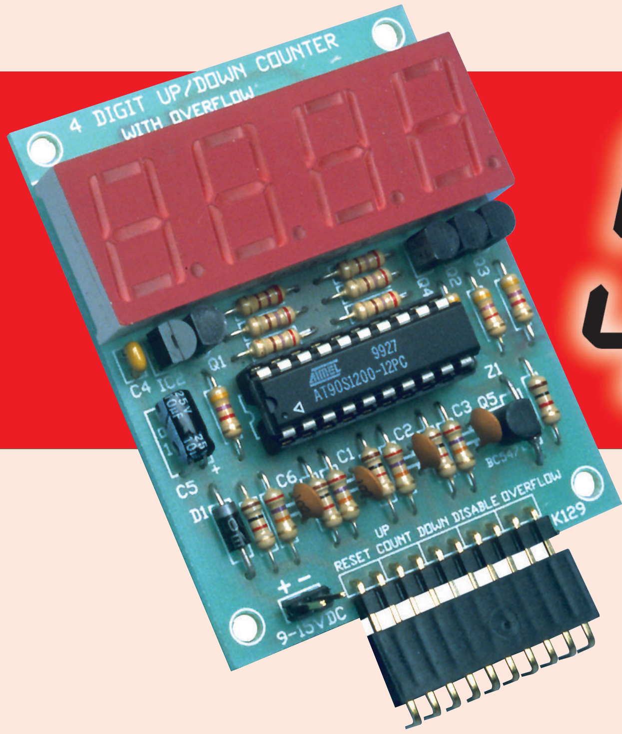


MICROCONTROL
4-DIGIT COUNTE

This article presents two simple, low
One will count up or down and the
user-defined ways from a preset val
the modules is the software in

By Peter Crowcroft and

Modern electronics allows products – consumer, industrial and scientific – to be produced with ***more*** features in ***smaller*** packages at ***less*** cost than ever before.

Not too long ago, the controller for an appliance such as a washing machine or microwave oven would have been a mechanical timer, or perhaps discrete components (switches, transistors and 4000 series logic, etc).

However, all these things take precious space and are costly to produce. Often they're difficult to update or reuse for different product models or revisions.

Today, these problems are neatly and cheaply solved with microcontrollers – single chip computers complete with IO pins, RAM, pProgram storage (ROM) and sometimes other useful features like ADCs, UARTS and PWM drivers.

One simply arranges for relevant inputs (switches and sensors) and outputs (motor and solenoid drivers, LEDs and displays) to be connected to the microcontroller and then write some software to manage the lot.

The space saving and cost effectiveness of these small wonders are reason enough to use them. But when you consider the flexibility they provide to adapt the control system to changes in the device or consumer demanded functionality they are indispensable.

Changes are simple: you change the software (which can often be done in-circuit) and the same hardware will perform the new task.

There are very few fields left in electronic engineering where microcontrollers have not made their mark. It is becoming more and more important to understand how microcontrollers work and how they are applied in designs – and how to develop and debug their software.

Fortunately, there are many sources on the Internet open to the engineer and hobbyist alike that provide free tools, examples and designs. Microcontroller manufacturers have lots of details in their datasheets and application notes, so that is a good place to start.

The counter circuits

The use of an ATMEL AVR microcontroller allows the circuit to be greatly simplified. A larger range of useful features can be provided than could be achieved with conventional logic circuits.

If we wanted to make a simple counter with conventional logic, we would need some components to condition the input and output signals, a counter for each digit (say a 74LS192 BCD Decade Counter), and then we would need to drive a 7-segment LED display using a BCD to 7-segment driver (74LS47). Straight away we have eight ICs (two per digit). Then we'd need some "glue logic" to hang everything together.

And we'd get a counter that can only count up. To fit this into a reasonable space we'd have to use a double-sided board with plated-through holes because of the large number of connections required between ICs.

