

A UNIQUE NEW ANTENNA TECHNOLOGY FOR SMALL (AND LARGE) SATELLITES

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Abstract

The application of large antennas in spacecraft is often limited by available volume, as well as by the more usual mass limitation. Shroud dimensions usually determine the maximum aperture which can be carried without resorting to complex and potentially unreliable unfurling mechanisms. This applies all the more in a small-satellite environment with the smaller available launch volumes and severe mass limits of this species.

FLAPS™ (FLat Parabolic Surface) is a newly-developed technology for RF reflector surfaces which frees the spacecraft designer from the packaging rigidity of the common parabolic dish. It offers the ability to essentially duplicate the capability of a parabolic reflector in a reflector of almost any shape. The surface is shaped electrically rather than physically, in much the same manner as in a phased array, but by a totally passive array of dipoles suspended above a conductive ground plane. The dipoles are sized and spaced for the particular frequency and feed arrangement desired, and can produce a beam of essentially any desired shape.

The FLAPS™ technology is applicable across the microwave and millimeter-wave spectrum. FLAPS™ reflectors have been built and tested at 2, 6, 16, 36, and 95 GHz, as well as at various other frequencies in this range. The technology lends itself to a variety of fabrication methods, which can be highly automated.

1. INTRODUCTION

"Flat Parabolic Surface" at first may seem like an oxymoron but in fact, it is possible to design a geometrically flat surface to behave electromagnetically as though it were a parabolic reflector (Figure 1). The FLAPS™ consists of an array of dipole scatterers, one of which is shown in Figure 2. The elemental dipole scatterer consists of a dipole positioned approximately 1/8 wavelength above a ground

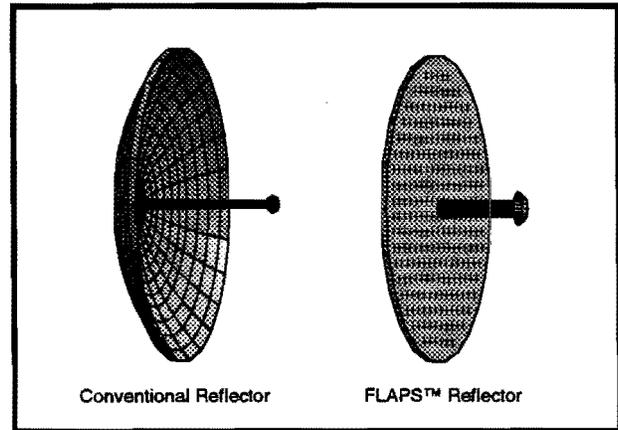


Figure 1
FLAPS™ Antenna vs Conventional Antenna
FLAPS™ Surface can replace parabola in reflector antennas

plane. Here, a crossed shorted dipole configuration is shown with each dipole controlling its corresponding polarization. Incident RF energy causes a standing wave to be set up between the dipole and the ground-plane. The dipole itself possesses an RF reactance which is a function of its length and thickness. This combination of standing-wave and dipole reactance causes the incident RF to be reradiated with a phase shift F , which can be controlled

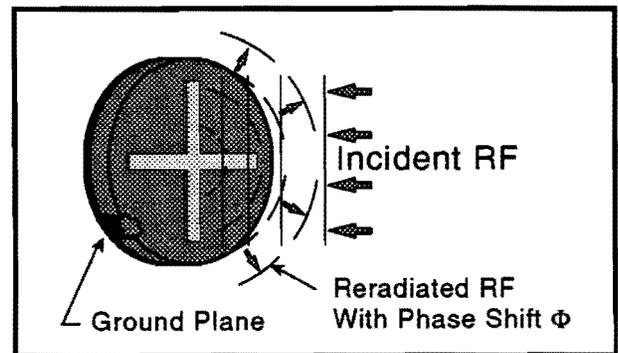


Figure 2
FLAPS™ Radiating Element
A dipole suspended above a ground plane reflects RF with a phase shift

by a variation of the dipole's length. The exact value of the this phase shift is a function of the dipole length, thickness, its distance from the ground-plane, the dielectric constant of the intervening layer, and the angle of the incident RF energy. When the element is used in an array, as discussed later, it is also affected by nearby dipoles.

