

DESIGNING AND MAKING AN AUTOMATIC WATER LEVEL CONTROL SYSTEM

WHAT YOU WILL LEARN

After completing this project, you should understand:

- How to design a control system using a block diagram.
- How a closed loop control system works.
- What hunting is in a closed loop control system.
- How hunting can be reduced by using damping.
- How a capacitor can be used to provide damping.
- How a field effect transistor (FET) can be used as an electronic switch.
- How a float switch can be used to monitor the level of a liquid.

After completing this project, you should be able to:

- Use the following components in control circuits:
 - FET
 - Capacitor
 - Resistor
 - Electrically powered water pump
 - Float switch.
- Build an automatic water level control system.

CONTROL - AUTOMATIC WATER LEVEL CONTROL

We often take water for granted. In the modern home, school or factory, there is always a plentiful supply of clean fresh water whenever you turn on the tap. Most people know that water is collected in large lakes or *reservoirs*, but few people are aware of the many problems that have to be solved to get the rainwater from the reservoir to your tap.

When you turn on your tap, you expect water to come out. But what is it that makes the water come out?

By turning on your tap, you open a gap for the water to come through. Turn the tap on a little bit and there is a small gap for the water to trickle through. Turn your tap on fully and there is a large gap for the water to gush through. By turning the tap on or off, you control the flow of water. But the amount of water that flows through the tap not only depends on the amount the tap has been turned on. It also depends on how much *pressure* pushes the water through it. The water must be under pressure in the pipes otherwise it will not go anywhere. If you turned on the tap and there was no pressure, nothing would come out.

This becomes clear when you think about it. Water only moves if a force is applied to it. The easiest way to do this is to let the water flow downhill like it does in a river, using gravity as the force. This is obviously not always possible in reality. Not all homes, schools, factories etc. are conveniently situated in positions below the reservoir.

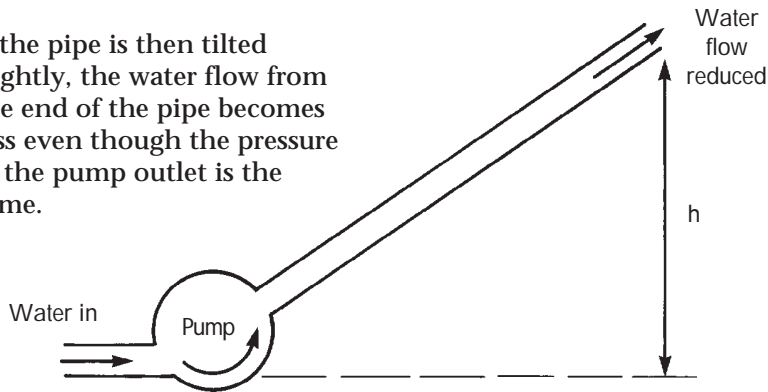
It is the responsibility of the water supply companies to maintain a reasonably constant pressure in the water supply pipes. This means that all consumers can expect a fairly constant supply of water no matter where they live. In practice, it is impossible for the water companies to be sure that the pressure they maintain is enough to meet the needs of all consumers. They can only decide what pressure will suit the majority of customers and use this as a guide. A simple explanation of how they arrive at this guide is given here.

CONTROL - AUTOMATIC WATER LEVEL CONTROL

If water is pumped into a pipe and the pipe is horizontal, water flows from the end of the pipe.