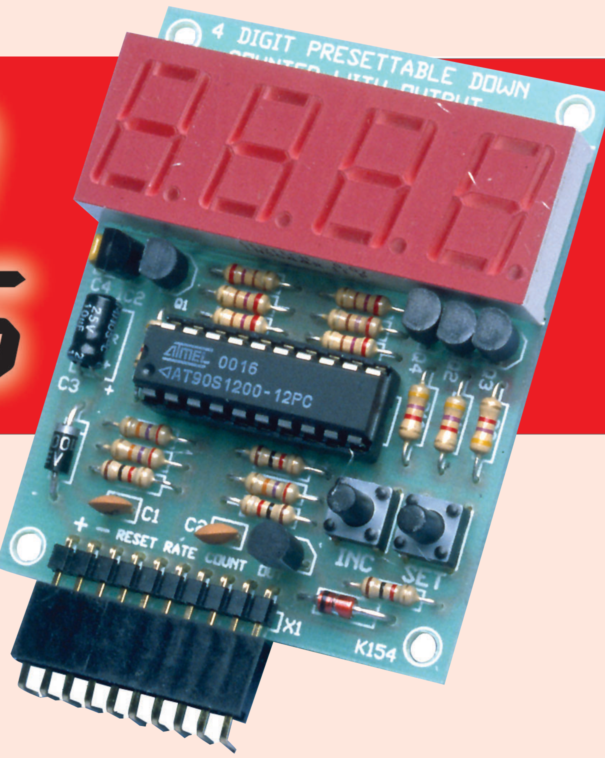
We might even need to go to surface mount components to reduce the size. It begins to get very expensive and complex, not to mention tedious (if not impossible) for the hobbyist to assemble.

(Yes, some hobbyists work with surface mount components but they are very much the exception to the rule!)

TECHNICAL SPECIFICATIONS – Up/Down Counter

Supply voltage	9-15V DC (<40mA @ 12V)
Operating modes	Count Up (default), Count Down, Count Disable, Overflow, Reset
Count range	0000 to 9999 or 0000 to 0001 (0000, 9999, 9998, ... 0001)
Count rate	Maximum count rate of 30 to 35 counts per second
Inputs	Reset, Count (negative edge triggered), Count down
Output	NPN Transistor,100mA @ 30V
Display	14mm red LED, 7-segment common anode
Physical size	51mm x 63mm
Connection	10-pin SIL header pins, 0.1"

ROLLER-BASED
NTER MODULES



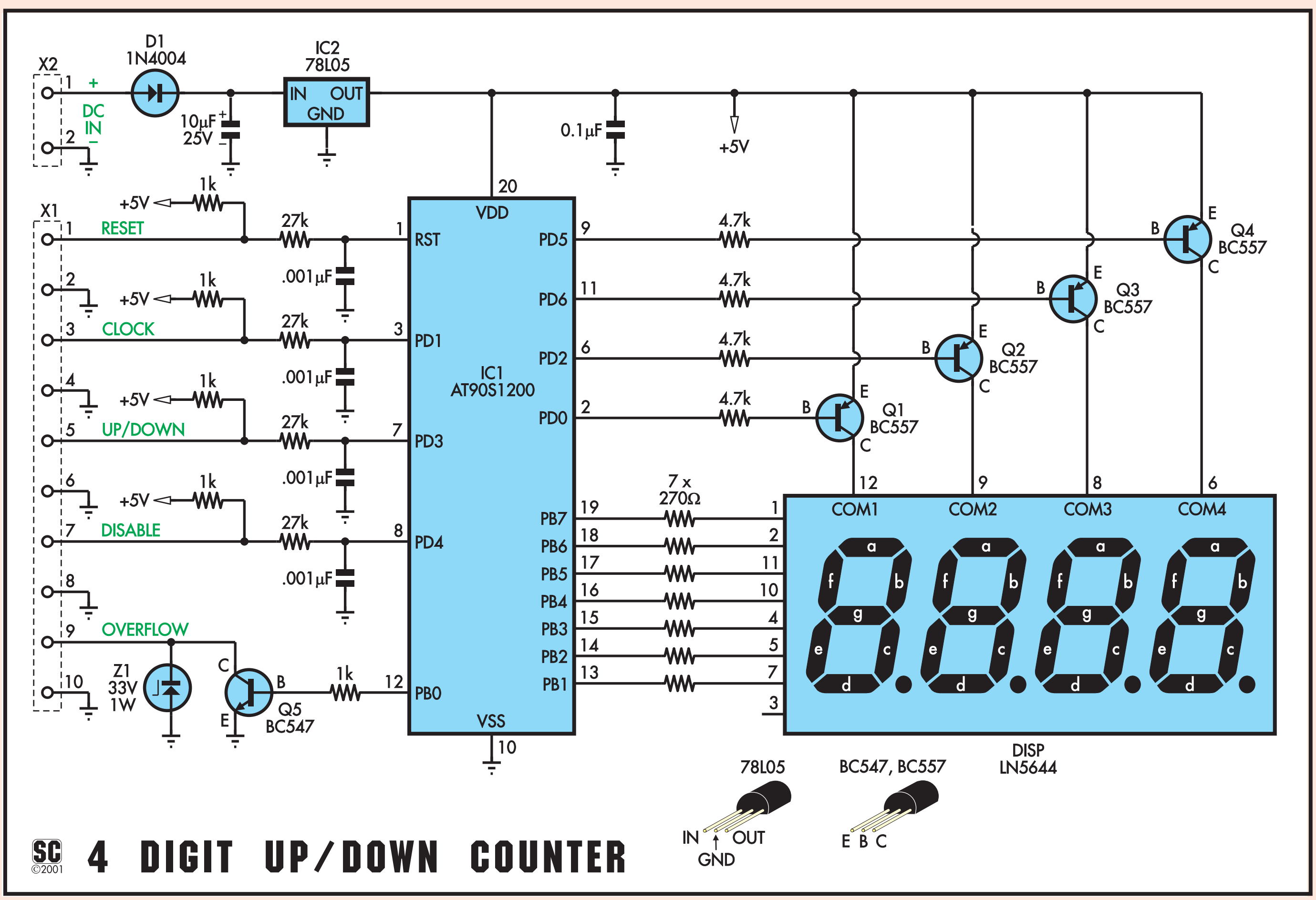
le, low-cost, four-digit counter modules.
and the other will count down in several
set value. The main difference between
are in the microcontroller.

