AN780

15-Kilogram Scale Using the TC500A and the TC520

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INTRODUCTION

A 15kg weighing scale was designed using Microchip's TC500A Analog Processor and the TC520 16-bit Controller. The scale is required to resolve down to 1/8 gram and correct to within 61/2 gram. This project takes into account all aspects of a functional scale:

- Dynamic Range
- Strain Gauge Compensation
- Zeroing
- Oversampling
- Units Conversion (kilograms to pounds)

The TC500A is an analog processor device which performs a dual-slope analog-to-digital conversion function. All of the counting and timing for the conversion must be controlled by an external source. In nearly all applications, this control source is a microprocessor. The microprocessor is programmed to monitor the status and to control the timing of the TC500A. It must also be programmed to count the conversion results.

The TC500A has no agenda of its own so it can be used to generate slow, high resolution conversions or fast, low resolution conversions. The trade-off for accuracy is about 1000 counts per millisecond of integration time, i.e., 16-bits with T_{INT} approximately equal to 60mS. Typically, the total conversion time is about 4 times the integration time but, with the TC500A, this is quite flexible.

$$T_{INT} = C_{INT} R_{INT} V_{INT}/V_{IN} \text{ (max)} \qquad \text{eq1}$$

The TC520 is a digital interface device which can be used to replace all of the TC500A timing and counting functions performed by a microprocessor. The TC520 can use either a crystal or external clock as a time-base to control the operation of either a TC500 or a TC500A.

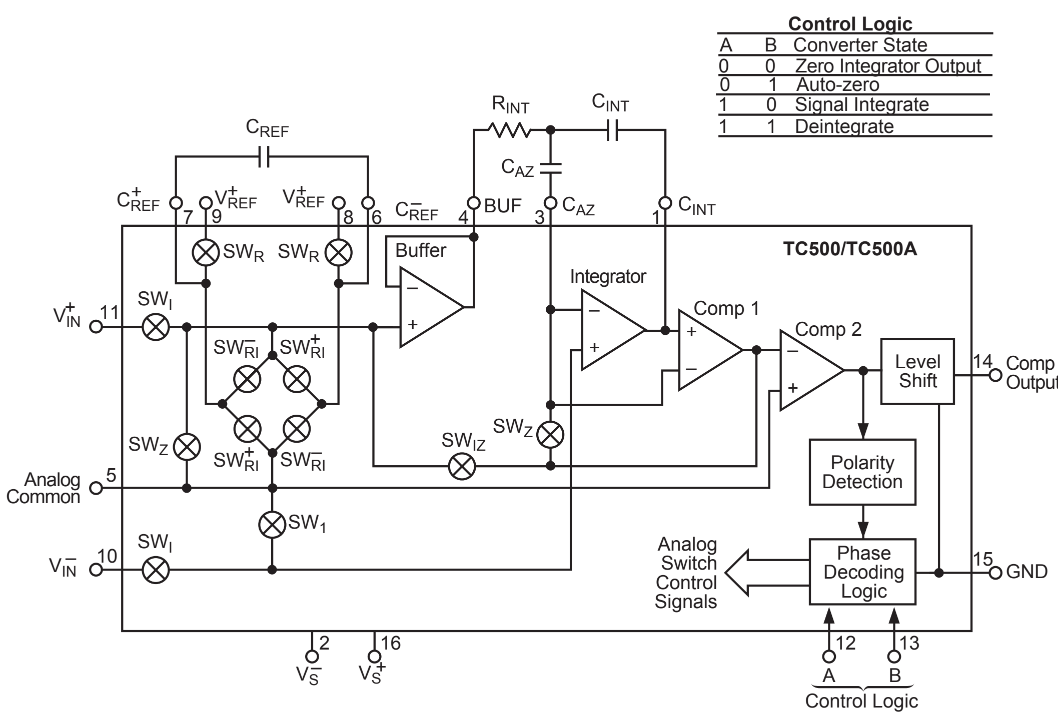


FIGURE 1: Functional block diagram.

