DESIGN STUDIES ON THE DEVELOPMENT OF A NEW TECHNOLOGY INVOLVING ELECTROSTATIC ANTENNAE

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ABSTRACT

A collaborative design study is conducted on the various possibilities for a new type of technology called an electrostatic antenna. In the design of an electrostatic antenna, an extremely interesting and challenging problem for both engineers and product designers is uncovered. The design can take many different forms depending on the antenna application. The objective of this study was to investigate the different applications of electrostatic antenna technology and to develop corresponding designs. Toward this end, an interdepartmental design effort was conducted between engineers and product designers which focused on developing new electrostatic antenna designs. The findings from this effort are provided here along with an evaluation of the designs produced in this effort.

In designing this new technology, a new and innovative approach was implemented as well. The principles of design with regard to any product are often commingled; the result of various directions of research. Over the period of this study, two distinct philosophies of design were utilized. One philosophy comes from the engineering design curriculum while the other comes from the product design curriculum. Each has merit and can succeed independently, but neither philosophy when used alone can produce the best quality product. As the two philosophies, engineering design and product design, unfold themselves, an obvious link between the two design approaches is uncovered. Each philosophy was trying to solve the same problem, but neither seemed to acknowledge the strengths from the philosophy of the other. This quandary is not related to the difficulty in recognizing the importance of the other philosophy, but rather to the lack of recognizing the synergistic potential of the two philosophies. In engineering, especially mechanical engineering, the typical objective is to build a product that will accomplish a particular function. In product design, the typical objective is to solve a problem in a new and innovative way. The "problem" in the two philosophies differ, but the philosophies also overlap in their design potential.

Utilization of both philosophies in a similar manner is the idea behind this study. Specifically, this study focused on generating innovative designs for a new type of space-based antenna called an electrostatic antenna. To generate new designs, a collaborative design effort was undertaken to bridge the gap between product design and engineering design for this new technology. The goal of the effort was to identify specific missions for which electrostatic antenna technology is best suited and then to design electrostatic antennae for these specific missions.

INTRODUCTION

Electrostatic antennas refer to antennas whose shape can be altered by the use of electrostatic forces. This concept was first developed by Perkins [1] in 1976, and laboratory experiments were performed by Goslee [2] in 1978 at NASA Langley Research Center and by Lang at MIT in 1982. In these efforts, the objective was to use electrostatic forces to maintain the shape of large antennas with diameters greater than fifty feet. The attraction of charges between the membranes, regulated the shape of the membrane enclosed by a hoop.

Later Silverberg in 1992 eliminated the compression hoop and replaced the back membrane with metallic segments. The electrostatic forces then could be implemented to deliberately change the shape of the membrane. By changing the shape of the membrane, this technology was expanded to enable the control of the associated beam pattern of the antenna. The control of the beam pattern is desirable in a variety of space-based antenna applications. Indeed the ability to control the beam pattern can be regarded as offering a significant advancement in the performance of space-based antennas. Beam pattern control can be viewed as offering three types of capabilities as shown in Fig. 1. First, the
size of the region that is being reached by the antenna can be altered. Second, the physical location of the region being reached can be altered. Finally, the integrity of the beam pattern throughout the region reached by the antenna can be tailored to meet specific mission requirements [3].

Fig. 1. Different Scanning Properties of the Electrostatic Antenna

The electrostatic antenna achieves these capabilities in various manners depending on the particular design. The current design of the electrostatic antenna has an antenna that utilizes a rigid back-plate structure with a flexible membrane of mylar whose shape can be altered as shown in Fig. 2. The rigid back-plate is segmented in order to provide a greater degree of control. Each of the segments on the back-plate is paired to a segment on the flexible membrane. As electricity is applied to the paired segments of the back-plate and the membrane, the two segments repel each other and thus the membrane surfaces move away from each other. The relative distance between the two surfaces depends on the electrical voltage applied. By altering the amount of electricity, the distances between the surfaces and thus the shape of the flexible membrane can be controlled. This controlled deformation provides the necessary beam pattern control aforementioned.

