ON SPACE-BASED S.E.T.I.

by

Willem Stuiver

Department of Mechanical Engineering
University of Hawaii at Manoa
Honolulu, Hawaii 96822

ABSTRACT

Space-based antenna systems for the search of signals from extra-terrestrial intelligence were first proposed in the mid-seventies. Tentative performance specifications for systems that might be built in the early part of the twenty-first century were established. Preliminary studies of system design and mission profile led to the consideration of the Sun-Earth collinear transterrestrial libration point (SEL2) as the ideal operational location for the system. Moreover, compatibility with current contingency plans for technology development in the geostationary orbit suggests that fabrication and assembly of major components of space-based antenna systems that might be built in the early part of the next century would most likely take place in that orbit. Consequently, deployment of these components to the operational location at SEL2 would require, first of all, an orbit transfer at geosynchronous altitude to the ecliptic plane, and then a transfer from the resulting ecliptic geosynchronous departure orbit to the heliocentric operational orbit at SEL2. Because both major components (dish and shield) of the antenna system would have structural configurations (of the shallow-shell and flat-plate type, respectively) that are associated with high values of the area-to-mass ratio, the possibility of component deployment in the ecliptic plane by means of solar sailing was early recognized. A literature review of papers and other publications dealing with Earth-orbiting and interplanetary solar-sailing missions was then conducted; however, relevant information concerning suitable attitude-control laws for solar-sailing flight to SEL2, and associated flight times, could not be obtained. For this reason, independent studies of the ecliptic solar-sailing transfer problem from the geosynchronous departure orbit to SEL2 have been conducted in recent years in the Department of Mechanical Engineering of the University of Hawaii at Manoa. These studies were based on a relatively simple mathematical model describing attitude-controlled spacecraft motion in the ecliptic plane as governed by solar and terrestrial gravitational attractions together with the solar radiation pressure. The resulting equations of motion have been integrated numerically for a relevant range of values of spacecraft area-to-mass ratio (as obtained from preliminary estimates for dish and shield established in earlier work) and for an appropriate spacecraft attitude-control law known to lead to Earth escape (as obtained from perusal of the solar-sailing literature). Experimentation with varying initial conditions in the departure orbit, and with attitude-control law modification after having achieved Earth escape, has established the feasibility of component deployment by means of solar sailing. Details are given in the paper.

ON SPACE-BASED S.E.T.I.

Space-Based Antenna Systems for the Search of Signals from Extraterrestrial Intelligence

INTRODUCTION

Space-based antenna systems for the search of signals from extraterrestrial intelligence were first proposed in the mid-seventies [1,2]. A study to determine their comparative cost-effectiveness relative to Earth- and Moon-based systems was conducted by the Stanford Research Institute (now SRI International) on behalf of the ETI Program Office of the NASA Ames Research Center at that time [3]. It was concluded that, for the very large antenna systems that would be required for small assumed values of the number of transmitting civilizations, an appropriate base location in space might well turn out to be cost-effective. For this reason, tentative performance specifications for SETI space-based radiotelescopes were established at Ames during that period [4]. Their authors envisaged a three-stage development program resulting in an ultimate antenna system the receiving element of which would consist of a 3 km aperture spherical reflector dish having a surface accuracy of $\pm$ 1 mm and a nominal maximum operating frequency of 15 GHz. Other components would include up to three free-floating feed modules equipped with sophisticated laser-ranging and attitude-control systems, as well as a 6 km diameter RFI (radio-frequency interference) shield for protection against Earth- or Earth-orbit based electromagnetic emissions. Maximum sky coverage for a minimum of dish movement would be obtained by moving the feed modules across the reflector dish. The system would operate in lunar orbit at one of the two Earth-Moon equilateral libration points. It would always be pointing away from the Earth, thereby sweeping 360 degrees of sky once each lunar period.

OPERATIONAL ORBIT

More recent studies of the SETI space-based antenna system have tended to invalidate the concept of a lunar operational orbit [5]. At the lunar distance and beyond, thermal gradients together with the solar radiation pressure would be the dominant environmental factors influencing the structural response of Earth-orbiting radiotelescopes of the sizes envisaged. It was postulated that unattenuated thermal loads on the reflector dish structure would so much degrade the shape accuracy of the reflecting surface that ensuing demands on the control system required for maintaining this accuracy would become excessive. Consequently, protection of the reflector dish structure against the solar thermal radiation would also be required. For operation in the lunar orbit

this would imply a requirement of two shields: one located between the dish and Earth providing RFI protection, and one located between the dish and the Sun providing thermal protection. The dynamic complexity of a two-shield orbiting antenna system was considered so undesirable that a search was initiated for locations in the solar system at which a single shield would simultaneously and continuously provide both RFI and thermal protection for the dish. Elementary considerations suggest that the only location for which this would be the case lies on the Sun-Earth line at a distance from Earth compatible with heliocentrical orbital motion in phase with it. Thus, the optimal location in the solar system for a SETI space-based antenna system as envisaged appears to be the collinear transterrestrial Sun-Earth libration point (here called SEL2). Even though this location, at 1,500,000 km away from Earth, is known to be dynamically unstable, it would be an excellent operational location for the following reasons: a single shield there interposed between the dish and Earth would provide almost continuous and complete RFI as well as thermal protection (the exception consisting of occasional interference from emissions generated on the outer planets), power requirements for system station-keeping at the optimum location along the Sun-Earth line would be minimal [6], and a direct line of communication with Earth could always be maintained.

