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NASA Capacitive Skin Project
Capacitive Skin Characterization

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Background

NASA is currently involved in research that utilizes a novel capacitive sensor that is used for proximity detection of objects. The capacitive sensor seen in Figure 1.0 was developed at NASA Goddard Space Flight Center. This sensor is sensitive to conductive and dielectric materials including metal objects and humans. The range of the sensor has been found to be about twelve inches. It is the goal of this research project to further characterize the sensor so that it can be tailored to specific requirements. The characterization of the sensor should be with respect to shield size, sensor size, object size, and object distance.

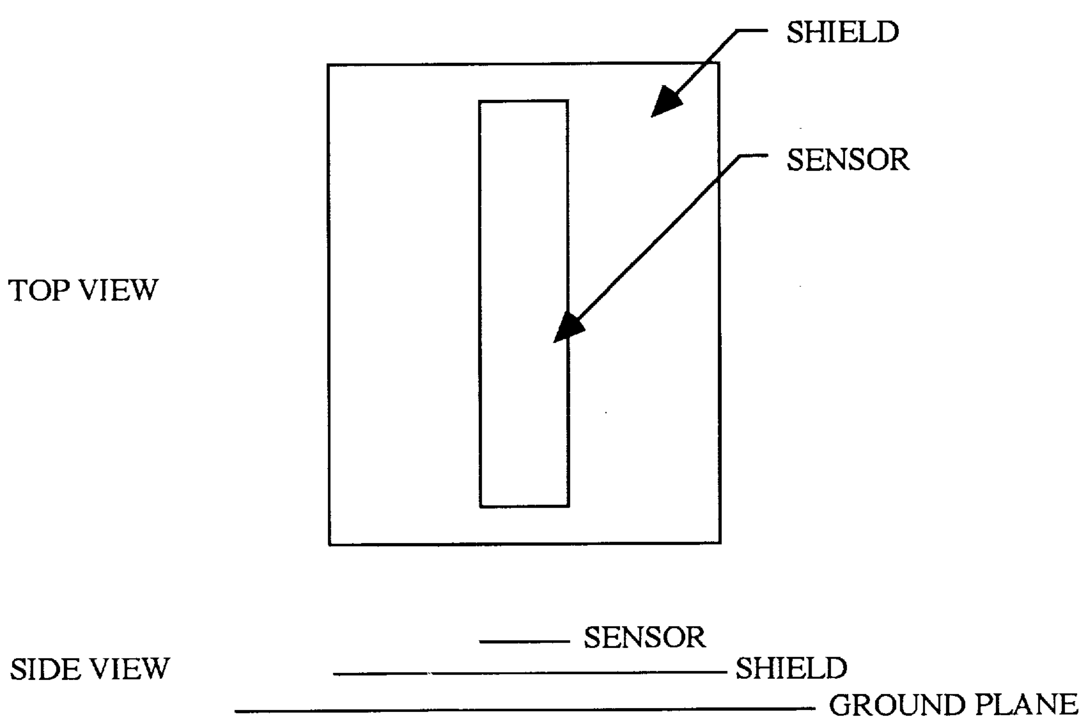

Figure 1.0 Capaciflector

A program written by Swami Mahalingam of Carnegei-Mellon University, uses the method of finite elements to calculate the capacitance of the sensor while varying different parameters. A percent change in capacitance is calculated by comparing the capacitance of the system with no object present, to the capacitance seen with an object within range of the sensor. This program enables the researchers to choose any object, sensor, or shield size as well as calculate capacitance for various positions of the object. Figure 2.0 shows the geometry used in this set up.