Fig. 2. First Idea Generation of an Electrostatic Antenna

These developments of the electrostatic antenna place the technology at a relatively mature state with respect to engineering concerns. The necessary elements have been developed: electrostatic forces can be accurately predicted, arcing is well understood, methods for making electrical connections are available, suitable conductive membranes have been developed, and so on [4]. The current issues being addressed in the technological development deal with extending the technology to handle complex antenna shapes (ongoing North Carolina State University Research Grant with Lockheed-Martin Corporation). From a product design standpoint though, the state of electrostatic antennas is at its infancy. The few antenna designs that have been developed exist to verify the technology rather than to meet specific mission requirements.

One of the major components of the electrostatic antenna design is the limitations caused by electrostatics. Because a lack of fundamentals in electrostatic antenna basic research existed, two problems were encountered, one in the engineering realm and the other in the product design realm. The engineers were forced to develop a theory from scratch which described our basic use of electrostatics. The product designers, because of the lack of information available, had to develop designs based upon a vague definition of the properties affecting the product. Thus they had to stretch the product design to the limit to find a different approach for the electrostatic antenna concept. The product designers though were able to use definitions of properties based upon several experiments to develop usable rule-of-thumb parameters [5].

Another major component of the design involved the antenna limitations. Various classifications of the missions provide a starting point in the development of the electrostatic antenna. A description of the missions of satellites, the antenna uses on satellites, the current technology for antennas, and the current variable direction antenna technology is necessary for an understanding of the development. The first step in this development is to define the missions that are currently feasible for.
applications of the electrostatic antenna. There are two types of missions for a satellite to be useful with regards to our particular type of antenna as shown in Fig. 3. The first mission is for the satellite to be in a low earth orbit and the second is in geosynchronous orbit. The low earth orbit is very useful both to the

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Fig. 3. Satellite and Antenna Mission Descriptions

These three different objectives associated with beam pattern control can be accomplished by using three distinctly different antennas: the phased array antenna, the mechanically controlled antenna, and the electrostatic controlled antenna. The first antenna is called a phased array antenna shown in Fig. 4. These antennas take an incoming signal and change the direction of the signal by altering the physical properties of the signal. Although these antennas are accurate, the relative cost of the phased array antennas is extremely high [8]. The second type of antenna is a mechanically controlled antenna. These type of antennas move the focal point of the actual antenna or move the reflecting surface of the antenna which allows the antenna to control the beam pattern. The electrostatic antenna is the third type of variable beam pattern antenna. This antenna alters the shape of the reflective membrane using electrostatics. No such space-based electrostatic antennas are believed to exist in the private sector. This solution though is simple and potentially cost effective [9].

If a design is going to be successful, there must be a consumer or client in mind for the design. The client will have a particular application or mission for this electrostatic antenna. The best design possible is no good if no one wants the design. This is critical and a big problem with many programs. It is crucial in the space industry to find a possible niche for new engineering technological developments. The product designers used potential consumers of antennas for which to develop an electrostatic antenna design. A key step in the product design philosophy is to design for a particular consumer. The following companies are interested in this technology for various reasons related to the benefits of electrostatic antennas.

ASTRO (Army Space Technology Research Office) is interested in the deployment application of the electrostatic antenna. Ball Corporation of Boulder, Colorado, and Martin Marietta are interested in the paraboloidal shape that can be
obtained with the electrostatic antenna. Dr. Bill Criswell of the electrical engineering department at the University of Houston is interested in this antenna because of his research in power beaming. The Mars Mission Research Center is interested in the dual feeding application of the electrostatic antenna. Each party has different needs and uses for this type of antenna and technology.

**METHOD**

The basic engineering relationships between the parameters that describe an electrostatic antenna are important in the proper design of this type of antenna. These relationships are used in electrostatic antenna engineering. One question regarding deformable antennas is associated with the difference between the achievable deflections and the desirable parabolic form. The deflection of a beam subject to a distributed load is used to model the deflection of the electrostatic membrane. The root mean square error (RMS) associated with the change in deflection, $\Delta Y$, can now be determined to help evaluate the relative error associated with different geometries of the antenna as follows:

$$RMS = \sqrt{\frac{1}{L} \int_{x=0}^{x=L} \Delta Y^2(x) \, dx}$$

(1)

The analysis described above can be extended to the deflection of segmented beams. The deflection of a beam with a gap between the fixed side of the beam and the distributed load as shown:

$$Y = \frac{f(L-Bl)^4}{EI} \left( \frac{x}{L-Bl} \right)^2 + \frac{1}{6} \left( \frac{x}{L-Bl} \right)^3 - \frac{1}{24} \left( \frac{x}{L-Bl} \right)^4$$

