THE UNIVERSITY OF MICHIGAN
RADIO ASTRONOMY OBSERVATORY

PHASE II FINAL REPORT

ENGINEERING FEASIBILITY STUDY
OF A KILOMETER WAVE ORBITING TELESCOPE

Submitted by
FRED T. HADDOCK

NATIONAL AERONAUTICS AND SPACE
ADMINISTRATION GRANT NGR-23-005-131

DEPARTMENT OF ASTRONOMY

PHASE II FINAL REPORT

ENGINEERING FEASIBILITY STUDY
OF A KILOMETER WAVE ORBITING TELESCOPE

Submitted by

FRED T. HADDOCK

NATIONAL AERONAUTICS AND SPACE

ADMINISTRATION GRANT NGR-23-005-131

UNIVERSITY OF MICHIGAN

RADIO ASTRONOMY OBSERVATORY

Ann Arbor, Michigan

July 1968

I. Introduction

The University of Michigan Radio Astronomy Observatory (UM/RAO) has completed the second phase of its investigation of the engineering feasibility of a Kilometer Wave Orbiting Telescope (KWOT). Phase one of the KWOT study was initiated in November, 1965, and completed in October, 1966. The principal conclusion (1) of the first phase study was that mission feasibility appeared favorable enough that the study should continue.

The present phase two study began February 1, 1967, and ended January 31, 1968. The investigation of the structural dynamics has been greatly extended and mission feasibility appears very favorable.

II. KWOT Concept

An antenna with high directional gain (small beam area) is required to map the sky and measure the flux density of radio sources at frequencies below 5 MHz. In order to measure several dozen sources, a beam area of not more than about 80 square degrees is required. To achieve this resolution at frequencies near 1 MHz, a large physical structure in orbit is required. A moderately broad-beam antenna is proposed for flux density measurements of discrete sources and contour mapping of the cosmic background noise. A compound interferometer will then be used to provide an estimate of source size for the larger and stronger sources and better data on the statistical character of the cosmic background due to many weaker sources. The KWOT structure that was studied (See Figure 1) has the required antenna directional gain and stays within reasonable system weight limits. The proposed KWOT structure consists of a central observatory surrounded by four sub-satellites, with all five bodies connected by a set of conducting and non-conducting filaments. The conducting portions of the connecting elements form a rhombic antenna and an interferometer array of dipoles. As seen in Figure 1 this structure is essentially planar since the maximum dimension out of the paper is only 4 meters. The overall diameter of the structure is 10 kilometers so that the rhombic leg length is 17 wavelengths long at 1 MHz. The radio astronomy signals from the rhombic and interferometer are combined in such a way that an antenna pattern is generated which combines the resolution of the interferometer with the unidirectional properties of the rhombic.

The entire KWOT structure spins about an axis perpendicular to its plane with a period of approximately one hour. This spinning motion serves to scan the antenna array over the sky and, with the precession of the spin axis which is brought about by an active thruster control system, will provide complete sky coverage. The centrifugal force generated by the spinning motion also aids in maintaining the shape of the structure for this mode of operation. Some types of observing programs may use the active control system to stop the antenna array from spinning and control the pointing of the antenna beam.

III. Phase Two Program

In view of the encouraging results of the phase one study [1], it was proposed that additional work be done in the structural dynamics area, the antenna electrical properties study area and the system study area. First priority was given to continuing those tasks which were started during the phase one study in that the phase two study was funded at a level of approximately 20% of that recommended in the proposal.[2]

IV. Summary and Conclusions of Phase Two Engineering Feasibility Study

A. Structural dynamics studies.

1. Motion of a lumped-mass model representing a kilometer wave orbiting telescope. This study is completely described in the special report listed as reference 3 which is being submitted as part of this final report.

The study consisted of a numerical analysis of the planar motion of a lumped-mass model representing the KWOT structure. The model consisted of a system of particles with interconnecting non-linear springs and an in-plane tangential thrust capability. Specifically, the effects of small perturbations from a free-space condition of uniform rotation due to the gravitational gradient and to control thruster activation were investigated. Orbital constraints were assumed, with the reference satellite describing a circular orbit at synchronous altitude. In addition, a coordinated spin-up deployment was studied. The effects of three-dimensional motion, structural damping and orbital eccentricity were not studied.

With the aid of a Scientific Data Systems (SDS)-930 computer, performing double precision arithmetic, and a CALCOMP-565 automatic plotter, studies of the motion of the model were made. Six types of graphical displays were produced.

a. Radial distance deviation time history.

b. Spin rate deviation time history.

c. Angular position time history.

d. Angular position deviation phase plane diagram.

e. Control switching function time history.

f. Expanded scale control switching function time history.

Over 150 of the most interesting and informative displays have been reproduced in reference 3.

The investigations performed using the computer may be classified in categories: verification of equilibrium, small perturbations from equilibrium, large perturbations from equilibrium and deployment.