Typically, the dipole lengths vary over the range of 0.25 to 0.60 wavelengths to achieve a full 360° range of phase shifts. The ideal spacing between the ground-plane and the dipole is 1/16 to 1/8 wavelength. The spacing affects form factor, bandwidth and sensitivity to fabrication tolerances.

2. ELECTRICAL DESIGN FEATURES

The FLAPS™ elemental scatterer performs the function of a radiating element and a phase shifter in a space fed phased array. Since dipoles of different lengths will produce a phase shift in the incident wave, arranging the distribution and the lengths of the dipoles will serve to steer, focus or shape the reflected wave. As Figure 3

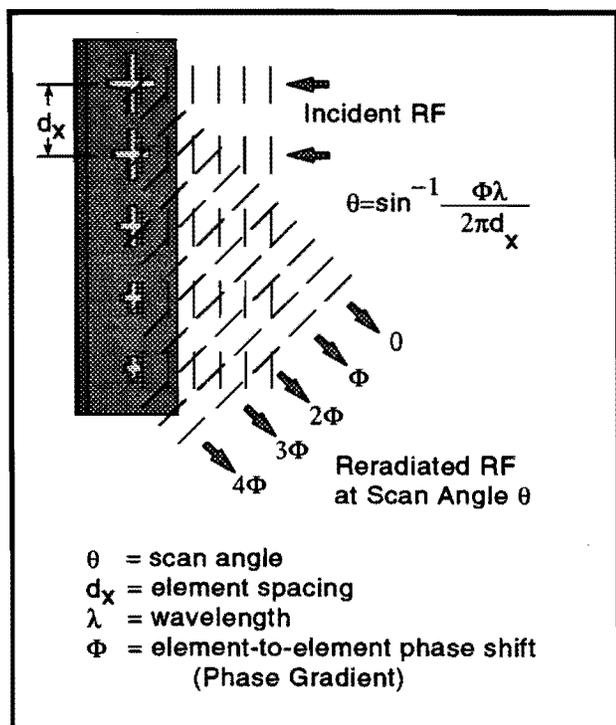


Figure 3
Linear Array of FLAPS™ Elements
An array of dipoles designed to reflect RF at a predicted angle

illustrates, an array of such elements is designed to reradiate with a progressive series of phase shifts $\Phi, 2\Phi, 3\Phi...$ so that an RF beam is formed in the direction Θ .

In a simple application, a parabolic surface can be directly replaced with a FLAPS™. It is possible to design a FLAPS™ as a substitute for any conventional reflector used in antenna design.

FLAPS™ surfaces can be up to 95% efficient. When designed as an offset reflector, the feed may be offset up to 60° from the flat surface. Bandwidths of 3% to 10% are achievable with a designed center frequency in the range from 1- to 100 GHz.

POLARIZATION CONVERSION AND ROTATION

The polarization isolation between the orthogonal dipoles is very high (greater than 50 dB). This valuable feature allows independent control of the separate eigenvectors of the RF energy reflecting off the FLAPS™.

Designing the orthogonal dipoles to reradiate with a 90° relative phase shift will result in a surface that will convert 45° linear incident RF into circular polarization. In fact, a surface designed in this manner will yield left or right hand circular or horizontal or vertical linear polarization with a single linear polarized feed depending upon the relative polarization orientation of the feed. (See Figure 4.)

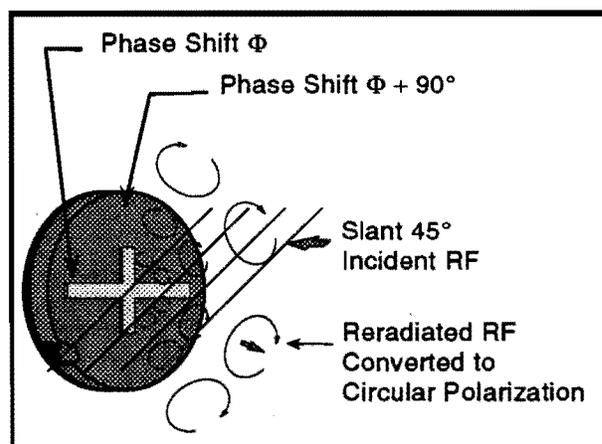


Figure 4
Polarization Conversion
Polarization control feature of FLAPS™ eliminates need for polarizers or complex feeds