(2)

where $B$ represents the percentage of the entire membrane that is not under the distributed load or the percentage of the segmented section. $L$, $x$, $E$, and $I$ are the length, horizontal position, material constant, and geometric constant, respectively. The maximum difference between the actual parabolic form and the deflected beam form is given by:

$$\Delta Y_{\text{max}} = \frac{3fL^4}{EI}$$

(3)

**Fig. 5. Root Mean Square Error Versus Geometric Consideration for a Segmented Membrane**

This value provides a bound for the rule-of-thumb precision necessary for the individual antennas shown below:

$$\lambda \geq \frac{3fL^4}{EI}$$

(4)

where $\lambda$ is the wavelength of the signal used by the particular antenna.

**Fig. 6. Wavelength Versus Root Mean Square Error**

The electrostatic force per unit length, $f$, across the gap between a pair of conductive segments was developed from Coulomb's law given by:

$$f = \left( \frac{\alpha kC^2}{gL} \right) V^2$$

(5)

where $V$ is the applied voltage, $g$ is the gap, $k$ is the electrical constant, $C$ is the bulk capacitance and $\alpha$ is an empirically found geometric design parameter (ideally equal to one).
Using (5) and assuming that the difference in the gap can be determined from the relative forces in (3), the force and the gap size required for equilibrium is realized. The gap size is determined based on the initial gap size and the force is given by:

$$g = g_0 + \Delta Y_{\text{max}}$$

(6)

Another parameter related to the basic principles of antennas is the necessary frequency range for the application of the antenna and the satellite. For the communication industry, which is the major application of the mission priorities, the frequency was between 5 to 10 GHz [7]. The overall size of the antenna was determined to be one meter in diameter. This is based upon the frequency range above. For the application involving power beaming, the actual diameter is around 100 meters because of the frequency for the power beaming. The physical separation between the conducting regions on the membranes was determined by the equation for arcing effects in electrostatics. The distance which was around 0.5 inches was determined experimentally for the voltages up to 30 kV. The equation for the arcing that occurs is governed by:

$$E_{\text{critical}} = \left(3 \times 10^6\right) \frac{V}{L}$$

(7)

where $E_{\text{critical}}$ is the critical value of the electric field or dielectric strength, $V$ is the voltage and $L$ is the length in meters. Arcing is based on the charge density in a unit area. After the charge density increases to a certain level, arcing occurs. This particular effect varies based upon the conditions of the atmosphere [10].

The antenna shape also is a major consideration because each shape has advantages and disadvantages for its particular functions. The two major shapes used by current antenna technology are the parabolic cylinder and the paraboloid. The parabolic cylinder is considered when a scanning motion is necessary. The parabolic cylinder can also change focus over a line segment area but not over specific locations. The paraboloid is of concern when the interest lies in focusing on specific locations. The scanning motion is more difficult with this type of antenna because of the difficulties altering the shape of the reflecting membrane in this motion. In this scanning motion, the membrane of the antenna has to be altered in two directions, instead of one as with the parabolic cylinder shape. These two different shapes vastly affect the possible implementations for each antenna [3].

### RESULTS

Many aspects of this product design process are similar to the aspects involved with the engineering design process. The differences are in the definition of the problem, the type of research done, and the idea generation concept called ideation. There are pros and cons of this system, but the system produces a fresh outlook to designing new products. The following five products were developed by implementing this new system. Each exhibits its own approach to the problem and provides a new and insightful look at different possible applications of the electrostatic antennas. The origins of the project are described along with the antenna and electrostatic application. An evaluation of the project is needed as well. There are two major areas which need to be critiqued while examining the pros and cons of the particular designs: the performance of the antenna and the feasibility of the project relative to the specific technology. This evaluation includes critiquing the five design projects in the following six different categories: performance, design principles, technology, deployment, actuators and construction.