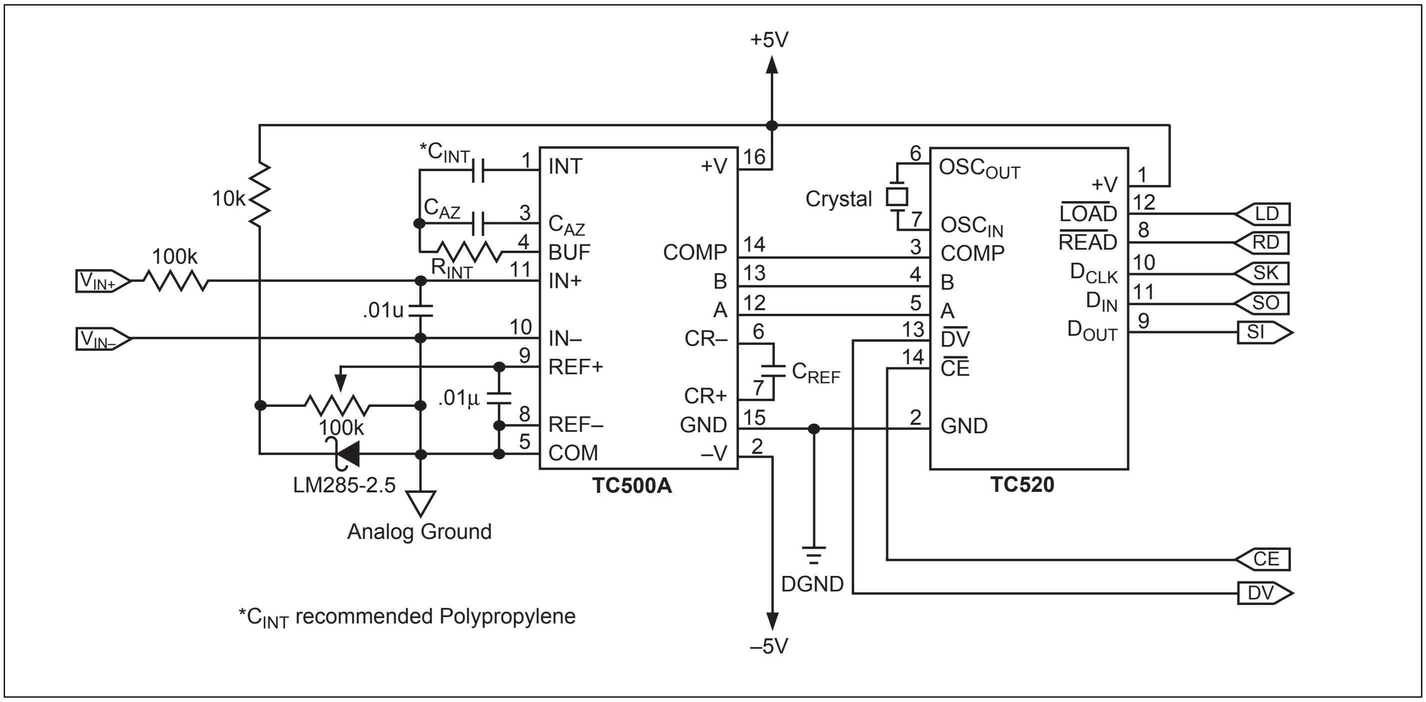


FIGURE 2: TC500A and TC520

The 16-bit conversion result is accumulated in the TC520 along with a polarity bit and an overrange bit. These bits are formed into one 18-bit serial word which may be read at any rate and at any time. Reading the serial data from the TC520 does not effect the TC500A/TC520 conversion cycle except that the output shift register will not update while reading is in progress.

