Unit 8 Design of Real World Logic Circuits

Structure:

8.1 Introduction

In the previous unit we studied about different types of counters and design of counters. With the advent of large and very-large-scale integration, systems of reasonable complexity are realized on a single chip. Reductions in the number of elements required to realize each function makes it possible to use fewer chips or to do more on a given chip. In high-performance systems, eliminating redundant gates not only frees up chip area, but also reduces power dissipation, often the limiting factor. There are of course factors that were not present in the days of discrete logic elements, such as the value of regularity in the arrangement of elements on a chip. But the need of powerful methods for generating efficient logic circuits has indeed returned. A major consequence of the larger scale of integration is the enormous size and complexity of our systems, and the increased importance of testing. In this unit you will study some real world logic circuits and their design.

Objectives:

By the end of Unit 8 the learners will be able to

- explain traffic signal systems
- explain the functions of switches
- electronic tennis scoring system
- discuss on temperature & weather forecast systems

8.2 Traffic Signal Systems

This is an automatic traffic light controller and can be implemented by programming any gate array based logic (GAL) device such as FPGA. The important features of this design are as follows.

1. The density of traffic is assumed to be same on all the roads.
2. The free left turn is regulated to enable safe crossing for the pedestrians during peak hours.
3. The implementation can be done using digital ICs.
4. The design is generic and can be customized to suit different type of road junctions with minor changes.
5. Manual operation and control is permitted if required.

The basic light signals red, green and yellow are given uniform importance in terms of time. Let us keep the duration for which these signals remain ‘on’ to be 8 seconds and its multiples. The figure 8.1 shown indicates the movement of traffic in all permitted directions in a cycle that covers all the four roads. We have 8 such signal combinations, each with 8 seconds duration. The traffic which takes left or right turns and all the pedestrian crossings are controlled by only two signals – red and green lights.

The table 8.1 displays status of all the signal lights for all the traffic conditions. Every row in the table indicates the status of each light for 8 seconds. We can see that for the traffic that moves straight, the ratio of red, yellow and green signal lights is 40:8:16. For the traffic that takes left or right turns, the ratio of red and green lights is 56:8. Similarly for the pedestrian crossing the ratio is 48:16.

In the table 8.1 each of the 8 rows is assigned a binary number that uniquely identifies it. Since we have 8 distinct combinations of signal lights, we need minimum of 3 bits to represent each state. Each of these bits is named as variable X, Y and Z respectively in table 8.1 and 8.2. As indicated in figure. 8.1, the two halves of each of the four roads are denoted by the alphabets A through H. The alphabet pairs with a single dash line between them represent valid directions of traffic movements. Also note that St, Lt and Rt mean straight direction, left turn and right turn respectively.