BEAM SHAPE SWITCHING

FLAPS™ technology allows the designer to independently control the RF reflecting characteristics of the FLAPS™ for orthogonal senses of polarization. This capability eases the design of an antenna system that requires two beam shapes. A typical requirement, for example, would be a dual mode radar system that requires a pencil beam pattern for the search mode and a $Csc^2\Phi$ pattern for ground mapping. A FLAPS™ solution for this application is a flat surface that reflects a pencil beam pattern when illuminated with one linear sense of polarization and a $Csc^2\Phi$ beam pattern when illuminated with the orthogonal sense of polarization. Furthermore, FLAPS™ technology allows the design of separate focal points for each polarization, thus simplifying the feed design (See Figure 5).

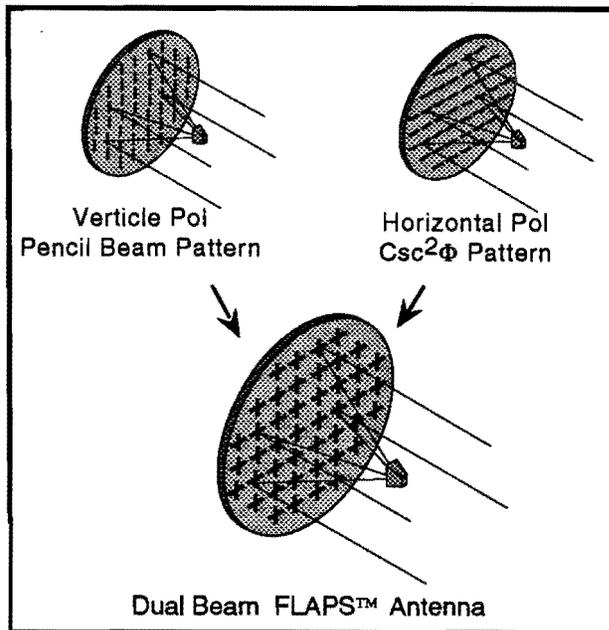


Figure 5

Independent Aperture Design at Orthogonal Polarizations

The Orthogonal dipoles have polarization isolation greater than 50 dB enabling dual-mode antenna design

DUAL FREQUENCY APPLICATIONS

In all the examples reviewed so far, the dipoles are suspended in front of a solid metal ground plane. By substituting the solid ground plane of a FLAPS™ reflector with an array of dipoles that are at resonance at the frequency of design, the

FLAPS™ reflector has the additional feature of being RF transparent at other frequencies as illustrated in Figure 6. Antennas designed in this fashion can be placed in front of a planar array for dual frequency applications as illustrated in Figure 7.

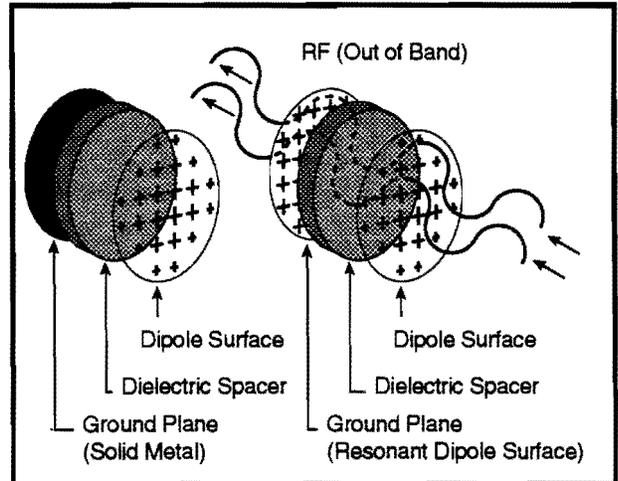


Figure 6

RF Transparent FLAPS™ Advantageous for Dual Frequency or Low Radar Cross Section Applications

Layered FLAPS™ reflectors can also be designed to operate at two or more frequencies. In a possible MILSTAR application, for example, a transparent FLAPS™ is designed to operate at 44 GHz and placed directly in front of another FLAPS™ designed to operate at 20 GHz. In this example the antenna feed is greatly simplified by designing separate focal points for each frequency and using separate feeds in lieu of one costly dual

