Novel and Forgotten Current-steering Techniques for Resistive Multitouch, Duotouch, and Polytouch Position Sensing with Pressure

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Abstract

A compendium of foundational circuits for interfacing resistive pressure and position sensors is presented with example applications for music controllers and tangible interfaces.

Keywords: Piezoresistive Touch Sensor Pressure Sensing Current Steering Multitouch.

1. Introduction

The recent surge in development of multitouch gesture systems is mainly around capacitive [28] and optical [5] sensing techniques. Although interesting and widely used by the NIME community, most musical applications of touch benefit greatly from concurrent acquisition of pressure or force at the touch points [1]. For this piezoresistive materials have proven most effective.

At least three generations of inventors have developed sensing circuitry for resistive arrays and piezoresistive materials with much duplication of effort along the way. This paper describes the key (and largely forgotten) methods and introduces new higher-performance circuits developed for musical instrument controllers.

2. The Current-flow viewpoint

Much recent electronics teaching in the NIME and tangible, physical computing communities starts with a voltage-centric view of resistive sensing with the potential divider on center stage. Even the wikipedia erroneously defines the potentiometer as an adjustable voltage divider [29]. This voltage-centric view is reinforced by energy efficient designs and also because ubiquitous, cheap a/d converters measure voltages not currents. Most of the circuits presented here exploit control of current flows in resistive networks so the reader is encouraged to review both Kirchoff's voltage and current circuit laws and Ohms law before proceeding.

3. Grounded wiper

Figure 1 shows an alternative to the well-known potential divider circuit often used with potentiometers. Instead of using the wiper to pick off a fraction of a constant voltage applied across the terminals, the wiper is grounded and two independent voltages are acquired at the terminals. This circuit offers no particular advantage over the potential divider in conventional mechanical potentiometers and sliders but has two advantages for resistive strip devices like the Softpot [23] or SlideLong [24]: providing some shielding and drawing no power when the wiper is physically disengaged from the resistive material, i.e. when there is no physical touch of the strip.

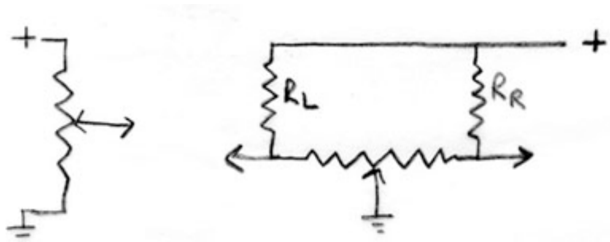

Figure 1. Potential divider (left), and Grounded wiper (right)

3.1 Duo Touch

Softpots and related devices differ from conventional potentiometers in that their “wipers” are continuous conductors suspended over contact points along the full length of the resistive material or for the SlideLong over conductors that tap into the resistive material. There is no standard schematic symbols for this so in Figure 2 we introduce the indented bar symbol to represent potentially multiple touch points. This schematic makes clearer the main benefit of sensing at the terminals: two touch positions can be sensed concurrently.

Figure 2 represents a flexible design pattern that can be applied to many position sensing applications so we will analyze it in more detail.

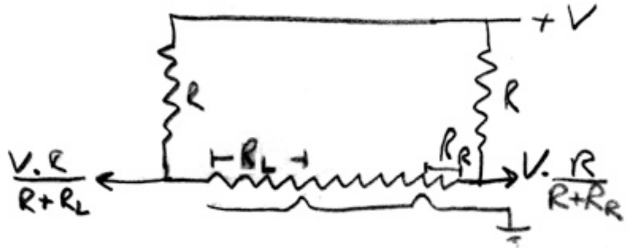

Figure 2 Sensing 2 points with Membrane potentiometers

The first case is easy to understand: If no touch is occuring there is no path for current to ground so both measurement nodes must be at the high potential. When the membrane contacts the resistive strip all we need consider is the outermost pair of points of contact. There can be no potential difference between these points as they are both shorted together and connected to ground. The resistive material between the outer touch points is shorted out of the circuit. We can estimate the position of these outer points by applying the standard potential divider formula to the resistances to the left and right of the contact points and their respective pull-up resistors.

