DEVELOPMENT OF A SMALL PROFILE DOPPLER RADAR FOR LABORATORY STUDIES OF ASTEROIDS.

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Introduction: 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 enhanced 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 (μ_c), radar albedo ($\hat{\sigma_o}$), and other radar properties in a controlled laboratory environment. By providing a better understanding of radar scattering processes, this effort would help improve existing models and techniques derived from inferences from ground-based radio telescopes like the Arecibo Observatory.

Proposed Solution: In order to expedite the design process, similar existing radar systems, specifically Infineon's Distance2Go and Position2Go evaluation boards, were considered as low-cost viable alternatives. Since these two radar systems are widely applied in the automotive industry, their high-frequency electronic components are mass produced and highly accessible, and offer ideal capabilities and performance. Furthermore, due to their extensive use in industry, vast amount of signal processing software and libraries are readily available which provide intuitive user interfaces. However, since these two systems only operate at one polarization at a time and have embedded phased-array patch antennas, a new more modular design had to be made to accommodate dual-polarization operation and independent, higher-gain antennas.

Methods: *Keysight Advanced Design System* (ADS) was used for the design and optimization of all microwave components. To prevent signal contamination, a maximally flat Butterworth filter with a cutoff frequency of 24.125 GHz was implemented using distributed components; moreover, a coupled line filter was implemented as a DC Block to prevent any DC signal component from contaminating our signal of interest at 24 GHz. A Wilkinson Power Combiner was used to merge the differential outputs of an Infineon BGT24MTR12 into a single-ended output. To ensure proper mixing, the input lines for the power combiner were designed to have a 180° phase shift and the component itself was optimized to minimize reflections and maximize transmission. Lastly, a quadrature hybrid was designed and optimized to ensure high isolation and transmission coefficients.

The antennas were designed and optimized using the *High Frequency Structure Simulator* (HFSS) tool of *ANSYS Electronics Desktop*. In order to comply with specifications, a dual-feed conical horn antenna was optimized to achieve minimal reflection coefficients (S_{11} and S_{22}), high gain and low axial ratio (below 3 dB) at $\theta = 0°$ and $f_0 = 24$ GHz. For simulation purposes, the ports were given excitations of equal magnitude with a 90° phase difference, the polarization sense was charged by changing the phase shift from 90° to $-90°$.

For the circuit design, *Cadence OrCAD Capture CIS* was used for the schematics alongside *Allegro PCB Editor* for the printed circuit board (PCB). The design was based mainly on a modified version of Infineon's Distance2Go and Position2Go evaluation boards and implemented in the PCB using the previously designed microwave components to guarantee minimal losses during operation. In order to keep a small profile, different layers were added to the PCB including: one top layer with all the components, all microwave connections, and some digital signal connections; one power layer for a ground plane; one power layer with all V_{cc} connections; and one bottom layer for all remaining digital connections.

Results: After simulating and optimizing the microwave components and the antennas, the following parameters were found.

Second harmonic filter. See Table 1

	24.15 GHz	**48 GHz**
$\mathbf{T}_{\text{dB}}$	-0.092 dB	-30.708 dB

Table 1: Transmission coefficients for the Second harmonic filter

DC Block. To ensure the DC block operated at the desired design frequency of 24.125 GHz, we plotted the S_{11} parameter in Smith Chart format (See Figure 1).

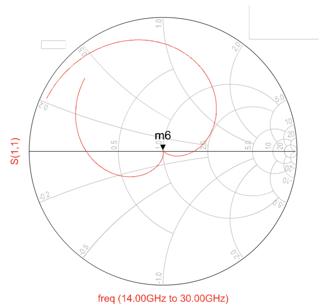

Figure 1: S_{11} parameters for DC-Block from 14 GHz to 30 GHz

Wilkinson power combiner. After optimizing for the phase shift, we obtained a phase shift of 180.016° and the scattering parameters summarized in Table 2

$\mathbf{S_{11}}$	$\mathbf{S_{21}}$	$\mathbf{S_{31}}$
-21.917 dB	-3.454 dB	-3.605 dB

Table 2: S-parameters of interest for Wilkinson power combiner at 24.125 GHz

Quadrature hybrid. For the quadrature hybrid, we were mainly interested in the reflection coefficient S_{11} and transmission coefficients S_{21}, S_{31}, and S_{41}. At the design frequency of 24.125 GHz, we got the S-parameters in Table 3

$\mathbf{S_{11}}$	$\mathbf{S_{21}}$	$\mathbf{S_{31}}$	$\mathbf{S_{41}}$
-47.096 dB	-2.817 dB	-3.397 dB	-47.794 dB

Table 3: S parameters of interest for quadrature hybrid at 24.125 GHz.

