California Institute of Technology
Experimental License Application
File Number: 0284-EX-CN-2021

Explanation of Experiment

The California Institute of Technology's High-Speed Integrated Circuits Group (Caltech) is submitting this application for an experimental license to test a low areal mass, flexible, deployable phased array architecture that will be hosted on a low earth orbit satellite. Caltech is a university.

Technical Synopsis:

- Area of Operations: LEO orbit, hosted on a Momentus Vigoride satellite
  - Orbit: sun synchronous, 90 minute orbital period estimated
  - Inclination: 97.5 degrees
  - Apogee: 550 km, Perigee: 500 km
- Emission designator: 10M0N0N
- Spectrum Required: 9984 MHz and 9900 MHz
- Power levels: 0.6 W output power, 38 dBm ERP
- Length of satellite operation: approximately six months

Description of Experiment:

The Caltech high-speed integrated circuits group has published an article on their flexible light-weight phased array work in the journal Nature. The Abstract to that article explains:

> Phased arrays are multiple antenna systems capable of forming and steering beams electronically using constructive and destructive interference between sources. They are employed extensively in radar and communication systems but are typically rigid, bulky and heavy, which limits their use in compact or portable devices and systems. Here, we report a scalable phased array system that is both lightweight and flexible. The array architecture consists of a self-monitoring complementary metal–oxide–semiconductor-based integrated circuit, which is responsible for generating multiple independent phase- and amplitude-controlled signal channels, combined with flexible and collapsible radiating structures. The modular platform, which can be collapsed, rolled and folded, is capable of operating standalone or as a subarray in a larger-scale flexible phased array system. To illustrate the capabilities of the approach, we created a 4×4 flexible phased array tile operating at 9.4–10.4 GHz, with a low areal mass density of 0.1 g cm^{-2}. We also created a flexible phased array prototype that is powered by photovoltaic cells and intended for use in a wireless space-based solar power transfer array.
>
> Taken from https://www.nature.com/articles/s41928-019-0247-9.

The current application seeks authorization for the operation of a light-weight flexible phased array system – called MAPLE - on board a Momentus Vigoride satellite, which will host MAPLE as an

operational payload on Vigoride. MAPLE is similar to the system described in the paper, however, it is more advanced.

MAPLE will be a small, low power, 32 element light-weight flexible phased array, constructed using technology that can later be used for larger systems. It uses constructive and destructive interference among the sources to generate focused pockets of energy that can be used for communication and power transfer. The concept of this experiment is to use a small, lightweight version to send into space to advance the technology development and explore its utility as a means of improving space-to-earth communications. If, as expected, this experiment proves the technology can be used, Caltech hopes to be able to follow with additional missions further proving the technology.

MAPLE is a 6U sized unit. The following images, Figures 1-4, help to illustrate the MAPLE system that will be embedded in the Momentus satellite.

Figure 1: An illustration of MAPLE, showing phased array, rectenna array receivers, & cameras, but not depicting the enclosure that will surround MAPLE when it will be in flight:

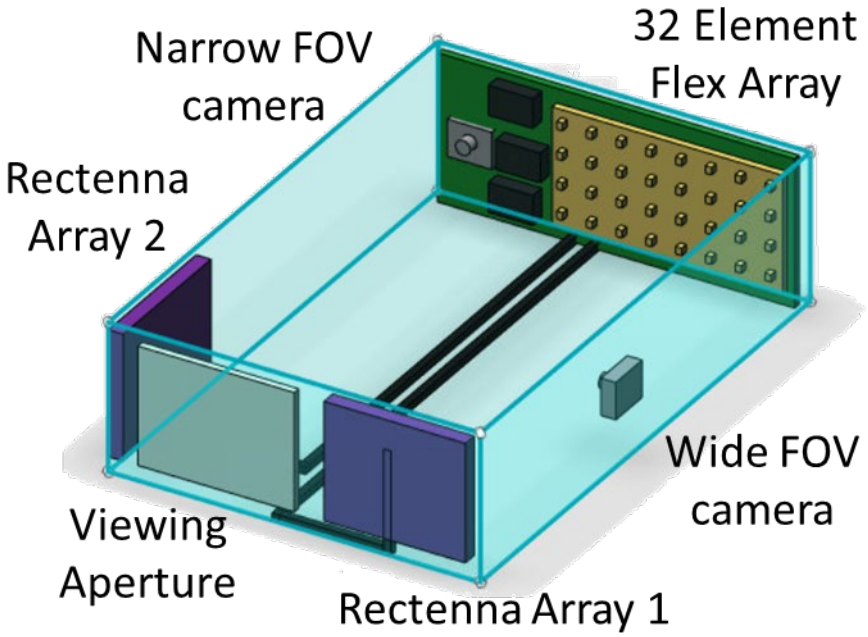


Figure 2: MAPLE, on the work bench, under construction: 10 cm high, 20 cm wide, and 30 cm long. The MAPLE frame will be enclosed in multiple layers of conductive MLI (multi-layer insulator) that serves as an electromagnetic shield, with the exception of the circular (5cm diameter) aperture seen in the lower part of the picture.