COMPONENT DEPLOYMENT   It is clear that the enormous size of the ultimate antenna system envisaged in the Ames specifications would make it necessary to plan for fabrication and assembly of its major components (the RFI/thermal shield and reflector dish structures) in the highest possible Earth orbit. The higher this orbit, the smaller the gravity-gradient torques to which these structures would be exposed during fabrication and assembly; and with gravitational loads negligible at the operational location (SEL2), the optimum location for fabrication and assembly would seem to be situated at an orbital altitude where the solar radiation pressure loads on shield and dish are dominant. Although the lowest such altitudes lie well below SEL2, they are also situated at much higher locations than those for which construction facilities and personnel may be expected to become available in the foreseeable future. Recent work in preliminary technology planning for space solar power stations postulates that the large structural components of these stations would be fabricated and assembled in the geostationary orbit; a concept that envisages the availability of construction facilities and personnel at 36,000 km above the Earth during the early part of the next century. It has therefore been assumed that fabrication and assembly of the major structural components of a SETI space-based antenna system that might be built

at some time during the next century would take place in the geostationary orbit. Consequently, deployment of these components to the operational location at SEL2 would require, first of all, on orbit transfer (at geosynchronous altitude) to the ecliptic plane, and then a transfer from the resulting ecliptic geosynchronous departure orbit to the heliocentric operational orbit at SEL2. Because the two largest components (shield and dish) would have structural configurations (of the flat-plate and shallow-shell type, respectively) that are associated with high values of the area-to-mass ratio, and because the ecliptic transfer problem would involve regions of space in which the influence of the solar radiation pressure on component motion would be dominant, the possibility of deployment of shield and dish by means of solar sailing was early recognized. A literature review of papers dealing with Earth-orbiting and interplanetary solar-sailing missions was then conducted; however, relevant information concerning suitable attitude-control laws for solar-sailing flight to SEL2, and corresponding durations of transfer, could not be obtained. For this reason, independent studies of the component deployment problem have been conducted in recent years in the Department of Mechanical Engineering of the University of Hawaii at Manoa [7,8,9]. These studies were based on a relatively simple mathematical model describing the attitude-controlled motion of a solar sail (representing shield or dish) in the ecliptic plane as governed by both solar and terrestrial gravitational attractions together with the solar radiation pressure. The resulting equations of motion were integrated numerically for a relevant range of values of component area-to-mass ratio (as obtained from preliminary mass estimates for shield and dish established in earlier work) and for an appropriate attitude-control law known to lead to Earth escape (as obtained from the solar-sailing literature). Numerical experimentation with varying initial conditions in the geosynchronous departure orbit, and with modifications of the attitude-control law (including free flight) after having achieved Earth escape, has established the feasibility of component deployment to SEL2 by means of solar sailing. This being the case, the principal focus of current work is on a broader definition and more exact solution of the solar-sailing transfer problem, including the case of asymptotic arrival at SEL2 as well as the case of smooth insertion into an appropriate halo orbit in its vicinity. Problems concerning the conceptual design and nominal operation of a fully deployed SETI space-based antenna system at or near SEL2 are also being considered.

349

REFERENCES

1. "NASA Contemplates Radio Search for Extraterrestrial Intelligence", R.Shoeffer, Spaceflight, Vol.18, No.10, October 1976 (343-347).

2. "The Search for Extraterrestrial Intelligence", J.Billingham and K.Joels, Journal for Aerospace Education, November 1976 (15-18).

3. "Parametric Study of Interstellar Search Systems", R.P.Basler, G.G.Johnson and R.R.Vondrak, Radio Science, Vol.12, 1977 (845-847).

4. Charles L.Seeger, private communication (1978).

5. "On the Composition and Deployment of a Space-Based Interstellar Search System", Willem Stuiver, Dana Southwood, and Francis Enomoto, Journal of the British Interplanetary Society, Vol.34, 1981 (247-250).

6. "Minimum Power for Nominal Operation of the Space Radiotelescope System", Willem Stuiver, Fifteenth International Symposium on Space Technology and Science, Tokyo, Japan, May 1986.

7. "Solar-Sail Trajectories in the Ecliptic Plane", Francis Enomoto, B.S. Honors Thesis, Department of Mechanical Engineering, University of Hawaii at Manoa, May 1979.

8. "Solar-Sailing Flyby Flight to Sun-Earth Transterrestrial Libration Point", Toechin Yu, M.S. Thesis, Department of Mechanical Engineering, University of Hawaii at Manoa, December 1986.

9. "Solar-Sail Deployment Trajectories for Space-Based Antenna System", Anurag Kakaria, M.S. Thesis, Department of Mechanical Engineering, University of Hawaii at Manoa, August 1989.