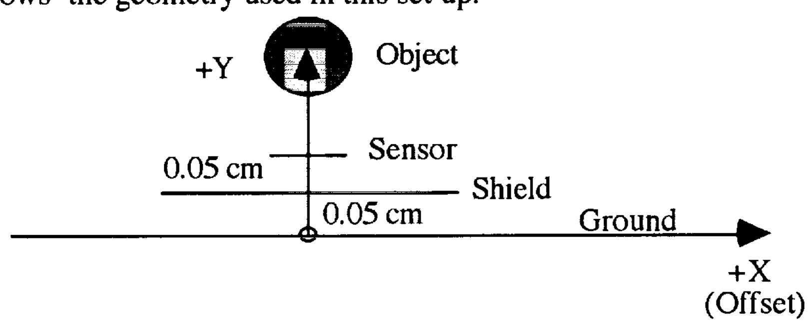

Figure 2.0 Capaciflector Geometry

Figure 3.0 shows the matrix of object positions when a simple test configuration is used. By setting the input conditions of the program, the user can set the +Y interval to any value desired. In most of the data that was calculated, the +Y interval was set to 20 cm. That is, change in capacitance readings were calculated for 5 positions of the object at 20 cm intervals away from the origin. The X offset is related to the width of the shield. The X offset starts at zero, or the centerline of the sensor. The next measurement is then half the distance to the edge of the shield and the third is with the object in line with the edge of the shield. For example if a shield width of 20 cm was chosen, measurements would be calculated at x=0, x=+5 and x=+10. In each case, five Y positions are calculated. Each point of the matrix corresponds to a single measurement in capacitance. In the example shown below the object is centered at x=+5 cm and y=80 cm.

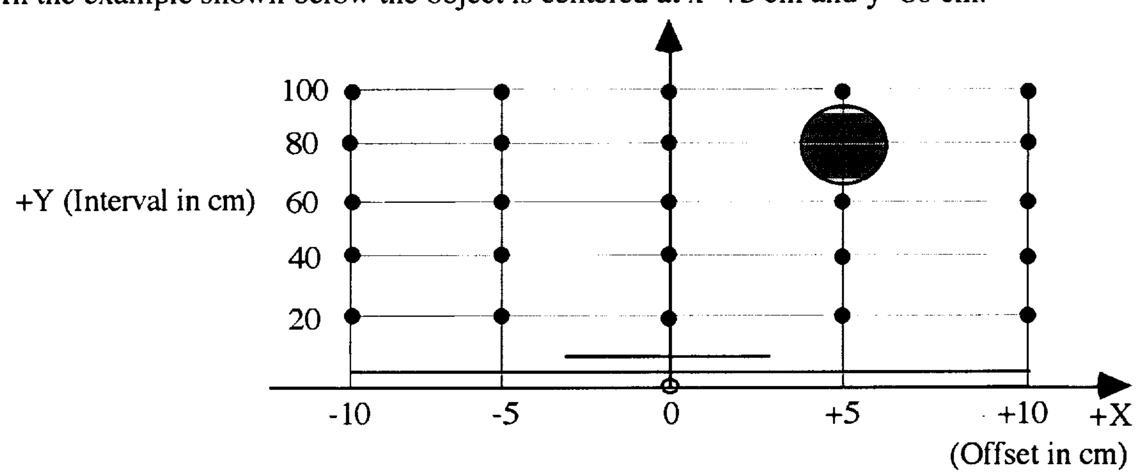

Figure 3.0 Matrix of Object Positions

Characterization

In order to develop an understanding of the sensor, it is necessary to look at individual changes in a single element while holding the other variables constant.

• **Variation in Y Distance**

Every computer run generated data as theY position was varied. Typical examples are shown in Figure 3.1. From theory, for the two dimensional case, one would expect the capacitance to vary as $\frac{1}{\sqrt{Y}}$. When $\frac{1}{\sqrt{Y}}$ is plotted, the data points form almost a straight line as expected. Therefore, it is concluded that the $\frac{1}{\sqrt{Y}}$ variation holds. In a 3-dimensional case, the variation should be approximately $\frac{1}{Y}$.

