National Aeronautics and Space Administration

All Solid-State Transmitter Module (ASTRAM) for Solar System Radar

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Program: FY21 R&TD Strategic Initiative   **Strategic Focus Area: Cis-Lunar Space Situational Awareness**

Objectives

The objective of this effort is to develop a 4kW all solid-state transmitter module (ASTRAM) operating at X-band frequency that can provide reliable high output power with graceful degradation and ease of replacement to minimize radar down time. The Goldstone Solar System Radar (GSSR) currently relies upon the use of high power (250kW) klystron tube amplifiers. The operating reliability of these klystron tubes has been in question for years. The ASTRAM will be developed with the ultimate goal in mind of eventual scaling such a system for implementation in the GSSR as a solid-state alternative to klystrons. This system builds upon previous work, utilizing our recently developed Spatial Power Combining Amplifier (SPCA) modules, each of which combines 16x 80W MMIC devices for a 1.1kW combined output power at X-band frequency. During this effort we are working to combine four of these SPCA modules into a 4kW transmitter unit using a waveguide combiner system as a proof-of-concept demonstration. We expect the solid-state based transmitter technology developed here will greatly improve the reliability of the GSSR and future high-power transmitter systems, reducing the antenna downtime required for repairs and mitigating the catastrophic nature of tube-based RF source failures by means of graceful degradation.

Background

The operating reliability of the GSSR's klystron tubes developed by Communications and Power Industries (CPI) has been in question for years. The company CPI is a sole-source vendor for tubes that operate at our required frequency and power levels. These tubes have been in operation as long as 5 years or as little as 4 months before they fail, and are extremely expensive to purchase and repair. Repair times from CPI vary from a couple of months to 20 months. After a tube fails, the GSSR transmitter is down until the tube is removed and replaced with a spare tube, which can take several days assuming a spare is on-hand. The relatively short lifetime of the tubes between failures, the time it takes to replace a tube, and the long lead time from the vendor all contribute to the unreliability of using klystron tubes as an RF source. Solid-state amplifiers are a rapidly emerging technology, with greater lifetime, reliability, and controllability compared to traditional vacuum tube devices. We expect the solid-state based transmitter technology developed in this effort can be used to greatly improve reliability, reduce the downtime required for repair, and mitigate the catastrophic nature of RF source failures for the GSSR.

Significance/Benefits to JPL and NASA

Our significant progress to date provides encouragement that by the end of this effort we will achieve a 4kW X-band all solid-state transmitter. The resulting proof-of-concept will be capable of being scaled to higher powers and additional frequencies for use in future radar and communications systems with minimal additional research and development costs. During the course of the year we have addressed the majority of the significant challenges associated with combining multiple SPCAs into a single transmitter system, none of which have proven insurmountable.

The technology we are developing will be of great value to NASA, including current and future radar missions. For example, the work here provides a stepping stone towards a new solid-state revolution in high power amplifiers in key strategic areas, such as next generation planetary radar, antenna array transmitter systems, and NASA's latest push towards Ka-band high-power ground and flight communications. In addition, the product demonstration being built by our team will prove pivotal in addressing particular areas where vacuum tube amplifiers fall short in providing suitable performance, such as tube reliability at very high powers in the X-band frequency range, high-power output at higher frequencies such as Ka-band, improved maintenance costs for antenna arrays, and graceful degradation.

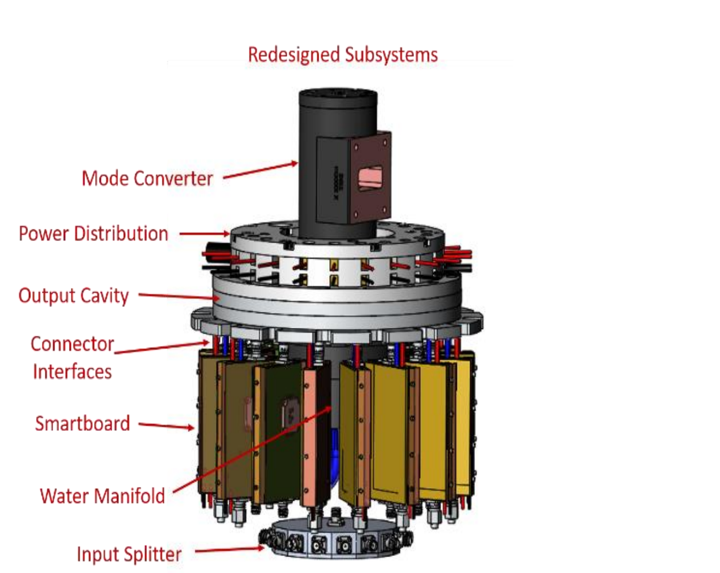

Figure 2. Redesigned Spatial Power Combining Amplifier (SPCA) showing modified subsystems.

