Phase 4 Space Funding Request

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Abstract

The mission of Open Research Institute project Phase 4 Space is to facilitate the design, development, deployment and operation of Open Source Amateur Radio satellites in geosynchronous orbit.

What is Open Research Institute?

Open Research Institute (ORI) is a non-profit research and development organization which provides all of its work to the general public under the principles of Open Source and Open Access to Research. ORI is a public charity with tax-exempt status under 501(c)(3) as of March 2018.
https://openresearch.institute/

ORI Participation fully in the Open Source Cubesat Workshop 2018 and the Small Satellite program at IEEE Antennas and Propagation Society Conference in 2017. ORI has presented open source satellite research and development results at Hamvention, HamCation, DEFCON, Burning Man, the JAMSAT Symposium, and across North America through the IEEE Distinguished Visitor Program. ORI has published in the AMSAT-NA Journal, the Proceedings of the AMSAT-NA Space Symposium, and the AMSAT-UK Journal. ORI members served on the review committee for Open Source Cubesat Workshop 2019.

What is Phase 4 Space?

Phase 4 Space is an ORI project. The goal is is to build and launch modern, innovative Amateur Radio Satellites to geosynchronous orbit. Phase 4 space is an open source, broadband, digital, regenerative payload with programmable multiplexing. The baseline design is four self-propelled 6U CubeSat stand-alone ham-dedicated satellites and four spares. This design requires 3-axis stabilization, propulsion, debris mitigation, and more. Phase 4 Space communications package can also be a ride share or hosted payload with appropriate integrator partners. Four flight payloads and four spares are spaced 90 degrees apart for global coverage. Initial informal talks with and presentations to JAMSAT, AMSAT-UK, AMSAT-DL about collaboration have been very positive.

Phase 4 Space works with individuals and other non-profit organizations throughout the world who share the common goal of placing Amateur Radio Satellites in geosynchronous orbit. Our closest partner is Libre Space.
https://libre.space/

What does Phase 4 Space need?

Funding is needed to achieve the goal. Technical progress to date has been very good and is described below. In order to have a reasonable chance of success, the project requires a fully funded payload. The hardware cost for four flight payloads and four spares is estimated to be 5 million dollars.

Introduction

ORI believes that amateur satellites should use high-speed digital uplinks and downlinks on microwave frequencies. The baseline design for the Phase 4 System has a frequency division multiple access uplink on 5GHz. These channels use 4-ary minimum shift keying. Channels can be flexibly deployed with the Theseus Cores polyphase filter bank channelizer. The downlink is an open source implementation of DVB-S2/X. This is a time division multiplexing protocol. DVB-S2/X is an open standard available from dvb.org.

We use Generic Stream Encapsulation (GSE) to transport multiple user data streams in a standardized way, in place of MPEG video transport streams that were the original purpose of the DVB protocols.

We use Adaptive Coding and Modulation (ACM). This technique is open and fully described in the DVB-S2 standard from dvb.org. Amateurs deserve the most efficient use of spectrum in an elegant closed-loop communications system.

Why Geosynchronous? Why not LEO?

Putting microwave uplinks and downlinks at low earth orbit (LEO), while certainly possible, has many technical challenges on the ground and does not offer as much value as it does at high earth orbit (HEO) or geosynchronous orbits (GEO). Digital broadband on one or very few LEO spacecraft does not have the mass appeal potential of Phase 4. LEO delivers nothing to the emergency communications community.

Qatar Amateur Radio Society's Phase 4A Geostationary satellite (QO-100) is now operational. This payload has delivered the value anticipated and has sparked an enormous amount of home-brew microwave band amateur equipment. While it's not a regenerative digital transponder, it delivers everything else that was anticipated. The question of whether GEO is “boring” has been answered firmly in the negative.

What Can be Done on the Ground?

Ground based regenerative repeaters can prove a lot, including all of the signal processing algorithms and control processes necessary for a space based repeater. But to be suitable for space, these all need to be moved into an FPGA/SoC/DSP environment that is then deployed to GEO. There is little motivation for moving things to FPGA and DSP's when they sit in the safe environment of the ground where 100's of watts for powering high-end processors is easily available. The motivation for doing such a port is so that they can be deployed in GEO where total DC power will likely be limited to 100W, or perhaps only 10W. While substantial FPGA/SoC/DSP work has been published and demonstrated, having a funded spacecraft is a game-changing and transformative motivation.

Summary of Recent Technical Work

The online repository for Phase 4 Space is https://github.com/phase4space
There are related papers and work in the Phase 4 Ground repository https://github.com/phase4ground Phase 4 Ground is an ORI project dedicated to building the necessary ground equipment for the air interface used by Phase 4 systems.

