ARTSAT

Seeking volunteers for cooperative data reconstruction from weak signals transmitted by a deep-space craft “DESPATCH”

ARTSAT Project

DESPATCH (DEep SPace Amateur Troubadour’s CHallenge) is the second spacecraft in the “ARTSAT: Art and Satellite Project” series. DESPATCH is scheduled for launch into an Earth escape trajectory in December 2014, carrying a CW beacon in the 435 MHz band.

An important purpose of this spacecraft is the trial reception of very weak signals from deep space using a "cooperative diversity communication" approach. This approach will be an attempt to gather fragmented data received by ham radio operators around the world for recombination into the original text from DESPATCH.

We ask you to join this experiment. This document summarizes the experiment and what you need to do to join. Further details will be provided in later documentation. If you are interested, please refer to them as they become available.

Version	Date of issue	Contents of the update
1.0	July 8th, 2014	Issue of the first edition
1.0.1	July 11th, 2014	CW frequency is corrected to 437.325 MHz

1. DESPATCH: Deep Space Sculpture

We, "ARTSAT: Art and Satellite Project,"[1] are developing a spacecraft called "DESPATCH"[2] for our second mission. It is a sequel to our first mission, "ARTSAT1: INVADER."[3] This spacecraft will be launched into an Earth escape trajectory in December 2014, along with the Hayabusa-2 asteroid probe, the main payload.

This spacecraft, 50x50x45 cm in size with a mass of 30 kg, has a helix-shaped segment making it a beautiful sculpture, as shown in Figures 1.1 and 1.2.

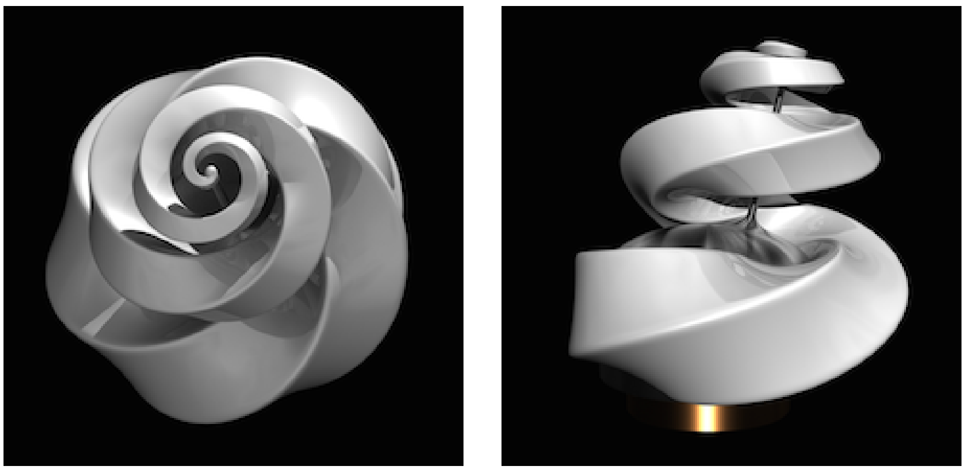

Figure1.1 CGI renderings of DESPATCH

Figure 1.2 The first prototype of DESPATCH

DESPATCH has both artistic and technical missions, as described below.

[1] About ARTSAT: http://artsat.jp
[2] DEep SPace Amateur Troubadour's CHallenge
[3] About INVADER (INteractive Vehicle for Art and Design Experimental Research): http://artsat.jp/invader

Artistic missions:

- To create a “deep space sculpture” by launching the spacecraft into an Earth escape trajectory
- To create “generative poetry in space” and transmit the poetry from the spacecraft for reception on Earth

Technical missions:

- To experiment with the possibilities of receiving very weak signals using a "cooperative diversity communication" approach, in which fragmented transmissions sent from the spacecraft are received around the world, gathered, and reconstructed
- To test the use of 3D-printed parts for spacecraft

One of the artistic missions, ”generative poetry in space,” is a broadcast of sentences in English. They are automatically generated by software running on the spacecraft’s on-board computer (OBC). The poetry generator is “seeded” using sensor readings such as temperature, angular velocity of the spacecraft, etc.