roft and Frank Crivelli.

With the microcontroller solution presented here, this complexity is reduced to **one** IC only and a handful of discrete components to condition the input and output signals, all on a small (cheap!) single-sided PC board. All the hardware complexity has vanished into the software where finding and fixing errors is easy.

As we shall see, we also get the ability to change and add more useful features and modes of operation easily.

The Up/Down Counter has an overflow output, allowing multiple units to be "daisy-chained" together for greater counter range. The unit will count between 0000 and 9999, producing the overflow pulse when the



SC ©2001 **4 DIGIT UP/DOWN COUNTER**

Table 1: Up/Down Counter Inputs and Outputs	
Name	**Description**
Reset	Reset the current value of the counter to 0000.
Clock	Increment (or decrement) the value of the counter. If the counter rolls over to 0000, an overflow pulse is generated. The clock input is debounced in software to prevent extraneous counts when mechanical switches are used. This is achieved by ensuring a high to low or low to high transition remains valid for more then 15ms. This means the maximum count rate is around 30 counts per second. The count is triggered on a high-to-low transition (falling edge)
Down	Controls the direction of the counter. When unconnected, the counter will increment; when driven low (grounded) it will decrement.
Disable	When grounded, the counter will not count even if the clock input is being pulsed.
Overflow	This is an open collector output. When the count rolls over to 0000, it is pulled to ground by the circuit for approximately 25ms. This may be connected to the Clock input of the next module to create a counter with a larger range or used to drive a relay, indicator or other circuit.

count rolls over to 0000.

The Presettable Down Counter allows the user to program a starting count and select one of four different operating modes which determine what happens when the count reaches 0000.

Circuit description

The modules are almost identical; in fact the display driver, the power supply and the output are identical. The differences are confined to the inputs and their "meaning" to the microcontroller. Let's start by looking at the identical parts of the modules.

The counter modules are designed around an AT90S1200 AVR microcontroller from ATMEL *(http://www.atmel.com)*. A detailed product datasheet is available from this website.

This particular device was chosen because it has an internal R/C oscillator, eliminating the need for an external crystal. This simplifies the circuit and further reduces component costs.

The display unit is a 4-digit, common anode, multiplexed, 7-segment LED display. This means that the LEDs in a single digit share a common anode (positive) connection. The cathodes (negative) of the segments (a, b, … g & dp) are connected across the four digits, forming a matrix.

Multiplexing results in fewer connections and less board space being devoted to the display and reduces the number of microcontroller outputs required to drive the display. One negative is that the drive signals become more complex but this is relatively simple to achieve in the microcontroller's program.

Bits 1 to 7 of the microcontroller's Port B are connected via 270Ω current limiting resistors (R1-R7) to the shared segment pins. Four of the Port D bits are then connected to drive the four common anodes via Q1-Q4, the PNP transistors. Resistors R8-R11 (4.7kΩ) protect the transistors from excessive base current which otherwise could destroy them.

To display the current count, the microcontroller cycles through each of the four digits one at a time, providing current to the anode of the digit by turning on the appropriate transistor (driving the base low).

It then arranges for outputs connected to the segments it wishes to light to be driven low so that current can flow from the transistor, through the LEDs in the display and to ground via the microcontroller port. The segments it wishes to remain unlit are driven high.

After approximately 1ms, the display is extinguished and another 1ms delay occurs, then the next digit is lit. This then continues for the remaining digits and the cycle starts again.

Therefore it takes about 8ms to fully display the current count, which is much too fast for the human eye to discern, so to us it looks like a constant display.

