

External Brown-out Protection for C51 Microcontrollers with Active High Reset Input

Features

- Low-voltage Detector
- Prevents Register and EEPROM/Flash Corruption
- One Discrete Solution
- Integrated IC Solution
- Low-power/Low-cost Solution
- Formulas for Component Value Calculations
- Complete with Sample Schematics

Introduction

This application note shows in detail how to prevent system malfunction during periods of insufficient power supply voltage. It describes techniques to prevent the MCU from executing code during periods of insufficient voltage by using external low voltage detectors. These events are often referred to as "Brown-outs", where power supply voltage drops to an insufficient level, or "Black-outs" where power supply voltage totally disappear for a period of time.

One discrete solution is discussed in detail, allowing the user to calibrate the system requirements. A complete guide to Integrated Circuit (IC) solutions is also included. By implementing these techniques, the following can be prevented:

- MCU Register Corruption
- I/O Register Corruption
- I/O-pin Random Toggling
- On-chip Memory Corruption (SRAM, EEPROM, Flash)
- External Memory Corruption

C51 Microcontrollers

Application Note



RST Pin Description

A high on the RST pin for several machine cycles while the oscillator is running, resets the device. An internal resistor to V_{SS} permits a power-on reset using only an external capacitor to V_{CC} . While this pin is forced high, the MCU Core is halted from executing code, the peripherals are stopped and the I/Os are tri-stated.

The RST pin is an output when the Hardware Watchdog Timer times out and forces a system reset. When Watchdog Timer overflows, it drives an output RST HIGH pulse at the RST pin. When the watchdog is used, a resistor R_{rst} mounted in serial with the external capacitor C_{rst} or reset circuit is necessary to allow the Hardware Watchdog to drive the RST pin.

Theory of Operation

For the MCU to successfully decode and execute instructions, the supplied voltage must always stay above the minimum voltage level specified by the product datasheet. When supplied voltage drops below this level, the MCU might to execute some instructions incorrectly. The result is unexpected activity on the internal data and control lines. This activity may cause MCU Registers, I/O Registers and Data Memories to get corrupted.

To avoid unexpected activity, the MCU should be prevented from executing code during periods of insufficient supply voltage. This is best ensured by using a Power Supply Low Voltage Detector. Below a fixed threshold voltage V_T , the detector circuit forces the RST pin high (active). Forcing RST high immediately stops the MCU from executing code. While the supplied voltage is below the required threshold voltage V_T , the MCU is halted, making sure the system stays in a known state. When the supplied voltage rises above this predefined voltage, the RST pin is again released, and the MCU starts to execute code beginning at the Reset Vector.

Preventing SFR Corruption

When the Detector keeps the MCU in Reset, all MCU activity is halted. When released from Reset, all the Special Function Registers (SFRs) are in their default state.

Without a Detector, random MCU activity such as described before might cause the Special Function Registers to get corrupted. See "Volatile Memory" below.

Preventing I/O Register Corruption

When using a Detector to keep the MCU in Reset, all I/O Registers are kept in their default state for the duration of the reset. Consequently, all on-chip peripherals will stay in their reset state.

Without a Detector, random MCU activity such as described before might write an unknown value to any I/O Register. This may cause unexpected behavior of the on-chip peripherals.

Preventing I/O Pin Random Toggling

A Detector will keep the MCU in Reset, and all I/O pins are kept in their default state for the duration of the Reset.

Without a Detector, random MCU activity such as described before might write a random value to the I/O Registers. This may cause random toggling of the I/O pins.

Preventing Volatile On-chip Memory Corruption

Using a Detector to keep the MCU in Reset, there will be no access to the volatile on-chip memory. The memory will keep its present content for the duration of the Reset.

Without a Detector, random MCU activity such as described in the introduction may write an unknown value to any volatile on-chip memory location.

Preventing External Components Corruption

Using a Detector to keep the MCU in Reset, prevents access to the external components such as memories, peripherals, latches, etc. These components will keep their contents or status for the duration of the Reset.

