National Aeronautics and Space Administration

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

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Program: FY22 R&TD Strategic Initiative
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 module (ASTRAM) operating at X-band frequency that can provide a reliable 4kW high output power with graceful degradation and ease of replacement to minimize radar down time (Fig. 1). 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 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 (Fig. 2). During the course of this effort we will combine four of these SPCA modules into a complete 4kW X-band transmitter 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.

Background:

Characterization of solar system bodies, particularly near-Earth objects (NEOs), has led to a number of high-profile scientific results and may be needed for assessing targets for future crewed missions; orbit determination is essential for robotic and crewed missions to near-Earth objects (NEOs) and for planetary defense. The Goldstone Solar System Radar (GSSR) plays a key role in tracking and identifying space targets at a lunar distance, and its use has a cross-cutting impact on NASA Directorates.

The GSSR transmitter output power is produced by combining two identical klystron amplifiers (vacuum tube amplifiers), each capable of delivering up to 250 kW, to produce a total of 450 kW of radiated power. The klystron tubes are custom devices which are available from a sole-source vendor, and have historically proven to have a limited lifetime due to degradation from the extreme power densities associated with the high-power electron beam. The focus on this Initiative is to develop an alternative technology to the current klystrons in an effort to make the GSSR more robust and less reliant on single point failures. The task expands upon several JPL technology development efforts in the past [1][2][3], in order to achieve high Rf power using solid-state components [4]-[11].

Approach and Results:

This year's effort has focused on the manufacture, assembly and testing of the various subsystems and components of the SPCA modules that will be combined into the 4kW transmitter system (Fig. 2, 3).

The bias board is necessary for biasing and balancing the output phase and amplitude of each MMIC device (Fig. 3). The bias boards are equipped with a microcontroller that allows real-time monitoring and control of critical variables such as bias current, output power, and temperature for each individual MMIC device in the transmitter via a software user interface. The software user interface was successfully completed and tested alongside testing of the bias boards.

The SPCA RF power splitters and combiners were manufactured, built and tested (Fig. 4.). The RF splitter is a 16-way integrated waveguide radial splitter built on substrate. Test results showed that the device performed well and as designed. The RF combiner is a low-loss 16-way spatial cavity combiner, and is a critical component for efficient combining of the MMIC output signals. We have tested an initial cavity, and are currently having a refined version manufactured prior to test.

In addition to the SPCAs, we manufactured, assembled and tested a low-loss 4-way radial spatial combiner and mode converter that will be used for combining the power outputs of each SPCA into a single high-power output signal. The mode converter converts the radial TM01 cavity mode to a TE11 mode for waveguide output coupling. S-parameter measurements through the combiner were evaluated across frequency range using a vector network analyzer (Fig. 5). Testing yielded a -28dB reflection loss coefficient, and an insertion loss of ~0.1dB through the cavity and mode converter, confirming the radial combiner is a very low-loss method for combining multiple high-power devices.