One of the technical missions, “cooperative diversity communication” is detailed in Section 2, “Cooperative diversity communication.”

To complete these missions, DESPATCH will be operating under three unusual parameters:

1. The spacecraft will transmit the signals for only a week until it reaches a distance of 3 million km from Earth.
2. It is battery-powered (rather than solar-powered) enabling a highly flexible design.
3. No uplink command will be sent to the spacecraft — the unit being designed to operate autonomously.

2. Cooperative diversity communication

The signals from DESPATCH are very weak and will be fading, because the spacecraft has no attitude control system and uses only a low-directivity antenna. The signals will carry not only the generative poetry created in deep space but also “housekeeping” data — i.e., information about the spacecraft, especially its health and safety.

The ARTSAT project asks that you attempt reception of these very weak signals at your radio stations. As mentioned in Section 1, “DESPATCH: Deep Space Sculpture,” we are conducting an experiment in cooperative diversity communication. In the experiment, we hope to collect signals from the spacecraft received not only at our own radio station in Tokyo, but at many ham radio stations around the world. The design is to have transmissions decoded by volunteer ham-radio operators throughout the world forwarded to our data server via the Internet for reconstruction back into the original poetry from the spacecraft. With this experiment (schematized in Figure 2.1), we would like to verify the practical effectiveness of cooperative diversity communication.

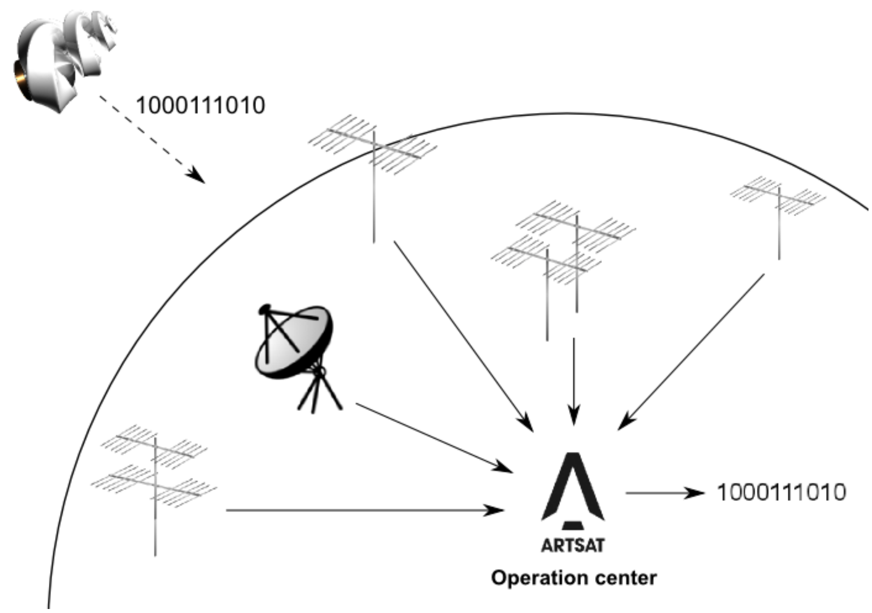

Figure 2.1 A schematic drawing of cooperative diversity communication

To conduct this experiment, we will need the cooperation of as many ham operators as possible. For this reason, the 435 MHz band was selected, being the most commonly used frequency in amateur radio satellite communications.

CW[4] was selected as the modulation mode — one of the simplest modulations each bit (1/0) represented as existence or non-existence of the carrier signal. Transmitting high-power signals modulated in this simple manner is expected to raise the probability of the signals being received. In addition, simple modulation will make it easier for ham operators to add their own "hacks" to their hardware — which should result in a heterogeneous redundant system for reception.

The spacecraft is equipped with a transmitter specified in Table 2.1. This transmitter is controlled by an on-board computer and an integrated-circuit timer. Signals are transmitted using a monopole antenna.

[4] In this document, the term "CW" includes signals encoded by codes other than Morse code.