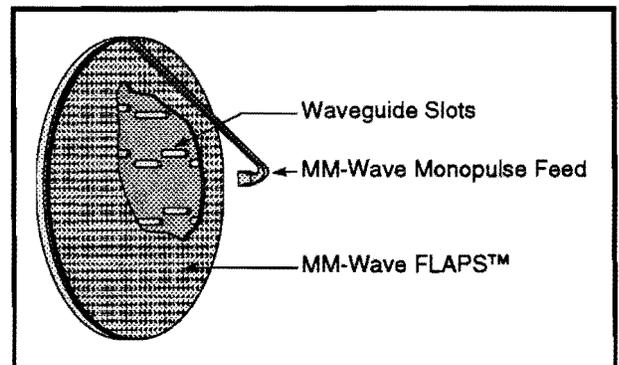


Figure 7

Common Aperture Airborne Radar Existing radar antenna modified with FLAPS™ antenna resulting in dual frequency operation

frequency feed. Considerable freedom is allowed in the design of the feed locations. Figure 8 illustrates this concept using widely separated feeds.

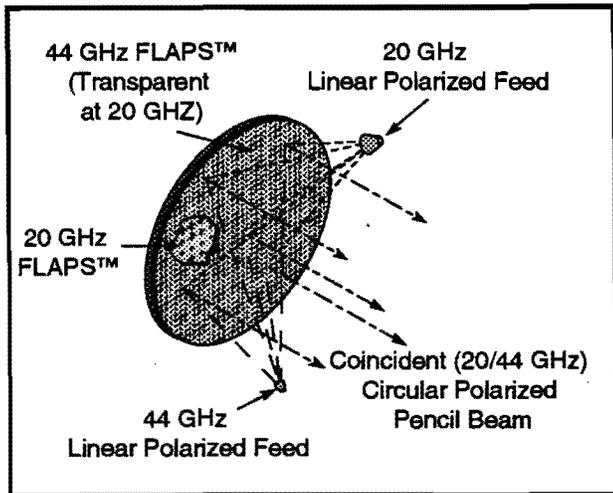


Figure 8

Low-Cost FLAPS™ MILSTAR Antenna
Thin sandwiched reflector designed to operate at widely separated frequencies

LOW RADAR CROSS SECTION ANTENNAS

Unlike conventional reflectors or planar arrays, FLAPS™, which are frequency specific, exhibit Low Radar Cross Sections in all directions and at RF frequencies other than the frequency of design. Because a FLAPS™ with a resonant dipole groundplane is RF transparent at frequencies out of the design band, no incident RF is reflected. The radar cross section can be further reduced by adding radar absorbing material behind the FLAPS™ to prevent RF from reflecting off the other surfaces behind the antenna.

CONFORMAL FLAPS™

Nearly any geometrically shaped surface can be "electromagnetically reshaped" with FLAPS™ technology to yield the desired reflection pattern characteristics. This feature is not only useful for antenna aperture shaping, but is also an effective method of altering the radar cross section of an object to appear as a disguise or a decoy. Various surfaces of buildings, vehicles and other structures can function as the FLAPS™ host. Figure 9 shows one possible conformal configuration in which the leading edge of an airplane wing was used as a radar antenna.

In difficult siting environments the surface of a building, fence, or parking lot, for example, can function as the FLAPS™ reflector of a fixed satellite earth station antenna even though it is not normal to the direction of the satellite of interest. Furthermore the ability to orient the feed at any location with respect to the FLAPS™ greatly simplifies the antenna design.

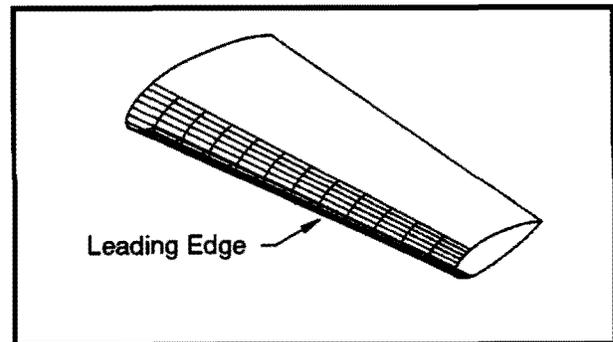


Figure 9

Conformal FLAPS™ Reflector
Conformal surfaces can be modified with FLAPS™ technology to perform as an antenna reflector or radar cross section reducer

WIDE ANGLE SCAN

Typically, the beam of a conventional parabolic reflector is scanned by moving the feed and the reflector via a gimbal mechanism. The beam can also be scanned a small amount by moving only the reflector and keeping the feed fixed, or vice versa, but not more than a few beam widths without significant pattern distortion.