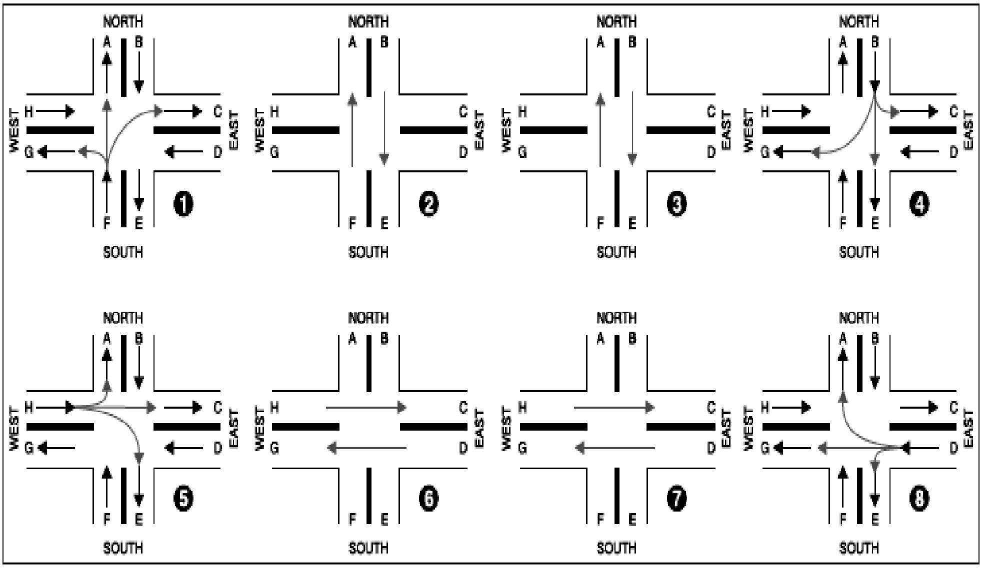

Figure 8.1: Flow of traffic in all possible directions

Table 8.1: States of Signals for All the Traffic

X	Y	Z	B-C/B-G Lt/Rt	B-E St	D-E/D-A Lt/Rt	D-G St	F-G/F-C Lt/Rt	F-A St	H-A/H-E Lt/Rt	HC St	WALK (N-S)/(S-N)	WALK (E-W)/(W-E)
0	0	0	R	R	R	R	G	G	R	R	R	R
0	0	1	R	G	R	R	R	G	R	R	G	R
0	1	0	R	G	R	R	R	Y	R	R	G	R
0	1	1	G	Y	R	R	R	R	R	R	R	R
1	0	0	R	R	R	R	R	R	G	G	R	R
1	0	1	R	R	R	G	R	R	R	G	R	G
1	1	0	R	R	R	G	R	R	R	Y	R	G
1	1	1	R	R	G	Y	R	R	R	R	R	R

Table 8.2 lists the Boolean functions for all the signal lights, in terms of Boolean variables X, Y and Z.

Table 8.2: Boolean Functions for All the Signal conditions

Signal	Reference	Boolean functions
Green	B-C(Lt)/B-G (Rt)	$X'YZ$
Green	B-E (St)	$XYZ' + X'Y'Z$
Red	B-E (St)	$X + Y'Y'Z'$
Yellow	B-E (St)	$X'YZ$
Green	D-E (Lt)/D-A (Rt)	XYZ
Green	D-G (St)	$XYZ' + XY'Z$
Red	D-G (St)	$X' + XY'Z'$
Yellow	D-G (St)	XYZ
Green	F-G(Lt)/F-C (Rt)	$X'Y'Z'$
Green	F-A (St)	$X'Y'$
Red	F-A (St)	$X + X'YZ$
Yellow	F-A (St)	$X'YZ'$
Green	H-A (Lt)/H-E (Rt)	$XY'Z'$
Green	H-C (St)	XY'
Red	H-C (St)	$X' + XYZ$
Yellow	H-C (St)	XYZ'
Green	Walk (N-S/S-N)	$X'YZ' + X'Y'Z$
Green	Walk (E-W/W-E)	$XYZ' + XY'Z$

Note. *X', Y', and Z' denote complements of variables X, Y, and Z, respectively.*

From the table 8.2, we can note that both the left and right turn signals have similar switching pattern and hence they have identical functions. Hence these signals can be controlled by a single block of control logic.

Figure 8.2 shows the logic diagram that generates all the control signals which can be used to activate all the signal lights according to the Boolean functions listed in table 8.2.

The IC1 is a 555 timer and is used to generate the clock signal for the counter IC2. Note that the timer IC is configured as an astable multivibrator. The duration T for which the IC1 output (clock to IC2) remains HIGH is given by,

$T = 0.695\ C2(R1+R2)$

Hence we can vary T by varying the values of R1, R2 or C2.

The 4 bit counter IC2 works like a 3 bit counter. The connection to reset pin 1 from the output Q3 via inverter N1 achieves this. The remaining counter outputs Q2, Q1 and Q0 map to the variables X, Y and Z respectively.