The EAGLE antenna involves implementing the concepts of storage and compactness of form. This form is similar to the functioning of an umbrella. The antenna opens up like an umbrella and functions as a reflecting antenna once deployed. The electrostatics control the shape of the membrane of the antenna. The idea was to generate an antenna that was easy to use, simple in structure, ergonomically correct for application, and compelling in design. The EAGLE uses compactness of form and the study of nature to determine its final shape and construction [11]. The antenna begins in the form of a cylinder or a closed umbrella. The antenna is then charged at the outer ends of the antenna causing repulsion to take place. The individual components at the ends of the antenna move away from each other and the antenna folds out into the form of a regular reflecting antenna similar to an opened umbrella. There actually are two individual membranes on the opened antenna with one membrane as the back-plate and the other membrane as the reflecting medium. As soon as these are both unfolded, the back-plate membrane and the reflecting membrane are both charged up to the same electric potential. Then as the voltage is altered, the stationary back-plate membrane attracts and repels the reflecting membrane, allowing the antenna to focus by altering the overall shape of the reflecting membrane.

Because the EAGLE antenna works like an umbrella opening, the structure is simple and reliable. The design principle that was adapted for this umbrella structure was a study of compactness of form. In other words, space-saving structures were examined. The technology used in the EAGLE is an electrostatic membrane with an electrostatic deployment of the umbrella structure. The deployment uses the original shape of a folded cylindrical antenna that opens when repulsive electrostatic forces are applied to the ends of the membrane. The actuators are placed at the ends of the membranes for deployment and also in concentric

![Gap Size Versus Iteration](image)
circles on the two membranes for control of the paraboloidal shape. The construction is simple with the membranes attached to a central member.

The greatest advantage of this antenna is its simplicity because the performance of an antenna is directly related to the simplicity of the structure. Constructing this antenna is similar to building an umbrella, so the performance is good because of the knowledge in the construction of the latter. The implementation of electrostatic technology is more difficult on this antenna. The electrostatic membrane has trouble matching the paraboloidal shape necessary when focusing because the mylar membrane may not deform in multiple directions. The deployment is not difficult because the force generated is enough to spread apart the membrane to the proper gap size in the upper atmosphere. The actuators are placed on the base of the antenna and then they charge the outer concentric circles. The construction of this antenna is a bit tricky for the same reason that the construction of a similar structure such as an umbrella might be, i.e. because of the large number of moving parts. The only question for this type of antenna is the relative control of the shape of the antenna that can be achieved. The overall idea is feasible and adding this antenna to already existing satellites would be very effective since it is like connecting a cylinder to a satellite.

The Gregorian antenna was derived from simple research into the history of antennas. The Gregorian antenna is a state-of-the-art antenna which not only collects information by focusing the incoming beams into a feed, but also reflects the beam off two reflecting paraboloidal forms to allow for a better distribution pattern shown in Fig. 9. The design uses research which provides insight into the application of the antenna. The structure uses a current antenna technology and applies basic electrostatics to its functioning. This antenna has many characteristics that are an improvement over the basic antenna. The major benefit of this particular antenna is that the actual deflections necessary for the Gregorian antenna are less than the deflections of a regular antenna. The electrostatic forces necessary are proportional to the magnitude of these deflections. Thus this antenna maximizes the efficiency of the electrostatic characteristics. The Gregorian antenna also maximizes the efficiency of antennas and its ability to receive and transmit signals.

The Gregorian antenna focuses on using a secondary reflective paraboloidal shape. The control of the shape is simpler because the reflective surface has a smaller area. The actual performance of this antenna is better because the amount of interference from the feed is minimal in an off-set Gregorian antenna. The design principle was the research of current antennas. The search revealed a Gregorian antenna that could focus using a secondary reflector with easily applicable electrostatic properties. The technology is the electrostatic control of the secondary reflector. The deployment is negligible since the motion comes from the secondary reflector deformation not motion from the entire antenna. The actuators are set behind the secondary reflecting membrane in order to control its relative shape. The construction is reliable with the two reflectors set up in proximity to each other on the satellite at a pre-set position.