The software programmed into the microcontroller uses a timer that triggers an interrupt about every 1ms to achieve this. When the interrupt occurs the next display is set up or the current display is extinguished. This allows it to be monitoring the inputs without constantly worrying about handling the display, simplifying the design of the software.

Transistor Q5, an NPN device, provides an active low open collector output for the overflow signal in the up/down counter version and the output signal in the presettable down counter version. The remaining bit (Bit 0) of Port B drives this transistor via R18, a 1kΩ resistor.

Q5 is protected by Zener diode Z1 which will break down and conduct if the voltage across Q5 exceeds 33V, or it will conduct if a negative voltage is

Table 2: Presettable Down Counter Inputs and Outputs	
Name	**Description**
Reset	Reset the current value of the counter to the preset value.
Count	Decrement the value of the counter. If the counter rolls over to 0000, the current operating mode determines the output pulse and new count value. For more information see "Using the Modules". The count is triggered on the high to low transition. Software debouncing is optionally applied to the count signal using the Rate input. If it is enabled, it is identical to the Up/Down counter.
Rate	Select if software debouncing is applied to the count input signal. If high (by default), debouncing is applied; if driven low (grounded), debouncing is not applied. This is useful if the count is derived from another logic circuit that doesn't exhibit extraneous pulses like a switch can do. If debouncing is disabled, the count input can be clocked a lot faster. Note that this input is not debounced at all as it is meant to be set permanently.
Output	This is an open collector output. When the count rolls over to 0000, the current operating mode determines what this output does.

applied to the collector. This is needed when driving inductive loads such as relays, as the back EMF generated by the collapsing magnetic field in the coil when the current is turned off can easily exceed the rating of the transistor and destroy it.

Power for the circuit is provided by an external 9-15V DC power supply and is regulated by IC2, C4 and C5, resulting in a 5V supply.

IC2 looks like another transistor but is a 78L05 low-current voltage regulator in a TO-92 case. This regulator needs about 2.2V of headroom (ie, voltage in minus voltage out) to ensure regulation.

Diode D1 provides reverse bias protection in case the power supply is connected the wrong way around. As there is about 0.6V or so drop across this diode, you must ensure that the voltage supplied to the circuit doesn't drop below about 8V (5V + 2.2V +0.6V ≈ 8V)

Now let's look at the input circuits for the different modules.

Up/Down counter

The Up/Down counter has four inputs and one output. These are detailed in Table 1.

TECHNICAL SPECIFICATIONS – Presettable Down Counter

Supply voltage	12VDC @ 50mA
Operating modes	Count Stop, Output Hold Over-Count, Output Hold Auto-Reset, One-Shot Output Over-Count, One-Shot Output
Count range	0000 to 9999 (10,000 max)
Count speed	Low (selectable) High 30 cps (15mS high, 15mS low) 30,000 cps (measured)
Inputs	Reset, Count, Rate
Output	NPN Transistor, 100mA @ 30V
Display	14mm red LED, 7-segment common anode
Physical size	51mm x 63mm
Connection	10 pin SIL header pins, 0.1"

The four inputs are all pulled high by the 1kΩ resistors and have a low pass filter formed by a 27kΩ resistor and .001µF capacitor to filter out high frequency noise from the line to reduce the chance of false triggers. This filter's time constant is approximately 20µs and any pulses shorter then this won't make it to the microcontroller. A 20µs time constant equates to a frequency of 50kHz. The inputs are also debounced in software with the level in the input needing to be constant for 15ms before it is recognised as a valid input.