The history of duo-touch goes back at least to early music keyboard switch patents with shorted capacitor and resistor networks [8] and shorted inductors [26]. Figure 3 shows how ARP used a constant current source for a duophonic keyboard in the ARP 2500 and the 3620 keyboard for the ARP 2600 [22]. The ARP circuit topology was also used on the TVS-1A by Oberheim in 1975 using a single transistor for the current source [11].

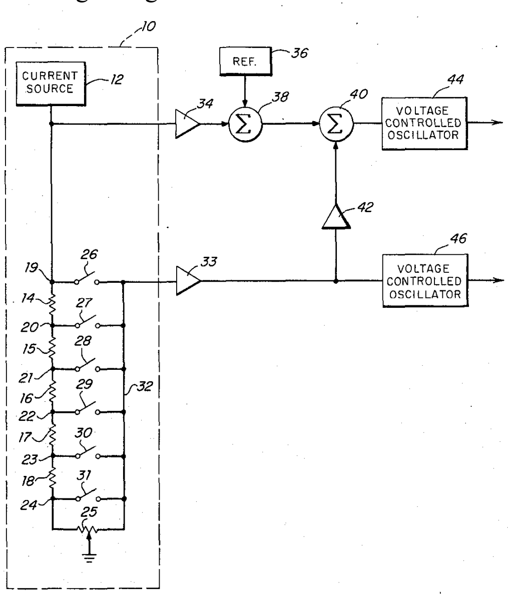

Figure 3 1974 ARP dual keyboard circuit

A more modern implementation of the same idea is available from PIAI [18] for a dual touch ribbon controller. These analog-output solutions do provide a linear, position-to-voltage output relationship obviating the voltage divider computation of equation 1. They are however more expensive in parts and space than one using the pull-up resistors in Figure 2 with a modern microcontroller with integrated A/D converter(s). A useful hybrid of the benefits of both implementations is to replace the pull up resistors of Figure 2 by integrated constant current sources such as those integrated on the TI REF200.

The Moog Modular Synthesizer duophonic keyboard module 952 [10] puts the resistor ladder around the feedback loop of an inverting opamp – another well-known constant-current technique we will see later in section 4.

The circuit of Figure 2 appears in a 1994 digital reimplementation [19, 21] of the Trautonium [25]. Trautonium sensors differ from the membrane potentiometers discussed earlier in that the resistive material (a helical wire) is pressed against the conductive wiper. In the "digital" trautonium analog voltages at both ends of the wire were made available to the A/D converters but only one was used in the music synthesis mappings [20].

The duotouch technique was revived more recently by the author for controllers in an interactive installation [3]. For a two-foot position sensor a resistor chain was wired between the switches of a burglar alarm floor-sensing array. A two-finger input pad was also presented combining two Infusion Systems SlideWide devices stacked orthogonally to each other yielding independent x and y position estimates.

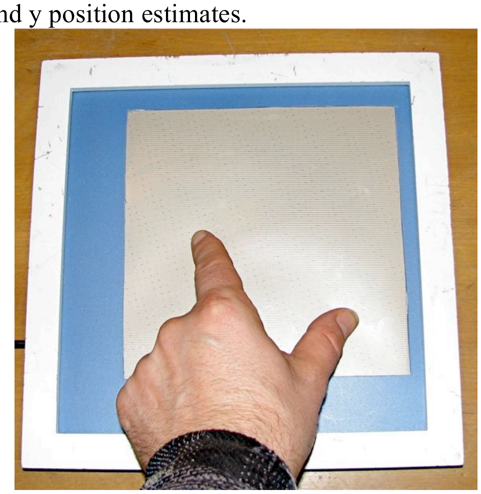

Figure 4: DuoTouch sensing pad

Independently, this technique was rediscovered for 4-wire resistive touch screens [9].

