VENUS INTERFEROMETRIC SYNTHETIC APERTURE RADAR INSTRUMENT PERFORMANCE AND OPTIONS

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1. INTRODUCTION

The Venus Interferometric Synthetic Aperture Radar (VISAR) is one of two instruments carried by the VERITAS Discovery Mission to Venus that was selected by NASA in 2021 [1, 2]. VERITAS (Venus Emissivity, Radio Science, Insar, Topography And Spectroscopy) is a partnership between scientists and engineers at NASA/JPL in an international cooperation with the Germany Aerospace Center (DLR), the Italian Space Agency (ASI) and the French Space Agency (CNES). VISAR aims to be the first to image Venus at $30\,\mathrm{m}$ resolution on a global scale and deliver a digital elevation model at $6\,\mathrm{m}$ height accuracy in addition to proving interferometric deformation maps of activity on another planet. The VISAR instrument has several interesting features and challenging aspects. The focus is put on SAR performance and the options for the radar operation and imaging mode parameters given the constraints inherent to a planetary mission.

2. VISAR MISSION OVERVIEW

Venus and Earth are similar in size, density and composition – Venus often called Earth's twin. Despite their similarities, the two planets have had very different geologic histories. Venus lacks plate tectonics and a strong magnetic field and evolved very differently with a surface dominated by volcanic features. It's atmosphere is 90 times denser than Earth's and the mean surface temperature is $452\,^{\circ}\mathrm{C}$. Understanding how these two planets evolved so differently is critical to understanding the evolution of early Earth and which rocky Earth-sized exoplanets could be habitable. The VERITAS spacecraft in Fig. 1 shows the VISAR instrument and two antennas. VISAR data collection will be in the second science phase (SP2) operation scheduled after a 16-month

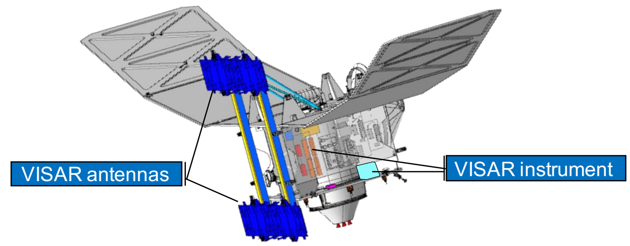


Fig. 1: The VERITAS spacecraft with its two VISAR antennas and the instrument [1, 2, 3].

aerobraking phase initiated when arriving at Venus and needed to achieve the desired circular polar orbit varying between $180\,\mathrm{km}$ and $252\,\mathrm{km}$ in altitude. SP2 lasts for 4 Venus sidereal days or cycles, each of which is 243 days in duration owing to the very slow rotation rate of Venus (Venus rotates $10\,\mathrm{km}$ at the equator during a VERITAS orbit). Data are collected for 11 orbits on both ascending and descending passes followed by 5 orbits of data downlink to Earth. The huge amount of collected radar data and the downlink capacity is one of the major constraints of VISAR operation. On-board data processing to multi-looked imagery and interferograms will reduce the amount of data up to a 1000 fold. The exception to this is when repeat pass interferometric (RPI) data are collected [3] in which case the raw data are downlinked to Earth for processing. For this reason, the number of RPI sites are limited to 12-18 sites.

3. SYNTHETIC APERTURE RADAR INSTRUMENT

The VISAR instrument, shown schematically in Fig. 2, is an X-band imaging radar at $7.9\,\mathrm{GHz}$ center frequency designed to generate global imagery and topography of Venus. Two $3.5\,\mathrm{m}$ (azimuth) by $0.65\,\mathrm{m}$ (elevation) antennas separated by a fixed baseline of $3.1\,\mathrm{m}$ oriented at $30°$ off-nadir angle allow single-pass interferometry. The radar transmits chirps of $20\,\mathrm{MHz}$ bandwidth at $400\,\mathrm{W}$ power imaging a $14.4\,\mathrm{km}$ swath at $32°$ incidence angle.

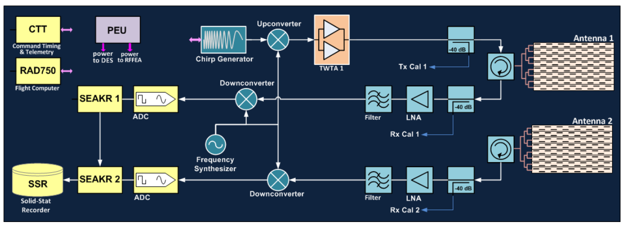


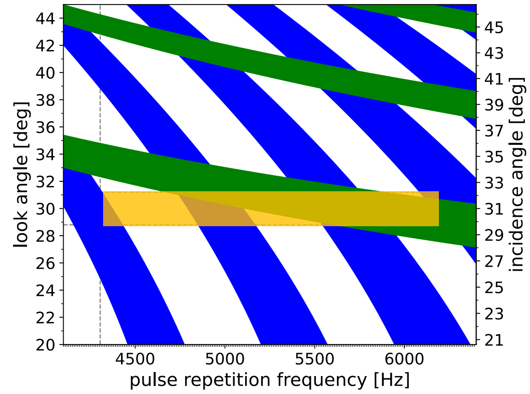
Fig. 2: VISAR instrument functional block diagram.