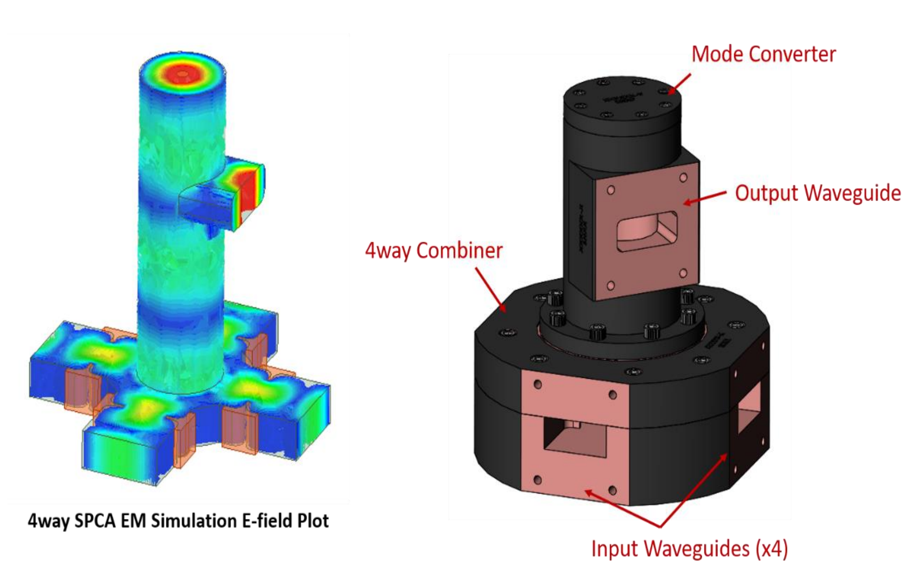

Figure 3. 4kW multiple-SPCA 4-way combiner.

Approach and Results

This year's effort has included a number of important focus areas:

500kW SPCA transmitter system analysis – One important milestone of this task was to evaluate how a 500kW SPCA-based transmitter system might be ultimately implemented in the Goldstone 70m antenna (Fig. 1). A system analysis was performed which involved developing a full-scale transmitter layout in the antenna, and determining where each subsystem could be placed in the antenna. In addition, RF loss estimations were determined for each RF path and component throughout the system.

SPCA redesign – The initial SPCA prototype was redesigned to improve the performance and manufacturability for the device (Fig. 2). This included reworking a number of subsystems, including the input splitter, MMIC Smartboards, output combining cavity, power distribution terminal, and water manifold. Specific to the MMIC Smartboards, modifications were made to improve the output power coupler performance, which reports real time power data to the CPU for balanced power combining. The connectors were better matched to the boards to minimize power losses and improve efficiency. EEPROM memory was added to store calibration data for each Smartboard, minimizing maintenance and troubleshooting effort. The output cavity was redesigned to include a mode-converter output to transform the output TM02 RF signal to a TE11 mode in WR112 waveguide. This method of mode conversion will reduce heating from the previous version's method of mode conversion consisting of a coaxial to waveguide transition.

Transmitter combiner design – Another significant milestone accomplished this year was the development of a multi-SPCA module combiner. This is a 4-way combiner which will be used to combine four SPCA modules for a combined 4kW X-band output (Fig. 3). This design is easily scalable to up to 32 inputs for future transmitter configurations utilizing more modules. The combiner was developed initially using HFSS electromagnetic simulations, followed by CAD design using Solidworks. It is currently being manufactured, and will be tested at the beginning of next year.

High-efficiency SSPA development – During this year's efforts we have been developing a discrete transistor SSPA as a potentially cost-effective approach to custom high-efficiency devices. We identified candidates for discrete transistors that will operate at our desired center frequency, and performed simulations to narrow down which candidates will ultimately yield the highest efficiency performance. A matching network and architecture were subsequently developed to combine multiple of these transistors into a single SSPA with our desired output power and efficiency (Fig. 4). We have procured the desired transistors, and we will begin assembling and evaluating the SSPA design at the beginning of next year.

Software architecture development– We established a secure CPU alternative for the SPCA from the previously used Raspberry Pi to the TI Teensy. We developed an expandable software interface architecture for the transmitter system (Fig. 5), including a graphic user interface (GUI) written in C#, which is scalable to a large number of SPCA amplifier modules. This also included establishing communication protocols and programming language (C++) for the transmitter interface between the SPCA CPUs and Smartboard microcontrollers. The transmitter program and user interface were successfully tested using actual Teensys, microcontrollers, and supporting hardware.

