The Use of Printed Microstrip Antennas Designed for Small Spacecraft at Ultra High Frequencies

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Abstract: The cost for putting instruments into space grows immensely as the size and weight of a spacecraft increases. This constraint has urged NASA to pursue technology that will enable smaller, cost efficient spacecraft. Antennas are required for spacecraft communication, tracking, and radioscience and size is often a limiting factor. At low frequencies, the size of antennas can become significant. Microstrip antennas are relatively inexpensive to design and fabricate and are desirable at Ultra High Frequencies (UHF) due to the properties of the antenna that are directly tied to the wavelength at the resonant frequency. Microstrip antennas are electrically small (small relative to a wavelength) and therefore are ideal for use on very small satellites (CubeSat, PicoSat, and NanoSat). We are investigating the properties of electrically small UHF antennas for use on small spacecraft. Technologies that are currently being used for antenna design in various applications will be evaluated and compared. These designs will then be adapted and optimized for small spacecraft environments.

Limitations of Antennas Used in Space Applications

- To maximize antenna performance, many antennas use the wavelength of the resonant frequency as a guide for the dimensions of the antenna. At lower frequencies (e.g., UHF, 300 MHz), the wavelength is 1 meter, resonant antennas such as electric dipoles can be very large.
- Ammonia and methane in the atmospheres of giant planets absorb microwaves, and the absorption increases approximately as frequency squared. To improve link margins it is preferable to use lower frequencies which generally requires larger antennas.
- Deployable antennas often require additional mass, volume, and deployment mechanisms, and these resources are not always available on small satellites. Microstrip antennas provide a method of increasing antenna performance without adding the additional complexity that are associated with deployable systems.

Antennas Used in Current Space Applications

Deployable Antennas

- Antennas such as dipoles and folded dipoles are being researched. The designs consist of a compact system for launch and a mechanical system that will deploy the antenna when the satellite has reached orbit.
- Concepts such as the Northrup Grumman Storable Tubular Extendable Member (STEM) monopole JIB antenna is being used as a size effective solution for deployable antennas.
- There is also work on compact deployable designs such as the Boeing Miniature Deployable High Gain Antenna for Cubesats. This system provides an antenna with high gain (approx. 18 dBi at S-Band frequencies), but requires a large space (approx. 9.2x9.2x5.0cm), in this case, this is the only instrument (along with associated circuitry) that is flown in a 1U cubesat system (no scientific sensors).