Without a Detector, random MCU activity could write an unknown value to any External Components address (SRAM locations, peripheral command registers, etc.).

Preventing Non volatile On-chip Memory Corruption

Non volatile memories such as EEPROM, and Flash are designed to keep their contents even when power is completely removed from the system. By the use of a Detector to keep the MCU in Reset, activity on the control lines ceases. The memory contents are then prevented from unintentional writes from the MCU for the duration of the Reset.

Without a Detector, random MCU activity could initialize an unintended write to the non-volatile memory. This may cause random corruption of the memory contents. Since the C51 MCU is capable of writing to its own program memory, the internal Flash Program memory contents could be affected by a power failure situation.

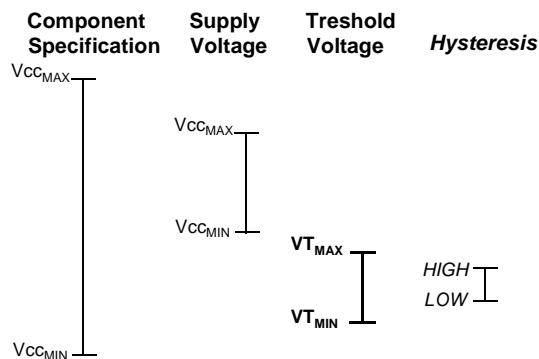
- Notes:
1. For any write to non volatile memory, a minimum voltage is required to successfully write the new values into the memory. If supplied voltage at any time during the write cycle drops below the minimum voltage, the write might fail, corrupting the location written to.
 2. When the reset activates during a write to the internal EEPROM, the operation is aborted. The result can be seen when the location being written get corrupted.

Design Criteria

Threshold Voltage

It is recommended to set the threshold voltage below minimum V_{CC} to allow for small fluctuations in supplied voltage (VT_{MAX} must be less than "Supply Voltage Min"). The threshold voltage should always be selected to ensure that the Detector keeps the device properly reset when supply voltage drops below the critical voltage required by the MCU (VT_{MIN} must be greater than "Component Specification V_{CC} Min"). Care should be taken to ensure sufficiently high detector threshold voltage even in worst case situations. See Table 4 on page 14 for examples.

Figure 1. Threshold Voltage Choice



Hysteresis

Hysteresis is the difference in the voltage between the positive-going switching threshold and the negative-going switching threshold. Without hysteresis, it is possible that system or environmental noise could cause a rising signal to toggle from low to high, then high to low again in immediate succession. Hysteresis must ensure that any noise on the V_{CC} input is unable to cause a rising RST signal to toggle once it has gone from low to high or a falling RST signal to toggle once it has gone from high to low. Typical values for hysteresis are 0.2 - 0.3V, it must be selected according to V_{CC} characteristics. The hysteresis thresholds must be contained between VT_{MIN} and VT_{MAX} .

Operating Voltage Range

Carefully monitor the MCU since it can operate with a supply voltage below its V_{CC} min. However, its behavior may be erratic. The MCU oscillator can run with a supply voltage near 1 volt. Under these conditions, the Brown-out circuit must generate a valid RST signal.

Output Transition Delay

Output transition (propagation delay and slew rate) must be fast enough to stop the MCU before it causes memory corruption or unexpected behavior of peripherals.

Implementation

A variety of Integrated Circuit (IC) solutions are available from different manufacturers. These solutions offer high accuracy at a low price, typically they guarantee the threshold voltage to be within $\pm 1\%$. Although the elementary three-pin fixed voltage detector is available, there is also a whole range of devices offering additional features such as Reset Pulse stretching, Power-on Reset Time-out, Watchdogs, Power regulation, dual supply switching for uninterruptible Power Supply operation and more. Included in this application note is a guide to integrated circuit solutions available. As an alternative, this application note also presents one discrete Low-power Supply Voltage RESET Detector.

- Alternative 1: Minimum Power Consumption. Well-suited for battery-powered applications where power consumption is the most critical parameter.
- Alternative 2: High accuracy, low-power consumption using commercial semiconductor ICs.