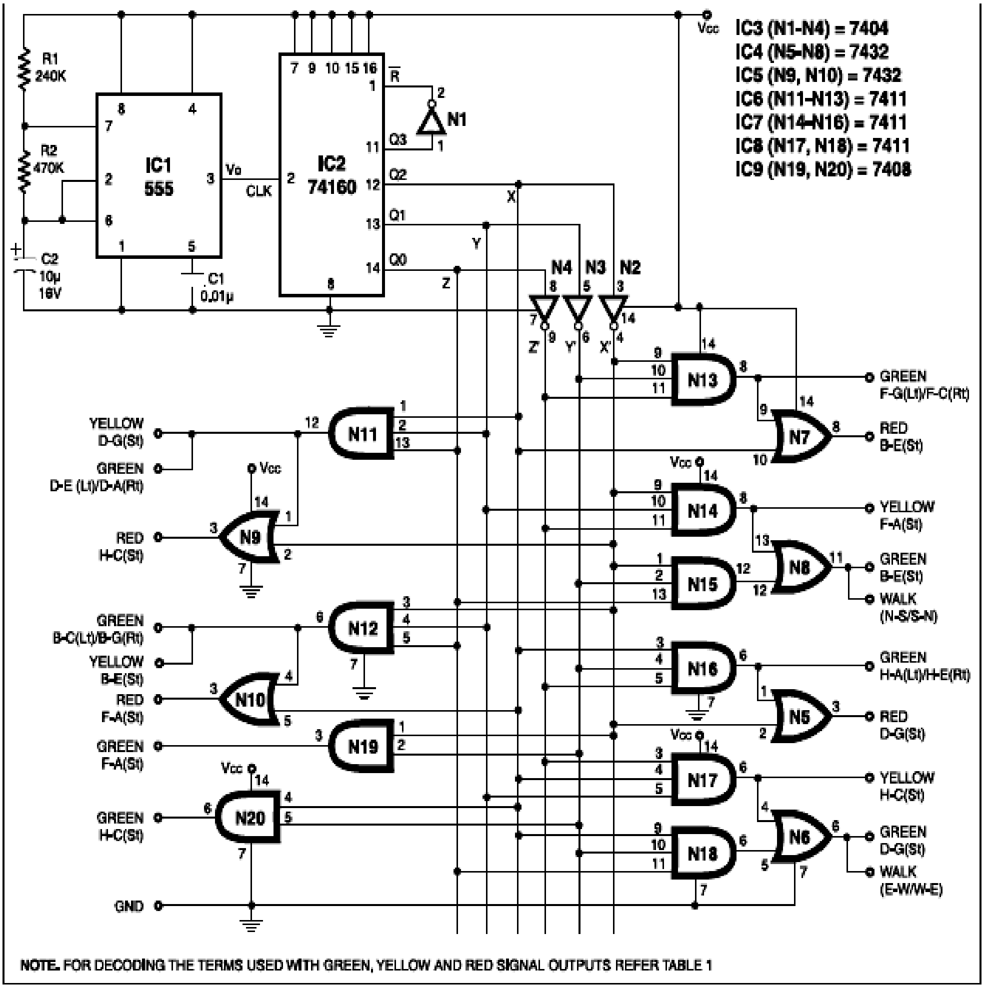

Figure 8.2: The circuit diagram for traffic light signaling

We can check the working of the traffic light controller by connecting the light control outputs to red, yellow and green LED's which represent the actual signal lights. To limit the current through the LED's, we can connect a resistor (typical value 470 Ohms) in series with each. As we stated before, only. If in a particular junction, some direction of movement is restricted, then signals can be suitably merged with the next state.

For the manual control of the traffic lights, one can load the desired binary state code (indicated by X, Y, Z variable values) into the counter IC. For this purpose the counter must be wired in a pre-settable mode. We can also reset the signal lights to the initial state (XYZ = 000), by resetting the counter. This can be achieved by having an external switch which can feed a LOW (0) to reset pin (pin 1) of IC2. A computer program in C language which can simulate the traffic light controller circuit on a PC is shown in figure 8.3. Table 8.3 shows the results of execution of the program.

TRAFFIC.C

```
#include < stdio.h >
#include < conio.h >
#define TRUE 1
#define False 0

int not(int x);
int or2(int x,int y);
int or3(int x,int y,int z);
int and2(int x,int y);
int and3(int x,int y,int z);
int main(void)
{
int a,b,c;
int seq,green_bl,green_bs,red_bs,yellow_bs;
int green_dl,green_ds,red_ds,yellow_ds;
int green_fl,green_fs,red_fs,yellow_fs;
int green_hl,green_hs,red_hs,yellow_hs;
int walk_ns,stop_ns;
int walk_ew,stop_ew;

clrscr();
printf(" SIG-B     SIG-D     SIF-F     SIG-H
WALK(N-S) WALK(E-W)\n");
printf("G G R Y  G G R Y  G G R Y  G G R Y
G R     G R\n");

for(seq = 0;seq < 8;seq + + )
{
c = (seq&1);b = (seq&2) > > 1;a = (seq&4) > > 2;
green_bl = and3(not(a),b,c);
green_bs=or2(and3(not(a),b,not(c)),and3(not(a),not(b),c));
red_bs = or2(a,and3(not(a),not(b),not(c)));
yellow_bs = and3(not(a),b,c);
green_dl = and3(a,b,c);
green_ds=or2(and3(a,b,not(c)),and3(a,not(b),c));
red_ds = or2(not(a),and3(a,not(b),not(c)));
yellow_ds = and3(a,b,c);
green_fl = and3(not(a),not(b),not(c));
green_fs = and2(not(a),not(b));
red_fs = or2(a,and3(not(a),b,c));
yellow_fs = and3(not(a),b,not(c));
green_hl = and3(a,not(b),not(c));
green_hs = and2(a,not(b));
red_hs = or2(not(a),and3(a,b,c));
yellow_hs = and3(a,b,not(c));
walk_ns = green_bs;
stop_ns=or3(and3(not(a),not(b),not(c)),and3(not(a),b,c),a);
walk_ew = green_ds;
stop_ew=or3(not(a),and3(a,b,c),and3(a,not(b),not(c)));
printf("%d %d %d %d   %d %d %d %d
%d %d %d %d   %d %d %d %d    %d %d
%d %d\n",
      green_bl,green_bs,red_bs,yellow_bs,
      green_dl,green_ds,red_ds,yellow_ds,
      green_fl,green_fs,red_fs,yellow_fs,
      green_hl,green_hs,red_hs,yellow_hs,
walk_ns,stop_ns,
walk_ew,stop_ew);
getch();
}
return;
}
int and2(int x,int y)
{
return(x && y);
}
int and3(int x,int y,int z)
{
return(x && y && z);
}
int or2(int x,int y)
{
return(x || y);
}
int or3(int x,int y,int z)
{
return(x || y || z);
}
int not(int x)
{
return(!x);
}
```