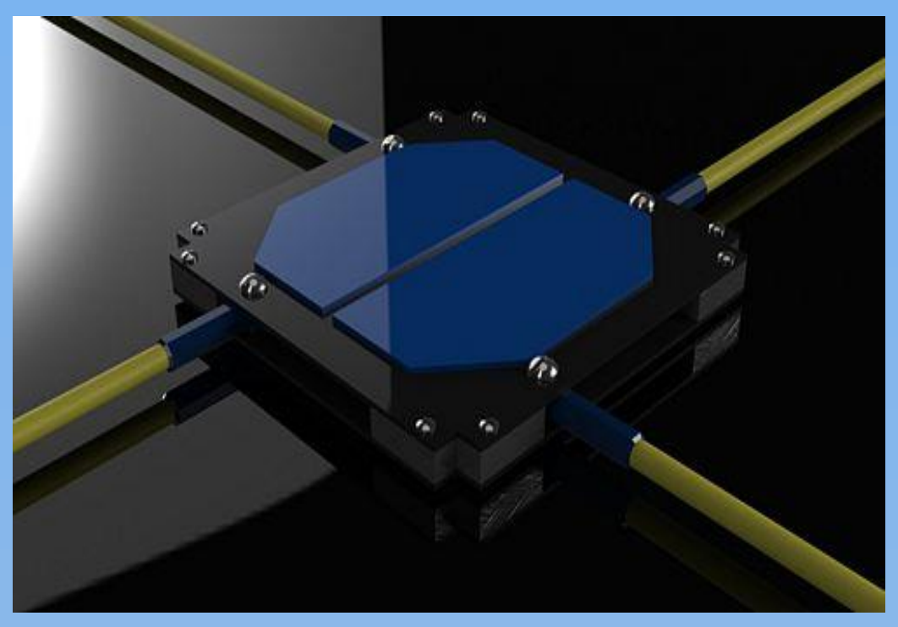


Figure 1: ISIS Deployable Antenna System

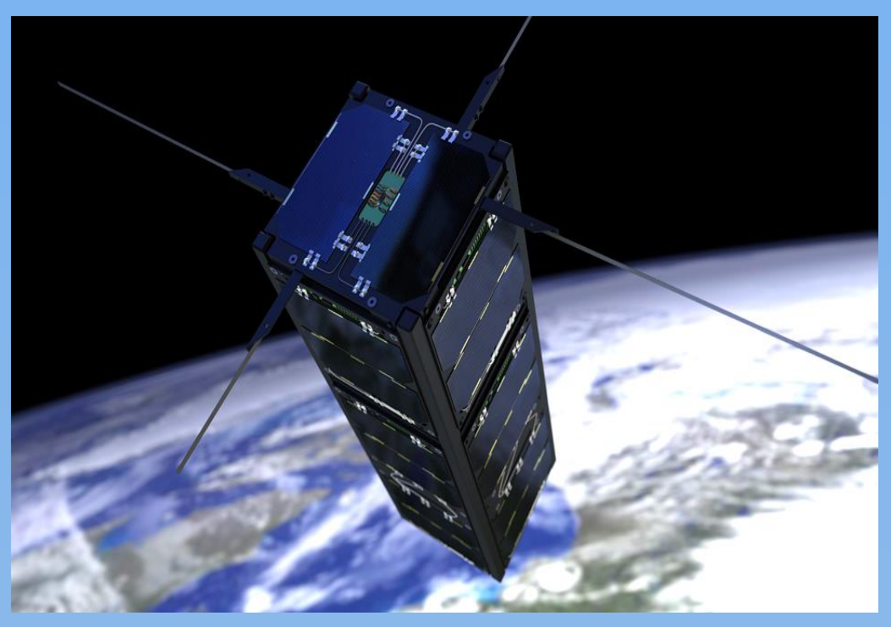


Figure 2: ISIS Deployable Antenna on a Cubesat

Compact Rover Antennas

- **Mars Science Laboratory (MSL)** is equipped with multiple antenna systems for use during different stages of Cruise. and Entry, Descent, and Landing (EDL). A high gain antenna, a medium gain antenna, and four (4) low gain antennas.
- The **High Gain Antenna (HGA)** is deployed after MSL lands and consists of a 48 element microstrip patch array. This system is mounted on a 2-axis gimbal system that allows the antenna to be pointed towards any of the DSN antennas. This lets MSL communicate with the DSN without requiring the rover to adjust its position.

Gain:	Transmit: 25.5 dBi
	Receive: 20.2 dBi
Ploarization:	Right Circular
Antenna Type:	48-Element Microstrip Array
Frequency:	Transmit: 8401.4 MHz
	Receive: 7150.8 MHz

