Amplitude- and Phase-Based R-F Direction Finding Systems for Spacecraft Rendezvous and Formation Flying

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Requirements for spacecraft formation flying, including rendezvous, span a broad range. Some applications, such as interferometry, demand an r-f system to measure ranges at the centimeter level and bearing angles with arcminute accuracy. Such a system may act as an "initializer" for an infrared or optical system that does orders of magnitude better. It generally requires a complex signal structure, measurement of both range and phase observables, and complex signal processing. At the other end of the spectrum are rendezvous and docking applications that, at least in their early stages, can meet their requirements with rather crude ranging and angular accuracy of a few degrees. Systems of this kind can perform adequately using only amplitude measurements, no direct range measurements or phases, and very simple signal structure and processing. Like phase-based schemes, they may ultimately give way to an optical system better adapted to the final steps of the positioning task.

This paper describes prototype systems of both types, amplitude- and phase-based, that are appropriate for spacecraft rendezvous. In each case, design features and performance analyses are drawn from existing studies.

The amplitude-based scheme was devised for the ST4/Champollion Mission, to guide the lander spacecraft (with its sample of cometary material) back toward the orbiter. However, the approach is equally applicable to similar missions. On the sample-return vehicle, three receiving antennas receive a monochromatic signal from the orbiter. Their beams are fairly broad and point in different directions, each offset by several tens of degrees from the incoming signal. Since the antenna gain patterns are known, the relative amplitudes of the three received signals allow the lander to estimate the bearing angles of the orbiter. Furthermore, the absolute signal strengths enable the lander to estimate its distance from the orbiter. Performance is limited by system noise and knowledge of the antenna power patterns, but directional accuracy of a few degrees is readily attainable.

The phase-based scheme also involves three antennas, but now the observables are carrier phases differenced between antennas. Design principles and analysis are drawn from experience with the ST3 separated-element interferometer mission, but again, the design is highly adaptable. Although the phase observable is intrinsically more accurate than amplitude, it is also more vulnerable to systematic errors of various kinds, so that system calibration assumes a crucial role in determining the performance actually achieved by a phase-based system. In some situations, a hybrid approach using both phase and amplitude measurements may be the best way to meet system requirements.