FY23 Strategic Initiatives Research and Technology Development (SRTD)

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

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Strategic Focus Area: Cis-Lunar Space Situational Awareness | **Strategic Initiative Leader:** Joseph Lazio

Objectives: The goal of this effort is to develop an **all solid-state transmitter (ASTRAM)** prototype for solar system radar operating at X-band frequency that can provide a reliable 4kW high output power and gracefully degrades to minimize radar down time. The ASTRAM is being developed with the ultimate goal in mind of eventual scaling such a system for implementation in a **solar system radar** as a solid-state alternative to klystrons. This system will build on previous work, utilizing our low-loss **spatial power combining amplifier (SPCA)** technology. Each SPCA module will combine 16x 80W solid-state monolithic microwave integrated circuit (MMIC) devices for a 1.1kW output power at X-band center frequency of 8.56 GHz. We are combining four of these SPCA modules into a complete 4kW X-band transmitter (TXR) unit using a radial waveguide combiner. The TXR design will be modular and scalable in output power and include bias control hardware for performance monitoring and control of each individual MMIC device, as well as a graphical user interface.

Approach and Results: Two SPCAs were assembled along with a testbed for evaluation (Fig. 1), and output power testing was performed. A maximum output power of 1.26kW centered on the desired 8.56GHz center frequency and a gain of 53dB was achieved with a 5% (~440MHz) usable 1dB bandwidth (Fig. 2). The ability to algorithmically control the output power and phase through the GUI software was verified. The resulting power-added-efficiency (PAE) for the SPCA was 27% (directly driven by the MMIC efficiency of ~29%), and an expected cavity combining efficiency of 91% based on prior passive S-parameter insertion loss measurements was confirmed. Further testing included a 24-hour test run (Fig. 3), which demonstrated that the output power is stable and reliable over long duration operation. During this time thermal data was also taken which included ambient air, cavity, MMIC bias-board, and water coolant temperatures. It was observed that there is a significant inverse correlation between output power and water coolant temperature (2.6W/˚C) (Fig. 4). This indicates that output power fluctuations are driven by coolant temperature fluctuations, which could be an important consideration for future application of this technology. Following SPCA combining evaluation, various GSSR phase modulation schemes were introduced to the RF input for evaluating signal integrity and bit error rate, including binary phase-shift keying (BPSK) and chirp modulations commonly used for asteroid analysis (Fig. 5). Some minimal amount of spectral regrowth was introduced, as one might expect from harmonics produced by SSPAs, but overall signal integrity was maintained.

Significance of Results/Benefits to NASA/JPL: As a concept demonstration, this work has far-reaching implications for the communications industry as a whole. The availability of a solid-state alternative to tube amplifiers will provide a new option of high-powered transmitters available to NASA/JPL for both ground and flight-based communications and radar systems. Solid-state transmitters, while not likely to replace tube transmitters, hold certain advantages over their counterparts in areas such as lifetime, reliability, graceful degradation, decreased system complexity, power conditioning, and size/weight/footprint among others. In addition, solid-state TXR technology lends itself well to active array-based antenna TXR systems. As solid-state technology continues to mature and advancements are made in output power and efficiency, the power combining innovation we are developing plays a necessary and key role for applying this new technology into a new set of instruments that will significantly impact future ground and flight mission capabilities.

