 QSO's x 3 =
Total Up/Downloads 8 x 3 = 24
Grand Total = 25

Please provide the following information:

Your Field Day Callsign

Your Group Name

ARRL Field Day Classification
ARRL Section
Power Source (Select 1)
Emergency
Commercial

Your name and home call

Home address

Any Comments

And please attach pictures.

AMSAT Recognizes 2021 President Club Donors

We would like to thank the following AMSAT members who have made a generous contribution and were inducted into the 2021 President's Club. All members receive a full color certificate, polished gold finish commemorative coin and embroidered "Remove Before Flight" key tag. Members at the Silver Level and above also receive a handsome personalized acrylic desk plaque. Gold level and above members also receive complimentary tickets to Hamvention and Symposium events.

See the inside back cover of this issue to learn more about the 2021 President's Club!

Core Level

John Botti	KC8OKB
Gerald Buxton	N0JY
Joe Domaleski	KI4ASK
David Grebe	WA4LM
Sam Hancock	K4NAV
Raymond Hart	KN6DPI
Stephen Howard	AB0XE
John Kludt	K7SYS
Dale Peer	KF7ZBK
Richard Polena	WW8W
Jay Schwartz	WB8SBI
Alston Simpson	WA5TJB
Carl Starnes	W4EAT
Richard Steegstra	K1LKR
Paul Stoetzer	N8HM
Timothy Tapio	K4SHF
Dave Taylor	W8AAS
Frank Westphal	K6FW

Bronze Level

Anton Giroux	KF3BX
Edward F. Krome	K9EK

Silver Level

Jeffrey Davis	KE9V
W. Fisher	WB1FJ
Mark Hammond	N8MH
William Hudzik	W2UDT
Joseph Lynch	N6CL
Ronald Parsons	W5RKN
Jason Schwarz	N4JJS
David A. Vine	WA1EAW

Gold Level

Barry Baines	WD4ASW
Glenn Miller	AA5PK

Platinum Level

Alan P. Biddle	WA4SCA

Titanium Level

William Brown	–

Report of the AMSAT Bylaws Committee: Recommended Revisions to the Radio Amateur Satellite Corporation Bylaws

March 1, 2021

A committee was formed in 2020 to recommend amendments to the Radio Amateur Satellite Corporation (AMSAT) Bylaws (the "Bylaws"), as adopted in 1988 (replacing the previous document from 1969) and amended in 1989. The Bylaws Committee was chaired by AMSAT Secretary, Brennan Price N4QX, and included AMSAT Members Douglas Tabor, N6UA, Tom Mikkelsen, WA0POD, and AMSAT President, Clayton Coleman W5PFG.

Brennan Price included the recommended revisions of his committee to me on October 19, 2020. These recommendations included:

(1) clarification of the terms of membership in determining eligibility to serve as an Officer or Director,

(2) elimination of the 30-day notice requirement for resignation of Officers,

(3) removal of the mandate to hold an Annual Meeting only during the months of October and November,

(4) inclusion of electronic notice and balloting in the election of Directors,

(5) the allowance of Directors to consult by electronic mail and allowance of Board actions if a quorum is present and the Secretary has kept the minutes, and

(6) allowing other methods to record the approval of two-thirds or more of the Directors to amend the bylaws, besides written, and to notify members of the intended amendment, besides mailing.

It is important to note that this committee's recommendations were not a finished product nor submitted to the Board as a final report. In addition, the recommendation of allowing Board actions via electronic mail was in direct conflict with the Code of the District of Columbia, § 29–406.21, Action without Meeting, which requires written consent from each Director. As such, a follow-on committee was formed to complete the work of recommending revisions to the Bylaws. This committee consisted of AMSAT Secretary, Jeff Davis KE9V, AMSAT Executive Vice-President, Paul Stoetzer N8HM, AMSAT Director, Mark Hammond N8MH, AMSAT Immediate Past President, Clayton Coleman W5PFG, and AMSAT President, Robert Bankston KE4AL, as Chair.

The Committee completed its recommendations for revision of the Bylaws and submitted a redline and clean copy to each Director on February 22, 2021, for review and consideration at a called Special Meeting on March 2, 2021.

In summary, the recommended revisions include the work of the previous committee, correction of various grammatical and punctuation errors, and the following additional recommendations:

(1) Removal of the redundant First, Second, and Third Articles restated verbatim from the Radio Amateur Satellite Corporation Articles of Incorporation;

(2) Clarification on the Membership Application process to emphasize AMSAT Membership is by application [example provided by the Amateur Radio Relay League (ARRL)];

(3) Including both classes of AMSAT Membership, Member and Member Society, when discussing matters related to Membership;

(4) Adding the requirement for Directors to maintain their membership while serving as a Director (example provided by the ARRL);

(5) Removal of the Manager from named Officers and description of duties, as this position was created specifically for Martha Saragovitz, who has since retired;

(6) Further define responsibilities of the President (example provided by the ARRL);

(7) Adding guidance on Special Meetings in accordance with the Code of District of Columbia;

(8) Add the requirement of three years of continuous membership for nominees for position of Director (example provided by the ARRL); and

(9) Substituting "electronic methods" for "electronic mail" for Board consultations to correct previous committee's recommendation, which conflicted with the Code of District of Columbia.

Respectfully,
//Signed//
Robert Bankston, KE4AL
AMSAT President and Bylaws Committee Chair

Bylaws of the Radio Amateur Satellite Corporation

(As Amended ~~1989)~~ May 9, 2021 *[NOTE: The period for members to object to the Amendment to the Bylaws expired on May 9, 2021, with an insufficient number of objections received to require a Member vote. Therefore, the Approved Amendment to the Bylaws of the Radio Amateur Satellite Corporation are hereby adopted, with an effective date of May 9, 2021.]*

~~These Bylaws have been adopted pursuant to the Articles of Incorporation, which provide, in part, as follows:~~

~~FIRST: The name of the corporation is Radio Amateur Satellite Corporation.~~

~~SECOND: The period of duration is perpetual.~~

~~THIRD: Said corporation is organized exclusively for scientific purposes, including, for such purposes, the making of distributions to organizations that qualify as exempt organizations under sec tion 501(c)(3) of the Internal Revenue Code of 1954, as amended (or the corresponding provision of any future United States Internal Revenue Law).~~

~~The scientific purposes for which said corporation is organized shall be the carrying on of scientific research in the public interest by the means of:~~

~~A. Developing and providing satellite and related equipment and technology used or useful for amateur radio communication and to conduct experiments by suitably equipped amateur radio stations throughout the world on a non-discriminatory basis.~~

~~B. Encouraging development of skills and the advancement of specialized knowledge in the art and practice of amateur radio communications and space science.~~

~~C. Fostering international goodwill and cooperation through joint experimentation and study, and through the wide participation in these activities on a noncommercial basis by radio amateurs of the world.~~

~~D. Facilitating communications by amateur satellites in times of emergency.~~

~~E. Encouraging the more effective and expanded use of the higher frequency amateur radio frequency bands.~~

~~F. Disseminating scientific and technical information derived from such communications and experimentation, and encouraging publication of such information in treatises, theses, publications, technical journals or other public means.~~

~~G. Conducting such lawful activities as may be properly incident to or aid in the accomplishment of provisions A-F hereinabove, and which are consistent with the maintenance of tax-exempt status pursuant to Section 501(c) of the Internal Revenue Code.~~

ARTICLE I
Members and Member Societies

Section 1: Membership as Member or Member Society shall become effective upon receipt of the appropriate completed application form and dues by the Secretary, and shall cease immediately upon resignation or upon expiration of the period for which dues have been paid.

Section 2. Applications for membership or renewal as Member or Member Society shall be submitted to and in the manner prescribed by the Secretary. In the case of any applicant whose character, reputation or conduct might make him or her an undesirable member, the Secretary shall refer the application to the Board of Directors (the "Board") for review; in all other cases, the Secretary shall have the authority to grant membership.

Section 3. The Secretary shall provide a minimum of one renewal notice to each Member and Member Society prior to the expiration of their membership. Memberships renewed within fourteen days of expiration shall be regarded as continuous, and the period for which dues have been paid shall be deemed to begin as of the end of the previous period.

Section ~~2~~ 4: Dues for Members and Member Societies shall be those established from time to time by the Board ~~of Directors (the "Board")~~, ~~a majority~~ the votes of two-thirds of the Directors being required for adoption. A Member or Member Society submitting the appropriate application and paying such amount as may from time to time be so established for this purpose shall be forever exempt from annual dues, and shall be known as a Life Member or Life Member Society. ~~A minimum of one renewal notice shall be sent to each Member and Member Society prior to the expiration date of its membership.~~

ARTICLE II
Elected Officers, Committees, Appointed Officials and Their Responsibilities

Section 1: The Board shall have the power to hold meetings, adopt rules for its functioning (including the determination of an agenda for each meeting), appoint committees, elect, suspend or remove Officers, fix their duties to the extent not otherwise provided in these Bylaws, and take all necessary and proper steps to carry out the purposes of the corporation and these Bylaws. At least annually, the Board shall determine a budget for the corporation's revenues and expenditures in accordance with the system of accounts prescribed in Section 5 of this Article and may amend such budget at its discretion. No financial obligation shall be incurred by or on behalf of the corporation except by prior approval of the Board; provided, however, that the Board may, at its discretion, authorize any Officer or Officers to incur such obligations and/or to approve such necessary or incidental obligations as may be incurred by officials acting under such Officers' authority, subject to such limits and procedures as the Board shall determine.

Section 2: The Board shall consist of seven Directors, who shall be Members elected according to the procedure set forth in Article Ill of these Bylaws. Each Director shall be elected for a two-year term and remain a member in good standing during the elected term. Four Directors shall be elected in odd- numbered years; three shall be elected in even-numbered years. Directors and Alternates shall assume office immediately upon the announcement of their election by the Secretary as provided in Article Ill. The retiring Directors shall be responsible for assuring the orderly and effective transfer of records and responsibilities to the incoming Directors.

Section 3: The Board, at its first meeting following each election of Directors, shall elect the Officers from among the Members. Officers shall serve at the pleasure of the Board until the next annual election of Officers. Newly- elected Officers shall assume their respective duties immediately upon their election and acceptance. The retiring Officers shall be responsible to the Board for assuring the orderly and effective transfer of records and responsibilities to the incoming Officers.

Section 4: Officers of the corporation shall be the President, the Executive Vice President, the Vice President-Engineering, the Vice President-Operations, the Secretary, and the Treasurer ~~and the Manager~~. Additional Officers may be elected, and their duties established, by the Board at its discretion subject to these Bylaws. A Member may hold more than one office. Officers shall be charged with the execution of policies, programs and directives of the Board of Directors.

Section 5: The duties of the Officers shall be as follows:

A. The President shall preside over all meetings of the Board of Directors, at the Annual Meeting, and at all other meetings of the membership. Except as the Board may direct, the President shall be responsible to the Board for coordinating all activities of the corporation and for all matters not otherwise assigned herein or by the Board. The President shall, subject to instructions from the Board of Directors, represent the corporation in its relationships with the public and the various governments, governmental agencies and officials with which the corporation may be concerned, and shall be the official spokesperson of the Board of Directors in regard to all matters of corporate policy. The President shall be an ex- officio member of all Committees unless otherwise designated. The President shall report to the Board at each meeting on the status of the corporation's affairs and shall, as required by the Board prepare and distribute a proposed budget of the corporation's expenditures, prepared according to the system of accounts prescribed in this Section 5, which proposed budget shall be based upon the revenue estimate prepared and submitted by the Treasurer. The President may, on his own motion, and shall, at the request of at least three directors, call special meetings of the Board of Directors. The call for any special meeting shall specify the matters to be considered. Special meetings may consider or act upon only those matters. Special meetings may be conducted using electronic methods whereby all participants are able to communicate with one another in real time.

B. The Executive Vice President shall act in the place of the President in the President's absence and shall have such other duties as the Board may determine.

C. The Vice President-Engineering shall be responsible for managing the activities of such technical staff as the corporation may have and shall have such other duties as the Board may determine.

D. The Vice President-Operations shall be responsible for managing the activities of such operations staff as the corporation may have and shall have such other duties as the Board may determine.