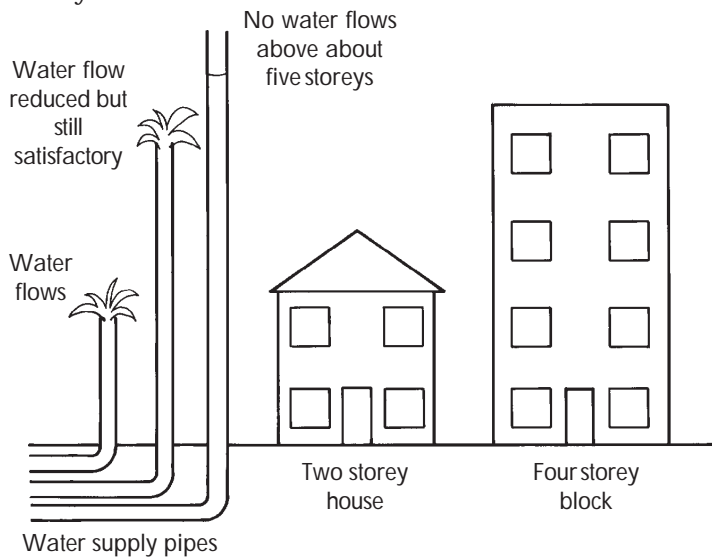


If the pipe is then tilted slightly, the water flow from the end of the pipe becomes less even though the pressure at the pump outlet is the same.



By tilting the pipe, the height (h) the water has to reach increases. The pressure pushes the water against the force of gravity. If the height (h) is increased further and the pressure stays the same, the flow decreases further. If you continue to increase the height, the flow from the end of the pipe continues to decrease. A limiting point is eventually reached when no water flows from the end of the pipe. This is because the pressure is insufficient to lift the water to the desired height against the force of gravity.

Water companies maintain a pressure in the supply pipes that will lift water to the top floor of most buildings - about four or five storeys in most cases.



◀ SCIENCE OPPORTUNITY

E.g. "Hydrostatic paradox".

CONTROL - AUTOMATIC WATER LEVEL CONTROL

The fact that the amount of pressure affects how high water will travel up a pipe becomes very important when you think about how technology has changed the way in which we can construct buildings.

Until fairly recently, most buildings were no more than two or three storeys high. Certainly most homes were no taller than this.

During the 1930s, building technology made an important development. It became possible to construct very tall buildings using a steel frame clad in concrete. This revolutionised the building industry and the first of the 'skyscrapers' began to appear in places like New York City in the USA.

In the 1950s and 1960s, many tower blocks were built in this country. They were designed to provide housing for a growing population. Today, 'high-rise' buildings are built mainly for use as offices.

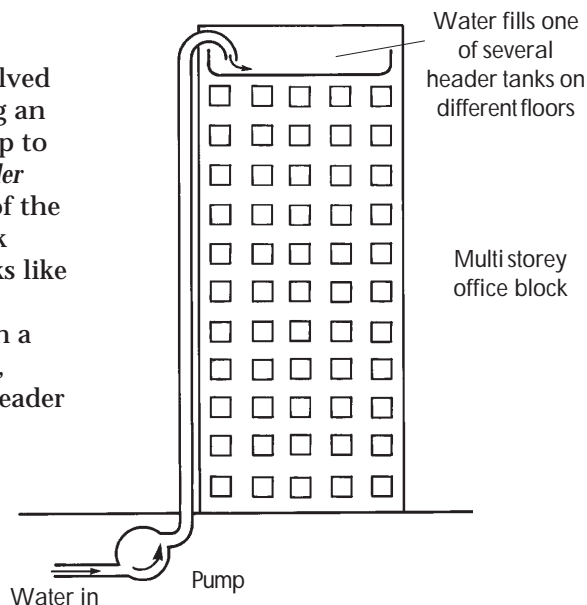
All modern buildings need a water supply. If the water supply company only pressurises the water enough to lift it to the fourth or fifth floor, how can you get a water supply to the top of a 20 storey office block?

◀ NOTE

Science opportunity: Calculation of pressure against head of water and pump characteristics (pressure - flow curve).

The water company could increase the pressure in the supply pipes, but this would not be economic. Most buildings are four storeys or less so the pressure is sufficient. A higher pressure in the supply pipes would also mean that the pipes would need to be stronger to withstand the higher pressure. This would increase the cost of installing and maintaining the supply pipes.

The problem has to be solved by the consumer by using an electrically powered pump to pump the water to a *header tank* installed at the top of the building. The header tank stores the water and works like a small private reservoir. When somebody turns on a tap or flushes a toilet etc., water is taken from the header tank.



Any water taken from the tank flows downhill. This means that the water flows naturally from the tank to the tap.