Results indicate that the amplitude of the structural oscillations excited by the deployment method are within the limits defining allowable structural distortion, and that a simple configuration control system can counteract small perturbations from a freespace equilibrium rotating condition for a lifetime in excess of one year.

2. <u>Motion and stability of a spinning cable-connected system in orbit</u>. This study is completely described in the special report listed as reference 4 which is being submitted as a part of this final report.

The problem of a cable connected system spinning in orbit raises two basic stability questions: will the system continue to move at a fairly constant spin rate in the predicted orbit and will the internal motion of the system, in this case the connecting cable, remain bounded near some desired motion? Several papers on these two problems appear in the literature. All deal only with motion in the plane of the orbit.

The purpose of this study was to present a more general approach. The methods of analysis described can be applied to general cable connected structures. The method presented is specificially applied to the problem of a point mass spinning about a much heavier body to which it is connected by a linear elastic, constant density, constant cross sectional area cable. The system, in turn, is in orbit about the earth.

The Lagrange equations of motion for the lumped system were shown to be a system of nonlinear, ordinary differential equations. Damping was included in the equations and its effects on stability investigated.

The simplest lumped mass model, the dumbbell, was used to examine in more detail the bounds on the types of motion which can occur within the energy levels of the conservative system. The orbits in which the dumbbell may move were shown to be essentially those in which a point mass may move; however, a small change in orbit of the dumbbell means a sizable change in spin rate.

The bounds are found by examining the fictitious potential functions for the dumbbell system. Results from a numerical integration of the exact equations for the dumbbell indicate that, for most cases, it is reasonable to assume that the center of mass of the system moves in a Keplerian orbit. This affords one the luxury of being able to calculate the position of the center of mass independent of the relative motion of the system. It was shown that the motion of a dumbbell whose center of mass moves in an undisturbed Keplerian orbit, and that of a light mass spinning about a very heavy mass which also moves in an undisturbed Keplerian orbit are almost identical. The latter model is henceforth referred to as the single mass model since only the lighter mass moves relative to the orbital point. The above result was used to justify the original model and orbital assumptions.

B. Resistive losses on thin wire antennas.

This study is completely described in the special report listed as reference 5 which is being submitted as a part of this final report.

The purpose of this study was to determine the effect of resistive losses on the current distribution of long, thin cylindrical antennas. The first section of this report describes a computational technique for obtaining the current on a thin antenna. The second section presents the results obtained for a 1 1/2 and a 3 wavelength antenna. These calculations were performed for a variety of source positions and for perfectly conducting and uniform lossy wires. The resistance per unit length of these imperfectly conducting wires was taken as 0.08565 ohms/meter. This choice was made in order to accentuate the effects of antenna losses and is larger than the value which will be encountered in the KWOT structure.

The final section describes an approximation to the current distribution which allows the resistive losses to be estimated and then extended to antennas longer than those considered in this work. This was done in the case of a 12 wavelength antenna and the behavior noted. The current peaks were decreased by a factor of $e^{-\alpha L} = 0.81$ and the position of the peaks and nulls, and magnitude of the nulls were unaffected by the addition of losses.

Since the resistance of 0.08565 ohms/meter is much larger than the value which will be encountered in the KWOT antenna, it appears that this problem of resistive losses will not seriously affect the antenna operation.

C. KWOT system studies.

Results of the systems investigation are described in the special report listed as reference 6 which is being submitted as a part of this final report. This special report was printed by Bell Aerosystems who participated in the systems investigation but at no cost to the project.

The basic KWOT system is attractive for the following reasons:

1. It lies entirely in a plane. The centrifugal force resulting from the spinning motion can be used to keep the structure extended. No compression members are required in the structure, but rather thin filaments which experience only tension.
2. The rhombic antenna has a unidirectional beam which lies in the plane of the structure. Therefore, the same spinning motion will sweep the beam about the celestial sphere. A broad-side array, on the other hand requires a three-dimensional structure to be unidirectional.
3. The rhombic antenna has directivity in both the E and H plane, is relatively broadband, and requires no interconnecting transmission lines.
4. When the rhombic signals are properly combined with those from the dipole array, a pattern results

which combines the E plane directivity of the dipole array with the unidirectional character of the rhombic.

5. The KWOT structure is compact when stowed, but is easy to deploy and adjust.
6. Being composed of flexible filaments, the KWOT structure is not subject to serious deformation from temperature gradients as are long rigid booms.
7. There are no metallic structural members to distort the antenna field.
8. The KWOT antenna generates a real beam, which is physically scanned over the celestial sphere in a controlled manner. Thus, the reduction of the data is simple and straightforward, with none of the uncertainties that arise in aperture synthesis due to changes in the strength of emitting objects, or in the parameters of the receiving system.

REFERENCES

(1) Haddock, F.T., Phase I Final Report, Engineering Feasibility Study of a Kilometer Wave Orbiting Telescope, NGR 23-005-131, University of Michigan Radio Astronomy Observatory, Ann Arbor, Michigan, October, 1966.

