Self-Erecting Space Antennas*

W. F. CROSWELL†, MEMBER, IRE, M. C. GILREATH†, AND V. L. VAUGHAN, JR.†

Summary—**A self-erecting technique for erectable space-vehicle antennas is proposed. Working models of Yagi disk antennas utilizing this new principle are described.**

General Introduction

ONE OF THE MAJOR problems that occur in space-vehicle communications is that of achieving sufficient RF system gain for wide-band data transmission. A possible solution to this problem is the use of high-gain directional antennas on the space vehicle. The use of such antennas is limited by three major factors. First, for space communications the approved or suggested channels are in the range of 960 to 2300 Mc. In this band, particularly for the lower frequencies, an antenna of relatively large size is necessary to achieve high gain. Second, since high gain results in narrow beamwidths, a precise stabilization and antenna pointing system must be employed on the vehicle. Third, it is not possible to have large external surfaces on space vehicles during the launch phase since such surfaces create an intolerable amount of drag. Therefore, erectable antennas which are stored during launch and released when the additional drag becomes small are required to provide appreciable gain.

Due to the fact that narrow-beam antennas will require a precise control system, the choice of a particular gain level for a given vehicle must be a compromise between desired RF system gain and the pointing-system capability. For the present design study a nominal gain level of 20 db (14° beamwidth) was chosen as a value that would give a significant increase in space-vehicle RF system performance without requiring unusual complexity in a control system. Also the space communication frequency band of 0427 Mc to 0435 Mc was chosen as typical of the general space frequency region mentioned previously.

This paper will be devoted to a brief discussion of erection techniques reported by other authors and a description of so-called self-erecting antenna models. In particular, a self-erecting Yagi disk element will be described.

Erection Techniques

Techniques for erecting antennas can be classified in three primary categories. These are pressure-erection, mechanical-erection, and self-erection.

The feasibility of pressure-erection, which uses the principle of expanding vapor or bottled gas to inflate a structure, has been demonstrated.[1,2] This method allows the use of very lightweight structural materials, offers high packaging ratios (30 to 1 or higher), and is not limited by structural configuration. Since these structures are subject to punctures and leaks in a space environment, which can cause collapse, they must become rigid after inflation. This can occur due to the properties of the structural material itself or by the addition of concretionary materials. For example, an inflated parabolic structure has been made rigid by expanding foam into hollow areas on its rear surface.[2]

The mechanical-erection technique uses an assembly of parts which are placed and fixed into position by mechanical means. The feasibility of erecting various structures (parabolas, arrays of helices, etc.) by this method has been demonstrated.[1,3] Most materials proposed for use in antennas of this nature require no special protection in a space environment. However, with the mechanical-erection technique the structure is usually limited to small packaging ratios (5 to 1 or less) and small sizes due to packaging considerations or weight.

The self-erection technique uses the materials in the structure as the erecting mechanism. When the material is deformed (compressed, folded, rolled, etc.) without exceeding its elastic limit, internal stresses are built up within the material. Upon release from the deformed condition, the material will return to its original size and shape by alleviation of the internal stresses. This technique offers packaging ratios in the range of 10 or 15 to 1. It does not suffer from the puncture or leak hazard as does the pressure-erected structure, but it does not have the inherent rigidity of the mechanically-erected structure. To use the self-erection technique, then, an antenna scheme which is relatively insensitive to mechanical tolerances is desirable. A Yagi disk array is one such scheme.

Design of a Self-Erectable Yagi Disk Array

There is a wide latitude in the choice of antenna types to obtain 20-db gain over the bandwidth of proposed communication channels from 960 Mc to 2300 Mc. The type described here is a four element array of uniformly spaced

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† National Aeronautics and Space Administration, Langley Research Center, Langley Air Force Base, Va.

[1] "Study and Design of Unfurlable Antennas," Lockheed Aircraft Corp., Sunnyvale, Calif., Final Rept. LMSD-704036, WADD TR-61-26; November, 1960.

[2] "Solar Concentrator Development and Evaluation Program," Goodyear Aircraft Corp., Akron, Ohio, Rept. No. GER-10084, vol. 1, January, 1961.

[3] D. S. Sanborn, "The Development of Deployable Solar Concentrators for Space Power," presented at 1961 SAE Natl. Aerospace Engineering and Manufacturing Meeting, Los Angeles, Calif.; October 9–13, 1961. (Ryan Aerospace Div., Ryan Aeronautical Co., San Diego, Calif.)