Table2.1 Specifications of the transmitter

Transmission power	7 W
Transmission frequency	437.325 MHz
Modulation mode	CW
Power supply voltage	+7 V DC
Power consumption	Max. 24.5 W
Carrier frequency stability	Max. ±0.3 ppm (±130 Hz)

3. When can the signals be received?

Spacecraft in Earth escape trajectory will appear to move more slowly in the sky than satellites in low Earth orbit. It is estimated we should be able to receive the signals for most of each visibility period.[5]

The trajectory of DESPATCH[6] has been simulated in order to predict its visibility times at ham radio stations around the world. The visibility times in five cities — Tokyo, Sydney, Berlin, Boston, and Buenos Aires — are shown in Figure 3.1 as black bars. Please note that the times in Figure 3.1 are expressed in Coordinated Universal Time (UTC).

The visibility time for each city is almost the same time of day, every day, as shown in Figure 3.1. For example, visibility time in Tokyo is from 6:00 to 18:30 each day. Note that visibility times depend on the location of the radio stations, which are by no means limited to these five cities. Continuous signal acquisition 24 hours a day is a theoretical possibility if the signals can be intercepted by ham operators in enough different locations.

DESPATCH moves away from Earth soon after launch. The simulation shows that DESPATCH reaches lunar distance (385,000 km) from Earth within 16 hours of separation from the launcher. The change in distance from Earth to the spacecraft is shown in Figure 3.2.

Figure 3.1 indicates when signals can be received at your radio station. You can estimate the spacecraft's distance from Earth during each visibility period by referring to Figure 3.2.

[5] "Visibility period" means a period in which the spacecraft is above the horizon and its signal can be received at a radio station. The time of day corresponding to this period is referred to as "visibility time."
[6] This simulation is based on current information and the results are subject to change.

