# Development of small profile Doppler radar for laboratory studies of asteroids.

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## BACKGROUND

Planetary radar observations are invaluable for post-discovery characterization of near-Earth objects (NEOs) by providing precise line-of-sight astrometry, direct measurement of size and binarity, and information on surface geology, composition, density, spin, and 3-D shape. Both ground- and space-based radar observations have enabled the surface exploration of planetary bodies, such as Mars (e.g., [1]), and the search for hidden volatile resources essential for in-situ resource utilization (ISRU), such as ice in permanently shadowed lunar craters (e.g., [2]). Several phenomena have been discovered via radar, including a potential relationship between polarization and asteroid taxonomy [3] and coherent backscatter from ices [4]; however, insights into such phenomena have largely relied on models [5,6], which are not well constrained due to the deficit of laboratory measurements. Therefore there exists an available niche for laboratory studies of radar scattering processes.

In order to enable higher order characterization of NEOs and other planetary surfaces via improved understanding of radar scattering processes, this project aims to design and build a small profile and relatively low cost radar system capable of measuring circular polarization ratio ($\mu_c$), radar albedo ($\hat{\sigma}_o$), and other radar measured properties in a controlled laboratory environment. By providing a better understanding of radar scattering processes, this effort would help improve existing models via improved inferences from ground-based radio telescopes like the Arecibo Observatory.

## METHODS

- Modified existing radar designs (e.g. Infineon's *Distance2Go* and *Position2Go* Evaluation Boards).
- Designed and optimized microwave passive components with *Keysight Advanced Design System* (ADS).
- Implemented a distributed maximally flat Butterworth filter with a cutoff frequency of 24.125 GHz to prevent harmonics from affecting our signal of interest.
- Designed and optimized the antenna with *Ansys High Frequency Structure Simulator* (HFSS)
- Designed printed circuit board (PCB) using *Cadence OrCAD CIS* and *Allegro PCB Designer*.