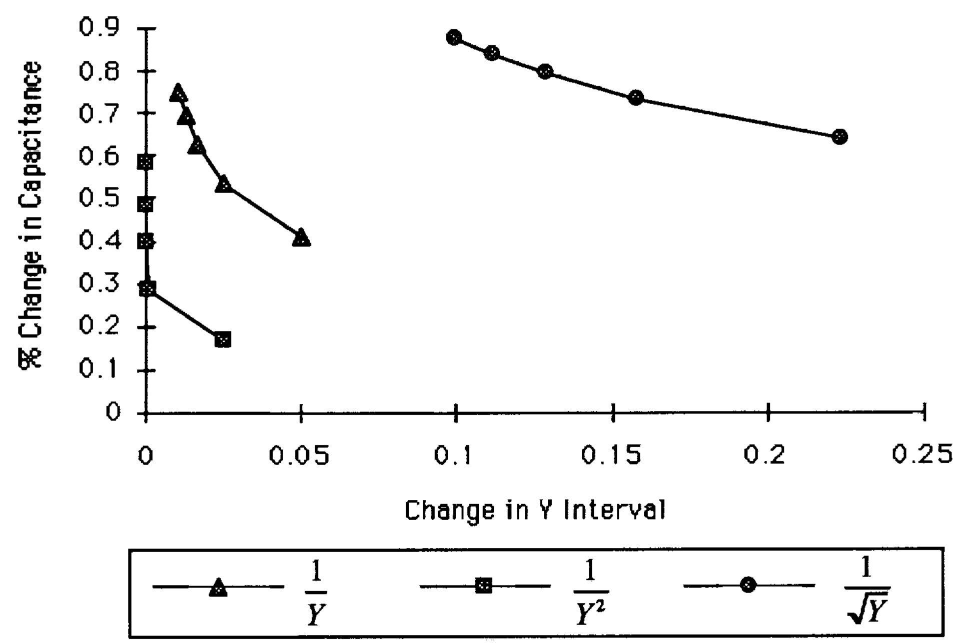

Figure 3.1 Typical Curves for Changes in Y

One test case that was chosen for analysis was changing the sensor size from 1 cm to 25 cm while holding the shield at 20 cm and the object at 1 cm. Figure 6.0 represents a typical log-plot of the change in the Y interval. A fairly linear representation exists as you proceed further away from the sensor. It was found that in all cases, a linear relationship exists between a change in the Y interval, and a percent change in capacitance.

• **Variation in Object Size**

The second area researched was the object size. A test case was developed to evaluate the effects of changing the object size (radius) from 1 cm to 10 cm while holding the shield size at 20 cm and the sensor at 10 cm. Figure 4.0 shows the theoretical results obtained for object sizes 1-5 cm.

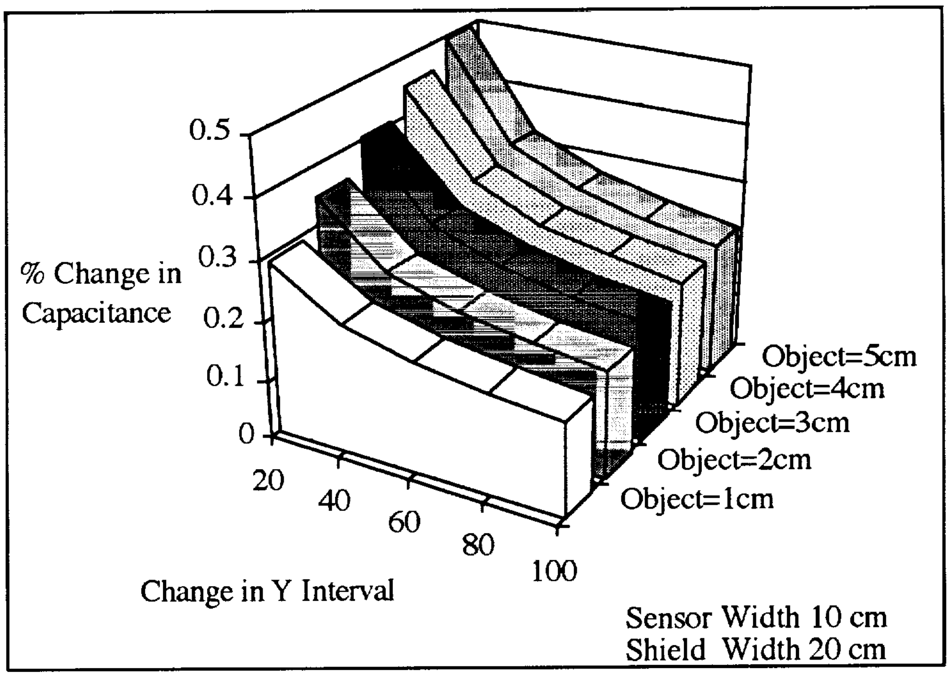

Figure 4.0 Change in capacitance with variation in object size (Object offset by 0 cm)

From the data shown, a steady increase in sensitivity is noted for subsequent increases in object size. Although this data only shows the first five runs, object sizes of 6-15 cm show this trend as well. There are two effects occurring simultaneously for this data. First, a larger object will have more surface area exposed to the sensor, thus more coupling can take place between the object and the sensor. Second, due to limitations in the program, the point nearest the sensor gets closer to the sensor as the object radius is increased. The second effect is most noticeable for objects already close to the sensor. If this effect is canceled out, there is still an increase in capacitance as the object size increases. From the graphs, this effect appears linear. One thing that should be noted however, that for objects far away, the object size seems to have only a small effect on the overall sensitivity of the system.