Design Hint: Supply Voltage Filtering, Oscillator Stability

Use low impedance capacitors (low ESR and ESL) on the V_{CC} and multi-layer PCB with power planes to improve transient rejection from the power supply.

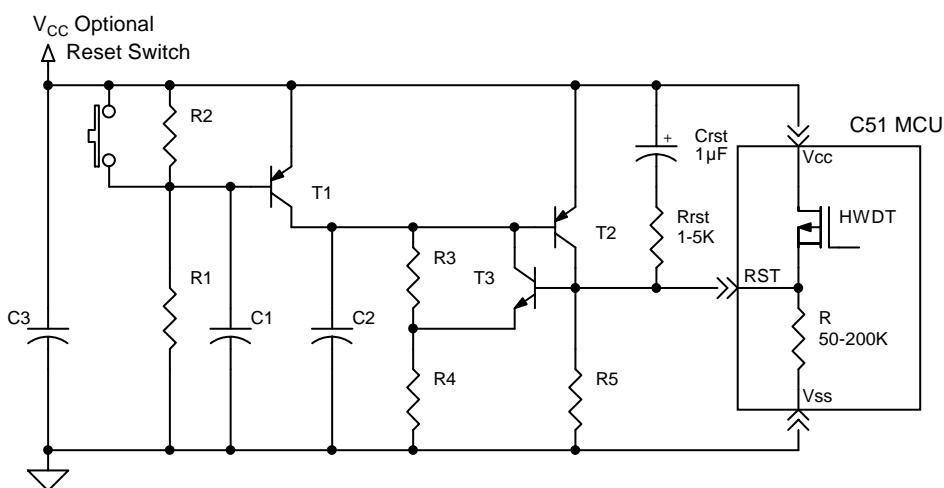
To provide good MCU startup, the oscillator must be stable for several cycles before releasing the RST signal (refer to the device documentation).

Alternative 1: Low-power Consumption

Characteristics

- Very Low-power Consumption, (Typ 0.5 μ A@3V, 1 μ A@5V)
- Low-cost Solution
- Large Hysteresis, Typ. 0.3 Volts
- Fast Output Transitions
- Accuracy \pm 5 - 10%
- High Component Count
- Long Response Time against V_{CC}

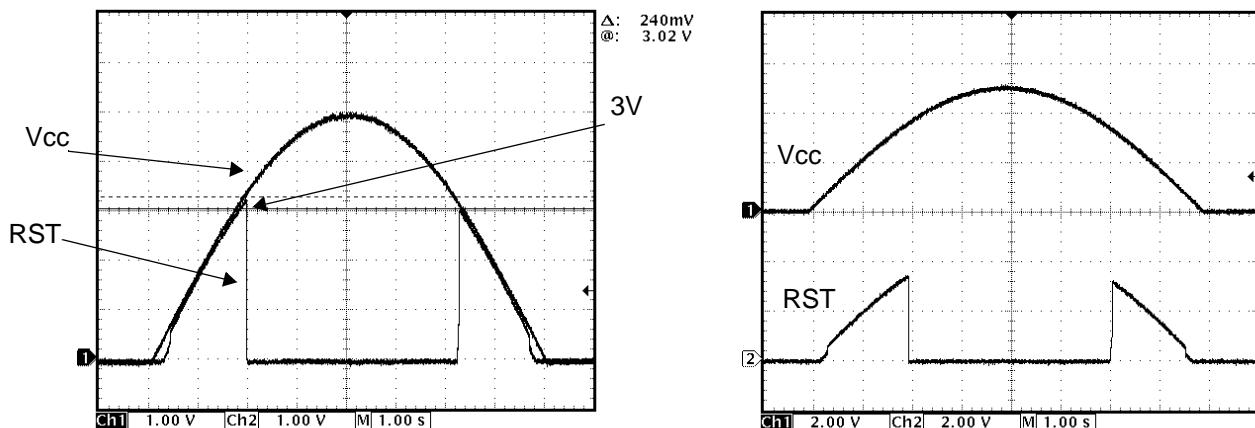
Figure 2. Low-power Consumption Brown-out Detector ⁽¹⁾⁽²⁾



Notes:

1. Refer to the component specifications, some products such as T89C51CC02 have an extended tolerance range from 20K to 200K.
2. HWDT: Hardware Watchdog Timer

Figure 3. Oscilloscope Plots Show how the Voltage on RST Varies with V_{CC}



Introduction

The circuit shown in Figure 2 on page 6 benefits from low-power consumption, which makes it suitable for battery operated applications. Standard discrete components provide a low cost design.

