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A Non-Linear Analog-To-Digital Converter with Sample and Hold Circuit Applied To Measure the Compressive Strength of Concrete

Lect. Ahlam Najim Abdul-Amir
Electrical Eng. Dept., College of Engineering
Al-Mustansiriya University, Baghdad, Iraq

Asst. Lect. Maicem Abdul-Jalil
Electrical Eng. Dept., College of Engineering
Al-Mustansiriya University, Baghdad, Iraq

Abstract

This paper introduces the design of a digital circuit, which employs a non-linear analog-to-digital converter technique useful to measure the compressive strength of concrete.

The output is in binary coded decimal suitable for readout purposes, and related to the velocity of the ultrasonic pulse transmitted through the material.

الخلاصـــة

يتضـمن البحـث تصـميم جديـد لقيـاس قـوة الانضـغاط فـي الكونكريـت بطريقـة اسـتخدام دائـرة التحويـل اللاخطـي التماثلي- الرقمي مع دائرة **(Sample and Hold)** والحصول على قراءة رقمية مباشرة لها علاقة مع سرعة انتقال الأمواج فوق الصوتية خلال مادة الكونكريت المراد قياس قوة انضغاطها.
وهذا يعنـي مساعدة المعنيين بالفحوصات في الاستفادة من القراءة عند موقع العمل.

1. Introduction

The ultrasonic testing of concrete is mainly based on straight forward measurements of longitudinal pulse velocity, the pulse is produced by an electro acoustical transducer, which is held in contact with one surface of the concrete member under test and received by a similar transducer in contact with the surface, This can be achieved using the (PUNDIT) which is the initials of Portable Ultrasonic Non-Destructive Digital Indicating Tester [1].

There are several ways in which the behavior of ultrasonic pulses in concrete can be used to obtain useful information, particularly with regard to elastic stiffness and strength.

Generally because the strength of concrete depends on many factors, all non-destructive methods for estimating it should be used with caution. Calibration data should be prepared for each particular mix and aggregate used. Care should be taken if any parameter having an effect on concrete strength changes after the calibration is complete.

The quality of concrete is taken as the compressive strength of specially prepared specimens from the mix used in the construction. In practice it has been found that many factors affect the correlation between the strength and pulse velocity, an increase in the water/cement ratio results in an increase in voids in concrete, which reduces both the strength and the pulse velocity. When concrete hardened both velocity and strength increases rapidly during the first few days.

However during the subsequent aging, the rate of increase in pulse velocity is considerably less than that of the strength. Most studies demonstrated that for a given mixture under uniform conditions there was a good correlation between strength and pulse velocity [2].

2. Estimation of Strength

The compressive strength-pulse velocity correlation was found to be of the exponential form:

$$C = a\,e^{bv}$$

where: C = Compressive strength N/mm^2.

v = Pulse velocity km/sec.

a and b = Constants whose values depend on the mix proportion and curing regime

As a result of a large number of experiments , and by using the "PUNDIT" to measure the pulse velocity, it was found that a is equal to 2.016 and b is equal to o.61 [3,4].

3. Circuit Operation

Figure (1) shows the basic design of the digital circuit, and **Fig.(2)** shows its waveforms and timing diagram.

At t < t0, a start pulse signal is applied to the system, this low logic level put S1 and S2 switches closed and the counter on the reset state.