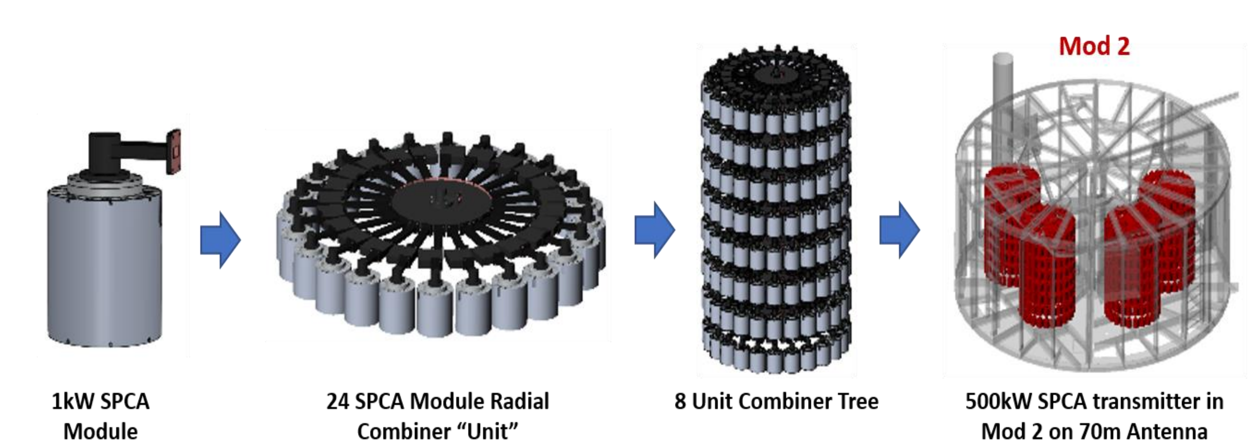

Figure 1. Conceptual diagram showing a combining scheme for tiered combining of SPCAs into a 500kW transmitter system in Module 2 located on Goldstone 70m antenna.

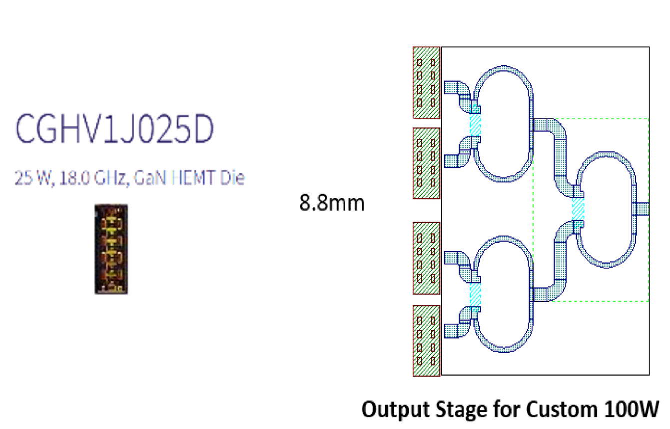

Figure 4. 100W discrete transistor SSPA with output matching network.

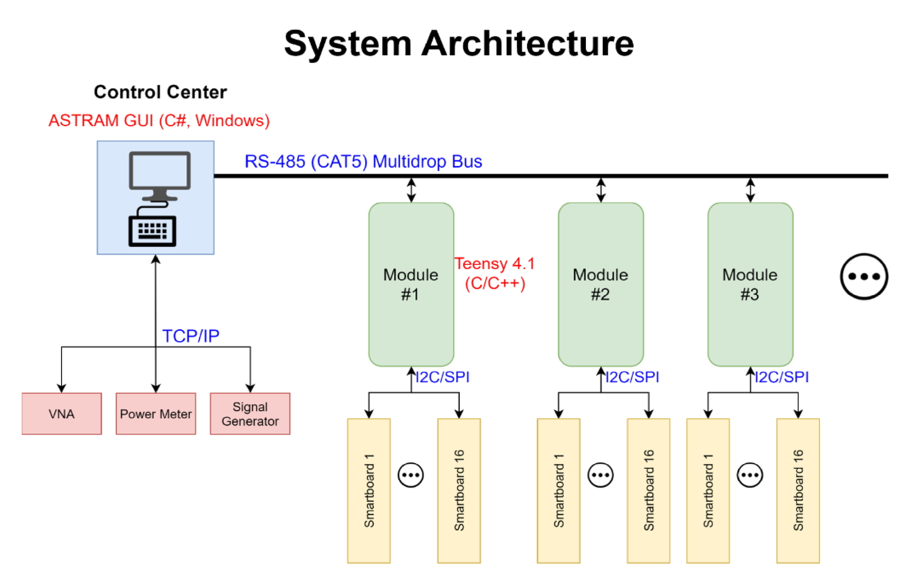

Figure 5. High level scalable software architecture for transmitter system combining undefined number of SPCA modules.

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