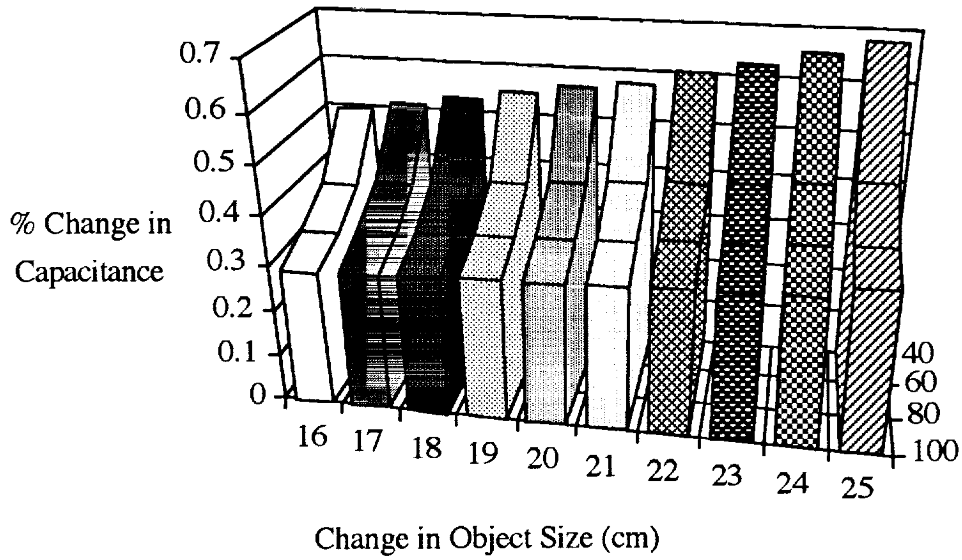

Figure 5.0 Change in capacitance with variation in object size (Object offset by 0 cm)

• **Variation in Sensor Width**

The sensor width was varied in the same manner as the object. It can be seen from Figure 6.0 that the sensitivity generally decreases as the sensor increases in size. As the sensor gets larger, and the shield remains constant, the "shielding" effect is reduced. That is, there is a substantial amount of coupling going on between the sensor and ground, thus reducing the effectiveness of the sensor.

Another interesting aspect of Figure 6.0 is the large decrease in sensitivity around 5 cm. Many test runs were made to determine the cause of this decrease. However, subsequent runs failed to substantiate this effect and the results at this point are considered anomalous. It was thought that a ratio existed that somehow lessened the effects of the sensor, but this was disproven by subsequent verification runs.

