Fully-Differential Capacitive Sensors
for Seismometers

(Poster presentation)

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BACKGROUND:

(1) Capacitive and Optical Sensors are the least invasive and provide the greatest signal to Noise ratio (SNR).
(c.f., Braginsky, V. B., Mitrofanov, V. P. and Panov, V.I., 1985: *Systems with Small Dissipation*, The University of Chicago Press.)

(2) Industry standard for capacitive sensing (all technologies including seismometry) has been the *half-differential form*, *which has, at best, only one-half the sensitivity of the fully differential form which began to be developed in the late 1980's.*

(3) *Fully-differential sensor* -- first used by Peters in his "Linear rotary differential capacitive transducer" (LRDCT), a variant of the later ***"Symmetric differential capacitive (SDC)"*** devices (both patented).

(Basis for roughly 50 publications, incl. ones concerned with ***Mesodynamics*****).** Described online at:
http://physics.mercer.edu/petepag/sens.htm

SDC Sensor:

(1) Endorsed in the mid 1990's by ***R. V. Jones***, pioneer of capacitive detector development.

(2) Used as a pair in the heart of a commercialized ***Cavendish balance*** -- TEL-Atomic's computerized instrument with a mechanical common mode feature, described online at
http://www.telatomic.com/sdct1.html

(3) Basis for a ***scanning squid microscope*** -- M. Barker, Univ. of Birmingham, U.K.

(4) Installed in two ***force feedback seismometers***, one a horizontal and the other a vertical -- amateur seismologist A. Coleman, Edmonds, Washington.

(5) Equivalent sensors used (without reference to the earlier work of Peters) in ***MEMS devices***, such as *accelerometers* built at Carnegie Mellon, Berkeley, and Singapore.

(6) Variants used:

(a) for *micropositioning in two dimensions* -- Kolb et al, Univ. of Maryland.

(b) in a *Position detection device* -- U.S. patent by Hewlett Packard.

(7) Fundamental experiments using LRDC or SDC device (in addition to mesodynamics studies) to measure :

(a) *Stress evolution and surface deformations in high dose MeV energy He implanted Si* (Prof. Hajdu, Hungary).

(b) S*hear modulus and internal friction of magnetoelastic amorphous wires*, (Prof. Squire, England).