The voltage transition on the RST pin is very steep. Combined with the large hysteresis, the accuracy is high. However, the response time is slow, which makes it unsuitable for rapidly varying supply voltages.

Theory of Operation

The Brown-out Detector has two stages, the Detector and the Amplifier. In the Detector stage, the threshold voltage is set by the resistors R1 and R2 in relation to the critical voltage of transistor T1. Under normal operation, this transistor is conducting. When the supply voltage drops below the threshold voltage, the transistor shuts off.

The output from this Detector leads to the input of the ultra low power Amplifier stage. Under normal operation, the low voltage of the base of transistor T2 causes it to remain shut, allowing resistor R5 to pull the RST input low. The Amplifier stage also contains a hysteresis feedback loop through transistor T3, short-circuiting a resistor R3 in the amplifier when the RST output is kept high.

Selecting Components

T1, T2, and T3

The production spread of current gain β (or h_{FE}) in transistor T1 affects the threshold voltage V_T (typically ± 0.2 volts). Most small signal transistors can be used, but low production spread transistors are recommended.

CAUTION: If transistor T1 is changed from one type to another. The emitter-base threshold voltage of T1 affects the constant (V_{BE}) in the equation for threshold voltage (below). As a consequence, a change of transistor could cause a change in the threshold voltage of the detector, which requires the voltage divider $R1 + R2$ to be recalculated.

R1 and R2

R1 and R2 form a voltage divider that defines the threshold voltage V_T . As the threshold voltage depends on these resistors, it is recommended to choose resistors with 1% tolerance or better. See "Noise Sensitivity".

R1 is usually chosen equal to $10\text{ M}\Omega$ to ensure the lowest power consumption possible. R2 is then found by the equation below. The constant (V_{be}) in the equation may vary slightly with variations in transistor T1:

$$V_T = (R1 + R2) \cdot \left(\frac{V_{be}}{R2} \right), \text{ or } R2 = \frac{V_{be} \cdot R1}{V_T - V_{be}}$$

Note: V_{be} is the T1 base to supply voltage and typically it equals 0.4V to 0.6V.

R3

R3 is a non-critical pull-up resistor that has very little influence on the threshold voltage. It should be selected as large as possible to minimize power consumption. A resistance of R3 greater than $10\text{ M}\Omega$ is not recommended, see "Noise Sensitivity" below.

R4

Resistor R4 defines the hysteresis of the threshold voltage (V_T). By choosing R4 to $3.3\text{ M}\Omega$, the resulting hysteresis will be approximately 0.3 volts. A smaller R4 will give a larger hysteresis, a larger R4 gives smaller hysteresis. A larger R4 will also result in a less sharp transition in the output slope of the RST signal. Large deviations from the recommended value will eventually alter the constant V_{BE} in the threshold voltage equation above. As the hysteresis is only slightly changed with variation in R4 resistance, the accuracy is not critical.

R5

Resistor R5 pulls the RST pin low in normal operating mode. A value in the range of 100 kΩ is recommended to tie RST securely to GND. As no current goes through this resistor in normal operating mode, its value and accuracy is of little importance. When RST is pulled high, this resistor will start conducting a relatively large current.

C1 and C2

Capacitors C1 and C2 reduce RF noise picked up in the circuitry and amplified by the transistors. Both capacitors can be omitted, but a value greater than 1 nF is recommended. For maximum noise immunity, 100 nF (LF) or capacitors with lower ESR (HF) should be selected when possible. Also see "Response Time" below. The accuracy is not critical, but to ensure proper RF decoupling, the capacitors should have Z5U dielectric or better.