Although this is a good solution to the problem, there are a few more things to consider. If the header tank is to work effectively, it must remain reasonably full. If the tank empties too far, there is a danger that the water supply will dry up if too many people try to use it at once. The flow out of the tank would never be constant as different numbers of people would be using it at different times.

This means you have to control the pump. You cannot leave it running all the time as the tank would overflow when no water was being used. You cannot switch the pump on for timed periods because you cannot be sure how much water is going to be used in any one day. You need to control the pump so it automatically keeps the header tank full at all times.

DESIGNING A CONTROL SYSTEM

Control systems can be represented using *block diagrams*. There are three basic building blocks and each block is used to represent a stage in the control system.

The three blocks are:



The Input Block - *Enters information into the control system. It will normally contain a switch or sensor.*

The Process Block - *Receives the information from the input block and uses it to control the output block, switching it on or off depending upon the state of the input.*

The Output Block - *Gives out information or makes things happen. The output block would normally contain components that either light up, make a noise or move.*

Control systems can be designed using these basic blocks in a simple and effective way without necessarily knowing too much about the electronic circuits contained in each block. A simple control system would normally contain one of each type of block.

◀ NOTE

To find out more about header tanks and controlling the flow of liquids see Technology Study File 12

YOUR TASK

Design and make an automatic water level control system that can be used to keep a header tank full. The water must be electrically pumped into the tank. The finished product should be in the form of a fully functioning model.

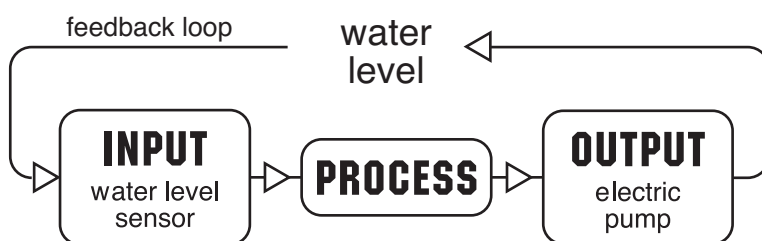
DESIGNING THE CONTROL SYSTEM

The input block needs to contain some kind of switch or sensor to monitor the level of the water in the tank. The process block needs to contain something to receive the information about the water level from the input block. It needs to use this information to control a pump in the output block, switching it on when the water level becomes too low and off when the tank is full. The basic block diagram for the control system looks like this:



The basic block diagram is not quite complete. You need to add some extra information to the block diagram. When the pump is on, it puts more water into the tank. When this happens, the input block monitors the change in the water level and passes the information on to the process block which controls the pump.

What happens at the output affects what happens at the input. From this, you should see that the control system does not work in a **line** but in a **loop**.



This is an example of *closed loop control*, where information is passed back from the output to the input in the form of a loop. This passing back of information is called *feedback*. All automatic systems must have some form of feedback so that the input knows what the output is doing.

◀ NOTE

To find out more about open and closed-loop control systems see Technology Study File 3 ('What is Control')

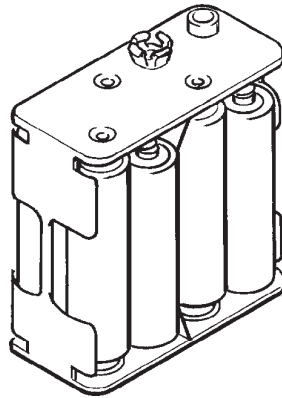
When you have drawn a block diagram for an electronic control system and decided what function each block will perform, you can use a kit to model a prototype system.

CONTROL - AUTOMATIC WATER LEVEL CONTROL

DESIGN CONSTRAINTS

Before you design and make the motor control system, you need some more information. You must know what power supply to use, what components are available to make up each system block and how they are used.