E. The Secretary shall be responsible to the Board for maintaining minutes of all meetings of the corporation and of the Board, and, with the assistance of the other Officers, for maintaining the corporate status of the corporation and for preparing and submitting such documents as may be required in connection therewith. The Secretary shall also be responsible to the Board for maintaining the membership records of the corporation and shall receive all applications for and renewals of membership. Under the authority of the Board, the Secretary shall conduct the elections for the position of Director as provided hereunder. The Secretary shall have such other duties as the Board may determine.

F. The Treasurer shall be responsible to the Board for managing the funds and investments of the corporation, and shall report to the Board at each meeting on the corporation's financial condition. Subject to the Board's approval, the Treasurer shall establish and maintain a system of accounts for the corporation's use. With the assistance of the other Officers, the Treasurer shall be responsible to the Board for accounting for all revenues and expenditures of the corporation, for preparing such financial reports as may be required, and for ensuring compliance by the corporation with the Internal Revenue Code and with the tax laws of such jurisdictions as may apply. The Treasurer shall prepare and submit to the President, as required for the budget process provided for herein, an estimate of the corporation's revenues including a statement of the assumptions upon which such estimate is based. The Treasurer shall have such other duties as the Board may determine.

~~G. The Manager shall operate the principal business office of the corporation and shall assist such other Officers in the performance of their duties as the Board may require. The Manager shall have such other duties as the Board may determine.~~
Section 6: Subject to the authority of the Board, any Officer may appoint officials who shall serve in accordance with the terms of their appointments. Such officials shall not be considered Officers for purposes of these Bylaws unless also elected as such by the Board.

Section 7: Resignations and vacancies in office shall be dealt with as follows:

A. ~~Thirty days' written or telegraphic n~~Notice of resignation to the Board, in care of the Secretary, shall be required before the resignation of any Officer can be effective.

B. In event of the resignation, death or incapacity of the President, the Executive Vice President shall assume the office of President until the next meeting of the Board, at which time the Board shall elect a President.

C. In event of the resignation, death or incapacity of any other Officer, the President shall appoint a temporary Officer to fill the vacancy until the next meeting of the Board, at which time the Board shall elect a successor.

D. Officers elected pursuant to this Section 7 shall serve at the pleasure of the Board until the normally scheduled expiration of the term of the Officer whose resignation, death or incapacity gave rise to their elections.

E. In event of the resignation, death or incapacity of a Director, the First Alternate shall fill the position until the next annual election of Directors, and the Second Alternate shall become First Alternate. At that election, a Director shall be elected to fill any unexpired term of such former Director, in addition to the Directors scheduled to be elected at that time. In event of the resignation, death or incapacity of the First Alternate, the Second Alternate shall become First Alternate.

ARTICLE III
Meetings and Election of Directors

Section 1: An Annual Meeting of the corporation shall be held ~~during October or November of~~ each year at such time, ~~and~~ place, and manner as the Board shall determine. At this meeting, the President shall present a report to the members.

Section 2: Written nominations of Members for the position of Director, which nominees shall have agreed to serve if elected, shall be received by the Secretary on or before June 15 of each year. Such nominations must be in the form specified by the Secretary and, to be effective, must be found by the Secretary to be in compliance with the requirements of the Articles of Incorporation, and to name nominees whose membership has been continuous for at least three years immediately preceding nomination.

Section 3: Voting shall be conducted by secret ballot in a fair and democratic manner. The Secretary shall prepare paper or electronic ~~written~~ ballots listing in alphabetical order by last name all candidates found to be duly nominated and eligible for election. Such ballots shall be made available on or before July 15 of each year to every person who was a Member as of July 1 of that year ~~mailed to all Members or, at the Secretary's discretion, included in a publication of the corporation mailed to all Members, in either event such mailing to take on or before July 15 of each year.~~ Duly nominated and eligible candidates shall be afforded equal opportunity to circulate statements of their qualifications and positions to the Members through the corporation's publications and shall have use of the corporation's mailing lists for election-related purposes at no cost to the corporation.

Section 4: Ballots, to be counted, must be received by the Secretary not later than September 15 of each year. As soon thereafter as is reasonably practicable, the ballots shall be counted under the Secretary's supervision. Results shall be publicly announced by the Secretary not later than September 30 of each year, such announcement to include ~~written or telegraphic~~ notice to all candidates for election as well as all current Directors. The candidates receiving the largest number of votes shall be declared elected to the seats being contested. The two candidates receiving the next largest number of votes shall be declared First Alternate and Second Alternate, respectively, to serve until the next annual election of Directors or as provided in Article II, Section 7 hereof.

Section 5: The Board shall meet ~~in person~~ as soon as practicable after the Secretary's announcement of election results for the purpose of electing Officers and for such other business as may properly come before the Board. Additional meetings of the Board may be held at its discretion. The Board may also establish rules providing for ~~telephone or telegraphic~~ consultations using electronic methods, in addition to the meetings required under these Bylaws~~, but no such consultation~~. Such consultations may result in official actions of the Board, if ~~unless~~ all Directors have been given timely and adequate notice of such events and afforded reasonable opportunity to participate, and if ~~unless~~ the Secretary has kept the minutes of such consultation. At any meeting or consultation of the Board, a ~~simple~~ majority of Directors shall constitute a quorum.

ARTICLE IV
Amendment of the Bylaws

Adoption of and amendments to these Bylaws shall require the written approval of two-thirds or more of the Directors. Notice of an adoption or amendment which has received such approval, including the text thereof, shall be ~~mailed~~ sent to all Members by the Secretary, or, at the Secretary's discretion, included in a publication of the corporation ~~mailed to all Members~~. Such adoption or

Working FalconSAT-3 Packet Digipeater with the Yaesu FT-3DR, HDSDR, Soundmodem, Yagi Antenna, and QFH Antenna

Ramadhan Ibrahim, YD1RUH
Juliadi Satyo Pramudito, YD0AVI
Creflo Teodoro Sebastian, YD2UUY

Introduction

Last year, Brian Wilkins, KO4AQF, successfully worked the FalconSAT-3 packet BBS using a Kenwood TH-D72A HT transceiver, PacSat ground station software, and an Elk log periodic antenna. He wrote about it for the November/ December 2020 issue of The AMSAT Journal. Before that, Kevin Zari, KK4YEL, successfully worked FalconSAT-3 packet BBS with his Kenwood TM-701 GA. Based on that interesting experiment, we tried working FalconSAT-3 but in a different mode and with different equipment. We operated the packet digipeater with a Yaesu FT-3DR soundmodem decoding software by UZ7HO. We chose the Yaesu FT-3DR because it supports AX.25 with a 9600 baud rate.

Figure 1 — Set APRS modem.

Figure 2 — Set APRS digipath.

Figure 3 — Set APRS becon text.

Referring to the AMSAT website (amsat.org) Getting Started with Amateur Satellites: FalconSAT-3, we found that the uplink is 145.840 MHz and the downlink is 435.103 MHz, with the digipath PFS3-1 for digipeater mode. For our experiment, YD1RUH transmitted from Tangerang, Indonesia, and YD0AVI transmitted from Jakarta, Indonesia, with YD2UUY receiving at Jogyakarta, Indonesia. We chose the locations of the transmitters and receiver with a distance far enough at about 250 km to ensure that the APRS packets that go to FalconSAT-3 really work and can be received completely.

We used two types of antennas in our experiment. YD1RUH and YD0AVI used a Yagi antenna to transmit the APRS packets, and YD2UUY used the QFH antenna to receive them. YD2UUY used a RTL-SDR device to receive and HDSDR and soundmodem by UZ7HO to decode the APRS 9600 signal.

Yaesu FT-3DR settings for FalconSAT-3 digipeater

We chose the Yaesu FT-3DR radio because it has a built-in TNC. Several settings are required including the APRS modem at 9600 baud as shown in Figure 1 and the digipath set to PFS3-1 as shown in Figure 2.

To ensure that the APRS packet was successfully received by FalconSAT-3, we added a status text beacon in APRS. The status text consisted of our three callsigns, as shown in Figure 3.

Connecting the Yaesu FT-3DR with the Yagi antenna

The items needed to connect Yaesu FT-3DR with the Yagi antenna are SMA male to RG6 male connector, female to female RG6 connector, and a male-to-male RG6 jumper cable, as shown in Figures 5, 6 and 7.

We first connected the SMA male to RG6 connector to the FT-3DR Yaesu, then

Figure 4 — Display FT-3DR after setup for FalconSAT-3.

Figure 5 — SMA male to RG6 male connector.

Figure 6 — Female to female RG6 connector.

Figure 8 — Yaesu FT3DR with the Yagi antenna.

Figure 7 — Male to male RG6 jumper cable.

connected the female-to-female connector RG6 with SMA male to RG6, then the RG6 male to male jumper with the RG6 female to female connector. Lastly, we connected the antenna with the RG6 male jumper cable. The Yaesu FT-3DR connection to the Yagi antenna is shown in Figure 8.

Figure 9 — QFH antenna used by YD2UUY.

Preparing the receiver

The equipment setup for the receiver included a QFH antenna connected to an LNA (low noise amplifier). Then we connected the LNA output to the RTL-SDR, which is then processed in the HDSDR. Figures 9 and 10 show the shape of the QFH antenna used and the LNA to reduce noise from the incoming signal.

The output that can be displayed on the new HDSDR is only a sampling spectrum and waterfall, so a decoder is needed to translate the sampling signal into readable APRS data packets. To do this, the soundmodem application developed by UZ7HO was used to decode the signal into APRS data packets. Figure 11 shows the setting used on the soundmodem.

Accessing the digipeater on FalconSAT-3

We conducted our transmission on Wednesday, January 26, 2021 at 10:11 local time, 03:11 UTC and Thursday, January 27, 2021 at 09:30 local time, 02:30 UTC.

To track and determine the time when FalconSAT-3 passed through Indonesia, we used DOS-based software, namely

Figure 10 — LNA used by YD2UUY.

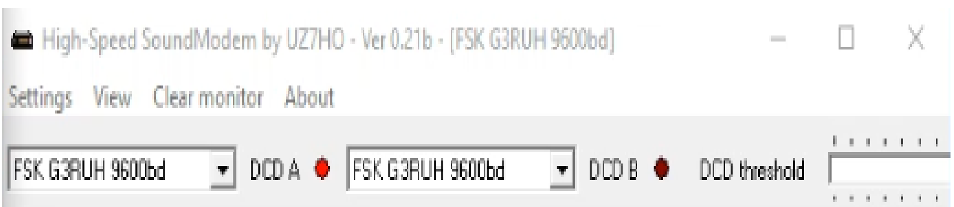

Figure 11 — Setting used on soundmodem.

STSPLUS Figures 12 and 13 show the display when FalconSAT-3 started to enter Indonesia.

We transmitted the APRS 9600 packet to the satellite when it passes through Indonesia. Figure 14 depicts the form of spectrum and waterfall HDSDR at the receiver when receiving APRS packets from FalconSAT-3.

The HDSDR output was reprocessed by the soundmodem to decode the APRS packet. Figure 15 shows the result of the decoded packets.

The results displayed on the soundmodem indicated that the Yaesu FT-3DR connected to the Yagi antenna transmitted the APRS 9600 package and was successfully digitized, as evidenced by the appearance of our callsigns, YD1RUH, YD0AVI, and YD2UUY.