Table 1: MSL HGA Characteristics

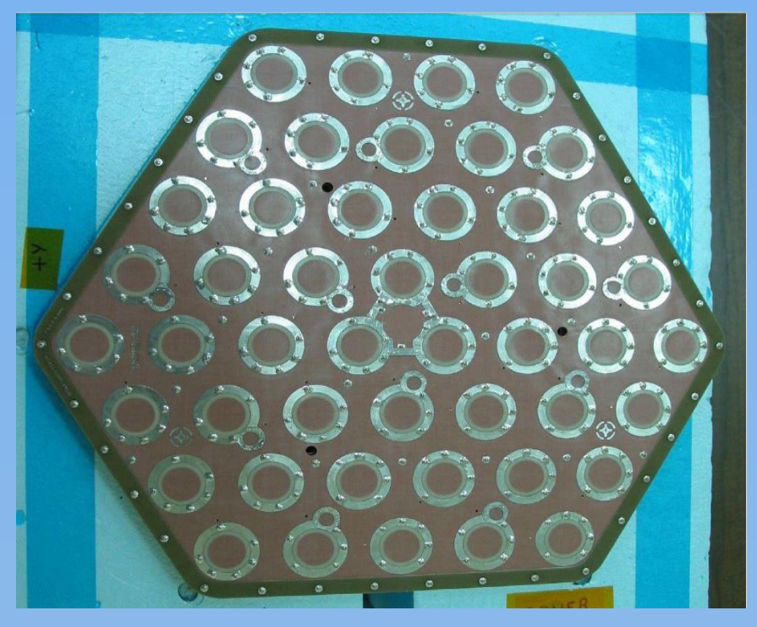


Figure 3: MSL HGA Array

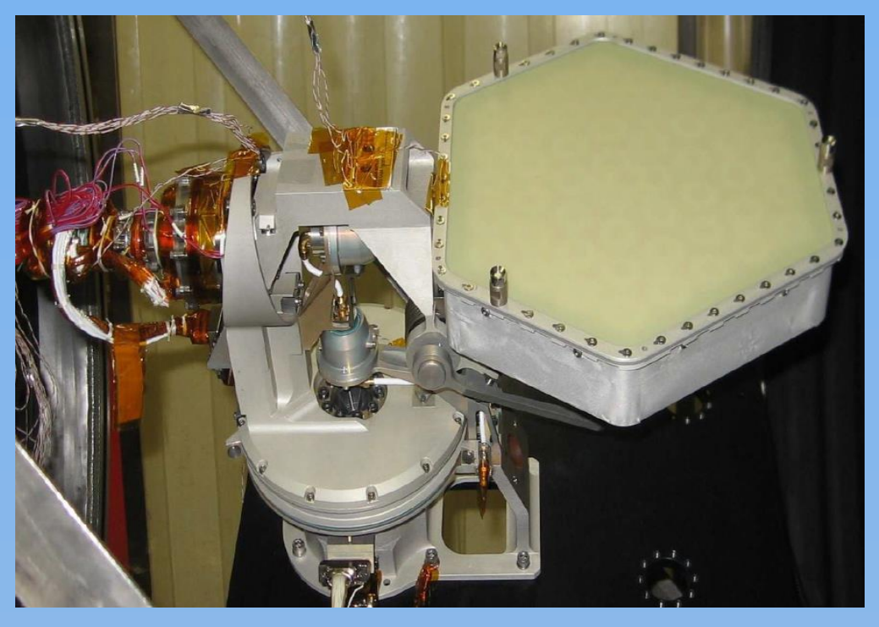


Figure 4: MSL HGA Array (Assembled)

Inflatable Antennas

- A private company, L'Garde, in conjunction with NASA, developed a 14-meter inflatable reflector antenna that was flown and deployed from the STS-77 space shuttle. This high gain antenna was designed for Deep Space Communications.
- Inflatable antennas are a good alternative for larger spacecraft; however for cubesat systems, inflatable antennas may not be applicable due to the compact size of the launch package. Electrically small antennas provide cubesats systems with a good alternative to creating deployable/inflatable mechanisms.