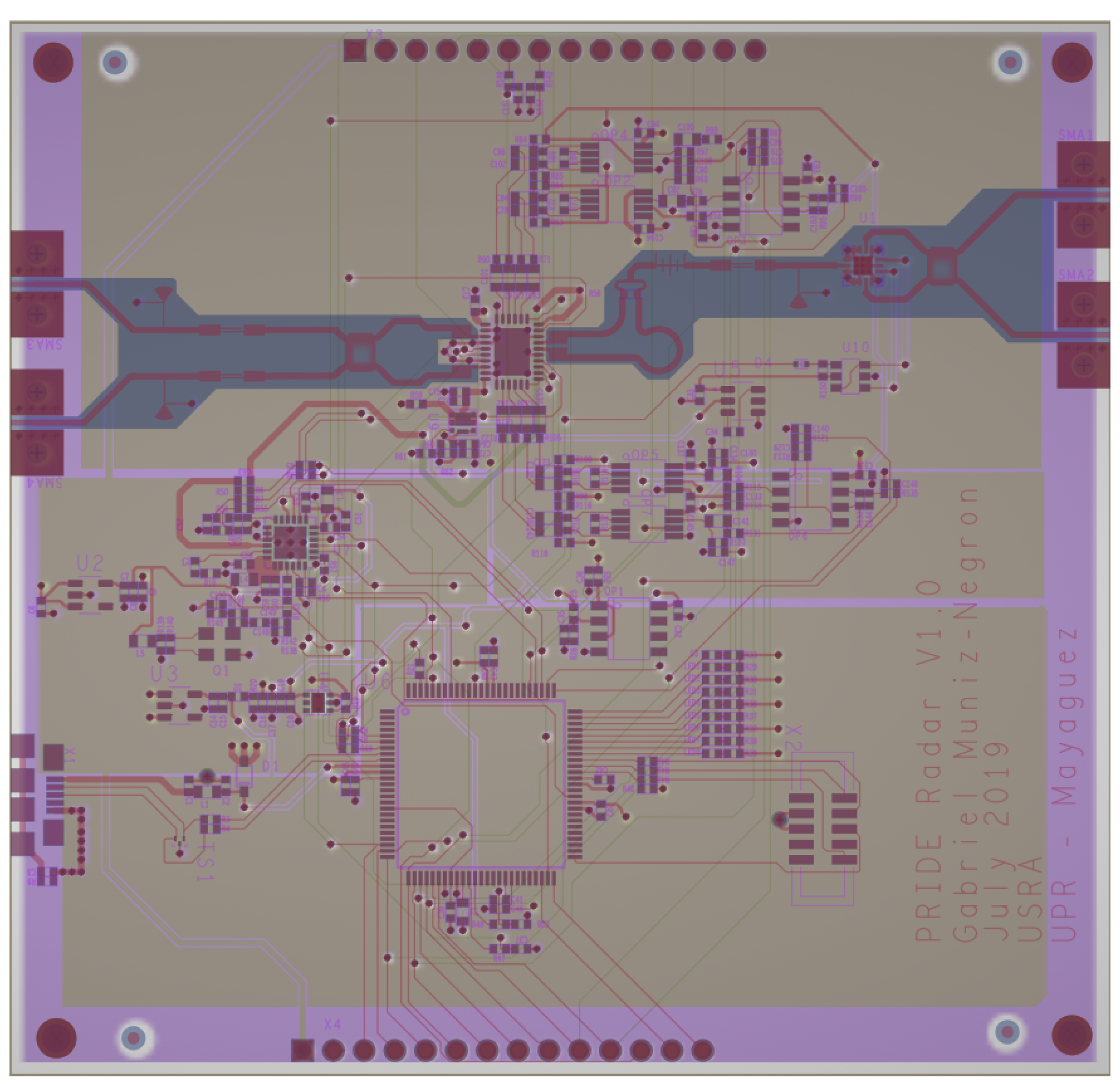


Fig. 1: Final Board Layout

## RESULTS

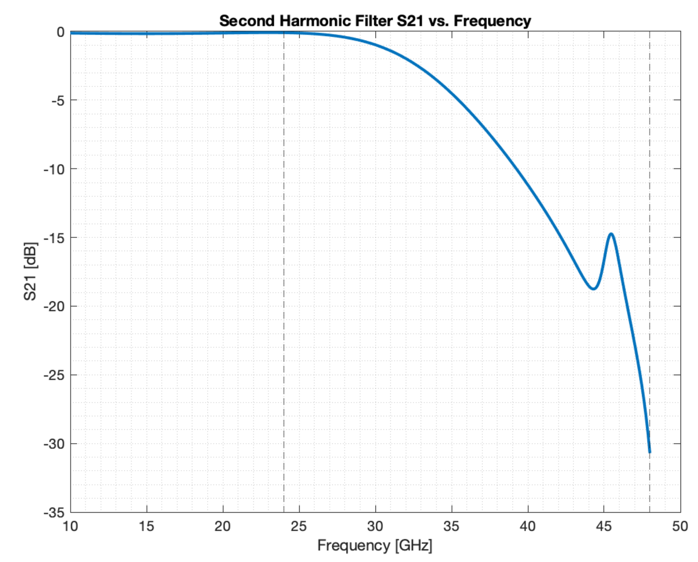


Fig. 2: Second Harmonic Filter Frequency Response

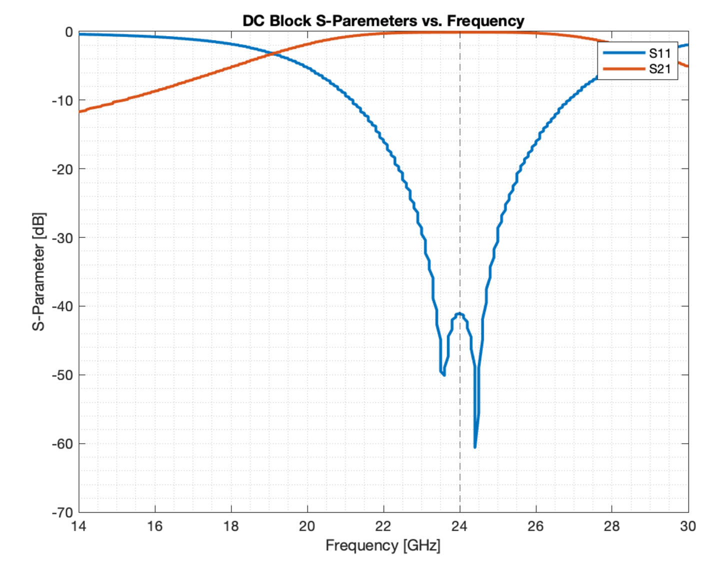


Fig. 3: DC Block S-Parameteres