Conclusions and further experiments

Compared to previous experiments, using the Yaesu FT-3DR, APRS settings for the digipeater on FalconSAT-3 can be

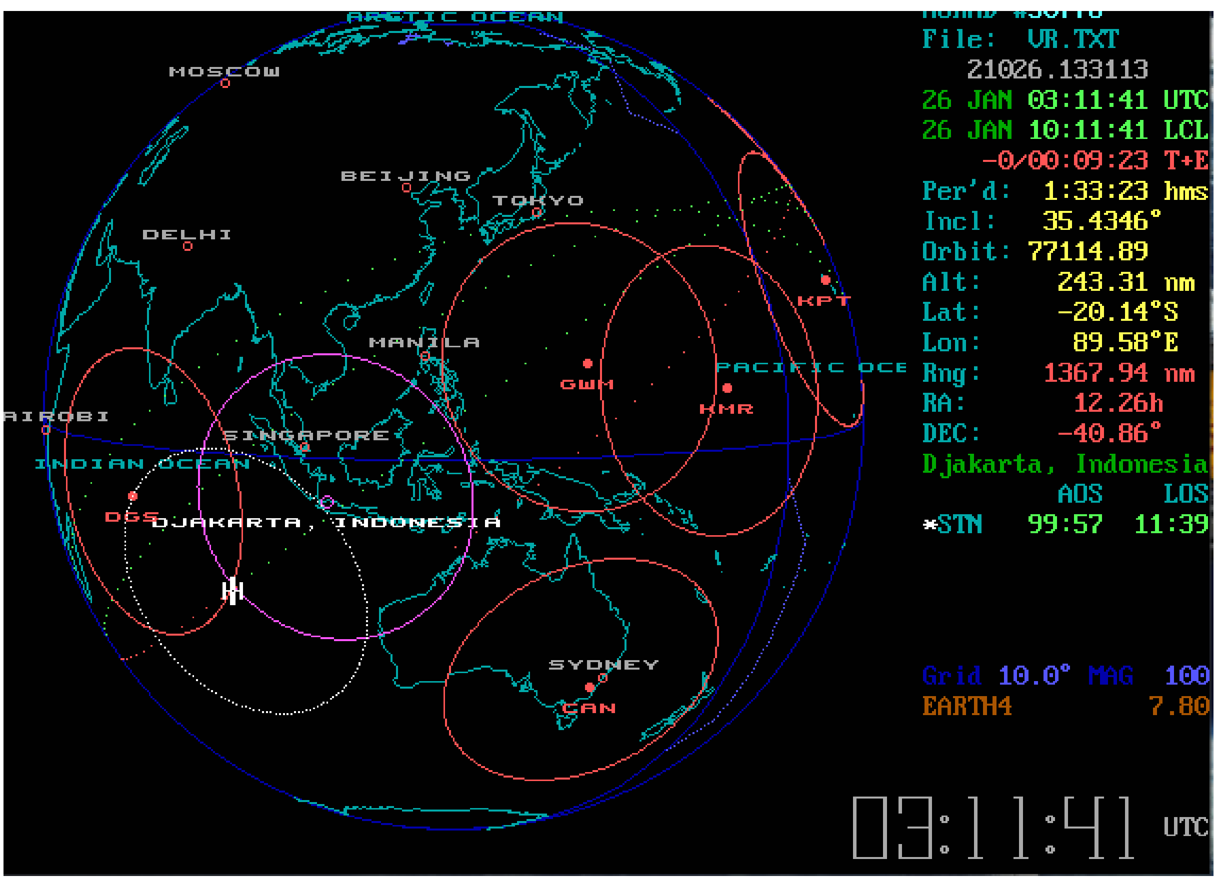

Figure 12 — FalconSAT-3 on January 26, 2021 at 03:11 UTC by YD1RUH from Tangerang.

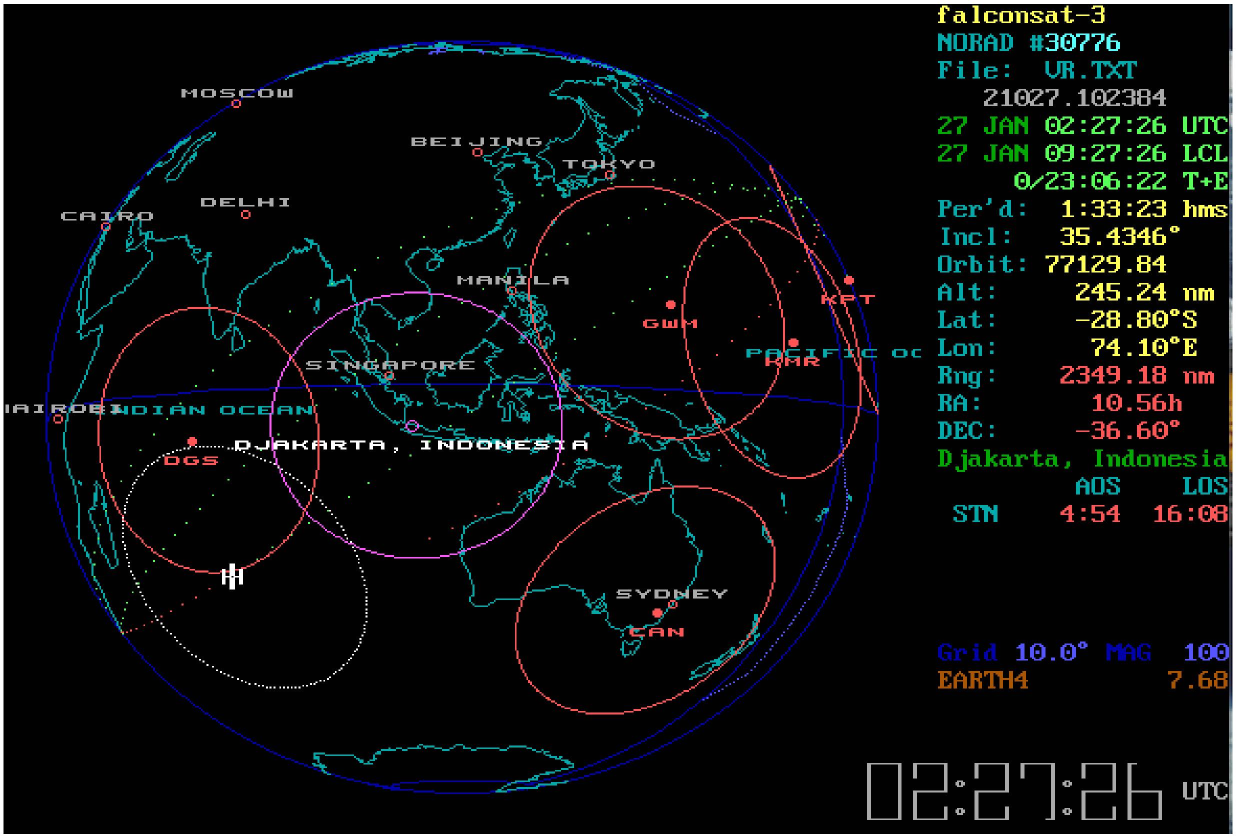

Figure 13 — FalconSAT-3 on January 27, 2021 at 02:11 UTC by YD0AVI from Jakarta.

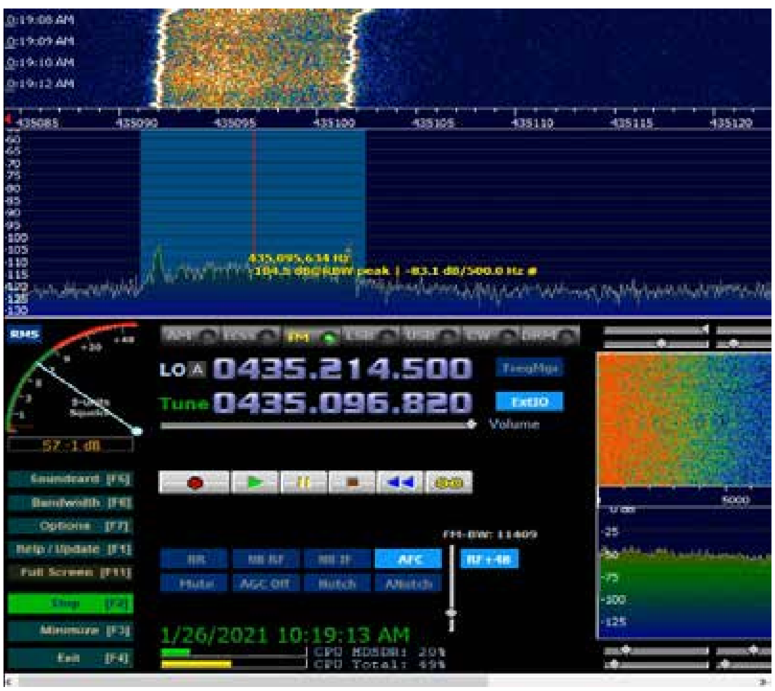

Figure 14 — Digital Signal Processing while FalconSAT-3 passes through Indonesia.

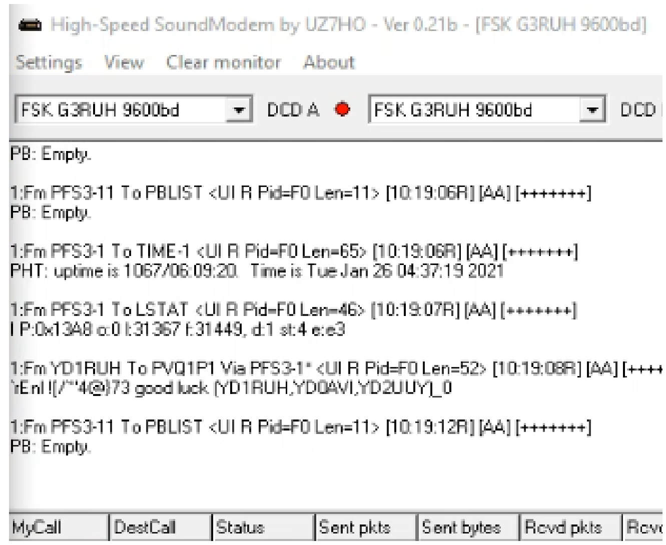

Figure 15 — Using soundmodem by UZ7HO to decode APRS packets..

done easily on the HT with 5 W. The materials needed are commonly available, such as connectors, jumper cables and Yagi antennas. The packets received within 250 km from the transmitter can be decoded clearly using the sound modem by UZ7HO, as seen in Figure 15. For our next experiment, we will try the APRS 9600 modulation using a regular HT with 5 W configured at 9600 baudrate and a direwolf virtual soundmodem rather than HTs like Yaesu or Kenwood. Good luck, and never give up!

Arizona Roving in an Afternoon

Patrick Stoddard, WD9EWK/ VA7EWK
Board Member
patrick@wd9ewk.net

I have been active on satellites – at home and away – for over 15 years. Roving has been a part of my operating since almost the beginning. Whether on road trips out of state (or outside the USA), day-trips to locations in and around Arizona, or the Walmart Parking Lots on the Air events in 2018 and 2019 from many locations in the Phoenix area – this is fun. When Endaf, N6UTC, asked about getting some new Arizona grids for his activity around the DM06/DM16 grid boundary in California on 27 February 2021, I came up with a plan for that day....

Road trip map.

Arizona straddles 112 degrees west, which is the dividing line between a few grids. In Phoenix, this line separates grids DM33 and DM43. I live a few miles east of the DM33/ DM43 line and have many thousands of satellite contacts from a Phoenix city park on that line. North of Phoenix, the DM34/ DM44 line is very close to I-17, about halfway between Phoenix and Flagstaff. The DM32/DM42 grid boundary is in farmland south of the metro Phoenix area, less than an hour away. I took advantage of this geography and planned to visit 3 different grid boundaries along 112 degrees west on this trip:

- DM34/DM44 line – south of Camp Verde AZ, along AZ-169, west of I-17 exit 278
- DM33/DM43 line – in a city park in northeast Phoenix, near the AZ-51/ AZ-101 interchange
- DM32/DM42 line – southeast of Maricopa AZ, east of AZ-347

At DM34/DM44.

N6UTC and I identified five passes that could be worked during the afternoon of 27 February, while he was in the DM06/ DM16 area in California:

- SO-50 at 1901 UTC
- NO-84 at 1929 UTC
- SO-50 at 2044 UTC
- PO-101 at 2056 UTC
- PO-101 at 2232 UTC

Given the distances between these three locations, along with the pass times, I decided to start north of Phoenix. I would begin at the DM34/DM44 line for the

NO-84 packet QSO between WD9EWK and N6UTC - 27 February 2021

WD9EWK at DM34/DM44 in Arizona

N6UTC at DM06/DM16 in California (578km WNW of WD9EWK QTH)

N6UTC called WD9EWK first...

... and WD9EWK replied. The "*" in the upper-left corner shows N6UTC's radio received my message.