3.2 DuoTouch and Pressure

In the duotouch tablet of Figure 4 an independent layer of piezoresistive fabric sandwiched between two conductors provides a single composite pressure value. This layered approach proved too unwieldy for the sensing strips in a new stringless cello controller (Figure 5) [4].

Instead a novel circuit was developed to allow for dual position sensing and aggregate pressure using a modified Interlink FSR strip [7].

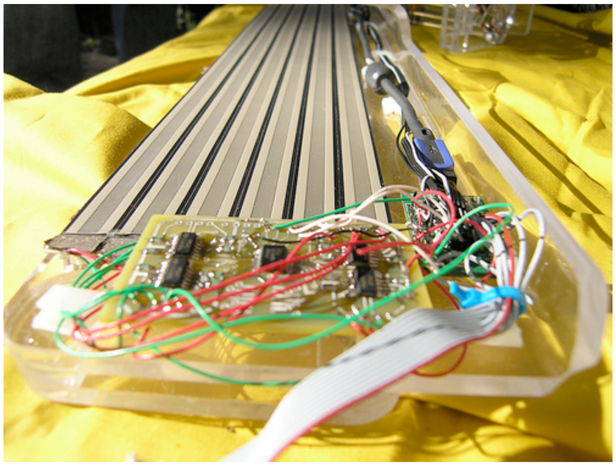

Figure 5: Stringless Cello Position and Pressure Strips

These strips were originally intended for pressure-only sensing. The basic FSR is a two lead device corresponding to each side of an interdigitated array of silver conductors printed on a plastic strip. In the novel duotouch strip extra sensing nodes are added by connecting wires to conductive adhesive fabric strips taped at each end of the piezoresistive material. These are the nodes that are connected to pull-up resistors and to the data-acquisition channels for position estimation (from the "nut" and "bridge in the stringless cello) as shown in Figure 6.

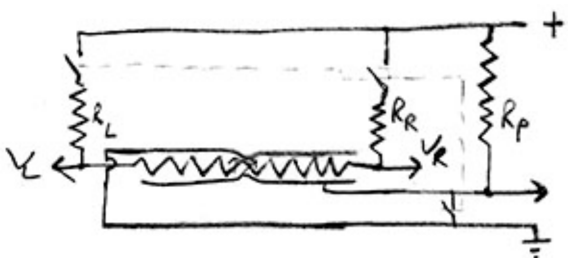

Figure 6. Dual Position and Pressure Circuit

When position data is being acquired the microcontroller maintains both silver pressure conductors at ground potential resulting in a circuit equivalent to Figure 2. When pressure is to be acquired, current is sent down one of the silver conductors (via pull up-resistor Rp) and the voltage at that node is measured. The endpoint pull-up resistors are switched out of the circuit during this measurement. The key to efficiently doing this on the large scale of the stringless cello (12 strips) is the flexible and dynamic assignment of roles to pins now possible on modern microcontrollers. This allows for other dynamic current steering techniques such as Charlieplexing [13], and bidirectional LEDS [15]. These techniques have been generalized in uOSC and are easily accessible by carefully constructing OSC messages sent to the microcontroller [16].

Note that these current mode sensing techniques are energy efficient because the pull-up voltage source may be enabled briefly in each data-acquisition cycle – for just long enough for stray capacitances to settle and for the few microseconds needed for the ADC's sample and hold phase to complete.

4. Polytouch

David Wessel's polytouch "slab" [27] consists of a 4x8 array of piezoresistive touch pads from Interlink (Figure 7) with two axes of position sensing (X/Y) and pressure (Z).