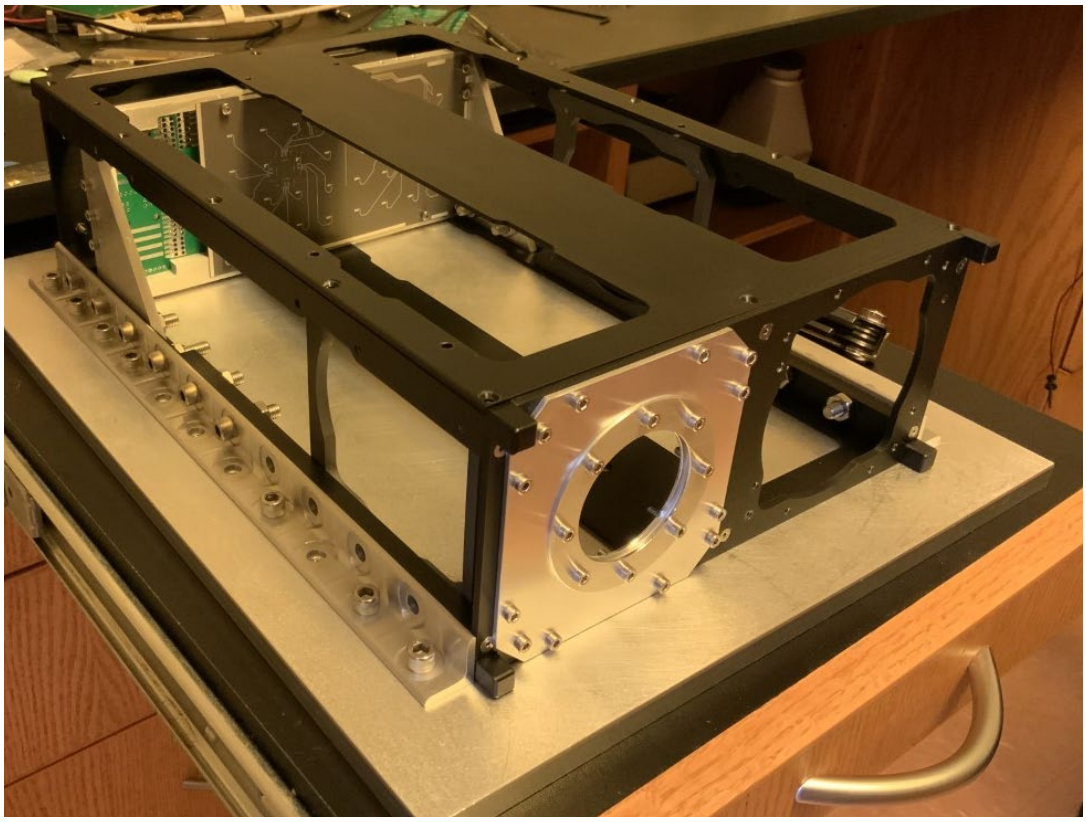


Figure 3: Flight Flex Board Mount, note relatively small size of MAPLE, only 10 cm high