C3

Capacitor C3 decouples the power lines. It can be omitted if there is RF decoupling of the power lines somewhere nearby on the circuit board, otherwise 1 nF is recommended. For maximum noise immunity, 100 nF (LF) or low ESR (HF) should be selected.

Crst

Capacitor Crst (typically 1 μF) from the RST pin to the V_{CC} supply rail is the simplest way to achieve a reset time of approximatively 100 msS. This reset time is dependant on the sink current defined by the microcontroller (refer to the device specification). Crst must be selected to ensure that the RST signal is high during at least two machine cycles after the power on (refer to the device specification).

Rrst

Rrst is necessary when the Hardware Watchdog of the MCU is used. It allows the MCU to drive the RST pin high and it limits the output current of the RST pin. The recommended value is 1 to 5K.

Reset Switch/In-System Programming

If a push button reset is required, it is simply connected in parallel as shown in Figure 2. As the switch/programmer will pull RST high, power consumption in R5 will be relatively high for the duration of the event. Also see "Power Consumption".

Response Time

Choosing large values for capacitors C1 and C2 will slow down the circuit's response time. This is not a problem with battery driven applications where the supply voltage decreases slowly over time. Although the response time also applies to the time immediately following power-on. This could affect operation when a flat battery is loaded. When power can drop more rapidly, the long response time due to C1 and C2 should be taken into consideration.

Noise Sensitivity

Choosing values of R1 and R3 greater than 10 MΩ is not recommended, as it makes the circuitry sensitive to thermal noise generated in the resistor. When noise is not critical, the values of R1 and R3 can be raised to 20 MΩ. Choosing larger values will result in the resistors not conducting sufficient current, giving in a non-functional Detector. If more noise immunity is required, these resistors can be reduced with smaller ones, at the expense of increased power consumption.

Capacitors C1, C2 and C3 are decoupling capacitors to minimize noise sensitivity to both RF and 50/60 Hz fields. They can all be omitted, but the noise immunity greatly depends on the values selected.

Threshold Accuracy

Because the threshold voltage is defined mainly by R1 and R2, inaccuracies in these resistors directly influence the threshold voltage accuracy. It is recommended to choose these with $\pm 1\%$ tolerance.

Power Consumption

The current consumption in normal operating mode (sufficiently high V_{CC}) is found by:

$$I \approx \left(\frac{V_{CC}}{(R1 + R2) \parallel (R3 + R4)} \right) = V_{CC} \left(\frac{1}{R1 + R2} + \frac{1}{R3 + R4} \right)$$

When reset switch or programmer force RST to GND, the current increases to:

$$I \approx \frac{V_{CC}}{(R1 + R2) \parallel (R3 + R4) \parallel R5 \parallel R_{RESET}}$$

When voltage drops to the level where the detector activates, transistor T1 closes, T2 opens and the current is:

$$I \approx \frac{V_{CC}}{(R1 + R2) \parallel R5 \parallel R_{RESET}}$$

As resistor R5 is usually chosen much smaller than the other resistors R1-R4, the last two expressions both simplify to:

$$I \approx \frac{V_{CC}}{R5 \parallel R_{RESET}}$$

Note: The \parallel operator indicates resistors are parallel.

Table 1. Example Values when MCU RST Internal Pull-down is in the Range 50 - 200K

Component	Example Values		Recommended Tolerance
	3.0V	4.5V	
T1, T2	BC558/BC888/2N3906		$I_{CE} \geq 2.5 \text{ mA}, V_{CE} \geq 8 \text{ V}, \beta/h_{FE} \geq 100$
T3	BC548/BC848/2N3904		$I_{CE} \geq 2.5 \text{ mA}, V_{CE} \geq 8 \text{ V}, \beta/h_{FE} \geq 100$
R1	10 M Ω		$\leq 1\%$
R2	1.54 M Ω	976 k Ω	$\leq 1\%$
R3	6.8 M Ω		$\leq 20\%$
R4	3.3 M Ω		$\leq 20\%$
R5	100 k Ω		$\leq 20\%$
C1, C2, C3	100 nF		$\leq 20\%, Z5U$ dielectric or better

In Table 1 the values are calculated to minimize the power consumption.