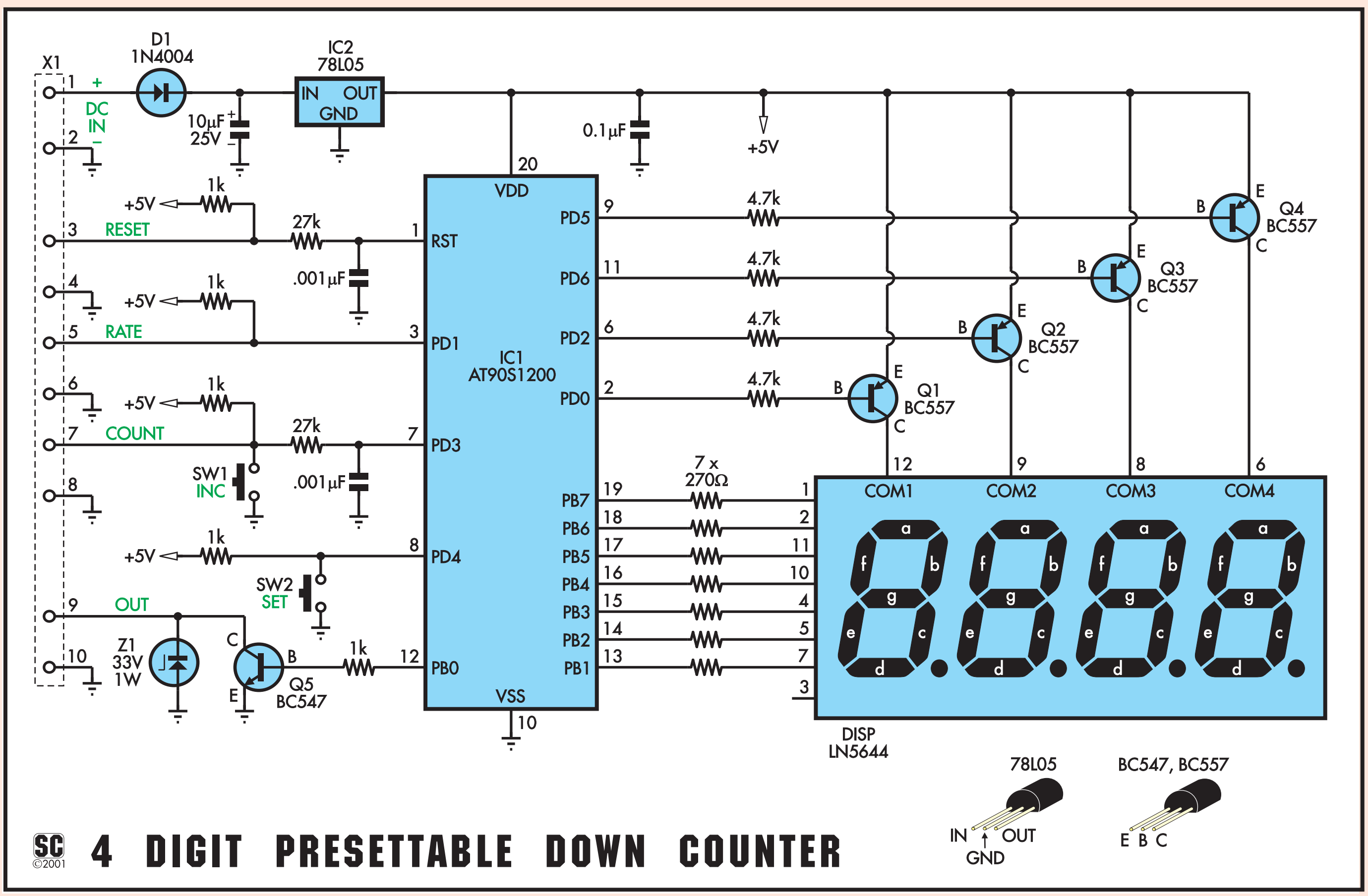
Presettable Down counter

The Presettable Down counter is a little more complex. It has two push-button switches added to its inputs. These are used to program the preset value and operating mode. This module has three inputs and one output, as detailed in Table 2.

Like the other module, the inputs are pulled high by 1KΩ resistors. The Count and Reset inputs have the same low pass filtering applied with the 27KΩ resistors and .001µF capacitors.

The SET switch (SW1) is connected directly to Port D, Bit 4 with a 1kΩ pull-up resistor. There is no need for filtering on this input as the microcontroller will debounce it in software.

The INC (SW2) switch is interest-



4 DIGIT PRESETTABLE DOWN COUNTER

Parts List - Up-down

1 PC board, 51 x 63mm, code K129
1 20 pin IC socket
1 set male and female 10 pin right angled connectors
1 2-pin SIL header

Semiconductors
1 AT90S1200-12PC preprogrammed microcontroller, (IC1)
1 78L05 5V regulator (IC2)
4 BC557 PNP transistors (Q1-4)
1 BC547 NPN transistor, (Q5)
1 1N4004 power diode (D1)
1 33V 1W zener diode (Z1)
1 LN5644R 4 digit, common anode LED display (DISP1-4)

Capacitors
1 .001µF ceramic (C1,2,3,6)
1 0.1µF monobloc (C4)
1 10µF 25V electrolytic (C5)

Resistors (0.25W, 5%)
4 27kΩ (R13,15,17,20)
4 4.7kΩ (R8-11)
5 1kΩ (R12,14,16,18,19)
7 270Ω (R1-7)