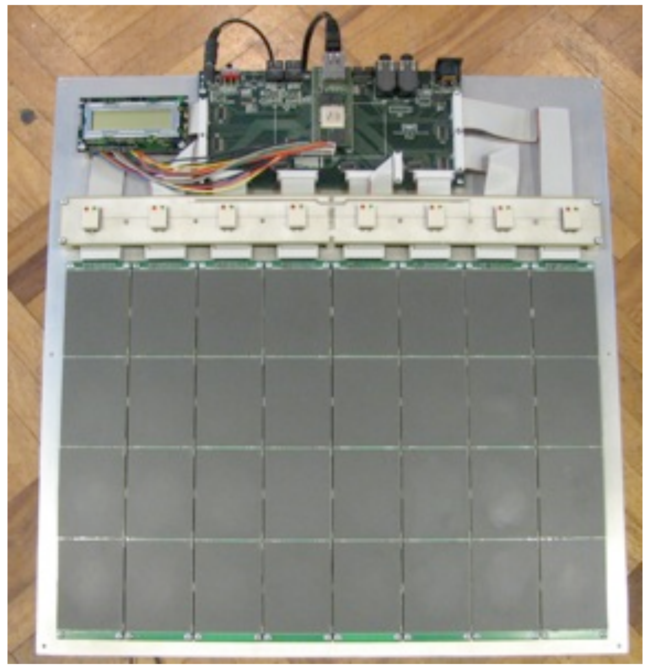

Figure 7. Slab

A novel custom circuit (Figure 8) was developed to meet the challenging requirements of the performer: high-speed data acquisition rate (<1mS) and concurrent acquisition of the measurands for all 32 pads.

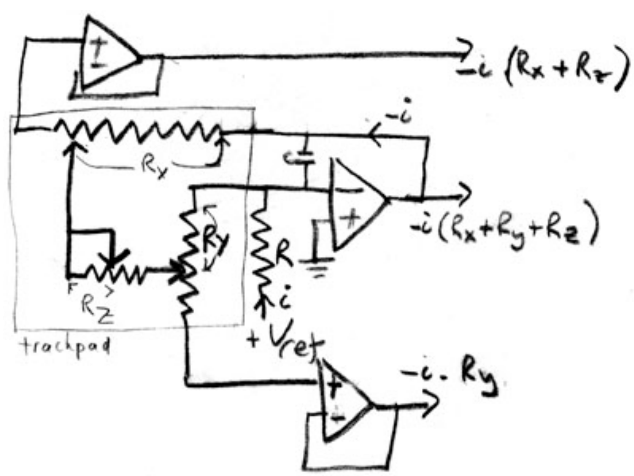

Figure 8 Concurrent Sensing for the Slab

Only 4 conductors are accessible from these resistive trackpads. This makes it challenging to isolate the pressure-sensing axis. Sandbach patented the same constant-current source/difference amplifier approach [14] we saw in the ARP dual keyboard approach for their fabric implementation of the same kind of touchpad. Interlink themselves uses a microcontroller to measure charge rates of capacitors driven via the resistive array[6] as shown in Figure 9.

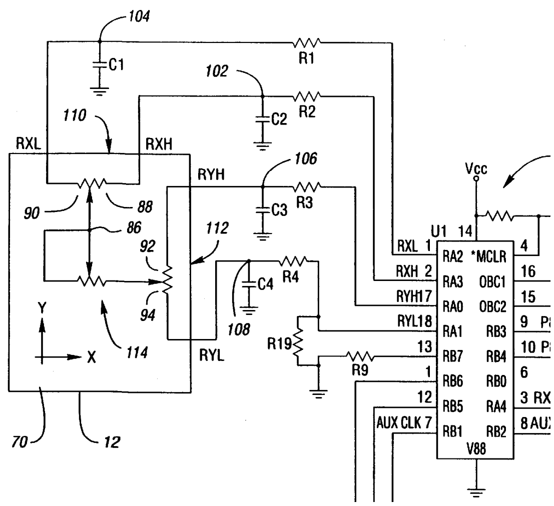

Figure 9 Interlink Versapad Scanning

The solution developed by the author is to provide a small constant current through the touch pad array inverting op-amplifier shown in Figure 8. This is similar to the approach Moog employed on his 926 duo keyboard. The inverting input is a virtual ground at the same potential as the non-inverting input. The current through the pad resistors is established by two constants in the circuit, the summing node input resistor R and the source voltage reference applied to one leg of this resistor. The three measurands (XYZ) are computed by subtraction of the three op-amp outputs. The op-amps should be selected to have low input offset voltage. External noise sources are controlled by limiting the op-amp bandwidth with a low value capacitor from its output to the summing node (C). This circuit has a lower parts count than Sandbach's and has the advantage over Interlink's solution of forming the outputs concurrently.

