Three-chip digital scale zeroes tare weight

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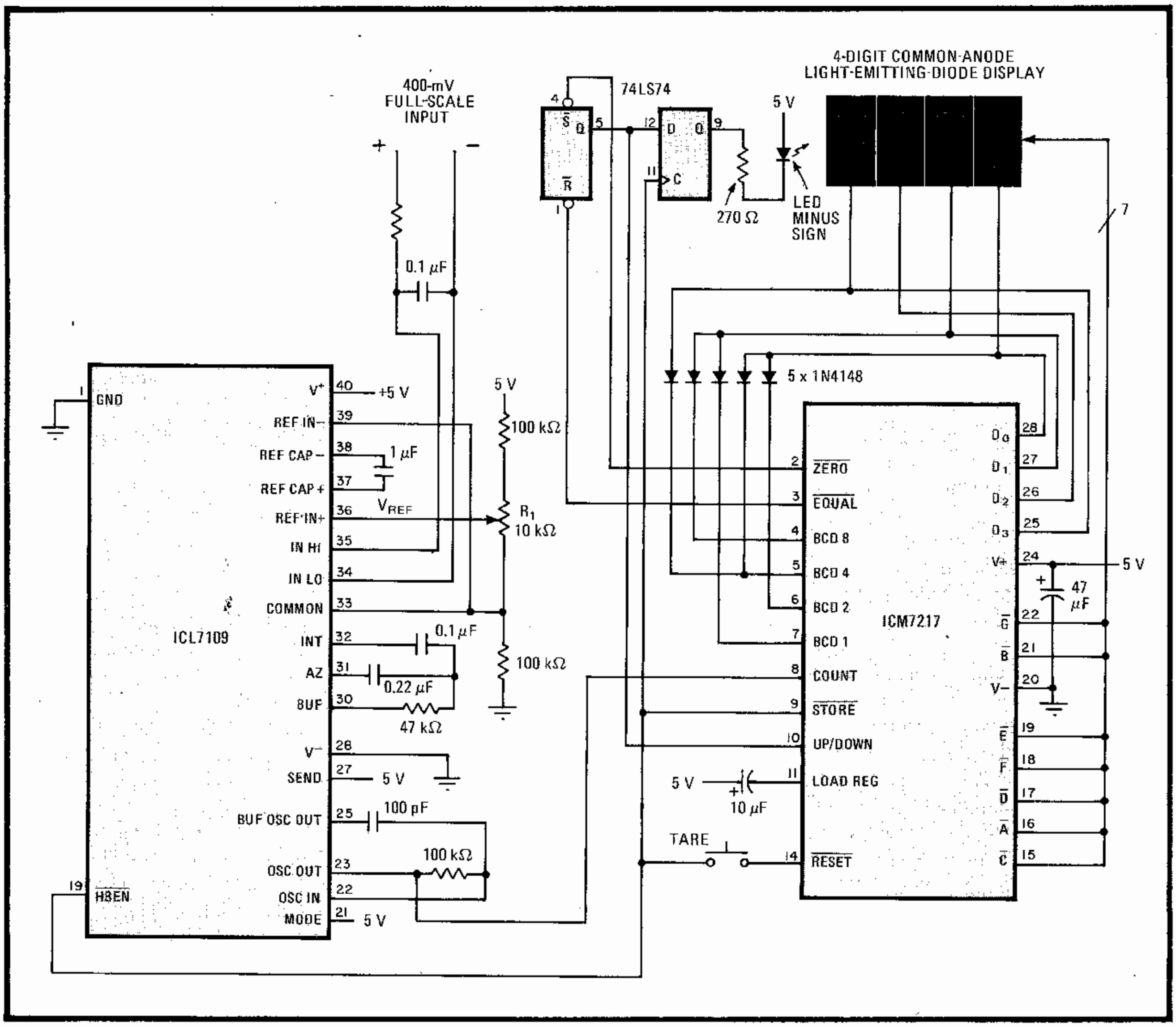
A 12-bit analog-to-digital converter forms the nucleus of this digital scale, which compensates for the tare (the weight of the container holding the material to be measured) so that the net poundage can be determined. Combined with a decade counter that drives common-anode light-emitting-diode displays and a flip-flop for coordinating circuit activities, the unit makes for an accurate, compact, and direct-reading instrument that costs under $40.

An analog voltage corresponding to the object under measurement (obtained here from a 2-kilogram load cell transducer) is applied to the ICL7109 a-d converter, which uses the highly accurate dual-slope method of transforming analog potentials into their digital equivalent. In this technique, a two-step auto-zero and input-voltage integration phase is carried out in 4,096 clock periods, serving to eliminate offset voltages and deter-

Weight reduction. Digital scale in effect subtracts weight of container holding object to be measured so that true (net) poundage can be determined and displayed. Compact and accurate three-chip circuit can be built for less than $40, including display.



mine the magnitude and polarity of the sampled voltage. During this time period, the converter's oscillator delivers clock pulses to the ICM7217 counter/display. The deintegrating phase that follows steps the voltage to 0 in inverse fashion. When the voltage reaches 0, the $\overline{\text{HBEN}}$ signal is generated to freeze the counter/display, with the number of oscillator output pulses generated during this phase being proportional to the magnitude of the input voltage.

The counter's up and down line is controlled by the 74LS74 flip-flop, which is alternately set and reset by the zero (counter at zero) and equal (input equal to 4,096) lines of the ICM7217. Because the counter is preloaded to 4,096 on power up, it is thus free to cycle between 0 and 4,096 during each conversion. Therefore, a number between 0 and 4,096 will be displayed that is equal to the number of output pulses emanating from the converter during the deintegrating phase. With suitable scaling (selected with potentiometer R_1) and the appropriate choice of a presettable number in the counter, the displayed value can be made to correspond directly to the magnitude of the input voltage. As shown in the figure for the general case, the analog input that is required to generate a full-scale output of 4,096 counts occurs when $V_{in} = 2V_{ref}$.