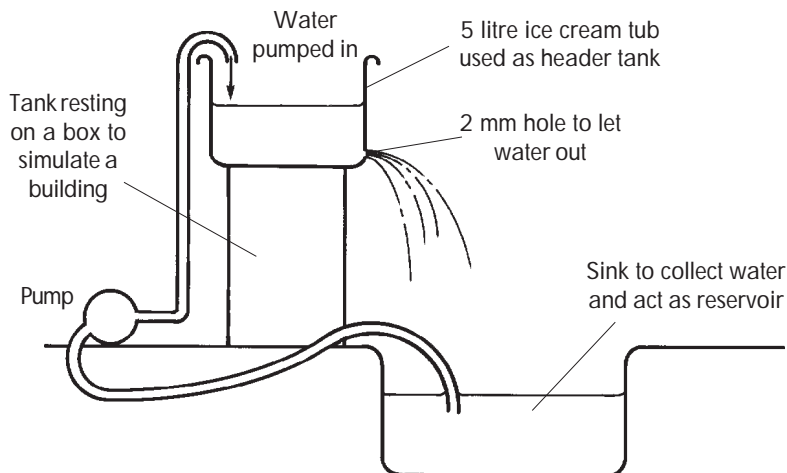
Power Supply - You will be using a 12 Volt power supply which will be provided by eight 1.5 Volt cells in a cell holder.



◀ SYSTEM OUTPUT
POSSIBILITIES

The output block will contain the pump. The type of pump you will be using to model the system is a car windscreen washer pump. There are many different types of these available but they all operate on a 12 Volt supply. Any car windscreen washer pump will pump sufficient water to complete this project.

You need to set up a test rig to simulate the header tank. A good way to do this is to use an old 5 litre ice cream tub or any other similarly sized container. This needs to have a hole drilled near the base to let the water out - this simulates people using it. There will need to be a tube from the pump to feed the water into the tank. **It is important that the pump supplies more water to the tank than the hole near the base lets out.** If it doesn't, the tank will never fill. You can make sure of this by only drilling a small hole of about 1 - 2 mm diameter to let the water out.



CONTROL - AUTOMATIC WATER LEVEL CONTROL

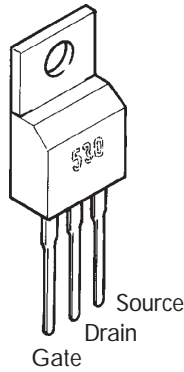
If there are a number of you doing this project, it makes good sense to use only one test rig. In this way, you can all use the same pump and tank and so save on materials and time. You will also be able to evaluate the effectiveness of your control system against the others in the group.



The main component used in the process block is a field effect transistor or **FET**.

You will be using a type IR530 which looks like this.

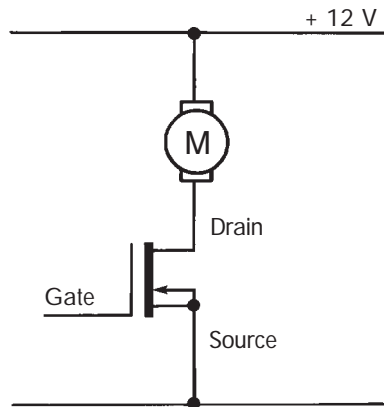
The three legs of the FET have names. It is easy to see which leg is which from the picture.



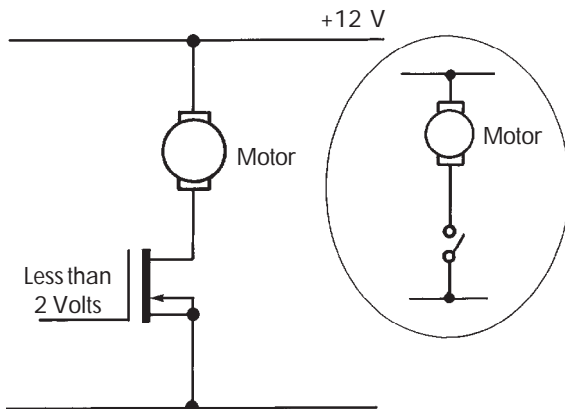
◀ SYSTEM PROCESSING
POSSIBILITIES

You need to connect the FET and the pump like this.

The FET works like an electronic switch. To turn it on, you need to put a positive voltage onto the **gate**. This allows current to flow through the FET from **drain** to **source**.