5. Resistive Manytouch with Pressure

The author's "tablo" controller integrates sensing of displacement and "aftertouch" pressure using resistive sensing of conductive fabric drape position and piezoresistive fabric sensing of pressure. A silver-plated flexible fabric is held in a circular embroidery hoop. When the hoop is attached to the base of the Tablo, the highly conductive fabric is grounded by a ring of conductive copper fabric at the top of the trapped inverted cereal bowl. Strips of resistive carbon-loaded plastic form a ring of potential dividers completed by pullup resistors under the bowl. The drape of the fabric is estimated from the voltage at these divider nodes as it varies according to how much of the plastic strips is shorted to ground. If the performer presses the flexible fabric to contact one of the two piezoresistive, divided annular rings on the base it grounds the leg of another potential divider for pressure sensing.

Although already described briefly at Nime in 2008 [2] it is included here because current-steering techniques are used in an unusual context: a single gesture results in the grounding of multiple independent circuits with nodes at different parts of the fabric. This provides for a higher gesture sampling rate and accurate, concurrent support of large and small distance gestures – both unobtainable in current camera-based drape sensing systems [12].

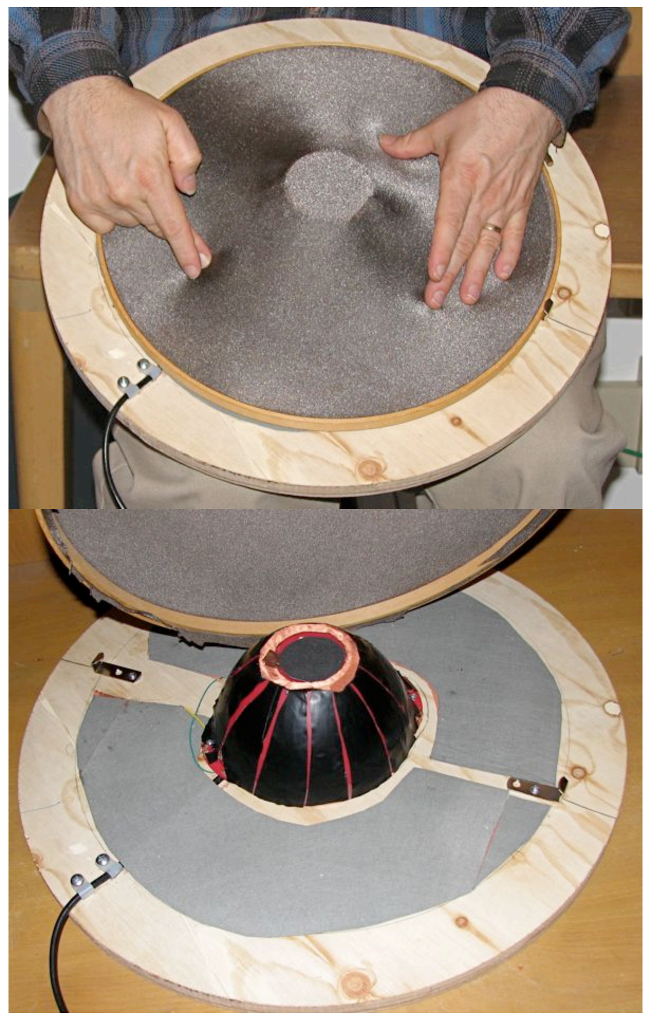

Figure 10 Tablo Drape and Pressure controller.