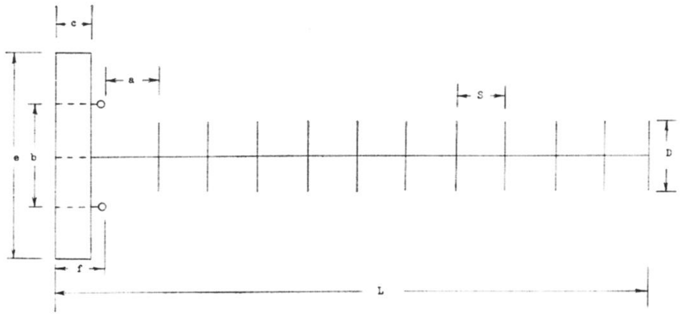
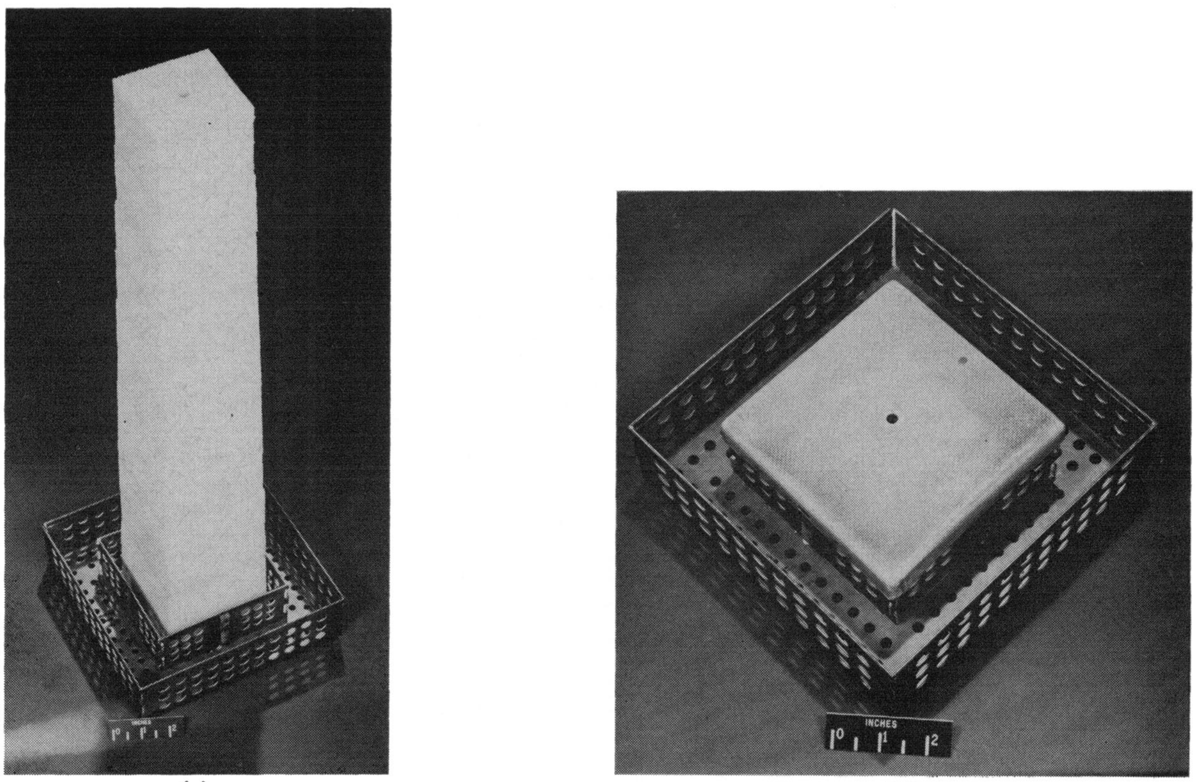


Fig. 1—Diagram of Yagi disk element.