By using a unique non-parabolic shaped reflector that is "phase corrected" with FLAPS™ technology, however, it is possible to scan the beam a very large number of beam widths by only moving the reflector and still maintain good pattern integrity. This unique feature of FLAPS™ (called "Tilt Flaps"), as shown in Figure 10, is currently being used in a prototype landing radar system. This antenna yields rapid beam scanning using light weight FLAPS™ surfaces and no rotary joints.

3. MECHANICAL DESIGN FEATURES

FLAPS™ surfaces can be fabricated in a variety of ways, since the only mechanical requirement is to support the double-layer of dipoles with the desired spacing between layers and be-

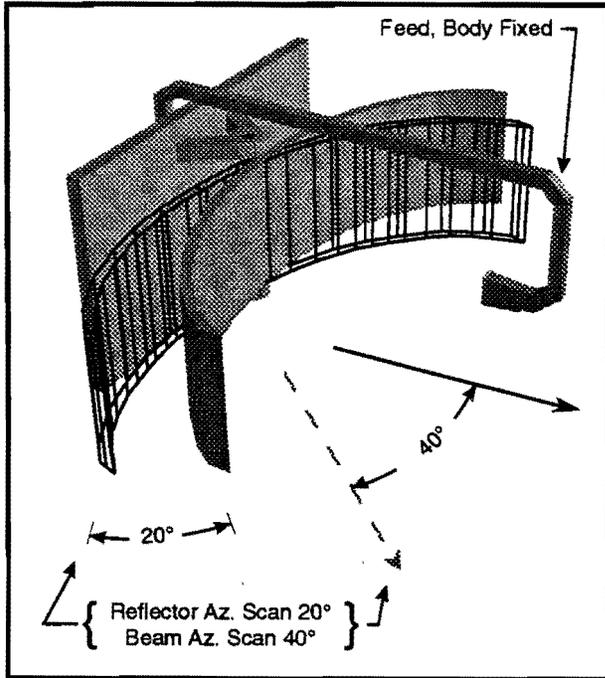


Figure 10
"Tilt FLAPS" Scanning Reflector Antenna
A non-parabolic surface phase corrected with FLAPS™ yields wide angle beam scanning with no rotary joints.

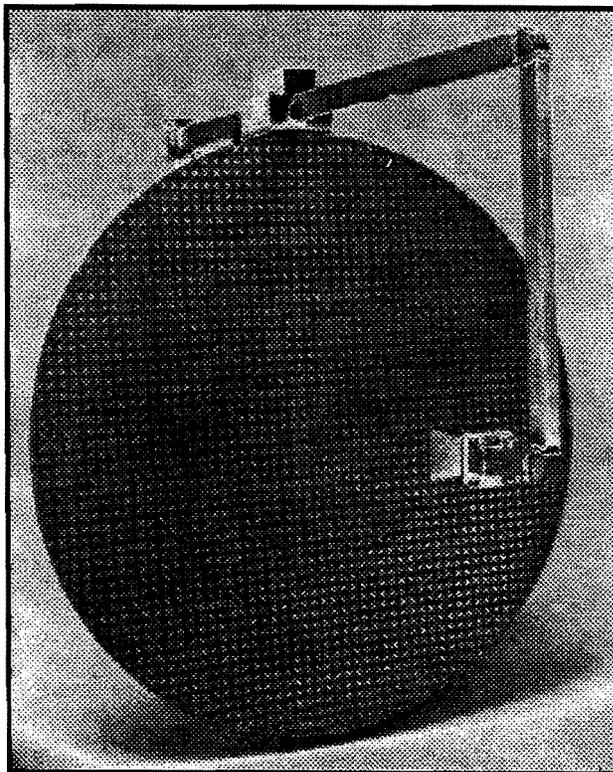


Figure 11
FLAPS™ Antenna with Test Feed
Manufactured using simple printed circuit board technology

tween dipoles, and with adequate mechanical integrity to maintain the spacing and surface shape under the anticipated operating loads. For most ground-based applications to date, FLAPS™ surfaces have been etched from double-layer printed-circuit boards, as shown in Figure 11. Such design lends itself readily to low-cost CAD/CAM fabrication. An even lower cost panel has been produced by silk-screening onto plastic panels intended for direct-broadcast consumer TV reception (Figure 12). These panels readily produce the required surface shape (e.g. flatness) and surface smoothness, even at 94 GHz frequencies.