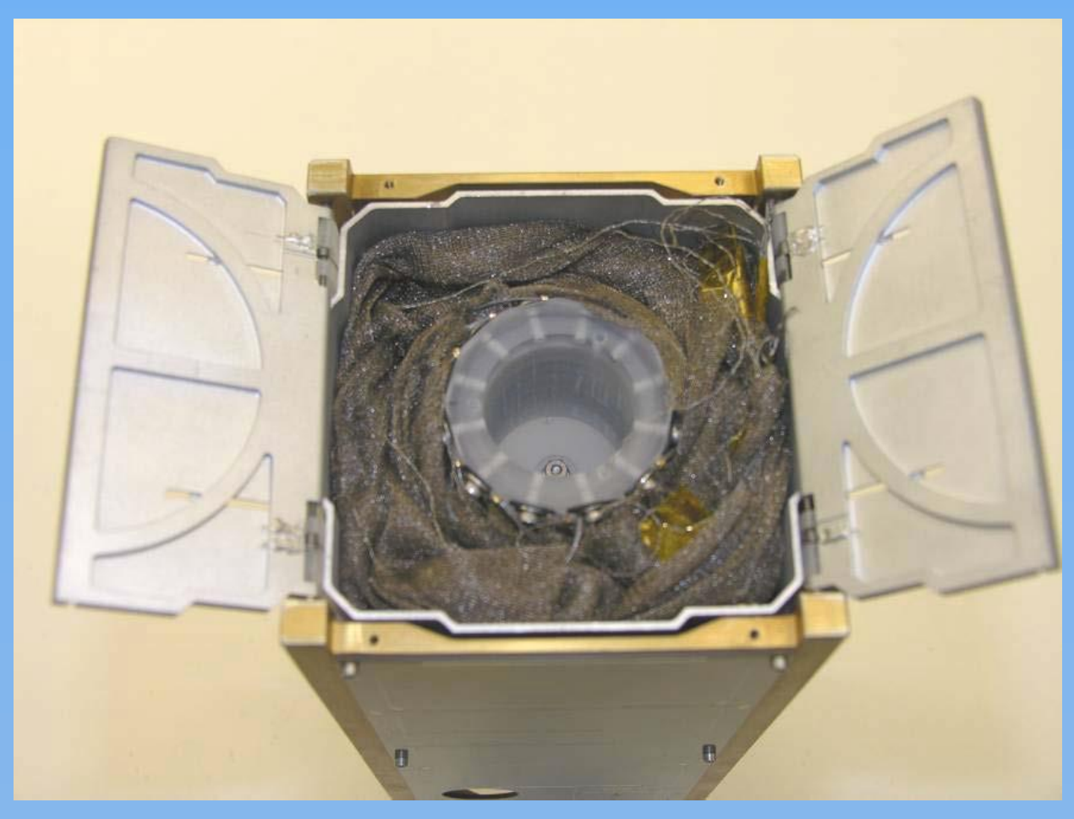


Figure 5: Boeing Miniature Deployable HGA (Compact)

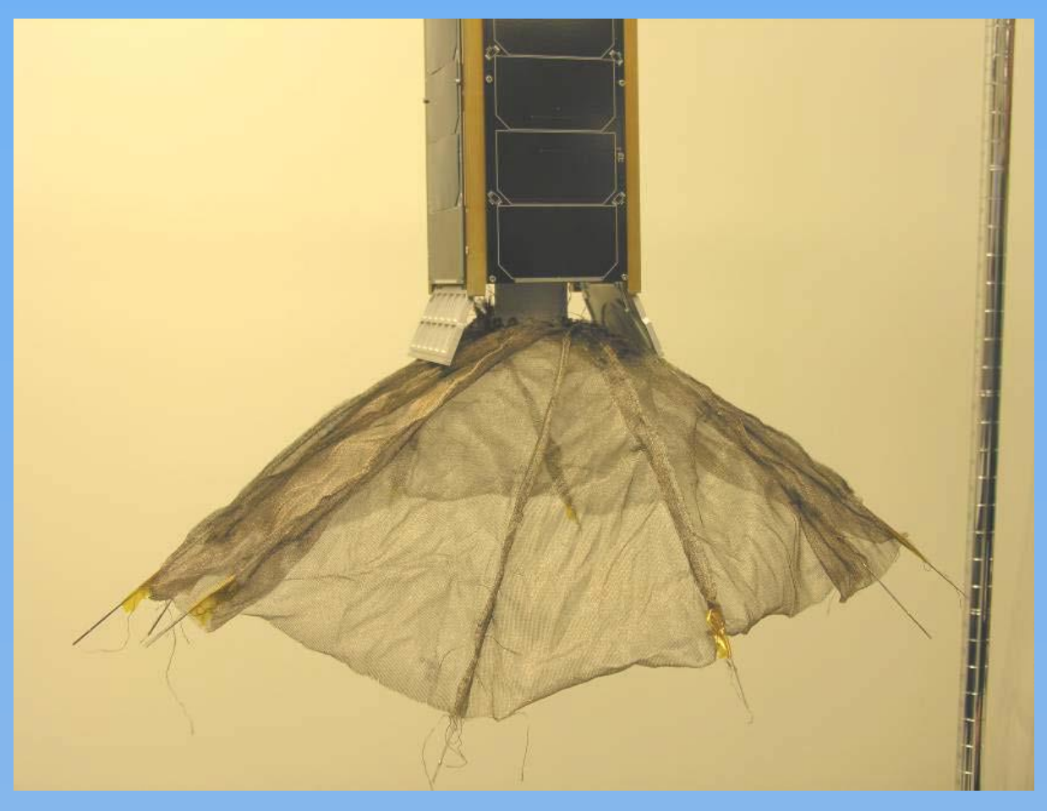


Figure 6: Boeing Miniature Deployable HGA (Being Deployed)