Figure 8.3: C program for simulate the traffic light controller

Table 8.3: Execution Results of Software Program

SIG-B	SIG-D	SIF-F	SIG-H	WALK(N-S)	WALK(E-W)
G G R Y	G G R Y	G G R Y	G G R Y	G R	G R
0 0 1 0	0 1 0 0	1 1 0 0	0 0 1 0	0 1	0 1
0 1 0 0	0 1 0 0	0 1 0 0	0 0 1 0	1 0	0 1
0 1 0 0	0 1 0 0	0 0 0 1	0 0 1 0	1 0	0 1
1 0 0 1	0 1 0 0	0 0 1 0	0 0 1 0	0 1	0 1
0 0 1 0	0 1 0 0	0 0 1 0	1 1 0 0	0 1	0 1
0 0 1 0	1 0 0 0	0 0 1 0	0 1 0 0	0 1	1 0
0 0 1 0	1 0 0 0	0 0 1 0	0 0 0 1	0 1	1 0
0 0 1 0	0 0 1 1	0 0 1 0	0 0 1 0	0 1	0 1

Note. *The first column under G (green) in each group of four signals indicates the turn signal, while the next three columns under GRY indicate signal for the straight traffic.*

8.3 Two Way Switches

In applications where multiple switching options are required (e.g., a telephone service), mechanical switches have long been replaced by electronic switching devices which can be automated and intelligently controlled.

We can define a switch in terms of its operation and use. In general, a switch is a device that can be used to either establish or remove (also called make or break) connections between at least two points in an electric or electronic circuit.

The figure 8.4 shows ON-OFF switch along with its symbol.

(a)

(b)

Figure 8.4: Switch (a) ON-OFF switch (b) Circuit symbol

The most common type of switches is the one that we use to turn our lights on and off. Depending on the power that is switched, size and physical nature we have a wide range of switches, ranging from sub-micron transistors to big switches that can switch megawatts of power. Although there are many types of switches, we are more accustomed to one-way and two-way electrical switches. The main difference between them lies in the number of contacts they have. A one-way switch only has two contacts and a two-way switch has three.

A one-way switch basically operates as a make or break switch. So when it is turned on, the two terminals are connected, and when it is turned off, the contact between the two is broken. In contrast, a two-way switch is basically two, one-way switches combined into one. Here one of the terminals can be connected to either of the remaining two but not both at the same time. When we make a connection with one terminal, the connection with the other is broken.

A switch can be considered to be a 'gate' which either allows or disallows certain entity. When such a switch can be operated using some logic, then we can call this switch as a 'logic gate'. Electronic hardware technology provides us with miniature logic gates which can be put together in large numbers (several millions) on a single chip, which can function as a system of logic. A computer is a classic example of such an electronic system composed of electronic logic gates.

On the other side we have mechanical arrangements that can switch the track of a train from one to another.

A regular electric switch that can be used to control power to domestic appliances has small metallic pieces called contacts. And these contacts are made to physically touch each other to make a circuit, while separation between them breaks it. The desirable properties of these metallic contacts are low resistance, very good electrical conductivity, resistance to corrosion, mechanical strength to name a few. To achieve the desirable properties, sometimes the contacts may be plated with metals such a gold, copper etc.

