FY24 Strategic Initiatives Research and Technology Development (SRTD)

Low Power Radio Technologies for Enabling Mars SmallSat Radio Occultation Missions

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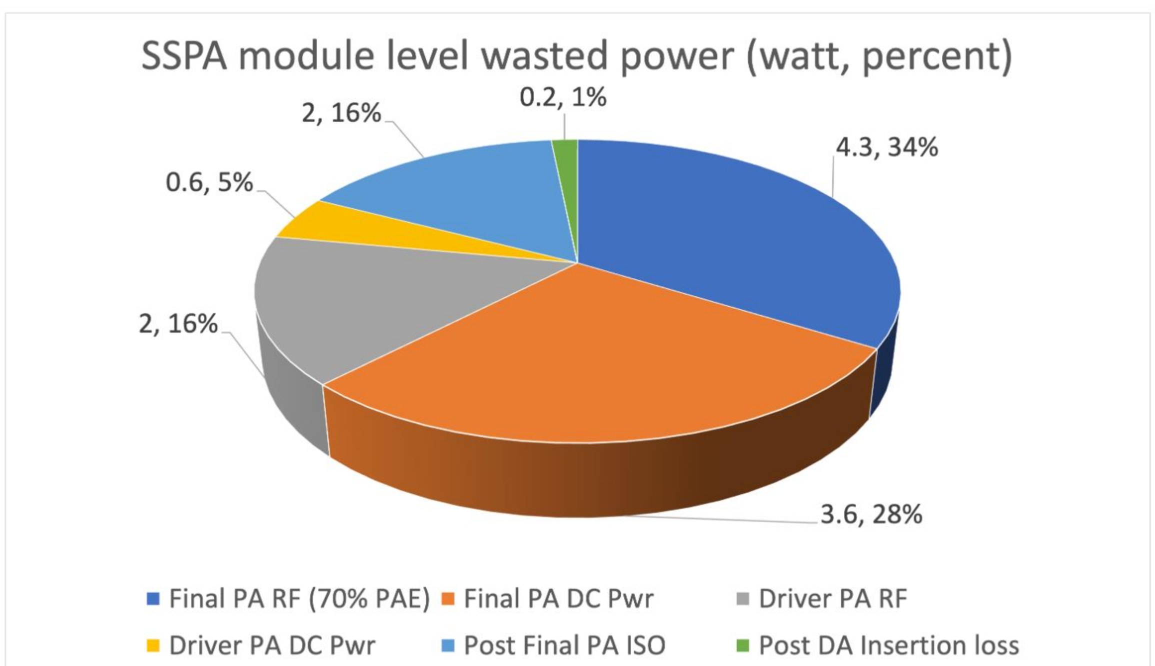
Strategic Focus Area: Radio and Gravity Science **|** **Strategic Initiative Leader:** Sami W Asmar

OBJECTIVES

This proposal aims to significantly improve the power efficiency and reduce the power consumption of the telecommunication system, which is used as a radio science instrument. The power saving will reduce the mass and size of the solar panel, heat dissipation, and power system, and lower the cost of the overall mission, which can be proposed as a shared ride with other large missions. Alternatively, a higher X-band power from the transponder without significantly increasing the overall power consumption is also beneficial to providing margin for orbital design, instrument lifetime, reliability screening of electronic components, etc. The proposed effort will also benefit Venus and enable outer planet missions with radio occultation measurements using small spacecraft. In addition, the high temporal and spatial resolution radio occultation measurements near the Mars surface may benefit weather forecasting for human exploration on Mars in the far future.