When the tare weight is being measured, the $\overline{\text{HBEN}}$ pulse activates the store input of the counter every 8,192 clock periods, and a constant but initially random number is observed. When the tare button is momentarily engaged, the counter is reset by $\overline{\text{HBEN}}$ and the display will be zeroed. The display will remain cleared thereafter, because with an unchanged weight, $\overline{\text{HBEN}}$ enables the display at the same time in each measurement cycle. In this instance, the display is enabled when the counter reaches 0.

When a variable weight (the object weight) is added, corresponding to N counts of the a-d converter's internal clock, $\overline{\text{HBEN}}$ latches up N counts later than previously; therefore, a number greater than 0 is displayed. Conversely, if N bit values of weight are removed, −N will be displayed. Note that the minus-sign LED will be activated in this case, because F_1 will be low.

Because of input noise, the resolution of the a-d converter will be nominally limited to about 40 microvolts per count, and it will be much worse in industrial environments. Typically, the output of a load cell having 1-millivolt/volt sensitivity will be 2.5 microvolts/gram when operated at 5 volts. Under these circumstances, a stable preamplifier such as the ICL7601 commutating auto-zero (CAZ) device may be required. The input of the ICL7109 accommodates differential inputs, and thus the amplifier need not provide differential single-ended output ports.

If a resolution of greater than 4,096 counts is required, an a-d converter of greater accuracy can be readily substituted for the ICL7109. The ICM7217 can be cascaded with similar units to handle the increased number of bits. ☐

Kitchen Scales

PROJECT

We now turn our attention to weighty matters. Surely it's time, in these days of digits with everything, that we got rid of the analogue scales readout? You bet it is. Design and development by Rory Holmes.

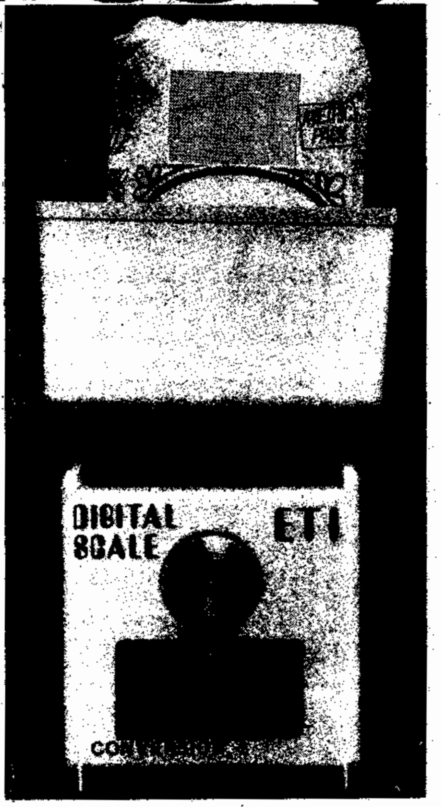
AT LAST, the electronics enthusiast can make amends for the state of the kitchen table, sinking beneath an ever-growing pile of constructional debris. The ETI Digital Kitchen Scales offer a means of adding a digital readout to an ordinary mechanical pointer type of instrument.

The mechanics of weighing scales are particularly difficult for the DIY approach, requiring a frictionless movement with only one degree of freedom — vertical displacement. We decided to use the ready-built mechanics of a low cost spring movement scale and concentrated on the electronic problem of measuring displacement with high linearity, high resolution, and zero friction!

The resulting design consists of an easily wound inductive displacement transducer and the associated drive electronics on a small PCB, all supplied from a 9 V battery. An analogue voltage proportional to weight is obtained, which is then displayed on a 3½ digit LCD panel meter module. Up to 2 kg can be displayed on the scales, but a zero-offset control allows a given weight to be re-zeroed. This provides the useful facility of weighing and mixing ingredients simultaneously — when preparing cake mixture, for example.

The accuracy and resolution obviously depends a great deal on the initial accuracy of the spring and pivot system used in the scales, but ¼% (5 grams in 2 kilograms) should be easily obtainable.

The inductive transformer we are using is known as a Linear Variable Differential Transformer, or LVDT for short. These are used extensively in industry for just such applications as this project — weighing machines, load cells, machine positioning and so on. The circuit features some