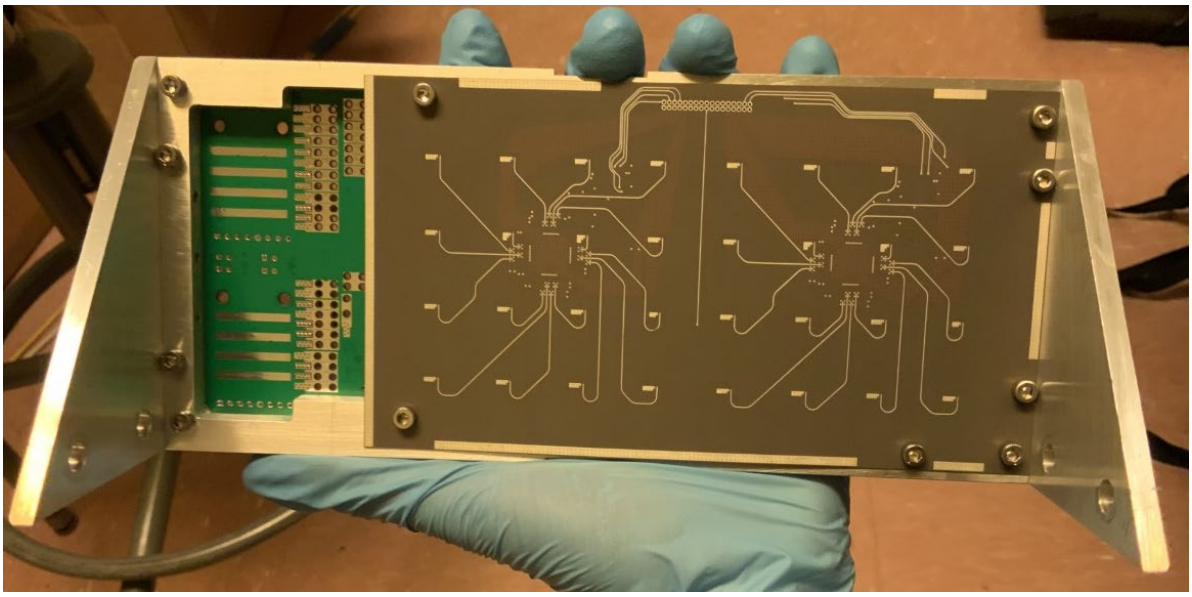
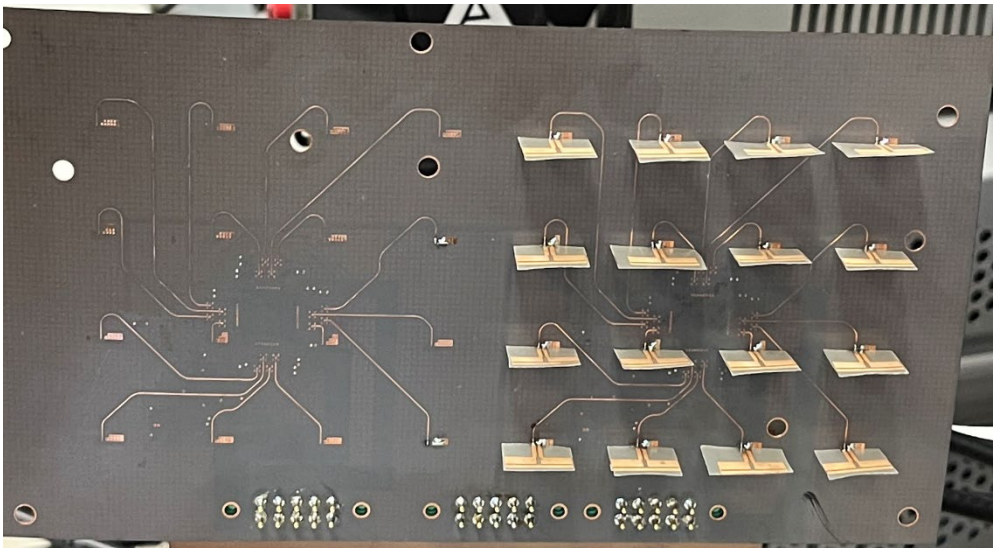


Figure 4: ½ of the phased array antennas installed



Radio Operations

On-board satellite operations: The phased array will focus the microwave beam at close proximity targets within the MAPLE system, rectenna arrays 1 and 2. Repeated focusing with a variety of algorithms and conditions will provide valuable insight into the operation, robustness, and aging of the system.

Transmissions to earth: The second experiment will focus the microwave beam out of a small window in the payload enclosure, the viewing aperture in figure 1. The focused beam will be directed toward earth for detection by a ground station. The ground station will be receive-only.

As explained above, the MAPLE system will be embedded in Momentus Vigoride as a payload. The host satellite will provide the power, data uplink and downlink, and all the command and control of the satellite.

Caltech will be able to provide instructions to MAPLE over the Vigoride links, but not independently. Data from MAPLE will be sent to Caltech over the Vigoride communications links as well.

The transmissions to earth from MAPLE will have no content, they are simply radio pulses.

Satellite Orbital Information:

In this case, the altitude, inclination, and nature of the orbit are all to be determined by Momentus as it makes its plans for Vigoride. According to the satellite host, Momentus' Vigoride, the orbital information is:

- Orbit: Sun synchronous
- Inclination: 97.5 degrees
- Altitude: apogee: 550 km, perigee: 500 km

As a hosted payload customer, Caltech is responsible for providing certifications to the host that it is in compliance with all regulatory requirements. Caltech is making this submission to initiate regulatory review, understanding that the FCC will need to approve the Momentus application before the satellite can be launched.

