6 Conclusion

This report investigated the designs of circularly polarized telemetry and GPS microstrip antennas on cylindrical surfaces. The impetus for these investigations was to provide ASRP with information describing the design and performance of microstrip antennas on a sounding rocket. This section will briefly summarize the results of these investigations and conclude by specifying recommendations and future work that would aid in the design and use of microstrip antennas by ASRP.

6.1 Design of Circularly Polarized Elements and Arrays

Microstrip antennas are thin, lightweight, durable, and can easily be conformed to cylindrical surfaces. Another advantage, when compared to other types of antennas, is that they can achieve circular polarization using simple and small geometries. Circularly polarized antennas have less polarization mismatch loss than linearly polarized antennas when transmitting and receiving antennas change orientation relative to each other. This is of particular interest when designing a sounding rocket antenna, because its orientation and position continually change in reference to the ground station antenna. Because of these and other advantages, microstrip antennas are well suited for use on ASRP sounding rockets.

The operation of microstrip is generally very complicated. By applying fullwave analysis techniques, a microstrip antenna can be analyzed very accurately. However, for practical purposes, fullwave methods are very difficult and time consuming to apply. For basic microstrip geometries, the simpler analysis techniques generally provide results that are accurate to within a few percent.

Using the basic transmission line model, cavity model, and HED equations, both linearly and circularly polarized antennas can be designed very quickly. Although, when these antennas are fabricated and tested, they will have to be tuned slightly, by changing the patch dimensions until the desired antenna characteristics are obtained. If a fullwave CAD program is available, then the tuning process takes less time because the initial design results are usually more accurate than those of the simple models.

The design of an array of microstrip elements is more challenging than the single element design. The main reasons are that arrays require more complex feeding networks and are affected by mutual coupling. Again, an array of patches can be designed using the elements designed from the simple models, but the tuning of the antenna is more time consuming. A fullwave CAD program can save significant time in the design and tuning of a microstrip array because they can accurately model both the complex feed networks and the mutual coupling effects.

6.2 Tuning of Fabricated Microstrip Antennas

Using equations from the basic models, both linearly and circularly polarized microstrip elements can be designed quickly and with reasonable accuracy. In this paper, the design of circularly polarized telemetry and GPS antennas using microstrip were presented using both the basic equations and CAD software. If a CAD program was not used in the design, the patch elements would require tuning after fabrication, until the intended design frequencies and axial ratios were obtained. This tuning generally takes a considerable amount of time. The results from the element designs presented in this paper give practical guidelines for tuning patch elements (see tables 4.9, 4.10, 4.13, 4.14, 4.17, and 4.18). With this data, the tuning of the axial ratio and resonant frequency for circularly polarized patch elements can be accomplished by changing the perturbation segment lengths and patch lengths accordingly. For example, if the axial ratio is 1 dB, then the factors listed in the tables specify how much the perturbation segments need to be modified to achieve an axial ratio of 0 dB. While these tables were derived from the analysis of individual elements, they can also be used to effectively tune arrays.

6.3 Number of Elements to Achieve Omnidirectional Radiation

Microstrip antennas radiate broadside to their surface. A planar microstrip antenna has a unidirectional radiation pattern. When an array of patches is equally spaced around the cylindrical surface of a sounding rocket, the radiation pattern becomes azimuthally symmetric. To achieve a pattern with minimal ripple, a sufficient number of patch elements must be used in the array. The results from the array analysis sections in chapter 4 relate the ripple to the element spacing and guided wavelength, (tables 4.6, 4.22-24, 4.26-28, and 4.31-33). For practically all the antennas analyzed, both linearly and circularly polarized, and for both telemetry and GPS frequencies, it is clear that the radiation pattern has very little ripple when the element spacing is less than a guided wavelength. Generally, there is no requirement for the exact number of elements, as long as this guideline is met. However, the number of elements do affect the complexity of the corporate feed design. The only case where this element spacing rule-of-thumb did not apply was with the GPS array on the 6 inch cylinder. For this case, the effect of curvature was significant because the radius was nearly half the guided wavelength.

6.4 The Decision to use Linearly or Circularly Polarized Antennas

Linearly and circularly polarized telemetry antennas were compared to provide insight as to which type of antenna should be used by ASRP on their sounding rockets. The circularly polarized elements used in the study were single fed elements; this was because of their simple design and small size. The comparisons showed that the impedance bandwidths, directivities, and gains were very similar for circularly and linearly polarized antennas. The main difference was their polarization mismatch losses. Another difference was that the linearly polarized wraparound patch had significantly greater impedance bandwidth than the linearly and circularly polarized antenna arrays.