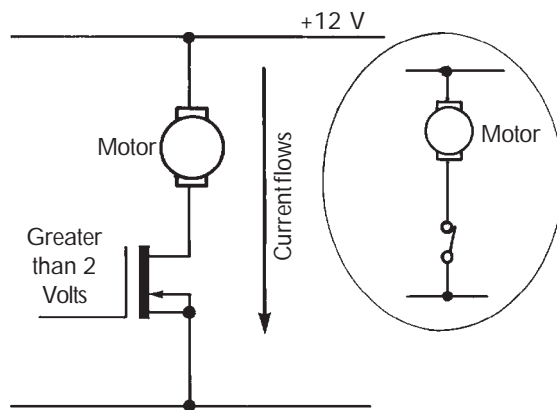


A gate voltage of **less** than 2 Volts turns the FET fully off.

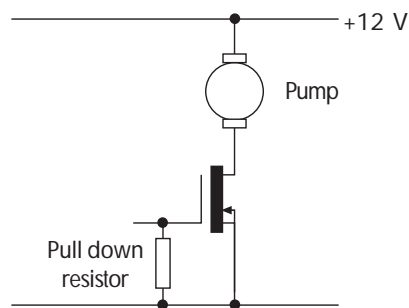


CONTROL - AUTOMATIC WATER LEVEL CONTROL

A gate voltage of **greater** than 2 Volts turns the FET fully on.



When you use a FET like this, you need to connect a *pull down* resistor to the gate like this:

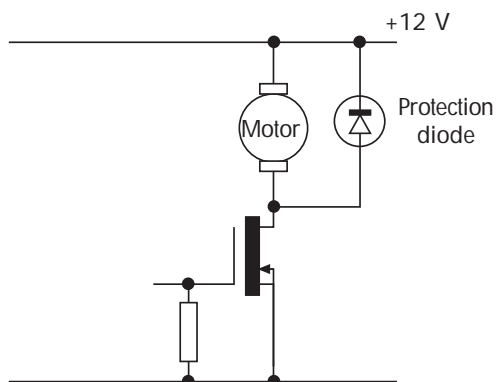


◀ NOTE

This is a good example of "common sense" terminology in microelectronics.

This makes sure that the FET stays switched off when there is no input voltage on the gate.

One final addition to the output circuit is needed. This is to connect a diode across the pump like this:



This protects the FET from any *interference* the pump might create.

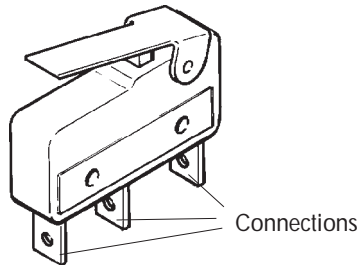
INPUT BLOCK

◀ SYSTEM INPUT
POSSIBILITIES

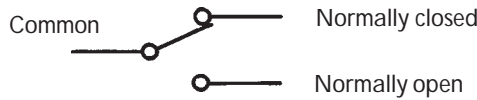
The input block monitors the water level and passes the information to the process block. You know that the FET in the process block is controlled by a voltage on its gate. The input block must therefore provide a voltage of less than 2 Volts when the water level is high enough and greater than 2 Volts when the water level falls. This will switch on the FET and therefore the pump whenever the water level falls.

The easiest way to do this is to use a *float switch*. This normally consists of two main components - a float and a switch. The float rests on the surface of the water and moves up and down when the water level changes. The switch is fixed at one level. The float operates the switch so that it turns on when the water level is low and off when the water level is high.

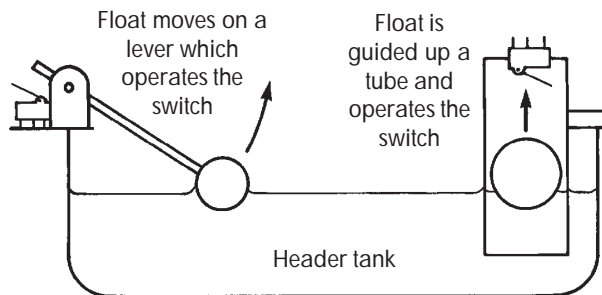
The best switch to use for this is a *micro-switch*. These are small sensitive switches that need only a small force to switch them on or off.