Such solid-dielectric designs may be applicable in space applications as well. However, a

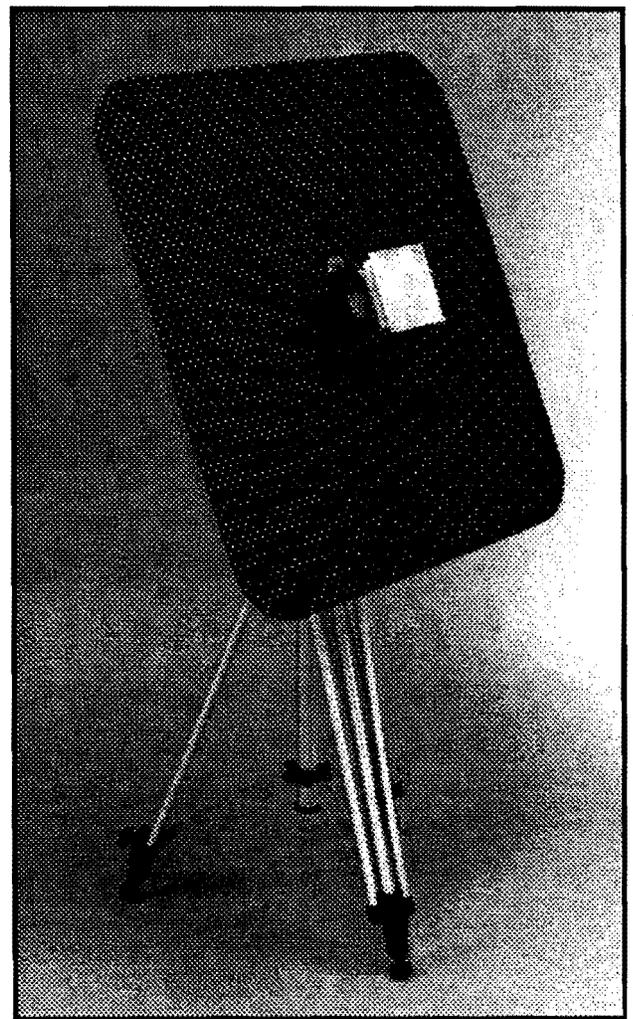


Figure 12
Low-Cost FLAPS™
Dipoles are silk-screened on low cost plastic dielectric

much lower-mass FLAPS™ is possible, since the dielectric layer can be lightened considerably. In a companion paper¹, designs are shown based on lightened-foam-plastic dielectric layers with the dipoles deposited on thin Kapton films. Such designs are shown to result in reflector masses as low as 0.05-to-0.1 kg/m², not including the supporting structure.

A FLAPS™ design which eliminates the (solid) dielectric layer entirely has been built for ground-based applications where high wind loads are anticipated (Figure 13). This consists of Kevlar

