Control Solution using Logic, Analog Switches, and Discrete Semiconductor Devices for Reversing a One-Phase Motor

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APPLICATION NOTE

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INTRODUCTION

In the huge variety of the AC motors, one–phase motors are an excellent option when only single–phase power is available to supply electrical energy which motors require to operate. One of the most common single–phase motors is the split–phase motor which is used in many applications, such as pumps, bench drills, compressors, vacuum cleaners, electrical sewing machines, etc.

In some of these applications it is necessary to reverse the motor which requires two conditions. The first condition is the removal of power to the motor in order to stop it. The second condition is to change the electrical connections between the main and the start windings.

One of the most common methods to reverse a motor is to use mechanical relays. This would not be a good solution for an application in which a fast inversion of its rotation is needed, since it would be necessary to wait about 5 seconds before being able to change the motor rotation. Otherwise, it will operate in the same direction due to the open function of the centrifugal switch which remains closed until the motor reaches a low speed.

This application note shows a possible solution to control a 1/3 HP split–phase motor by taking advantage of different functions performed by some devices ON Semiconductor offers in its product portfolio. In addition, the circuit proposed in this application note eliminates the use of the centrifugal switch, since its function is being replaced by the same triacs which are performing the reversing function for the motor.

DEFINITIONS

Split–Phase Motor

Split–phase motors have two stator windings, a main winding and a start winding, with their axes displaced 90 electrical degrees in space. The start winding has a higher resistance–to–reactance ratio than the main winding, so the two currents are out of phase. Thus, the stator field first reaches a maximum about the axis of one winding and then later (about 80 to 85 electrical degrees), reaches a maximum about the axis of the winding 90 electrical degrees away in space. The result is a rotating stator field which causes the motor to start.

At about 75 percent synchronous speed, the start winding is cut out by a centrifugal switch. The rotational direction of the motor is determined during its start by the initial fields arrange which is generated in the stator by the main and start windings. This means, as result of the connection illustrated in Figure 1 between both windings (M2–S1 and M1–S2), the motor will start with a certain rotational direction. If reverse direction is desired, the connection between both windings must be changed as follows: M2–S2 and M1–S1. With this new connection, the fields arrange in the stator will be changed and, as a result, the rotational direction will be reversed. The previous statement will work whenever the connection change is done with the centrifugal switch closed.

Figure 1 shows a typical representation schematic for a split–phase motor.

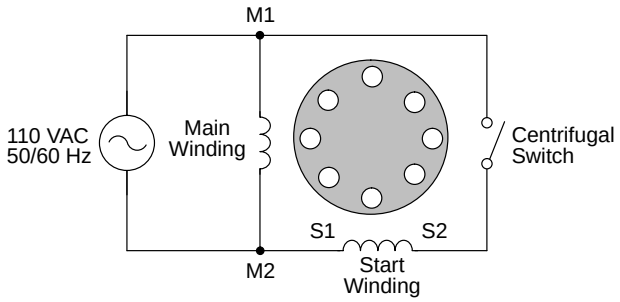

Figure 1.