Phase 4 Space has evaluated Libre Space OpenCube standard for adoption.
https://wiki.librecube.org/index.php?title=LibreCube_Board_Specification
This standard serves LEO well, but does not address some of the needs of GEO. Work needs to be done in this area to augment the OpenCube standard for higher orbits. Libre Space is willing to collaborate on this.

Phase 4 Space has evaluated several propulsion systems for purchase. Top choice is the Busek BIT-3. Public missions relying upon the BIT-3 for high delta-v propulsion include Morehead State University’s Lunar IceCube and Arizona State University’s LunaH-Map.

Phase 4 Space has completed a summary study of the minimal cost required to build four 6U flight payloads and four spares. The cost is $5,000,000 USD. Launch costs have not been included due to the enormous flux in the market. Strenuous efforts to secure a donated launch are assumed to be necessary. Securing a launch will be dramatically easier if the payload was funded and the engineering process proceeded.

The central enabling technology of the broadband microwave GEO payload is an open source polyphase filter bank channelizer. The one we use, support, and contribute towards is from Theseus Cores and can be found here: https://gitlab.com/theseus-cores/theseus-cores

This Theseus Cores channelizer is under active and successful development. Stability and efficiency are good and demonstrations have been effective and popular. These cores are RFNoC Modules that work with GNU Radio.

Phase 4 Ground has published two high performance Low Density Parity Check decoders. This is the required forward error correction in DVB-S2/X. Libre Space has published a third. The time is now for deploying a high quality open source digital regenerative multiplexed repeater. DVB-S2/X is the best downlink solution. The most difficult pieces of the receiver have been published as open source work and have been incorporated into GNU Radio.

A dual-band feed was developed by Paul Wade W1GHZ for the project. This feed has been professionally tested and results are in the Phase 4 Ground repository.

GSE functions have been integrated into both GNU Radio and Wireshark by project participants.

FlexRadio is our manufacturing partner for ground equipment. They will not provide software development, but have provided substantial support with hardware R&D.

Phase 4 Ground and Space have a healthy and growing number of active participants. The mailing list and Slack have over 200 people between them. Recruitment for Space has been more challenging without a payload, but it has not been impossible. The examples of progress listed above shows that there is interest, enthusiasm, competence, and great potential for advanced digital amateur payloads.

Purpose

Why Phase 4 Space in Particular?

The mission of Phase 4 Space is distinguished from that of existing Amateur-Satellite Service organizations in that most of these organization expend the vast majority of their resources on LEO satellites. While these efforts are worthwhile, the Geosynchronous orbits offer far greater capabilities than LEO or Medium Earth Orbit (MEO) orbits. This includes 24 x 7 operation and coverage extending across many countries. For example, the Phase 4A amateur radio Geosynchronous Orbit (GEO) Payload from AMSAT-DL covers 1/3 of the globe.

Emergency Communications

Amateur Satellites in GEO are able to reach a much broader user community with greater ability to further the radio arts as well as greater capabilities that can be applied to disaster assistance. The value proposition for Phase 4 Space emergency communications is 24/7 operation, simple low cost fixed antennas, and low cost equipment ($500 or less) when leveraging an existing PC. Nothing in LEO can deliver this, short of a huge constellation.

Advancing the Radio Arts

This project provides one of the best ways to advance the radio arts. Developing satellites for GEO presents much greater technical challenges than those in lower orbits, including a much more hazardous radiation environment than LEO. Accordingly, a committed exclusive focus on GEO is expected to be required to successfully produce GEO satellites for the Amateur Satellite Service. Phase 4 Space, supported by ORI, has that committed exclusive focus.

Regulatory Relief, Innovation, Documentation

A final motivation for Phase 4 Space is the management of the US ITAR/EAR regime. Given its International focus, one of the policy goals of ORI is to limit to the maximum extent possible the negative impacts of the United States International Traffic in Arms

Regulation, and the somewhat fewer negative impacts of the Export Administration Regulations. ORI maintains ITAR and EAR policies for the Phase 4 Space project that take full advantage of the public domain carve-outs.

Phase 4 Space development activities occur in an Open Source Public Domain ITAR/EAR environment. This encourages full international cooperation among Amateur Service licensees around the world. ORI policies can be found here: https://openresearch.institute/itar-ear-notice/

There is an ongoing effort to consult with lawyers recommended by Electronic Frontier Foundation, Mozilla, and Open Source Initiative to write a formal legal opinion about the use of the public domain carve outs in ITAR and EAR. ARDC is aware and informed of those efforts.

Method of Approach

This is an ambitious open source project that will actively enforce the ORI Code of Conduct, regulatory and participant policies, and engineering best practices.

The below chart outlines the current practices as well as anticipated administrative functions for Phase 4 Space.