In Table 2 the transistor T2 can source more current. The V_{be} constant is approximately 0.5V.

Table 2. Example Values when MCU RST Internal Pull-down is in the Range 20 - 200K

Component	Example Values		Recommended Tolerance
	3.0V	4.5V	
T1, T2	BC558/BC888/2N3906		$I_{CE} \geq 2.5 \text{ mA}$, $V_{CE} \geq 8 \text{ V}$, $\beta/h_{FE} \geq 100$
T3	BC548/BC848/2N3904		$I_{CE} \geq 2.5 \text{ mA}$, $V_{CE} \geq 8 \text{ V}$, $\beta/h_{FE} \geq 100$
R1	6.04 MΩ	6.19 MΩ	≤ 1%
R2	1.3 MΩ	820 kΩ	≤ 1%
R3	1.5 MΩ		≤ 20%
R4	510 KΩ		≤ 20%
R5	100 kΩ		≤ 20%
C1, C2, C3	100 nF		≤ 20%, Z5U dielectric or better

Alternative 2: Integrated Circuit Solutions

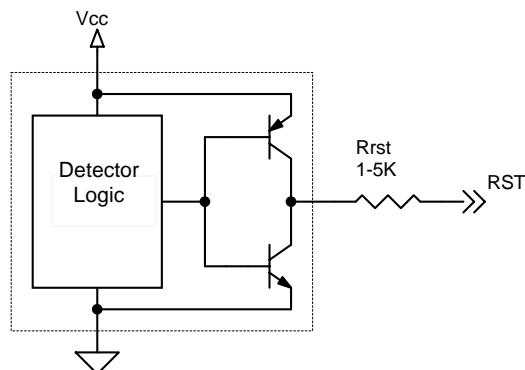
Characteristics

- Easy to Mount
- Very Accurate Threshold Voltage
- Low Power Consumption
- Small Footprint
- Low Component Count
- Wide Variety of Additional Functionality

Introduction

A selection of integrated circuits is available from various semiconductor suppliers. They vary from simple 3-pin fixed voltage detectors to advanced circuitry containing Watchdog Timers and Power-on Reset (POR) Time-outs. Because some C51 MCUs have built-in Watchdog and POR circuitry, these functions do not need to be handled by the external IC. The threshold accuracy is better than $\pm 1\%$ for most circuits. Current consumption is in the μA range. Make sure to choose a device with an active high output. A wide variety of package types are available, ranging from miniature 3-pin SOT-23 to large packages with high-pin count.

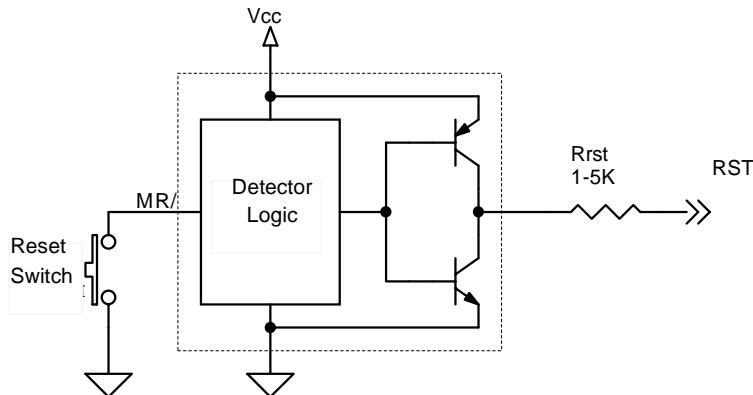
Figure 4. Detector with Push-pull Output



Output Driver

Generally, a standard IC has push-pull Reset output, either CMOS or TTL output levels. A manual reset button can be implemented with this type of output, with the addition of a resistor in series with the output. The manual button is connected between the resistor Rrst and the RST pin (see Figure 4). This resistor is also necessary when the Hardware Watchdog of the MCU is used. An alternate location for the reset button is given on Figure 5.

