1. Introduction

The quickest way to see results with the Smartec Universal Transducer Interface is by using the UTI Application Development Board, which can be obtained from Smartec. It contains one UTI chip, a PIC microcontroller, which processes the UTI digital output and a RS232 interface driver, for communications with your PC, as well as the software you need. On the printed circuit there is an area available, for connecting wires and components, such as capacitors, resistors etc.

However, if you don't have this board available, or if you want to start developing your own application with the UTI from scratch, we wrote this Quick Start Guide. All the information you need for using the UTI can be found in the UTI specifications booklet and in the UTI application note booklet, but we like to give you a little extra hand in understanding the basics and seeing how beautifully simple these basics are.

In order to achieve this, we will first explain how you would measure a capacitor with an unknown value of less than 2 pF, using the UTI. When you know to do that on your own, you will have no problems using the UTI in any of its other operating modes, with which, for example, you can measure three unknown capacitors simultaneously, resistors, resistor bridges etc.

2. A little theory

Measuring the value of a capacitor accurately, without dedicated electronics, is not easy. Even if you are using a UTI chip, which all the necessary technology on board, you have to understand the principle of three signal technique, to make things work properly.

Suppose you want to measure the value of a capacitor using a digital multimeter, with a dedicated input for this task. If you insert the capacitor directly with its leads as short as possible, you might get a reasonable accurate reading, depending on the quality of the multimeter. This is called the two-pole method and works fine if you don't need real accuracy, there is no distance involved, you just need a single reading and there's no processing of data involved

If you need to measure the value of a capacitor accurately over a certain distance using connecting wires, the situation is shown in fig. 1.

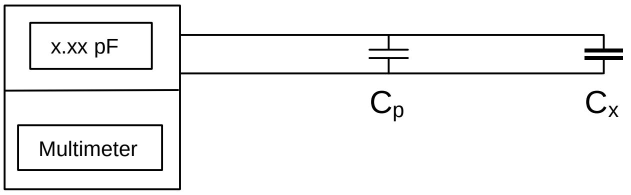


Fig. 1 Failing Two-pole multimeter measurement

The multimeter would simply give you the value of $C_x + C_p$, where C_p is the parasite capacitance of the connecting wires. As you can see, in this situation the two-pole method fails, and there is no simple workaround.

3. Four-pole measurement

If we move from two-pole measurement to four-pole measurement, the situation completely changes. Fig.2 shows how the four-pole principle works. For clarity we have drawn the UTI in two halves, with the UTI output on one side and the UTI input on the other.

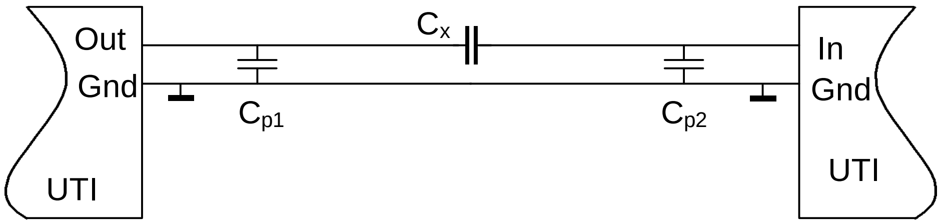


Fig.2 Four-pole UTI approach

The left-hand plate is excited with a signal from a voltage source with zero Ohm impedance. The result is that C_{p1} has no influence. By collecting the charge which is induced on the right hand plate, with the aid of a current input, which also has an impedance of zero Ohm, we avoid C_{p2} collecting any of the induced charge. In fact C_{p2} is short-circuited by the UTI input. The effect is that C_{p1} has lost its parasite property and does not influence the measurement of C_x.

Because there's only one signal ground, the actual measurement can be performed with three connecting UTI pins, as shown in fig.3.

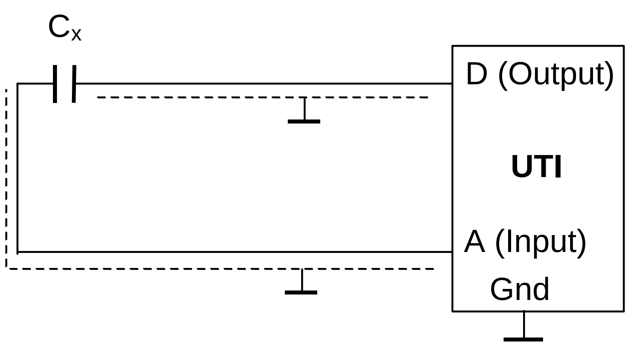


Fig. 3 Practical UTI connection

We still call this method the 'four pole' method, however. Because UTI input A is a very sensitive input the connecting wires - in any case the wire(s) connected to input A - should be of the shielded type, with the shield(s) connected to the UTI signal ground.

Using the set-up from fig.3, the UTI would give you a good indication (timer period) for the value for C_x, with the parasite capacitance from the connecting wires eliminated.

If we would replace the UTI with another one, it would probably give you a slightly different value (just as another multimeter would!) For this problem the UTI also has a beautiful solution and its called Three-Signal Technique.

4. Three Signal Technique

We will use a second capacitor – with a well-known value, the so-called Reference capacitor -, connected by a second, similar wire. Fig. 4 shows how this would look.