Assumptions:
1. Final PA output 10watt w/ 70% PAE, 15dB gain mmic
2. Driver Amp (DA) using high efficient COTS
3. DC-DC converter efficiency using space qualified (80%)

Fig.1 Wasted power analysis for a typical SSPA module

BACKGROUND

The concept of spacecraft-DSN radio science links has been extended to spacecraft-spacecraft links (e.g., GRACE, GRAIL, GRACE-FO), and the advent of small spacecraft (notably Mars Cubesat One [MarCO]) has opened up new mission possibilities, such as atmospheric studies involving radio occultations that are analogs of the COSMIC mission or determining the interior structure of bodies via their gravity fields. The recent Mars Exploration Program Analysis Group (MEPAG) 2020 document[MEPAG2020a] has set a high priority to "characterize the dynamics, thermal structure, and distributions of dust, water, and dioxide in the lower atmosphere", and a medium priority to "characterize the state and controlling processes of the upper atmosphere and magnetosphere". Inter-spacecraft cross-links can provide full temperature and pressure profiles from 0-20 km altitude in dust-laden environments inferred from the radio occultation measurements [Ao2007]. A constellation of two or more small spacecraft orbiting Mars provides dense occurrences of radio occultations offering improved temporal and spatial resolutions than previously achievable [Moeller2021]. Such a mission may fit into a small mission with a cost of <$200M. Radio science is carried out via the spacecraft's telecommunication system, in which the SSPA dominates the power consumption in small spacecraft.

REFERENCES

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[MEPAG2020a] "Mars Science Goals, Objectives, Investigations, and Priorities: 2020 Version", Goal II, Objective A, Sub-Objective A1, A4.
[Moeller2021] Moeller, Gregor, Chi O. Ao, and Anthony J. Mannucci. *Radio Science* 56.7 (2021): 1-10.