Micro-switches normally have three connections. The circuit symbol for a switch with three contacts looks like this.

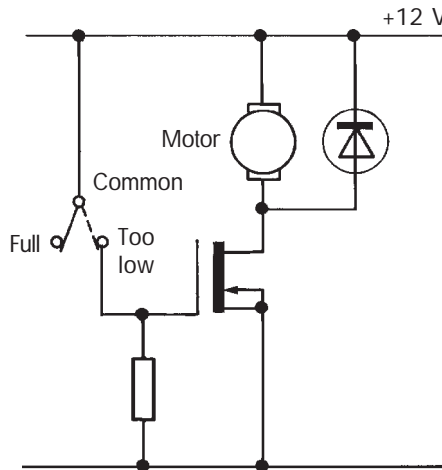


There are many different ways in which you can arrange the float and the switch. They all work on the same principle but some are more effective than others. A couple of ideas are shown here to get you thinking. You are going to have to make your own float-switch and design it so it can be fixed onto the model header tank.

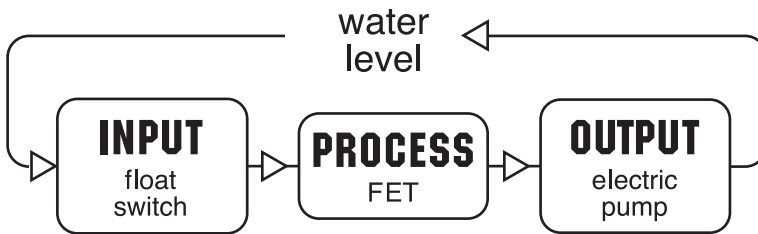


CONTROL - AUTOMATIC WATER LEVEL CONTROL

The switch should be connected like this to control the pump correctly.



With this detail added, the block diagram for the automatic water level control system now looks like this:

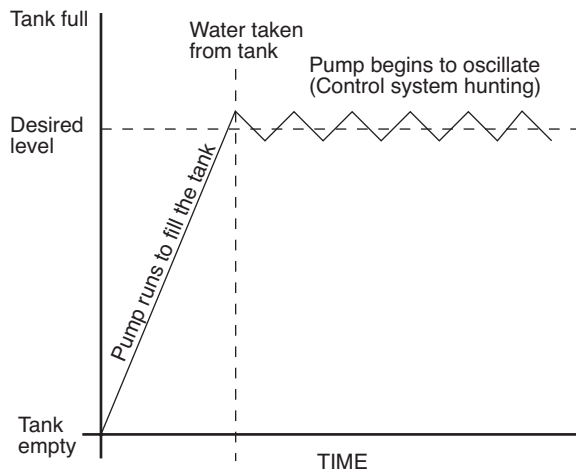


The input block senses the level of the water. When it becomes too low, the pump switches on until the water level is high enough again. Although this works well in theory, before you can go ahead and draw the final circuit diagram, you have one last problem to solve.

To recognise the problem, you have to think more carefully about how the control system actually works. When the water level falls below a set level, the pump is switched on by the float switch and refills the tank. Once it reaches the upper limit allowed by the float switch, the pump is switched off again.

◀ SCIENCE OPPORTUNITY

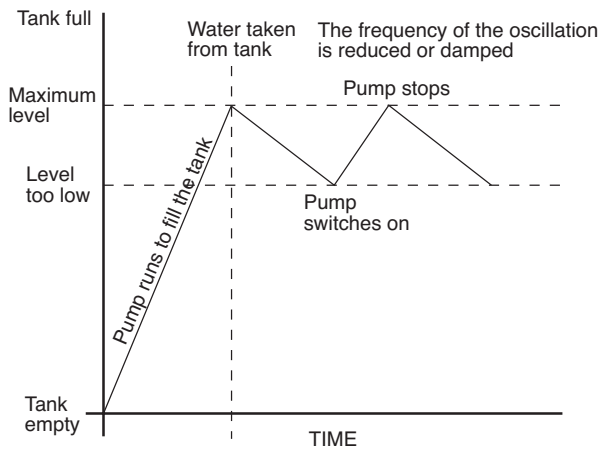
These upper and lower limits, however, are quite close together which means that, when water is being run from the tank, the pump is continually being turned on and off as shown in the graph.