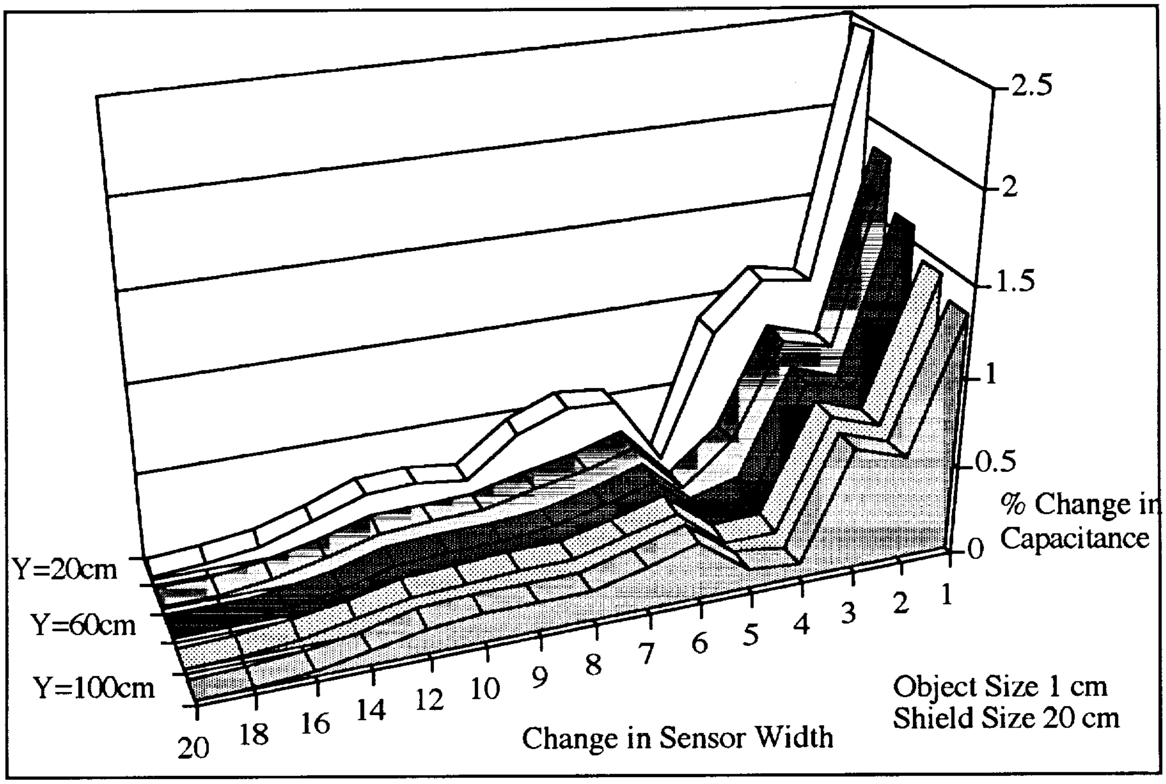

Figure 6.0 Change in capacitance with variation in sensor size (Object offset by 0 cm)

If the anomalies are ignored, the curves in Figure 6.0 appear to be exponential. Figure 7.0 shows an attempt to linearize this data by plotting on a logarithmic scale. Once again, the anomalous data can be seen by the large dip in the curve. In figure 8.0, data points near the 5 cm sensor width were replaced by averaging the two adjacent points. The results show a fairly linear plot until the sensor exceeds one half of the shield width. It can be seen that as the sensor exceeds one half the width of the shield, the sensor rapidly becomes less sensitive.

Based on these results, the percent change in capacitance decreases exponentially as the sensor size increases. If the sensor goes beyond 1/2 the shield, sensitivity decreases even faster. This second area was not investigated further because high sensitivity is usually desired.