Station	
Call Sign	WD9EWK
DXCC	UNITED STATES OF AMERICA (291)
CQ Zone	03
ITU Zone	06
Grid	DM34XM,DM44AM
State	Arizona (AZ)
County	Yavapai
Worked Station	
Worked	N6UTC
DXCC	UNITED STATES OF AMERICA (291)
CQ Zone	03
ITU Zone	06
Grid	DM06,DM16
State	California (CA)
County	Inyo
Date/Time	2021-02-27 19:02:00
Mode	FM (PHONE)
Band	2M
Frequency	145.85000
Receive Band	70CM
Receive Frequency	436.79500
Propagation Mode	SAT
Satellite	SO-50
QSL	2021-02-28 05:00:05

Record ID 1314098467 **Received:** 2021-02-28 04:23:21

Station	
Call Sign	WD9EWK
DXCC	UNITED STATES OF AMERICA (291)
CQ Zone	03
ITU Zone	06
Grid	DM34XM,DM44AM
State	Arizona (AZ)
County	Yavapai
Worked Station	
Worked	N6UTC
DXCC	UNITED STATES OF AMERICA (291)
CQ Zone	03
ITU Zone	06
Grid	DM06,DM16
State	California (CA)
County	Inyo
Date/Time	2021-02-27 19:32:00
Mode	PACKET (DATA)
Band	2M
Frequency	145.82500
Receive Band	2M
Propagation Mode	SAT
Satellite	NO-84
QSL	2021-02-28 05:01:11

Record ID 1314098472 **Received:** 2021-02-28 04:23:22

Station	
Call Sign	WD9EWK
DXCC	UNITED STATES OF AMERICA (291)
CQ Zone	03
ITU Zone	06
Grid	DM33XP,DM43AP
State	Arizona (AZ)
County	Maricopa
Worked Station	
Worked	N6UTC
DXCC	UNITED STATES OF AMERICA (291)
CQ Zone	03
ITU Zone	06
Grid	DM06,DM16
State	California (CA)
County	Inyo
Date/Time	2021-02-27 20:57:00
Mode	FM (PHONE)
Band	70CM
Frequency	437.50000
Receive Band	2M
Receive Frequency	145.90000
Propagation Mode	SAT
Satellite	PO-101
QSL	2021-02-28 05:06:12

Record ID 1314098646 **Received:** 2021-02-28 04:23:31

Station	
Call Sign	WD9EWK
DXCC	UNITED STATES OF AMERICA (291)
CQ Zone	03
ITU Zone	06
Grid	DM32XW,DM42AW
State	Arizona (AZ)
County	Pinal
Worked Station	
Worked	N6UTC
DXCC	UNITED STATES OF AMERICA (291)
CQ Zone	03
ITU Zone	06
Grid	DM16
State	California (CA)
County	Inyo
Date/Time	2021-02-27 22:35:00
Mode	FM (PHONE)
Band	70CM
Frequency	437.50000
Receive Band	2M
Receive Frequency	145.90000
Propagation Mode	SAT
Satellite	PO-101
QSL	2021-02-28 05:13:16

Record ID 1314098724 **Received:** 2021-02-28 04:23:36

LOTW QSOs with N6UTC.

SO-50 and NO-84 passes in the 1900 UTC hour and then drive back to Phoenix for the second SO-50 pass and the first PO-101 pass in the park on the DM33/DM43 line. After the stop at the park, I would drive south of the Phoenix area to the DM32/DM42 line for the second PO-101 pass. As I drove around central Arizona, I would transmit my location to the APRS network on 144.390 MHz, a way to ensure N6UTC could keep track of where I was (and others, too).

From my house, the DM34/DM44 line along AZ-169 is about 90 minutes away. I left home just after 1700 UTC and made it to the spot with time to spare. I parked on the wide shoulder along the highway at that point, took pictures of my station – an Icom ID-5100 2 m/70 cm mobile radio, an Elk log periodic, and a Garmin GPS receiver to document my location, and waited for SO-50 to come up from the southwest.

This SO-50 pass was an overhead pass in Arizona and a high pass for N6UTC in central California. N6UTC went in my log early in the pass, and I logged five other contacts with stations across much of the continental US, and a pleasant surprise at the end of the pass – John, VE1CWJ, in Nova Scotia. I had a nice view between hills to the northeast, allowing me to work SO-50 closer to the horizon near my LOS time. After SO-50 went away, I scribbled the contacts in my logbook.

Even with the SO-50 contact in the logbook, N6UTC and I wanted to try NO-84 for another contact. We both enjoy making satellite contacts using packet through the orbiting digipeaters, and the NO-84 pass was good for both of us. We worked each other, and I worked the other two stations I heard on the pass (KB6LTY in southern California, K7TEJ in the Phoenix area). I logged these NO-84 contacts, stowed my gear in the car, and went back to Phoenix for the next two passes on the DM33/DM43 line.

The drive back to Phoenix took about an hour. I arrived at the Phoenix city park just as the 2045 UTC SO-50 pass was starting. I did not hear N6UTC on that pass but worked a couple of stations in the last few minutes of the pass. I put the PO-101 frequencies in the ID-5100 and was ready for that pass. My first contact on that pass was N6UTC, and I proceeded to work four other stations. N6UTC was also busy working stations from his location on the DM06/DM16 grid boundary.

After PO-101, I quickly put my gear away, and drove south to the DM32/DM42 line.

This drive typically takes around 45 minutes, but on this day took over an hour. Two traffic accidents on AZ-347 brought traffic to a crawl. Instead of having a half-hour or more to prepare for the last PO-101 pass, I arrived at the DM32/DM42 line about 10 minutes before starting that pass.

The spot on the DM32/DM42 line I chose is along a road in the middle of farmland, east of AZ-347, and west of the sprawling Nissan Technical Center North America complex. This was the first time I tried this particular location on the grid line in Pinal County instead of parking along a state highway south of here or on another road on an Indian reservation north of here. I took some pictures at this spot and waited for PO-101 to come up from the horizon.

When PO-101 came up, I heard KJ7COA in Washington state and made a quick contact with him. Then N6UTC appeared, and we worked each other. A few other stations were on later in the pass; both N6UTC and I made additional contacts.

After these five passes, our goal was met. N6UTC made contacts from DM06/DM16, picked up new grids from other stations and me, and I operated from three locations in six different Arizona grids in less than four hours. When I returned home, I saw that I drove 273 miles. This trip took about six hours in total, from when I left my driveway until parking back in the driveway. This was the first time I took my ID-5100 out to work satellites away from home, and it performed very well.

I have operated from spots on these grid boundaries in the past, but this was the first time I visited these six grids on one trip in one afternoon. It was fun! 73!

Design and flight results of the VHF/UHF communication system of Longjiang lunar microsatellites

- **Mingchuan Wei,**
- **Chaoran Hu,**
- **Daniel Estévez,**
- **Mier Tai,**
- **Yuhao Zhao,**
- **Jiahe Huang,**
- **Cees Bassa,**
- **Tammo Jan Dijkema,**
- **Xibin Cao &**
- **Feng Wang**

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Abstract

As a part of China's Chang'e-4 lunar far side mission, two lunar microsatellites for low frequency radio astronomy, amateur radio and education, Longjiang-1 and Longjiang-2, were launched as secondary payloads on 20 May 2018 together with the Queqiao L2 relay satellite. On 25 May 2018, Longjiang-2 successfully inserted itself into a lunar elliptical orbit of 357 km × 13,704 km, and became the smallest spacecraft which entered lunar orbit with its own propulsion system. The satellite carried the first amateur radio communication system operating in lunar orbit, which is a VHF/UHF software defined radio (SDR) designed for operation with small ground stations. This article describes and evaluates the design of the VHF/UHF radio and the waveforms used. Flight results of the VHF/UHF radio are also presented, including operation of the radio, performance analysis of downlink signals and the first lunar orbit UHF very-long-baseline interferometry (VLBI) experiment.

Introduction

Longjiang-1 and Longjiang-2 are a pair of lunar micro-satellites for low-frequency radio astronomy, amateur radio, and education, developed by Harbin Institute of Technology, as a part of the Chang'e-4 lunar far side mission1. The satellites, each with a volume of 765 × 420 × 570 mm3 and a mass of ~47 kg, were launched into a lunar transfer orbit on 20 May 2018 by a CZ-4C rocket as secondary payloads, together with the Queqiao L2 relay satellite. Unfortunately, Longjiang-1 was lost because of a malfunction of thruster control logic during the first trajectory correction maneuver (TCM). The logic on Longjiang-2 was later patched, and after 113 h of flight since launch, the satellite successfully inserted itself into a lunar elliptical orbit of 357 km × 13704 km, and became the smallest spacecraft which entered lunar orbit independently.

Besides the S-band and X-band radios operated by the Chinese Deep Space Network (CDSN), Longjiang-1 and Longjiang-2 were equipped with identical VHF/UHF radios for amateur radio experiments and backup tracking, telemetry, and command (TT&C). The radio onboard Longjiang-2 is the first radio communication system operating on amateur radio bands that was placed into lunar orbit.

Radio amateurs have been building and tracking satellites since 1961[2]. Nowadays, many small satellites developed for universities and technology development projects use amateur radio frequencies and AX.25 link layer protocol[3,4]. With the development of the Internet, several global satellite tracking networks have been developed by radio amateurs, for example SatNOGS[5]. Besides that, radio amateurs around the word use the Moon as a natural reflector for moonbounce, or Earth–Moon–Earth (EME) communication. For these purposes, radio amateurs operate a large number of high gain antennas around the world, forming a possible non-governmental, non-commercial deep space network, though the size of antennas is relatively small. VHF/UHF is among the most popular bands used for EME.

Before Longjiang-2, several satellites operating on amateur radio bands have been launched into deep space, including UNITEC-1 (trans-Venus, Japan, 2010)[6], Shin'en2 (heliocentric orbit, Japan, 2014)[7], ARTSAT2-DESPATCH (heliocentric orbit, Japan, 2014)[8], and 4M-LXS (lunar flyby, Luxembourg, 2014)[9]. These satellites used CW or JT65 modulation schemes for data downlink because of the low demodulation thresholds of these modes, but the data rates are too low (<10 bps) for payload data, so only transmission of some very basic housekeeping data is possible. UHF frequencies, some of which are allocated to the amateur satellite service, are widely used by deep space missions for inter-probe proximity links, for example the link between China's Chang'e-3 lander and Yutu rover, and NASA's Electra proximity payload for Mars explorers[10].

In this paper, we report on the VHF/UHF communication system of the Longjiang lunar micro-satellites. As piggyback lunar micro-satellites, Longjiang-1 and Longjaing-2 were very restricted in many aspects. Each of the satellites has a wet weight of only 47 kg, including 15 kg of propellant for the necessary orbit maneuvers, so the mechanics and electronics must be very light-weight. Deployable solar panels were not used because of weight issues, which limits the capabilities for power generation. Antenna size is limited by the available envelope of the launch vehicle, making it difficult to achieve high gain and efficiency. Based on the analysis above, it was a challenge for the VHF/UHF radio to operate in lunar orbit with limited onboard and ground station resources. To overcome this, a low-power software defined radio (SDR) transceiver and new uplink and downlink waveforms were designed and successfully demonstrated in trans-lunar and lunar orbit.

Results

Mission analysis and system configuration
Longjiang-1 and Longjiang-2 were designed to separate from the launch vehicle at an altitude of ~200 km over the Pacific. Before orbiting the Moon, the satellites had to perform several trajectory correction maneuvers (TCMs) and a maneuver for lunar orbit injection (LOI), with their own propulsion. After that, a few maneuvers were needed to achieve a stable elliptical orbit. Their partner, Queqiao relay satellite passed by the Moon and continued its journey to the L2 halo orbit[1]. Figure 1a shows a picture of the Longjiang-1/2 satellites on the final stage of CZ-4C launch vehicle, together with the Queqiao relay satellite[11]. The orbit of Longjiang-1/2 from Earth to the Moon and the positions of maneuvers are shown in Fig. 1b.

Based on the designed orbit, after orbiting the Moon, the distance between the satellite and a typical ground station ranges from ~340,000 km to ~420,000 km, much larger than for LEO satellites. The line-of-sight velocity between the satellite and a typical ground station ranges between about ±2 km/s, much smaller than for LEO satellites.