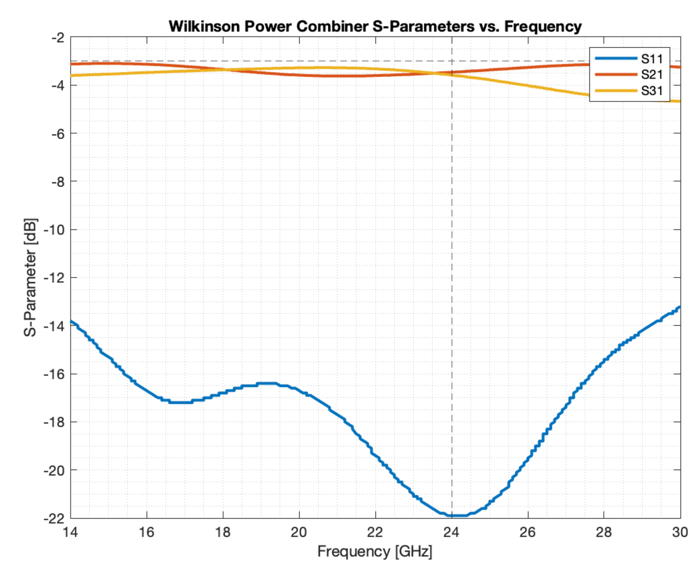


Fig. 4: Wilkinson Power Combiner S-Params

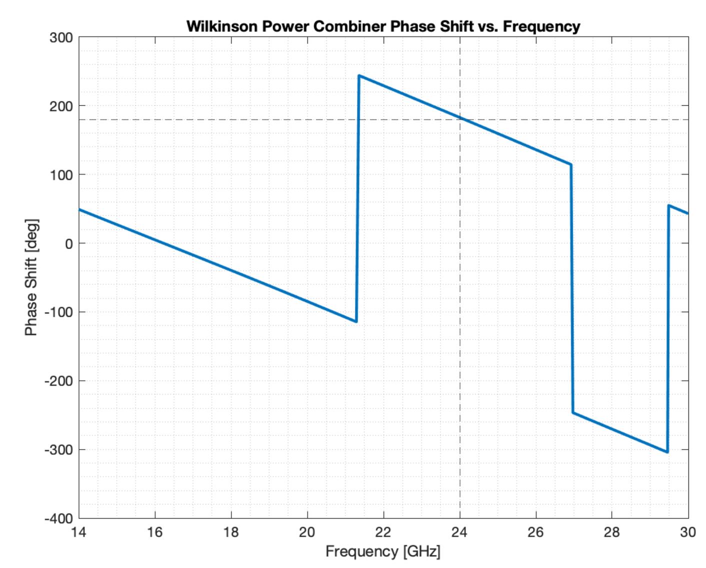


Fig. 5: Wilkinson Power Combiner Phase Shift

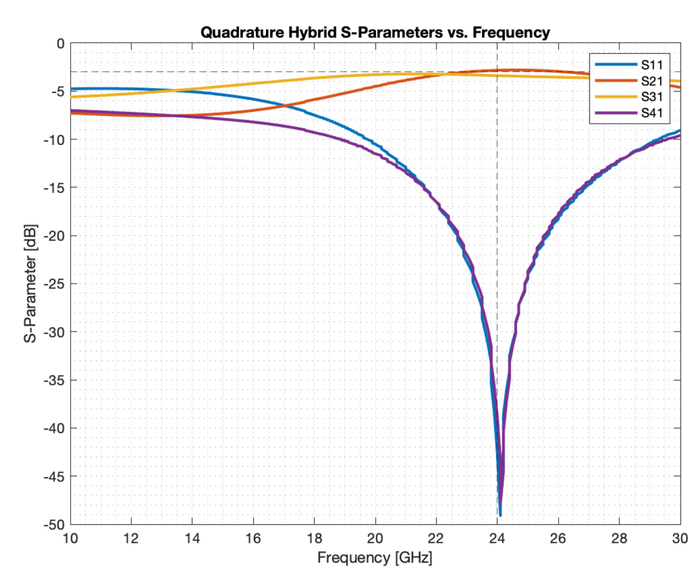


Fig. 6: Quadrature Hybrid S-Parameters