Microstrip Antennas

Background: Printed microstrip antennas, first introduced in 1972, are a very well known technology when working with microwave and millimeter-wave technology. Due to the ease of fabrication, low cost, and low volume and weight, microstrip technologies for antennas continue to be a field of active research. Microstrip antennas are constructed by placing copper traces onto a dielectric substrate in a shape or pattern. First introduced with the rectangular designed, the geometries that can be used and combined are essentially limitless. The most common geometries are circular and rectangular. However, research to specialize antennas for specific projects is becoming increasingly popular. Research using evolutionary and genetic algorithms provide an option to specialize the antenna characteristics for a specific project. Using these algorithms, microstrip antennas can be designed with desirable characteristics (polarization, impedance, bandwidth, gain, etc…) that can be tailored to meet specific projects and applications (e.g., Cell phone applications, space applications, omnidirectional or directional, etc...). Three possible geometries are shown below, note how the design of geometries can effect the characteristics of the antenna.

Pros:

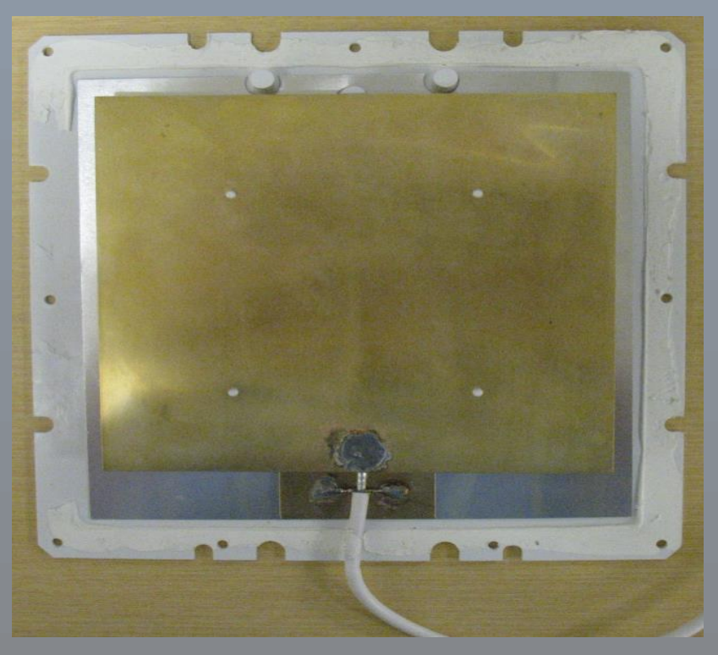
- Relatively low cost, easily manufactured, electrically small, low volume and weight
- Compatible with integrated circuit technology
- Can be configured into an array system that can be designed to better control beam patterns as well as gain
- Large number of geometries can be used to modify the properties of the antenna such as polarization, beamwidth, impedance, etc…
- Microstrip transmission strips can be easily implemented to decrease/increase the voltage standing wave ratio (VSWR)
- There is no need for a deployment system. The design can be mounted anywhere on the cubesat system that has a clear, smooth surface.