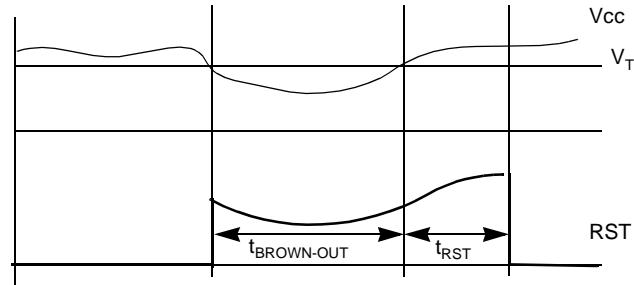
Figure 5. Optional Location of Manual Reset Switch



Reset Pulse Stretching

An additional feature in some of these circuits is stretching of the reset pulse. The Reset is held active for a defined amount of time after the condition (Power-on Reset, Brown-out Reset, etc.) that caused the reset has disappeared (see Figure 6). Some of these devices also provide this feature for the Manual Reset. The device senses the output level, detects the closing and opening of a reset button. When the button is released, the device keeps the RST line active for an additional amount of time.

Figure 6. Reset Pulse Stretching



Power Regulator

Several integrated power regulators include the Low-voltage Detector, combining both functionalities in one device. This reduces part count, and often adds the functionality at no extra cost.

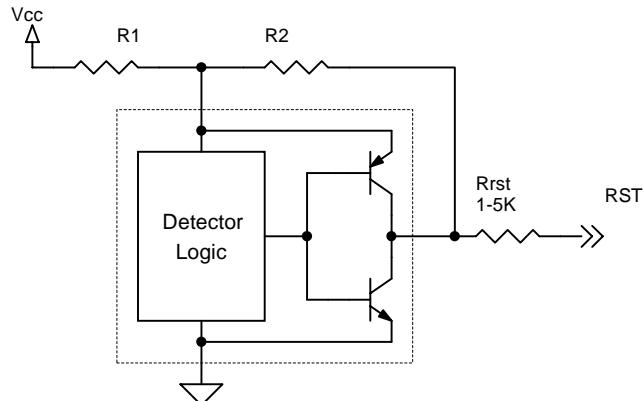
Battery Backup Solutions

Some systems contain a battery to supply power when the main power drops. The power regulator in such systems often provides a status signal to the MCU telling which source currently supplies power to the circuit. Connecting this signal to an input pin, the C51 MCU can detect the event and execute a safe power-down sequence, switching off power hungry peripheral equipment (motor, display etc.) before entering Power-down mode. When main power supply voltage returns to an acceptable level, the C51 MCU should detect the event, wake up and resume execution where it left off.

Hysteresis

Hysteresis in the Low-voltage Detector might be implemented in the integrated circuit, or can be added with external circuitry (Figure 7). This prevents the detector from oscillating when used in battery applications.

Figure 7. Adding Hysteresis to Threshold Voltage

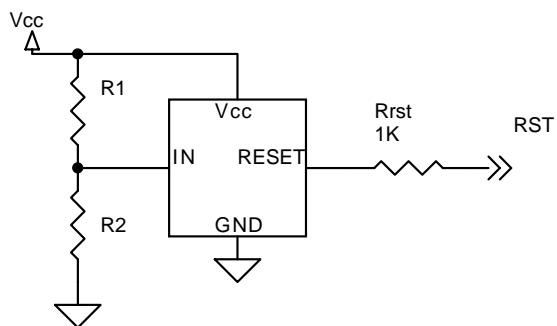


Fixed/Adjustable Threshold Voltage

Some circuits offer the threshold voltage V_T to be tuned by external components, while others have a preset threshold voltage reference. The use of a fixed threshold voltage IC is shown in Figure 8.

The typical connection for externally tuned threshold voltage is shown in Figure 8. This device offers an internal voltage reference and a comparator. If the voltage at the input pin is higher than the reference voltage, the output will be activated. The threshold voltage is easily defined by a voltage divider, R1 and R2.