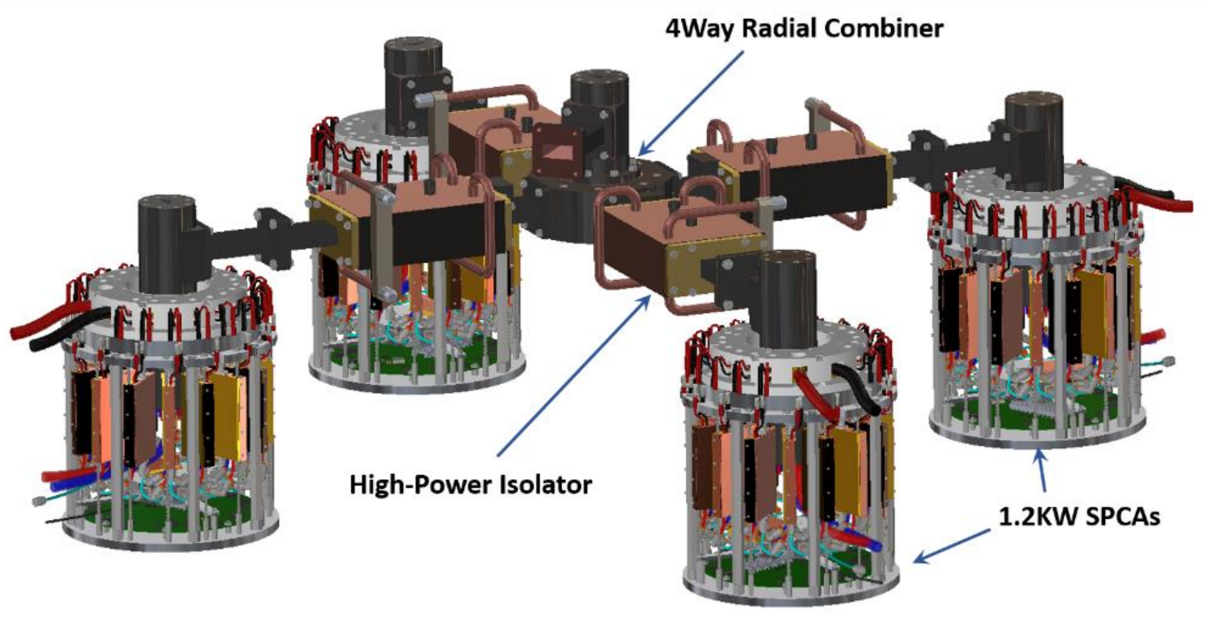

Figure 1. Four-kilowatt solid-state transmitter system.

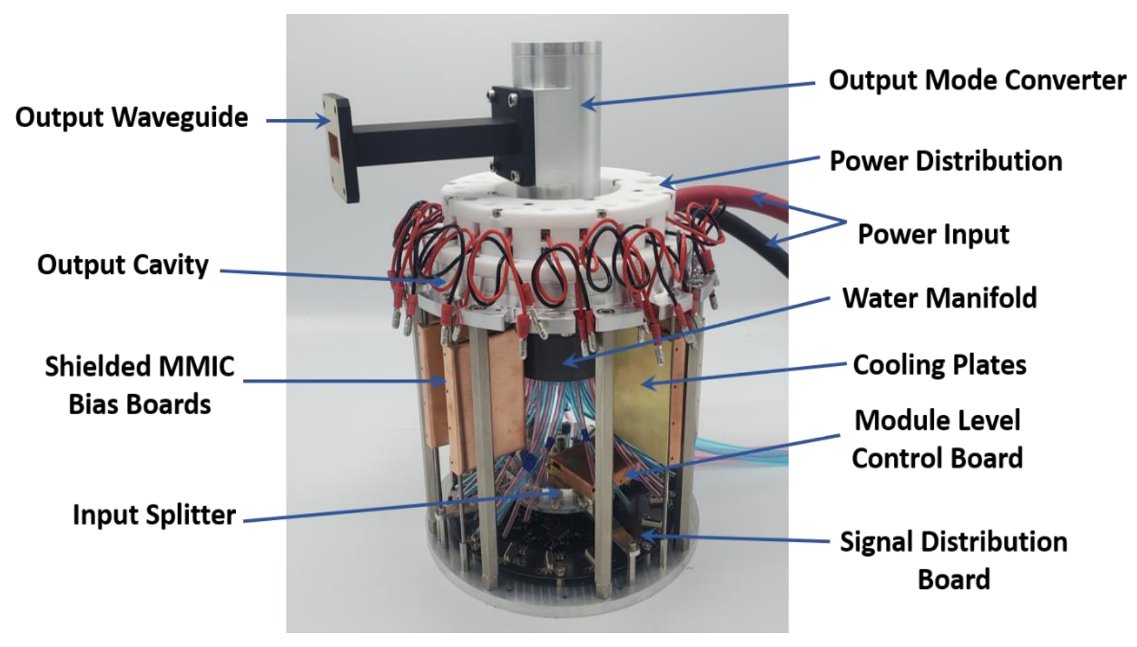

Figure 2. 1.2-Kilowatt Spatial Power Combining Amplifier (SPCA).