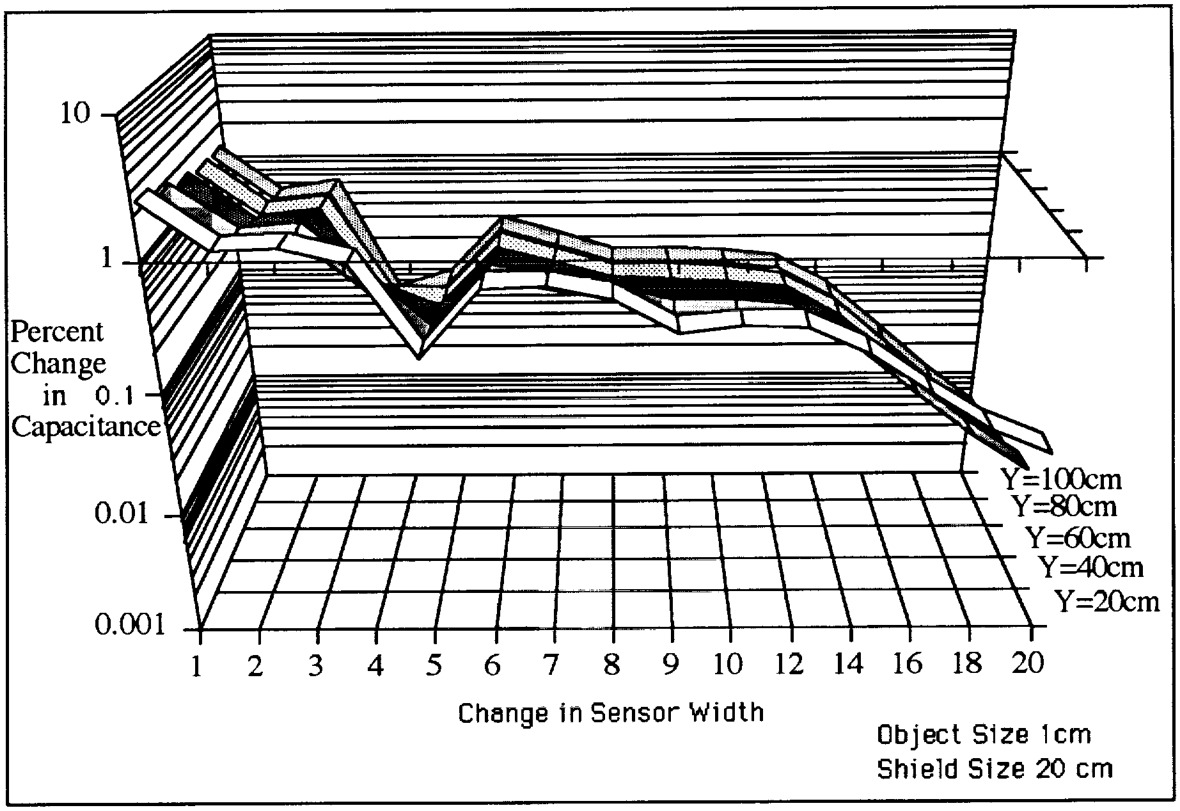

Figure 7.0 Linearized data for Change in capacitance

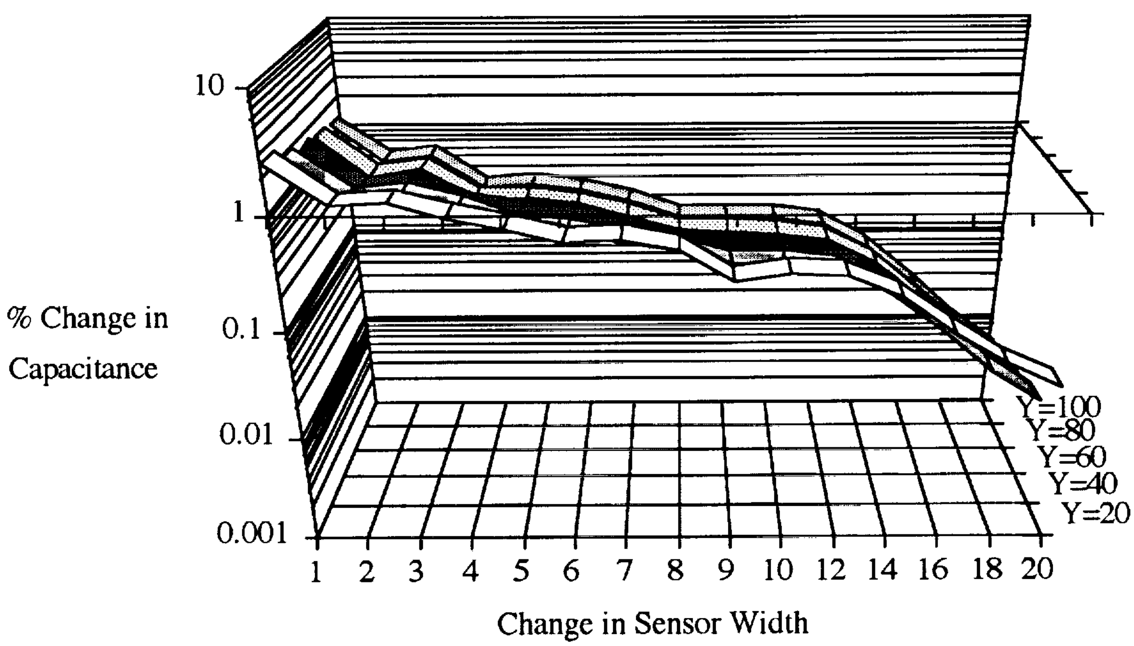

Figure 8.0 Altered Linearized data for Change in capacitance

• **Variation in Shield Width**

The final element to be analyzed was the shield. In this test case, the shield was varied from 10 cm to 24 cm while keeping the object and sensor at 1 cm and 10 cm respectively. Figure 9.0 shows the results obtained from the characteristic test set.

As can be seen Figure 9.0, when the shield is the same size as the sensor, a significant drop in sensitivity is observed. As the shield starts to block the sensor from the ground, the sensitivity rises in a exponential manner. This effect was first observed when the sensor was analyzed. This large change in capacitance can be attributed to the purpose of the shield: to block the parasitic coupling that occurs between the sensor and ground.

Another feature of Figure 9.0 is the extreme drop in sensitivity after a shield size of 22 cm. This can be attributed to the finite size of the ground plane used in the calculations. As the shield size approaches that of the ground, it is essentially blocking the ground from the other elements. When this happens, the shield is no longer acting as a barrier between the sensor and ground, and a significant decrease in sensitivity is observed.