(a) (b)

Fig. 2—Photograph of pyramidal erectable element. (a) Erected. (b) Packaged.

disk-on-rod or Yagi disk elements having a constant disk diameter. This element (see Fig. 1) is of interest because of its broad-band properties. These properties allow large physical tolerances on the structure if it is used in relatively narrow-band applications. Loose tolerances, of course, are desirable on any lightweight flexible structure. In addition, this element exhibits relatively small coupling when used in arrays with spacings greater than 1.25 λ.[4] This means that the array performance can be computed from the measured element patterns by simple pattern multiplication[5] and that low array sidelobe levels can be achieved by tailoring the individual element patterns.[4] A simple means of tailoring the element pattern is through the use of a metal shield around the feed, as shown in Figs. 1 and 2. Since the array performance can be computed from the single element performance, only a single erectable element is described in this paper. However, the dimensions used are those necessary for an element in a four element array having 20-db gain and low sidelobes.

The self-erection technique has been demonstrated with several erectable Yagi disk antenna elements, one of which is shown in Fig. 2. Briefly the elements consist of dipole-groundplane units made of formica printed circuit board and director assemblies made of brass or aluminum foil disks separated by polyether flexible urethane foam spacers. The precut and shaped foam acts as the supporting

[4] W. F. Croswell, M. C. Gilreath, and V. L. Vaughan, Jr., "Erectable Yagi Disk Antennas for Space Applications," presented at USAF Antenna Symposium, Univ. of Illinois, Urbana; October, 16–20, 1961.

[5] J. D. Kraus, "Antennas," McGraw-Hill Book Co., Inc., New York, N. Y.; 1950.

TABLE I

Number of disks	11
Distance (*a*) from dipole to first disk	2.0 in ($0.243\lambda_0$)
Distance (*b*) between feed dipoles	5.0 in ($0.608\lambda_0$)
Side (*e*) of the groundplane	8.0 in ($0.972\lambda_0$)
Height (*f*) of feed dipole above groundplane	2.0 in ($0.243\lambda_0$)
Design size of disk diameter *D*	2.5 in ($0.304\lambda_0$)
Design distance *S* between disks	2.0 in ($0.243\lambda_0$)
Design element spacing	12.0 in ($1.460\lambda_0$)
Feed bucket height	2.0 in ($0.243\lambda_0$)
Design frequency	1,435 Mc (λ_0 = 8.24 in)
Test frequency range, Mc	1200 to 1750

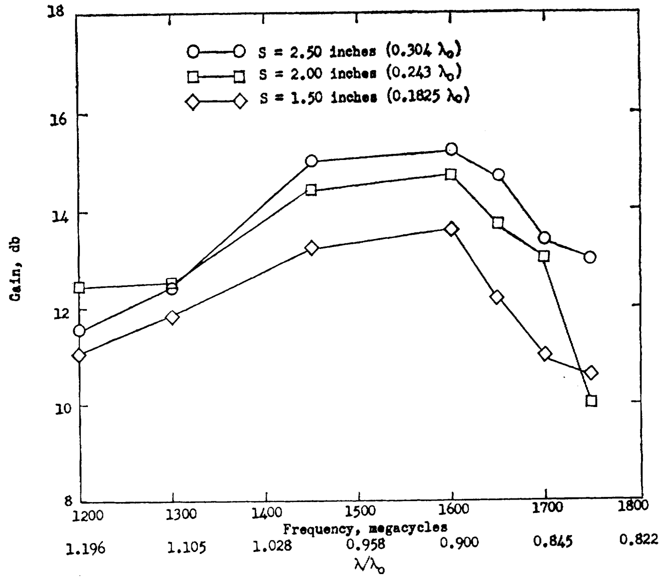


Fig. 3—Element gain vs frequency for various disk spacings, *S*.