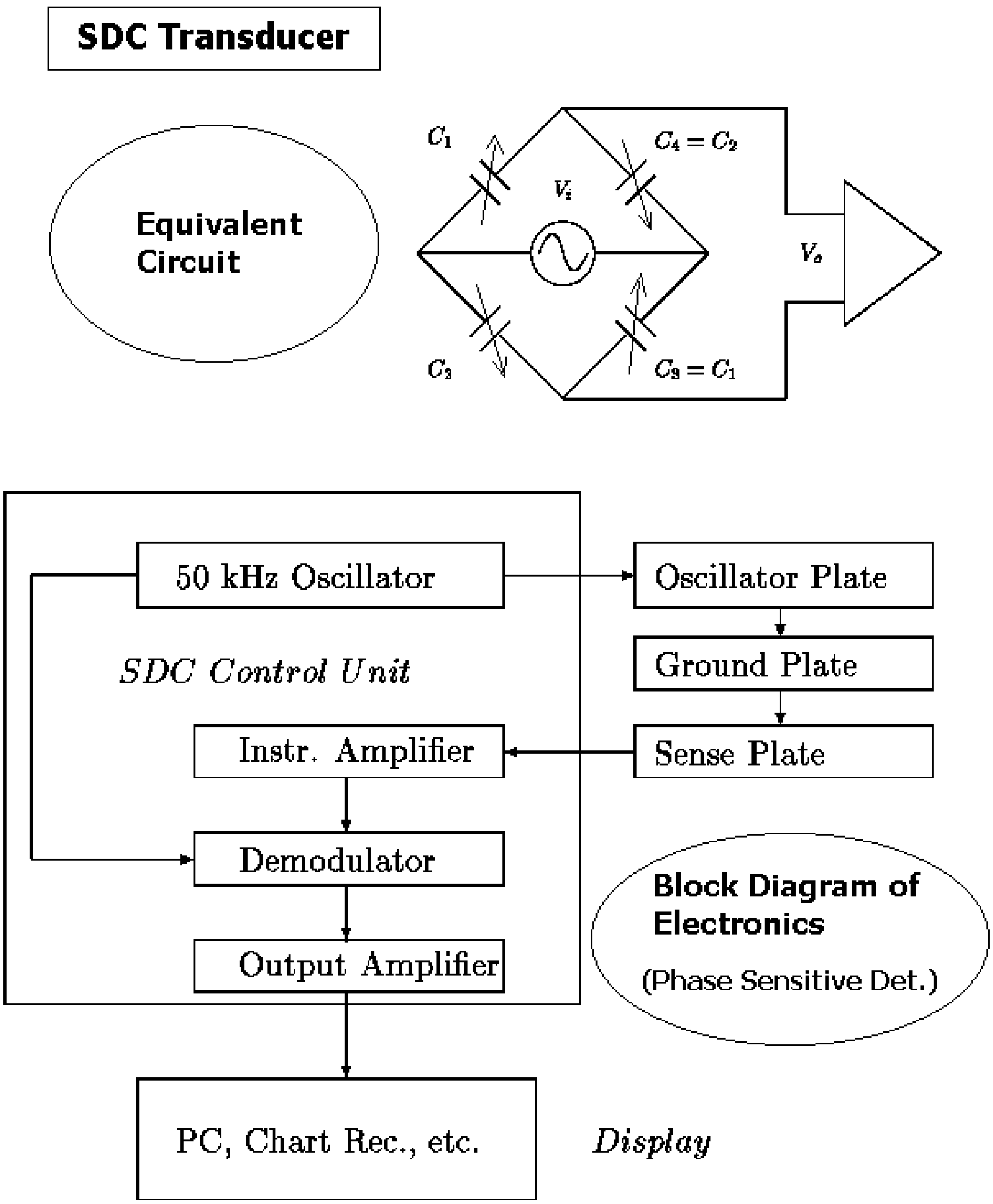

Figure 1. Equivalent circuit & Block diagram of the Electronics for an SDC Transducer.

Figure 2. Figures from a Tutorial, showing how the voltages change according to moving electrode position (area-varying, or 'shadow' type SDC sensor).

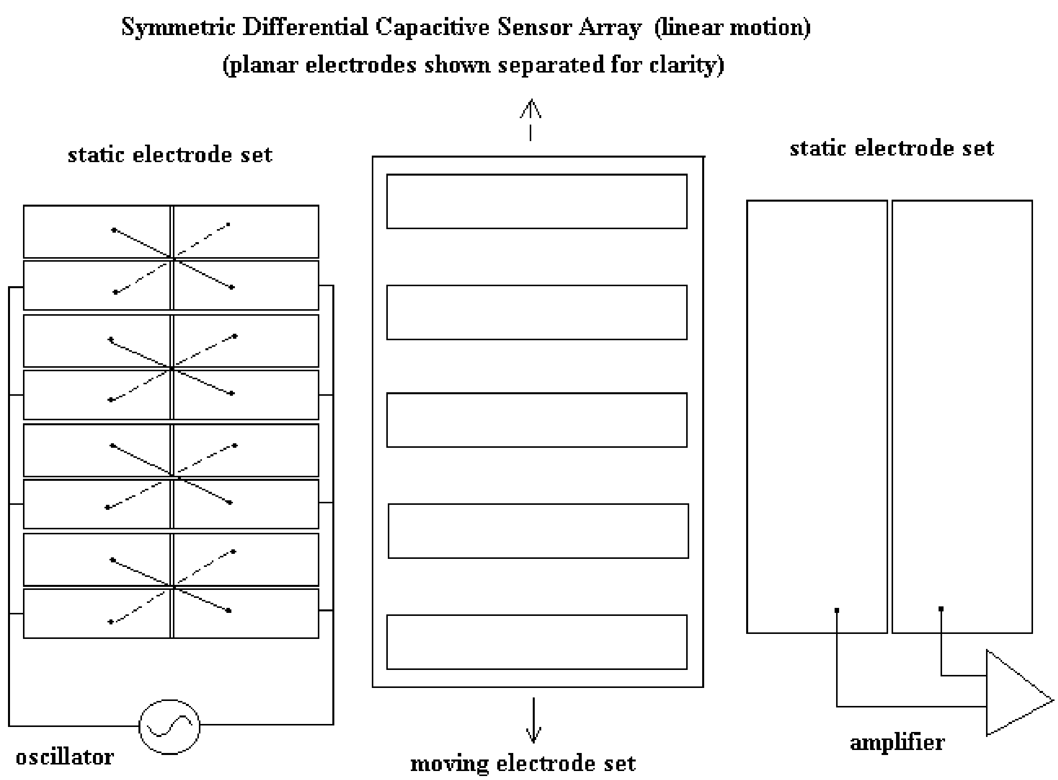

Figure 3. A linear array of four SDC position sensors (planar electrodes shown separated for clarity), to increase sensitivity.