DEVELOPING THE SCALE APPLICATION USING THE TC500A AND THE TC520

Input Stage

The first consideration for a low signal level source is the amount of gain required for the input amplifier. The TC500A has a CMOS input buffer which, due to unity-gain phase margin, must have no lower than about 68kΩ for R_{INT}. The maximum buffer current V_{IN}(max)/R_{INT}) should be no more than about 20µA. This means that the maximum input voltage to the TC500A should be about 1.5V. The 15kG strain gauge used for this application has an output of about 1mV/gram which gives a gain requirement of at least 50. The MCP606 CMOS operational amplifier is best suited for this because of its low noise and minimal drift. The output impedance of the strain gauge is only 300Ω so a single-ended configuration is more than adequate. Instead of 1.5V, the actual full-scale output wound up to be about 1V. The value of R_{INT} was set to 130kΩ, well above the 68kΩ minimum. This gives a maximum buffer current of 7.6µA instead of 20µA**.**

Integrator Stage

The signal-to-noise ratio of the TC500A's integrator stage is a function of the band-width. The 15kG scale needs to resolve 1g with at least 8:1 over-sampling. This means at least 120,000 counts. The above rule of "1000 counts per millisecond" requires at least 120ms for the integration time of the TC500A. Selecting 200mS will lower the band-width and get maximum rejection of 50/60Hz. The strain gauge is a balanced bridge so the output will have some common mode component. A value of 3.5V for V_{INT} instead of 4V will allow for some offset. Rearranging equation 1 gives an expression for C_{INT}:

$$C_{INT} = V_{IN}\text{ (max) } T_{INT}/V_{INT}\ R_{INT}$$
$$= 1V\ 200mS/3.5V\ 130k = .439mF \qquad \text{eq2}$$

The next higher common value is .47µF which was selected for $C_{INT.}$ It is essential that this capacitor is a polypropylene type for very low dielectric absorption.

REFERENCE VOLTAGE CIRCUIT

The differential reference voltage is derived by the standard, dual-slope ratiometric technique:

$$V_{REF} = V_{IN}\text{ (max) } T_{INT}/T_{DEINT} \qquad \text{eq3}$$

where T_{DEINT} is the deintegration time required for a full-scale conversion.

This application requires 120,000 counts which means that the TC520's overrange bit must be used as the MSB, i.e., 17-bits. A reference voltage with a tempco of 0.3ppm/°C would normally be required for stability over a 30°C range. This could be a prohibitive requirement. Fortunately the strain gauge has an output sensitivity which is directly proportional to the supply voltage applied,

$$V_{SG} = K (V^+ - V^-)P_{SG}, \qquad \text{eq3/a}$$

where K is the constant for a particular strain gauge and the dual slope converter produces a result which is inversely proportional to its reference voltage:

$$T_{DEINT} = V_{IN}\, T_{INT}/V_{REF}$$

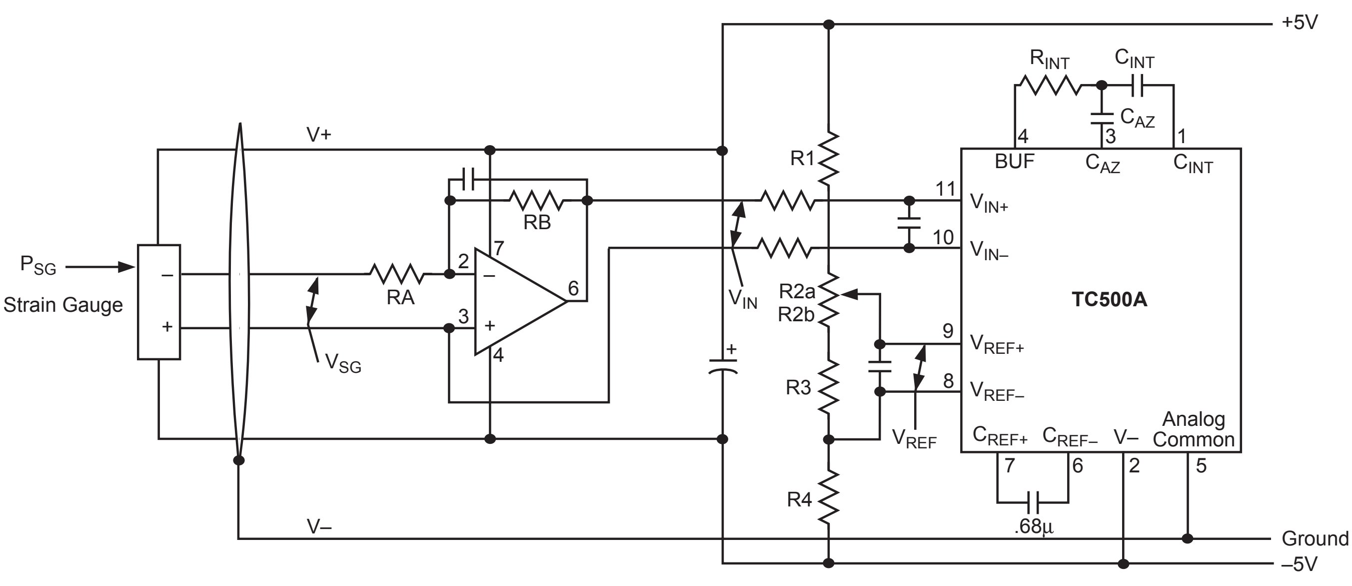
By deriving the reference from the supply voltage, any variations will exactly cancel.

$$V_{REF} = R_{REF} \times (V^+ - V^-)/R_{TOTAL} \qquad \text{eq3/b}$$

The TC500A has a differential reference input so the reference voltage need not be referenced to ground. Rather than using a precision reference for the TC500A and a precision supply for the strain gauge, combining eq3/a and eq3/b into eq4 produces an equation for the system:

$$T_{DEINT} = K\, G\, P_{SG}\, T_{INT}\, R_{TOTAL}/R_{REF} \qquad \text{eq4}$$

Notice that V_{IN} has been replaced by an expression for the pressure on the strain gauge (P_{SG}), the strain gage constant (K) and the gain of the amplifier (G). The actual differential reference voltage is determined only by the ratio of resistance values (R_{TOTAL}/R_{REF}).



$-V_{SG} = K\, P_{SG}\, (V^+ - V^-)$

$G = -R_B/R_A$

$V_{IN} = (V^+ - V^-)\, P_{SG}\, K\, G$

$R_{REF} = R_{2B} + R_3$

$R_{TOTAL} = R_1 + R_2 + R_3 + R_4$

$V_{REF} = (V^+ - V^-)\, R_{REF}/R_{TOTAL}$

$$T_{DEINT} = \frac{V_{IN}}{V_{REF}} \quad T_{INT} = \frac{(V^+ - V^-)\, P_{SG}\, K\, G}{(V^+ - V^-)\, R_{REF}/R_{TOTAL}} \quad T_{INT} = P_{SG}\, K\, G \;\frac{R_{TOTAL}}{R_{REF}}\; T_{INT}$$

FIGURE 3: Differential ratiometric reference voltage.

AUTO-ZERO AND REFERENCE CAPACITORS

The voltage on these capacitors stay very constant so dielectric absorption is not a consideration. The long integration time does require capacitors with very low leakage. A .68µF polyester capacitor was used in both cases.

TC520 TIMING

A 200ms integration time is already selected. There are a few options available with the TC520 to do this. The exact crystal (or clock rate) can be select in conjunction with one of the two default timings in the TC520 or, the microprocessor can be used to program the TC520 for the proper timing with some arbitrary crystal frequency. The main constraint is that the TC500A has a comparator delay of about 4µS. Also, the TC520 has a divide-by-4 on the clock input. This means that anything around 1MHz will be acceptable. The TC520 can be programmed by the micro to set the actual integration time to within approximately .5ms. The crystal used in this application is 1.0703MHz.