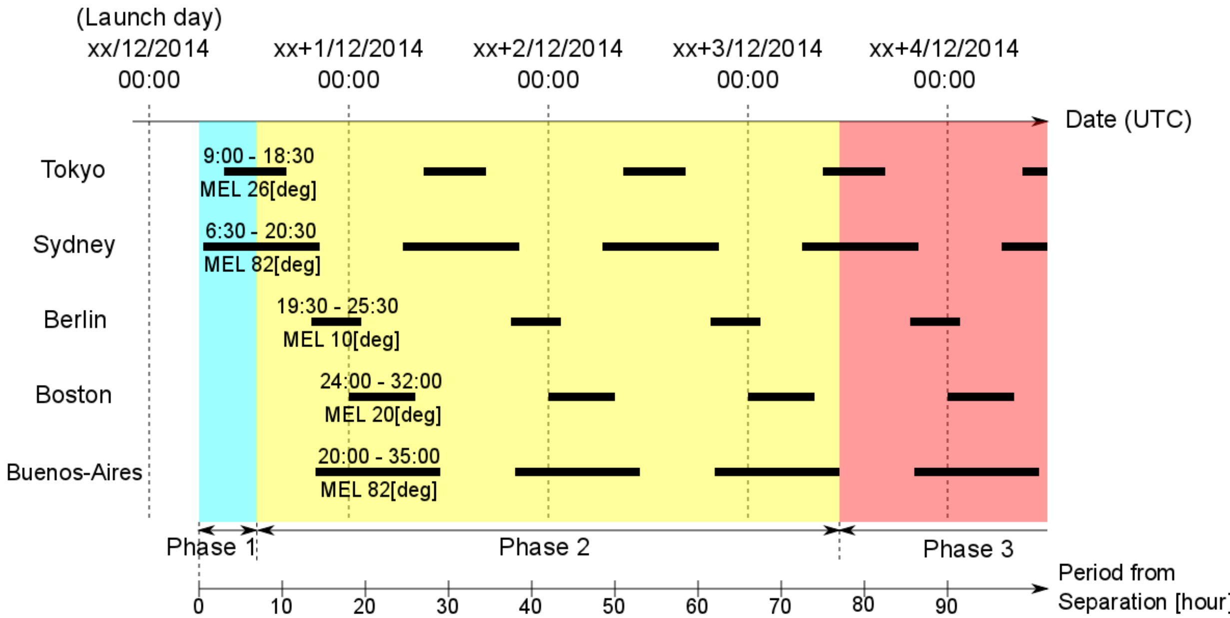

Figure 3.1 Visibility times in five cities and three mission-phases

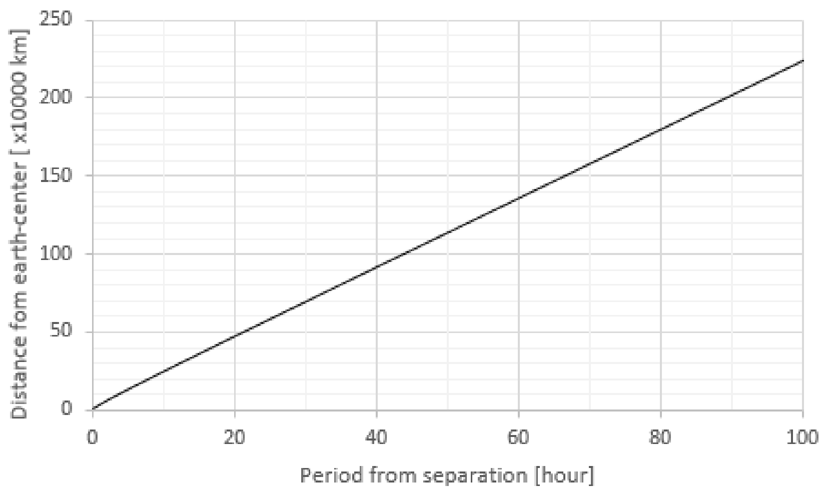

Figure 3.2 Transition in distance between Earth and the spacecraft

Since DESPATCH will be launched into an Earth escape trajectory, no TLE[7] (Two-Line Element set) will be available. Instead, we will provide the orbit information needed for spacecraft tracking on our website. This orbit information will include the directions of the spacecraft (elevation and azimuth angles) and the reception frequencies at various radio stations around the world. We plan to provide this information in a formatted text file. We ask for your help in developing the software needed to control the hardware, including the antenna-rotators and receivers in your radio stations, using this trajectory data.

[7] A data format to describe satellite orbits, commonly used to track Earth-orbiting satellites

4. Mission planning

We are hoping to receive three types of data — the generative poetry, housekeeping data, and a simple beacon. Accordingly, we have divided the mission period into three phases based on the spacecraft's distance from Earth, as shown in Table 4.1. In each of these phases, a different type of data will be transmitted by the spacecraft.

The phase changes are shown in Figure 3.1 — the colors representing each phase. Visibility times around the world were taken into account to determine the schedule for phase-switching, to maximize opportunities for operators to receive the signals.

Table 4.1 Types of data in each phase

Phase	Distance from Earth	Type of data received on Earth
Phase1	~ 200,000 km	Housekeeping data in Morse code
Phase2	200,000 ~ 1,730,000 km	Generative poetry in Baudot code
Phase3	1,730,000 km	Spacecraft temperature in a simple beacon

In Phase 1, housekeeping data encoded in Morse is received on Earth. This data is used to monitor the health of the spacecraft at our own station in Tokyo. For this reason, this phase ends at the middle of the first visibility period in Tokyo, as shown in Figure 3.1.

Phase 2 is where we conduct our experiment on cooperative diversity communication. In this phase, Baudot-encoded generative poetry will be transmitted for reception around the world. Reception will be limited to noisy and intermittent signals given the considerable distance between the spacecraft and Earth. We expect it will be difficult (in some cases, impossible) for any lone ham operator to decode and interpret the signals.

As such, we are attempting to gather all bit strings, received and decoded by ham operators around the world through the Internet so the bit strings can be patched together to reconstruct the original poetry. Figure 4.1 shows the reconstruction process. In the figure, the word "DESPATCH" is reconstructed from data acquired by five ham operators. Note that the red letters are those that were rejected by majority vote. The code or protocol of this poetry is explained in Section 5, "Specifications of the signals."