(2) Haddock, F.T., Proposal to NASA, "Phase Two Engineering Feasibility Study of a Kilometer Wave Orbiting Telescope",ORA-67-555-PBI November, 1966.

(3) Hegg, Daniel R., "Motion of a Lumped-Mass Model Representing A Kilometer Wave Orbiting Telescope", University of Michigan Radio Astronomy Observatory Report No. 68-6, March, 1968.

(4) Crist, S.A., "Motion and Stability of a Spinning Cable-Connected System in Orbit", University of Michigan Radio Astronomy Observatory Report No. 67-7 Revised December, 1967.

(5) Schoendorf, W.H., "Resistive Losses on Thin Wire Antennas", University of Michigan Radio Astronomy Observatory Report No 68-9, February, 1968.

(6) Bell Aerosystems/University of Michigan, "Kilometer Wave Orbiting Radio Telescope", 17 page brochure, 1968.

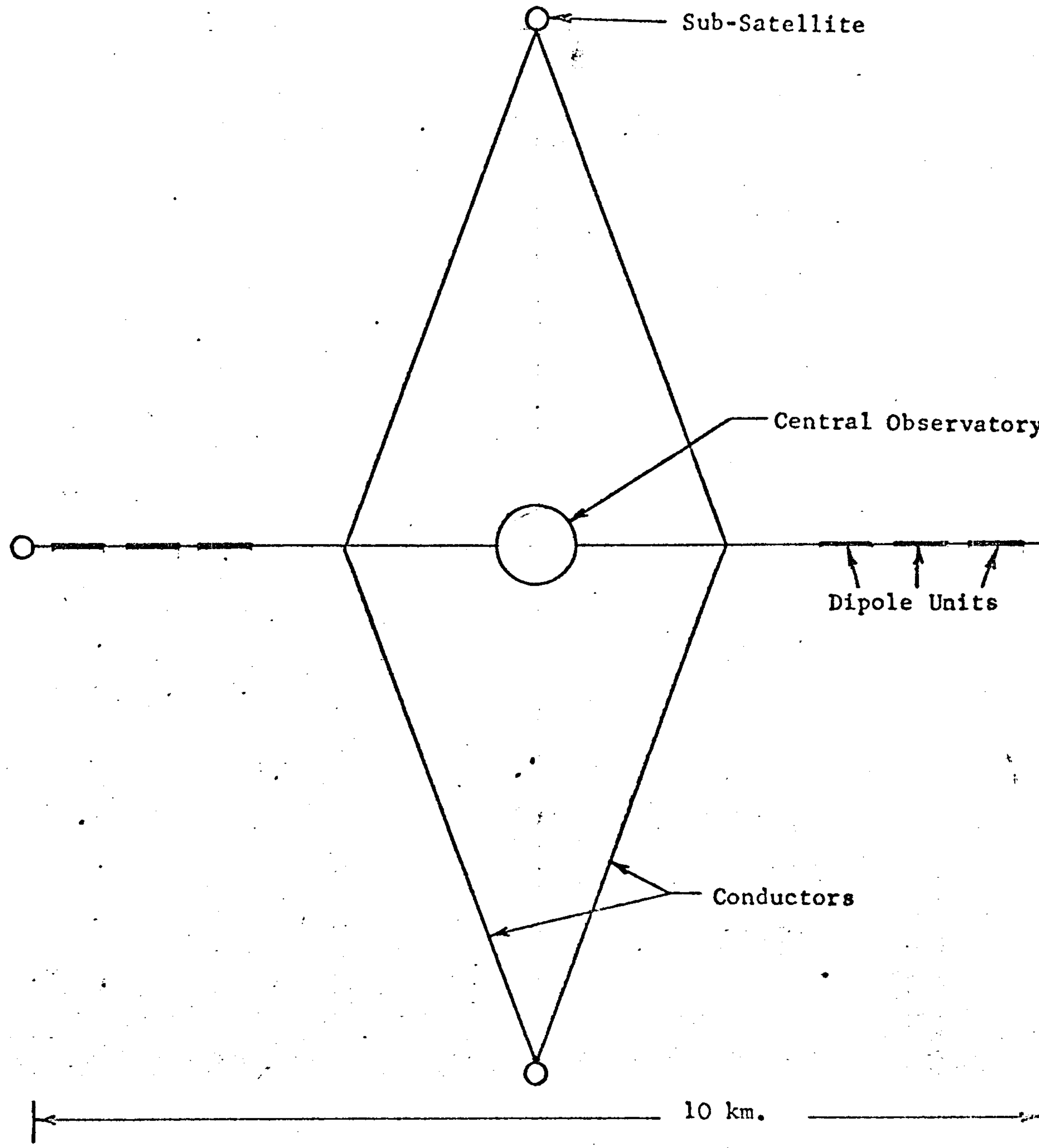

Figure 1 - KWOT Structure