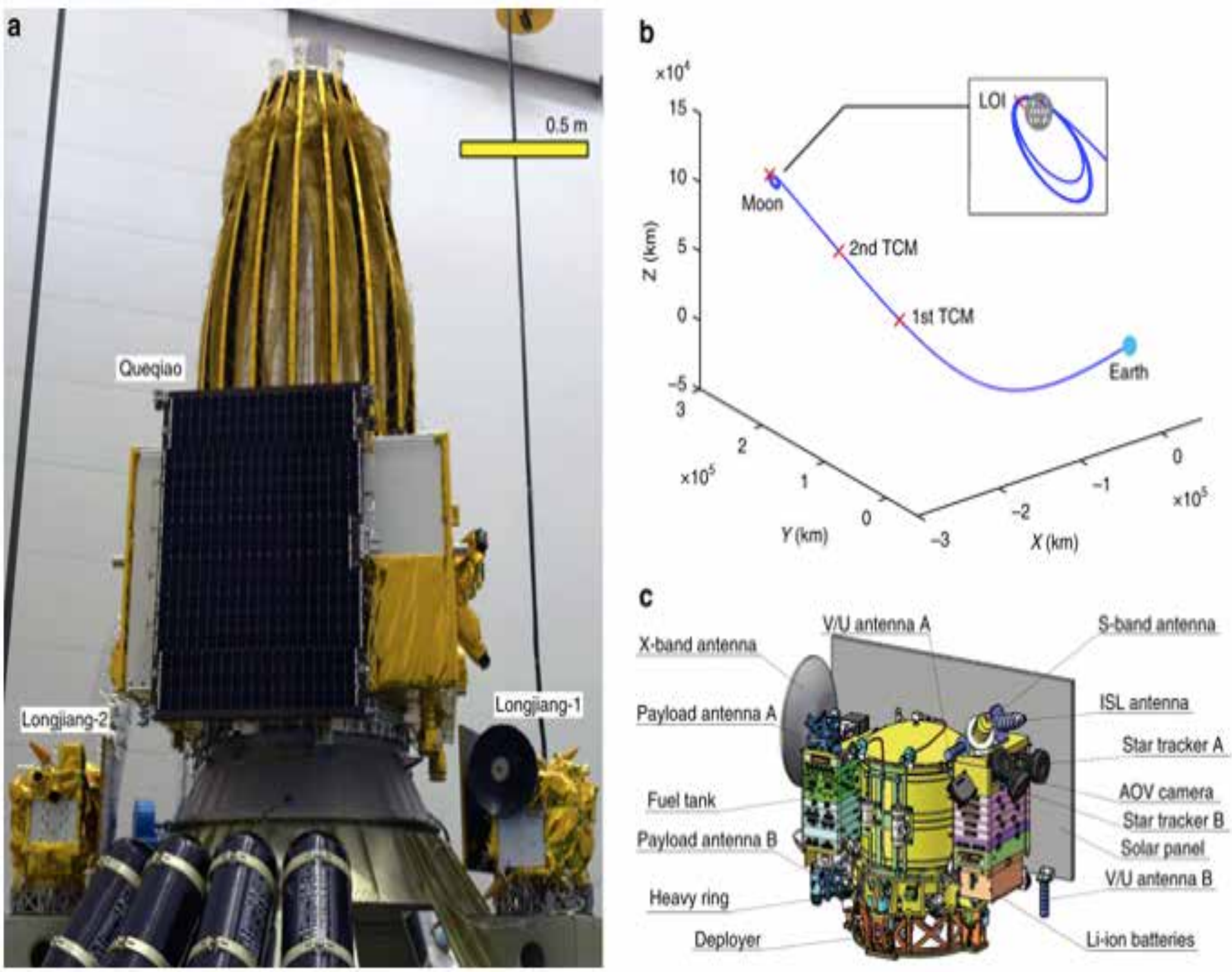
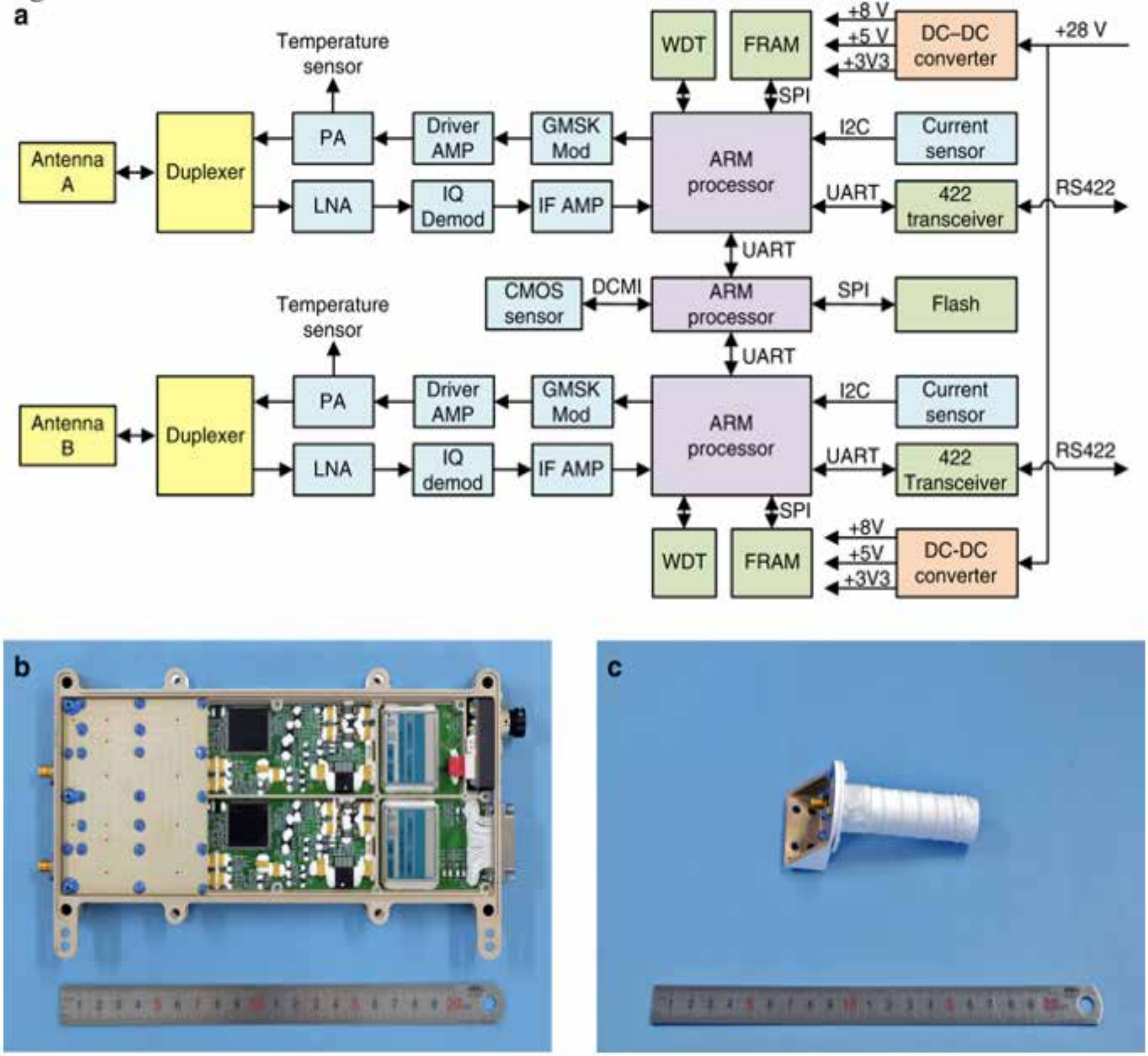


Figure 1 — Longjiang-1/2 satellites. a The Longjiang-1/2 microsatellites and Queqiao relay satellite on the final stage of the launch vehicle. b Orbit of Longjiang-1/2 from Earth to the Moon in moon-fixed reference frame. c Equipment arrangement of Longjiang-1/2.

Fig. 2: Hardware of VHF/UHF radio.



a Block diagram of VHF/UHF radio. b Flight hardware of the VHF/UHF transceivers and miniature CMOS camera. c Flight hardware of a VHF/UHF dual-band antenna.

The missions of the VHF/UHF radio are defined as:

1. (a) Lunar orbit amateur radio experiment. Downlink signals could be received with reasonable-sized antennas and commercial off-the-shelf receivers when the satellites were in lunar transfer orbit and lunar orbit.

2. (b) Backup telemetry and command, especially when S-band ground stations were not available. Particularly, after the satellites were deployed from launch vehicle, before S-band was available, first telemetries from the satellites were expected to be received on UHF.

3. (c) Provide power and control/data interface to a miniature CMOS color camera. Image data from the CMOS camera could be downloaded via UHF downlink.

4. (d) Provide an open command interface to allow radio amateurs to send commands to control the camera.

A conventional S-band or X-band satellite TT&C system typically uses two circular polarization antennas in opposite directions fed by an RF network consisting of circulators and hybrid couplers for an omni-directional coverage. But for VHF/UHF band, the size of circular polarization antennas and such an RF network is too large for Longjiang-1/2. On the other hand, VHF/UHF dual-band antennas are widely used by mobile communication systems. A simple duplexer consisting of a low-pass filter and a high-pass filter can be used to split the receiving and transmitting signals. A problem of VHF/UHF dual-band antennas is that they usually have linear polarization and deep nulls. To overcome this, two linear-polarization, dual-band shortened antennas were used and mounted in –X and +Z directions, as shown in Fig. 1c. These two antennas fill the nulls of each other, and result in an omni-directional coverage. The two antennas are connected to a pair of transceivers. The two receiving channels operate on the same frequency, and the two transmitting channels operate on two frequencies spaced by 1 MHz. For uplink, a command can be received by one or both of the transceivers. For downlink, the two transmitters usually work in burst mode to save power, and can be switched on simultaneously to increase available data rate, and get a wider bandwidth for VLBI measurement.

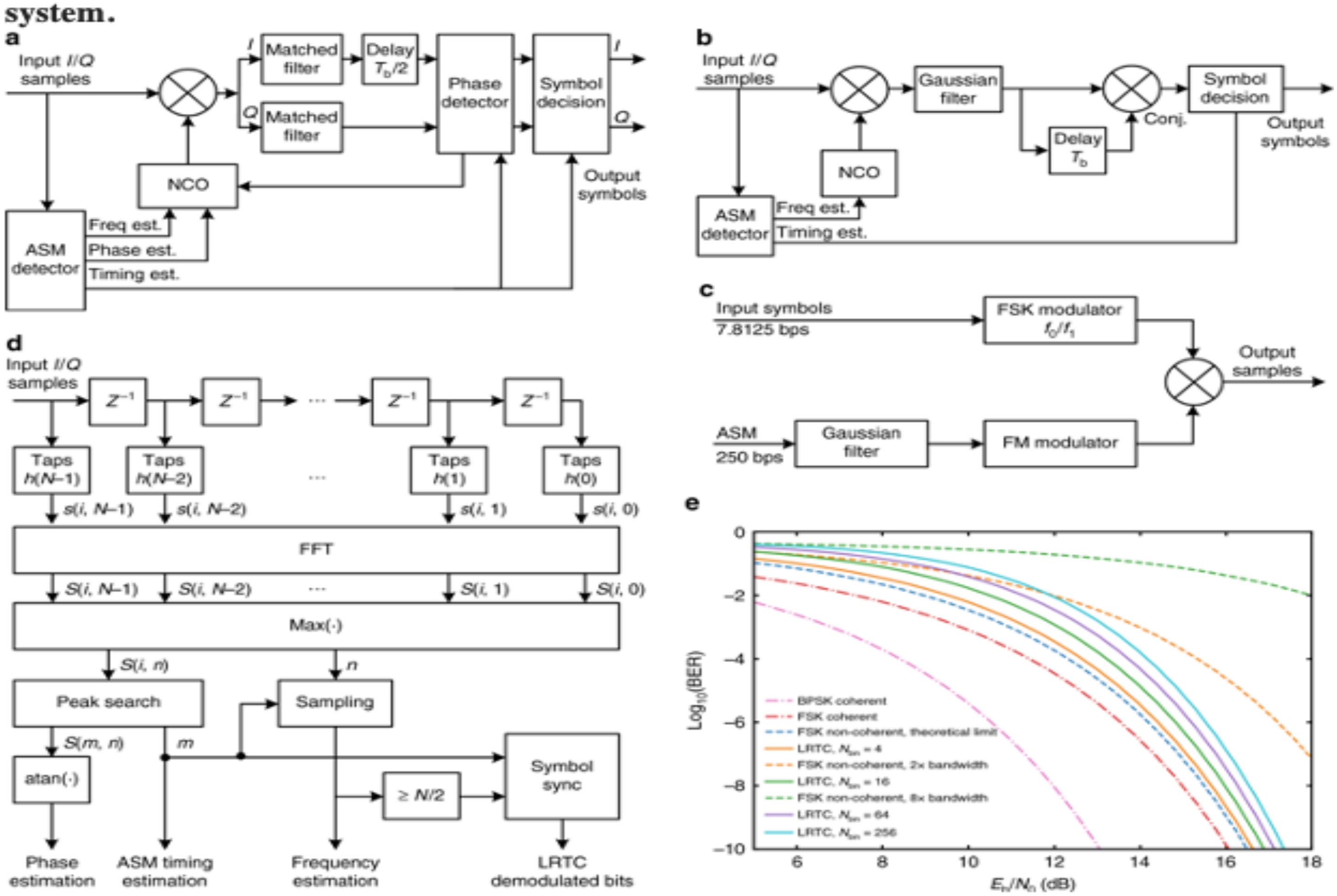
Transceiver design

The VHF/UHF radio design of Longjiang-1/2 includes two independent SDR transceivers and a miniature CMOS camera, integrated into a layer of the stack of onboard electronics. Each transceiver includes a low intermediate frequency (LIF) I/Q receiver and a direct modulation transmitter. Digital baseband processing is done by an ARM processor. The transceivers can be reconfigured for different uplink and downlink waveforms, without modifications on hardware. The block diagram of the VHF/UHF radio is shown in Fig. 2a, pictures showing the flight hardware of VHF/UHF radio and antenna are shown in Fig. 2 b, c.