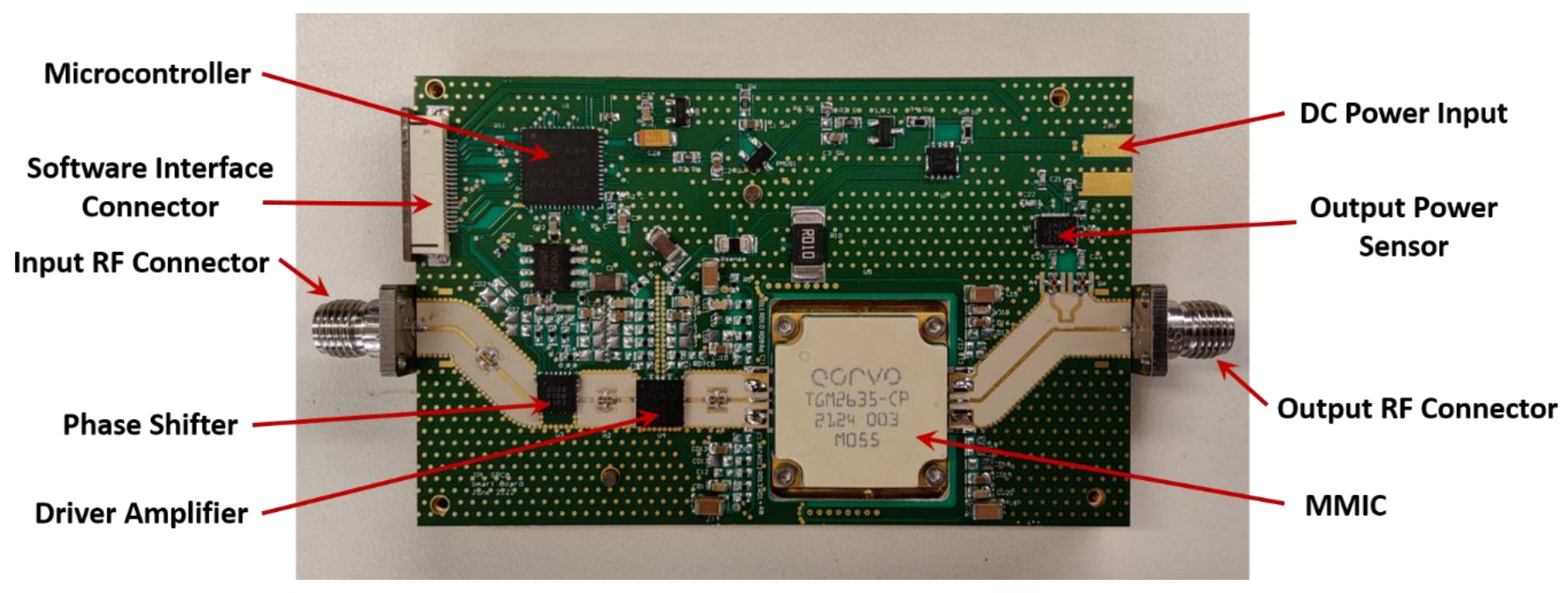

Figure 3. MMIC bias control board and components.

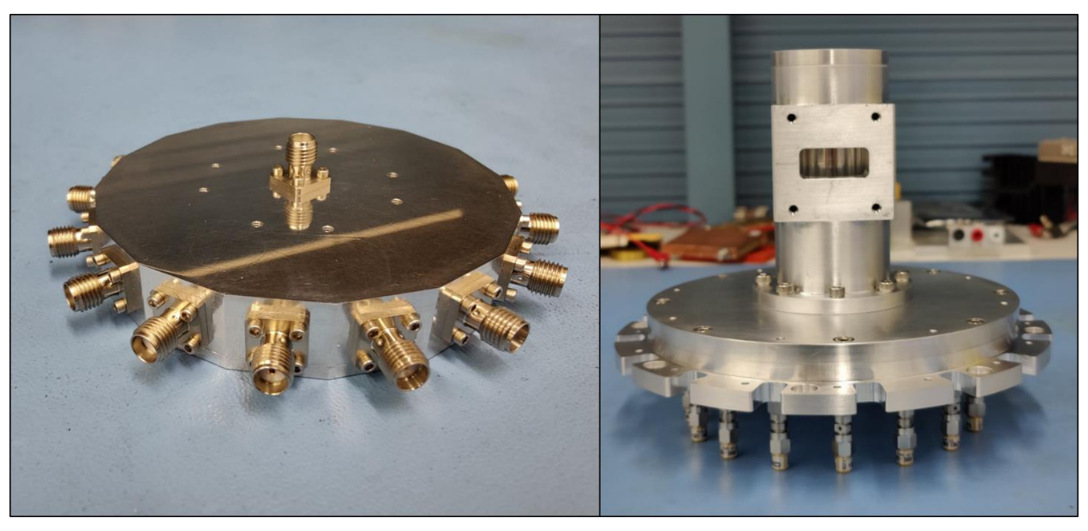

Figure 4. SPCA 16-way radial splitter (left) and cavity combiner (right).