The main difference in the linearly and circularly polarized antennas is the polarization mismatch between the rocket and the ground station. The circular polarization provides a 2.5 to 3 dB improvement, except in the regions exceeding +/- 60 degrees away from broadside in the elevation plane of the rocket. In other words, in the elevation plane, the circularly and linearly polarized antennas have similar polarization mismatch losses near the top and bottom ends of the rocket.

The other differences between the linearly and circularly polarized antennas are related to the degree of design complexity. First, the linearly polarized antennas much easier to design, match, and tune. When designing a linearly polarized element or array, or wraparound patch, it is only the length of the patch that is critical in the design and tuning processes. It is also quite easy to match a linearly polarized element by using a simple quarterwave transformer. In contrast, two parameters are critical in the design and tuning processes for the circularly polarized element and array; these parameters are the length of the patch and the size of its perturbation segment. Additionally, the circularly polarized antenna requires a more complicated matching network.

To determine which antenna should be designed and used on the rocket, several things must be considered. First, the trajectory and orientation of the rocket with respect to the ground station's antenna must be considered. If the station will be broadside to the rocket, then a circularly polarized antenna is attractive. Other considerations are how knowledgeable the person(s) designing the antenna, whether they have access to a CAD program, and whether they have access to accurate fabricating and testing facilities. If the person lacks significant knowledge in antennas and their tests, and there is no CAD package available, then the linearly polarized antenna is the more attractive choice. It is much more difficult to design and test a circularly polarized microstrip antenna and array.

6.5 Recommendations and Future Work

6.5.1 Recommendations

A fullwave CAD program is needed in the electrical engineering department. While it is possible to design linearly polarized microstrip antennas and arrays without a CAD program, it is almost essential when more complicated microstrip antennas are to be designed. Since the curvature effects of microstrip antennas on a cylinder are significant only when the radius of the cylinder is small relative to the guided wavelength, a planar CAD package would suffice for the designing of sounding rocket antennas with large radii. CAD software packages currently available can accurately design microstrip antennas having complex geometries and multi-layers. Other benefits of having a CAD program is that microstrip antennas can be designed in less time, for less cost, and can serve as a learning tool for students studying microstrip lines and microstrip antennas.

A standard antenna, whose parameters are known, is needed to make accurate antenna measurements. Additionally, for circular polarization measurements, a precise rotating mount for the standard antenna should be constructed or purchased.

The electrical engineering department needs access to accurate testing facilities. This means that the current anechoic chamber must be upgraded. It currently is too small for antenna arrays whose largest dimension exceeds approximately 1 ft. The chamber also needs a fixed (mounted) source antenna. Also needed is a rotating platform for the antenna under test. Ideally the measurement system, consisting of the source antenna, the antenna under test, the rotating platform, and a network analyzer should be controlled by a personal computer with ability to execute GPIB commands.

In order to make accurate measurements, it is also important that design engineers have access to cylindrical structures that accurately represent the sounding rockets. These cylinders should be made with the same materials as the rocket and should allow the microstrip antenna to easily be mounted and unmounted for testing purposes.

Finally, there are two miscellaneous items that are necessary to make antenna tests. First, an array having multiple feed points will require a power splitter to feed the antenna elements under test. Also, if the antenna is tested outside, the transmitter and measuring equipment will require battery operated power supplies.

6.5.2 Future Work

The most important future work that was not considered in this paper is the effect of temperature on a microstrip antenna's performance. It is much colder outdoors when the sounding rockets are typically launched at Poker Flat. Additionally, the atmosphere is much colder at the high altitudes where the antennas will operate. Temperature change will affect the physical dimensions of the copper and substrate lengths and the dielectric's permittivity. Since both the physical length and the permittivity affect the resonant length of the patch, it is critical to know both the operating temperature and temperature changes of the antenna while in flight. Apparently, extreme cold temperatures result in an increase in substrate permittivity and a decrease in copper length. While together these appear to mitigate any detrimental changes in the antenna's operating frequency, the effects that temperature has on the microstrip antenna's resonant frequency, bandwidth, beamwidth, and axial ratio must be investigated.

Another important area that should be investigated is the effect superstrate loading has on microstrip antennas. This is important because superstrate layers are often used to protect the antenna from the environment. Additionally, if any moisture or ice forms on the rocket, this loading may affect the antenna's performance.