Parts List – Presettable

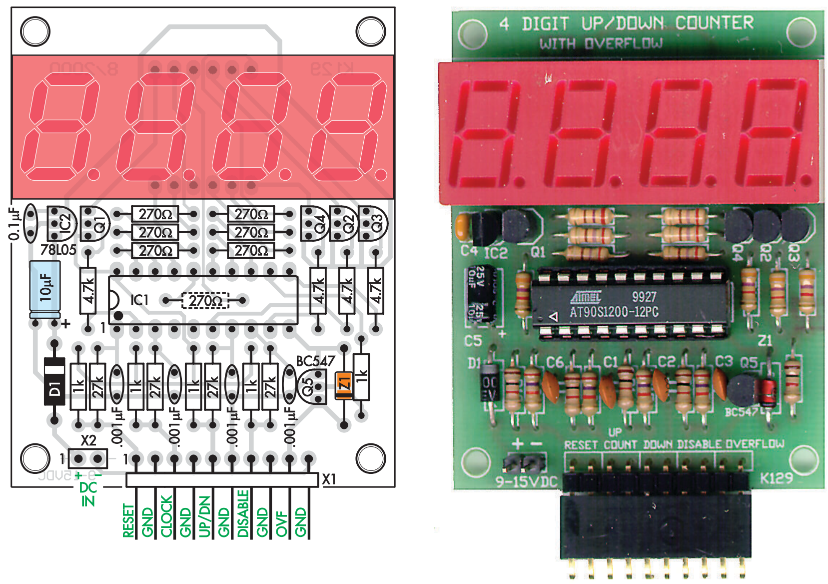
1 PC board, 51 x 63mm, code K54
1 20 pin IC socket
1 set male and female 10 pin right angled connectors
2 PC mount pushbutton switches (SW1, SW2)

Semiconductors
1 AT90S1200-12PC preprogrammed microcontroller (IC1)
1 78L05 5V regulator (IC2)
4 BC557 PNP transistors (Q1-4)
1 BC547 NPN transistor, (Q5)
1 1N4004 power diode (D1)
1 33V 1W zener diode (Z1)
1 LN5644R 4-digit, common anode LED display (DISP1-4)

Capacitors
2 .001µF ceramic (C1,2)
1 0.1µF monobloc (C4)
1 10µF 25V electrolytic (C3)

Resistors (0.25W, 5%)
3 27kΩ (R13,15,18)
4 4.7kΩ (R8-11)
4 1kΩ (R12,14,16,17)
7 270Ω (R1-7)

4-Digit Up-Down Counter



Here is the component overlay and and matching photograph of the 4-digit Up-Down Counter, reproduced same size so you can see exactly where all of the components go. Note the 270Ω resistor is mounted *under* the IC socket.

ing as it is shared with the Count input. This is an example of making efficient use of the available inputs. This can be done because in set-up mode, no counting in done. This also means that the INC button can be used to decrement the counter when it is running.

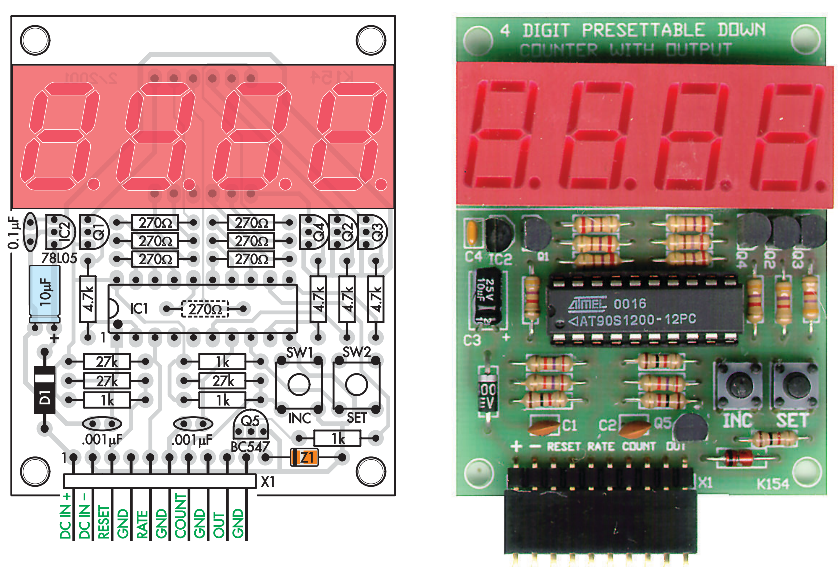
Software

The software listing for the microcontroller is not supplied, however this description is provided for those who are curious or want to have a go at creating their own.

The first thing the code does is set up all the inputs and outputs and initialises all the internal states. It then sets the count to the default value (0000 or the preset depending on the module) and starts the internal timer.