There are 4 clocks/count in the TC520 and the base integration counter is 256 counts. This calculates to a timebase period of 0.9567mS with the crystal being used. The 200mS integration time requires 209 timebase periods. Since the TC520 gives 256 timebase periods, 47 of them need to be taken away. The value can be determined from the equation:

$$N = 256 - \frac{f_{OSC} \times T_{INT}}{1024} = 256 - \frac{1.0703\text{MHz} \times 200\text{mS}}{1024} = 46.957$$

The micro was programmed to load a "47" ($2F_H$) into the TC520 at the start of the program. This will cause the TC500A to have an integration time of 199.96mS. This value will give at least 120dB of rejection at 50/60Hz.

The TC520 will also use the integration timing for the TC500A's Auto-Zero phase. A 17-bit conversion will require a deintegration time which is a function of the oscillator frequency, i.e., $2^{17} \times 4 \div f_{OSC}$ = 490mS.

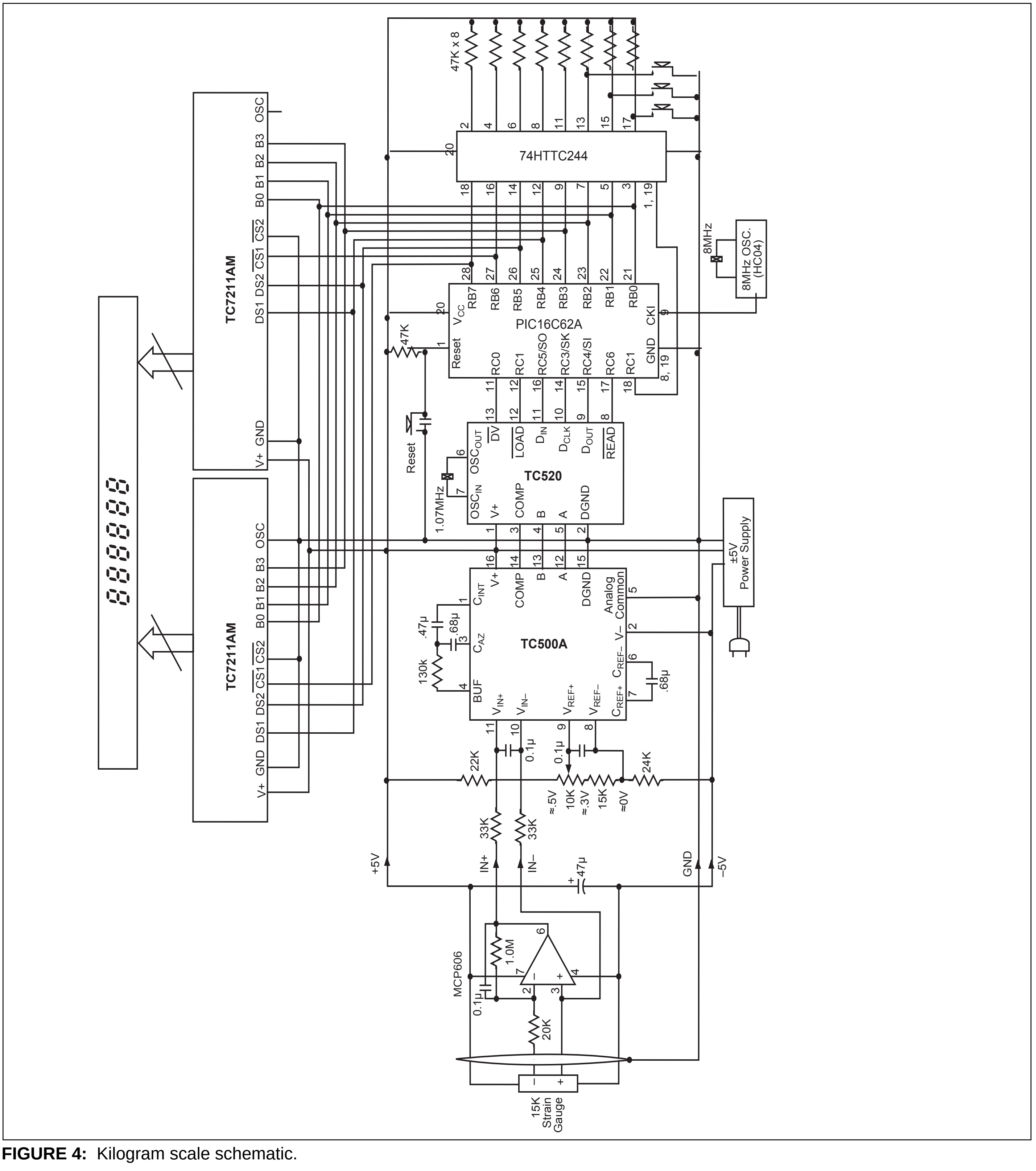


FIGURE 4: Kilogram scale schematic.

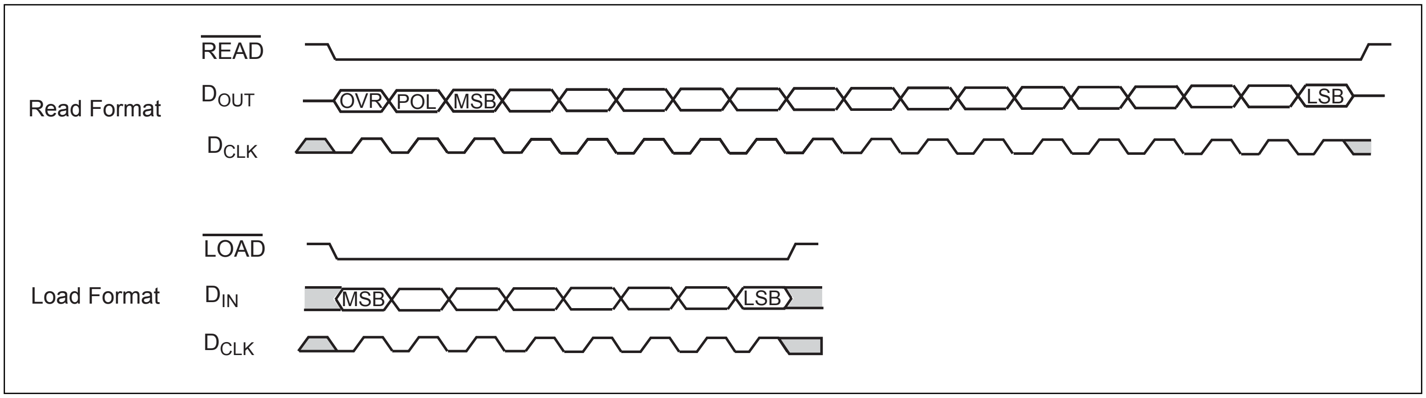


FIGURE 5: Serial interface protocol.

REFERENCE VOLTAGE CALCULATION

Now that the timing has been determined, eq3 can be used to calculate the reference voltage:

$$V_{REF} = V_{IN}\,(max)\ T_{INT}/T_{DCINT}$$
$$= 1V\ 200mS/490mS \approx .408V$$

The reference voltage does not need to be calculated very precise since it will have to be trimmed during calibration. A ±25% adjustment range is enough to make up for just about any minor calculation error.

MICROPROCESSOR PROGRAMMING

The PIC16C62A 8-Bit microcontroller was selected but any reasonable processor/controller will suffice. The PIC16C62A is a 28-pin part that has EPROM programmability.

CONCLUSION

The scale works extremely well. The 8X oversampling makes it very smooth and noise-free. The response time is within one conversion (≈1/2 sec) for changes of 2 grams or more. Changes of less than 2 grams are accumulated in an integrating register until it gets to either +1 gram or –1 gram. When this happens, the current conversion is allowed to "get through" and a new base is established in the accumulator.