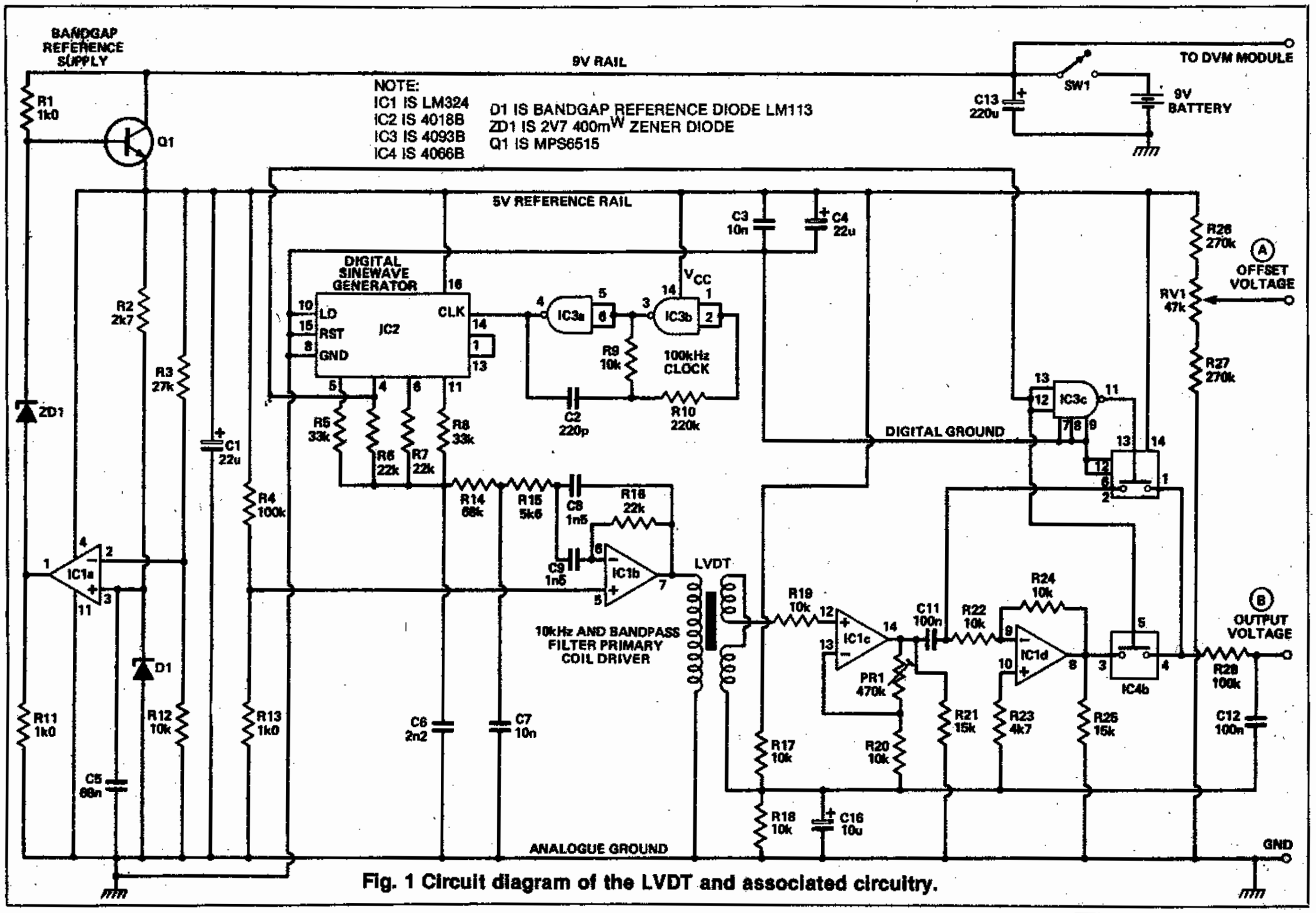


Fig. 1 Circuit diagram of the LVDT and associated circuitry.

novel techniques for allowing an LVDT of few turns to be used; specifically, a phase-lock detection system based on a digital sine wave generator, and a self-stabilising bandgap power supply for precision voltage levels. The block diagrams and boxed-off text give an explanation of the circuit operation and explain how the displacement measurement works.

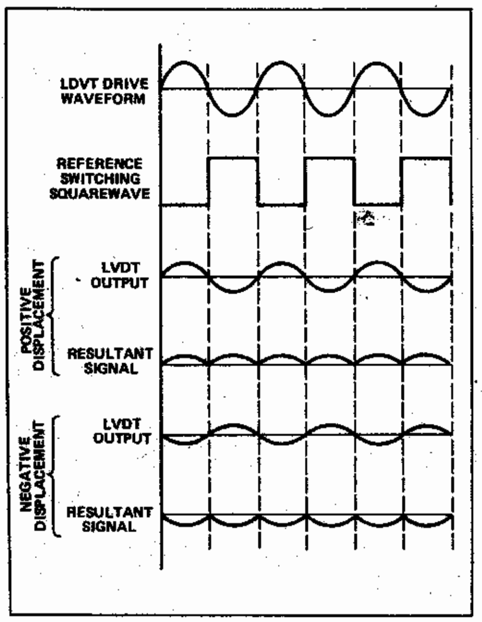


Fig. 3 The output signals generated by the circuit.

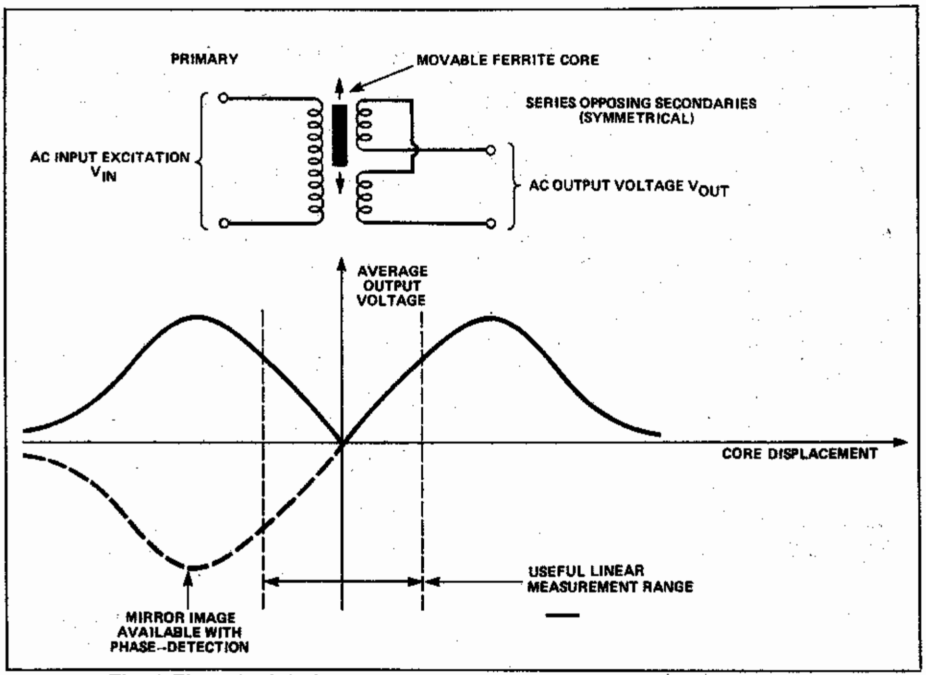


Fig. 2 The principle behind the LVDT, using an AC input waveform.