CONTROL - AUTOMATIC WATER LEVEL CONTROL

This 'oscillating' effect is common in closed loop control systems and is known as **hunting** because the control system is constantly hunting for a position where it can remain at rest. This is not a very effective way to control the pump as it increases the wear and tear on it and also wastes energy.

Hunting can be stopped in a number of ways in closed loop control systems. The most effective method in this case is to use **damping**. To do this, you must damp or delay the operation of the float switch so that the pump runs for longer than the float switch actually tells it to. The water level therefore rises to a higher level than before. The graph showing how the control system operates now looks like this:



◀ SCIENCE OPPORTUNITY

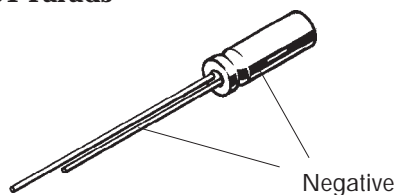
There are now two **different** points at which the pump switches. This lengthens the time period between the pump switching off and on again. The frequency of the oscillation is reduced or damped.

The easiest way of introducing damping into your circuit is to add a capacitor before the process block. A capacitor is a device that stores electrical charge. If it is connected to a power supply, it charges (or fills) up. The amount of time it takes to charge up depends upon two things.

First, it depends on the size of the capacitor. A big capacitor takes a long time to charge. Capacitors are measured in Farads. Most capacitors are only a fraction of one Farad in size and so they are measured in micro-Farads (μF).

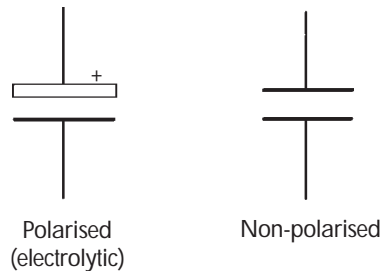
$$1 \mu\text{F} = 0.000001 \text{ Farads}$$

The capacitor you will be using will probably look like this:



CONTROL - AUTOMATIC WATER LEVEL CONTROL

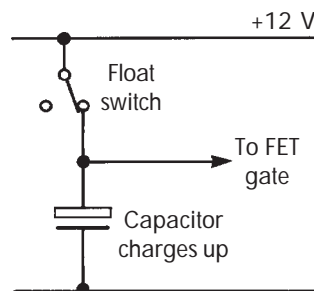
Notice that the negative leg is clearly indicated. This means that this capacitor must be connected correctly into the circuit. This is because it is an *electrolytic* capacitor. Not all capacitors are like this. Most don't have positive and negative connections so they can be connected in any direction. Notice the difference in the two circuit symbols:



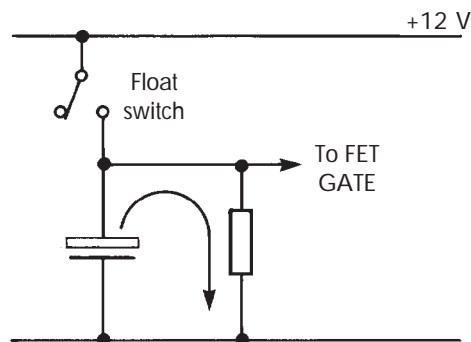
When using capacitors, it is always important to check whether they are polarised.

The second thing that affects how long a capacitor takes to charge up is how much resistance it is charging through. The larger the resistance, the longer it will take to charge.

The capacitor is connected as shown on the right. When the float switch falls past the level that is 'too low', the switch turns on and applies a positive voltage to the gate of the FET. This switches on the FET and the pump begins to run. The capacitor charges up very quickly as the switch has a very small resistance.



When the water level rises past the 'too low' level, the switch turns off. The capacitor, however, is still charged and it continues to keep the FET switched on and the pump running. The capacitor discharges slowly through the pull-down resistor until the charge falls below 2 Volts. At this point, the FET switches off and the pump stops.