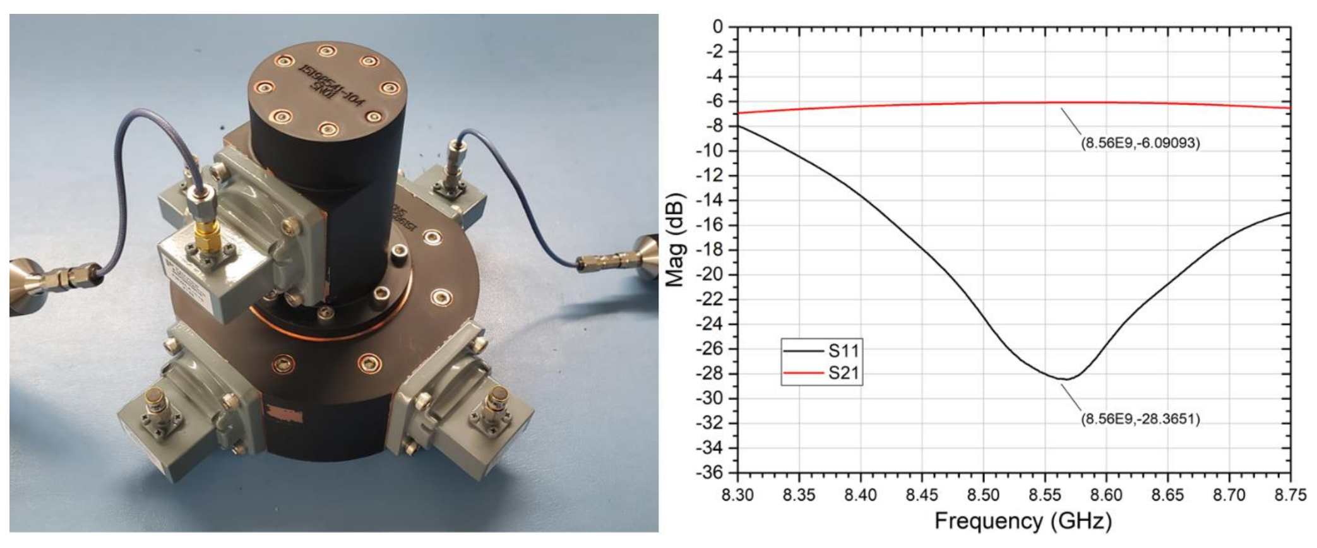

Figure 5. TXR level 4-way radial spatial power combiner.

Significance/Benefits to JPL and NASA:

The progress and results we have achieved thus far are a positive indication that combining multiple solid-state SPCAs for a 4kW total output will be achieved by the end of this effort. 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 matures and advances are made in output power and efficiency, these two areas of innovation when taken together are likely to lead to a new set of instruments that will significantly impact future ground and flight mission capabilities.

New Technology Reports (NTRs)

50016, Spatial Power Combining Mechanism (SPCM) for the Generation and Amplification of Electromagnetic Radiation
50641, Spatial Power Combining Amplifier (SPCA) for W-Band Radar in Earth and Planetary Science
50981, 6-Way Spatial Power combining Amplifier (SPCA) for W-Band Radar in Earth and Planetary Science

References

[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.
[3] Velazco, Jose E. "Spatial power combining mechanism (SPCM) for the generation and amplification of electromagnetic radiation." U.S. Patent No. 10,218,325. 26 Feb. 2019.
[4] Harp, R., & Stover, H. (1973, February). Power combining of X-band IMPATT circuit modules. In 1973 IEEE International Solid-State Circuits Conference. Digest of Technical Papers (Vol. 16, pp. 118-119). IEEE.
[5] Otake, Y., Judkins, J., & Schwarz, H. (1990). Cavity combiner for S-band solid-state amplifier for the high-power Klystron at SLAC. SLAC-Pub-5179.
[6] Pérez, F., Baricevic, B., Sanchez, P., Einfeld, D., Langlois, M., Buge, J. P., ... & TED, T. E. D. (2006, June). High power cavity combiner for RF amplifiers. In European Particle Accelerator Conf. EPAC06, Edinburgh, Scotland (pp. 3215-3217).
[7] Epp, L. W., Hoppe, D. J., Khan, A. R., & Stride, S. L. (2008). A high-power Ka-band (31–36 GHz) solid-state amplifier based on low-loss corporate waveguide combining. IEEE transactions on microwave theory and techniques, 56(8), 1899-1908.
[8] Schellenberg, J. (2015, May). The evolution of power combining techniques: From the 60s to today. In 2015 IEEE MTT-S International Microwave Symposium (pp. 1-4). IEEE.
[9] Brown, K. W., Gritters, D. M., & Kazemi, H. (2015, October). W-and G-band solid state power combining. In 2015 IEEE Compound Semiconductor Integrated Circuit Symposium (CSICS) (pp. 1-4). IEEE.
[10] Deo, N. (2018, March). Microwave and millimeter wave solid state power amplifiers for future space-based communications and radars. In 2018 IEEE Aerospace Conference (pp. 1-7). IEEE.
[11] MORIYOSHI, T., SHINBO, G., TSUJI, N., NAGAYAMA, S., DOUGUCHI, H., & IIDA, K. New Video Coding Technology Provides the Foundation for the Forthcoming Digital Transformation (DX) of the Broadcasting Industry.

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