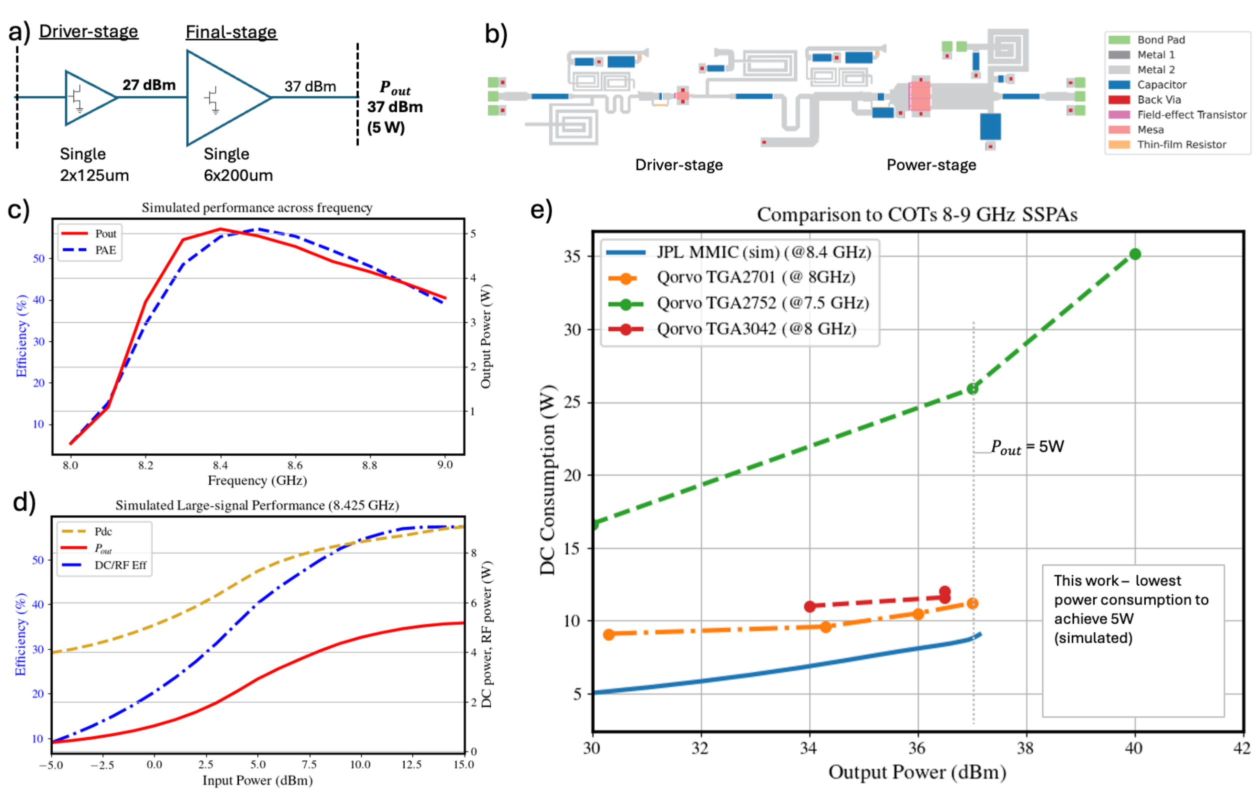

Fig.2 a). Diagram of Driver-stage and Final-stage in the MMIC. b). MMIC design of a) using WIN 250nm model (pre-Aug 2024), c). Simulated output power and efficiency of the designed MMIC across frequency. d) Simulated DC and RF power and efficiency across different input power of the designed MMIC. e), comparison of this work with COTS SSPAs.