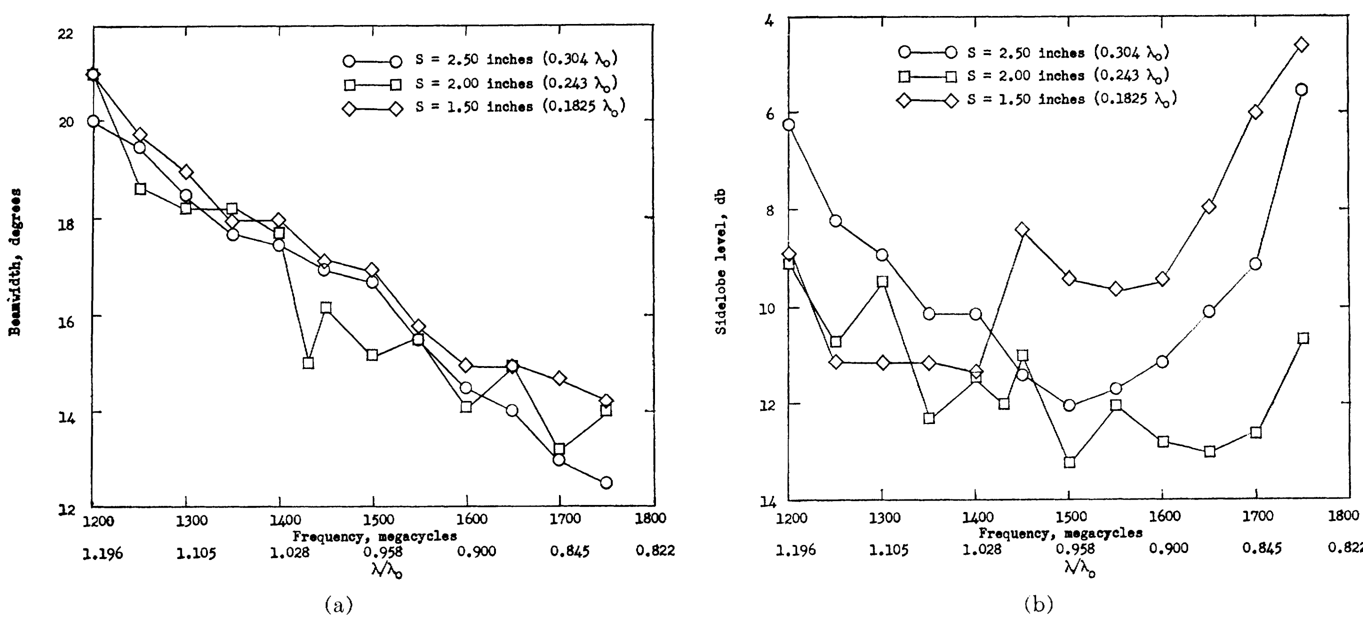


Fig. 4—(a) Array beamwidth (*E* and *H* plane average) vs frequency for various disk spacings, *S*. (b) Array sidelobe level (maximum value) vs frequency for various disk spacings, *S*.

structure for the disks and as the erecting mechanism for the whole director assembly. The foams used in these elements have low dielectric constants, are lightweight (1.7 and 1.0 lb/cu ft), and can be compressed to ratios of 8 to 1 and 12 to 1, respectively. The height of the dipole-groundplane units is made to correspond with the minimum height the foam can be compressed without excessive compression load. The director assemblies are packaged into these units by compressing the foam along the assembly axes [Fig. 2(b)].

The only erectable part of the described Yagi disk array is the disk structure. Therefore, in studying the effects of tolerances in the array structure it is assumed that the disk diameter, disk thickness, and spacing between elements are fixed. Table I gives the nominal dimensions of a four-element array with a gain between 18 and 20 db at a design frequency of 1435 Mc.

There are two dimensional variations that could occur on the erectable structure. First, the spacing between disks could be in error. Secondly, the cantilever foam structure could be deflected from the normal position by external loads. The effects of an error in spacing were measured both on a rigid model of a single element and on a four-element array. The results of these measurements are shown in Figs. 3 and 4 where the disk spacing was changed ±25 per cent from the design value. An inspection of the data presented demonstrates that the structure is relatively insensitive to large changes in