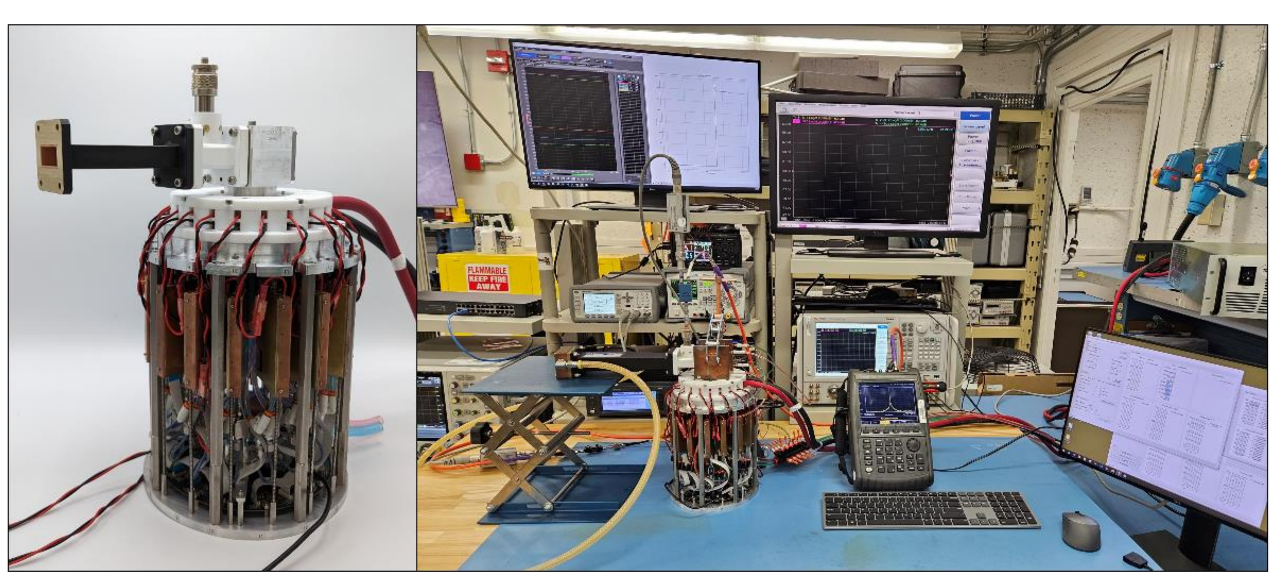

Figure 1. Left: Fully assembled 1kW SPCA. Right: 1kW SPCA testbed.

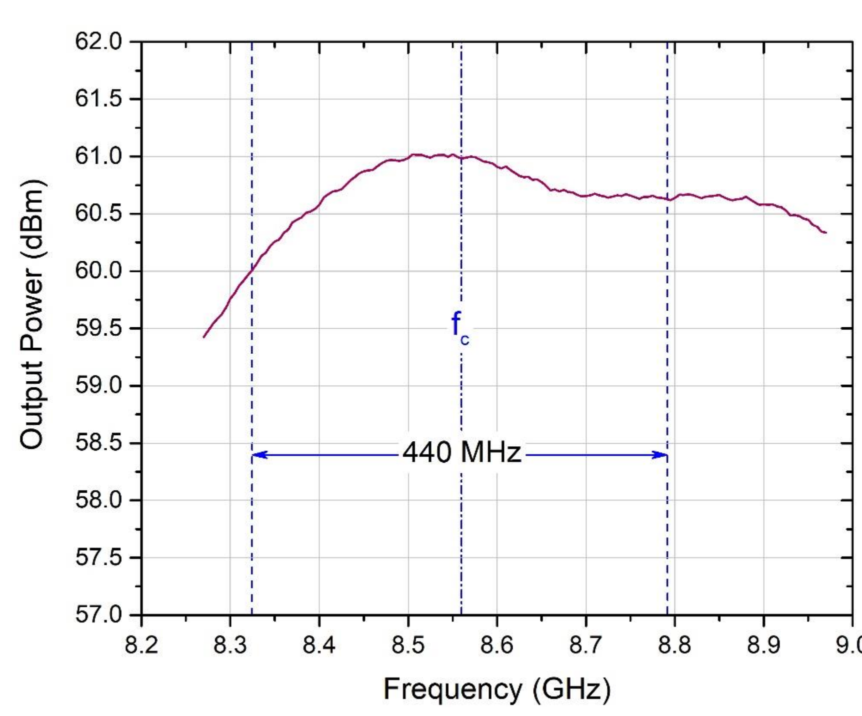

Figure 2. SPCA output power vs. frequency and bandwidth data.