Many SDRs use an FPGA for signal processing, making it a complex and large power consuming system. For low data rate applications, using processors for signal processing is also possible. The satellite ARISSat-1, developed by AMSAT, had an onboard SDR transponder based on dsPIC processors and was launched in 2011[12]. Harbin Institute of Technology also developed a series of SDR transceivers based on ARM Cortex-M4F processors for LilacSat-2, BY70-1, LilacSat-1[13], etc. The unit onboard LilacSat-2 has been operating in LEO for more than 4 years. For Longjiang-1/2, an ARM Cortex R4F processor with lockstep CPUs and EDAC protected memories was selected for the radiation environment in lunar orbit.

In the receiver path, the 145-MHz input signal is first amplified by a low noise amplifier, then down-converted to 98 kHz intermediate frequency (IF) by an image rejecting I/Q demodulator, then filtered and amplified by the IF filter and amplifier which also convert the differential signal to single ended. Finally, the I and Q signals are digitized by a dual channel A-D converter at a sample rate of 56 ksps. No analog auto gain control (AGC) was used for the receiver path, and the gains of amplifiers were set as low as possible. This improved the performance

Fig. 3: Modulators and demodulators of the VHF/UHF communication system.



a Block diagram of ground station GMSK coherent receiver. b Block diagram of onboard GMSK telecommand receiver. c Block diagram of ground station LRTC transmitter. d Block diagram of onboard LRTC receiver. e BER performance of LRTC demodulator compared with some other demodulators.

for a very weak burst uplink. Floating point operation is used in demodulators to provide sufficient dynamic range.

The transmitting path is quite simple. An FSK/GMSK modulator directly modulates the data to the 435-MHz transmitter carrier. Then the modulated signal is amplified by a class A driver amplifier, then by a high-efficiency class C power amplifier. A temperature sensor is used to monitor the temperature of the power amplifier. The output signal is filtered to suppress emissions on receiver and harmonic frequencies, before the port is combined with the receiver using a duplexer.

The transceivers also provide power and data interface to the miniature CMOS camera. Both the transceivers can take control of the camera.

Waveform design

Two downlink waveforms and two uplink waveforms are designed for the Longjiang-1/2's VHF/UHF radio: GMSK telemetry, JT4G telemetry, GMSK telecommand, and low rate telecommand (LRTC).

The telemetry link is the most critical link of Longjiang-1/2's VHF/UHF radio. GMSK modulation was selected because of several advantages:

1. (a) Continuous phase. GMSK is a continuous phase modulation. The output stage of the transmitter can use a class C amplifier.

2. (b) Good bit error rate (BER) performance. When using a coherent demodulator, a BER performance quite similar to BPSK/QPSK can be achieved, especially when BT = 0.5.

3. (c) Simple modulator hardware. GMSK signals can be generated from several methods, including with an OQPSK modulator or a simple FM modulator, even by direct control of the frequency control word of a VCO.

4. (d) High spectrum efficiency. GMSK is one of the modulations that was recommended by CCSDS for medium rate telemetry, mainly because of its high spectrum efficiency. However for Longjiang-1/2, bandwidth is not a main concern because the data rate is quite low.

GMSK telemetry can operate in burst mode to transmit basic status of the satellite and the radio itself as a bacon, or stream mode to transmit detailed housekeeping of all the subsystems. The symbol rate can be switched between 250 and 500 bps. Turbo code is selected for channel coding, as it provides the highest coding gain among the codes recommended by CCSDS. The block size selected is 1784, and coding rate can be switched among 1/2, 1/3, 1/4, and 1/6.

On the ground side, variations on offset quadrature phase shift keying (OQPSK) receivers can be used for GMSK demodulation. S. Shambayati and D. K. Lee provided the FER results of the standard DSN OQPSK receiver and some of its variations for medium rate telemetry[14]. For the case of Longjiang-1/2, the situation is more difficult. The data rate and signal C/N0 for Longiang-1/2 is quite low, so a narrow loop filter has to be used. The resulting acquisition time of the carrier tracking loop is too long for burst mode operation, which is used to reduce power consumption. To improve the system performance, an attached synchronization marker (ASM) detector, which acts as a correlator in both time and frequency domain, is used to aid the acquisition of the carrier tracking loop, as shown in Fig. 3a. The input stream is first multiplied by a set of taps, which are the conjugates of the ASM, before calculating an FFT, then the FFT output bin with maximum power is searched in both time and frequency domain. The power of the bin is used for an open loop auto gain control (AGC) and estimation of Eb/N0, which is needed by the turbo decoder. The frequency and phase of the bin is used to set the initial state of NCO. The time when the maximum power is found is marked for symbol timing.

An OQPSK carrier tracking loop is used for carrier recovery. A matched filter, which is the first order Laurent decomposition of BT = 0.5 GMSK signal, is also included for bit sharpening[15]. The output of the matched filter is then sampled at the proper time to generate the demodulated symbols.

To work with the coherent demodulator, a precoder is used to avoid the propagation of bit errors introduced by the inherently differential property of GMSK modulation as recommended by CCSDS[16].

The demodulators were implemented with C++ and Python on GNU Radio. The resulting C/N0 threshold for 500 baud GMSK with r = 1/4 turbo code or 250 baud GMSK with r = 1/2 turbo code with a packet error rate of 0.1 is ~24 dBHz. With a good low noise amplifier (LNA), a sensitivity of ~−149 dBm can be achieved.

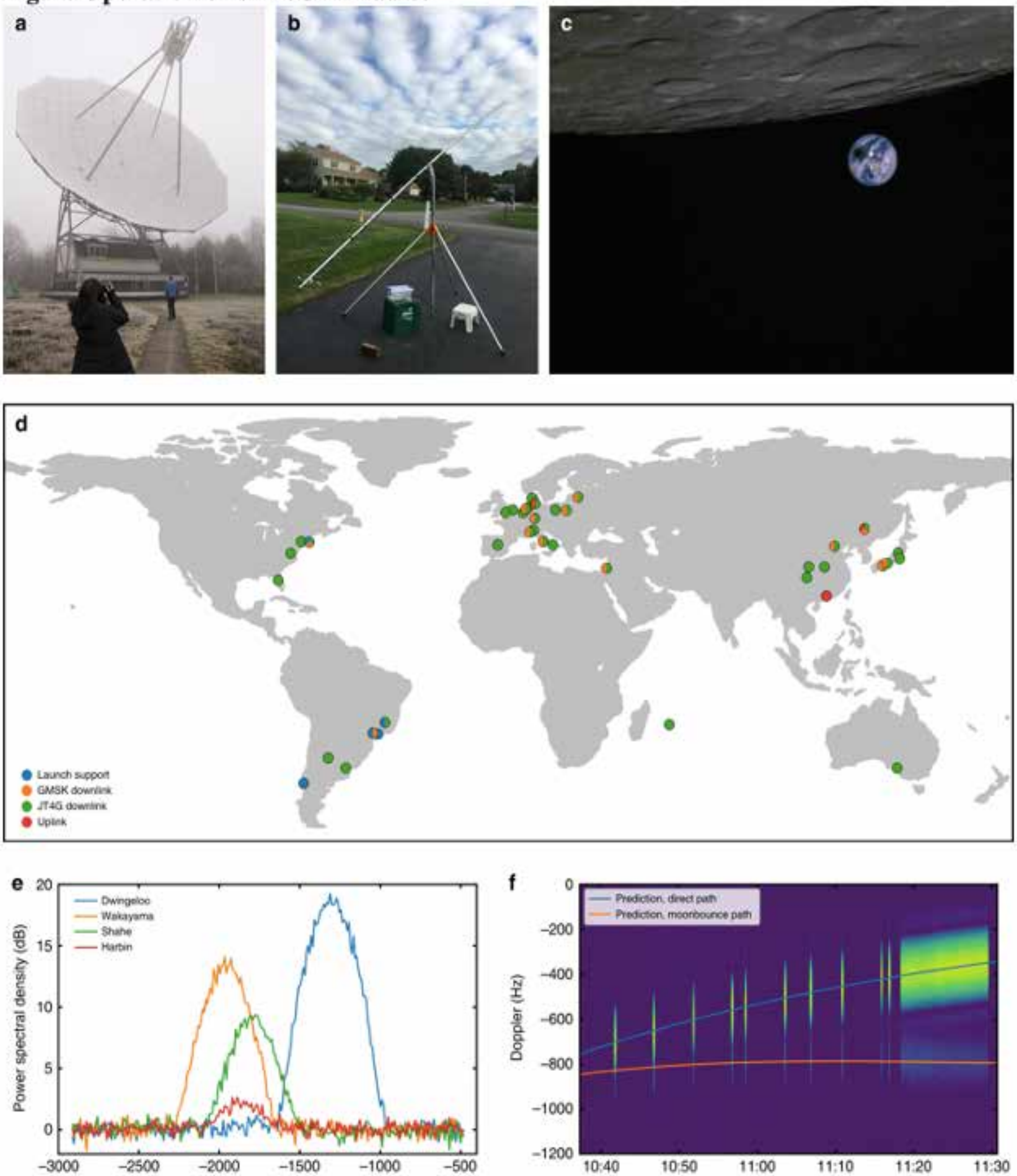
The JT4G beacon was designed to be capable of being received by very small ground stations and included some very basic status of the radio for trouble shooting purposes. The mode is selected from the modes designed by Joe Taylor for EME communications[17]. The most popular mode among these is JT65B, which uses 2.69 bps 65-FSK with (63, 12) Reed-Solomon code, and was used by 4M-LXS lunar flyby mission. For Longjiang-1/2, as it was designed to orbit the Moon in an elliptical orbit, the Doppler rate at perigee would be quite large. For this reason, the JT4G mode was selected, which uses 4.375 bps 4FSK for better robustness for larger Doppler spread and Doppler rate. An r = 1/2, k = 32 convolutional code is used by JT4G for channel coding. The resulting C/N0 threshold is ~17 dBHz.

GMSK is also the modulation selected for telecommand uplink. The symbol rate is 250 bps. For robustness and onboard simplicity, a non-coherent demodulator was developed based on a complex version of the one-bit differential detector introduced by M. K. Simon[18]. The input signal is first filtered by a Gaussian filter, then divided into two arms. One arm is delayed by one symbol time then conjugated, and another not changed. Then the two arms are multiplied together, then sampled to get the recovered symbols. The ASM detector described before is also used to provide frequency and timing estimation. A (64, 32) Reed-Solomon code is used for channel coding. The resulting C/N0 at threshold is ~33 dBHz and the receiver sensitivity is −132 dBm. A block diagram of the onboard GMSK telecommand receiver is shown in Fig. 3b.

A new LRTC system was developed for better sensitivity than GMSK telecommand. The idea is to represent the symbols by transmitting GMSK-modulated ASMs on two different frequencies. It can be regarded as FSK-DSSS-GMSK, though the frequency shift of GMSK is narrower than the frequency shift of FSK. Alternatively, it can be considered that the modulated ASM is used as the symbol shaping of FSK symbols. This results in a symbol rate of 7.8125 bps. Figure 3c shows the block diagram of the low rate telecommand transmitter.

