National Aeronautics and Space Administration

Implementation of a Solid-State Amplifier Module for a 1 Megawatt Solid-State Solar System Radar

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Program: Strategic Initiative

Project Objective:

The Goldstone Solar System Radar (GSSR) is a state-of-the-art planetary radar used by NASA to track spacecraft and near-earth asteroids. This effort seeks to develop a new generation of transmitters for the GSSR that is based on mature and reliable solid-state technology. The proposed concept should deliver 1kW of power at X-band (8.56GHz) and is based on the clever power combining of amplifiers in a module that we refer to as spatial power combining amplifiers (SPCA). The proposed SPCA is an amplifier in which the output power of 16 solid-state monolithic microwave integrated circuit (MMIC) amplifiers is spatially combined to produce 1kW of power (Figure 1). The SPCAs are modular, and could be further combined for eventual implementation into a much larger radar transmitter system. The proposed SPCA, with the use of reliable solid state amplifiers and clever power combining approach, would greatly improve reliability and reduce the downtime required for repairs to the GSSR.

Figure 1. 1kW SPCA final version.

FY19 Results:

The SPCA module utilizes 80W monolithic microwave integrated circuit (MMIC) power amplifiers. The SPCA splits an input signal evenly among each MMIC amplifier using an input splitter, and recombines the amplified signal spatially within a microwave cavity using a resonant cavity mode. The SPCAs, being modular, can be further combined into larger "units" using a waveguide combiner. During this reporting period two separate prototypes were developed as a strategic path to achieving a full 1kW SPCA module. The first prototype was built specifically to achieve the desired 1kW output power, without concern for optimization of other features of the system. The second prototype was developed as a final field deliverable model.

a. The first prototype (Fig. 2) was successful in achieving the desired 1kW output power. It was designed specifically to test output power and combining efficiency. It requires manual device biasing using external circuit boards and biasing controls, and is time consuming to set up and operate. It uses 16x 80W MMICs to achieve the 1kW output power. The input power was split among the 16 MMICs using two external commercial 8way splitters in parallel. One issue that was recognized during testing was a lack of stable output power due to heating of the output coupling coax. The device could only be operated for ~30 seconds at a time to avoid runaway heating and power drop. This problem was addressed in the final deliverable prototype model.

b. After the power combining was sufficiently demonstrated with the initial prototype, a number of significant design changes were implemented to optimize size, weight, and performance, and address operational issues. This culminated in a final field deliverable version of the 1kW SPCA (Fig. 3).

The final version of the SPCA was made more compact to minimize its size; the diameter was reduced from 12in. to 6in. from the previous version. The cooling manifolds and power distribution were reduced in size and are located within the center of the device to better utilize space. A 16way radial input splitter was designed separately (Fig. 4) to be incorporated as part of the module, replacing the large external splitters. The manual MMIC bias boards were replaced with digital "smartboards" (Fig. 5), which allow real-time monitoring and control of each MMIC board from a central CPU. This provides the ability to control output phase and amplitude to balance the outputs between each device and achieve optimal power combining and efficiency. All aspects of the amplifier are controlled from a computer via a user interface. The output stability and heating issues from the previous version were mitigated by replacing the output coax cable with an air core coaxial waveguide.

Testing of the final SPCA version was successful. A stable, continuous output power of ~1.13kW at 8.56 GHz was measured. Figure 6 shows the measured output power curve for the module. The amplifier was operated at saturation for ~25 minutes continuously and demonstrated stable output power for the entire duration, confirming that the air core coaxial waveguide successfully mitigated the heating and output power stability issue. By comparing the expected gain based on measured cavity s-parameters with the measured gain with devices included, we determined that the combining efficiency is ~90%. A comparison of the output RF power to the supplied DC power yields an overall module efficiency of 26.6%. This is primarily driven by the device efficiency (29%), and could be improved in the future by replacing the current MMICs with higher efficiency devices. The measured 1dB bandwidth is ~180MHz, shown in Figure 7.

Significance of results:

This effort has succeeded in developing a 1kW digitally controlled solid-state SPCA module, and demonstrates a potential game-changing technology for future transmitter development and possible replacement of the non reliable klystron tubes. Next steps and future effort will be pursued for the purpose of further combining SPCA modules to produce much higher powers for an implementable solar system radar transmitter system. The results achieved here are very promising towards this end. We have demonstrated an effective spatial technique of overcoming the power combining limits associated with traditional substrate combining.

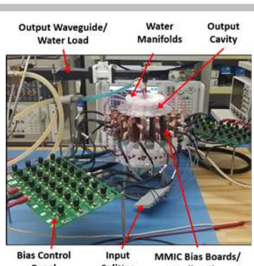

Figure 2. Initial 1kW SPCA prototype.

f_c	8.56	GHz
V_{dc}	28.0	V
I_{dc}	152.7	A
P_{dc}	4275.6	W
P_{mmic}	75.0	W
P_{in}	1.34	W
P_{out}Meas	1130	W
P_{out}Ideal	1200.0	W
$\eta_{combining}$	90	%
η_{spca}	26.6	%
Gain	29	dB

Figure 3. Final digital 1kW SPCA.

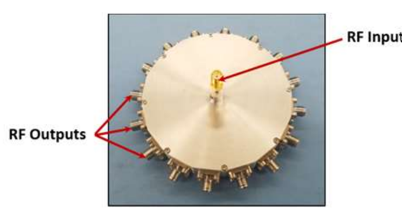

Figure 4. Radial 16-way SPCA input splitter.

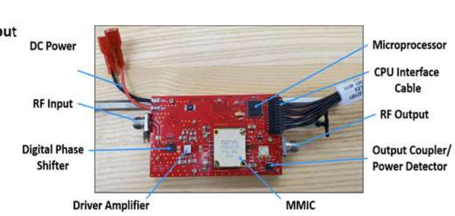

Figure 5. Digital smartboards used for MMIC.

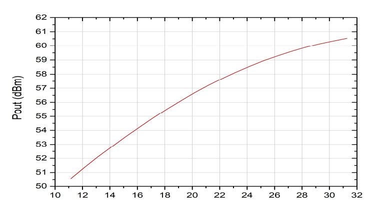

Figure 6. SPCA power curve plot.

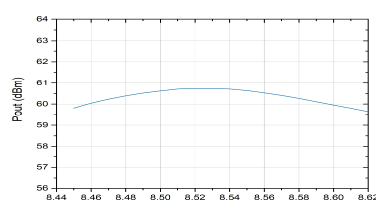

Figure 7. SPCA bandwidth plot.

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