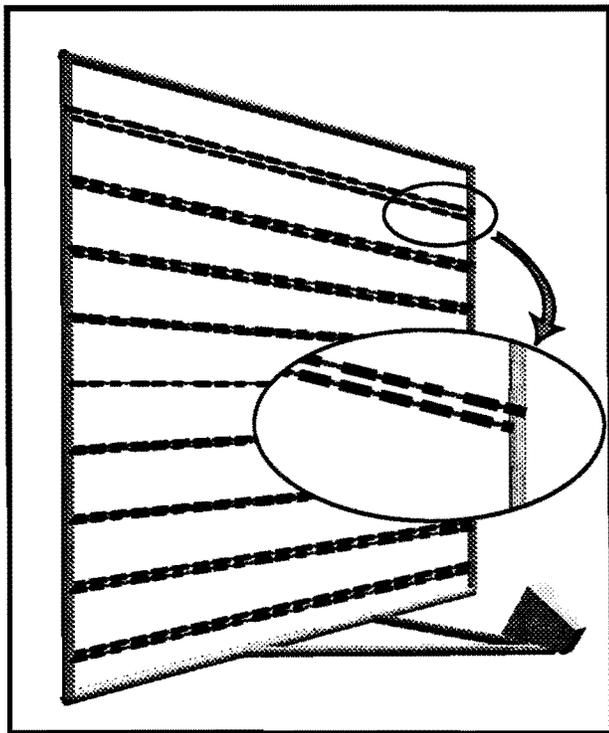


Figure 13

Low Wind-Load FLAPS™ Antenna

Linear Polarized dipoles suspended with Kevlar strands results in lightweight, load-insensitive surface

strands stretched across an aluminum frame, with conductive tubes fixed to the strands at the proper positions to form the dipole arrays. This open structure has considerable promise for space applications as well, particularly for the lower frequencies (e.g.; C- and L- band) due to its minimal mass and insensitivity to launch and thermal loads.

4. PACKAGING FOR SPACE

Because FLAPS™ reflectors can be configured in so many different ways, packaging and deployment is limited mainly by the imagination of the designer. The planar configuration lends itself to the simple folded approach as shown in

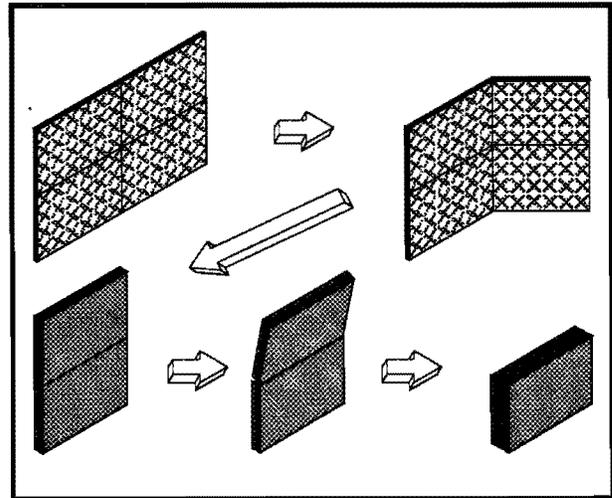


Figure 14

Folding FLAPS™ for Portability

Large apertures can easily be packaged to satisfy space and deployment requirements

Figure 14, or an accordion fold as shown in Reference 1. Another possible approach is illustrated in Figure 15, where the reflector is arranged to fit

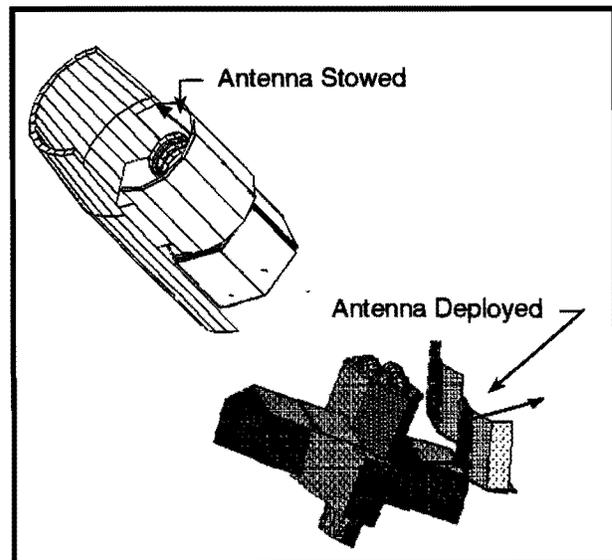


Figure 15

FLAPS™ Antennas Ideal for Small Satellites

Large apertures can conform to a Pegasus shroud and deploy with a simple hinge arrangement

within the shell of a Pegasus shroud, surrounding a small remote-sensing satellite. In this example, a single hinge motion deploys the surface, which, although irregular, is "corrected" by the FLAPS™ pattern to duplicate a paraboloid. Each panel can be fashioned from an array of Kevlar strands, or from a laminated sandwich of conductors and dielectric. The deployed aperture may be used to establish a TDRSS link, for example.