Vigoride Radio Operations:

Because the Vigoride radios are under the ownership and control of Momentus, Caltech is not seeking authorization for their use. MAPLE will receive instructions and send reports over the communications system that is part of Vigoride. The Vigoride radios will be shared by a variety of hosted payloads on the satellite. Once the data is downlinked by Vigoride, it will be transmitted to Caltech across a terrestrial network. Commands from Caltech up to the MAPLE unit will be sent to Momentus for uplink to the Vigoride. The Caltech team will not have control over the uplink and down link radios.

The Vigoride flight is expected to last only 6 months.

Time of Spectrum Use:

On-board satellite operations: When the satellite is on orbit, the phased array system will be operating relying on the host's power system and data links. As a result, the operations will be very limited. For the first few days of experimentation, MAPLE is expected to operate for 6 hours per

day. Then, by the end of a week, the time of use is expected to drop to one hour per day, broken out into four periods of 15 minutes of operation each. Thus, the time of use is very limited.

Transmissions to earth: The time of use of the radios for transmissions to earth is much more limited. These transmissions may take place in 15-minute increments only three to four times per week. With proper satellite tracking and system programming, MAPLE will activate when Vigoride is over the ground station at Caltech, and then turn off again until the next scheduled transmission period, when again the Vigoride is flying over Caltech. This is expected to be a very limited time.

Caltech can work with others to coordinate its time of operations for any transmissions to earth, if necessary.

This experiment is expected to last for the duration of the Vigoride flight, which is anticipated to last only six months.

No Likelihood of Interference:

MAPLE's proposed output power level and ERP are very low. The power levels are constrained, in part, by the power source available on the satellite host. By using a high-gain ground station antenna, Caltech will be able to pick out the MAPLE signal, even though the receive level of the signal on the ground will be exceedingly low.

The anticipated orbital altitude is a minimum of 300 km. It will likely be higher. Momentus has not yet informed Caltech of the specifications for the satellite orbit.

Taking free space pathloss into account with a minimum distance (elevation) of 300 km, the anticipated signal level is something less than -120 dBm when MAPLE's signal reaches earth. This signal is not likely to cause any interference to other operations in the band.

Orbital Debris Assessment Report:

MAPLE will be hosted for its entire mission on the Momentus Vigoride satellite. Because it will not have independent flight, the Momentus Vigoride ODAR will apply to MAPLE and its operations.

In Attachment A to this exhibit, Caltech is attaching a statement from Momentus that it will include MAPLE in the Momentus ODAR.

ITU Cost Recovery:

Caltech is submitting as an additional exhibit to this application an ITU cost recovery letter in which it commits to paying any fees required by the ITU to coordinate the proposed operations.

Stop Buzzer POC:

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Conclusion:

Caltech is submitting an application for an experimental license for testing of a planar array system that will be hosted on a low earth orbit satellite. The radio testing will mostly be contained on the satellite. Occasionally, when the satellite passes over Caltech, the MAPLE transmitting device will send a signal to the earth, which Caltech hopes to receive and analyze.

The time of use is limited, with an expected one hour of use per day, divided into four 15-minute segments.

The satellite flight is expected to last only about six months.

The orbital details will be supplied by Momentus filing for the particular Vigoride flight, which will host this experiment.

Coordination of spectrum use is possible.

For questions about this application, please contact Anne E. Cortez, Counsel, at 520-360-0925 or alc@conspecinternational.com.

Attachment A

From: Daniel Larrabee
To: alc@conspecinternational.com
Subject: Momentus-Caltech Hosted Payload
Date: Tuesday, March 30, 2021 4:12:42 PM

Hello Anne,
It was a pleasure to speak with you today regarding the Caltech Hosted Payload riding on the Momentus Vigoride.

For the FCC and ITU submission the following information can be communicated, i.e. requested information:

Launch Window: 1-31 December 2021
Rocket: SpaceX Falcon 9
Vehicle: Vigoride
Orbit: SSO (Sun-Sync Orbit)
Altitude: 525 km +/- 25 km
Inclination: 97.5 +/- 0.1 degrees
Orbital parameter: 10:00 LTDN -0/+60min

Additionally,
Momentus will evaluate and include MAPLE in the Vigoride orbital assessment report.

Best,
Daniel

On Tue, Mar 30, 2021 at 1:30 PM <alc@conspecinternational.com> wrote:

Anne E. Cortez, Esq.

Managing Partner

Washington Federal Strategies

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