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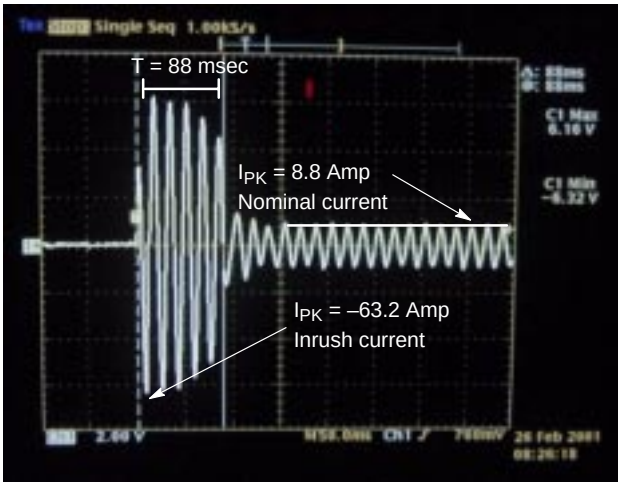
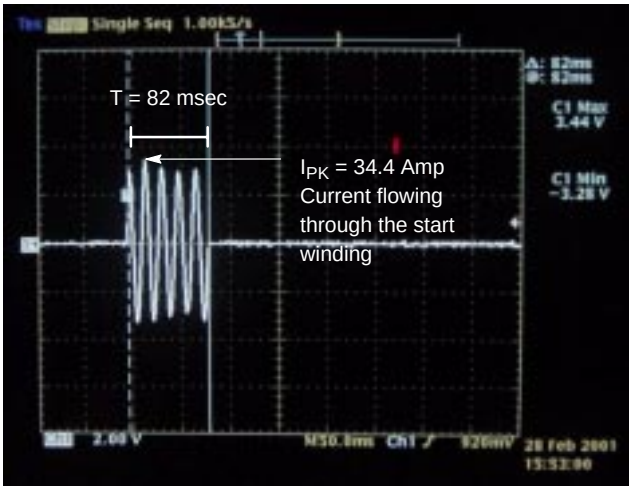
Motor Characterization

In order to properly design the power and control circuits, it is essential to characterize the motor. This means, measure the maximum peak of inrush and nominal current conditions, and determine how long these conditions take.



This plot shows the waveform of the total current flowing through both windings (Main and Start) during the motor starting condition. This current must be driven by the triac device selected for this purpose. The picture was taken when the motor was not driving any kind of mechanical load.
(Conversion factor: 100 mV = 1 Amp)

Figure 2. Plot #1



This plot shows the waveform of the current flowing only through the start winding. This current condition must be driven by triac devices which will replace the centrifugal switch function. The picture was taken when the motor was not driving any kind of mechanical load.
(Conversion factor: 100 mV = 1 Amp)

Figure 3. Plot #2

Based on the previous motor characterizations, the MAC15N triac device was selected as the main device in the power circuit. The MAC15N is able to handle up to a 90 A peak during five, 60 Hz cycles, in a nonrepetitive mode. Based on this, the MAC15N would be able to drive the total current demanded by the motor every time it starts to operate. Based on the same criteria, the MAC9N triac device was selected to perform the reversing function. The MAC9N is able to drive up to a 50 A peak during five, 60 Hz cycles; the inrush current condition only involves a 34.4 A peak of about 90 msec. In addition, both the MAC15N and the MAC9N devices were selected due to their high immunity to noise (snubberless devices). Since the dV/dt capability is very critical for this kind of application, a short–circuit condition could occur if a thyristor device is triggered by noise conditions.

Once the triacs have been selected based on the motor characterization, the power schematic diagram can be generated (Figure 4).

Figure 4 shows the proposed power schematic to perform the start–stop and reversing functions of the motor. The MAC15N device switches one of the two terminals of the 110 V, 60 Hz power line. This device basically performs a function of a start–stop switch. Before it can be triggered by optocoupler 5, two MAC9N devices should be triggered in order to connect the main and start windings, to define the initial rotational direction (motor connections M1–S1 and M2–S2).

Once the motor has started to operate completely, the trigger signal supplied to optocouplers 1 and 2 of the two MAC9N devices must be removed; the start winding would be disconnected from the power circuit. This replaces the centrifugal switch function while the main winding would remain connected to the power line through the MAC15N triac and, therefore, the motor would continue operating until a stop or reverse function is chosen.

If a reverse function is selected, the control signal provided to optocoupler 5 (MAC15N) must immediately be removed. The motor would be turned off and, at the same time, the control circuit would activate optocouplers 3 and 4 which would trigger the other two MAC9N triacs to select different connections between the main and start windings (motor connections M1–S2 and M2–S1).