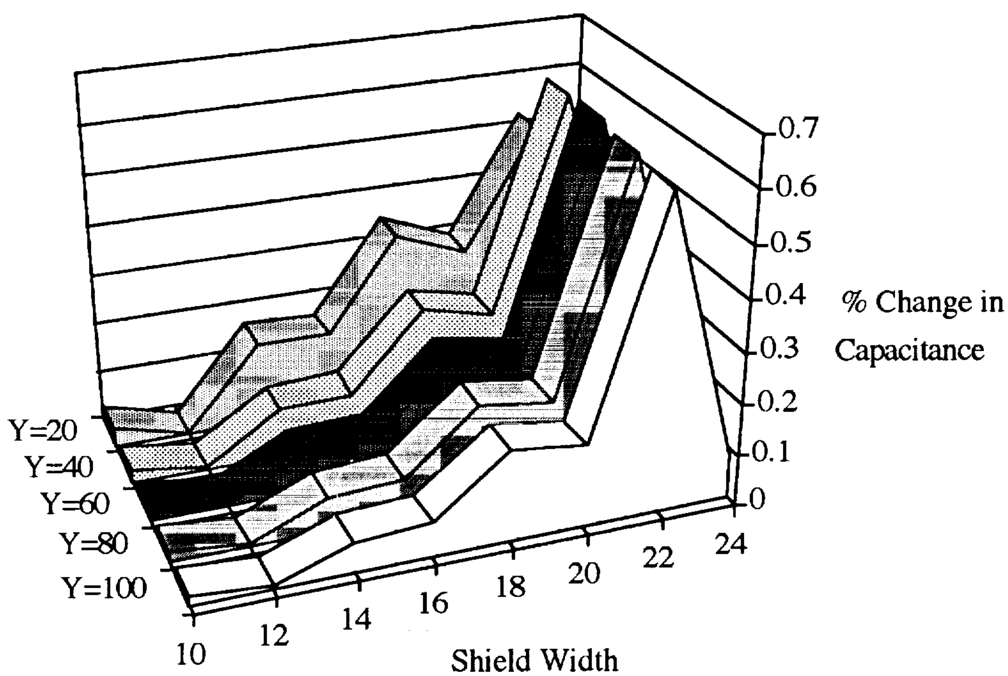

Figure 9.0 Change in capacitance with variation in shield size (Object offset by 0 cm)

To get a better understanding of what is actually happening, Figure 10.0 shows the log plot of the data of Figure 9.0. After the shield size becomes larger than the sensor, (shield=12 cm) and starts to block the parasitic coupling, it becomes clear as to what influence the shield has on the entire system.

Once again, in order to get a better understanding of what the characteristic curve looks like, the apparently anomalous points for the shield at 12 cm were averaged. Figure 11.0 shows a what the linearized data looks like. The resulting log-plot shows an approximate linear relation up to 22 cm. This linear relationship implies that sensitivity increases exponentially with shield size. However, more data should be collected using a smaller sensor size to improve confidence in this result.