Actuator

The mechanical or electromechanical part which helps the contacts to physically touch and separate are called actuators. These could be a spring loaded toggle, a rocker, electrically operated relay, a push-button etc.

Contact arrangements

A switch is said to be ‘closed’ if the contacts of the switch are in physically touching each other, which allows electric current flow through it. When the contacts are separated with a gap, current cannot flow through the switch. Now the switch is said to be ‘open’.

Generally electric switches can be classified according to the number of contacts and mechanical movements required to operate them. A SPST switch means, single pole (contact) - single throw (movement). But electrical power supply industry and wiring technicians also have alternate nomenclature like ‘one-way’ switch; ‘three-way’ switch etc.

The figure 8.5 shows the some of the types of switches based on their method of contacts.

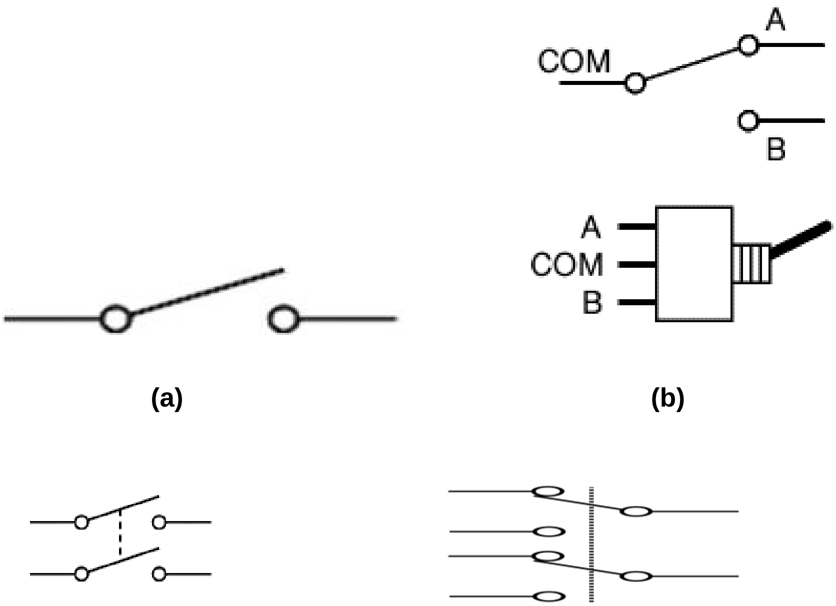

Figure 8.5: Types of Switches
(a) SPST (Single Pole, Single Throw)
(b) SPDT (Single Pole, Double Throw)
(c) DPST (Double Pole, Single Throw)
(d) DPST (Double Pole, Double Throw)

A normally open ('NO') switch has its contacts open by default and the contacts close only when the switch is operated. Similarly a normally closed ('NC') switch has closed contacts until opened by operating the switch. These are shown in figure 8.6. The nomenclatures are normally used in logic and wiring diagrams to enhance the clarity of operation. This helps in minimizing assembly line errors and troubleshooting faults. A switch with both types of contacts is called a changeover switch or "make-before-break" switch contact, whereas most switches have a spring loaded action which momentarily disconnect the load and so are "break-before-make" types by contrast.

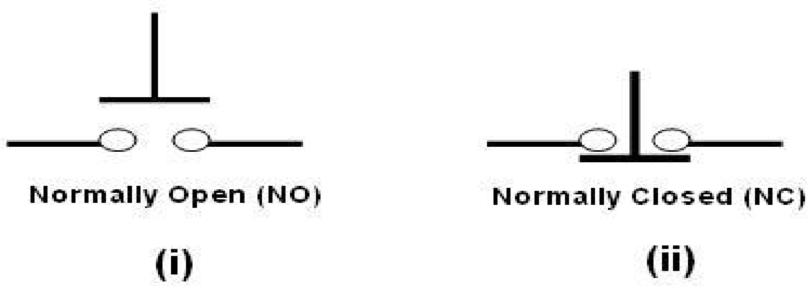

Figure 8.6: (i) Normally Open ('NO') switch (ii) Normally Close ('NO') switch

The type of switch to be used depends on particular application. For example, if interruption of power to a load is not acceptable, then a "make-before-break" switch could be used to select an alternate power source to the load. The terms pole and throw are also used to describe switch contact variations. A pole is a set of contacts, the switch's electrical terminals that are connected to and belong to a single circuit, usually a load. A throw is one of two or more positions that the switch can adopt, which normally, but not always correspond to the number positions the switch handle or rotor can take when connecting between the common lead of the switch and a pole or poles. A throw position which connects no terminals (poles), has a mismatch between positions and positions which connect terminals, but are quite useful to turn things "Off" or for example, alternatively select between two scaled modes of operation. (e.g. Bright illumination, moderate illumination, no illumination). Switching a load on or off from two locations (for instance, turning a light on or off from either end of a flight of stairs) requires two SPDT switches.