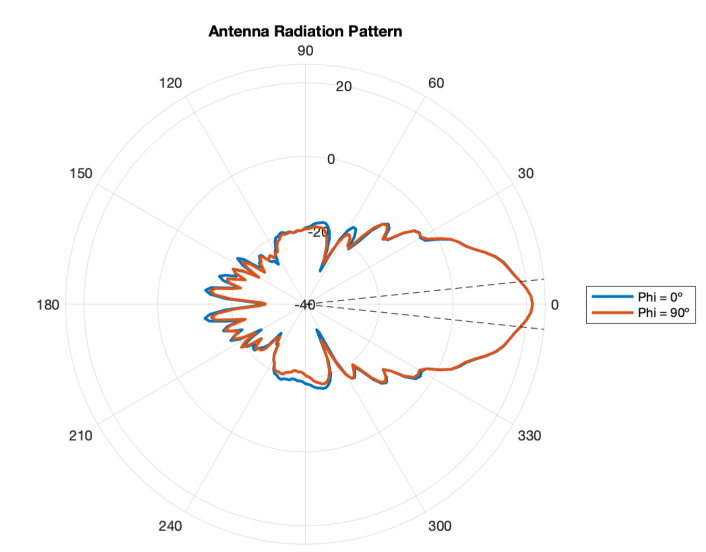


Fig. 7: Antenna Gain (Polar Form)

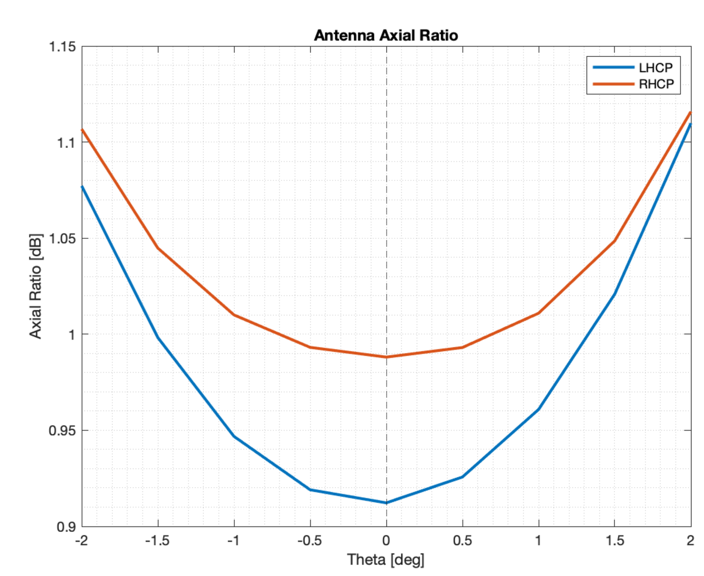


Fig. 8: Antenna Axial Ratio for Both Polarizations

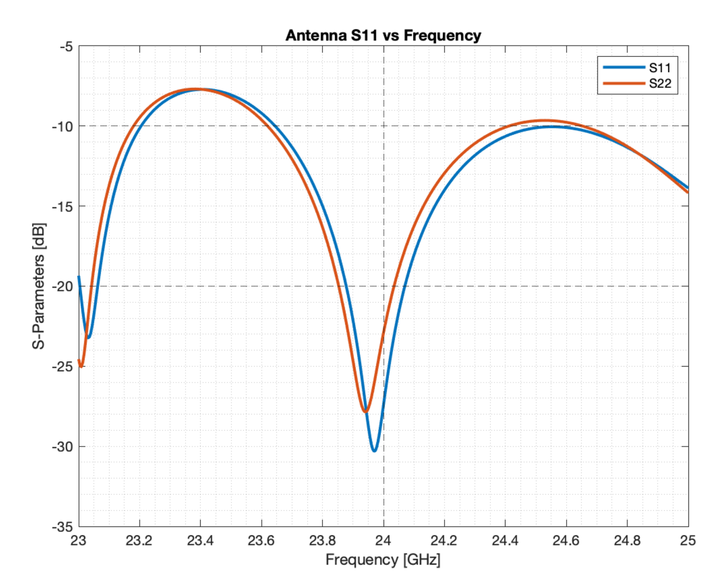


Fig. 9: Antenna $S_{11}$ and $S_{22}$ (Rectangular Form)