- Administration
  - Advocacy
    - Participation in Public Events that Support the Mission
    - Establish Collaborative Ties with Like-minded Organizations
  - Membership
    - Phase 4 Space is *Radically Inclusive*
    - Recruiting Continues Indefinitely
    - Code of Conduct Compliance
    - Quality Member Communications
    - Quality Member Support
  - Regulatory
    - ITAR Compliance
    - EAR Compliance
    - Strong Advocacy for Public Domain Best Practices under ITAR/EAR
  - Engineering
    - System Engineering
    - Propulsion
    - Power
    - Attitude Determination and Control
    - Payload Integration
    - Structural
    - Thermodynamics
    - Communications
    - Telemetry, Tracking, and Control

        Orbital Mechanics
    Operations
        Spacecraft Operations
        Information Technology
    Finance
        Operations Account with Wells Fargo
        Accounting and Financial Reporting
        Transparent Analysis of the Cost Benefits of Purchases

Phase 4 Space is a project within a registered research institution. General best practices of research institutes will be followed. As transparency is key to using the public domain carve-outs in ITAR and EAR, that same commitment to transparency is extended to finances and engineering decisions. Phase 4 Space is open source but also open process. This means that not just the final result is freely accessible to the general public, but the process of creating the work products is done in the open as well.

<u>Phases of the Project</u>

The open source amateur radio satellite community, spearheaded by the Phase 4 Ground, has been working for several years on technologies for a new generation of digital regenerative transponders. These regenerative transponders are based on advanced Software Defined Radio technologies. Regenerative repeaters offer many advantages over the traditional bent-pipe analog technologies. When deployed aboard a satellite in GEO, such repeaters could provide 24/7 access using very low-cost amateur earth stations. A single satellite could provide coverage over 1/3 of the globe for thousands of simultaneous users. With several such satellites in service, global 24/7 coverage could become a reality.

With digital regenerative technologies, the cost and complexity of the earth station component can be dramatically reduced by an order of magnitude or more. At the same time the number of simultaneous users can be expanded by two orders of magnitude. An easy to operate earth station costing only a few hundred dollars is feasible and would be well within the technical capability and budget of hundreds of thousands of Amateur Radio operators around the globe. Such capability would also transform Amateur Radio disaster response by allowing low cost go-kits that can serve as gateways to an entirely new level of disaster relief communications. Phase 4 Ground refers to these gateways as Amateur Radio Access Points, and has demonstrated simple versions at amateur radio conferences and events.

While the Earth stations for these GEO repeaters would be cheap, the repeaters are relatively expensive. Their cost as terrestrial equipment (central nodes in a network) is in the tens of thousands of dollars. The engineering effort to develop them would easily be in the millions of dollars if pursued as a commercial project. Fortunately, the Amateur Radio community includes thousands of engineers, many with suitable skillsets in the various disciplines required to successfully complete the required engineering effort. The major impediment is that it is nearly impossible to find qualified volunteer engineers that are also willing to contribute thousands of dollars' worth of equipment and/or software tools in addition to their valuable time. The is the case most especially when the risk of project completion is high – as it is absent project funding.

Despite this impediment, the list of successes from Phase 4 Ground and Space to date is substantial.

Phase 4 Space proposes to bring the various technologies pioneered by the open source
collaboration to fruition through a structured and funded effort that will ultimately produce ready to fly payloads and their ground-based support systems. Such transponders will then be ready for deployment to take advantage of ride-share opportunities or to serve as the payload package for an Amateur Developed standalone GEO platform. The Phase 4 Space project will use 100% volunteer engineering effort,

but the project will need to supply some specialized test equipment and software tools, as well as components for prototyping and deployable hardware.

Phase 4 Space repeater development will have three major phases.

Phase 1 will involve commercially available PC and FPGA Development Hardware supplemented by some custom microwave electronics. This package will be deployed in Europe for testing through the analog transponders of the Qatar Oscar - 100 Analog Transponder presently in GEO over Europe. In this configuration the transponder will operate on the ground instead of space with two hops for uplink and downlink. While not optimal this would provide a complete end-to-end test and demonstration environment.

Phase 2 will provide the actual representative transponder hardware in a cube-sat compatible form factor with the best radiation hardening that can be achieved in the open source environment. The hardware description language (HDL) code and the various software components will then be ported to this compact form-factor.

An eventual Phase 3, if necessary, would develop further modifications of the open-source design as might be necessary for a specific space application using technologies subject to ITAR/EAR. Phase 3 is not strictly part of the open-source effort. Phase 1 and 2 provide all of the non-ITAR/EAR technology.

Budget

Summary Description	Amount
Four flight payloads and four spares	5,000,000

Launch costs not included. This is a low-end estimate of the cost of enough flight-ready hardware to make a viable global amateur radio satellite service system at GEO, with the payloads spaced 90 degrees apart for global amateur radio satellite coverage.

ORI asks ARDC to consider providing financial support for this project. Participation is open internationally to all that can comply with the developer and participant policies and code of conduct. They can be found at https://openresearch.institute/developer-and-participant-policies/