Antenna. As of December 2019, the optimal beamwidth obtained for the antenna was approximately 42° with a corresponding insertion loss ($S_{11,\,\mathrm{dB}}$) of -25.17 dB and an axial ratio of 24.42 dB.

Discussion: For the microwave components, we focused on their scattering parameters at the frequencies of interest. In the case of the second harmonic filter we required, and achieved, an S_{21} as close to 0 dB as possible at 24 GHz and well below -20 dB at 48 GHz.

For the DC block, the S_{11} is of special interest; to ensure minimal losses, we require it to be as low as possible and, from Figure 1, we can see its magnitude is essentially 0 at the design frequency of 24.125 GHz. The closeness of the S_{11} to the center of the Smith Chart also indicates that the input impedance of the component is practically 50 Ω meaning almost no parasitic effects are taking place in the component.

For the Wilkinson power combiner, we focus on the phase shift between the two input ports and parameters S_{11}, S_{21}, and S_{31}. Since we want to convert two differential inputs into a single-ended output, we need the phase shift between our input branches to be nearly 180°. We also need S_{11} to be below -20 dB (-21.917 dB in our case), and S_{21} and S_{31} to be as similar and as close to -3 dB as possible (-3.454 dB and -3.605 dB respectively in our case). The difference between S_{21} and S_{31} may lead to minimal errors in signal mixing.

For our quadrature hybrid, we based our analysis on parameters S_{11}, S_{21}, S_{31}, and S_{41}. Since we need the signal coming from port 1 to be divided equally between ports 2 and 3, we need S_{11} and S_{41} to be below -20 dB and S_{21} and S_{31} to be as similar and close to -3 dB as possible. Since we greatly exceeded the requirement for S_{41}, we can say we have a high-isolation hybrid; however, the difference between S_{21} and S_{31} may lead to slight errors in polarization later on.

For our antenna, we focus on 3 major variables: HPBW, S_{11}, and axial ratio. To comply with requirements, we need our antenna to have a "pencil beam" (HPBW below 30°), have circular polarization (axial ratio below 3 dB), and have an S_{11} below -20 dB at 24 GHz. As of December 2019, the antenna still requires further optimization; however, for horn antennas, the beamwidth can be easily manipulated by changing the aperture's flare angle and making the axial ratio/S_{11} tradeoff the major design queue.

Future Work: Further optimization of the antennas are needed in order to achieve a lower half-power beamwidth that would allow for less ambiguous measurements. Before any preliminary data is gathered, antenna and radar parameters should be tested under a controlled environment.

For the radar programming, existing Infineon *Digital Application Virtual Engineer* (DAVE™) applications may be used to expedite the data gathering process and modified later on to better fit needs. Additional algorithms to calculate polarization ratio will be needed as part of the experiments that will be run with this radar equipment. Software and antenna design improvements could be used to reduce noise figure and improve overall radar capabilities and functionalities.

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References: [1] Putzig N. E. et al. (2017) *Space Sci Rev* 1–12. [2] Patterson G. W. et al. (2017) *Icarus* 283(C):2. [3] Benner L. A. et al. (2008) *Icarus* (198):294. [4] Ostro S. J. et al. (1980) *Icarus* 44(431-440). [5] Black G. J. et al. (2001) *Icarus* 151:167. [6] Virkki A. et al. (2014) *MAPS* 49(1):86. [7] Hudson S. (1994) *Remote Sensing Reviews* 8(1-3):195. [8] Black G. J. (2002) in *Single-Dish Radio Astronomy: Techniques and Applications* vol. 278 271–290 Astronomical Society of the Pacific. [9] Pozar D. M. (2012) *Microwave Engineering* John Wiley and Sons, Inc., New Jersey 4th edn. [10] Balanis C. (2016) *Antenna Theory: Analysis and Design* John Wiley and Sons, Inc., New Jersey 4th edn.