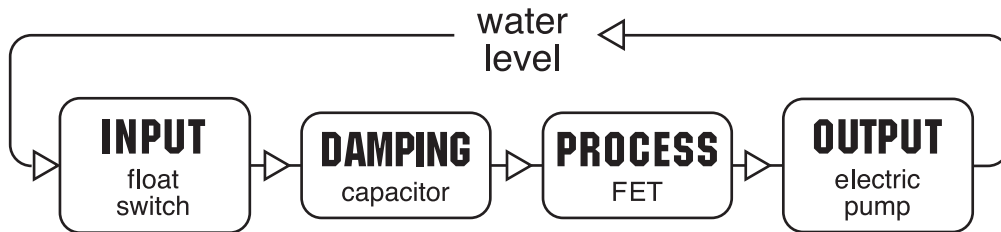
Capacitor discharges via pull down resistor. FET stays on until capacitor voltage falls to less than 2 volts

CONTROL - AUTOMATIC WATER LEVEL CONTROL

How long the capacitor keeps the pump running depends on the size of the capacitor and the size of the pull-down resistor. Larger values of either will keep the pump running for longer. You cannot experiment with the size of the resistor as this is fixed so you will have to experiment with the size of the capacitor to find the best value.

- **A capacitor that is too small will not prevent the system from hunting.**
- **A capacitor that is too large will allow the tank to overflow.**

With the damping capacitor added, the block diagram for the control system looks like this:



PUTTING IT ALL TOGETHER

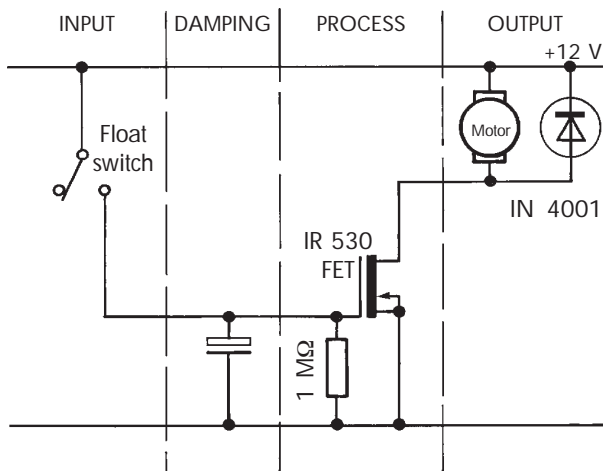
The circuit diagram for the automatic water level control system is shown below. It has been divided into blocks to help you understand what each component is doing.

When you build it, you will need to make a printed circuit board (PCB) on which to mount the components.

◀ SYSTEM SYNTHESIS

◀ NOTE

To find out about this see Technology Study File 2 (Making a PCB)



Remember that the input switch will be part of the float switch assembly you have designed and made and the pump will be part of the test rig.

CONTROL - AUTOMATIC WATER LEVEL CONTROL

TESTING

When you have built the circuit, you need to test it to see if it works correctly. You have to experiment to find the correct value for the damping capacitor. The pump should switch on when the tank falls to a low level. It should run until the tank is nearly full again but must not overflow.

If the control system does not work at all, try following this simple fault finding procedure:

1. Check that the PCB layout is correct and that no tracks are bridged or broken. Repair if necessary.
2. Check that all soldered joints are good.
3. Check that all components are connected correctly. Pay particular attention to the FET as mistakes are easily made.
4. Check that the float switch is operating correctly by measuring the voltage on the gate of the FET (12 Volts for 'too low' and discharging from 12 Volts to 0 Volts for 'high enough').

◀ NOTE

To find out about this see Technology Study File 2 (Making a PCB)

EVALUATING THE AUTOMATIC WATER LEVEL CONTROL SYSTEM

There are a number of things to consider when evaluating your automatic water level control system:

1. How well does it work?

Will it maintain a level of water that never falls below the 'too low' level and does not overflow?

2. Will it work in the situation for which it was designed ?

Does the float switch fit easily onto the tank?

Does it operate effectively in the tank?

Is it sensitive enough ? In other words, does the float move easily and operate the switch effectively?

3. Was trial and error the best way to select the damping capacitor value?

Can you think of, or find out about, another way of doing it?