The technology behind the TC1 (Capacitance) Explained

Capacitance is...
Capacitance is the ability of an object or surface to store an electrical charge. It is simply a measure of the *capacity* of the *electrical storage capability* of the object. Capacitance is analogous to the ability of a jar to hold a fluid. Just as some jars have more capacity than others, some objects have more charge-holding ability than others. Like the jar, this ability is related in part to physical size. But the analogy breaks down after that, and things get a little strange....

What's distance got to do with it?
It may sound weird, but the electrical capacity of an object also depends on what the object is near to, and how near it is. While an object in the middle of outer space has a certain amount of capacitance (which is related to its physical size), as another object comes closer to that object its capacitance will actually increase. All objects obey this rule, and this principle has been known for a couple hundred years.

In 99% of all cases capacitance is thought of as being *between* two adjacent objects, where the objects are separated by some non-metal substance, or even just air or a vacuum. This is called *mutual* capacitance, and this form of capacitance is much more important and usually more dominant than simple 'free-space' capacitance. An engineer would say there is a so-and-so amount of capacitance *between* the two objects, and ignore the 'free space' capacitance because it is too small to consider or is simply not important.

Even a football flying in the air has a mutual capacitance with respect to the earth, as do the earth and the moon with respect to each other. Every object has a capacity to store charge with respect to another object, provided only that they are not connected to each other by something electrically conducting like a wire (which would prevent charge from building up on one object with respect to the other, because the charge would simply short-circuit over to the other object). The amount of capacitance between two objects decreases with distance and increases with the sizes of the two objects.

The TC1 first measures the *background* amount of capacitance on an object, and treats that like a 'tare'. It then looks at very small changes in the measured signal from that point on, caused by nearby objects. While older capacitance sensing technology can monitor changes in capacitance, the technology used within the TC1 is superior at ignoring huge amounts of background capacitance automatically; this is one of the things that gives it the amazing ability to 'turn anything (well, almost) into a sensor'.

What's material got to do with it?
Capacitance is affected by what the object is made of. For example, a metal object is vastly better at storing charge than an identically shaped one made of plastic. And some plastics are better than other plastics. Also, what is between two objects strongly affects the amount of mutual capacitance between them. For example, when two metal objects are separated by a layer of plastic, there will be more mutual capacitance than if the two are separated by a similar spacing of air.

This variation is expressed in physics terms as the *dielectric constant* of a material. The higher the dielectric constant, the better the plates are at holding charge. Vacuum (and for all practical purposes, air) is rated at 1, while various plastics come in between 2 and 5. Pure water is close to 80, and some ceramics are in the low 1,000's. So, a plastic separator with a dielectric constant of 3 will give the two plates in our example 3 times more charge holding ability than an air gap.

The human body is a remarkably good electrical conductor and so can accumulate charge very nicely. The human body is thus very easy to detect using capacitance, even across an air gap. Detecting people ½ meter away is not a hard trick to accomplish with a reasonable size of metal plate and a TC1.

Yes they sell capacitance devices!
You can actually buy things called *capacitors*, which are designed specifically to store electrical charge. These come in some amazingly small sizes. Virtually all modern electronic devices contain many if not hundreds of these handy gadgets. Some are no bigger than a grain of sand! Without these most electronic gadgets would not be possible. Capacitors were formerly called *condensers*, a term that must have made sense to someone a long time ago; what they *condense* is now a mystery to the rest of us! Capacitors in automobile ignition systems are still often called condensers.

Putting on a charge
A charge can be placed on an object by anything that can generate electricity. This can be a battery, or it can be friction between two objects (friction-generated electricity is called *triboelectricity*). All electronic circuits shuffle charge around from one circuit to another with wires. To put a charge onto an object, you simply need to connect a wire to the object and attach one end of a battery to the wire, and connect the other end of the battery to another nearby object or to an earth ground (which is just a very handy, very large nearby second object, namely the planet Earth).

If the object is non-metal, you can stick on a piece of metal to the object somewhere, and then charge ups the metal. The object will absorb some of the charge from the wire, even though the object does not conduct electricity well. If the object does not conduct electricity at all, this will cause charge to *separate* into opposite polarities across the surface of the object, but that's another story...

Commercial capacitors have two electrical connections on them; to put a charge onto the capacitor, you hook up each battery lead to one lead of the capacitor. When you disconnect the battery, the capacitor will still hold the charge (but see *Can Charge Leak?*, below).

Some other examples
When you walk across a carpet on a dry day, you accumulate a static charge. The charge comes from friction between your shoes and the carpet. But if your body had no capacitance, you could not accumulate the charge. In any event, the charge will eventually *leak off* of your body and return to earth, leaving you chargeless.

Because capacitance depends on physical size, an adult has more capacitance and hence can store more charge for a longer time than a child, all other things being equal (like the type of shoes being worn).
If you walk across a carpet while next to a wall, you will accumulate slightly more charge than if you do so in the middle of a room. This is true because your body has more capacitance the closer you stand next to another object.

Measuring capacitance
There are many ways to measure capacitance. One common way involves putting a current into the object (or a commercial capacitor), and seeing how long it takes to reach a certain voltage. The longer it takes to reach a particular voltage, the higher the capacitance. Another way is to use a *bridge circuit*, which work a lot like a balance beam for capacitance. There are also *tuned circuits*, which involve gnarly things called inductors (you don't want to get involved), that measure capacitance by watching how the 'resonance' (like the ringing of a tuning fork) alters with changes in capacitance. Each of these has its pro's and con's. Most are relatively unstable or hard to make.
The TC1 sensors work by placing a fixed voltage on the object, then 'stealing' the charge back, and transferring the charge into a measurement circuit. This 'charge and transfer' sequence is what gives the sensors within the TC1 their special qualities.

Can Charge Leak?
Like a leaky bucket, the charge on an object can gradually vanish. This is, appropriately, called *leakage*. Some objects or capacitors are more leaky than others. For example, the human body standing on normal flooring is pretty 'leaky'; your charge from walking across the carpet will leak off over a few minutes. Even commercial capacitors have leakage, although usually not very much. Mostly leakage is a bad thing if you want to measure capacitance since it interferes with the measurement. The TC1 is terrific at ignoring leakage, because it takes the measurement before any significant amount of leakage can occur.

Can I build a capacitor?
Yes! In fact a few hundred years ago capacitors were discovered by accident: an old Hellmann's® mayonnaise jar, filled with water, was found to store electrical charge as determined by the 'zap test' - presumably the discoverer walked across a polyester shag rug, zapped the water in the jar, and came back later to get a strange second zap. It was made a bit more practical by replacing the water with an inside coating of metal, and then improved even further by lining the outside with metal too. This was called a *Leyden Jar* after the city in Holland where Hellmann's was once made. To this day Leyden is renowned for its shocking shag rugs and strange looking used mayonnaise jars in the second-hand shops. Anyone can make one of these from any old glass jar and some aluminium foil. They are not terrifically 'capacious' at storing charge, but are terrifically good at holding a charge for many days: they have a remarkably low amount of leakage, especially if cleaned of excess mayo. Critical experiments have since shown that used Miracle Whip® jars will mysteriously hold a charge for nearly twice as long!