There is also a facility in the programming that allows the raw data to be displayed. These displays show the full 17-bit conversion results. The basic converter noise is as predicted, typically 1 to 2 counts of flicker (16-bit accuracy) with an intermittent jump of about 3 or 4 counts (1/f noise). One count is equivalent to 1/8 gram.

The actually 60Hz power line rejection ration of the TC500A was not measured, but judging from the 6 to 8 counts of "rolling noise" before preloading the TC520 with $2F_H$, it is quite adequate.

The effect of the differential ratiometric reference was tested by changing the supply voltage from +4V to +6V. Although there was a 1 – 2 second delay due to unmatched time constants between the reference and the strain gauge, the final readings were exactly the same. This shows that the power supply rejection is better than 100dB.

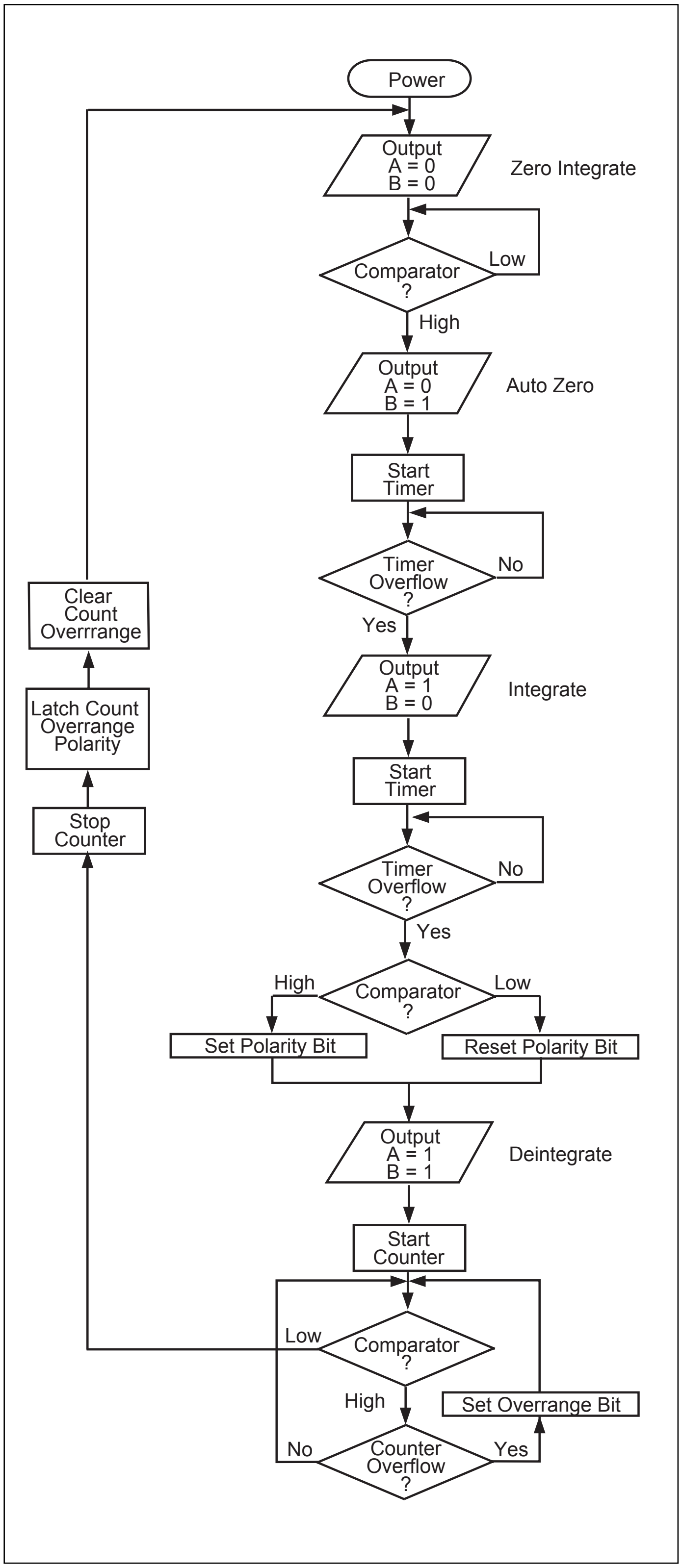


FIGURE 6: TC520 program flow chart.