The timer is set to trigger an interrupt every 200µs (observant readers may notice I said 1ms earlier – I lied

4-Digit Presettable Down Counter



There's not a lot of difference between the Presettable Down Counter and the Up/Down Counter above . . . but there are differences! Follow this component overlay and photo and you shouldn't have any problems.

Table 3: Presettable Down Counter Modes

Name	Description
Mode A (Default)	**Count Stop, Output Hold.** When the count reaches 0000, the output goes low and stays low. The counter stops counting. The counter must be reset to continue counting again and to reset the output. When reset the count is set to the preset value.
Mode B	**Over-Count, Output Hold.** When the count reaches 0000, the output goes low and stays low. The count will wrap around to 9999 on the next count input and continue counting from there. The output will remain low until the module is reset.
Mode C	**Auto-Reset, One-Shot Output.** When the count reaches 0000, the counter automatically resets itself to the preset value and the output pulses goes low until the next count pulse occurs.
Mode D	**Over-Count, One Shot Output.** When the count reaches 0000, the output goes low until the next count pulse occurs. The count will wrap around to 9999 and continue

for simplicity).

When the interrupt occurs, the handler routine updates various internal counters used for debouncing inputs, output pulse timing and the display timer routines.

If any of these counters reach zero they need attention and are processed. For example, every 1ms the display routine is called to update the display.

The main loop constantly monitors the inputs and sets up the debounce counters when they change. If a valid clock pulse is detected and the count isn't disabled, a routine to either count up or down is called.

The count is stored as four binary coded decimal (BCD) values, so constant conversion is not required in the display driver routine.

This is updated by the count up or down routines and if the value changes to 0000, the overflow output of the counter is activated and a counter set up to turn it off in about 25ms. In the Presettable Down Counter, the output is determined by the current operating mode.

The display update interrupt routine uses a BCD-to-7-segment conversion routine to map the 0-9 value of the digit being displayed to the correct output for driving the segments in the display.

The Presettable Down Counter also has a set-up mode that is entered when a high-to-low transition is detected on the Set input. This allows the preset count value to be set one digit at a time and the mode to be selected.

Construction

Both kits include all components, a high quality PC board and a pre-program-med microcontroller. All you will need is a power supply and a clock source.

Start construction by separating out all the components into values, using the parts list as a guide. I'd suggest a fine conical tip on your soldering iron, as there are some small, closely spaced pads especially for the transistors. The PC board is very good quality and has a solder mask so it isn't too difficult to avoid solder bridges.

Start by installing the resistors. Pay particular attention to R4 as it is situated under the socket for the microcontroller. You may want to leave it until last and ensure the socket fits over it before soldering it and the IC socket in.

Next put in the capacitors, paying attention to C5 as it is polarised and laid over on its side. I'd suggest that you bend the leads at a right angle first and then insert it into the board and solder it, to avoid having the legs too short to bend over later.

Install the two diodes next, ensuring that the cathode (striped) end matches the stripe on the PC board overlay.

Now install the transistors and IC2. Don't get these confused, there are four BC557s (Q1-Q4), one BC547 (Q5) and the 78L05 (IC2). Use the outline on the PC board as a guide for orientation.

Q1-Q4 and IC2 are close together and close to the edge of the LED display so get them as low as possible and as straight as you can so they wont get in the way. Double check that you don't have any solder bridges across the transistor pins as they are close together.

If you're building the Presettable Down Counter, install the two switches. They will fit with the pins coming out towards the display and the connector.

Install the LED display; the decimal points go towards the microcontroller. Then install the 2-pin header for power (Up/Down Counter only) and the 10-pin 90° header for the inputs and outputs. The kit also includes a socket for this header; this doesn't mount on the PC board but can be used to make connections to the completed module.

Carefully install the microcontroller into its socket (noting its polarity) and assembly is finished. After checking your board, apply power and you should see 0000 displayed (this is the power-on default for both modules. If you short the two count pins (or press the Inc button on the Presettable Down Counter) the display should increment (or decrement).

If it doesn't work

Poor soldering (dry joints) is the most common cause of problems. Check all your joints under a good light; they should all be smooth and shiny. Resolder any suspicious ones. Keep an eye out for solder bridges and for any pads that you may have forgotten to solder as well.

Make sure that you inserted the diodes the correct way and that the microcontroller is also the correct way around and securely sitting in the socket. Also check the orientation of electrolytic capacitor C5. Make sure that you didn't mix any of the transistors up and that they are in their correct places and the right way around – including the voltage regulator.