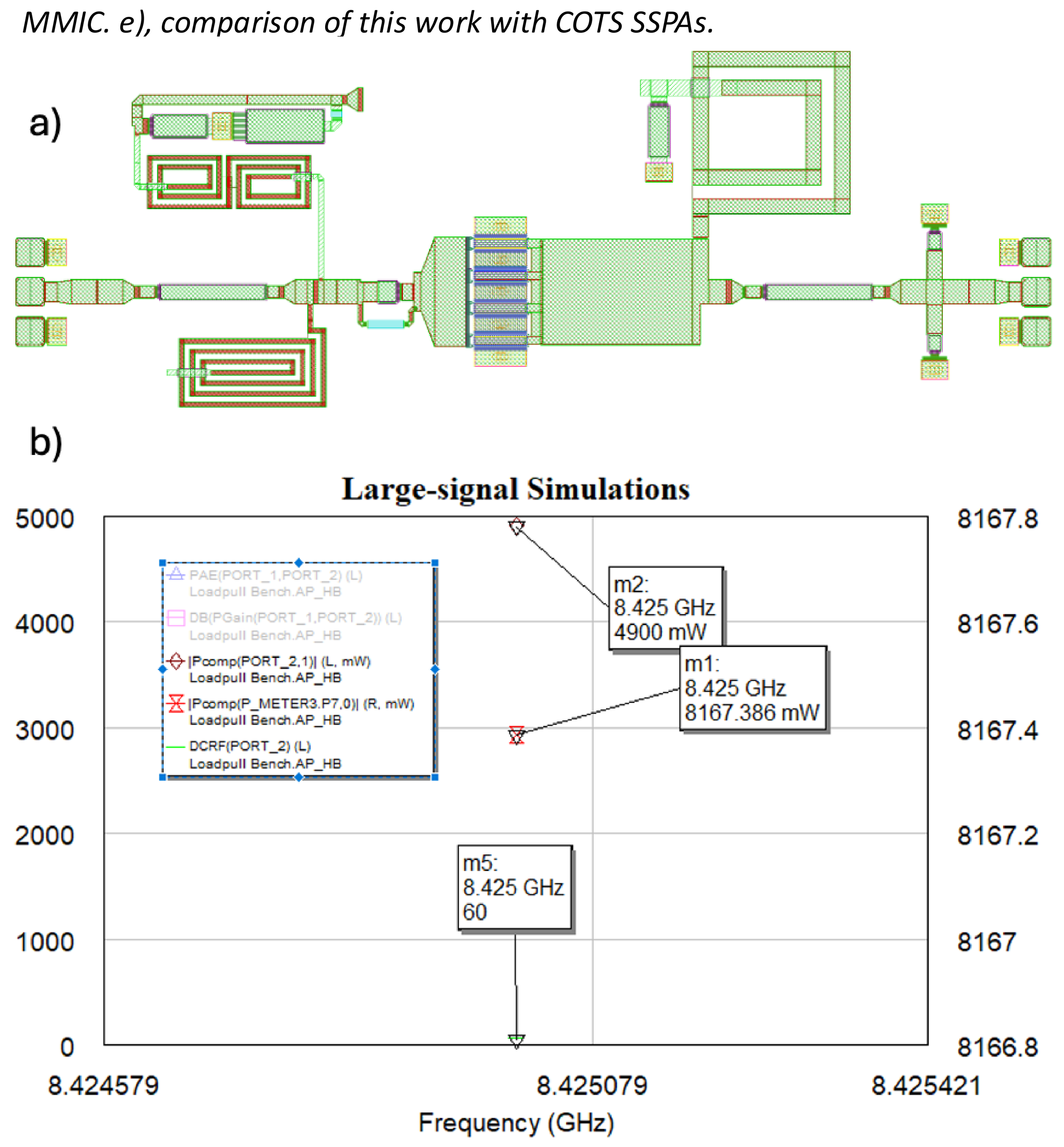

Fig.3 a). Preliminary retuned 5W design after model updates (Aug 2024), b). Preliminary large-signal simulation

APPROACH AND FIRST 6 MONTHS PROGRESS

The team analyzed models of high-frequency transistors across every major GaN foundry to determine a manufacturable GaN-on-SiC process that would lead to an 8.4-8.5GHz MMIC SSPA with the lowest DC power consumption for a target output power of 5-10W. After additionally considering costs, risks, and lead time, the team identified WIN Semiconductors' 250nm GaN-on-SiC as the most promising pathway forward. The team formulated an architecture for a 10-W SSPA module, informed by architectures previously used for flight transmitters and using COTS components for driver stages, power electronics, and necessary passives such as isolators. A module-level analysis of power consumption across the proposed transmitter confirmed the need for a custom-designed final stage to keep DC consumption under 40W for a 10W transmitter - an analysis that, in turn, informed the design of the MMIC. The team then designed a 5-W MMIC SSPA with a simulated efficiency of 70%, which included designing on-chip networks to ensure stability, low-loss bias networks with a high degree of DC-RF isolation in the band of interest, harmonic resonators for improved efficiency, and low loss matching networks. The "Opportunity" wafer run which was originally budgeted in FY24 in the format of sharing with other customers, is descoped to avoid a large procurement during FY24's budget uncertainties. The procurement relevant was instead diverted to designing a driver stage on the same chip as the final stage. The on-chip driver stage design is partially finished. The above pivotal effort in FY24 is to prepare a mandatory single-customer wafer-run which was budgeted in early FY25. We descope to a 5W-only module due to the FY24 budget cut.

We have analyzed the wasted power of different portions in a typical SSPA module. As shown in Fig.1, assuming the final stage of the SSPA has an efficiency of 70%, we have identified the top three biggest portions that are important to improve the efficiency: A) MMIC efficiency of the last stage SSPA; B) The DC-DC voltage supplier for the last stage PA, and C) The efficiency of driver SSPA (driving the last stage of SSPa). The first-year effort focused on these three areas. As shown in Fig.2, we used the foundry's model (pre-Aug 2024) and designed a combined Driver Stage + PA Stage MMIC at a 5-watt output level with a last stage efficiency of 68%, and an overall efficiency of >50%. In Aug 2024, the foundry released an updated model and we updated our design preliminarily to reach an efficiency of 60% for the last stage of the efficiency, as shown in Fig.3. Finally we designed the SSPA module in Fig.4. Notably, we specifically designed a DC-DC voltage supplying circuit with 89% efficiency with a critical voltages switch-on/off sequence required by the GaN MMICs.