This new motor configuration would allow the motor's rotation to invert as soon as the main switch (the MAC15N device) is triggered. This main switch would only trigger after about 190 msec has elapsed. 190 msec is the minimum period of time required to start the motor in the opposite direction when optocouplers 3 and 4 of the MAC9N devices are triggered. The motor would continue operating until a stop or reverse function is selected by the user.

The operational sequence of the previously described power schematic diagram must be commanded by a control circuit which is described as follows (Figure 8).

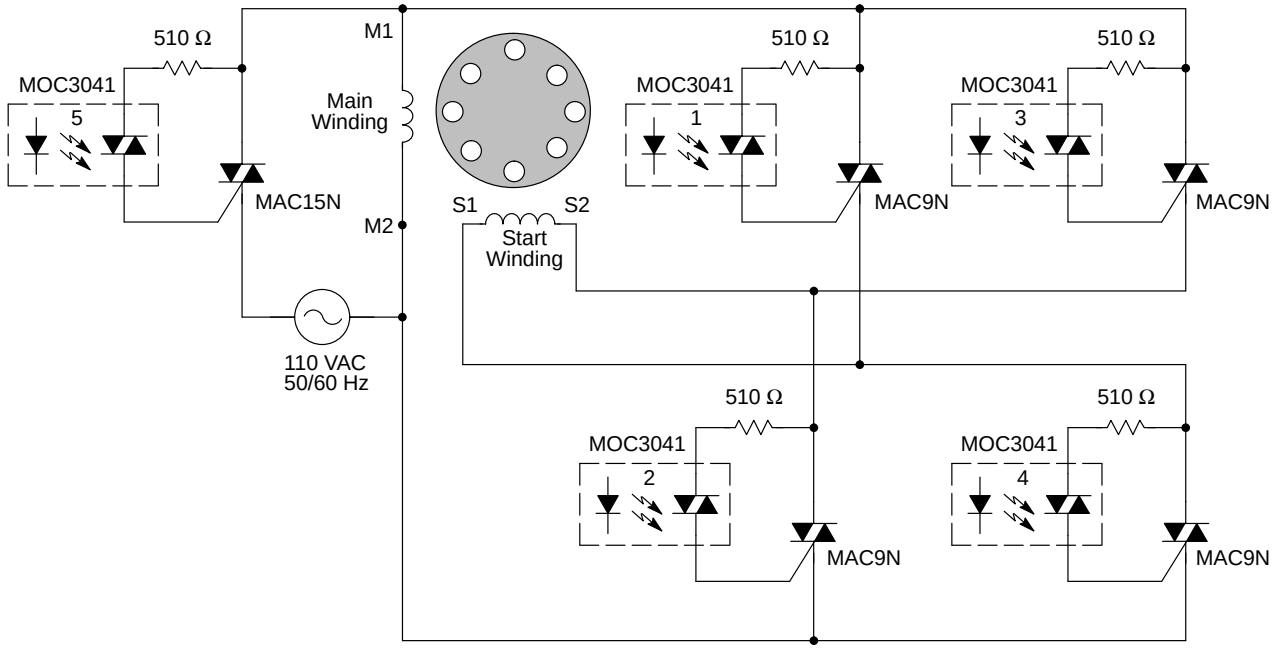


Figure 4. Power Schematic Diagram

Control Circuit

Figure 8 shows the proposed control circuit which commands the functions involved in the power circuit to control the start and stop of the motor in either direction.

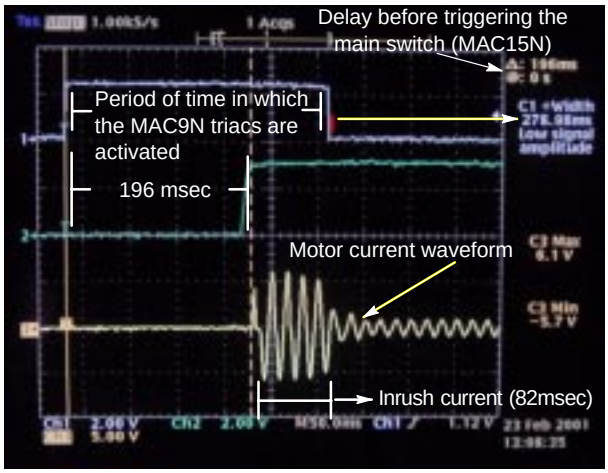
The control circuit (Figure 8), which is explained as follows, was developed based on the operational sequence of the power schematic diagram (Figure 4).