Construction

Assemble the PCB in the usual fashion, noting the IC orientation, and the polarity of ZD1 and the tantalum capacitors. Also check the MPS6515 pinouts; these often cause confusion. Twelve Veropins should be inserted at the points marked for external connections. Another point to watch is the hole marked beneath preset PR1; this should be drilled out to 3 mm diameter before mounting the preset, thus allowing its adjustment from either side of the board. Likewise, a 3 mm hole drilled on the other centre allows a secure 4-40 or 6-32 mounting bolt for the board.

When complete, the board may be initially tested by inserting all the ICs into their sockets and connecting a 9V battery to the supply terminals as indicated. If a scope is available,

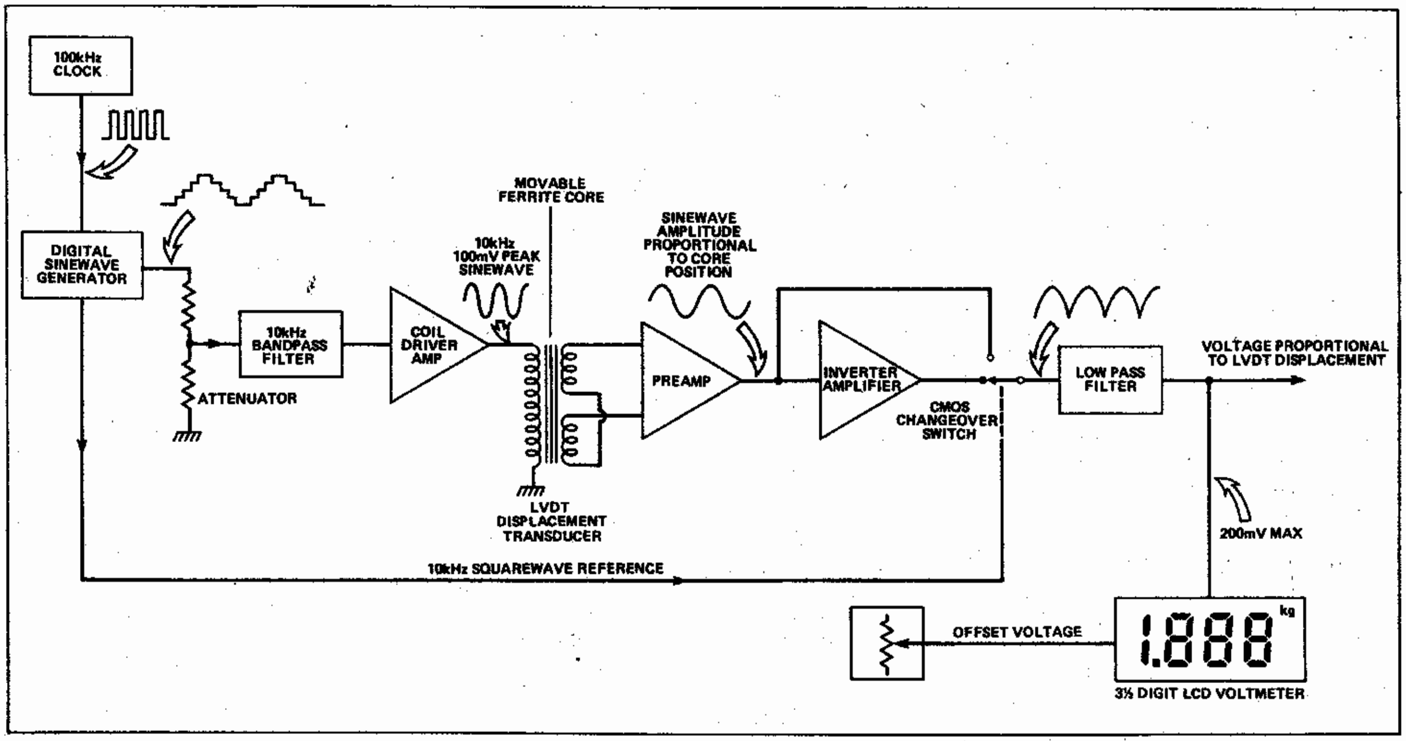


Fig. 4 Block diagram of the Digital Kitchen Scales.

the digital sine wave approximation should be observed at the junction of R14 and C6; it could also be checked with a crystal earpiece, when a high pitched tone of 10 kHz should be heard. The reference supply voltage can be measured with a multi-meter across the wire link and a 0 V terminal. It should be in the region of 5 V if all is well, the exact value being unimportant. At this stage the transducer should be built and wired up before further testing of the PCB.

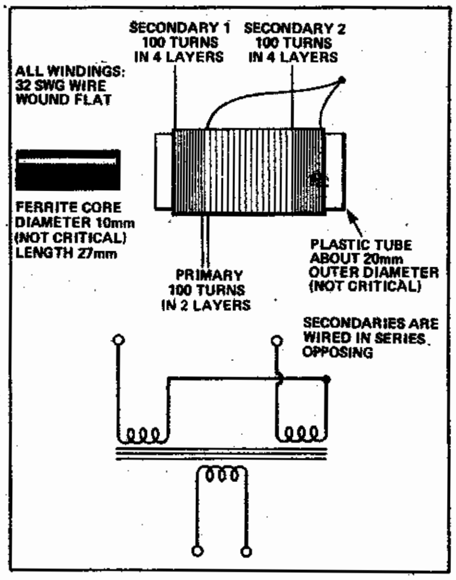


Fig. 5 Coil winding details.