Use a multimeter to check the supply voltage. Measure it from the cathode (stripe end) of D1 and 0V. It should be at least 8V or the 5V regulator will

Table 4: Resistor Colour Codes

	No.	Value	4-Band Code (5%)
❏	3	27kΩ	red violet orange gold
❏	4	4.7kΩ	yellow violet red gold
❏	4	1kΩ	brown black red gold
❏	7	270Ω	red violet brown gold

have difficulties and not operate correctly. The voltage from the output of the regulator should be within a few tens of millivolts of 5V.

If it's much lower, then you probably have the regulator in back-to-front or something (such as a solder bridge or misplaced component) is causing too much current to be drawn from the regulator, shutting it down. If it's much higher, check for a solder bridge across the regulator pads (or the regulator itself might be shot).

Using the modules

The counter module has three or four inputs and one output that are accessed via a 10-way header. The input lines are all active low, which means that grounding them performs their function. More correctly, each of the inputs is normally pulled high by the module circuitry and must be pulled low to become active.

Each of the lines has a corresponding ground pin beside it, simplifying the connection to a switch. The input lines may be connected to simple 'make' contacts, switches, relays or even open collector outputs from other circuits.

The module requires a 9 to 15V DC power supply and consumes between 20mA and 40mA, depending on the number being displayed. A small plugpack will easily supply enough power for several modules. Alternatively, the module could be battery powered.

The Up/Down Counter is fairly straightforward. Just connect a switch to the count input and set the direction on the Down input and you're ready to go. However, the Presettable Down Counter, is a little more complex.

Connect the count input and output as needed, and then apply power to the unit. By default, it will display 0000. It will overflow to 9999 and continue counting down with clock inputs until it reaches 0000 again. This is Mode A and it is the default mode. A description of each of the modes is given in Table 3.

The two pushbuttons marked, SET and INC are used to configure both the preset value and the operating mode. The preset value is entered one digit at a time starting at the thousands and then the Mode is selected.

To enter the programming mode, press the SET button. The display will show the preset value for the thousands digit and the rest of the display shows a minus (-) sign. Use the INC button to select the required value then press the SET button to advance to the next digit.

Continue setting each of the preset digit values unit the last one is set. The display will now show the current operating mode with the letters A, b, C or d. Use the INC button to select the desired mode and press the SET button to accept it. This will also exit programming mode and the counter is ready for use.

Software flexibility

To illustrate the power of using a microcontroller versus discrete logic circuit the following "user requested" modifications have been made to the Up/Down counter at no cost to the user since the change was very easy to do in software (note these changes are not included in the kit software – they are mentioned only to illustrate the ease of change).

1. Count by five instead of by one.
2. Show digits "upside down" so the PC board could be placed in a predesigned box upside down.
3. Only display digits on a "keypress" so that the kit could be more efficiently battery powered.

These were done by simply changing the software. Try doing that with discrete logic circuits!!!

Further information

The following may be good starting points to find more information:

- ATMEL (makers of the microcontroller used in this project) have a website at ***www.atmel.com*** There you will find data-sheets for all their micro-controllers with detailed information about using and programming them.
- DIY Electronics (the kit manufacturer for this project) have a website at ***http://kitsrus.com***

They also have an AVR Programmer kit (Kit 122) and BASCOM Basic Compiler which are useful for people wishing to experiment with AVR micro-controllers.

PROGRAMMING THE DOWN COUNTER

Two pushbutton switches, marked "SET" and "INC", are used to preset the starting count and select the operating mode. Presetting the count value is done one digit at a time, starting with the thousands digit.

Press the SET button to enter programming mode. The display shows the current preset value of the thousands digit and the rest of the display shows minus (–) signs. Use the INC button to set the value required. Press the SET button when done.

The current preset hundreds digit is shown. Use the INC button to set the value required. Press the SET button when done.

Repeat the above steps for the tens and units digits.

After setting the units digit the display shows the current operating mode. The mode is indicated by the letters "A, b, C or d". Use the INC button to set the operating mode then press SET to exit programming mode. The display will blank momentarily to indicate that programming mode has ended.

The counter is now ready for use.

As mentioned before the RESET input resets the counter to its preset value. It does not change the operating mode. If the counter loses power it will restart in Mode A with a preset value of "0000" (count = 10,000).

Questions or comment about the Kit can be directed to Peter Crowcroft, ***peter@kitsrus.com***, while technical questions may be directed to the kit's designer, Frank Crivelli, ***frank@ozitronics.com***

Kit availability

A kit of parts for either of these kits may be obtained from Jaycar Electronics stores, Jaycar mail order or via their online store at www.jaycar.com. au.

Both kits sell for $39.95.

The 4-Digit Up/Down Counter is Cat No KD-6084, while the 4-Digit Presettable Down Counter is Cat No KD-6058. SC