This antenna has a good basic idea, utilizing one of the most efficient current antenna systems while controlling the smallest area possible for the reflector of an antenna. The performance of this antenna is directly related to the performance of the electrostatic control on the paraboloidal reflector. The technology is the simple control of paraboloidal form with electrostatic actuators. This antenna does not deploy and thus causes problems for given cargo limitations. Though this makes the construction easy because the antenna can be attached to the satellite surface. The major question is the amount of control that the reflector has for the desired accuracy necessary. Overall, this is a very effective way of maximizing the performance of an electrostatic controlled antenna with the minimum use of the electrostatics.
The perimeter controlled antenna was created after examining the properties of the electrostatic antenna and the paraboloidal shape. This antenna utilizes a different outlook for accomplishing the task of focusing an electrostatic antenna. A paraboloidal shape, when cut into different segments, can increase and decrease the focus area of an antenna by adjusting the perimeter of the paraboloidal. This interesting development was discovered while examining the paraboloidal shape, keeping the function desired from the electrostatic antenna in mind. The concentration on the definition of the electrostatics and the form of the antenna was used to provide insight into the functioning of this type of antenna. This structure implemented the basic idea of the paraboloidal form of an antenna [11]. After exploration of the possibilities of this antenna, the electrostatic problem of controlling the perimeter of the antenna was examined. Interestingly enough, the electrostatic problem was solved with a straight-forward application of the electrostatic principle. This particular model can control the focusing of the antenna by using a perimeter controlled electrostatic apparatus which controls the size of the perimeter. This controls the relative deflections of the antenna.

The design principle is a form study of the paraboloidal shape. A paraboloidal shape was constructed, then relative properties of the shape were examined, and an idea formed. The deployment of this antenna is simple with the antenna opening like a Japanese fan into a paraboloidal shape. There are few actuators in this antenna and they are placed at the perimeter between the sections of the antenna. This antenna is constructed by creating a pre-form structure, adding actuators, and creating spacing at pre-determined distances in the paraboloidal form based upon the accuracy necessary for the mission.

The perimeter controlled antenna has a tremendous advantage because it controls the paraboloidal shape in a simple but effective way using only one membrane. This is a problem with the other antennas because the control of the others is still nebulous. The performance of this antenna is extremely good because very few actuators are necessary for focusing the antenna. The electrostatic technology adds to this performance because the electrostatic actuators, being placed on the outer rim, only have to push and pull a small distance to get the desired shape control. The shortcoming of this antenna is the deployment might be difficult.

The unfolding fan technique may be hard to accomplish without the proper mechanical devices, which would take away the advantage of electrostatics. The construction, because of the deployment issues, might be difficult to create a proper functioning antenna. The overriding problem with this antenna is the deployment and construction. The idea of controlling the perimeter of the antenna has great merit because of the ease of the electrostatic functioning.

Fig. 9. Gregorian Antenna Project Basis - Gregorian Antenna

Fig. 10. Perimeter Controlled Antenna

The discretized element antenna was developed for a power beaming application that has a magnitude of 100 times the size of the other antennas. This antenna was developed by utilizing the concept of creating a basic element which, when duplicated a multitude of times, could provide the size that is necessary for the development of this antenna. This is similar to creating a basic floor tile and placing a large number of tiles on the ground to create an entire floor. This idea is very common when developing various large structures. The idea comes from an architectural principle and is a very feasible application of the electrostatic principle. In this design, research into the form of general structures provides insight into the functioning and form of this antenna [12]. This electrostatic principle is that when these individual elements are charged, they repel each other. The elements then move as far away from each other as possible until they reach the proper position and create a particular form. The form is the parabolic cylinder or paraboloidal shape which is a preset structure for the antenna created in its initial construction. This antenna can go from a very compact size by area into a very large size when the voltage is applied.

The performance of the discretized element antenna is similar to inflating a balloon. The structure begins in a small area and expands like a balloon inflating as the individual elements repel each other. The design principle is constructing a basic unit element and then multiplying the number of these elements to create a larger structure. The technology is applying electrostatic repulsion between the individual elements to cause them to repel
and thus expand into a pre-set form. The deployment is the beauty of this design because it can expand from a small area and with minimal effort can create a very large paraboloidal or parabolic form. The actuators are on the individual elements but the control of the actuators is unnecessary because the on-and-off repulsion between each of the elements causes the antenna to open. The construction is simple as well, because the basic element needs to be built in the same manner a multitude of times. Then the basic unit elements are connected and attached to a unit base.

The greatest advantage of this discretized element antenna is the ability for the antenna to become large scale without having to consume the cargo space that is normally required. This antenna can expand from a very small area into a large antenna with good accuracy. This ability has not existed for these types of antenna before now. The construction and application of this antenna are simple but the question of the functioning of the structure is still arguable. If this antenna is able to deploy in the proper manner, then this particular family of antennas will have a great advantage. Even if the idea is not directly applicable, the idea has tremendous merit and may lead to large antenna structures.