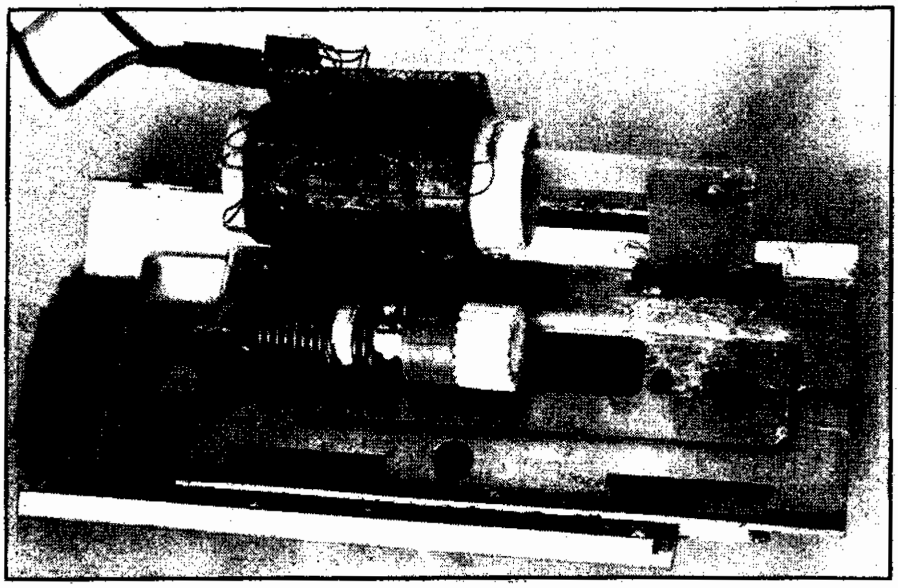
Winding You Up

The LVDT is wound using 32 swg enamelled copper wire on a piece of 20 mm diameter plastic tubing of the type used for electrical conduit, and available from DIY shops. Any similar piece of tubing will suffice since the dimensions are not critical. Figure 6 shows the winding arrangements. Two separate secondaries are wound either side of the central primary winding. All the windings consist of 100 turns wound in the same direction in flat layers; four layers of 25 turns for each secondary, and two layers for the primary. The accuracy and linearity of the LDVT transducer depends upon the two secondaries being as similar as possible and symmetrically positioned about the primary winding. Care should thus be take to ensure the layers are evenly wound and tightly packed. Super-glue may be used to retain each layer as it is wound. After completing the windings and finishing with a liberal coat of glue the two secondaries are then wired in series opposition to form one coil by connecting together the end of each winding.

The LVDT should now be wired up to the PCB using shielded leads as illustrated on the overlay diagram. On our prototype assembly we used a four way 'Molex' PCB plug and socket for this connection since the transducer assembly could then be conveniently plugged in.

Figure 7 shows how the LVDT is mounted to measure displacement. As described last month the mechanics of an ordinary pointer scale are utilised to provide the linear displacement with weight via the in-built spring and pivot.

For our prototype we used a small low cost scale which incorporated a ball-race slide mechanism to support the weighing pan. Practically any type of scales could be converted to a digital readout, provided these is room to mount the LVDT and its associated driver electronics.



A typical scale with the LVDT added.

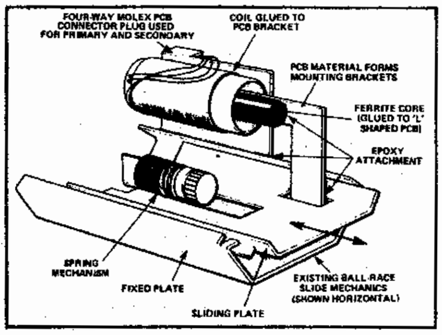


Fig. 6 An artist's impression of the sensor to help with construction.

Scaling The Heights

Obviously, the more precise the mechanics of the original scale, the greater the degree of accuracy that can finally be achieved with the electronic transducer. The principle is to attach the main coil to a fixed part of the scale while the ferrite core is attached via some rigid element to the weighing pan movement, such that as weight is put on the scale the core moves linearly along its axis into the coil former.

In our prototype the two steel plates of the slide were used to support the transducer as represented in the diagram. Two pieces of PCB material fixed with epoxy act as brackets for the coil former and ferrite core.

The mounting arrangement is not too critical but the following points should be observed. The coil must not be too close to steel or other magnetic material and likewise the ferrite core mounting should be non-magnetic and non-conductive. Remember to allow sufficient leeway on the ferrite mounting for the full displacement (about 1 cm). The ferrite core must be central in the tube, with the axis of both coil and core parallel to the direction of weight displacement. Sufficient rigidity can be achieved using epoxy glue on the transducer, but initially the ferrite core should only be secured to its bracket with tight rubber bands until the calibration procedure.

Having completed the transducer the entire unit can now be tested by wiring up to the LCD meter-module. This module comes as the ICL7106 Evaluation Kit from Intersil distributors, and contains all the components you'll need to make a working DVM with the exception of the PC board and decimal drive circuit. We've included the PCB foil pattern, and the three resistors, capacitor, and transistor for the drive are shown on the schematic of the DVM. Complete the module and connect a flying lead from the drive output to DP1. RV1 is adjusted to give a full-scale reading of 1.999 for a 200 mV input.

PARTS LIST

Resistors (all ¼W, 5%)

R1,11,13	1k0
R2	2k7
R3	27k
R4,28	100k
R5,8	33k
R6,7,16	22k
R9,12,17,18, 18,20,22,24	10k
R10	220k
R14	68k
R15	5k6
R21,25	1k5
R23	4k7
R26,27	270k