6. Resistive Multitouch with Pressure

The main challenge with resistive multitouch arrays is achieving sufficient spatial resolution. Even modest sensing areas require thousands of taxels for seamless position and pressure sensing. Multiplexing addresses this problem requiring only n+m edge connections for an n by m sensing array. The well-established approach to avoid crosstalk along the orthogonal wiring array is to place a series diode at every node.

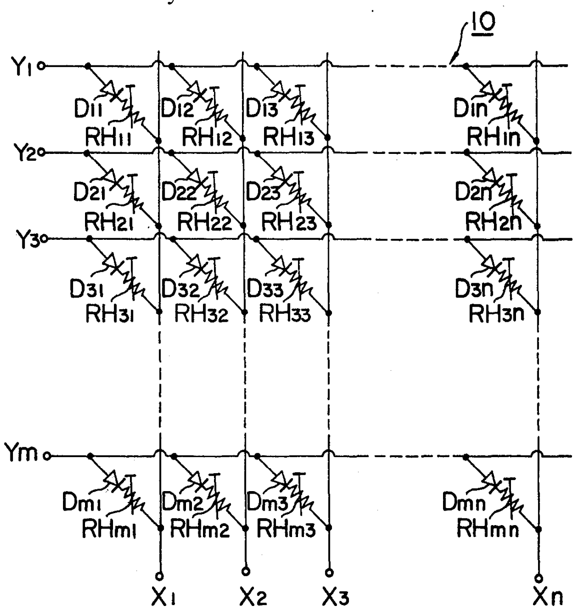

Figure 11 Diode isolated variable resistor array.

The array of Figure 11 is scanned by bringing each Y_i to a high potential in turn and measuring the currents at X_i - typically with an inverting op-amp and A/D converter. By carefully considering the possible current sources for each output node X_i it is evident that the diodes block current flows between taxels.

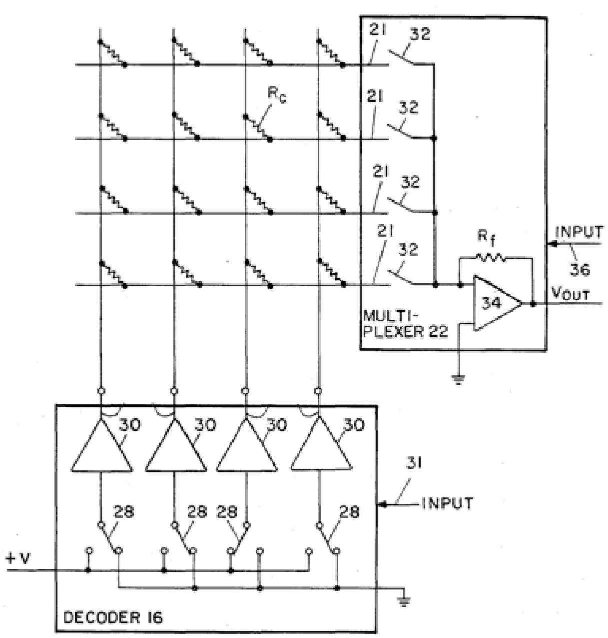

Figure 12 Grounding and virtual ground sensor isolation

The number and nature of the diodes in Figure 11 may be prohibitive in many applications. For example in piezoresistive fabric array sensing [2] flexible diodes may be difficult to create. Independence of sensed values in a pure resistive array is done by grounding all the rows that are not being addressed and using virtual grounds for the input sensing. In this case it can be verified that the voltage across all the resistors that are not being sensed is 0 so no current flows are possible to interfere with the measurands. Figure 12 shows how this is done with multiplexing of both row and column signals. Acquisition speed and sensing performance can be improved by omitting the row multiplexer and providing an inverting-opamp and A/D converter channel for each row [17].

7. Conclusion

Although, certainly not the final word on resistive sensing circuits, the combination of older designs from the 1970's and 1980's and newer implementation strategies described here provide a solid baseline for future tangible interface developments. These circuits are not the most glamorous part of development of new instruments for musical expression but they have been the enabling innovation for instruments now used regularly in live performance, e.g., [27] [4].

8. Acknowledgements

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