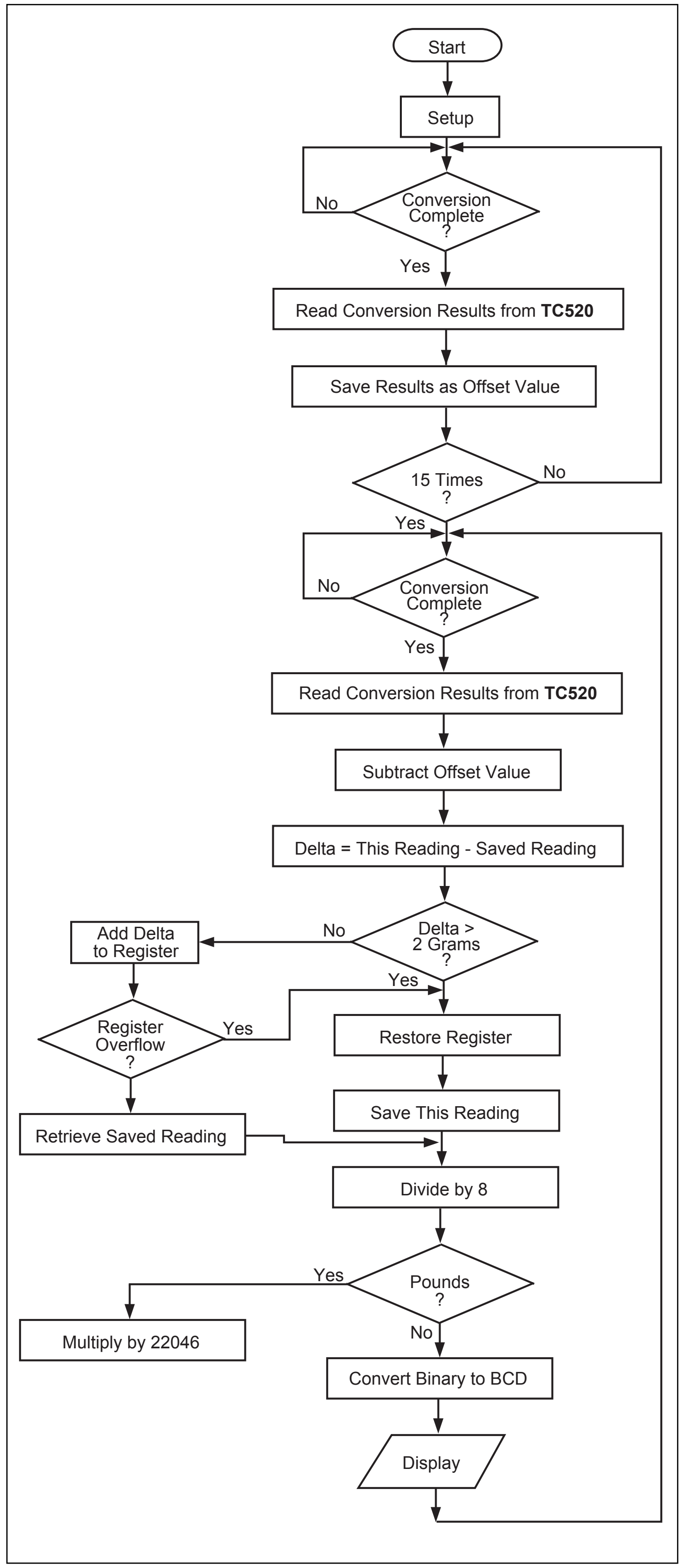


FIGURE 7: PIC16C62A program flow chart.

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