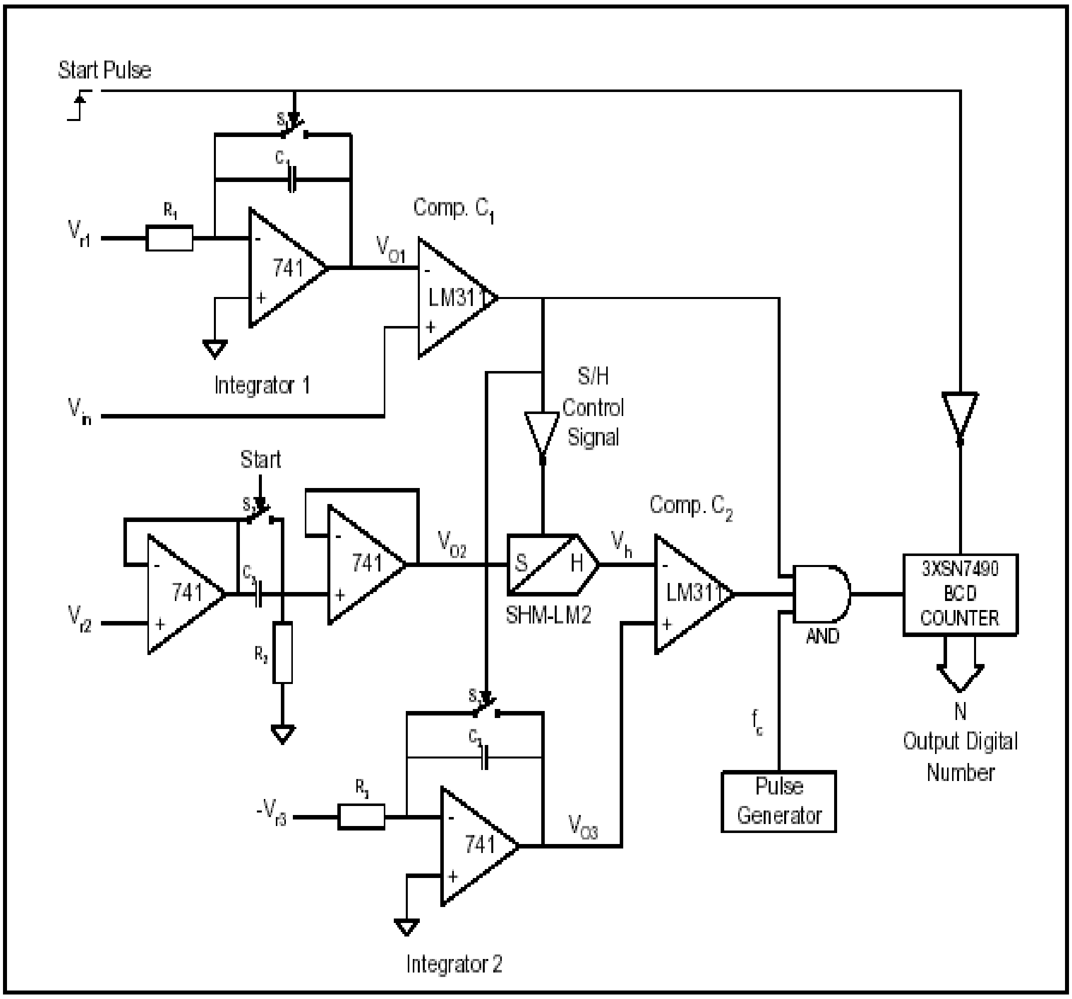

Figure (1) Circuit Diagram

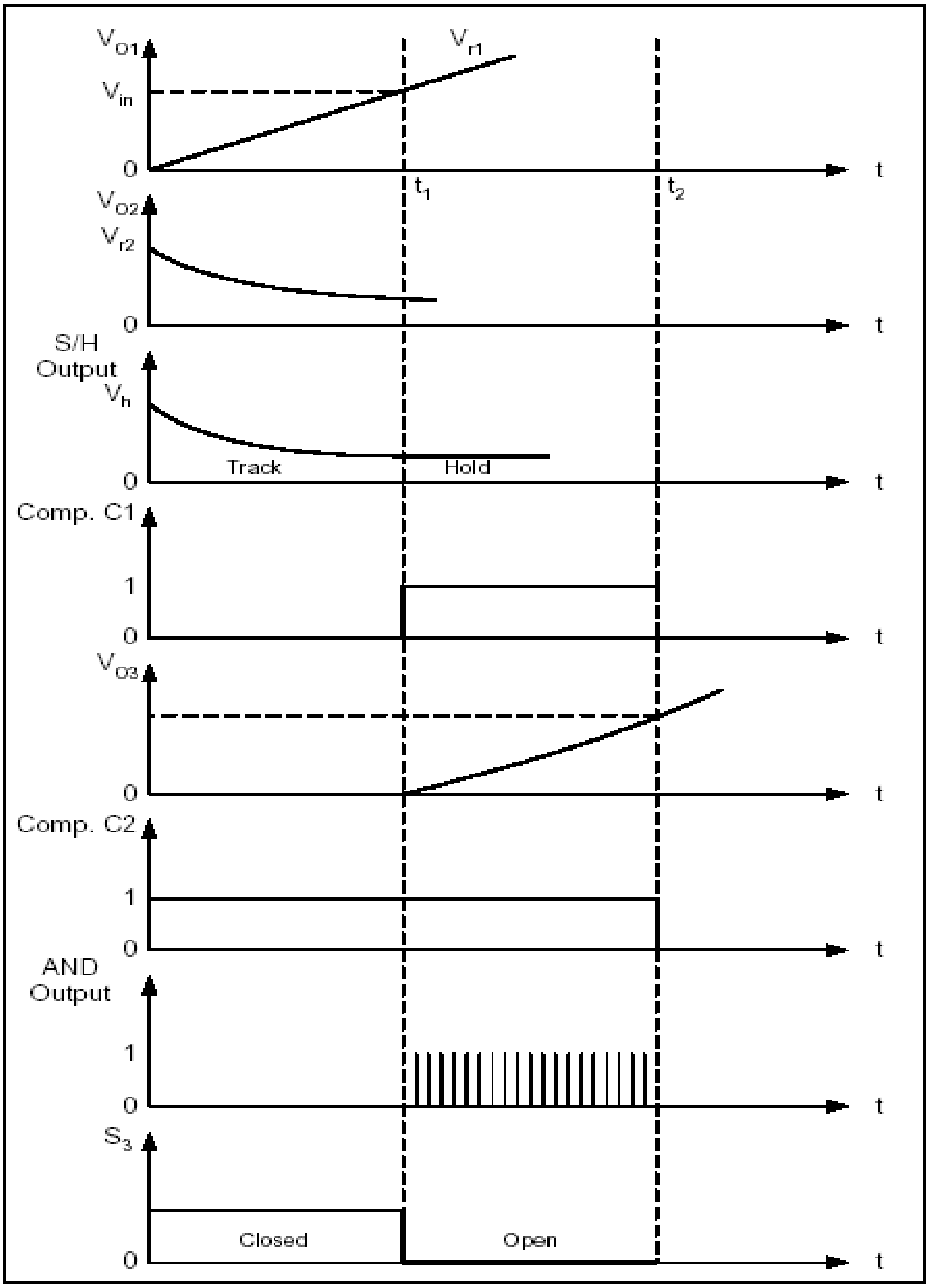

Figure (2) Waveforms and Timing Diagram

At $t = t_0$, the start signal will be high where S1 and S2 open and the counter is enabled for the count mode. Because of the low logic level output of the comparator (C_1) S3 switch is closed and the sample and hold circuit (S/H) is on the tracking mode.

The reference voltage-Vr_1 is applied to integrator 1 and the reference voltage Vr_2 is applied to the exponential function generator which yields Vo_1 and Vo_2 respectively;

$$Vo_1 = \frac{1}{R_1C_1}\int_{t_o}^{t} -Vr_1\,dt = \frac{Vr_1}{\tau_1}(t - t_o) \quad \text{.......... (1)}$$

$$Vo_2 = Vr_2 \exp\left[(t_o - t)/\tau_2\right] \quad \text{.......... (2)}$$

where: $\tau_1 = R_1C_1$ and $\tau_2 = R_2C_2$, the time constants of the RC networks. At $t = t_1$, Vo_1 becomes equal to the input voltage V in the output of C_1 changes state from low to high logic level and returns the Sample and Hold circuit to the hold state, thus holding the value of Vo_2 (t_1).