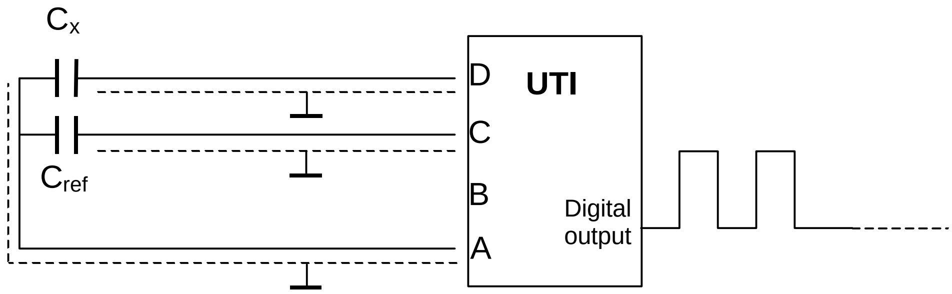


Fig. 4 Three Signal Technique

The digital UTI output gives us three time intervals. Two of these intervals depend on the values of C_x and $C_{ref.}$

In the next paragraph we will show you that we can eliminate the so-called offset and gain errors, which results form the physical nature of the UTI. By eliminating these errors, we also eliminate differences between different UTI and at the same time increase the accuracy of the outcome. We can do so by processing the timer information together with the known value of C_{ref}.

We could have connected a third capacitor between B and A, an external offset capacitor $C_{off,\ ext}$, but at this moment it is preferable, to give this one a value of zero, i.e. the capacitor is non-existent.

5. Practice and a little math

If you connect a UTI to two capacitors, using three wires, as shown above in fig. 4 and make the UTI operate in mode 1 (which is the 1 unknown capacitor mode), you will get an output signal like in fig. 5.

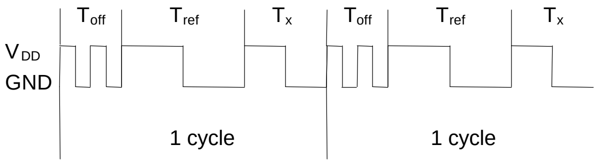


Fig. 5 Digital output from UTI

The signal consists of three phases, with duration of Toff, Tref and Tx respectively. The duration of the first phase, Toff, is always the shortest and corresponds to the value of open output B. It gives you information about the offset error and is always recognizable from the double period (two high's and two low's).

Let's be more specific. All capacitor values are represented by the UTI through their corresponding period duration. The general formula is:

$T = a_0 + a_1 * C_{ext}$, where a_0 represents the internal UTI offset and a_1 represents the UTI gain.

With two capacitors, we have the following two equations:

$T_x = a_0 + a_1 * C_x$ (I)
$T_{ref} = a_0 + a_1 * C_{ref}$ (II)

Because we have not connected any external capacitor to output D, the value of $C_{off,\ ext}$ is zero. This gives us equation (III):

$T_{off} = a_0$ (III)

Now we have three equations and also three unknowns (C_x, a_0 and a_1) we can solve these equations. Lets compute

$M = (T_x - T_{off}) / (T_{ref} - T_{off})$ (IV)

$T_x – T_{off} = (a_0 + a_1 * C_x) - (a_0) = a1 * C_x$
$T_{ref} – T_{off} = (a_0 + a_1 * C_{ref}) - (a_0) = a1 * C_{ref}$

Thus $M = C_x / C_{ref}$, and

$C_x = M * C_{ref}$ (V)

===

This means that the value of C_x can be found by computing the value of *M* according to (IV) and multiplying the result with the value of our reference capacitor.
When the UTI is used in mode1, typical values for a_0 and a_1 are

a_0 = 2 [ms]
a_1 = 1 [ms/pF]

6. An example

Suppose three capacitors has to be measured in the range of 0 to 12 pF.
Use therefor mode 2.

From the datasheet:	N = 1024	(slow mode, page 7)
	K1 = 1.7 µs/pF	
	C0 = 12 pF	(Table 8 page 14)

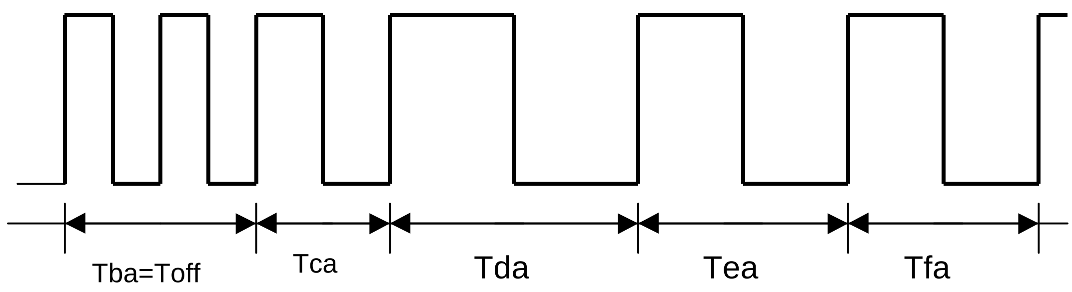
Cba Smallest capacitance for offset measurement and left open.
Cca to be measured f.i. 3 pF
Cda to be measured f.i. 5 pF
Cea to be measured f.i. 4 pf.
Cfa reference capacitor 10 pf

From the formula given in table 5 the times can be calculated and will be:

Tba = 20.89 ms
Tca = 26.11 ms
Tda = 29.60 ms
Tea = 27.85 ms
Tfa = 38.30 ms

These times has to be measured by the microcontroller and calculated with the above mentioned three signal technique.

OUTPUT SIGNAL



The value for Cca can be calculated by:

$$\frac{Tca-Tba}{Tfa-Tba}$$

And the values for Cda and Cea by

$$\frac{Tda-Tba}{Tfa-Tba} \qquad \frac{Tea-Tba}{Tfa-Tba}$$

When the capacitance that has to be measured changes the time *Tca* or *Tda* or *Tea* will change in accordance

7. Software

All kind of software examples can be found in other application notes.