Onboard the satellite, the ASM detector for GMSK telemetry is reused as a frequency discriminator. The ASM detector is a correlator for a pseudo-random sequence. It is known that this introduces processing gain that attenuates several kinds of interfering signals. Figure 3d shows the block diagram of onboard low rate telecommand receiver. Figure 3e shows the BER performance of LRTC demodulator with different

Fig. 4: Operation of VHF/UHF radio.



a Dwingeloo 25 m radio telescope (PI9CAM) in the Netherlands, as the largest participating ground station antenna. b 28-element Yagi antenna on a tripod, used by radio amateur Robert Mattaliano (N6RFM) in the US, as an example of a small ground station antenna. c Image of the 2 July 2019 total solar eclipse (color corrected). d Positions of the ground stations taking part in the operation of the VHF/UHF radio. e Spectrum plot of GMSK downlink received by different ground stations. f Waterfall plot of GMSK downlink from direct path and moonbounce path comparing with prediction.

values of Nbin, compared with some other modulations and demodulators, where Nbin is the number of FFT bins used to search for maximum power. When Nbin = 2, the bandwidth and BER performance of LRTC demodulator is identical to the theoretical limit of non-coherent FSK demodulator. Indeed, the LRTC demodulator is a special kind of non-coherent FSK demodulator. When the symbol rate is very low, a much larger frequency shift and receiver bandwidth than the symbol rate is usually used to achieve better tolerance of frequency error. In this case, the LRTC demodulator provides much better BER performance than the typical non-coherent FSK demodulator, and is more robust against narrowband interference.

Operation of the VHF/UHF radio

The VHF/UHF radios onboard Longjiang-1 and Longjiang-2 were powered on as soon as the satellites were separated from the launch vehicle at 20 May 2018 21:54:50 UTC and 20 May 2018 21:55:20 UTC. Radio amateurs in Brazil, Chile, and the US spotted the downlink signals of both satellites, and kept tracking the satellites until 21 May 2018 02:49 UTC, when the VHF/UHF radios were powered off because of overheating of the batteries. Meanwhile the maximum distance from the satellites to the ground stations was <70,000 km, so just a small antenna was required for receiving. The radios were operating in burst mode, and transmitted the housekeeping parameters of the satellite buses and the radios themselves every 5 min. 37 packets were received from Longjiang-1, and another 37 packets from Longjiang-2.

On 23 May 2019, the VHF/UHF radio of Longjiang-2 was switched on after the first course correction, from UTC 12:31 to 12:55. Signals from the satellite was received by the 12-m dish antenna in Shahe, China and radio amateurs in Poland.

Longjiang-2 achieved a lunar elliptical orbit of 357 × 13704 km after a successful lunar orbit insertion at 25 May 2018 14:08 UTC. The first activation of the VHF/UHF radio after orbiting the Moon was from 2 June 2018 22:00:00 UTC to 2 June 2018 23:50:00 UTC. Downlink signals from the satellite were received in the Netherlands, Poland, UK, and China. This was the first transmission on amateur radio bands from lunar orbit.

The first image transmission via the VHF/UHF radio was on 4 August 2018, to download an image of starry sky with Mars in view. The VHF/UHF radio provided the team with a direct link to control the onboard miniature CMOS camera, allowing the satellite to respond to some occasional imaging tasks. Figure 4c shows an image of total solar eclipse in South America taken by Longjiang-2, with the Moon, Earth, and eclipse shadow in view. The image was taken by the miniature CMOS camera on 2 July 2019, and transmitted via the VHF/UHF radio using slow scan digital video (SSDV) format[19] on 3 July 2019. The file size of the image is 19.1 kbytes and took ~22 min to download at 500 baud with r = 1/4 turbo code.

On 7 October 2018, the UHF downlink signals bounced off the Moon were first observed. The direct path and the moonbounce path signals are distinguished by different Doppler, and match the prediction quite well, as shown in Fig. 4f. The difference of Doppler frequency shift is very small, so this phenomenon can be barely observed for a transmitter with larger bandwidth.

To prevent potential collisions or debris for future missions, the mission of Longjiang-2 ended with a planned lunar impact on 31 July 2019, as a result of a maneuver performed on 24 January 2019 to lower the periapsis of the satellite and the orbital perturbations over time. During the whole mission, the VHF/UHF radios have been activated for 177 times. 20945 GMSK packets and 883 JT4G packets were collected by 50 different ground stations from 17 countries, including the Netherlands, Germany, Japan, Spain, the US, Mauritius, Israel, Chile, UK, Italy, Argentina, Denmark, Brazil, Poland, Australia, Latvia, and China. In all, 763 uplink commands were sent via VHF from one ground station in Germany (the ground station of radio amateur Reinhard Kühn DK5LA) and two ground stations in China (the ground station of radio amateur Zhang Jianhua BA7KW and the ground station of Harbin Institute of Technology). In total, 135 images taken by the miniature CMOS camera were fully or partially download.

Performance analysis of downlink signals

A study of the performance of the communications system has been made using IQ data gathered by four stations around the world: Dwingeloo in the Netherlands, Wakayama in Japan, and Shahe and Harbin in China. The data was recorded on 5 July 2019 from 07:40 to 08:00 UTC and consists of a 500-baud GMSK transmission at 436.400 MHz sending a single image in SSDV format. An r = 1/4 turbo code was used as FEC. Below we show an evaluation of some key parameters of the communications system: spectrum, ASM detection and constellation diagram. These measure the performance of the whole communications chain, including the transmitter, propagation path, ground station, and software receiver.

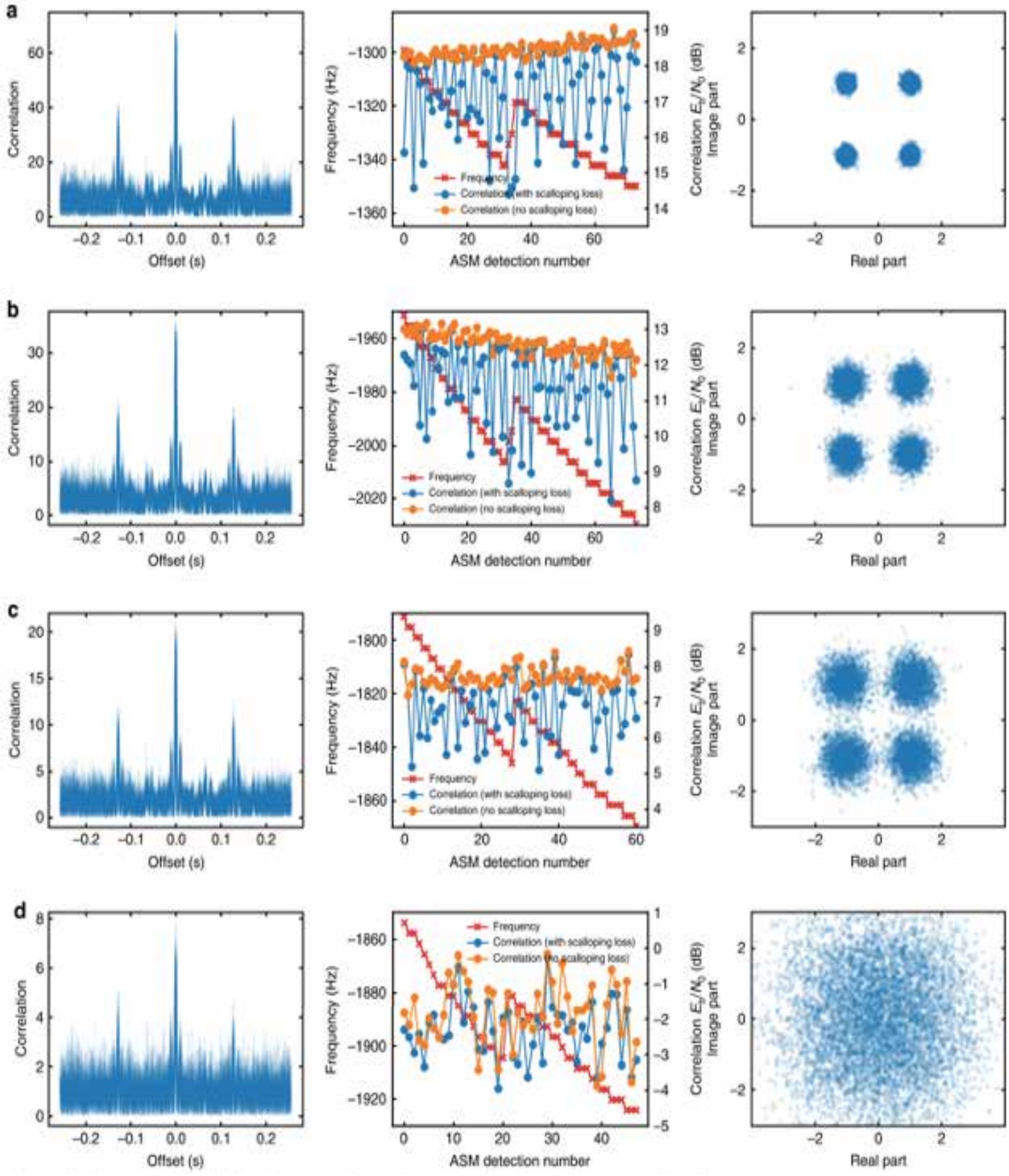
The spectrum of the GMSK signal, as received in each of the ground stations, is shown in Fig. 4e. The signal-to-noise ratio (SNR) of the signal received in each ground station is different, owing to their different antennas.

The figures in the first column of Fig. 5 show the correlation of the signal with the ASM, in the FFT bin where the main peak is detected. As described in Section 3, the ASM detection algorithm works by multiplying the signal with the complex conjugate of the ASM and taking an FFT to search in frequency and integrate coherently for the complete duration of the ASM. In the figures the signal amplitude is normalized so that the noise power in each of the FFT bins is one when the signal is not present. Note that the correlation of the signal with the ASM is significantly larger than one even well away from the main peak. This is caused by the transmitted data having a nonzero cross-correlation with the ASM.

Additionally, the amplitude and frequency of the main peak is evaluated in the figures in the second column of Fig. 5. The "correlation (with scalloping loss)" trace shows the magnitude of the main peak in the FFT bin where the power is largest. Some of the signal power is thus lost to other FFT bins due to scalloping loss. The "correlation (no scalloping loss)" trace sums over several FFT bins instead to recover most of the signal power. Hence, it gives a good estimate of the signal Eb/N0.

We make the following remarks about the ASM figures. First, we see that the frequency at which the ASM is detected keeps decreasing steadily due to changing Doppler, but there is a jump of some 20 Hz in the middle. This was caused by an occasional frequency jump in the temperature compensate crystal oscillator (TCXO) of the Longjiang-2 transmitter, as the compensation was done by digital switching. This problem was observed during ground test, but we did not have enough time to find a replacement. During spacecraft operations, these occasional jumps of the TCXO corrupted some of the received packets, since they made the receiver PLL lose lock. Second, the data recorded at Harbin shows a reliable detection of the ASM for a weak signal of ~−2 dB Eb/N0.

Fig. 5: Downlink performance of Longjiang-2 received by different ground stations.



Correlation peaks, ASM detected, and constellation plots received at a Dwingeloo, b Wakayama, c Shahe, and d Harbin.

Since decoding the turbo coded data requires an Eb/N0 ~0 dB, this shows that the ASM detection is robust enough.