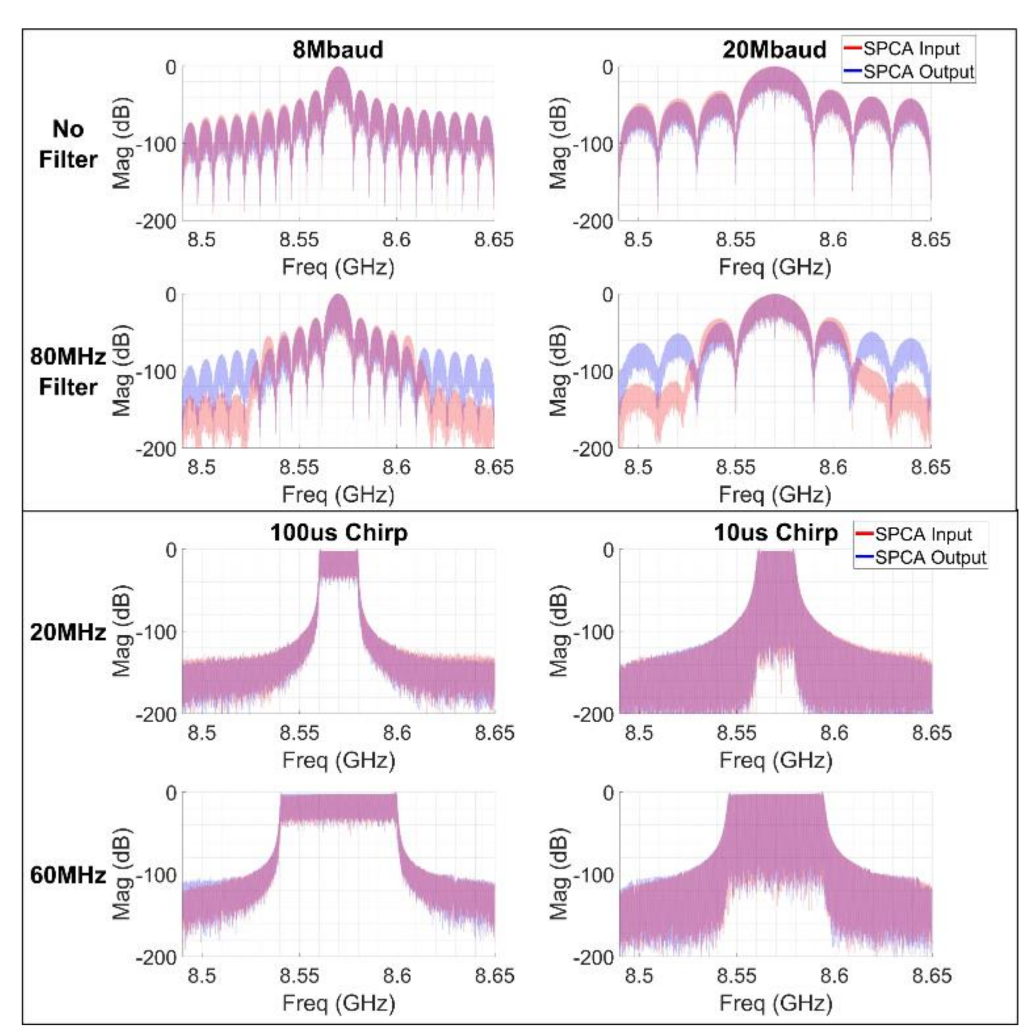

Figure 5. Top: BPSK modulation through SPCA. Bottom: Frequency chirp modulation through SPCA.