Let's start from the supposition that the motor is not operating. Under this condition, the four 2N2222 transistors illustrated are in the saturation region. None of the triac devices (MAC15N, MAC9N) are being triggered in this condition; therefore, neither of the two possible connections between the main and start windings have been established.

If the left button is pushed on, flip–flop 1 (MC41013B) is activated and immediately transistor 1 is changed from the saturation to the cutoff region. Optocouplers 1 and 2 are activated, triggering two MAC9N triac devices which establish a connection between the main and the start windings (M1–S1, M2–S2). This connection will remain approximately 280 msec (timer conformed by operational amplifier 1).

At the same time, flip–flop 1 actives a circuit (operational amplifier 2) which delays (about 190 msec) the triggering of the MAC15N triac device to allow the connection between the main and starting windings. There is a period of time (about 85 msec) during which the MAC15N device and the two MAC9N devices are being triggered simultaneously (see Plot #3, Figure 5). In this condition, the motor is able to start with its rotation in a certain direction and will remain operating until a stop or reversing function is selected.

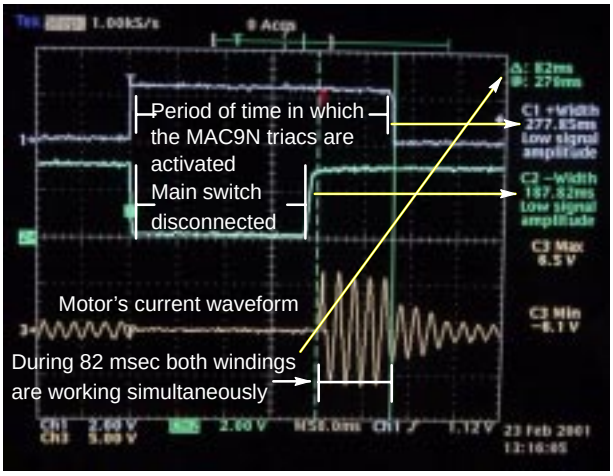
If a stop condition is chosen, the control and power circuits will return to their original conditions (motor stopped) but if the right button is pushed on, then flip–flop 2 is activated which will command a control sequence similar to the one explained for the flip–flop 1. However in this case, the connection between the main and start windings is changed by the other two MAC9N devices (M1–S2, M2–S1) to invert the rotation of the motor.



This plot shows trigger signals for the optocouplers during the initial sequence control:
Ch1 – Pulse control for the MAC9N devices (Start winding)
Ch2 – Pulse control for the MAC15N device (Main switch)
Ch3 – Current waveform (Conversion factor: 0.1 V = 1 Amp)

Figure 5. Plot #3

At the same time flip–flop 2 is being activated, a reset signal is provided to flip–flop 1, so its $\overline{Q}$ output activates one–gate analog switch 1 (MC74VHC1G66). This drains the capacitor discharge of the RC network of operational amplifier 2 to ground, so as a result, transistor 2 returns to its saturation region and optocoupler 5 is deactivated. Because of this, the gate signal to MAC15N is removed and the power to the motor will be removed after about 190 msec (see Plot #4, Figure 6). 190 msec is the minimum period of time required to start the motor in the opposite direction when the MAC15N triac device is again triggered by optocoupler 5.

