Commentary on Design Project #1
Fields and Waves I
Fall 1995

There were three tasks to be performed in this project. First, you were to describe a situation wherein a human plays a significant role as one electrode in some kind of capacitor. This description should be adequate to provide enough information such that the capacitance can be estimated, which was the second task. The third task was to develop a technique for measuring the capacitance considered in the first two tasks.

1. A variety of situations were considered by the class:
- A person in proximity to some electronic apparatus
- A capacitance sensor to trigger a car alarm as a person comes near the car
- A person in a car, walking across a rug
- A person near a power cable

2. Models
- Parallel plate capacitor
- A section of a coaxial cable
- 2D spreadsheet method
- 3D spreadsheet
- Spherical capacitor
- Spherical conductor near conducting plane
- Two nearby spheres

3. Measurements

- Charge up the person, connect to known capacitor, measure the voltage on the known capacitor. To determine the capacitance it is necessary to know the voltage on the person before touching the known capacitance. This can be found by noting the conditions that cause a spark, which requires 30 kilovolt per centimeter field.
- Measure all dimensions of system including gap just as spark occurs. This is not really a measurement unless a very accurate model is also used.
- Make person/object capacitor part of a circuit in which frequency depends on capacitance. This approach seems to have been influenced by experiences in IED.

Grading Philosophy

I have assumed that the overall group is trying to get a start on a problem. The grade is based on the contribution of a report to the goal of the group.

For each of the three tasks, 10 points were given for satisfying the basic requirement.

Contributions to group understanding of the problem were generally given 5 points each:

- Good use of references
- Unique methods
- Quality of work
- Effective estimation of errors
- Good writing

- Good pictures
- Clear justification of method
- Interesting situation
- Trying a difficult method, even if not complete or totally correct
- Effectively considered nearby structures

Serious negatives resulted in deductions of 5 points each:

- Guessing without substance
- Leaving the reader in the dark as to which configuration was used.
- No numbers calculated. Some people apparently assumed that they were not supposed to come up with an actual number for capacitance.
- Unrealistic number for capacitance

A bonus (extra credit): actually doing an experiment

Some remaining questions: (These are not part of the project. However, the project should generate some additional inquiry if useful work has been done)

- How does a grounding strap work?
- How much time does it take to fully discharge a person?
- Can we really clear all the charge off of a person or only the charge from some limited area on our bodies?

The class determined a great variety of values for human capacitance. I have plotted a histogram of all the log of these values. Also, the median is 10 pF, which is not really such a

bad value.

Before I began considering what each of you had to say, I tried a variety of cases to get some ballpark values for human capacitance. Each is erroneous in some manner, but taken as a whole, they should more-or-less bracket practical values.

Parallel Plate Capacitor
Assume that the plate area is equal to the area of a hand and the plate separation is roughly the gap between an open hand and some object. Then

$$C = \frac{\epsilon A}{d}$$

which for A = .02 m^2 and d = 1mm, C = 200 pF. This seems like a good number for a small gap, but if the hand is charged up to 15 kvolts, the gap cannot get smaller than 5 mm without a spark occurring. Thus, the capacitance is actually C = 40 pF. In terms of standard constants, C = $4\epsilon_o$.
Spherical Capacitor If we assume that a person is a sphere and the room he or she is in is also spherical, then

$$C = \frac{4\pi\epsilon_o}{\frac{1}{a} - \frac{1}{b}}$$

where a is the radius of a person (1 m) and b is the radius of the room (3 m). Then C = 20 ϵ_o = 200 pF.

Coaxial Cable

We can easily calculate the capacitance of a coax, but then we must use a short length of it to find C of a human. For one meter of length

$$C = \frac{2\pi\epsilon_o}{\ln\frac{b}{a}}$$

so that $C = 6\epsilon_o = 60\text{pF}$.

Two Nearby Spheres

If we model both objects as spheres, then

$$C = \frac{4\pi\epsilon_o}{\frac{2}{a} - \frac{1}{d}}$$

where a is the sphere radius and d is the distance between their centers. For a person 0.5 m in radius and .2 m another sphere, you can see that this is not a very good model.

Sphere Near Plane

Cheng has an expression for a capacitor consisting of a sphere near a conducting plane

$$C = 4\pi\epsilon_o a(1 + \alpha + \frac{\alpha^2}{1-\alpha^2} + \ldots)$$

where $\alpha = a/2c$, a = radius, c = distance from sphere center to plane. For a = 0.2 m and c = 0.3 m, $C = 10\epsilon_o = 100$pF. If we are interested in a finger tip, then $C = 0.2\epsilon_o = 20$pF.

The numbers I found where 40 pF, 200 pF, 60 pF, 100 pF, and 20 pF. Thus, there is quite good agreement with my average and the class median. Are we good or what? I am pretty sure that actual number are a bit higher, since we really should consider a parallel combination of capacitors. A handful of such capacitors would give us something around 500-1000 pF.