Interferometric data acquisition, instrument calibration, images formation (focusing), multilooking and interferogram generation is done on-board of VERITAS to reduce the downlink data volume. On-ground processing involves phase unwrapping, DEM generation, bundle adjustment, and atmospheric corrections. The final product consists of $30\,\mathrm{m}$ global image products and digital elevation model (DEM) data with $250\,\mathrm{m}$ spatial resolution and $6\,\mathrm{m}$ elevation accuracy.

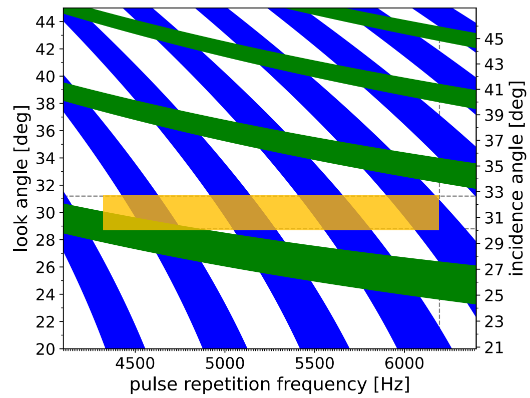
The paper addresses the radar instrument operation parameter values which have a direct effect on the SAR performance on one side and the hardware complexity and required on-board processing effort on the other. The particularities of the planetary mission (e.g., GPS cannot be used for determining the satellite position) and Venus (e.g., dense atmosphere affects the interferometric measurements) impose additional restrictions which has an impact on the mission trade space and the operation parameters [4, 5, 6].

3.1. Orbit Height Variation

The requirement for a global coverage suggests a fixed swath position relative to nadir direction, while also ensuring a small overlap between the consecutive swathes necessary for DEM calibration. However, the strong variation in spacecraft altitude of 182 to $210\,\mathrm{km}$ (periapsis) and 225 to $252\,\mathrm{km}$ (apoapsis) results in timing issues and a degradation of the range ambiguity performance. Fig. 3 show the timing diagrams for the minimum and maximum orbit heights indicating that clearly an operation at a fixed pulse repetition frequency and look angles is not possible.



(a) $182\,\mathrm{km}$ spacecraft altitude



(b) $252\,\mathrm{km}$ spacecraft altitude

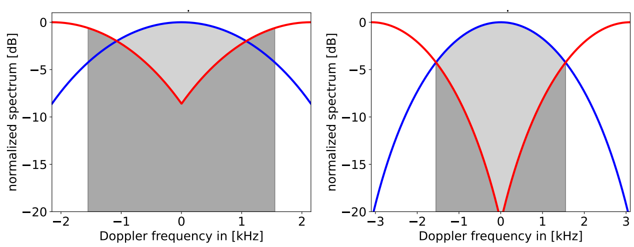
Fig. 3: Timing (diamond) diagram of VISAR instrument for different spacecraft altitudes. The blue and greed strips mark the blockage due to transmit instances and nadir echo return, respectively, while the orange box indicates the PRF operation range.

3.2. Azimuth Phase Coding

Azimuth phase coding (APC) [7, 8, 9] successfully mitigate this effect but require a pulse-to-pulse quadratic phase change of the transmitted pulses and additional processing effort. The basic idea of APC is to "remove" the quadratic phase change on received echo signals such that the residual phase change is zero. The range ambiguities which are delayed with respect to the signal exhibit a residual linear pulse-to-pulse phase shift, which causes a cyclic shift of the azimuth spectrum (pattern).

The effect is seen in Fig. 4 indicating that shift reduces the power of the range ambiguities of odd order —proportional to the area within the processed Doppler bandwidth— compared to the power of the signal. The

APC gain, G_{adc}, represents the additional attenuation of the range ambiguity and thus does not consider the effect of the suppression due to the elevation antenna patter. Generally $G_{apc} \geq 0\,\mathrm{dB}$ provided that the azimuth signal is oversampled, i.e., the pulse repetition frequency (PRF) is higher than the processed Doppler bandwidth. The APC gain is mainly determined oversampling factor and the radiation pattern shape. In the case of VISAR the PRF is varied from approximately $4.3\,\mathrm{kHz}$ to $6.2\,\mathrm{kHz}$ to accommodate the timing due to the orbit height variations while the processed Doppler bandwidth is $3.1\,\mathrm{kHz}$ corresponding to a single look azimuth resolution of $2.3\,\mathrm{m}$. As a result the APC gain varies from $2.1\,\mathrm{dB}$ to $8.5\,\mathrm{dB}$.



(a) PRF $4.3\,\mathrm{kHz}$ (b) PRF $6.2\,\mathrm{kHz}$

Fig. 4: Signal and odd range ambiguity spectrum after applying APC for two different values of the PRF.

4. CONCLUSION

VERITAS is a highly innovative mission with a manifold of science applications. It's synthetic aperture radar VISAR will generate global science data of Venus at an unprecedented quality and quantity exceeding by far any of the previous or other planed missions to Venus. The SAR instrument is based on mature space qualified technologies for radar data acquisition, calibrations, and on-board processing. While the feasibility of VERITAS is unquestioned it still utilizes new and innovative techniques to achieve the required performance

5. REFERENCES

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