Potentiometers

RV1	47k 10 turn wirewound potentiometer
PR1	470k miniature horizontal preset

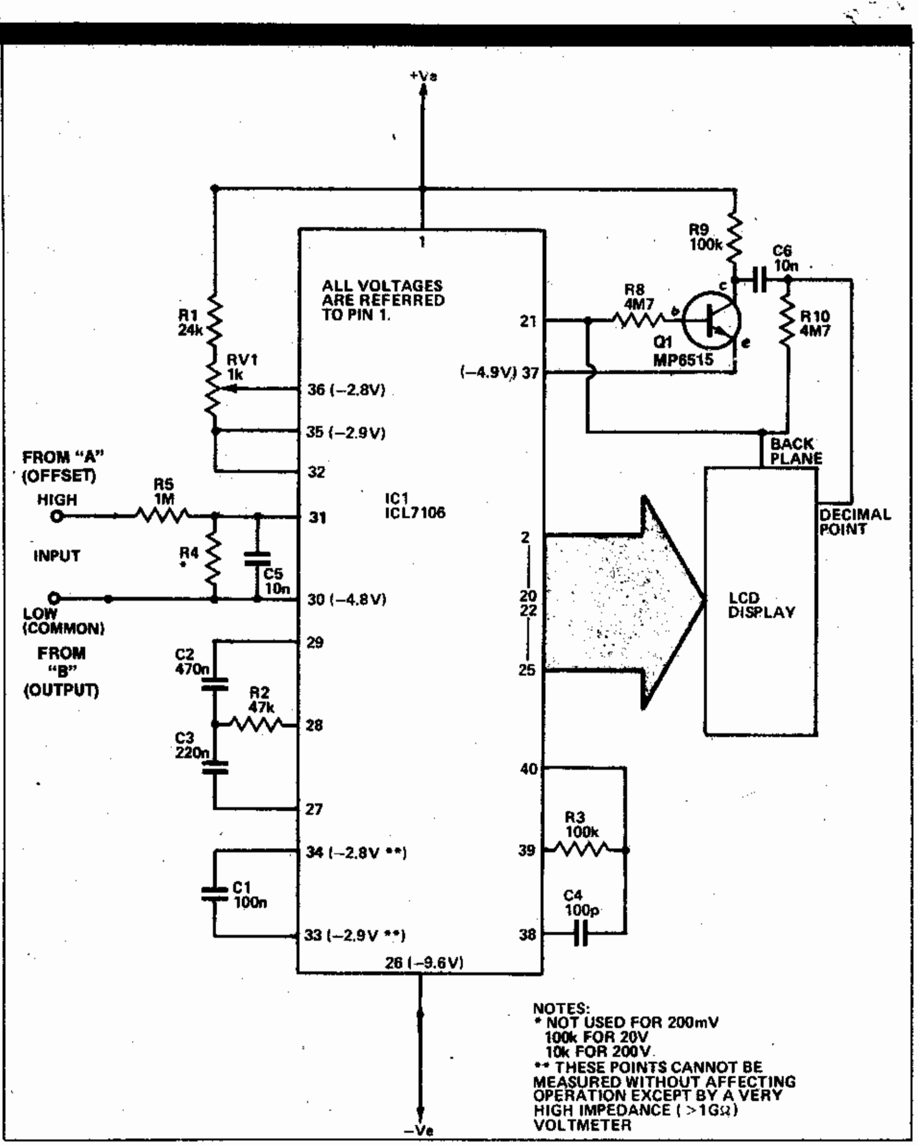
Capacitors

C1,4,10	22u 16V tantalum
C2	220p polystyrene
R3,7	10n ceramic
C5	68n ceramic
C6	2n2 ceramic
C8,9	1n5 polystyrene
C11,12	100n polycarbonate
C13	220u 16V electrolytic

Semiconductors

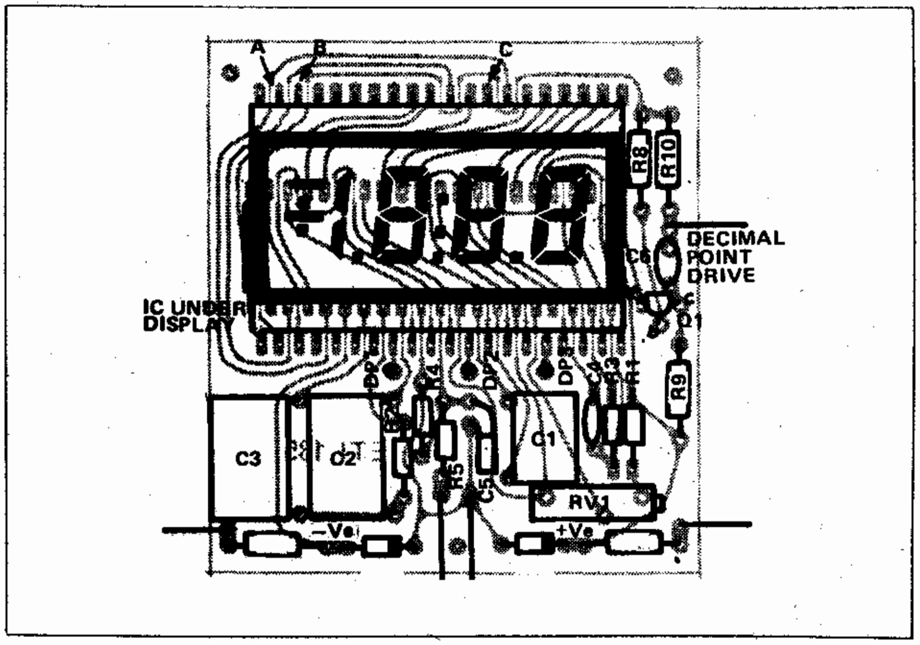
IC1	LM324
IC2	4018B
IC3	4093B
IC4	4066B
Q1	MPS6515
D1	LM113
ZD1	2V7 400 mW zener diode

3½ digit panel meter evaluation kit, Intersil ICL 7106.



NOTES:
* NOT USED FOR 200mV
100k FOR 20V
10k FOR 200V
** THESE POINTS CANNOT BE MEASURED WITHOUT AFFECTING OPERATION EXCEPT BY A VERY HIGH IMPEDANCE (>1GΩ) VOLTMETER

Circuit diagram of the complete panel meter.



Component overlay with the display in place. Points marked A, B, and C are the unused display segments — the vertical part of the + sign, the arrow, and the semicoln respectively. The IC is under the display with pin 1 at top right.