8.4 Electronic Tennis Scoring System

The present tennis scoring system includes input devices for each player to indicate whether one player or the other has won a particular point. These input devices for each player may be in the form of transmitters each having two recessed pushbutton switches, one to indicate that one player has won the point and the other to indicate that the opposing player has won the particular point.

The input device may take the form of a belt buckle size unit worn at the waist or on the wrist. Electronic scoring circuitry provided is responsive to the concurrent depressing of buttons by both players indicating who has won a particular point. Electronic scoring equipment keeps track of the points, games, sets and matches won by each player and each side. Suitable electronic equipment is provided to accommodate slight differences in the timing of the pressing of input switches by the two players. Special logic circuitry is provided for accommodating the tennis scoring situation involving deuce games. Transmitters with unique signals to indicate who has won a point are provided. A common display and annunciator unit may be used which receives signals from input devices of each player. Alternatively, small LED displays may be provided on each of the input units to display the points, games, sets and matches won by each player and each team. The annunciator may provide a unique sound to indicate points won by one player as compared with a different sound for points won by the other player.

A league and tournament system is disclosed which includes a centralized league machine that transmits data to one or more of a plurality of electronic dart games via modem or using a wireless portable data storage device. The electronic dart machines are configured to receive and utilize league and tournament database information from the league machine for a variety of purposes, including automatic implementation of player handicaps, automatic control of match play, and team and player registration using the dart machine. The dart machine has a monitor that displays context sensitive menus using information obtained from the league or tournament database. The dart machine includes a barcode card reader that permits identification of league and tournament participants using barcode cards. The dart machine can also respond to other types of barcode cards for such purposes as crediting games and providing access to machine performance data and certain machine servicing functions. Inter-game communication within an establishment is provided either by hardwiring the dart machines or using infrared communication.

8.5 Temperature and Weather Forecast Systems

We consider here weather forecasting. Weather is the state of the atmosphere like it is hot or cold, wet or dry, calm or stormy, clear or cloudy. Weather forecasting is predicting the state of the atmosphere for a future time and a given location. A barometer is a scientific instrument used in meteorology to measure atmospheric pressure. When atmospheric pressure is measured by a barometer, the pressure is also referred to as the *barometric pressure*. Now let us study 1-wire Barometer.

1-wire Barometer:

Assumptions/Design Criteria

- The barometer will be operated indoors. This will minimize output variations caused by temperature and will lengthen the calibration intervals. It also means the circuit board will not have to be weatherproofed.
- Will be easy to calibrate. Maximum of 1 calibration adjustment.
- The operating range will be from 28.00 inHg to 32.00 inHg
- Resolution will be greater than .01 inHg from sea level to 10,000 feet.
- The interface will be standard Dallas Semiconductor 1-wire.
- Unit will be designed for indoor operation, so it can be externally powered.
- Will utilize the Motorola MPX4115A pressure transducer.

Based on these assumptions, table 8.4 is generated.