## DISCUSSION

- **Second Harmonic Filter**: The filter's frequency response (Figure 2) shows great attenuation ($\sim$ -30 dB) at the second harmonic frequency (48 GHz) meaning it effectively eliminates harmonic pollution.
- **DC Block**: Low $S_{11}$ and high $S_{21}$ (Figure 3) indicate our component does not attenuate our signal of interest (24 GHz) while still acting as an open circuit at DC (0 Hz).
- **Wilkinson Power Combiner**: Low reflection coefficients and high transmission coefficients to port 1 (Figure 4) indicate low losses in our component and proper differential signal merging after considering the $\sim 180^{o}$ phase shift between ports 2 and 3 (Figure 5).
- **Quadrature Hybrid**: With low reflection coefficients ($S_{11}$ and $S_{44}$) and high transmission coefficients ($S_{21}$ and $S_{31}$) (Figure 6), our quadrature hybrid presents great port isolation and proper power division at all ports.
- **Antenna**: With a $12^{o}$ half-power beamwidth (Figure 7), an axial ratio below 1 dB for both polarizations (Figure 8), and reflection coefficients ($S_{11}$ and $S_{22}$) below -20 dB (Figure 9), the antenna greatly exceeds our requirements and expectations.

## FUTURE WORKS

1. Do in-depth testing on the PCB, microwave components, and antenna to ensure hardware's proper operation and calibrate the system.
2. Program the on-board microcontroller using Infineon's *Digital Application Virtual Engineer* (DAVE$^{TM}$).
3. Test final system under a controlled environment with known targets.
4. Zap some rocks!

## ACKNOWLEDGMENTS

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## REFERENCES

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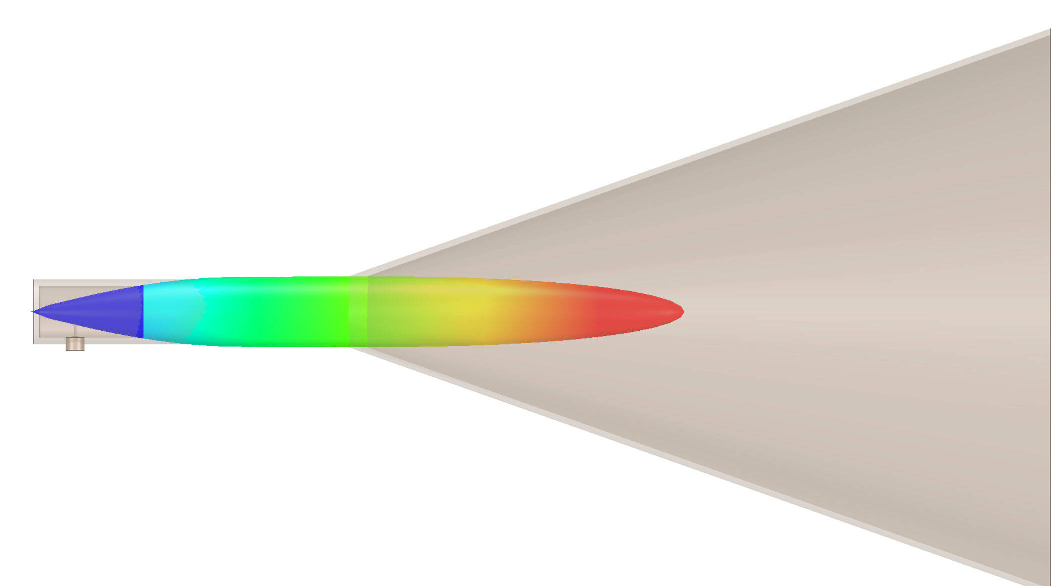

Fig. 10: Antenna Model with Radiation Pattern Overlay