Figure 8. Integrated Reset Circuit with Preset Threshold Voltage



Operating Voltage

The Brown-out device should guarantee the generation of an active RST signal when the supply voltage is out of the operating voltage range of the MCU and while an activity of the MCU is possible. See “Operating Voltage Range” on page 4.

Table 3. Example of Integrated Circuit Devices

Device	Features
MAX810/LM810/ADM810 ⁽¹⁾	Fixed Threshold Voltage, Fixed Pulse Stretching
MAX812 ⁽¹⁾	Fixed Threshold Voltage, Fixed Pulse Stretching, Low Power, Manual Reset Input
MAX822 ⁽¹⁾	Fixed Threshold Voltage, Adjustable Pulse Stretching, Low Power
DS1812 ⁽²⁾	Fixed Threshold Voltage, Fixed Pulse Stretching
DS1813/18 ⁽²⁾	Fixed Threshold Voltage, Fixed Pulse Stretching, Feedback Monitor
V6301 ⁽³⁾	Fixed Threshold Voltage, Fixed Pulse Stretching, Low Power
TLC7703/33/05 ⁽⁴⁾	Fixed Threshold Voltage, Ajustable Pulse Stretching

Notes:

1. Maxim Integrated Product, Inc./ON Semiconductors/National Semiconductor/Analog Devices
2. Dallas Semiconductors.
3. EM Microelectronic-Marin SA.
4. Texas Instruments

Table 4. Threshold Voltage Example Values

Component	Component Specifications	Nominal Power Supply	Regulator Examples	Threshold Voltage Range Possibilities	Brown-Out IC Example
AT89C51RB2/RC2-M	$V_{CCMIN} : 2.7V$ $V_{CCMAX} : 5.5V$	3.3V	LM1086-3.3 : $V_{OUTMIN} : 3.235V$ $V_{OUTMAX} : 3.365V$	$VT_{MAX} > 2.7V$ $VT_{MAX} < 3.235V$	ADM810T $VT_{MAX} = 3V$ $VT_{MAX} = 3.15V$
		5V	MC7805 : $V_{OUTMIN} : 4.75V$ $V_{OUTMAX} : 5.25V$	$VT_{MAX} > 4.5V$ $VT_{MAX} < 4.75V$	ADM810L $VT_{MAX} = 4.5V$ $VT_{MAX} = 4.75V$
T89C51RD2-M	$V_{CCMIN} : 3V$ $V_{CCMAX} : 5.5V$	5V	MC7805 : $V_{OUTMIN} : 4.75V$ $V_{OUTMAX} : 5.25V$	$VT_{MAX} > 3V$ $VT_{MAX} < 4.75V$	ADM810M $VT_{MAX} = 4.25V$ $VT_{MAX} = 4.5V$
T89C51RD2-L	$V_{CCMIN} : 2.7V$ $V_{CCMAX} : 3.6V$	3.3V	LM1086-3.3 : $V_{OUTMIN} : 3.235V$ $V_{OUTMAX} : 3.365V$	$VT_{MAX} > 2.7V$ $VT_{MAX} < 3.235V$	ADM810T $VT_{MAX} = 3V$ $VT_{MAX} = 3.15V$
T89C51CC01 T89C51CC02	$V_{CCMIN} : 3V$ $V_{CCMAX} : 5.5V$	3.3V	LM1086-3.3 : $V_{OUTMIN} : 3.235V$ $V_{OUTMAX} : 3.365V$	$VT_{MAX} > 3V$ $VT_{MAX} < 3.235V$	ADM810T $VT_{MAX} = 3V$ $VT_{MAX} = 3.15V$
		5V	MC7805 : $V_{OUTMIN} : 4.75V$ $V_{OUTMAX} : 5.25V$	$VT_{MAX} > 3V$ $VT_{MAX} < 4.75V$	ADM810M $VT_{MAX} = 4.25V$ $VT_{MAX} = 4.5V$



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