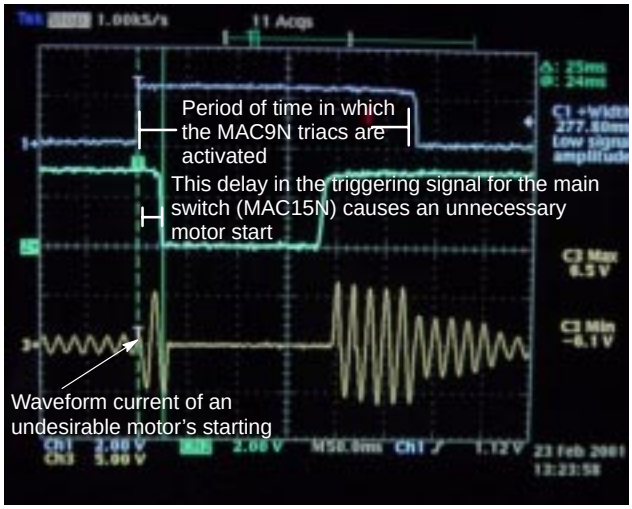


This plot shows the sequence of trigger signals for the optocouplers when the motor is reversed:
Ch1 – Pulse control for the MAC9N devices (Reverse function)
Ch2 – Pulse control for the MAC15N device (Main switch)
Ch3 – Current waveform (Conversion factor: 0.1 V = 1 Amp)

Figure 6. Plot #4

The first prototype of this control circuit was designed without contemplating the OR gates and the analog switches. It was observed that this prototype was neither a secure, nor a reliable circuit because without the OR gates (MC74VHC1G32), the flip–flop devices could be activated simultaneously. Due to this, the four MAC9N devices would be triggered at the same time causing a short–circuit condition in the power circuit. This why we decided to consider two, one–gate OR devices in our control circuit. They act as an electrical padlock which avoids the possibility of simultaneous activation of the four triacs.

The analog switch devices (MC74VHC1G66) optimize the reversing function for the motor since they avoid an unnecessary start of the motor when it is reversed (see Plot #5). This undesirable start is caused by the capacitor discharge of the RC network connected in the operational amplifiers. Since the capacitor remains charged, it causes a short activation of the main switch. This is why the analog switches were included in the control circuit.



This plot shows the sequence of trigger signals for the optocouplers when the motor is reversed (prototype without analog switches):
Ch1 – Pulse control for the MAC9N devices (Start winding)
Ch2 – Pulse control signal for the Main switch (MAC15N).
Ch3 – Current waveform (Conversion factor: 0.1 V = 1 Amp)

Figure 7. Plot #5

In conclusion, it has been shown and explained through this application note, a different alternative to control and reverse a split–phase 1/3 HP motor; replacing the function of the centrifugal switch with triac devices which improve the time in which the motor can be reversed.

Through a typical circuit using mechanical relays, it would be necessary to wait until the centrifugal switch opens which could take about 5 seconds (depending on the load and the power of the motor). While through this electronic option the motor could be reversed almost immediately;it is necessary to wait no more than 300 milliseconds.

In addition, the present note illustrates a different application for the analog switch devices. They are used to drain the capacitor discharge to ground. The one–gate OR devices protect the circuit against a possible short condition that may be caused by trying to operate the motor in either direction at the same time, which is commonly done by users.

It is important to mention that the devices for power management purposes (MAC15N and MAC9N) were selected, based on the motor characterization. If it is desirable to follow this kind of solid–state solution to control a bigger motor, the motor must be characterized in order to select the most proper triac devices, and the delays times that the motor will require to operate under its normal conditions. It is very important to mount the triac onto a proper heatsink to avoid overheating conditions; otherwise, they would not operate properly. Also, extreme environmental

temperatures could effect the proper functionality of the electronic circuit. If it is necessary to operate under extreme environmental temperatures, it would be necessary to characterize its operation at those temperature levels; however, it is a fact that this solid–state solution can operate in an environmental temperature range between 15°C to 40°C.