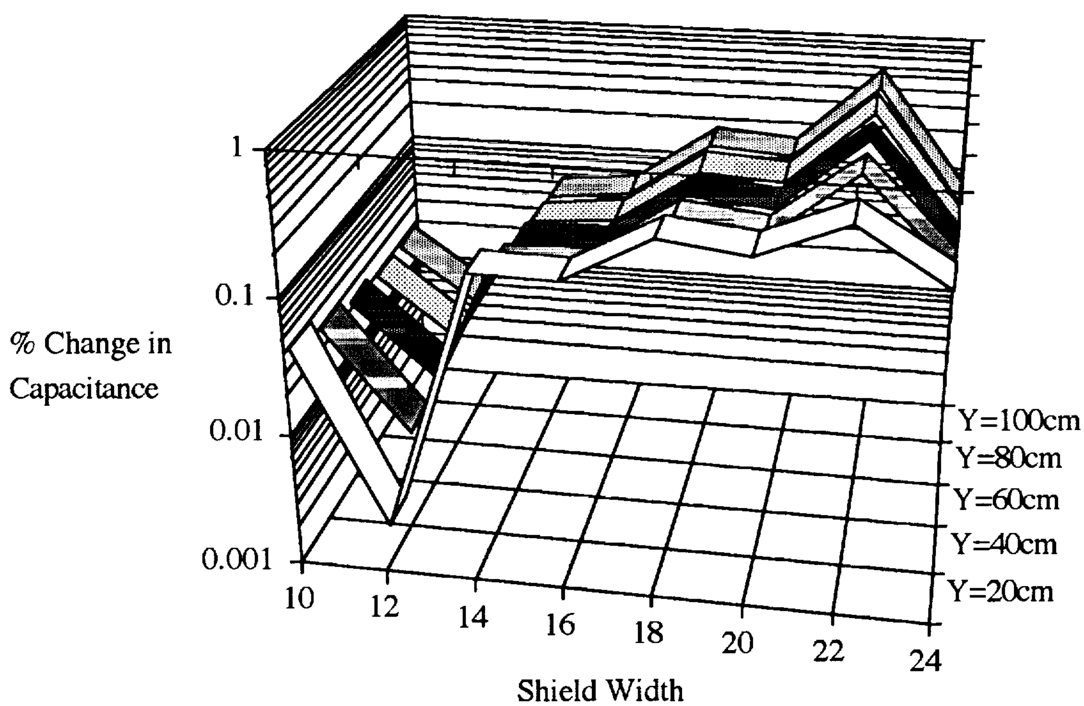

Figure 10.0 Linearized data for Change in capacitance

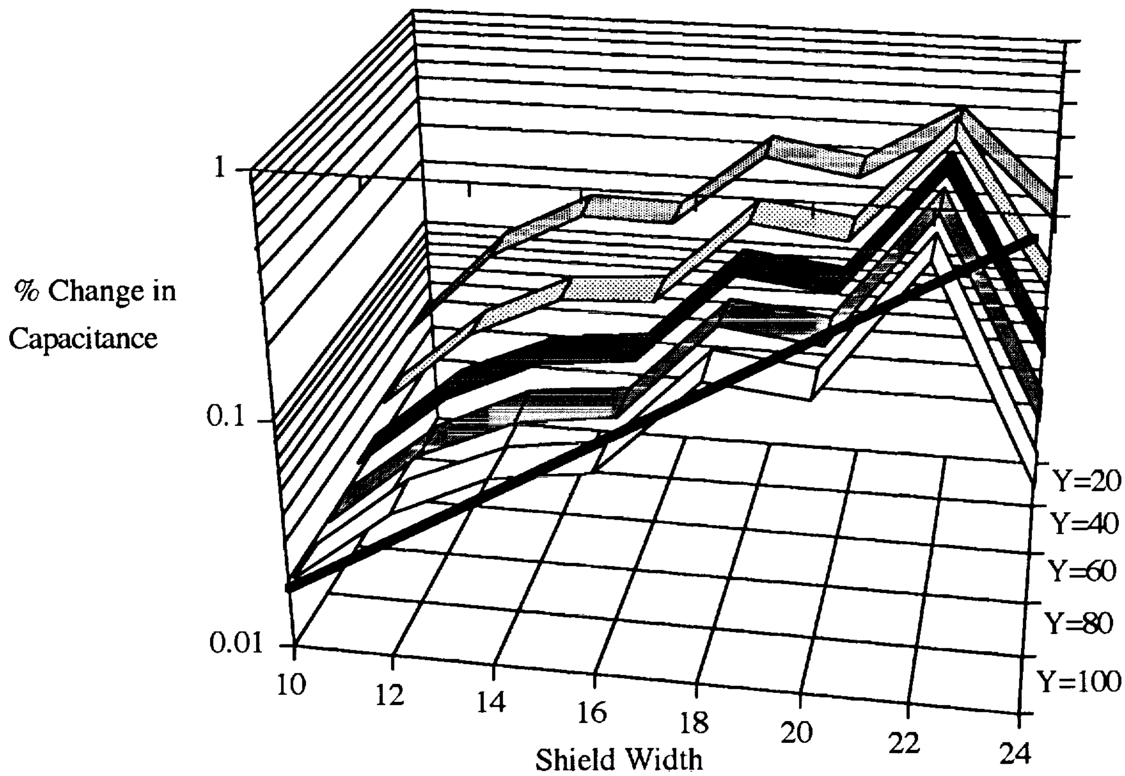

Figure 11.0 Altered Linearized data for Change in capacitance

Conclusion

While the finite-element program has some limitations, it has produced some reasonable results. One limitation is that the simulation is only for a 2-dimensional geometry. Another is that the variables cannot be independently controlled. A third limitation is the occasional result that appears anomalous. The anomalies probably arise from aliasing due to the way in which the elements are chosen.

Each of the parameters was varied in turn, often by selecting data points from different runs. The plotted results are shown and an apparent functionality developed for each.

1. **Distance from Sensor** - Inversely proportional to the distance. Probably inversely proportional to the square of the distance for the 3-dimensional case.

2. **Object Size** - Increases linearly with object size
More strongly affected with object closer to the sensor.

3. **Sensor Size** - Decreases exponentially with sensor size.
This result is probably due to a smaller base capacitance.

4. **Shield Size** - Increases exponentially with sensor size.
This result is questionable.

Sensor size seems to have the most dramatic effect at any given distance while object size seems to have little effect except in close.