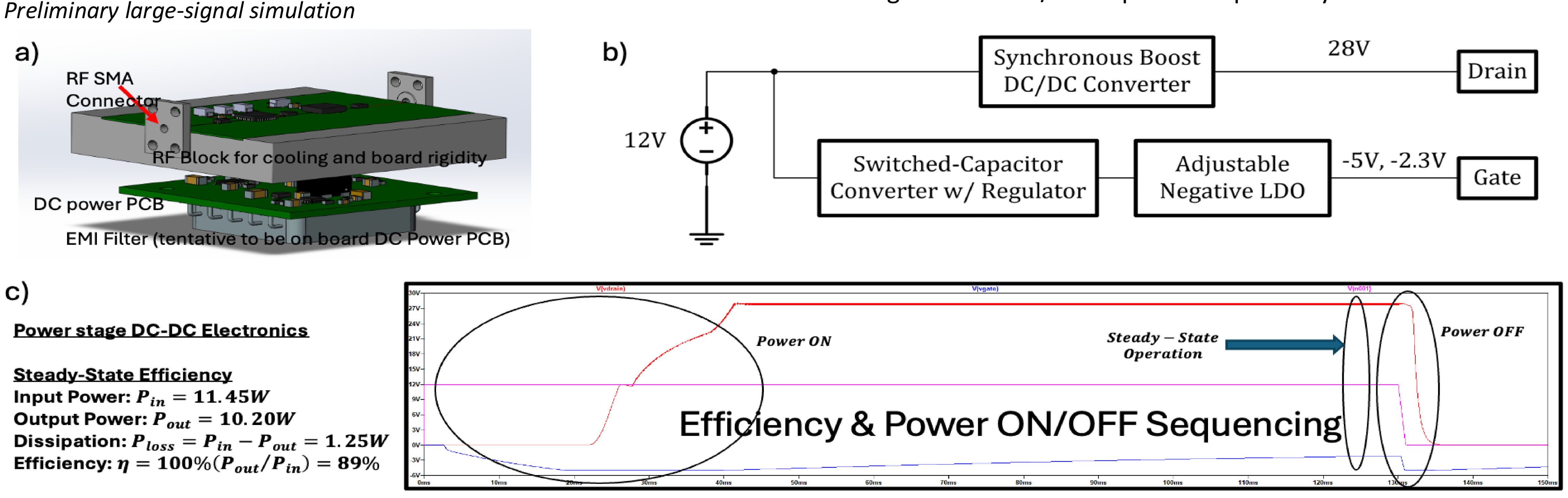

Fig.4 a). Overall module design including RF board, DC-DC power board(s), filter and connectors. b). Power stage DC-DC electronic diagram. c) Simulated performance of the power stage DC-DC electronics and on/off sequencing design for GaN-based SSPAs.

SIGNIFICANCE OF RESULTS/BENEFITS TO NASA/JPL

We plan to elevate the TRL from 5 to 6 or 7 by proposing the new generation of SSPA module and the modified radio transponder to NASA STMD's "NASA Internal Payloads" flight opportunities, "TechFlights" or "Flight Opportunities for SBIR/STTR Post Phase II" (via existing JPL-SDL collaborative effort) and Small Spacecraft Program in the timeframe of FY27-FY29. We plan to infuse the low-power radio occultation technology into a Mars-bound, low-cost, small spacecraft constellation mission proposal in the ~$200M cost category (i.e., M-class program). The opportunity timeframe, according to the 2023 MEPAG April meeting, is in the 2030s (M1 in 2031 and M2 in 2035). Given the current uncertainty of this "hypothetical" M-class program, seeking other low-cost missions of opportunities that may favor using smallsats is necessary.

Publications:
Lin Yi et al., "**Low Power Radio Technologies Enabling Mars SmallSat Radio Occultation Missions**", submitted to AGU Fall Meeting 2024.

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