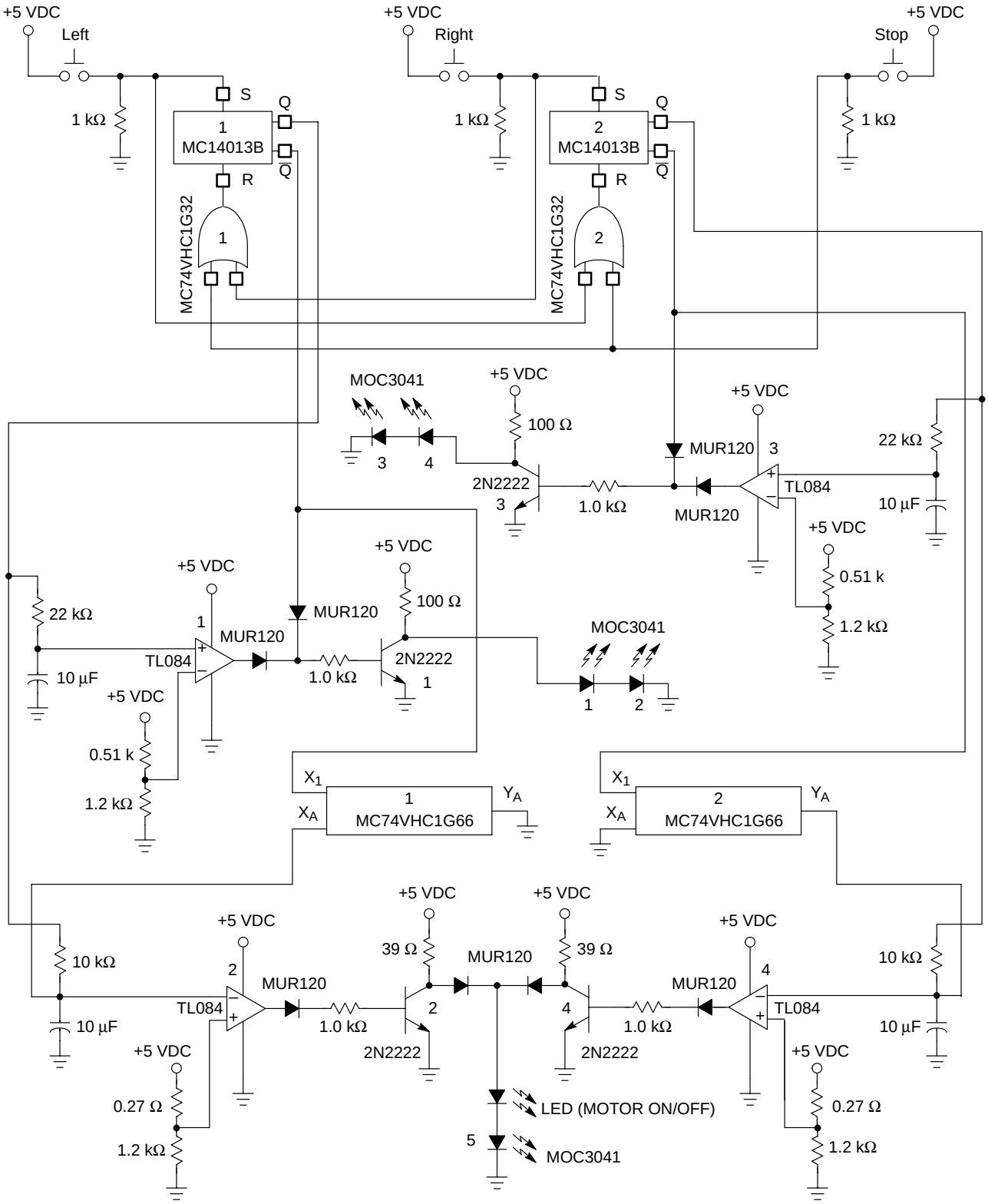


Figure 8. Control Circuit

Notes

Notes

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