For the reconstruction process, we are asking every operator to send us not only the decoded bit strings but timestamps, which will tell us when each bit was received. Any method will do to acquire timestamps, e.g., timestamps can be obtained from the public time servers listed under the Network Time Protocol (NTP) Servers Web[8].

[8] Lists of public NTP time servers are provided here: http://support.ntp.org/bin/view/Servers/WebHome

Phase 3 is the reception of a radio beacon whose rate changes depending on temperature of the spacecraft. Spacecraft temperatures can be derived by simply detecting periodic changes in the faint signal.

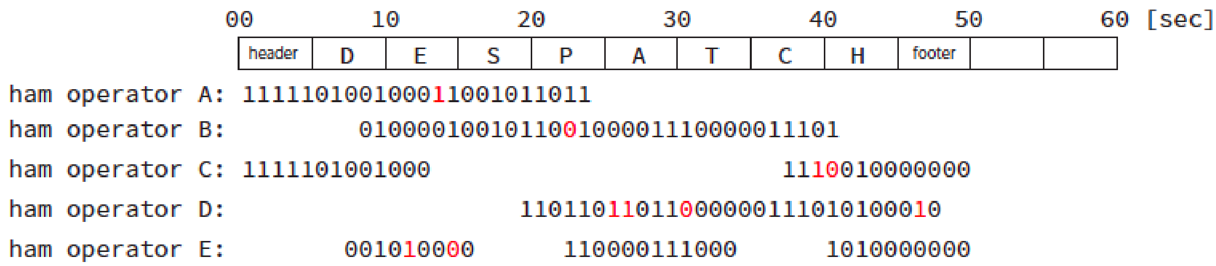

Figure 4.1 Process to integrate bit strings decoded by ham operators

5. Specifications of the signals

In Section 4, "Mission Planning," we explained that the mission period is divided into three phases. In each of the phases, a "cycle" is repeated. This cycle includes three sub-periods. The first sub-period is for transmitting the housekeeping data in Phase 1, the generative poetry in Phase 2, and the beacon in Phase 3. In the second sub-period the transmitter is turned off to cool the spacecraft, while the third sub-period is for transmitting unmodulated signals for measurement of the Doppler frequency. The time allocation for each sub-period in the cycle will be established later on, in light of the results of thermal analysis.

Table 5.1 shows the scheme used to encode each kind of data, and control the speed of their transmission. Housekeeping data is Morse code sent at 6 words per minute. This signal speed was determined from the receiving margin at our own receiving station.

We selected the Baudot code[9], which represents each letter as 5 bits, to encode the generative poetry because it was deemed suitable for the data-reconstruction process explained in Section 4, "Mission Planning." Transmission of the generated poetry follows the protocol shown in Table 5.2. The poetry is sent at a rate of 8 meaningful letters per minute.

Table 5.1 Code for generative poetry, housekeeping data, and speed of the signals

	Generative poetry	Housekeeping data
Code	5-bit Baudot code	Morse code
Encoding	Manchester encoding	Morse code
Signal speed	1 bps	6 WPM (5 bps)

[9] About Baudot code: http://en.wikipedia.org/wiki/Baudot_code

Table 5.2 Protocol of the generative poetry

Elapsed time [s]	Transmitted letters	Duration [s]
0 ~ 4	Header (Shift code : 11011/11111)	5
5 ~ 44	8 letters in 5-bit Baudot code	40
45 ~ 49	Footer (NULL : 00000)	5
50 ~ 59	No signal	10

We ask ham operators all over the world to receive the signals, especially the generative poetry, and to use the Internet to send us decoded bit strings with timestamps. We would also like to ask people to help us develop software — for example, a CW decoder for this generative poetry, and software for attaching timestamps to decoded bit strings.

6. How long can the signals be received?

The receiving margin at every radio station will continue to decrease after the launch as the spacecraft moves away from Earth. We calculated when the receiving margin will dip below zero for receiving antennas of different gains. The result is shown in Figure 6.1.