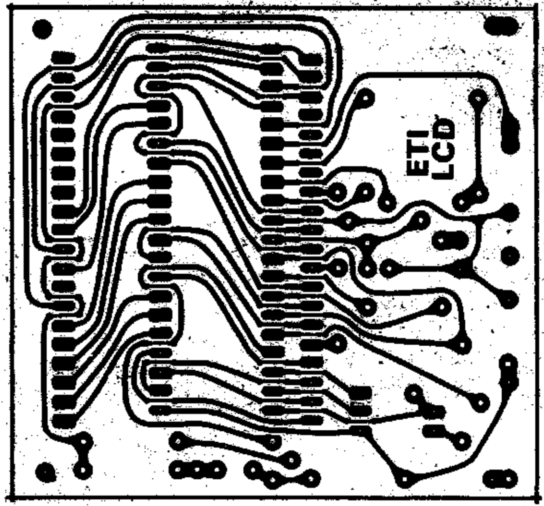
The input voltage at point B should then be connected to the corresponding point on the PCB; point A temporarily connects to the 2V5 reference terminal shown in Fig. 7. After connecting the DVM supply rails to the 9 V terminals on the PCB, power can be switched on. When the ferrite core is near the middle of the coil the meter should be close to 0 V and will indicate + or — readings as the core is moved to either side of the null position. The 100 mV sine wave across the primary coil can be observed on a scope along with the other waveforms illustrated last month. If all is well, the electronics can be assembled inside the scale. Figure 9 shows how we arranged the various components to fit into the existing scale box. The back of the case has now become the front to allow room for the LCD display! The 10 turn potentiometer, RV1, should also be connected up at this stage, along with the on/off switch, so completing the interwiring.

Calibration

Once you are satisfied with your mechanical arrangement for mounting the transducer and associated electronics, the scale should be calibrated using standard or known weights. First, the offset voltage input to the DVM module, marked as 'A' on the wiring diagram, should be temporarily connected to the 2V5 reference terminal shown on the PCB overlay. The preset PR1 should be set at roughly half travel, and the scale loaded up with about 1 kg. After switching on the supply, the ferrite core should be adjusted relative to the coil until it's approximately in the middle at the null output position (this corresponds to half scale deflection). As the null position is approached the DVM will accordingly decrease to zero reading. The ferrite core should now be fixed permanently to its mounting plate using epoxy and allowed to set. When set, the DVM reading must be brought exactly to zero by the addition of small increments of weight, sugar or salt being ideal. The known weight, which can be anywhere between ½ and 1 kg, should be added to the scale pan, and PR1 adjusted until this weight is shown on the LCD display (turning PR1 clockwise increases the reading).

Now remove the weight to check that the reading returns to zero, and adjust PR1 accordingly (a few adjustments to PR1 may be necessary to set the correct reading for the known weight).

Finally, the offset input 'A' can be disconnected from the 2V5 reference and wired to the slider of RV1. Rotating RV1 will alter the reading and the meter can now be easily zeroed for any weight measured, including the empty scale pan. You may now proceed to calibrate the pantry.



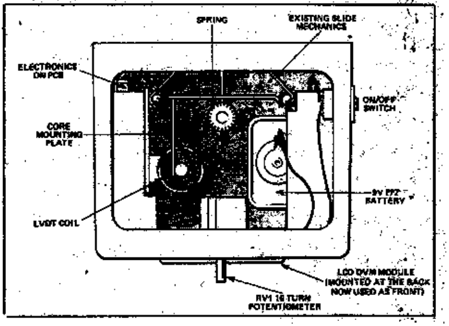


Fig. 8 Artist's impression of the 'view from the top'.

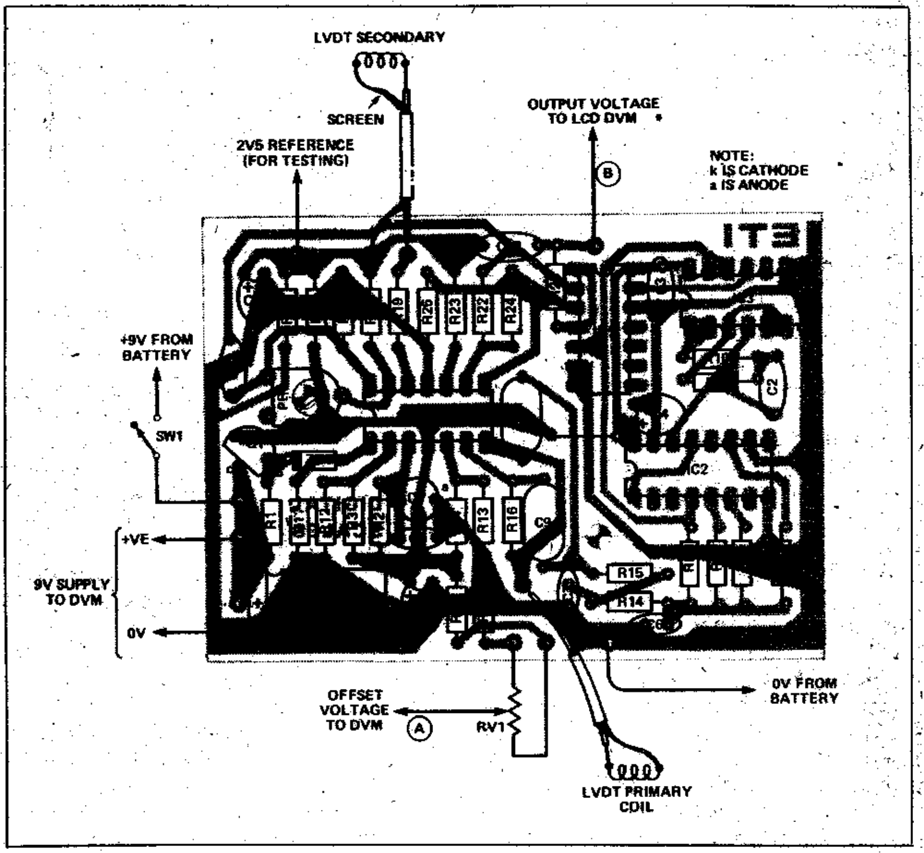


Fig. 7 Component overlay.