![Fig. 11. Discretized Element Antenna](image)

The Fresnel lens antenna was probably the most abstract of the antennas. The idea for this antenna was developed when the theory of a parabola was investigated. The parabolic shape of an antenna reflects the incoming signals into a feed. This same principle is applied to focus and enlarge pictures with a Fresnel lens. The principle behind this lens is that it reflects individual components of the signals into a particular area. Each reflecting section has a different deflection that when combined, focuses the Fresnel lens. This antenna is a combination of using research and the definition of the problem to determine a very plausible solution. The electrostatic principle has a very direct application with the characteristics necessary for this antenna. The individual sections are controlled by the electrostatics. The individual sections thus can change their own focus by charging each section differently. This antenna has more degrees of freedom than the other antennas because each section can function independently of the other sections. This allows the entire system to function more efficiently because the relative independence of the individual sections. This unique characteristic of each section focusing to a different position is a tremendous asset for this antenna.

The principle of this antenna is that each individual section is manufactured to focus onto a point or the feed. The design principle is the research of similar applicable systems. The Fresnel lens focusing system was found to have other possible implementations such as our electrostatic antenna. The technology is an electrostatic deflection of individual segments of a parabola with each segment being controlled separately. The deployment of this antenna is similar to a briefcase opening with the antenna segments being activated after it is opened. The actuators are set up on the back of the individual segments of the antenna. The construction is similar to the discretized element antenna because one segment is built and then many more are made. The elements are all connected to a unit base or central back-plate system.

The Fresnel lens antenna provides an insightful way to focus antennas in general. This system can focus an antenna without having the initial shape of a parabola. This is an extremely interesting use of a current technology. The performance of this antenna is good because the individual adjustments can be made for each section of the antenna. The technology can be implemented because the only force necessary is a simple push and pull with electrostatic actuators along the edge of the membrane. The briefcase deployment makes the antenna very compact and sturdy during launch. The construction consists of long pieces of the membrane in front of the actuators. These pieces are hinged on one edge and allowed to move relative to the actuators on the other edge which creates the focusing. The big question with this antenna is a phase shifting problem. If the signals are all coming into the feed at different phase angles after the reflection has taken place on the antenna, then the antenna is of no use. Overall this is a great application of a current technology with very good possibilities of implementation.

![Fig. 12. Fresnel Lens Antenna](image)

CONCLUSION

One of the largest problems in the design process was understanding the exact role that the team of designers would play.
When the idea of a design project was developed and used, a feasible idea for an electrostatic antenna already existed. There were doubts whether this design process would produce any results because of the innate limitations of antennas and electrostatics. In the end, the number of different ideas proposed for the electrostatic antenna was incredible for such a limited project. The large number of proposed ideas were the by-product of several key differences in the product design and engineering design philosophies. Each individual process has its own advantages and disadvantages, yet to get the best design, implementing both of the philosophies is the best solution.

Although reality dictates that one cannot go very far with a project before the problem has been defined, the relative amount and type of definition can affect the outcome of the project. The definition in the product design philosophy is related to identifying which bounds are immovable and which bounds are not. The best way to describe the project is to examine the individual components of the project and its possible solutions. In engineering design the focus is to look at ways to fix the problem instead of looking at the project in different ways to supersede the origin of the problem. Both philosophies solve the problem, but they each attack the problem from different ends. Many great designs come from a collaboration of knowledge gained from previous inventions that are implemented in some way. In engineering, the philosophy is to know the basics of what has been tried by individuals in the past. In product design, the philosophy is to look at any corresponding ideas that might provide insight for research. Spending a great deal of time on the research of a project can provide great benefits if a solution is found which reduces the problem to a simpler form. The research is conducted in both philosophies but once again the focus of the research is different. The ideas begin at a rudimentary level and then start to develop into new ideas as the research provides different avenues to investigate. This is a major thrust of problem solving that needs to be incorporated more into an overall design philosophy.

The overall prospects for future work and research include several extremely important aspects. The first aspect is determining which one of the ideas should be investigated in depth. After this has been determined, an actual working model for this particular design needs to be built. If the working model is successful, then the prototype needs to be built and tested. The other projects can be tested as well, but a focus on one particular type of antenna is necessary so that progress can be made. With the research in place, the progress has to be made next in the manufacturing and testing of a particular product which will take this technology to yet another higher level. This is currently underway.

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