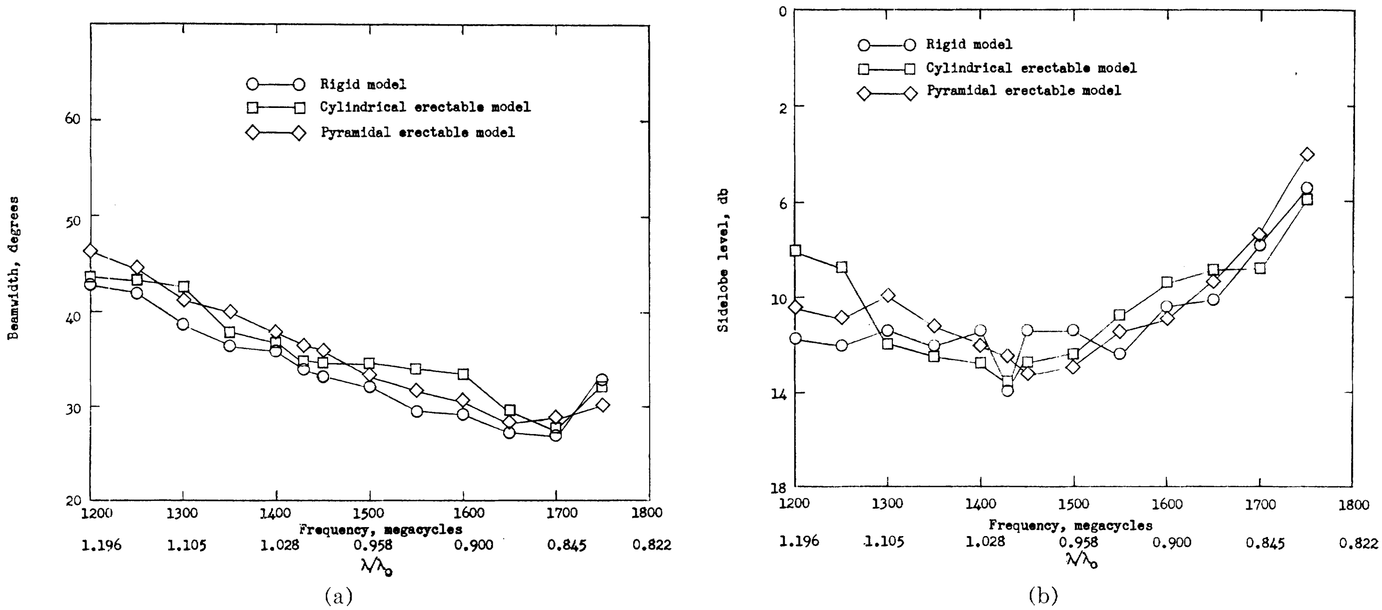


Fig. 5—(a) Comparison of beamwidth (E and H plane average) for rigid and erectable elements. (b) Comparison of sidelobe level (maximum value) for rigid and erectable elements.

disk spacing and in fact could operate with a partial failure in the erectable part of the structure.

Measurements were made to determine the effects on the array of deflecting the elements so that the element tips moved ± 1 inch and ± 2 inches. For deflections up to 1 inch, no significant effect upon the array patterns was observed. For deflections as large as 2 inches, the beam tilted slightly; however, the major effect was to increase the sidelobe level and to make the sidelobes asymmetrical.

In summary, the tolerance study shows that rather large variations in the array structure can be allowed without serious loss in antenna performance.

A. Mechanical Tests

Mechanical performance tests were made on these elements to determine their ability to erect after being packaged for as long as 20 hours. The elements erected to within 10 per cent of their original lengths immediately upon release from the packaged condition. They continued to recover for a period of 6 hours at which time they retained permanent compression sets of 3 per cent. For this particular application of the erection technique, the small amount of compression set can be allowed for in the construction of the element.

B. Space Environment

In an operational space environment there are two major factors which can cause deflection of the director assembly. These are forces, such as those caused by changes in vehicle orientation, and temperature differentials across the element, caused by the cold of space on one side and the heat of solar radiation on the other side.

Tests performed in a vacuum chamber have shown that if deflections of the elements do occur due to external forces, the elements will quickly regain alignment upon removal of the forces because of the rapid damping of the elements. For instance, the elements damped to half amplitude (while vibrating freely in a vacuum chamber) in 0.9 to 3.2 seconds, depending on the shape and amount of foam in the director assembly.

Temperature differentials across the element will cause the element to deflect and remain in the deflected condition until the differential is removed. There is no easy way to remove this differential in space; however, a small amount of deflection (up to 2 inches) can be tolerated. Tests have shown that temperature differentials of 250°F will cause 1.3-inch tip deflections of the elements. From the deflection tolerances previously stated it can be seen that even somewhat greater differentials will not seriously affect the antenna performance.

A more detailed discussion of the effects of a space environment on the erectable elements and the flexible foam used in these elements is presented in the literature.[4]

C. Comparison of Erectable and Rigid Elements

Radiation patterns of several erectable elements were measured and compared with those of a rigid antenna. The results of these measurements are given in Fig. 5. It can be seen that the antennas are nearly identical in performance.

Conclusions

The feasibility of a self-erecting technique and its application to a particular space vehicle antenna have been demonstrated. Tests have shown that the properties of the erectable antennas are acceptable within the tolerances necessary for adequate antenna performance.