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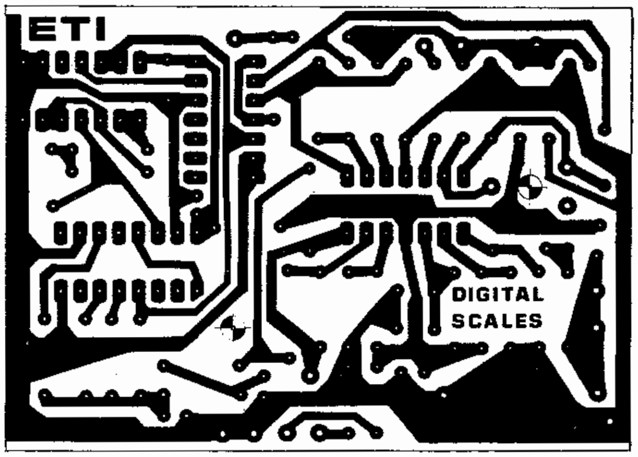
An internal view showing the arrangement of the boards.



HOW IT WORKS

The block diagram of Fig. 5 gives an overview of the circuit operation. essentially, a Linear Variable Differential Transformer (LVDT) is used as a transducer, providing a voltage proportional to the displacement of its moveable core (a spring movement initially provides the linear displacement with weight). The circuitry generates the LVDT drive waveforms and uses a phase-locked detection technique to recover a stable voltage related to position (and thus weight). The voltage measurement obtained is displayed on a 3½ digit LCD DVM module to give a direct readout in kilograms.

Figure 3 illustrates the principle of the LVDT using an AC excitation signal. All the circuitry on the left of the LVDT shown in Fig. 1 is involved in supplying a stable 10 kHz sine wave to drive the primary coil. To achieve the required amplitude and frequency stability the sine wave is generated digitally using an even length walking ring counter based on IC2, the 4018 divide-by-(2 to 10) synchronous counter. IC2 is configured as a five stage divide-by-10 counter by feeding back the Q5 output on pin 13 to the input on pin 1. The Q1-Q4 outputs are summed with selected resistors R5-8, thus approximating the sine wave. The counter is clocked at pin 14 from a 100 kHz astable oscillator formed from IC3a,b. Since the counter divides by 10 the sine wave generated with always be one-tenth of the clock frequency, ie 10 kHz. The coil excitation frequency thus depends only on the C2/R9 astable time constant, and the amplitude only on the CMOS supply voltage.

The stability of the voltage levels is ensured by using a precision 5 V supply based on the bandgap reference diode D1. The op-amp used to regulate this supply (IC1a) actually powers itself from the 5 V output, thus stabilising its own power rails. A bias current of about 1.5 mA (also taken from the 5V rail) is fed to the reference diode through R2, to produce an extremely stable voltage of 1V2 at the non-inverting input of the op-amp. The other (inverting) input of the op-amp is taken from the R3-R12 potential divider, the ratio of which sets the 5 V output due to negative feedback around the op-amp and series pass transistor Q1. ZD1, a 2V7 zener diode, allows the output of the op-amp to keep the base of Q1 at 5V6 while operating well below its own supply rail voltage.

The 5 V rail supplies all the circuitry but a separate digital ground is used for the logic ICs. This prevents digital noise from affecting the analogue signal measurement. C1 provides smoothing for the analogue supply rails, while C3 and C4 provide smoothing and decoupling for the digital circuitry.

Capacitor C6 filters the digital sine wave approximation from IC2, which is then attenuated to about 50 mV by the R14/C7 low-pass filter network. The resulting signal, a much better sine wave, is fed to the bandpass filter and coil driver amplifier based around IC1b. IC1b is configured as a standard 10 kHz active bandpass filter and gives a very pure sine wave on its output at pin 7 for driving the LVDT.

The LVDT primary coil has few turns and a correspondingly low resistance of about 4 ohms. Since IC1b (part of an LM324) can only supply about 25 mA of output current, the peak sine wave amplitude driving the coil should not be more than about 100 mV. Also, the output impedance of the op-amp should be very low. This is because the excitation voltage must remain constant as the primary coil inductance changes due to the core displacement. DC coupling is thus used between the coil and the op-amp output.

The sine wave swings ± 50 mV about a reference level set at 50 mV above the analogue ground. This is only possible due to the ground sensing capability of the LM324 op-amp. Potential divider R13/R4 directly divides the precision 5 V supply by 100 to provide this reference level at the non-inverting input on pin 5.

The voltage output from the differential secondary of the LVDT (illustrated in Fig. 3) is amplified by IC1c. This op-amp is configured as a non-inverting DC amplifier with a high input impedance and a gain of around 20, the latter being determined by PR1. The 10 kHz sine wave signal is directly coupled from the coil and will be centred around the 2V5 reference rail provided by the potential divider R17, R18. The secondary is wired 'series opposing' such that there will be no signal when the ferrite core is centred.

The phase-locked detection is performed by multiplying the signal by + 1 and − 1 on alternate half-cycles of the sine wave to produce a bipolar signal centred about the reference level. IC1d, the last op-amp in the LM324 package, is configured as a straightforward inverter, AC-coupled to the sine wave signal. Two CMOS analogue switches, IC4a, 4b, switch the signal either directly (x 1) or through the inverter (x − 1) on each separate half cycle. They are switched alternately, using logic inverter IC3c, from pin 4 of IC2, a square wave output of the digital sine wave generator. This produces the waveforms shown in Fig. 4 since the square wave edges correspond to the zero-crossing points of the sine wave after detection.

The resulting phase-detected signal is low-pass filtered by R28 and C12 to produce a ± 100 mV DC voltage, linearly proportional to the displacement of the LVDT. A further voltage is provided by the 10-turn potentiometer RV1 in conjunction with the potential dividers R26 and R27. A reference of ± 300 mV (relative to the 2V5 rail) is available at the slider of RV1. The two voltages are fed to the differential input of the LCD panel meter. This allows the digital scale to be returned to zero readout, allowing further measurements when, say, 1 kg is already being registered. The diagram of Fig. 2 shows how the LCD voltmeter is wired up for our application to give a 200 mV full scale deflection (corresponding to 2 kg).