Table 8.4: Station Pressure & Actual Pressure

Alt Feet	Station Pressure	Actual Pressure	PSI	MPA Output Volts	OA Offset	OA Gain	OA Output	Sofware Slope Value	Software Intercept Value	Resol inHg
0	28.00	28.00	13.7525	3.7922	3.5	10.0	2.9220	0.6562	26.0827	0.007
	32.00	32.00	15.7171	4.4018	3.5	10.0	9.0180			
1000	28.00	26.99	13.2566	3.6383	3.4	10.0	2.3834	0.6758	26.3894	0.007
	32.00	30.87	15.1642	4.2302	3.4	10.0	8.3024			
2000	28.00	26.01	12.7747	3.4888	3.2	10.0	2.8880	0.6960	25.9898	0.007
	32.00	29.78	14.6268	4.0635	3.2	10.0	8.6349			
3000	28.00	25.06	12.3071	3.3437	3.1	10.0	2.4372	0.7171	26.2523	0.007
	32.00	28.72	14.1048	3.9015	3.1	10.0	8.0153			
4000	28.00	24.13	11.8535	3.2030	3.0	10.0	2.0298	0.7389	26.5002	0.007
	32.00	27.69	13.5981	3.7443	3.0	10.0	7.4430			
5000	28.00	23.24	11.4136	3.0665	2.8	10.0	2.6647	0.7616	25.9706	0.008
	32.00	26.68	13.1063	3.5917	2.8	10.0	7.9169			
6000	28.00	22.37	10.9869	2.9341	2.7	10.0	2.3408	0.7851	26.1622	0.008
	32.00	25.71	12.6289	3.4436	2.7	10.0	7.4355			
7000	28.00	21.53	10.5733	2.8057	2.6	10.0	2.0575	0.8096	26.3343	0.008
	32.00	24.77	12.1656	3.2998	2.6	10.0	6.9983			
8000	28.00	20.71	10.1724	2.6813	2.4	10.0	2.8134	0.8350	25.6509	0.008
	32.00	23.85	11.7163	3.1604	2.4	10.0	7.6041			
9000	28.00	19.92	9.7838	2.5608	2.3	10.0	2.6078	0.8613	25.7538	0.009
	32.00	22.97	11.2805	3.0252	2.3	10.0	7.2517			
10000	28.00	19.15	9.4074	2.4440	2.2	10.0	2.4398	0.8887	25.8317	0.009
	32.00	22.11	10.8579	2.8941	2.2	10.0	6.9405			

This table 8.4 calculates the station pressure for both the minimum (28.00) and the maximum (32.00) pressures for altitudes from sea level to 10,000 feet in 1000 foot increments. The station pressure is then converted to MPX4115A pressure sensor volts. Looking at the table, you can see the predominant change in altitude in the offset voltage of the pressure sensor.

The OA Offset column is the op amp offset voltage that compensates for altitude. This will be the only calibration variable. Since the instrumentation amplifier is a rail-to-rail device, in theory it will operate down to 0 volts. However, to provide some margin, the offsets were chosen to allow a minimum of 0 .2 volts at the lowest pressure. The gain of 10 was chosen to allow maximum output voltage swing for all altitudes. The resulting op amp output voltages are listed in OA Output column. This is the voltage applied to the DS2438 Vad input.

Circuit Design:

The following circuit design satisfies requirements (refer figure 8.7). INA122 instrumentation amplifier was selected as it eliminated several external resistors and it provides a very stable gain over a wide temperature. It also provides excellent rail-to-rail operation allowing full use of the 10 volt input range of the DS2438. The 40.2K ohm resistor sets the gain to 10. The variable resistor allows adjustment of the offset voltage from 2.0v to 4.0v.