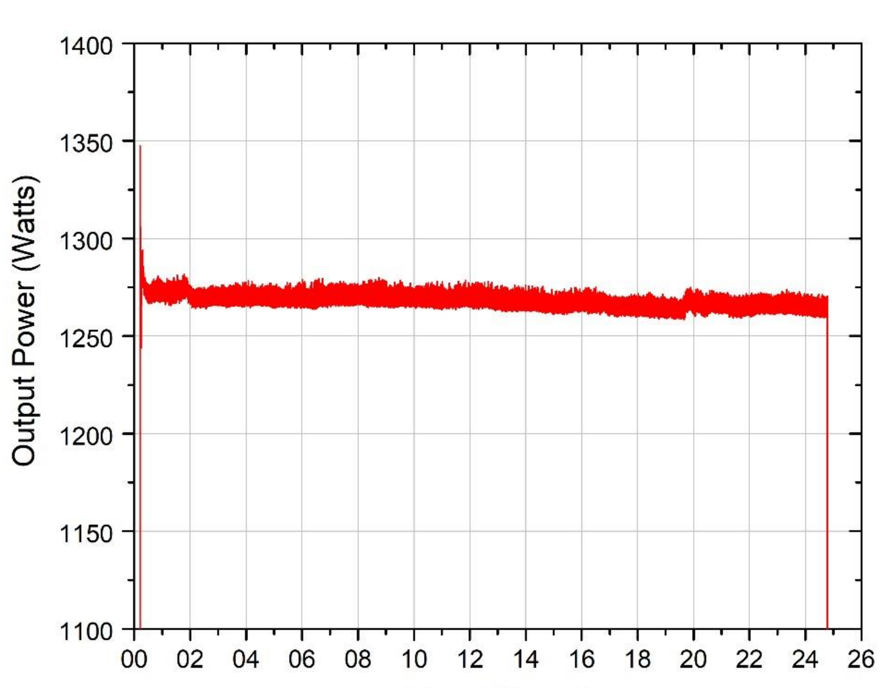

Figure 3. SPCA output power over 24-hour continuous operation.

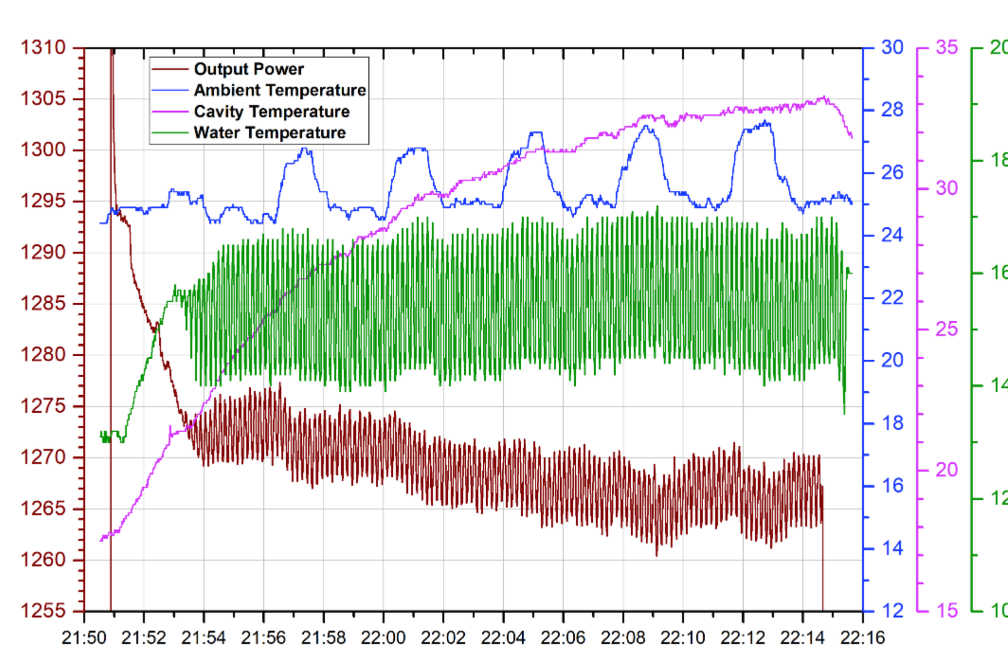

Figure 4. SPCA temperatures and corresponding output power.

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Publications:

[1] Velazco, J., Taylor, M. (2016). Spatial Power Combining Amplifier for Ground and Flight Applications. Int. Planetary Network Prog. Rep.
[2] Velazco, J., Samoska, L., Taylor, M., Pereira, A., Fung, A., Lin, R., & Peralta, A. (2019, June). Spatial power combiner using cavity modes in W-band. In 2019 IEEE MTT-S International Microwave Symposium (IMS) (pp. 991-994). IEEE.

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