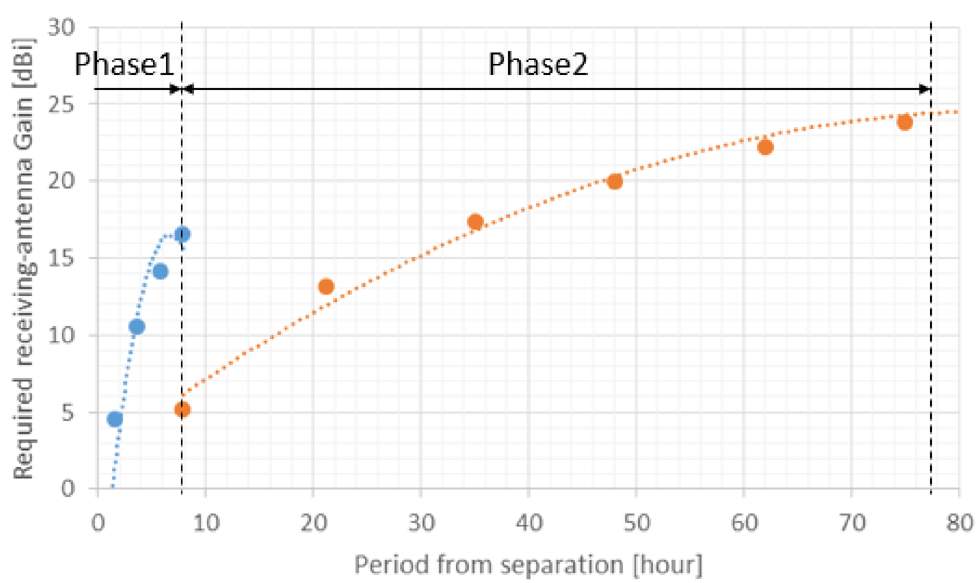

Figure 6.1 Required receiving antenna gain at each time period

The graph in Figure 6.1 takes time after separation from the rocket as the horizontal axis. The receiving antenna gain whose receiving margin is zero at each point (we call this gain “required receiving-antenna gain”) is taken as the vertical axis. This graph shows that you can receive signals only in periods during which the gain of your receiving antenna is higher than the curves in the graph.

Phase 1 and Phase 2 in Figure 6.1 are the mission phases explained in Section 4 "Mission Planning." The required gain is represented by two different curves in the graph because the signal speed is different in each phase. That is, the signal speed is 5 bps in Phase 1 and 1 bps in Phase 2, as shown in Table 5.1.

By referring to Figures 3.1 and 6.1, you can determine how long you can receive the signals at your radio station. For example, consider the case of using an antenna whose gain is 20 dBi for receiving signals in Tokyo. Firstly, in Figure 6.1, you will find that the period in which the required gain is less than 20 dBi is up to about 48 hours after payload separation. Then, in Figure 3.1, you will see that separation+48 hours is somewhere between the second and third visibility periods in Tokyo. Thus, you should be able to receive signals up to the end of the second visibility period in Tokyo using an antenna whose gain is 20 dBi.

Concluding remarks

Reception of such weak signals to reconstruct poetry from the spacecraft will require the expertise of exceptionally skilled ham operators. We are hereby providing a rare opportunity to receive radio signals transmitted by a spacecraft in deep space, and ask for your cooperation in this project, which we also hope will be an opportunity to further enhance your skills.

We also plan to open a site on the Internet using social network services such as Facebook and Twitter, where ham operators can share their know-how for receiving signals and the conditions of data acquisition at each ham radio station, with the hope that this project may further deepen the sense of community among ham radio operators worldwide.

We will be reporting our activities, including the development of DESPATCH, on our Facebook group page (https://www.facebook.com/artsat). If you are interested in the ARTSAT project, please follow us.

Thank you for reading this document through to the end. We would deeply appreciate your cooperation in this mission, and support of our dream. If you have any questions about this document, please email us at (info@artsat.jp).

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