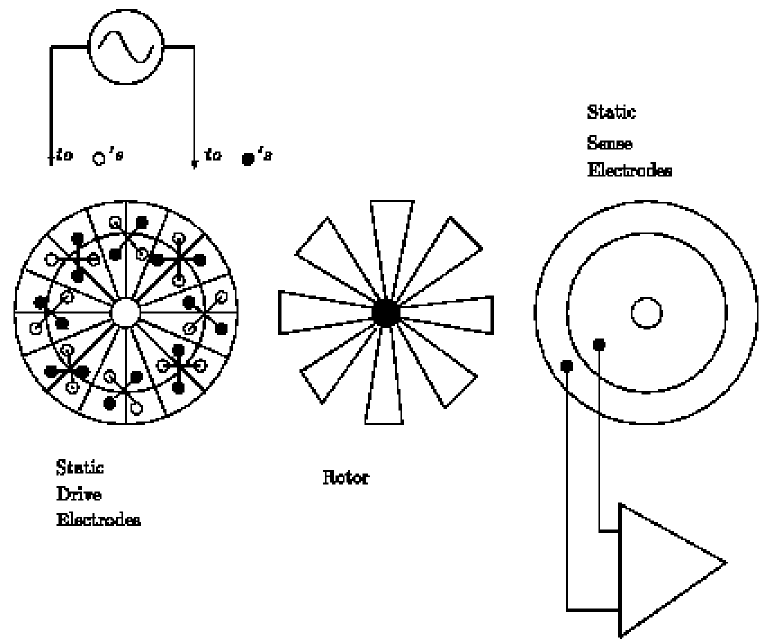

Figure 1:
An array for measuring angular position. (Electrodes shown separated for clarity.)

Figure 4. Angle array of eight SDC sensors for improved resolution, as allowed by mechanical dynamic range (electrodes shown separated for clarity). This detector is used in a sensitive tiltmeter.

SDC Sensors can measure on the basis of either:

(1) Area variation ('shadow' sensor)
(2) Gap Spacing variation (also used in the conventional half-differential capacitive sensor).

Gap spacing has been used (i) by an amateur builder in Edmond Wash.--Allan Coleman's broadband **force-feedback seismometers**, one horizontal the other vertical, and (ii) sensitive pressure sensor.

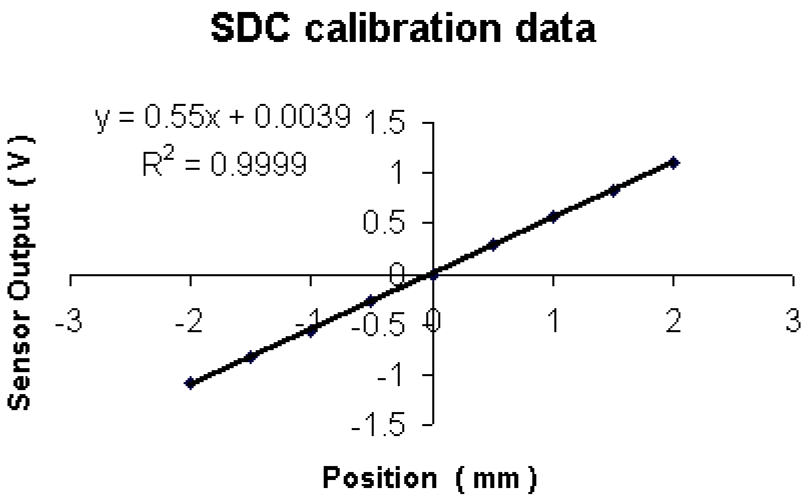

Figure 5. Calibration results for an SDC linear position sensor.