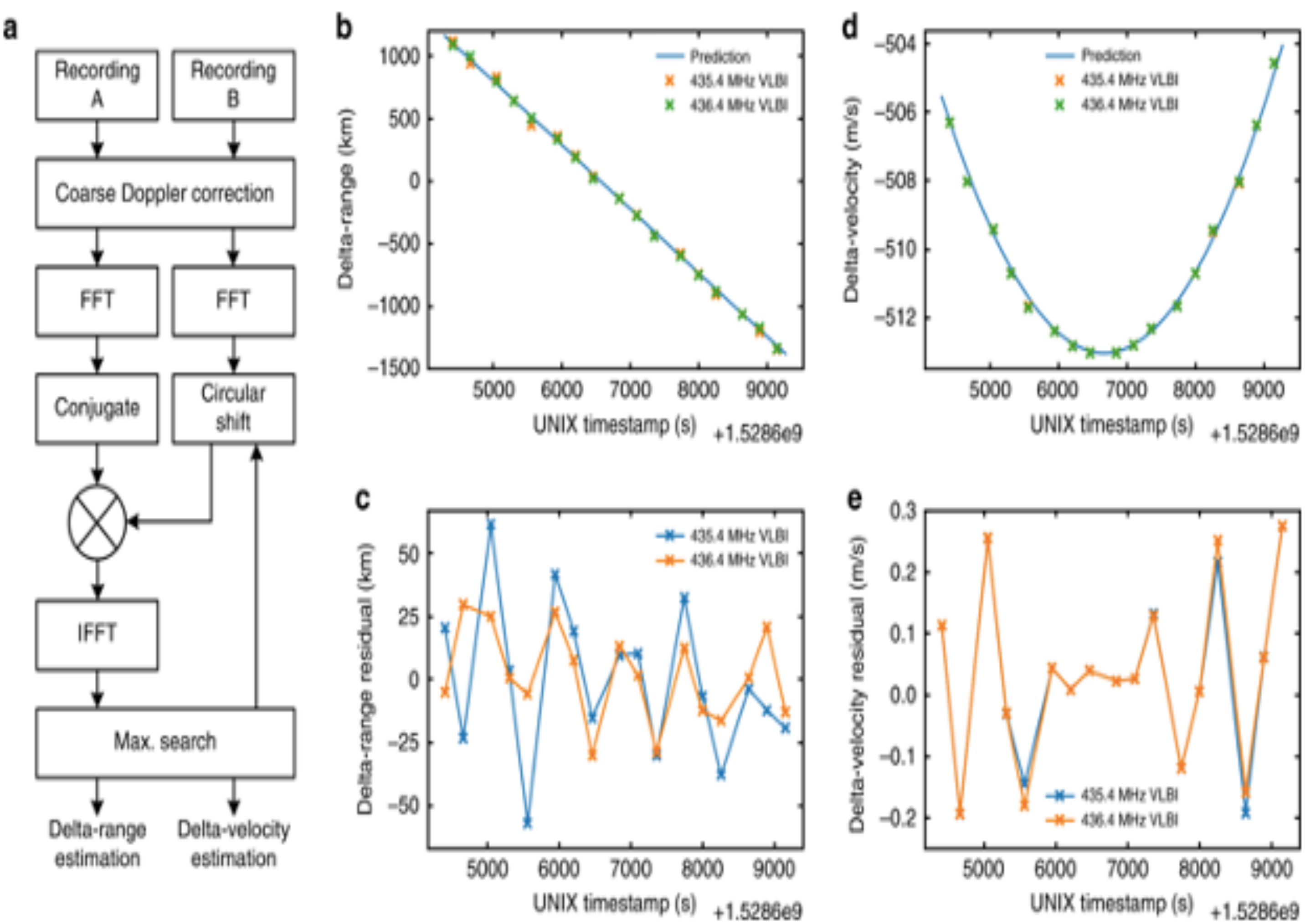
By examining the symbols at the output of the OQPSK demodulator, we can make the constellation plots, as shown in the third column of Fig. 5. A PLL bandwidth of 8 Hz was used in this analysis. The data frames used to draw the plots have no error at turbo decoder output. As the SNR decrease, the constellation points become larger due to the additive noise. If one of the points is misidentified as another, a symbol error happens. The SNR in Harbin was low enough that the symbols were no longer recognizable in the constellation plot. However, the turbo decoder was still able to recover valid frames. This shows that the receiving system has good performance even at very low SNR.

First lunar orbit UHF VLBI experiment

Very-long-baseline interferometry (VLBI) is an interferometry technique used in radio astronomy and spacecraft orbit determination. In VLBI a signal from a radio source is collected at multiple synchronized ground stations separated by a few hundred or thousand kilometers. The time difference between the arrivals of the radio signal at different ground stations is measured to locate the direction or position of the radio source. As the baseline is very long compared to the wavelength of the radio signal, the measurement can be quite accurate. The frequency difference can also be measured to determine the velocity of the radio source. The block diagram of signal processing used for Longjiang-2 VLBI is shown in Fig. 6a. The synchronization between distant receivers was historically quite difficult to achieve. Nowadays it is much easier with the help of GPS. Each UHF VLBI ground station of Longjiang-2 has a GPS disciplined oscillator (GPSDO) to provide a 10-MHz reference output with a Allan deviation of 1 × 10–11 at 1 s, and a pulse per second (PPS) signal output with an accuracy to UTC of ±50 ns RMS. The local oscillator of the receiver is locked to the 10 MHz reference, and the sample moment of the receiver is marked referenced to the PPS signal.

The first synchronized I/Q recordings of Longjiang-2 UHF downlink were made in Dwingeloo and Shahe from UTC 04:20 to 5:40 on 10 June 2018. It was the first VLBI experiment with a lunar orbit spacecraft operating on UHF band. The distance between the ground stations is ~7250 km. The satellite was transmitting 250 bps GMSK with r = 1/2 turbo code in burst

Fig. 6: Results of the first VLBI experiment with Longjiang-2.



a Block diagram of VLBI signal processing. b Delta-range result from VLBI comparing with prediction from CDSN elements. c Delta-range residual result from VLBI. d Delta-velocity result from VLBI comparing with prediction from CDSN elements. e Delta-velocity residual result from VLBI.

mode on 435.4 MHz and 436.4 MHz. The recordings are at 40 ksps sample rate centered at these two frequencies.

As Longiang-2 has both VHU/UHF and S-band radios, the orbital elements (measured by CDSN with S-band two-way ranging, which have a known position error of no more than 10 km) can be used to evaluate the performance of UHF VLBI. Figure 6b–e shows the delta-range and delta-velocity results of the VLBI observation. The curves fit the prediction from CDSN elements quite well, with delta-range residuals of 29.23 km RMS and 17.84 km RMS on 435.4 MHz and 436.4 MHz, and delta-velocity residuals of 0.1406 m/s RMS and 0.1437 m/s RMS on 435.4 MHz and 436.4 MHz.

Discussion

Despite the regretful loss of Longjiang-1, the mission of the VHF/UHF radio of Longjiang-2 has been a great success. It was the first amateur radio communication system operating in lunar orbit, and provided a lot of data return during its 14 months lifetime. With the help of new hardware and waveform design, the VHF/UHF radio provides excellent performance at the cost of limited available weight, power, and envelope resources, enabling the use with small ground stations and simple hardware, making it the lunar mission with most ground stations involved. The first lunar orbit VLBI experiment on UHF band was also carried out based on the VHF/UHF radio. The concepts and techniques developed can be used for the communication system design of future miniature or low-cost deep space missions.

Data availability

Datasets for telemetries from Longjiang-1/2 are available in the DSLWP public data release v1.0 repository, **https://doi.org/10.5281/zenodo.3571330**. Datasets for the raw signal recordings from Longjiang-2 are available in the CAMRAS DSLWP data repository, **https://charon.camras.nl/public/dslwp-b**. Other data that support the paper and other findings of this study are available from the corresponding authors upon reasonable request.

Code availability

The code that supports this paper (including modulator, demodulator, correlator, plot drawing, etc.) is available in the gr-dslwp repository, **https://github.com/bg2bhc/gr-dslwp**.

References

1. Wu, W. et al. Design of Chang'e-4 lunar farside soft-landing mission. J. Deep Space Explor. 4, 111–117 (2017).
Google Scholar

2. Jakhu, R. S. & Pelton, J. N. (eds) in Small Satellites and Their Regulation 13–20 (Springer, 2014).

3. Burleigh, S. C. et al. From connectivity to advanced Internet services: a comprehensive review of small satellites communications and networks. Wirel. Commun. Mob. Comput. 2019, 17 (2019).

4. Davoli, F., Kourogiorgas, C., Marchese, M., Panagopoulos, A. & Patrone, F. Small satellites and CubeSats: survey of structures, architectures, and protocols. Int. J. Satell. Commun. Netw. 37, 343–359 (2019).
Article Google Scholar

5. White, D. et al. Overview of the satellite networked open ground stations (SatNOGS) project. In AIAA/USU Conference on Small Satellites (AIAA/USU, 2018).

6. UNITEC-1 Development Team. Call for support on tracking and receiving RF signal for first interplanetary university satellite UNITEC-1. Preprint at **http://www.unisec.jp/unitec-1/files/text/UNITEC-1operation_en.pdf (2009)**.

7. Bendoukha, S. A., Okuyama, K.-i, Bianca, S. & Nishio, M. Control system design of an ultra-small deep space probe. Energy Procedia 100, 537–550 (2016).
Article Google Scholar

8. Sawada, K., Chin, M., Usami, N., Kimura, M. & Kubota, A. Structural design of 3D printed spacecraft - ARTSAT2: DESPATCH. Trans. Jpn Soc. Aeronaut. Space Sci. Aerosp. Technol. Jpn 14, Pf_45–Pf_50 (2016).
Google Scholar

9. Moser, H. et al. Manfred Memorial Moon Mission (4M): development, operations and results of a privately funded low cost lunar flyby. In AIAA/USU Conf. Small Satellites (AIAA/USU, 2015).

10. Edwards, C. D. Jr. et al. Relay communications strategies for Mars exploration through 2020. Acta Astronaut. 59, 310–318 (2006).
ADS Article Google Scholar

11. Li, Y., Chen, Z., Liang, Y., Gu, Y. & Wang, Y. Long March-4B/4C: a low-cost multi-launch solution for micro lunar probe. In 13th IAA Low-Cost Planetary Missions Conference (IAA, 2019).

12. Severance, M.T., Tate-Brown, J. & McArthur, C.L. NASA education activities on the International Space Station: a national laboratory for inspiring, engaging, educating and employing the next generation. In IAC Meeting (IAC, 2010).

13. Hu, C. et al. LilacSat-1: a member of QB50 and a new mode amateur radio satellite. In 9th European CubeSat Symposium (VKI, 2018).

14. Shambayati, S. & Lee, D. K. GMSK modulation for deep space applications. In 2012 IEEE Aerospace Conference (IEEE, 2012).

15. Laurent, P. Exact and approximate construction of digital phase modulations by superposition of amplitude modulated pulses (AMP). IEEE Trans. Commun. 34, 150–160 (1986).
Article Google Scholar

16. CCSDS Secretariat. Recommendations For Radio Frequency And Modulation Systems Part 1 - Earth Stations And Spacecraft (CCSDS, 2019).

17. Moncur, R. & Taylor, J. Small station EME at 10 and 24 GHz: GPS locking, doppler correction, and JT4. Preprint at **https://www.physics.princeton.edu/pulsar/K1JT/small_station_eme.pdf (2013)**.

18. Simon, M. K. & Wang, C. C. Differential detection of Gaussian MSK in a mobile radio environment. IEEE Trans. Vehicular Technol. 33, 307–320 (1984).
ADS Article Google Scholar

19. Heron, P. SSDV (Slow Scan Digital Video). In 31st Annual AMSAT-UK International Space Colloquium (AMSAT-UK, 2016).

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Author information

Affiliations

1. Harbin Institute of Technology, No. 92 Xidazhi Street, 150001, Harbin, China
Mingchuan Wei, Chaoran Hu, Mier Tai, Yuhao Zhao, Jiahe Huang, Xibin Cao & Feng Wang

2. Oceano Atlantico 38, Tres Cantos, 28760, Madrid, Spain
Daniel Estévez

3. C.A. Muller Radio Astronomy Station, Oude Hoogeveensedijk 4, 7991 PD, Dwingeloo, The Netherlands
Cees Bassa & Tammo Jan Dijkema

4. ASTRON, Netherlands Insititute for Radio Astronomy, Oude Hoogeveensedijk 4, 7991 PD, Dwingeloo, The Netherlands
Cees Bassa & Tammo Jan Dijkema

Contributions

M.W., X.C., and F.W. generated the design concept. M.W. designed the overall system architecture and transceiver hardware. M.W. and D.E. designed and analyzed the performance of the waveforms. C.H. designed and tested onboard antennas and ground station antennas in Harbin and Shahe. M.T. designed and tested the CMOS camera. Y.Z. designed the ground station software. C.B. and T.J.D. led the observations in Dwingeloo and spotted the moonbounce propagation. D.E., M.W., and J.H. designed the VLBI observations and processing. M.W., C.H., and D.E. wrote the manuscript. X.C. and F.W. supervised the project. All authors reviewed and commented on the manuscript.

Corresponding authors

Correspondence to Xibin Cao or Feng Wang.

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Subjects
- Aerospace engineering
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