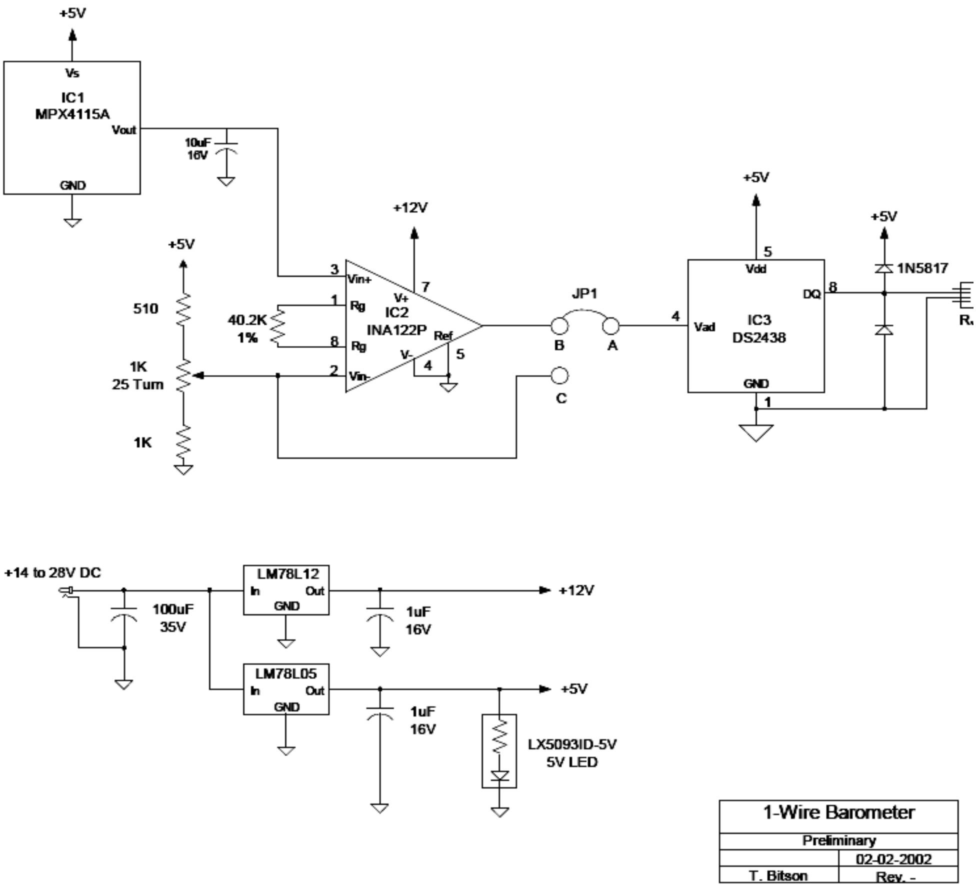

Figure 8.7: Circuit for 1-wire Barometer

Calibration:

Hardware calibration is simply a matter of setting the offset voltage to the value listed in table 8.4 for your altitude. A jumper on the input of the DS2438 allows the use of the DS2438 to measure the offset. Put the jumper in the A-C position and using the iButton Viewer for the DS2438, set the voltage to the table value using the 25-turn pot. Once it is set, put the jumper in the A-B position to read pressure.

For altitudes in between the values listed in the table, simple interpolation will give accurate results. An Excel spreadsheet can be used to calculate intermediate values.

Routines currently exist to measure the DS2438s Vad voltage. Once this voltage is measured, the pressure is calculated using:

Press = slope * Vad + intercept

Where the slope and intercept are the values listed in table 8.1 for your altitude. The prototype code had an external text file to store the slope and intercept values. This allows the user to edit the file to fine-tune the calibration if desired.

Fine-tuning can be accomplished by monitoring the pressure and comparing it with a known reference source, such as a nearby airport or national weather service. Start by adjusting the intercept. When the reference station indicates a pressure near mid-scale (30.00 inHg), adjust the software intercept value until your weather station matches. Now monitor the pressure extremes to determine if the slope needs adjustment.

Future Options:
A fixed resistor could replace the variable resistor. This would eliminate any hardware adjustments. The value would have to be calculated for a given altitude. Another possibility is to use several DS2406 1-wire switches or a programmable potentiometer to set the offset programmatically.

8.6 Summary

In this unit some example of real world electronic design were presented. All the designs require clear understanding of application requirements, and accordingly design decisions are taken. While the traffic light controller was purely digital, temperature and weather forecast system design included use of sensors and analog components. We also learnt about various types of switches and the terminology associated with them.

Let us recapitulate the important concepts discussed in this unit.

- Traffic Signal Systems is an automatic traffic light controller and can be implemented by programming any gate array based logic (GAL) device such as FPGA.
- Switch is a device that can be used to either establish or remove (also called make or break) connections between at least two points in an electric or electronic circuit.
- Actuator is the mechanical or electromechanical part which helps the contacts to physically touch and separate.
- A normally open ('NO') switch has its contacts open by default and the contacts close only when the switch is operated.
- Electronic scoring circuitry provided is responsive to the concurrent depressing of buttons by both players indicating who has won a particular point.
- 1-wire barometer design will utilize the Motorola MPX4115A pressure transducer

Self Assessment Questions

1. The mechanical or electromechanical part which helps the contacts to physically touch and separate are called ______________.
2. All control signals that drive traffic lights can be mapped into _____________functions.
3. A switch can be considered to be a _________which either allows or disallows certain entity.
4. Electronic scoring equipment keeps track of the points, games, sets and matches won by each player and each side (True or false).
5. ________________is pressure transducer.

8.7 Terminal Questions

1. Design a traffic light controller for a three road junction.
2. Describe various types of electrical switches.
3. Explain the design of an electronic tennis scoring system.

8.8 Answers

Self-Assessment Questions

1. Actuators
2. Boolean
3. Gate
4. True
5. Motorola MPX4115A

Terminal Questions

1. Refer Section 8.2
2. Refer Section 8.3
3. Refer Section 8.4