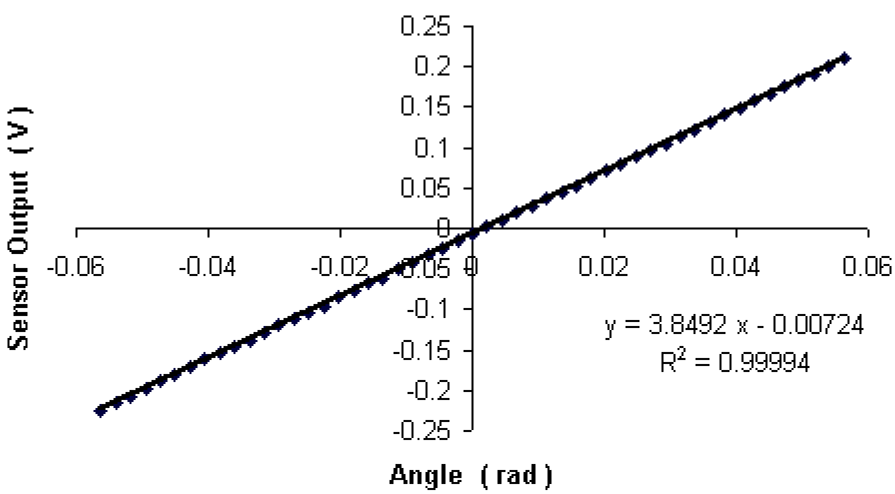

Figure 6. Calibration results for an SDC angular position sensor.

The SDC sensor is ideal for the study of ***internal friction*** that limits the performance of seismometers (such as the STS-1) in the frequency range below 1 mHz. Shown in Fig. 7 are examples of internal friction complexity in a tiltmeter, which uses the angular array of Fig. 4. The instrument (undamped except by internal friction of its tungsten torsion wire) was driven through various sequences involving both (i) resonance, and (ii) anti-resonance -- by stepping back and forth on either side (and thus deforming) the concrete floor on which the tiltmeter sat.

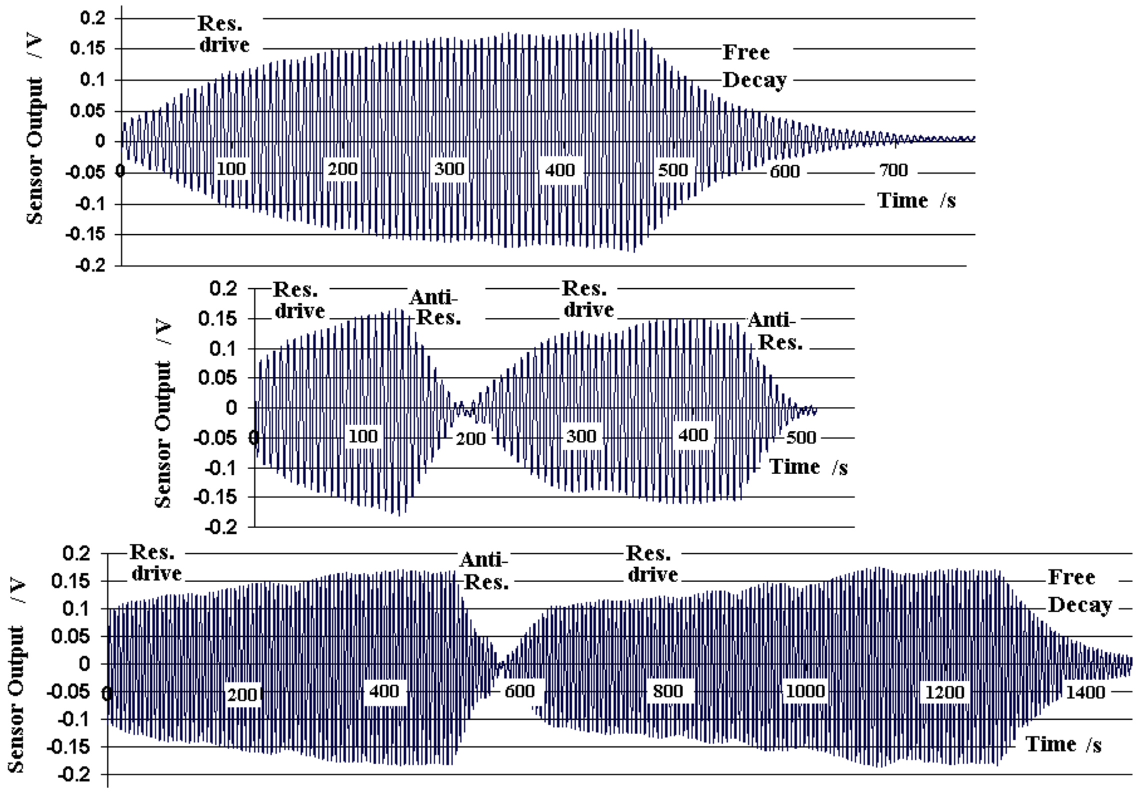

Figure 7. Tiltmeter rersponse to drive at resonance, followed by either (i) free-decay, or (ii) drive at anti-resonance.