Kevlar strands with vapor-deposited conductors can be wound around a mandrel and deployed by STEM™² or TEE™³ deployers, as illustrated in Figure 16, with positive tension applied to stabilize the strands under the minimal space loads. For very large apertures (20 meters or larger), inflation-deployment might also be possible, as illustrated in Figure 17. In a diameter of 40 meters, the active surface of an inflatable FLAPS™ can weigh less than 100 kg.

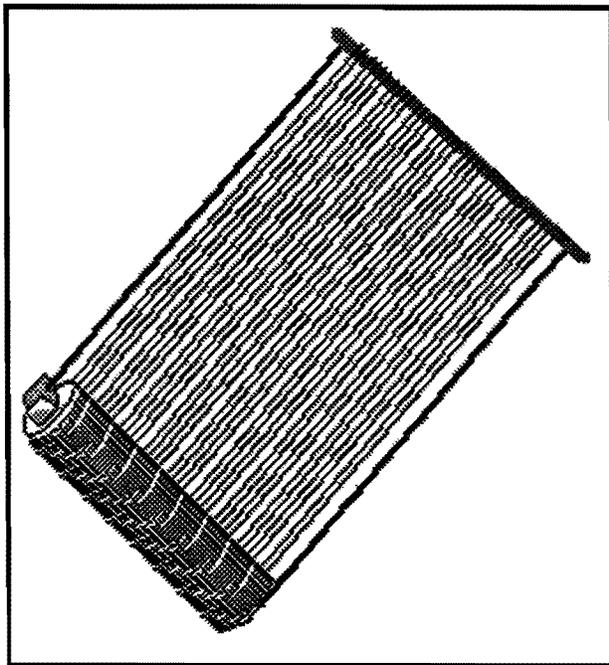


Figure 16
FLAPS™ Antennas Deployed in Many Ways
FLAPS™ Surfaces wound around a mandrel

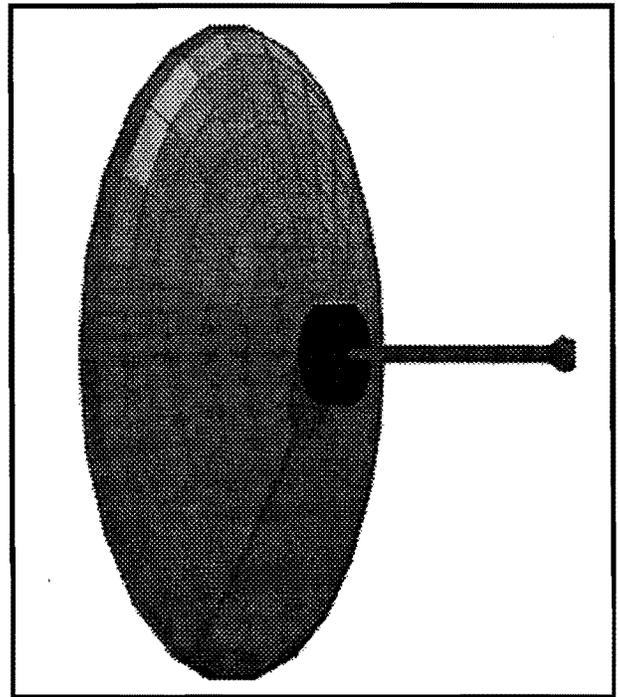


Figure 17
Inflatable FLAPS™ Antenna
Inflated FLAPS™ surface supported from center cylinder

ADVANTAGES OF A FLAPS™

A flat reflector has many advantages over a parabolic reflector. One significant advantage is its low production costs. FLAPS™ fabrication costs are comparable to those associated with manufacturing single-layer printed circuit boards. Alternative fabrication techniques such as silk-screening conductive ink on low cost dielectric material can further reduce fabrication costs

5. CONCLUSIONS

FLAPS™ technology offers a new level of freedom to the satellite designer in the packaging and deployment of large-aperture antennas for use by small (and large) satellites. For example, a TDRSS cross-link antenna can be fitted within a Pegasus shroud within the available volume. FLAPS™ is especially attractive for applications requiring large apertures, polarization control, specialized beam-shaping, and low recurring costs.

¹ B. Raab, R O. Bartlett; A Low-Cost Small Satellite Space Radar System, 6th Annual AIAA/Utah State University Conference on Small Satellites, 1992

² trademark of Astro Aerospace Corp.

³ trademark of Fairchild Space