Cons:

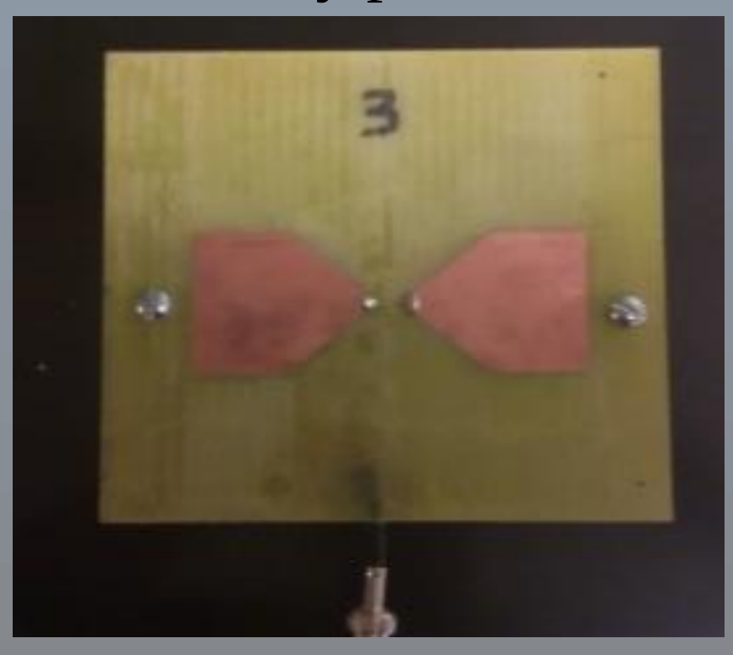
- Designing a microstrip patch antenna with required gain, beam pattern, and input impedance can be challenging
- Reactive input impedances are generally higher in microstrip antennas and make power transfer difficult
- At low frequencies, microstrip patch array antennas are usually electrically small (small physical size relative to a wavelength), making it a challenge to design an antenna of reasonable gain and beamwidth.
- Poor cross polarization purity

Microstrip Examples Using Different Geometries

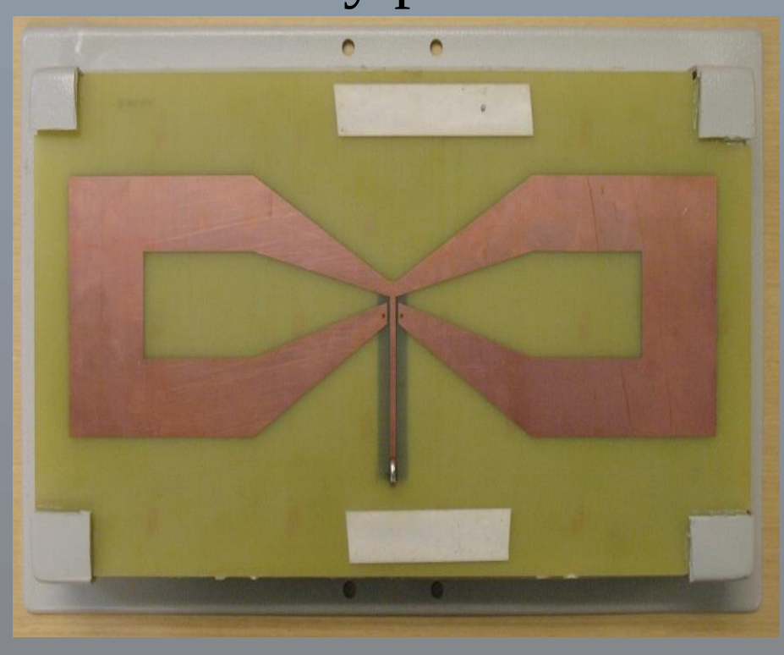
Patch (Rectangular) Microstrips:
Gain approx. 5-7 dBi
HPBW ~ 60°
Linearly polarized



Bowtie Microstrips:
Gain approx. 5-9 dBi
HPBW ~ 45°
Linearly polarized



Folded Diploe Microstrips
Gain approx.10 dBi
HPBW ~ 35°
Linearly polarized



Conclusion

Although deployable and inflatable antennas may provide an alternative option for high gain antennas, microstrip antennas require very little mechanical structure after the initial mounting procedure, and do not require a deployment system. In many cases, small satellite systems lack the mass, volume, power, and structural integrity to provide deployment mechanisms for electrically small antennas. Continued development of microstrip antenna technologies can provide a relatively cheap, lightweight, and efficient alternative to larger and more mechanically and electrically complex antennas.

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