$$Vo_1 = \frac{Vr_1}{\tau_1}(t_1 - t_o) = Vin$$

thus $(t_1 - t_o) = \frac{Vin}{Vr_1}\tau_1$

and $Vo_2 = Vr_2 \exp\left[(t_o - t_1)/\tau_2\right]$

So:

$$Vo_2 = Vr_2 \exp\left[\frac{Vin}{Vr_1}\frac{\tau_1}{\tau_2}\right] = Vh \quad \text{.......... (3)}$$

where: Vh is the output voltage of the S/H circuit. Also, the high logic level of C_1 opens switch S_3 and enables the AND gate.

The reference voltage-Vr_3 is applied to integrator 2 and at $t = t_1$;

$$Vo_3 = \frac{1}{R_3C_3}\int -Vr_3\,dt$$

The output voltage of integrator 2 is a ramp-up voltage, where at $t = t_2$ it becomes equal to Vh, and the output of the second comparator C_2 is high during conversion, while it goes low at the end of this process which disables the AND gate. The counter stops counting holding a digital number N, so we have,

$$Vo_3 = \frac{Vr_3}{R_3C_3}(t_2 - t_1) \quad \text{.......... (4)}$$

Since $(t_2 - t_1) = \frac{N}{Fc}$

So: $Vo_3 = \frac{Vr_3}{\tau_3} \frac{N}{fc} = Vh$

Thus, $N = \frac{\tau_3 fc}{Vr_3} Vh$

By substituting the value of Vh from equation (3),

$$N = \frac{\tau_3 fc}{Vr_3} Vr_2 \exp \frac{Vin}{Vr_1} \frac{\tau_1}{\tau_2} \quad \text{...} \quad \textbf{(5)}$$

So, N = Ka exp [Kb Vin]

where,

N = the number held by the counter at t = t_2 and represent the compressive strength of concrete.

fc = the counter clock frequency.

$\tau_3 = R_3C_3$, time constant of integrator 2.

$$Ka = \frac{\tau_3 fc Vr_2}{Vr_3} = constant$$

$$Kb = \frac{\tau_1}{Vr_1 \tau_2} = constant$$

4. Results and Conclusion

The digital converter will consider three sources of error. These are the comparator threshold voltage effect, the error in capacitance value effect and imprecise adjustment or tolerance in passive components values.

Although the counter clock frequency fc is appearing directly in the final equation of the output digital number N, but highly stable clock generators are available, such as crystal oscillators.

Another source of error to be mentioned is the error associated with reference voltage accuracy. Finally, the output digital number may have a + ½ LSB uncertainty (output code alternation), due to clock pulses a synchronization with the start of the integration period.

The designed converter has the following specifications:

1. Make use of the exponential discharge of linear RC-network and it is based on the single-slope principle of linear A/D converter.
2. Analog input voltage range; unipolar, 0.05 to 5 volts.
3. Normalized output digital code with a resolution of 3- BCD digits.
4. Fixed presentable power value.

5. External precision reference voltage: + 5 volts.
6. Power supply requirements: + 8 volts.
7. It has a status output of logic (0) for end of conversion and logic (1) during reset and conversion.
8. Convertion time for τ_1 = 1 msec, τ_3 = 1 msec, fc = 1 MHz and Vin = 0.06 volts is about 4.7 msec.
9. Maximum possible absolute error is less than 1.5 LSB.

In achieving the required strength for concrete, it is needed to specify a proper mix design with appropriate mix proportions of water, cement, fine aggregate and coarse aggregate for the trial mix. Hence, several mix designs need to be analyzed before coming up with a most suitable mix design. This is to configure the proportional content of concrete, which could also affect the pulse velocity.

5. References

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